ESTIMATION OF
ECONOMIC LOSSES
IN REAL TERM PER HECTARE
BASIS DUE TO

FOREST FIRE

IN UTTARAKHAND AND MADHYA PRADESH

(Summary)

2020-2023

Funded by
National Authority CAMPA,
MoEF& CC

ESTIMATION OF ECONOMIC LOSSES IN REAL TERM PER HECTARE BASIS DUE TO FOREST FIRE IN UTTARAKHAND AND MADHYA PRADESH (Summary)

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION
(An Autonomous Body of the Ministry of Environment, Forest and Climate Change, Government of India)
P.O. New Forest, Dehradun – 248 006 (Uttarakhand) www.icfre.gov.in


Going
green

FOREST FIRE

Estimation of Economic Losses In Real Term per Hectare Basis due to Forest Fire in Uttarakhand and Madhya Pradesh (Summary)

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

By
ICFRE
(2020-2023)

Funded by
National Authority CAMPA,
MoEF& CC, New Delhi

The summary for policy makers on 'Estimation of Economic Losses in Real Term Per Hectare Basis due to Forest Fire in Uttarakhand and Madhya Pradesh' is prepared by Indian Council of Forestry Research and Education, Dehradun

Citation

ICFRE, 2023. Estimation of Economic Losses in Real Terms on a Per Hectare Basis Due to Forest Fires in Uttarakhand & Madhya Pradesh (A booklet)

Published by

Indian Council of Forestry Research and Education,
P.O. New Forest, Dehradun- 248 006.

Material from this compilation may be used for educational purposes provided due credit is given.

Website

www.icfre.org

Editorial team

Dr. P.S. Rawat, ADG (RP), ICFRE
Ms. Ismita Nautiyal, Scientist- E, RP Division, ICFRE
Dr. Sanjeet Kumar Hom, Consultant, RP Division, ICFRE

Support rendered by

Dr. Shaliendra Kumar, CTO, RP Division, ICFRE

Team

Project Implementation Agency
Indian Council of Forestry Research and Education,
P.O. New Forest, Dehradun- 248 006

Direction & Guidance

Shri A.S. Rawat, IFS
DG, ICFRE

Shri R.K. Dogra, IFS
DDG (Admin.), ICFRE

Dr. Ratnaker Jauhari, IFS
DDG (R), ICFRE

Shri S.D. Sharma, IFS
Former DDG (R), ICFRE

Dr. Vimal Kothiyal, Scientist- G
Former ADG (RP), ICFRE

Project Coordinator

Planning, Coordination & implementation

Dr. Ratnaker Jauhari, IFS
DDG (R), ICFRE

Dr. P.S. Rawat, Scientist- G
ADG (RP), ICFRE

Ms. Ismita Nautiyal, Scientist- E
RP Division, ICFRE

Team leaders/Principal Investigators

FSI, Dehradun

Shri Sunil Chandra, Deputy Director, FSI
Shri Vikas Gusain, Senior Technical Assistant, FSI

NIHE, Almora

Dr. G.C.S. Negi, Scientist- G
Dr. K.S. Kanwal, Scientist- D

NIH, Roorkee

Dr. J.V. Tyagi, Director, NIH, Roorkee
Dr. R.P. Pandey, Scientist- G

ICFRE-FRI & ICFRE-TFRI

Dr. Praveen Kumar Verma, Scientist- C, FRI, Dehradun
Shri Dheeraj Gupta, Scientist- D, TFRI, Jabalpur

WII, Dehradun

Dr. B.S. Adhikari, Scientist G,
Dr. Salvador Lyngdoh, Scientist- D

Consultant

Dr. Satendra, IFS (Rtd.)., Noida

Acknowledgement

The Indian Council of Forestry Research and Education (ICFRE) has been at the forefront of several studies of national importance in the past. Their achievements include the development of improved varieties and clones of forestry species, preparation of DPR for the treatment of catchment areas of 14 major river basins, treatment of degraded sites and environmental impact assessment of development/ mining projects.

The recent study on "Estimation of economic losses in real term per hectare basis due to forest fire in Uttarakhand and Madhya Pradesh" is yet another significant contribution by ICFRE. This study was carried out with the support of partner Institutes including the Forest Research Institute (FRI), Tropical Forest Research Institute (TFRI),

National Institute of Himalayan Environment (NIHE), Wildlife Institute of India (WII), National Institute of Hydrology (NIH) and Forest Survey of India (FSI).

The study is a major effort towards understanding the economic losses caused by forest fires in Uttarakhand and Madhya Pradesh. By estimating these losses on a per-hectare basis, the study provides a more accurate picture of the impact of forest fires on the region's ecology and environment. ICFRE and its partner Institutes are to be congratulated on this significant endeavour. Heartfelt gratitude to the Principal Investigators (Dr. G.C.S. Negi, NIHE, Almora; Shri R.P. Pandey, NIH, Roorkee; Dr. B.S. Adhikari,WII, Dehradun; Dr. Praveen Kumar Verma, ICFRE-FRI, Dehradun; Shri Dheeraj Gupta, ICFRE-TFRI, Jabalpur and Shri Sunil Chandra, FSI, Dehradun) and project teams of partner institutes for their dedicated efforts in studying the impacts of forest fires on carbon, hydrology, flora, fauna, and loss. Their hard work has undoubtedly yielded a fruitful report. Deep appreciation to Dr. Satendra Singh, IFS (Retired) for skillfully synthesizing all the components of the study.

Heartfelt gratitude to Shri A.S. Rawat, Director General, ICFRE for his invaluable guidance, advice and encouragement in bringing this report to fruition. The study was conducted under the expert guidance of the ICFRE headquarters, with the valuable contributions of Sh. S.D. Sharma (Retired DDG (Research), Sh. R.K. Dogra, DDG (Administration), Dr. Ratnaker Jauhari, DDG (Research), Dr. Sudhir Kumar DDG (Extension), Director, FRI and TFRI, Dr. Vimal Kothiyal (Retired ADG (RP)), Mrs. Ismita Nautiyal, Sci-E, ICFRE. This document will serve as a practical guide for implementing effective fire control measures and estimating potential damages and losses in the future.

Last but not least the study would have not been possible without the funding and support of National Authority CAMPA, MoEF& CC. Heartfelt gratitude to Shri Subhash Chandra, CEO, CAMPA, Shri B.K. Singh, ADG (Forests), MoEF& CC, Shri Anand Prabhakar, Deputy CEO (CAMPA), MoEF& CC for their continuous support to accomplish the study.

सत्यमेव जयते

अरूण सिंह रावत, भा.व.से.
Arun Singh Rawat, IFS

महानिदेशक
भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद्
डाकघर न्यूफॉरेस्ट, देहरादून–248006

Director General
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun-248006, India

Foreword

Forests are an important ecosystem that has been valued since ancient times in India. They provide essential services to human civilization by acting as a source of livelihood for indigenous communities and serving as habitats for various animal species. Moreover, forests play a crucial role in protecting watersheds, reducing soil erosion, and mitigating climate change. The forest ecosystem operates on the principle of balance, where forest fires can either benefit or harm the environment, depending on their severity.

However, forest fires caused by natural or human factors are a recurrent problem during the summer season in India. These fires result in a significant transformation of the environment, with devastating impacts on natural ecosystems. Apart from the direct economic losses, such fires cause intangible losses, such as a reduction in biodiversity, carbon sequestration, soil fertility and hydrological functions. It is therefore essential to prevent and manage forest fires to maintain the ecological balance of the forest ecosystem.

In 2016,a severe forest fire broke out in Uttarakhand during the summer months. The incident prompted the parliamentary Standing Committee on Science and Technology, Environment, and Forest, Government of India, to visit Uttarakhand and Himachal Pradesh to investigate the causes of the fire. After conducting consultations with various stakeholders, the committee recommended developing a methodology to estimate the losses caused by forest fires.

Following the committee's recommendation, the Indian Council of Forestry Research and Education (ICFRE) collaborated with partner Institutes such as the Forest Research Institute (FRI), Tropical Forest Research Institute (TFRI), National Institute of Himalayan Environment and Sustainable Development (NIHE), Wildlife Institute of India (WII), National Institute of Hydrology (NIH), and Forest Survey of India (FSI) to undertake a study to estimate the losses caused by forest fires. The study was funded by the National Authority CAMPA.

The ICFRE-led study has resulted in a comprehensive report that provides valuable insights into the impact of forest fires on the environment and a proper methodology to estimate the losses caused by such forest fires. The report recommends measures to prevent and manage forest fires effectively. It highlights the importance of ecological restoration of fire-affected areas and promoting community participation in forest fire management. The study's findings and recommendations serve as a significant resource for policy makers,forest managers,and other stakeholders to devise effective strategies for forest fire management.

Overall,the study is an essential step towards understanding the impact of forest fires on the environment and developing measures to prevent and manage forest fires effectively. The collaborative efforts of the ICFRE and its partner Institutes,with support from the National Authority CAMPA have resulted in a valuable resource for promoting sustainable forest management and conserving India's rich biodiversity.

Arun Singh Rawat, IFS
Director General,ICFRE

Abbreviations

AWiFS	Advanced Wide Field Sensor
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CHNS	Carbon-Hydrogen-Nitrogen-Sulphur
ICFRE-FRI	Indian Council of Forestry Research and Education-Forest Research Institute
FSI	Forest Survey of India
NIHE	National Institute of Himalayan Environment
GoI	Government of India
HMTF	Himalayan Moist Temperate Forests
ICFRE	Indian Council of Forestry Research and Education
IRS	Indian Remote Sensing
MAPs	Medicinal and aromatic plants
MODIS	Moderate Resolution Imaging Spectro-radiometer
MoEF&CC	Ministry of Environment, Forest & Climate Change
MUSLE	Modified Universal Soil Loss Equation
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NIH	National Institute of Hydrology
NTFPs	Non-timber forest products -
SCS-CN	Soil Conservation Service - Curve Number
SFD	State Forest Department
SNPP-VIIRS	Suomi National Polar-orbiting Partnership - Visible Infrared Imaging Radiometer Suite
TDDF	Tropical Dry Deciduous Forests
ICFRE-TFRI	Indian Council of Forestry Research and Education-Tropical Forest Research Institute
TMDF	Tropical Moist Deciduous Forests
WII	Wild life Institute of India
WS	Wildlife sanctuary

Contents

1 Chapter

OVERVIEW

BACKGROUND, SCOPE AND APPROACH

1

1.1. INTRODUCTION AND BACKGROUND

Every year, forest fires are affecting millions of hectares of forest throughout the globe and change biodiversity patterns, landscape stability and ecosystem function. It results in huge damage and loss to the environment, ecology, forest produce and various other sectors. Several attempts have been made to assess economic loss due to fire in the past by many scholars and scientists. However, these estimates in general are restricted only to direct losses and do not include intangible services of forests such as loss of biodiversity, carbon sequestration, soil fertility, hydrological functions of forests etc.

In the summer of 2016, Uttarakhand witnessed a major forest fire (2069 forest fire incidences affecting 4423 ha of forests) and the loss was estimated to be Rs. 46.2 lakhs by the Uttarakhand Forest Department following the traditional method of damage and loss assessment methodology. This was a major disaster which has not only caused huge damage and loss to natural vegetation but also resulted in the death of persons and animals. Owing to the damage due to fire the Government of India decided to send the Parliamentary Standing Committee (PSC) on Science and Technology, Environment and Forests, Govt. of India to visit Uttarakhand and Himachal Pradesh. In June 2016, the PSC recommended assessing the damage and loss due to forest fires in a more comprehensive manner incorporating all essential elements related to forest fire impacts viz. socio-economic and environmental impacts, direct and indirect both.

Following the recommendations of PSC the present pilot project was developed after intensive rounds of discussion among the partner organization. The project was undertaken with the major mandate of "Estimation of economic losses in real terms per hectare basis due to forest fire in Uttarakhand and Madhya Pradesh", involving leading organizations of the region viz., Indian Council of Forestry and Research (ICFRE), Dehradun; Forest Survey of India (FSI), Forest Research Institute (FRI), Dehradun; Tropical Forest Research Institute, Jabalpur; 'National Institute of Himalayan Environment (NIHE), Almora; Wildlife Institute of India (WII), Dehradun, and National Institute of Hydrology (NIH), Roorkee with specific deliverables (Table-1).

Table-1 Deliverable for partner institutes

INDIVIDUAL INSTITUTIONS - DELIVERABLES
FSI/SFD/ICFRE: Burnt area identification,verification and finalization of study sites based on severity by:
ICFRE and Partner Institutions: Selection of Study Sites and Control Sites
ICFRE Institutes (FRI, TFRI): Economic loss assessment of damage to the terrestrial flora and 5-pools Carbon assessment
WII: Economic loss assessment of wild fauna, habitat etc.
NIH: Economic loss assessment of damage to regulating hydrological services
NIHE: Economic loss assessment of timber and non-timber forest produces
ICFRE in association with partner institutions: Overall Economic loss estimation of forest due to forest fire

1.2. SCOPE, STUDY AREA AND APPROACH

The pilot study with a broad scope of developing a framework methodology for estimation of economic losses in real terms per hectare basis for the forest types vulnerable to fire was initiated with the main objectives to quantify the forest loss in terms of total economic value i.e., the monetary value on a per hectare basis for the forest types (Fig.1). Along with this, the study also aimed at burnt area assessment and severity classification, economic loss assessment of terrestrial flora, faunal diversity, hydrological changes and provisioning services and cultural value of forest produce loss due to forest fire on a per hectare basis in the States of Uttarakhand and Madhya Pradesh.

Fig. 1 Scope of the project

Scope

- Estimation of total economic loss in real terms of monetary value on per hectare basis for the study states of Uttarakhand and Madhya Pradesh
- Developing methodology to estimate tangible and intangible losses due to forest fire on per hectare basis which may be used in other similar situations.

To initiate the project the selection criteria of the study sites in Uttarakhand (U.K.) and Madhya Pradesh (M.P.) were determined in such a way so that the sites selected represent the typical physiographic (altitude, slope, aspect), vegetation (forest types and plant composition) and forest fire intensity (low, medium and severe) in U.K. and M.P. (Fig. 2) Forest Survey of India, Dehradun validated the forest fire-affected sites of 2019 and provided a list of 289 forest fire affected polygons in U.K. and 228 forest fire affected polygons in MP respectively. The ICFRE, Dehradun further categorized the forest fire-affected polygons using several criteria and provided a list of 42 forest fire polygons (Table-2) and 49 forest fire polygons (Table-3) for intensive study by partner institutions. The area of studied polygons ranged from 4.23 - 883.12 ha (U.K.) and 3.607 - 3108.53 ha (M.P) and altitudes from 230 - 2488 meters above sea level in U.K. and 252 - 930 meters above the sea level in MP.

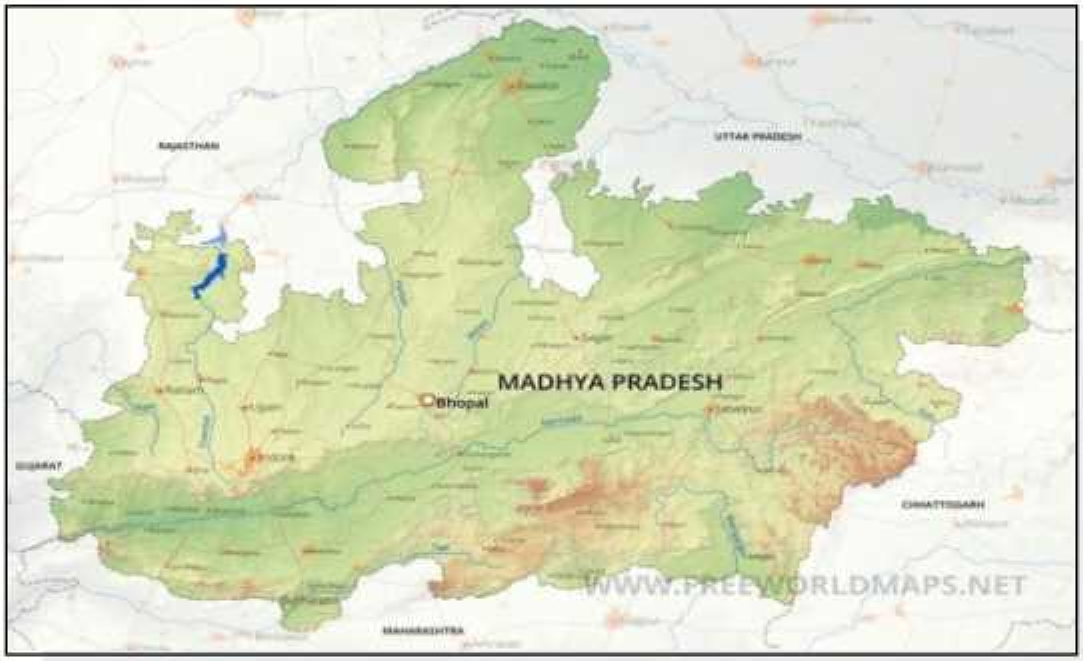


Fig. 2

Study area Uttarakhand and Madhya Pradesh

Table-2
Polygons in Uttarakhand

Selected burnt polygons in Uttarakhand: 42	Burnt Polygons		
Forest type	**Severely Burnt**	**Moderately Burnt**	**Low Burnt**
Group 3- Tropical Moist Deciduous Forests	Nil	4	2
Group 5- Tropical Dry Deciduous Forests	Nil	Nil	2
Group 9 - Subtropical Pine Forests	Nil	18	2
Group 12- Himalayan Moist Temperate Forests	Nil	9	2
Group- TOF/Plantation	Nil	1	2
Total	Nil	32	10

Table-3 Polygons in Madhya Pradesh

Selected burnt polygons in Madhya Pradesh: 49	Burnt Polygons		
Forest type	**Severely Burnt**	**Moderately Burnt**	**Low Burnt**
Group 3- Tropical Moist Deciduous Forests	2	4	8
Group 5- Tropical Dry Deciduous Forests	3	20	12
Group 9 - Subtropical Pine Forests	Nil	Nil	Nil
Group 12- Himalayan Moist Temperate Forests	Nil	Nil	Nil
Group- TOF/Plantation	Nil	Nil	Nil
Total	5	24	20

The tangible and intangible losses were estimated from two neighbouring plots (burnt and un-burnt) of 1 ha size in each of the identified fire-prone forests type-specific to each state based on the intensity and type of forest fire at different altitudes,slopes, and aspects. The total economic loss on a per ha basis was calculated by adding values derived from different components of the forest ecosystems services (ES), both tangible and intangible losses. The tangible loss of ES includes loss and damage of timber, NTFPs, fuel wood, fodder etc; and the intangible loss includes increased soil erosion and water runoff, adverse impacts on carbon stock and sequestration, habitat and cultural values etc. The methodology consists of the collection and use of simple and uniform physical indicators to assess ecosystem services in terms of provisioning, supporting, regulating and cultural for the damage assessment due to forest fire (Fig.3). The forest fire losses (i.e., tangible and intangible) were identified using the ecosystem services (ES) framework following the Economics of Ecosystems and Biodiversity Approach of Millennium Ecosystem Assessment (TEEB, 2010). The monetary value of each indicator was estimated for the total economic cost including direct, indirect and opportunity costs.

Fig. 3 Methodology

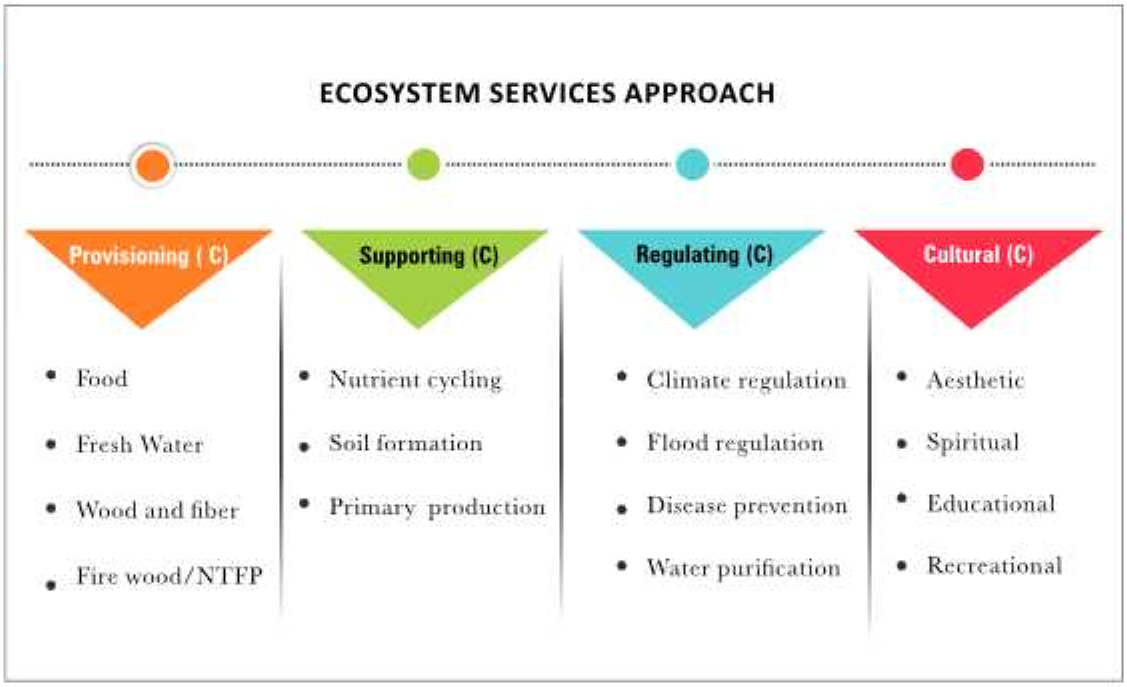
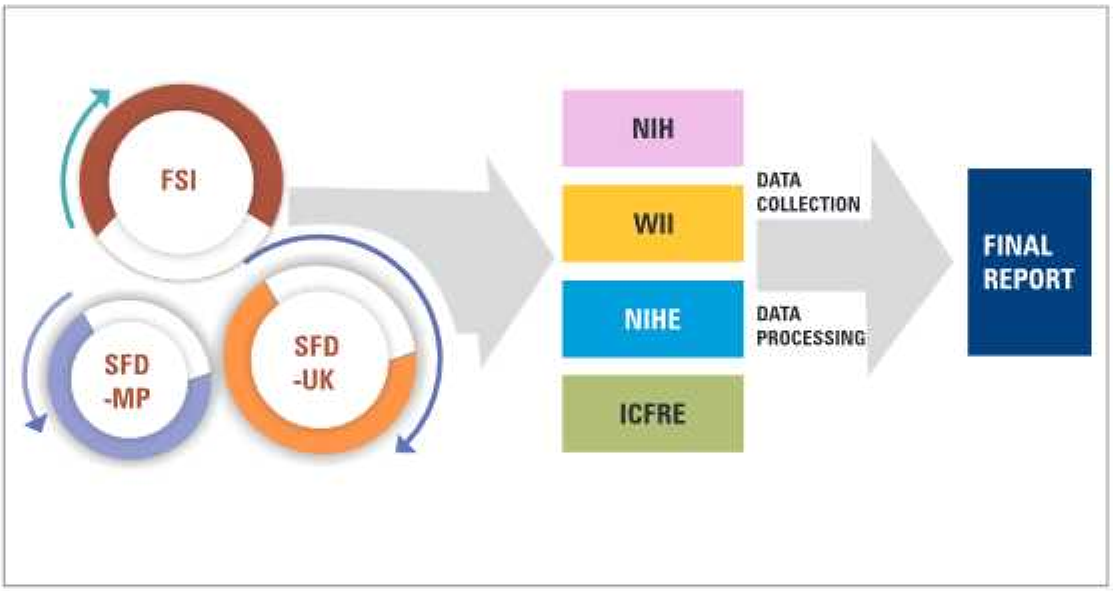


Fig. 4

Approach for study

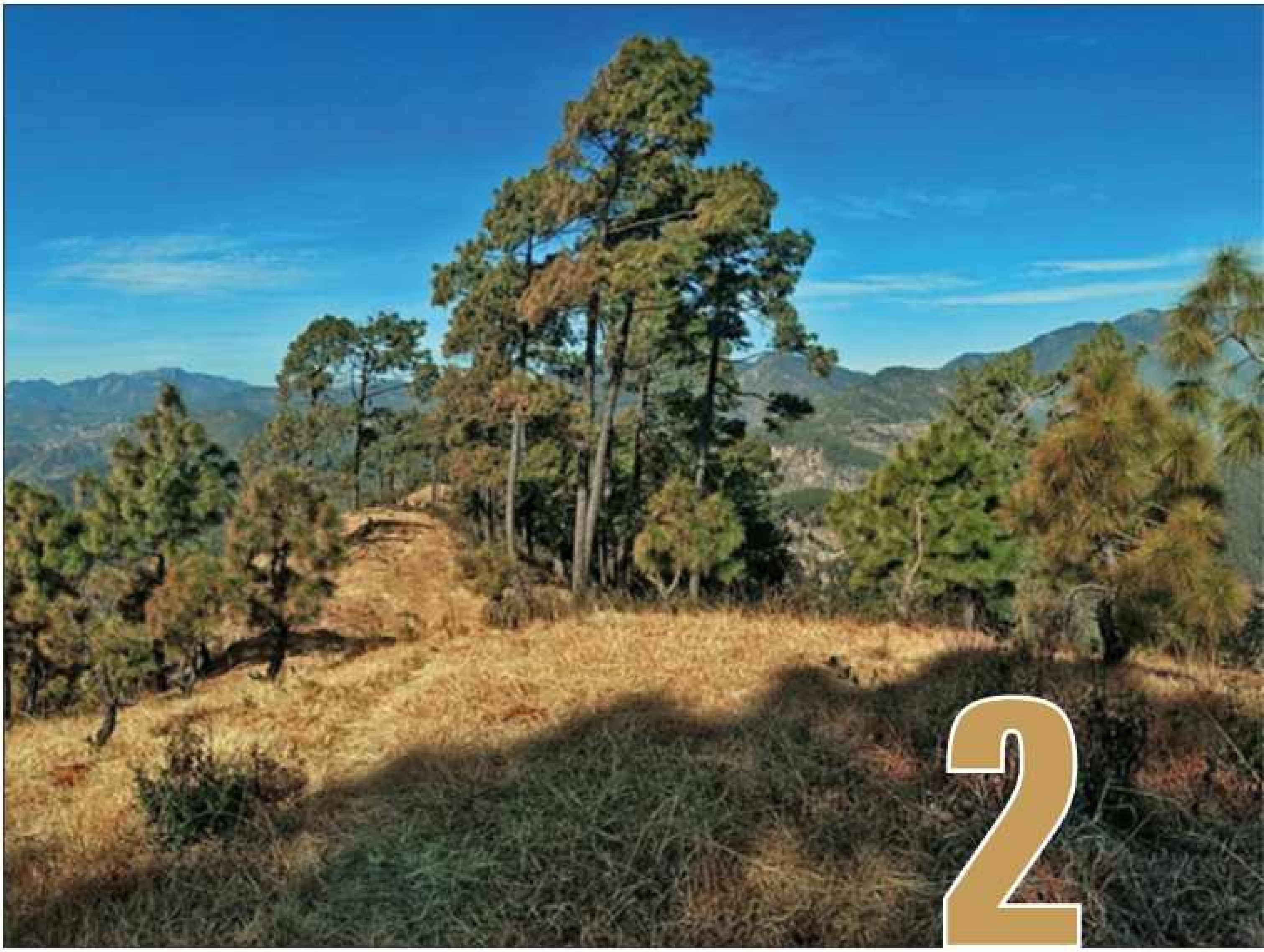


Given due consideration to the basic philosophy behind the project, the parameters identified were grouped under four major categories i.e. terrestrial floral variables (change in vegetation and carbon content), people's dependency on forest produces, wildlife and related variables, and hydrological variables to facilitate the loss assessment procedure in accordance with the mandate and expertise of partner institutions as mentioned in the chapters of the book.

Chapter 2

BURNT AREA IDENTIFICATION, VERIFICATION AND FINALIZATION OF STUDY SITES BASED ON SEVERITY

S. Chandra, V. Gusain, and S. Kumar
FSI, Dehradun



2

2.1. INTRODUCTION AND BACKGROUND

Forest fires cause unprecedented loss of timber,ground flora, fauna and biodiversity in the region. The losses from fires are long lasting and damage caused at a larger scale brings about secondary changes in terms of climatic variations, ecological and biodiversity changes, loss of wildlife, medicinal herbs, shrubs and other plant species. Overall, the impact of fires could be large and the only way to combat forest fires is to minimize the severity and extent of fires. Technological based measures have been useful in curtailing the severity and extent of damage caused by fires and resilience to measures in forest fire management.

Forest Survey of India disseminates forest fire alerts on a near-real-time basis based on the forest fire points detected by MODIS (Moderate Resolution Imaging Spectro-radiometer) and SNPP-VIIRS (Suomi National Polar-orbiting Partnership - Visible Infrared Imaging Radiometer Suite) sensors. The number of forest fire detections during the fire season (November, 2018 to June, 2019) in Madhya Pradesh and Uttarakhand are shown in Table 4.

Table-4
Number of Forest Fire detections (Nov. 2018 - June 2019)

State	Number of forest fires detected by MODIS sensor	Number of forest fires detected by SNPP-VIIRS sensor
Madhya Pradesh	2,723	22,108
Uttarakhand	1,578	12,965

While it is important to timely detect forest fires and to take remedial measures, it is equally important to assess forest areas burnt by forest fires. The extent of burnt scars largely depends on the fuel load, and the local physiographic, climatic and anthropogenic factors prevailing in the area. This information is important for the determination of the extent of tree and biomass loss, loss of important herbs and habitat, loss to wildlife, effects on human lives and property, etc.

In the study, FSI carried out a burnt scar assessment of the states of Madhya Pradesh and Uttarakhand using IRS RS2 AWiFS satellite data during the fire season from November, 2018 to June 2019. The delineated burnt scars polygons were shared with the respective State Forest Department for validation and finally forwarded to ICFRE for further analysis.

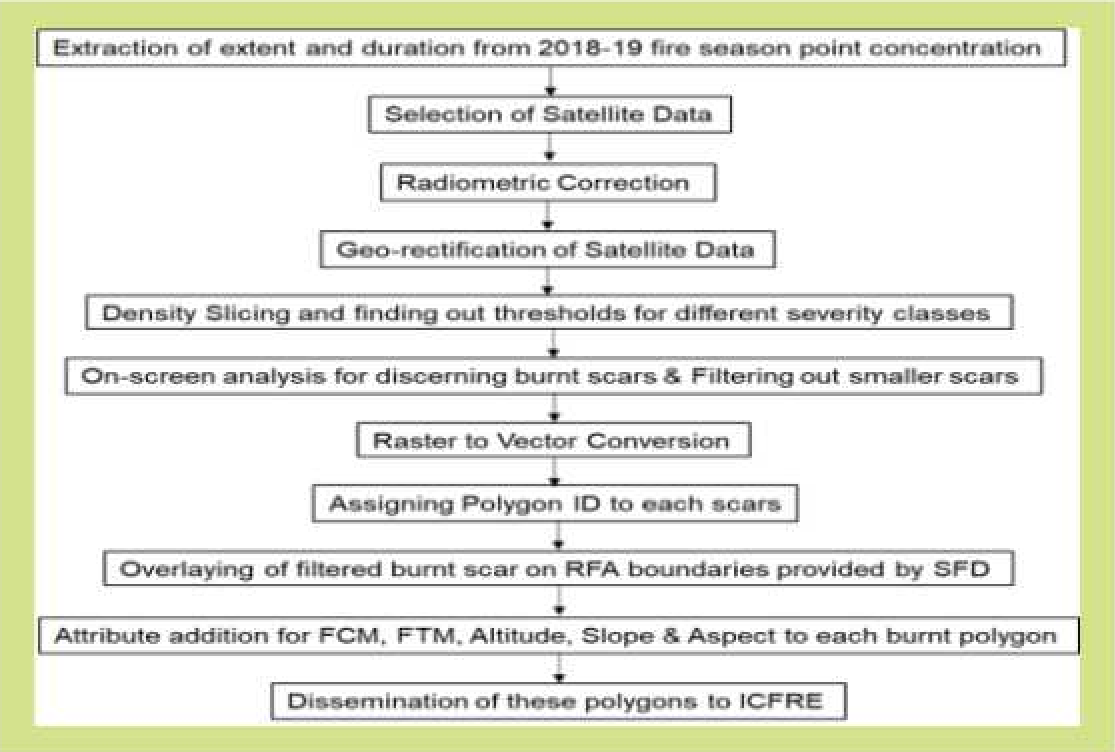
2.2. SATELLITE DATA USED

In this study, high temporal data from Indian Remote Sensing (IRS) Resource Sat-2 AWiFS (Advanced Wide Field Sensor) satellite data having a spatial resolution of 56 meters and covering a swath of 740 km have been used. The sensor is well suited for forest fire studies as it has the necessary spatial, spectral, temporal and analytical characteristics for mapping burnt areas. AWiFS data has a revisit period of five days and is operated in four spectral bands.

2.3. METHODOLOGY

The schematic diagram of the methodology followed in the burnt scar assessment is shown in Fig. 5. The minimum mappable unit for the study is 3 hectares. The burnt scar is mapped into Severely Burnt, Moderately Burnt and Low Burnt severity classes based on the reflectance of a pixel of the satellite data.

Fig. 5
Schematic diagram of the methodology followed in burnt scar assessment



Selection of Satellite data: Based on the concentration of forest fire detection by MODIS and SNPP-VIIRS sensors in Madhya Pradesh and Uttarakhand for the fire season 2019, 05 AWiFS scenes of Madhya Pradesh and 04 AWiFS scenes of Uttarakhand data were procured to carry out the study.

2.3.1. DISCERNING BURNT SCAR

After the images were radiometrically corrected, the images had undergone geometric correction. The pre-fire and post-fire images are utilised for the identification of burnt scars. The density slicing was carried out and the threshold for every image was identified for different severity classes based on the differences in the spectral behaviour of the pre-fire and post-fire images (as shown in Fig. 6). The concentration of forest fire detections by the sensor has been also used for delineating burnt scars.

2.3.2. ADDITION OF ATTRIBUTES

The burnt scar polygons were further overlaid on the RFA boundaries of respective States. Only scars within the RFA boundary are selected for analysis. Attributes such as Forest Cover Map, Forest Type Map, Altitude, Slope and Aspect are added to each burnt scar.

2.3.3. VALIDATIONS OF BURNT SCAR

The selected burnt scar polygons with all the attributes were sent to the respective State Forest Department (SFD) for validation. After receiving the validation report from the SFD, the burnt scar polygons were sent to the ICFRE and other partnering institutes/agencies to carry out their assigned work.

2.4. LIMITATIONS

Every remote sensing-based mapping exercise has certain limitations. The inherent limitations affect the accuracy of burnt scar mapping. Some of the significant limitations observed in the study are:

1. Since the resolution of the AWiFS sensor data is 56 m, the land cover features having a geometric dimension less than 56 m on the ground are not discernible.
2. Considerable ground details may sometimes be obscured due to the cloud,cloud shadow and hill shadows.
3. Non-availability of cloud-free data sometimes puts constraints on the interpretation of the features.
4. Burnt scar gets diminished due to climatic factors such as rainfall, thus making it difficult to map the affected area.
5. For the data in the off-nadir area, roughly two pixels (~ 100 meters) shift has been observed.

2.5. RESULTS

The analysis of the burnt scar of Madhya Pradesh and Uttarakhand has been carried out in the study and the abstract is presented in Table 5:

Table-5 State-wise burnt scar area in Uttarakhand and Madhya Pradesh

State	Geographical Area (GA)	Forest Cover as per 2021 Assessment	Severity Classes				% of GA	% of Forest Cover
			Severely Burnt	Moderately Burnt	Low Burnt	Total Burnt		
Uttarakhand	53,483	24,305.13	0.00	336.14	1,408.82	1,744.96	3.26	7.18
Madhya Pradesh	308,252	77,492.60	264.70	991.38	5,574.90	6,830.98	2.22	8.82

Fig. 6

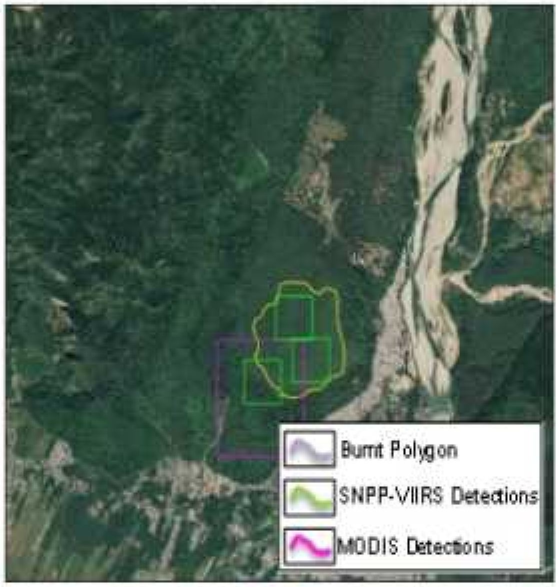
Pre-fire Image, Post-fire Image with sensor detections, Google Earth Image with sensor detections and the details of the delineated burnt scar polygons

IRS-RS2-AWiFS Path: 99 Row: 49
Date of Pass: 07 May 2019

IRS-RS2-AWiFS Path: 100 Row: 52
Date of Pass: 05 June 2019
Date of fire detection: 26 May 2019

Details of the Selected Polygon:

- Polygon ID: 2566
- Latitude: 29°24'21.01" N
- Longitude: 79°07'07.81" E
- Severity: Low Burnt
- Area: 65.46 ha
- FCM: Open Forest
- FTM: Tropical Moist Deciduous Forests
- Altitude: 0-900 m
- Slope: 0-3°
- Aspect: North



Google Earth Snapshot
Date of GE Image: 23 Oct. 2022

2.6. ANALYSIS OF BURNT SCAR OF UTTARAKHAND

A burnt scar map showing different severity classes based on the intensity of the forest fire of Uttarakhand has been shown in Fig. 7. Based on the analysis of satellite data,a total of 4,897 fire polygons of different sizes with a minimum area of 3 ha have been observed in Uttarakhand.

2.7 ANALYSIS OF BURNT SCAR OF MADHYA PRADESH

A burnt scar map showing different severity classes based on the intensity of forest fires in Madhya Pradesh has been shown in Fig. 8. Based on the analysis of satellite data, a total of 17,228 fire polygons of different sizes with a minimum area of 3 ha have been observed in Madhya Pradesh.

Fig. 7

Map showing burnt scars in Uttarakhand with different severity classes

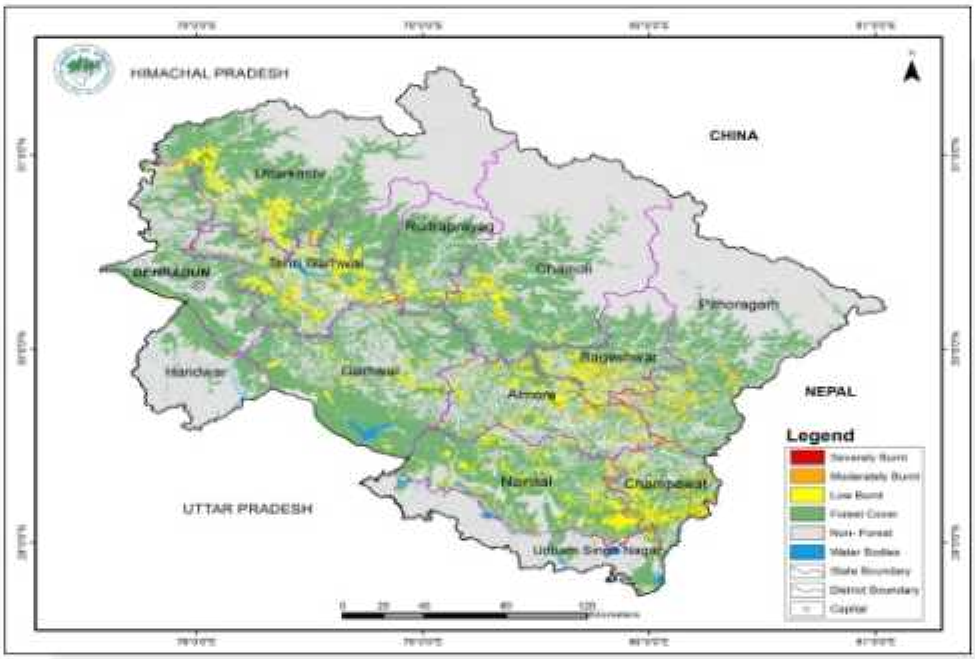
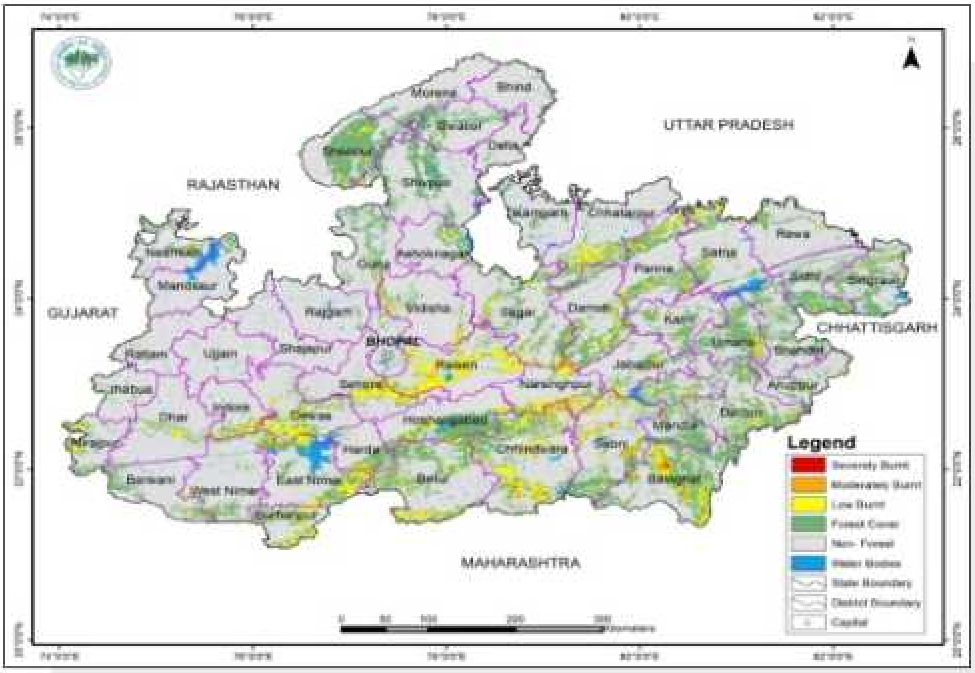


Fig. 8

Map showing burnt scars in Madhya Pradesh with different severity classes



2.8. CONCLUSION

The satellite data has been found very useful in the delineation of burnt scars. The high periodicity satellite data captures the severity more profoundly before getting diminished due to weathering effect. SWIR band has the capability to capture active fires. The classification of severity classes of burnt scars has been carried out based on the reflectance of each pixel. The accuracy of the classification should be followed by the reports of the ground verification by the field staff of the State Forest Department.

3 Chapter

QUANTIFICATION AND VALUATION OF LOSS OF ECOSYSTEM GOODS DUE TO FOREST FIRE

G.C.S. Negi, K.S. Kanwal,
Pradeep Singh and Himanshu Bargali
NIHE, Almora

3.1. INTRODUCTION

Forest ecosystems provide a wide range of goods and services that are essential for the survival and well-being of human beings. These goods and services include timber, fuel wood, fodder, leaf litter, wild edibles, non-timber forest products (NTFPs), medicinal and aromatic plants (MAPs), regeneration of forests, aesthetic services and many more. As per MEA (2005), these ecosystem services are categorised into provisional, regulating, supporting and cultural services. In India, forests contribute about 1.7% to the GDP, and the NTFPs alone provide about 40% of total official forest revenues and 55% of forest-based employment. This demonstrates the importance of forests in the livelihoods of people living in and around forests (Semwal *et al.* 2007). In spite of the immense importance of forest ecosystem services for human well-being, these services are although widely recognized but least evaluated in the economic calculus.

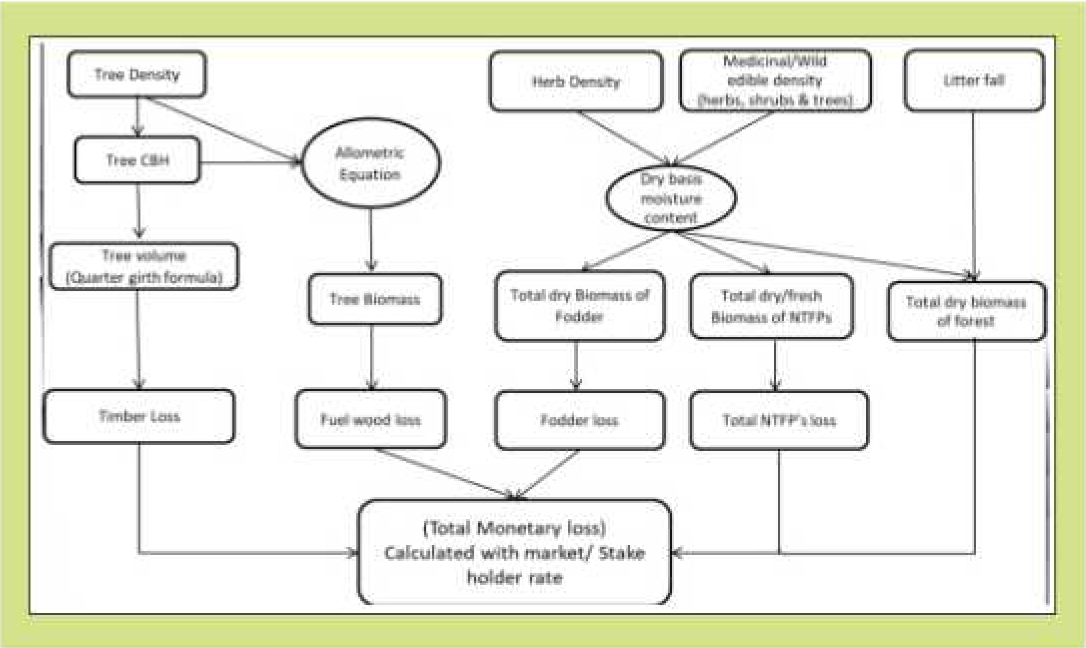
Frequent forest fires (FF), both natural and anthropogenic pose a significant threat to these ecosystem services and cause huge losses to the forest wealth every year and thus prove detrimental to the economy of the country. To estimate economic loss due to forest fire and devise compensation mechanisms it is essential to quantify and value the loss of various ecosystem goods and services due to FF. Hitherto, the monetary loss estimation due to FF is based on very old estimates (@ Rs. 1500/ha of burnt forest) which are far too less than the real loss accrued to the forest goods and services. Now,in the wake of an improved understanding of ecosystem services (MEA, 2005 and the MoEF& CC programme on TEEB- the Economics of Ecosystems and Biodiversity, 2015) there is a renewed interest and need for estimating the monetary value of ecosystem services worldwide (Costanza *et al.* 1997; Negi and Agrawal, 2006). Monetary valuation of loss of forest ecosystem services will help in formulating forest management plans to maximize the ecosystem services and ensure the quality of life of people, directly dependent upon them. Some of the notable efforts made on forest ecosystem services valuation in India include those of Verma (2000), Singh (2002), Hari priya *et al.* (2005), Joshi and Negi (2011), Kishwan *et al.* (2012) etc. However, the valuation methodology is still evolving.

3.2. STUDY AREA AND METHODOLOGY

This study carried out during 2020 and 2021 considered selected polygons (42 in Uttarakhand and 49 in Madhya Pradesh) across the 2019 FF affected areas of U.K. (289 polygons) and M.P. (228 polygons) provided by FSI, Dehradun. The study area was further classified based on fire severity classification by ICFRE, Dehradun so that the study sites selected represent the typical physiographic (altitude, slope, aspect), vegetation (forest types) and FF intensity (low,medium and severe) across these two states. In U.K. 42 FF polygons (32 moderately burnt and 10 low burnt) and in M.P. 49 FF polygons (5 severely burnt; 24 moderately burnt and 20 low burnt) were finalized for intensive study to estimate the monetary loss to forest ecosystem goods due to FF (i.e., timber, fuel wood, fodder, leaf litter, wild edibles, MAPs, NTFPs such as resin, tendu patta, bamboo, etc.) and forest regeneration. The area of studied polygons ranged from 4.2 - 883.1 ha (U.K.) and 3.6 - 3108.5 ha (M.P) and altitudes from 230 - 2488 m asl in U.K. and 252 - 930 m asl in M.P. Field work was conducted both during pre- and-post rainy seasons of 2020-21. However, due to the COVID-19 pandemic and restrictions on movements, a few polygons could not be studied in both states. To overcome this data deficiency, we used the values of similar nearby studied polygons based on their severity of burning,topography, forest vegetation types and richness of plant species. Thus, across Uttarakhand (770 quadrates for trees, 1540 for shrubs and 2310 for herbs) and M.P. (660 quadrates for trees, 1320 for shrubs and 1980 for herbs) were studied for quantification of loss of various forest goods due to FF following standard techniques (Mishra, 1968; Thakur, *et al.*, 2019. Monetary loss estimates were made based on rate lists of Forest Deptt. and other related agencies such as Forest Development Corporation, Bhesaj Sangh etc. and other relevant publications e.g., Goraya and Ved, 2017; Bhatt *et al.*, 2005. To estimate the leaf litter loss due to fire Singh and Singh (1992) for U.K. and Pandey, 2005 for M.P. and loss of bamboo ISFR (2019) and Gangopadhyay (2003) were followed. Stakeholders' consultations (35 meetings in U.K. and 31 meetings in M.P.) were

Fig. 9

Flow chart depicting broad methodology for monetary estimation of forest goods



organized among the villages nearby the studied polygons for estimation of the monetary value of certain forest resources (e.g.,wild edibles, MAPs, etc. for which market rates were not available) involving 323 forest officials/field staff and 817 local people including women. Field workshops were conducted frequently to standardize the methodology and sampling strategies. Plant species were identified using available flora of U.K. and M.P., research papers, books, taxonomists' expertise and the website (http://www.theplantlist.org/). The local names and ethnobotanical notes on plant species were recorded with the help of forest guards, beat chowkidar, local people, etc. during meetings in nearby villages. The outline of the methodology of quantification of forest resources is depicted in the Flow Chart (Fig. 9).

Fig. 10

Field work activities in Uttarakhand and Madhya Pradesh forests

3.3. RESULTS AND DISCUSSIONS

This component of the project dealing with the estimation of loss of forest goods (tangible services of forest ecosystems) reports monetary loss values according to various forest types (Rs. / ha) due to FF of 2019 in Uttarakhand and M.P. The mean monetary loss accounting for each of the forest goods in U.K. was highest for SPF-Sub-tropical Pine forests (170392 Rs. / ha) followed by HMTF- Himalayan Moist Temperate Forests (150243 Rs. / ha), ToF- Trees Outside Forest/plantation (51671 Rs. / ha), TMDF- Tropical Moist Deciduous Forests (40250 Rs./ ha) and lowest for TDDF- Tropical Dry Deciduous Forests (9595 Rs./ ha). Across the 42 polygons studied in U.K., the monetary loss value ranged between Rs. 9595 and 352752 / ha (Annexure-I). Similarly,in M.P. the mean monetary loss of the forest goods was estimated highest for TDDF- Tropical Dry Deciduous Forests (121888 Rs. / ha) and lowest for TMDF- Tropical Moist Deciduous Forests (92271 Rs. / ha). Across the 49 polygons studied in M.P., the monetary loss value ranged between Rs. 15892 and 249614 / ha (Annexure-II). The results of the entire study giving monetary loss values averaged across all the forest types and forest fire severity classes are summarized in Annexure 3. The average monetary loss (including all forest goods) due to FF was computed as Rs. 130387/ ha (Rs. 9696-352752/ ha) in U.K. and Rs. 114327 (Rs. 15892- 249614/ ha) across the studied polygons. Forests of U.K. were rich in flora, particularly MP (63 spp.) as compared to M.P. (41 spp.). However,in terms of tree species the forests of M.P. were richer (63 spp.) than the forests of U.K. (50 spp.) but the number of shrub species was greater in U.K. (45 spp.) than the forests of M.P. (31 spp.).

Considering slope as a factor of FF the monetary loss in polygons with > 18-degree slope was recorded higher (Rs. 138980/ha) than the polygons with > 18-degree slope (Rs. 102887/ ha) in Uttarakhand. Similarly, the highest monetary loss in M.P. was recorded in polygons with 0–5-degree slope (Rs. 150350/ha), followed by the polygons of 11-36 degree (Rs. 108566/ha), and lowest for 5–11 degrees slope (Rs. 101211/ha). Considering altitude as a factor of FF the monetary loss for Uttarakhand forest was computed highest in polygons having 1800-2200m altitude (Rs. 178473/ha), followed by 900-1800 m altitude (Rs. 162963/ ha), and minimum in 0-900 m altitude (Rs. 53527/ ha). Similarly, in M.P. forests the highest loss was recorded in polygons having 600-900 m altitude (Rs. 118692/ha), followed by 0-300 m altitude (Rs. 117982/ha), and minimum at 300-600 m altitude (Rs. 113330/ ha). Considering aspect as a factor the highest loss in Uttarakhand forests was recorded in the west aspect (Rs. 153285/ ha), followed by the north aspect (Rs. 136058/ ha), south aspect (Rs. 122775/ ha), and minimum in east aspect (Rs. 94597/ ha). In M.P. forests the highest loss was recorded in the east aspect (Rs. 123736/ha), followed by the north aspect (Rs. 114659/ha), west aspect (Rs. 113745/ha), and minimum at the south aspect (Rs. 106339/ha).

3.4. CONCLUSION

This pioneering study provided an opportunity to work on a subject of National importance. Although the constraints posed by the Covid pandemic have been substantial for undertaking field work, still we could carry out field work and generate crucial baseline data for this study. To sum up, across all the forest types in Uttarakhand the monetary loss of forest goods (Rs./ ha) due to FF was estimated in the order: SPF (17392)> HMTF (122788) > TDDF (32586) and ToF (51671) Table 6 a. In M.P. this value was estimated high for TDDF (121888) and low for TMDF (92271) Table 6 b (Annexure-III). However, it may be pointed out that the monetary values we have computed for timber, fuelwood and fodder should be considered in view of certain limitations. As all the burnt logs lying on the forest floor do not have a market value; all the ground herbage is not fodder,and all the trees and their branches/twigs are not used for fuel wood and do not bear fruits and other wild edibles. Also, in certain polygons, the positive effects of FF in terms of yield of MAPs/ NTFPs were not considered which needs further in-depth long-term studies. Also, the invasion of weeds following FF and reduced forest goods and services need to be looked into. A major limitation of this work was that this study was initiated in June 2020 under the restrictions of Covid-Pandemic, by this time the post-monsoon season of 2019 FF had already passed away. Further,participatory data collection and socio-economic valuation involving forest ecologists,economists and local communities should be an important part of such endeavours for policy-making and useful outputs and outcomes.

6a Uttarakhand

Table-6a
"Matrix for the loss (Rs./ ha) due to forest fire in different forest types in Uttarakhand "

(Values in parenthesis are range of monetary loss)

Losses of study	Forest type									
	Tropical Moist Deciduous Forests		Tropical Dry Deciduous Forests		Subtropical Pine Forests		Himalayan Moist Temperate Forests		Group-TOF/Plantation	
	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt
Forest produce	46,824 (20218-1,24837)	26,915 (21270-3,2560)	1,21328 (15892-2,49614)	9595	2,01,633 (13653-3,52752)	1,91,905 (1,66977-2,87532)	190024 (21270-2,80164)	217537 (1,19351-3,16473)	78105	38868 (21270-55639)

NA= There were no moderately burnt polygon (s) under Tropical Dry Deciduous Forests

6b Madhya Pradesh

Table-6b
"Matrix for the loss (Rs./ha) due to forest fire in different forest types in Madhya Pradesh"

(Values in parenthesis are range of monetary loss)

Losses of study	Forest type					
	Tropical Moist Deciduous Forests			Tropical Dry Deciduous Forests		
	Severe Burnt	Moderately Burnt	Low Burnt	Severe Burnt	Moderately Burnt	Low Burnt
Forest produce	115136 (92473-136006)	96155 (65974 - 134402)	83628 (34323-136006)	103348 (73170-133526)	120825 (15892-249614)	126287 (45469-222663)

NA= Forest types were not in Madhya Pradesh

4 Chapter

ECONOMIC LOSS ASSESSMENT OF HYDROLOGICAL CHANGES DUE TO FOREST FIRES

R.P. Pandey, J.V. Tyagi, P. Kumar,
P. K. Singh, R. Singh, and T. Thomas
NIH, Roorkee

4

4.1. INTRODUCTION

Forest vegetation plays an important role in the hydrological cycle by intercepting rainfall, reducing the velocity of raindrops, reducing runoff and increasing water infiltration. Fire, a common natural or anthropogenic phenomenon in forest ecosystems, affects the hydrology of the forested area particularly the moisture retention and recharge components. The forest fire is indirectly manifested in the post-fire changes in vegetationground cover, soil and environment affecting the components of the water cycle, water quality and aquatic life. The magnitude of the impact of forest fire varies with fire severity and frequency. Light wild fires or controlled fires do not affect the hydrology regime significantly but frequent burnings or intense fires can cause notable changes in the hydrologic regime nearly similar to that caused by clear cutting. Several studies conducted in different countries have pointed out that the effects of fire include reduction in infiltration rates increase in overland runoff, increase in soil erosion, nutrient losses,modifications in soil physicochemical properties and changes in vegetation dynamics. These changes in hydrological characteristics may also lead to economic loss to the ecosystem and society.

In India,very limited efforts have been made to understand the hydrological effects of fires. Therefore, it is necessary to assess and quantify the effects of forest fires through comprehensive hydrological studies of fire affected forest areas to answer many questions related to the hydrological changes. To fill the above knowledge gaps, this study has been carried out to assess the economic losses due to changes in hydrological behaviour caused by forest fires in Uttarakhand and Madhya Pradesh.

4.2. METHODOLOGY AND STUDY AREA

The paired polygon approach has been used in this study including field investigations,laboratory investigations,socio-economic surveys and the hydrological analysis and modelling at all the burnt polygons as well as at nearby unburnt (control)

Fig. 11

Index map of 42 selected burnt polygons in the forest areas of Uttarakhand

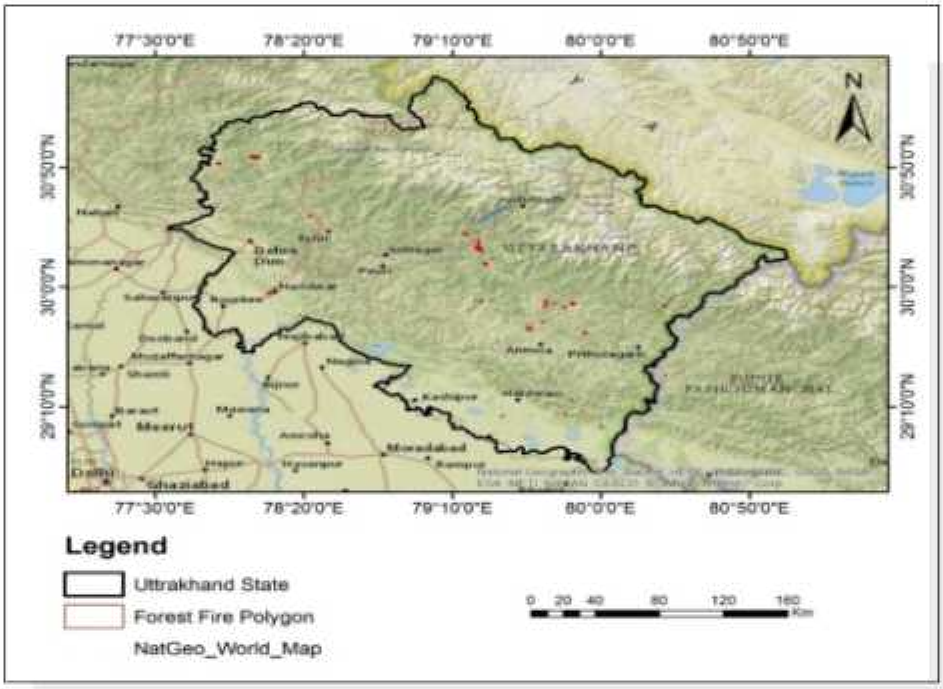


Fig. 12

Index map of 49 selected burnt plots in the forest areas of Madhya Pradesh

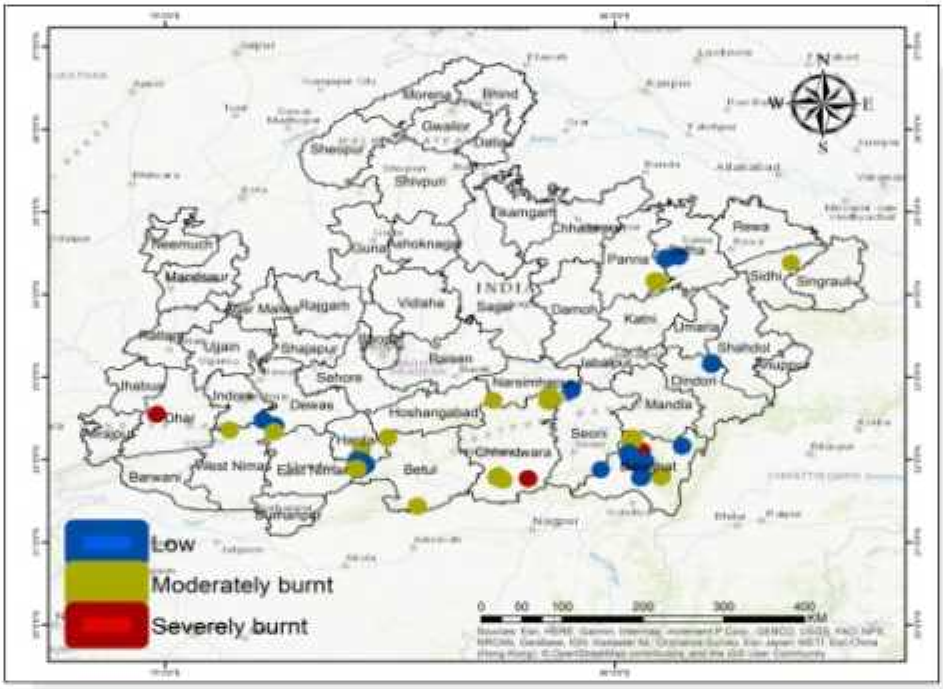


Fig. 13

Field investigations in Uttarakhand and Madhya Pradesh

Fig. 14

Laboratory investigations for analysis of soil samples

polygons. Index map of selected burnt plots in the forest areas of Uttarakhand and Madhya Pradesh are shown in Fig. 11 and Fig. 12. The field investigations involved the Infiltration Tests, the Guelph Permeameter Tests, physical verification of the site conditions and collection of soil samples for laboratory analysis (Fig. 13). Under the laboratory investigations, various hydrological,physical and chemical properties of the soils were analyzed (Fig. 14).

4.3. RESULTS AND DISCUSSION

4.3.1. ASSESSMENT OF CHANGE IN SOIL CHARACTERISTICS

The soils in Uttarakhand forest areas are mostly loamy skeletal and loamy as per the soil classification given by the National Bureau of Soil Survey and Land Use Planning, Nagpur (NBSS&LUP). The infiltration rates in the unburnt polygons vary between 2.46 cm/hr to 3.88 cm/hr and 1.02 cm/hr to 2.96 cm/hr, respectively for the loamy skeletal and loamy soil types. In the case of burnt polygons, these values vary from 2.28 cm/hr to 3.87 cm/hr and 0.51 cm/hr to 2.87 cm/hr, respectively. The average permeability rates in the unburnt polygons have been found to be 2.69 cm/hr and 1.65 cm/hr, respectively for the loamy skeletal and loamy soil types. In the case of burnt polygons, the corresponding values are 2.80 cm/hr and 1.70 cm/hr, respectively. The average soil moisture retention at field capacity in the unburnt polygons has been obtained as 11.80% and 15.46%, respectively for the loamy skeletal and loamy soil types. In the case of burnt polygons, the corresponding values were found as 11.25% and 15.52%, respectively.

The forest areas of Madhya Pradesh have mostly clayey and loamy soils as per the NBSS&LUP classification. The infiltration rates in the unburnt polygons range between 0.71 cm/hr to 2.46 cm/hr and 1.71 cm/hr to 3.80 cm/hr, respectively for the clayey and loamy soil types. In the case of burnt polygons, these values vary from 0.61 cm/hr to 1.91 cm/hr and 1.66 cm/hr to 3.45 cm/hr, respectively for the clayey and loamy soil types. The average permeability rates in the unburnt polygons have been found to be 0.89 cm/hr and 1.76 cm/hr, respectively for the clayey and loamy soil types. In the case of burnt polygons, these were found as 0.79 cm/hr and 1.56 cm/hr, respectively. The average soil moisture retention at field capacity in the unburnt polygons was obtained as 28.44% and 17.33%, respectively for the clayey and loamy soil types. In the case of burnt polygons, the corresponding values are 25.97% and 15.99%, respectively.

Summary statistics of soil properties of the burnt and unburnt polygons in the forest areas of Uttarakhand and Madhya Pradesh are given in Table 7. The hydrological study revealed that the infiltration rates and the permeability at unburnt (control) sites are relatively higher compared to that of the burnt forest sites. Typical changes in the infiltration rates are shown in Fig. 15 and Fig. 16 respectively for Uttarakhand and Madhya Pradesh. This is due to the deposition of finer ash particles of the burnt vegetation over the soil surface and into the soil pores. The deposition of the fine ash particles in the soil pores restricts the downward movement of water in the subsequent monsoon season causing coagulation and formation of soil aggregates that generally acts as a relatively less pervious medium and is responsible for relative reduction in the infiltration rate and permeability.

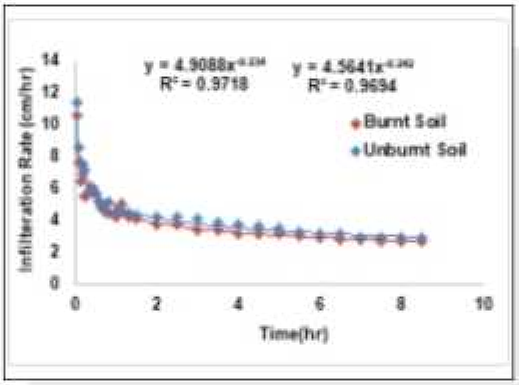
Typical changes in the soil moisture retention for the burnt and unburnt polygons in Uttarakhand and Madhya Pradesh are shown in Fig. 17 and Fig. 18 respectively. The soil moisture retention for the burnt plots has been found less in comparison to those of the unburnt plots. This may be attributed to the reduction in organic matter content which is the governing factor for soil moisture retention. Further,the analysis of Carbon-Hydrogen-Nitrogen-Sulphur (CHNS) components in the soil also confirmed that there is a significant reduction in CHNS content in the soil in the upper layer of burnt polygons and consequently reducing the soil moisture holding capacity in the burnt polygons.

Table-7 Summary statistics of soil properties of the burnt and unburnt polygons in the forest areas of Uttarakhand and Madhya Pradesh

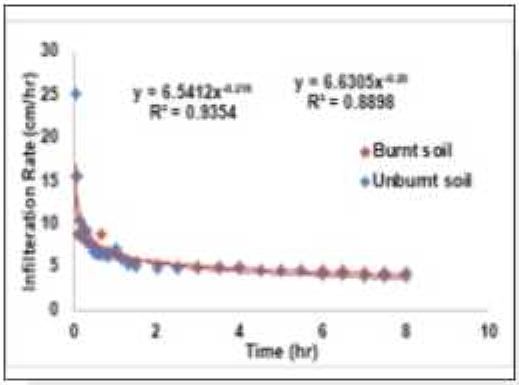
Uttarakhand								
	Infiltration Rate (cm/hr)		Permeability (cm/hr)		Field Capacity (%)		Wilting Point (%)	
	Burnt	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt	Unburnt
				Loamy Skeletal				
Average	3.25	3.27	2.80	2.69	11.25	11.80	5.40	5.66
Median	3.56	3.46	2.94	3.03	11.37	11.69	5.46	5.61
				Loamy				
Average	2.04	2.08	1.70	1.65	15.52	15.46	7.11	6.94
Median	2.13	2.16	1.84	1.78	14.86	15.24	7.11	7.40
Madhya Pradesh								
	Infiltration Rate (cm/hr)		Permeability (cm/hr)		Field Capacity (%)		Wilting Point (%)	
	Burnt	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt	Unburnt
				Clayey				
Average	0.99	1.13	0.79	0.89	25.97	28.44	11.69	13.36
Median	1.00	1.13	0.83	0.93	25.82	27.67	11.62	13.01
				Loamy				
Average	2.29	2.73	1.56	1.76	15.99	17.33	7.49	8.45
Median	2.19	2.35	1.59	1.86	16.08	16.28	7.41	7.98

Fig. 15

Typical changes in infiltration rates for the burnt and unburnt polygons in Uttarakhand



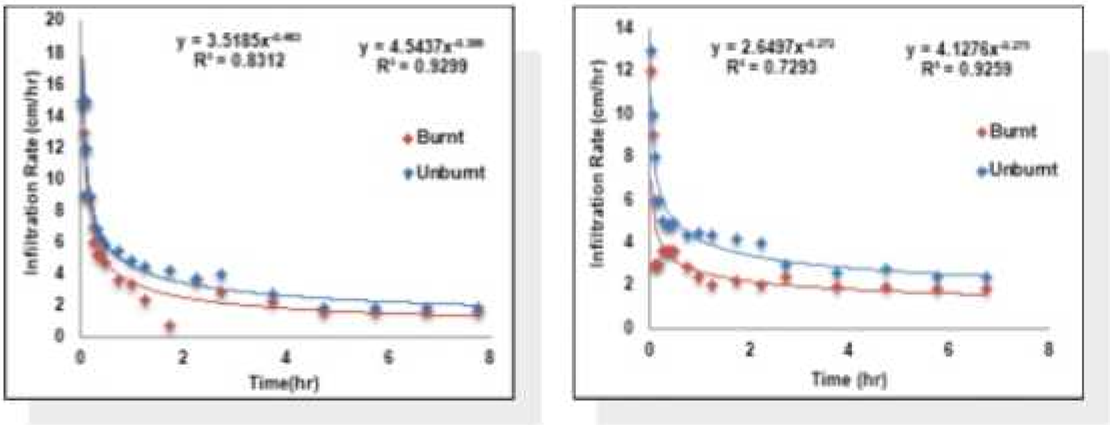
(a) Kishanpur Range (Low Burnt)



(b) South Jaspur Range (Moderately Burnt)

Fig. 16

Typical changes in infiltration rates for the burnt and unburnt polygons in Madhya Pradesh

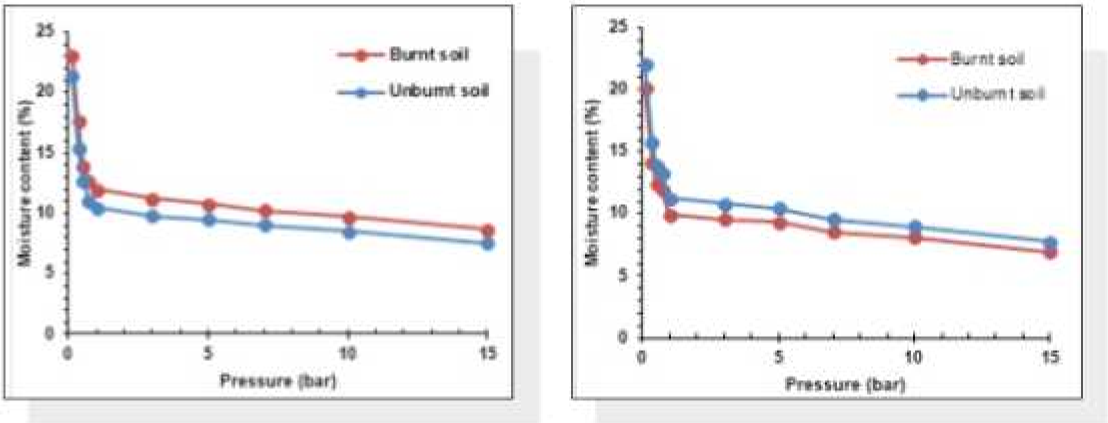


(a) Balaghat Range in MP (Low Burnt)

(b) Sidhi Range in MP (Moderately Burnt)

Fig. 17

Typical changes in soil moisture retention for the burnt and unburnt polygons in Uttarakhand

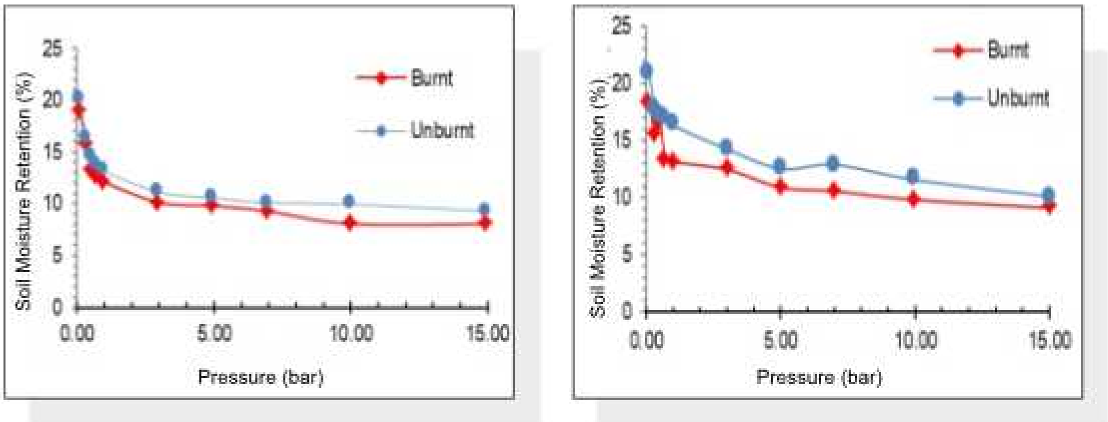


(a) Jaulkande forest site (Moderately Burnt)

(b) Ratarao forest site (Moderately Burnt)

Fig. 18

Typical changes in soil moisture retention for the burnt and unburnt polygons in Madhya Pradesh



(a) Usri forest site (Moderately Burnt)

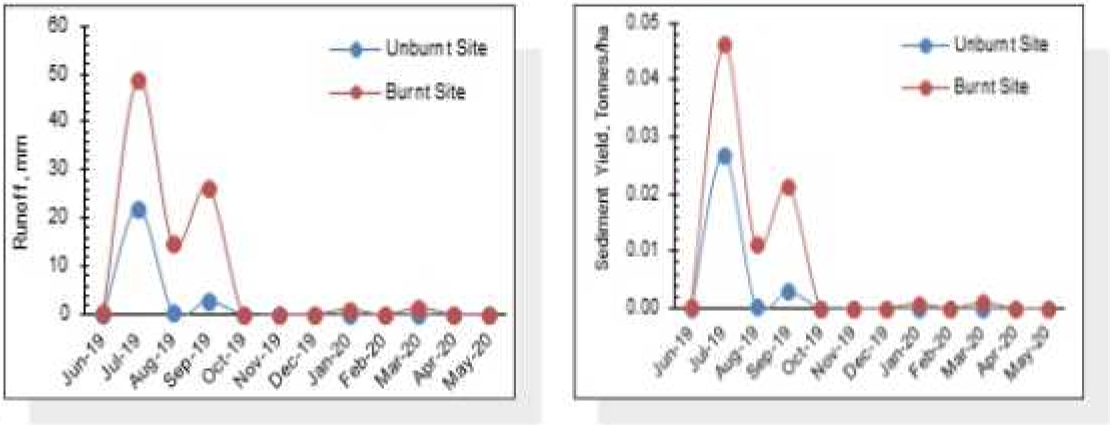
(b) Dongarbodi forest site (Severely Burnt)

4.3.2. ASSESSMENT OF HYDROLOGICAL CHANGES

For the assessment of runoff, the Soil Conservation Service - Curve Number (SCS-CN) methodology was used and the sediment yield has been estimated using the Modified Universal Soil Loss Equation (MUSLE). It was found that the runoff and sediment yields increased significantly after the forest fires. This is in line with the field and laboratory investigations, which show that the infiltration rates, permeability and soil moisture retention are decreasing after the forest fires. Typical changes in runoff and sediment yield can be seen in Fig. 19 and Fig. 20.

Fig. 19

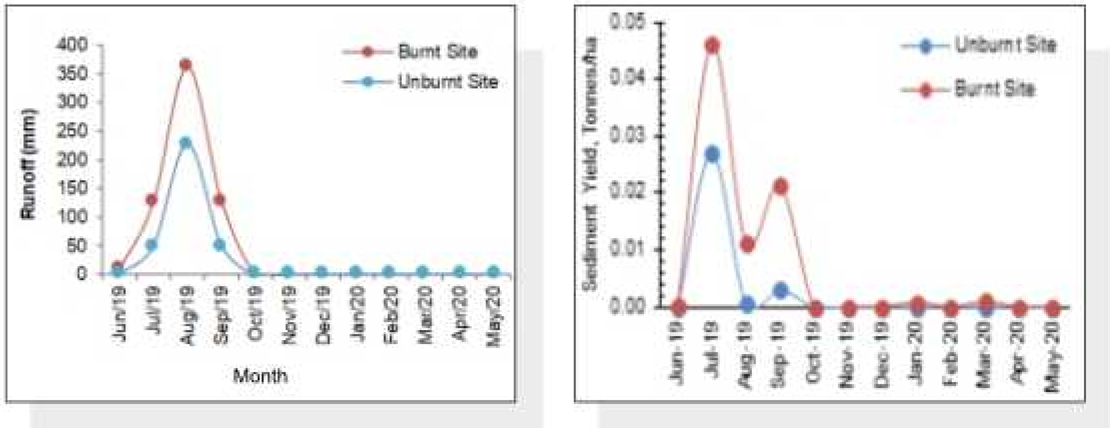
Estimated runoff and sediment yield for the burnt and unburnt polygons in South Jaspur Range in Uttarakhand (Low Burnt)



(a) Runoff in mm (b) Sediment Yield in Tonnes/ ha

Fig. 20

Estimated runoff and sediment yield for the burnt and unburnt polygons in Usri Range in Madhya Pradesh (Severely Burnt)



(a) Runoff in mm (b) Sediment Yield in Tonnes/ ha

4.3.3. ASSESSMENT OF MONETARY LOSSES

For the assessment of economic losses (net monetary losses) due to the hydrological changes caused by forest fires, the replacement cost method has been applied. Three hydrological variables i.e., change in runoff, change in sediment yield,and change in sub-surface water storage were considered in these assessments. The estimates of economic losses/gains due to the change in hydrologic behaviour of the burnt sites of Uttarakhand indicate that the value of SD (Rs.3392.72) is much higher than the mean value (Rs.2851.61) in the case of the low burnt category of polygons. The median value under the low burnt category is Rs.178.23, which seems to be a more realistic estimate due to the high magnitude of SD. In the case of moderate burnt polygons, the magnitude of SD (Rs.8731.15) is much higher than the mean value (Rs.4894.05). The median is Rs.1170.97. Since the median is not affected by minimum and maximum values, it is considered a better estimate than the mean. The overall estimate shows that the value of SD is much higher (Rs. 5119.80) than the mean value (Rs.3337.90), implying a high variation in the losses across polygons. The median value is Rs.1043.40, which seems to be a better estimate of the measurement of central tendency than the mean value. In the case of Madhya Pradesh, the median values were found as a better estimate of central tendency. The per hectare monetary losses due to changes in the hydrological indicators caused by forest fire escalate with the increase in the fire severity. The economic losses have been estimated at Rs.219.94 per hectare in low burnt, Rs.608.12 in moderately burnt, and Rs.958.01 in severely burnt polygons. Taking all polygons together, per hectare average losses comes out to Rs.421.35 when the median is considered and Rs.1168.62 if the arithmetic mean is taken into consideration.

4.4. CONCLUSIONS

The soil infiltration and permeability rates in burnt polygons have been found relatively less than those of unburnt polygons. The reason for the decrease in infiltration and permeability rates may be attributed to the repulsive behaviour due to the ashes of the burnt vegetation getting accumulated over the soil surface and soil pores. The deposition of the ash,as well as its downward movement in the subsequent monsoon season,causes coagulation and formation of soil aggregates that generally act as a relatively less permeable medium and thereby reducing the infiltration and permeability rates.

The soil moisture retention has been found to be decreasing due to forest fires. This is due to the reduction in organic matter content caused by the burning of upper soil layers. The presence of organic matter in soil is the foremost governing factor for soil moisture retention. The runoff and sediment yields in the burnt polygons have been found more than those in the unburnt polygons. The increase in runoff and sediment yield ultimately led to a decrease in sub-surface water retention/recharge after the forest fires. This is in line with the field and laboratory investigations,which show that the infiltration rates, permeability and soil moisture retention are decreasing after the forest fires. In the case of the forest fires in Uttarakhand, the economic losses due to hydrological change have been estimated as Rs.178.23 and Rs.1170.97, respectively for the low burnt and moderately burnt forest sites. In the case of the forest fires in Madhya Pradesh, the economic losses have been estimated as Rs.958.01, Rs.608.12 and Rs.421.35, respectively for the severely burnt, moderately burnt and low burnt.

8a Uttarakhand

Table-8a Matrix for the losses due to forest fire in different forest types in Uttarakhand

Losses of study	Forest type									
	Tropical Moist Deciduous Forests		Tropical Dry Deciduous Forests		Subtropical Pine		Himalayan Moist Temperate Forests		Group TOF/Plantation	
	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt
Hydrological loss	5550.57 (942.55 8333.33)	1382.31 (111.11 2653.50)	727.81 * (82.62 7055.67) *	4885.41 (1382.5 8388.28)	946.73 (264.14 5438.77)	178.24 (151.93-204.55)	3063.92 (105.12-11602.43)	86.17 (52.54 119.80)	1171.48 **	6121.66 (1140.07 (1103.24)
No. of Polygons	4	2	No polygon	2	18	2	9	2	1	2

* In Uttarakhand, no polygon existed in Moderately Burnt category in Tropical Dry Deciduous Forest in 2019, hence, the value of economic loss has been placed as that of the same type of fire severity class that occurred in the similar forest type in Madhya Pradesh.

** Only one polygon site is available for Moderately Burnt category in the forest type "Group - TOF/Plantation", therefore, the range cannot be given.

8b Madhya Pradesh

Table-8b Matrix for the losses due to forest fire in different forest types in Madhya Pradesh

Losses of study	Forest type					
	Tropical Moist Deciduous Forests			Tropical Dry Deciduous Forests		
	Severely Burnt	Moderately Burnt	Low Burnt	Severely Burnt	Moderately Burnt	Low Burnt
Hydrological loss	768.87 (72.83-1464.91)	132.88 (29.68-5450.23)	90.17 (33.95 7177.50)	958.01 (553.10 1388.08)	727.81 (82.62-7055.67)	305.69 (14.96 6583.01)
No. of Polygons	2	4	9	3	20	11

5 Chapter

ECONOMIC LOSS ASSESSMENT OF TERRESTRIAL FLORA DUE TO FOREST FIRE

P.K. Verma, D.K. Gupta,
J.V. Desai and D. Bhandari
ICFRE-FRI and ICFRE-TFRI

5.1. INTRODUCTION

Forest fires are now accepted as a natural part of ecosystem dynamics. There is evidence that forest fires happen in India both naturally and because of anthropogenic activities. The frequency of massive forest fire incidents appears to have increased in India, such as those in Uttarakhand in the 2016 summer (April–early June) which results not only in the loss of property but also in the loss of life. The main concern of national policymakers has been quantifying the loss of tangible benefits due to forest fires. In this pilot study on the states of Madhya Pradesh and Uttarakhand, an attempt has been made to quantify the losses in monetary terms. In this study, both institutes under ICFRE, Dehradun (FRI Dehradun and TFRI Jabalpur) were given components on quantification of terrestrial floral loss as well as five carbon pool losses among others.

5.2. STUDY AREA

The Forest Survey of India, Dehradun, validated the Forest Fire affected sites of 2019 and provided a list of 289 FF-affected polygons in the U.K. and 228 Forest Fire affected polygons in M.P. The ICFRE, Dehradun, further categorized the FF-affected polygons using several criteria and provided a list of 42 FF polygons (out of 289 polygons in the U.K.) and 49 FF polygons (out of 228 polygons in the M.P.) for intensive study. In M.P., the area of the studied polygons ranged from 3.607 to 3108.53 ha, with altitudes ranging from 252 to 930 a.m.s.l.

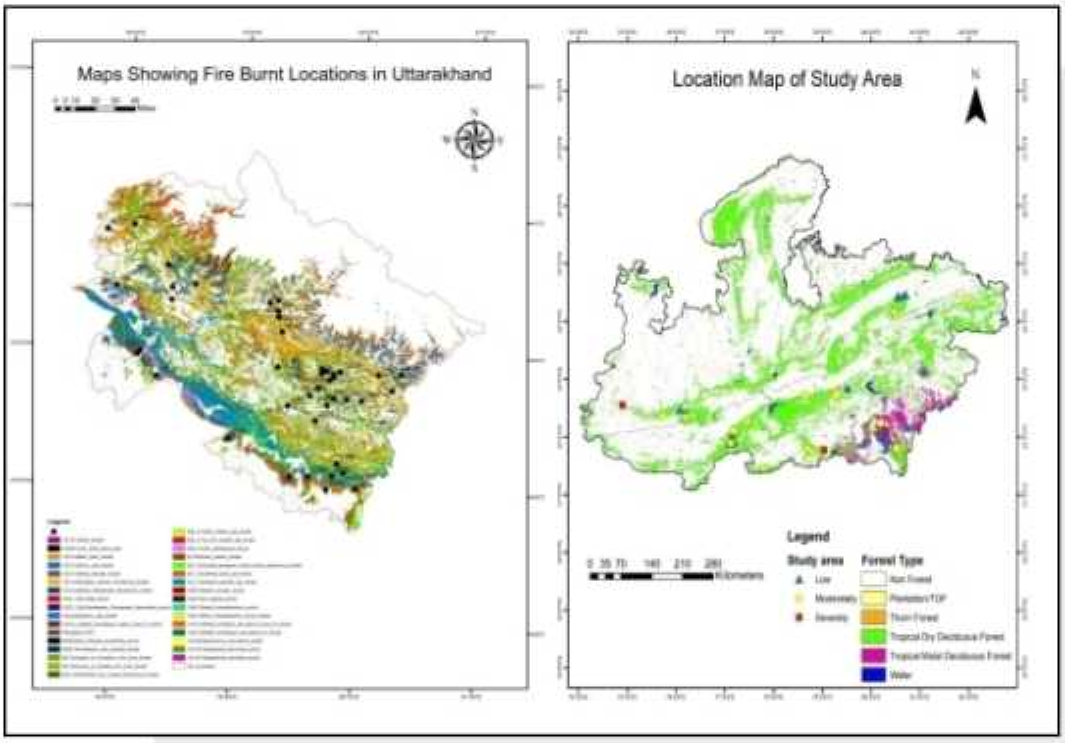
To estimate economic losses and vegetation changes, 49 burnt polygons and a similar number of control polygons in Tropical Moist Deciduous Forest and Tropical Dry Deciduous Forest were studied in Madhya Pradesh's 15 forest divisions. Uttarakhand has nine of India's 16 forest-type groups, four of which are vulnerable to forest fires. Most of the forest fires that occur in Uttarakhand are in Subtropical Pine forests, followed by Himalayan Moist Temperate forests. The severity of these fires is less in the lower parts of the state, which is dominated by Tropical Moist Deciduous Forest and Tropical Dry Deciduous Forest. Out of 289 polygons, 42 burnt polygons with a similar number of unburnt polygons in Tropical Moist Deciduous Forest, Tropical Dry Deciduous Forest, Subtropical Pine Forest, Himalayan Moist Temperate Forest, and ToF/Plantations located in different fire-prone forest divisions of Uttarakhand were selected for the present study. All 42 polygons fall under different forest divisions of Uttarakhand (Table 9).

Table-9 Forest divisions surveyed in Uttarakhand and Madhya Pradesh

States	Forest Divisions
Uttarakhand	Haldwani, Tarai Central, Tarai East, Tarai West, Haridwar, Rajaji National Park Division, Civil & Soyam Kalsi, Tons, Chakrata, Bageshwar, Almora, Pithoragarh, Nainital, Tehri, Binsar Wildlife Sanctuary, Almora, Badrinath and Kedarnath Wildlife Division
Madhya Pradesh	Barwah, Dhar, Dindori, Harda, Hoshangabad, Kanha National Park (Core), Khandwa, Narsinghpur, North Balaghat, Satna, Sidhi, South Balaghat, South Betul, South Chhindwara, and South Panna

The study was conducted in 0.10 ha plots in the states of Uttarakhand and Madhya Pradesh. In collaboration with NIH, and NIHE, two neighbouring plots (one burned and one unburned) of 0.10 ha size were also selected in each of the fire-prone forest types specific to the States based on the intensity and type of forest fire at different orography (altitude, slope, aspect) on the 49 sites in Madhya Pradesh and 42 sites in Uttarakhand provided by FSI, Dehradun (Fig. 21).

Fig. 21 Maps Showing Locations of Burnt Sites in Uttarakhand and Madhya Pradesh



5.3. METHODOLOGY

5.3.1. SAMPLING METHOD AND FREQUENCY

Using the concept of stratified random sampling under proportional allocation (with certain restrictions as per availability), the variable-wise number of sampling units was calculated for each category. From 2020 to 2022, the polygons in both states were surveyed. Herbaceous layer data were gathered for both the pre- and post-monsoon seasons. The quadrat-nested method has been used for vegetation sampling for tree, shrub, and understory flora. The phytosociological data for trees, shrubs, and herbs were collected from random quadrates of 10m × 10m, 5m ×5m, and 1m × 1m in size for biodiversity and carbon stock assessment. Total carbon stock loss (t/ha) in five pools (AGB (herbs and shrubs), BGB (deadwood, litter, and soil) was calculated by subtracting the value of the burned sites from the value of the control sites. In order to determine the monetary value ($/ha) of the loss caused by FF, the total carbon stock loss (t/ha) was multi plied by the monetary value of carbon ($50 per t).

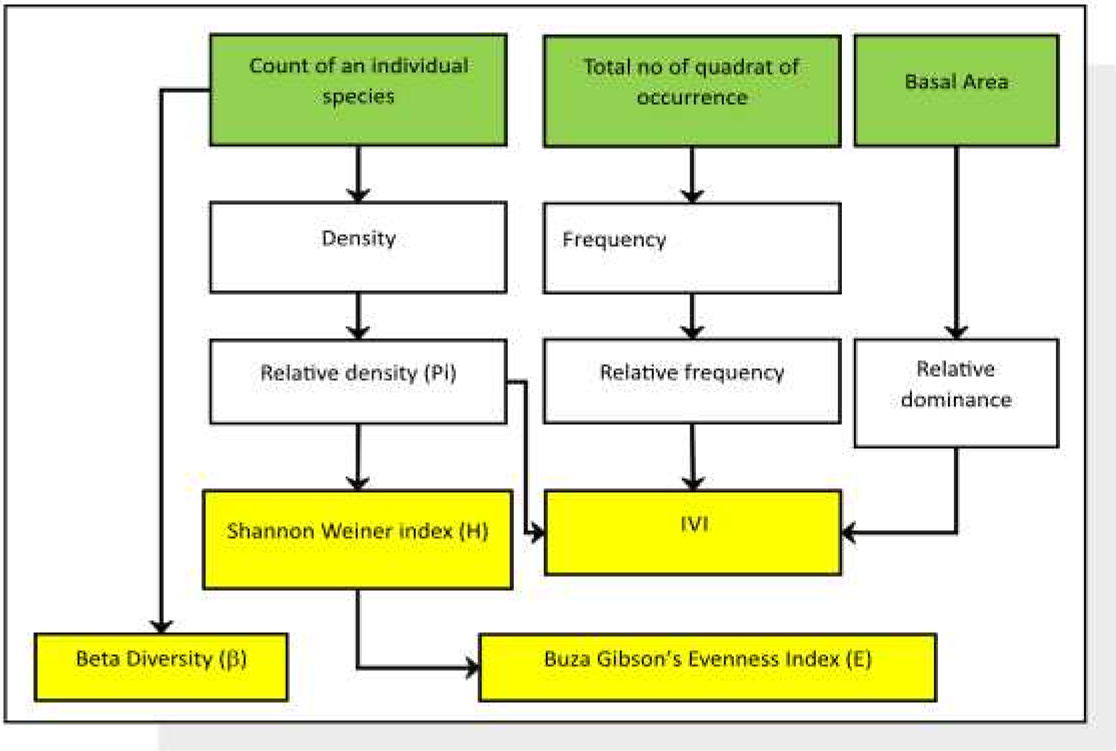
5.3.2. ASSESSMENT OF FLORAL DIVERSITY

The quantitative analysis of Phyto-social parameters was drawn from the vegetation survey. The biodiversity indices,such as the Important Value Index (IVI), Shannon-Wiener Diversity Index (H), Buzas and Gibson's Evenness Index (E), and Beta Diversity Index (β), were calculated to determine the changes in floral biodiversity between burnt and unburnt sites (Table 10 and Fig. 22). The Shannon-Wiener Index was calculated for diversity, which is based on a quantitative measure that reflects how many different species are in a given sample area.

Table-10 List of Bio-diversity indices and their purpose

Sl	Index	Purpose	Range
1	Importance Value Index (IVI)	Dominance of the plant species	0-300
2	Shannon-Wiener Diversity Index (H')	Species diversity	0-5
3	Buzas and Gibson's Evenness Index (E)	Evenness Index	0-1
4	Beta diversity index (ß)	Species dis-similarities	0-1

Fig. 22 Flowchart depicting methodology for the calculation of biodiversity indices



5.4. ASSESSMENT OF CARBON STOCK FOR 5 CARBON POOLS

5.4.1. ASSESSMENT OF CARBON STOCK IN TREES

Tree biomass was calculated using allometric equations. The below-ground tree biomass of trees was calculated using 0.28 times above-ground tree biomass as per the rules of the Intergovernmental Panel for Climate Change (IPCC, 2006). The carbon content was calculated as 0.475 times of the total dry biomass of trees.

The AGB and BGB have been calculated for all sites but not added to the total carbon pool as tree layers have not been completely destroyed or burned by forest fire in any of the forest types of the studied polygon as the nature of fire was surface. In some of the polygons especially in subtropical pine forests in Uttarakhand, the fallen tree logs were found in both burnt and unburnt sites (possibly due to landslides, wind-thrown, diseased, anthropogenic disturbance, and forest fire), and the carbon content of the fallen logs was calculated using an allometric equation and then added to the deadwood biomass carbon pool.

5.4.2. ASSESSMENT OF CARBON STOCK IN HERBS AND SHRUBS

The carbon stock for the shrub and herb layer has been calculated based on direct estimates using dry biomass. The carbon content was calculated as 50% of the total dry biomass of the collected herbs and shrubs. The Below Ground Biomass (BGB) or carbon was calculated as 1/3 of above-ground biomass or carbon.

5.4.3. ASSESSMENT OF CARBON STOCK IN LITTER AND DEADWOOD

The carbon content was calculated as 50% of the total dry biomass of the collected litter and deadwood. The fallen logs enumerated in the field were included in the calculation of deadwood. The Biomass and carbon of the fallen log were calculated from the total weight from field-based observation or proportion basis.

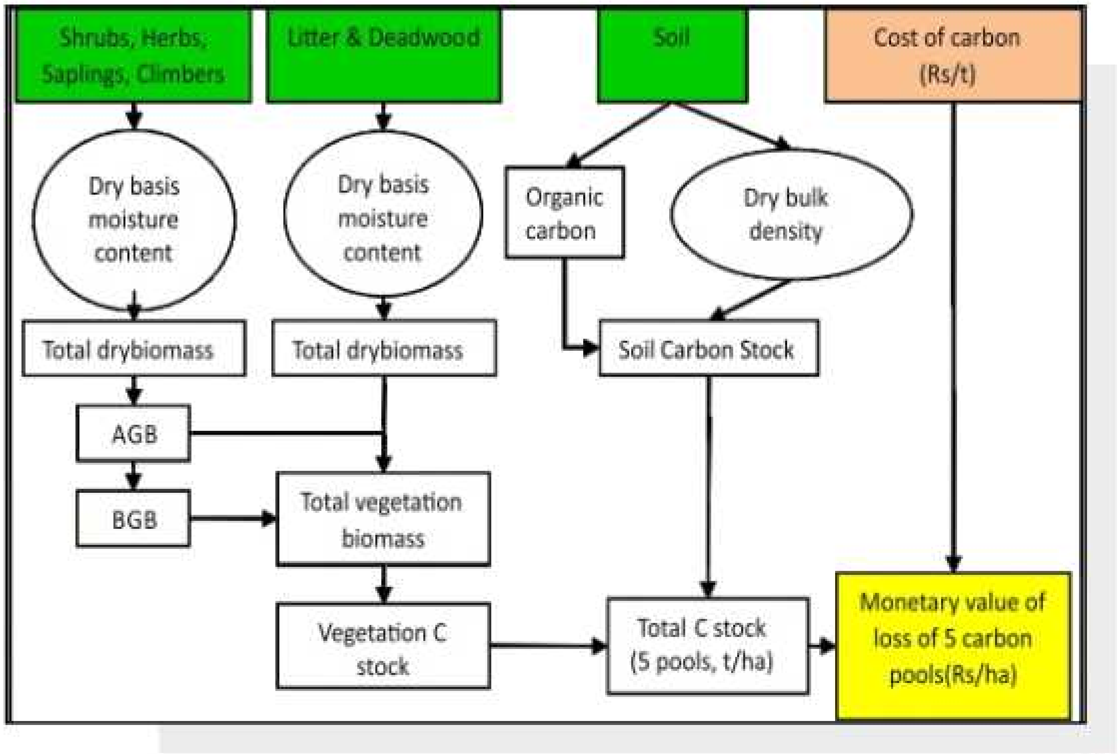
5.4.4. ASSESSMENT OF CARBON IN SOIL

Soil samples were collected for the depth (d) of 30 cm for organic carbon estimation and Carbon stock in soil was determined by the following formula.

Soil Carbon Stock = d * BD * % Organic carbon

Fig. 23

Flowchart depicting methodology for the calculation of the monetary value of carbon stock



5.4.5. CRITERIA FOR ESTIMATION OF LOSSES

The Delta method was used, which is the difference between the concerned vegetation parameter with its two scenarios,viz., control and burnt.

Vegetation Losses

Loss in vegetation = Vegetation parameter _Control− Vegetation parameter _Burnt

Losses in 5 pools carbon stock

Losses in 5 pools carbon stock = 5 pool C stock _Control- 5 pool C stock _Burnt

While calculating the average losses, the median was adopted as a measure of central tendency as the coefficient of variation was very high. Also, a median is unaffected by the extremes.

5.5. RESULTS AND DISCUSSIONS

In Uttarakhand and Madhya Pradesh, 42 and 49 sites respectively, were investigated on the ground, but none of them had experienced the crown fire. All sites were only impacted by surface fire, hence the standing trees and related BGB were unaffected. Therefore, only shrubs, herbs, litter, deadwood, and soil carbon were damaged. The monetary value of loss and damage due to forest fires in the states of Uttarakhand and Madhya Pradesh is given in Table no. 11 and 12 given below.

Table-11 Carbon and monetary loss based on forest types and fire severity in Uttarakhand

Sl. No.	Forest Types	Fire intensity	Loss Carbon (t/ha)	Loss (Rs/ha) (Median)	Ranges (Rs/ha)
1.	Tropical Moist Deciduous Forest	Moderate	4.76	17,619	13351-23339
		Low	0.86	3,179	1055-4026
2.	Tropical Dry Deciduous Forest	*Moderate	4.40	16,276	*5,362-55,761
		Low	2.17	8,026	**8026
3.	Sub-Tropical Pine Forest	Moderate	6.31	23,332	10,130-37,808
		Low	1.43	5,287	***-2,705-11,541
4.	Himalayan Moist Temperate Forest	Moderate	9.77	36,126	23,974-42,830
		Low	-0.185	-684	***-8,947-7,563
5.	ToF/Plantation	Moderate	6.21	22,962	**22,962
		Low	2.71	10,020	**10,020

* In Uttarakhand no fire occurred in moderate severity class in Tropical Dry Deciduous Forest in 2019 hence the value taken from the same type of severity class fire occurred in Madhya Pradesh.

** Only one site is available due to which no range is present.

*** The negative value in Sub Tropical Pine Forest and Himalayan Moist Temperate Forest in low severity class indicates the accumulation of carbon is higher in burnt areas than in unburnt areas which can be due to the negligible impact of low fire on biomass and carbon.

Table-12 Carbon and monetary loss based on forest types and fire severity in Madhya Pradesh

Sl. No.	Forest Types	Fire intensity	Loss Carbon (t/ha)	Loss (Rs/ha) (Median)	Ranges (Rs/ha)
1.	Tropical Moist Deciduous Forest	Severe	5.78	21,354	19,376-23,332
		Moderate	5.27	19,489	12,572-26,401
		Low	4.68	17,329	2,514-27,326
2.	Tropical Dry Deciduous Forest	Severe	5.60	20,670	2,884-72,918
		Moderate	4.40	16,276	5,362-55,761
		Low	2.15	7,977	1,109-59,754

The loss of carbon stock in 5 C pools between the burnt and control sites was categorized forest type-wise. However,the change was not significant with respect to fire severity. This may be due to a delay of 2-3 years in data collection by the time the sites passed through at least 2 consecutive years of rainy seasons (from 2019 to 2021) in the case of Madhya Pradesh

With the exception of shrubs, it has been shown that a forest replenishes its vegetation and diversity in a 2–3-year cycle. In fire-affected areas, the density of invasive shrub species increased while shrub species richness decreased in Uttarakhand and Madhya Pradesh. Fire reduces the shrubs' basal area because it completely burns the shrub layer, which then sprouts from underground live buds. Because of the increase in light brought on by the burning of tree and shrub branches and twigs, the number and diversity of herbaceous plants also increases after a fire in Uttarakhand and Madhya Pradesh.

5.5.1. UTTARAKHAND

In Uttarakhand, the moderately burnt forest shows more diversity in terms of species as compared to the unburnt site. The Buzas-Gibson's evenness index shows higher evenness in unburnt sites than burnt in all forest types. While in low-burnt fires, there are very few differences in terms of various indexes. β-diversity is used for better knowledge of compositional heterogeneity between two communities, which are burnt and unburnt in this study. In Tropical moist deciduous forests, the β-diversity has been calculated from 0.114 to 0.432; in Tropical dry deciduous forests, β-diversity is calculated 0.343; in Subtropical Pine Forests, β-diversity calculated from 0.106 to 0.528; in Himalayan moist temperate forests, β-diversity calculated 0.161 to 0.814; in ToF/Plantations β-diversity calculated 0.388 to 0.710. In addition, lists of bryophytes (37 species), lichens (31 species) and Invasive species (25 species) are also prepared for unburnt and burnt sites. The various ecosystem goods (timber for construction as well as fuel-wood purpose, fodder, gums and resin, medicinal plants, aromatic oil, green manure and other NTFP produce etc.) provided by plant species (Total-386) in all studied forest types also enumerated (Trees-82, Shrubs-56, Herbs-248).

5.5.2. MADHYA PRADESH

In Madhya Pradesh, In Tropical moist deciduous forests, the β-diversity has been calculated from 0.08 to 0.57; in Tropical dry deciduous forests, β-diversity is calculated from 0.07 to 0.056 for a better understanding of community heterogeneity due to forest fire. The various ecosystem goods (timber for construction as well as fuel-wood purpose, fodder, gums and resin, medicinal plants, aromatic oil, green manure other NTFP produce etc.) provided by plant species (Total- 272) in all studied forest types also enumerated (Trees- 88, Climbers - 21, Shrubs -25, Herbs -138).

In Madhya Pradesh, eleven invasive species viz., *Ageratum conyzoides, Chromolaena odorata, Hyptis suaveolens, Lantana camara, Parthenium hysterophorus, Pogostemon benghalensis, Senna tora, Spigelia anthelmia, Synedrella nodiflora, Tridax procumbens*, and *Urena lobata* established in almost all natural and semi-natural ecosystems, like protected areas,become in the agents of drastic environmental changes by threatening the native biodiversity. One of the regions of invasion of invasive species in natural forests is forest fire. Interestingly, in Uttarakhand, invasive species like *Lantana camara, Ageratum conyzoides, Galinsoga parviflora, Imperata cylindrica, Bidens pilosa, Erigeron karvinskianus, Parthenium hysterophorus* and *Senna tora,* have been reported in both the burnt and unburnt sites as most of the forests in the region repeatedly burnt, especially in the case of Subtropical Pine Forest and Himalayan Moist Temperate Forests. The presence of invasive species in an unburnt plot evidentially proves how past fires have been affected a lot by the change in herbaceous diversity due to the invasion of the invasive species over the native species in both forest types. In the case of tropical moist deciduous forests and tropical dry deciduous forests, the cause of the invasion of species in unburnt plots is fire and flood, apart from other anthropogenic factors.

5.6. CONCLUSION

The terrestrial floral damage and losses due to forest fire have been studied, and different biodiversity indices (Important Value Index, IVI, Shannon Wiener Index, Buzas and Gibson's evenness index, and β-diversity) were calculated. The Shannon-Wiener Index was calculated for diversity, which is based on a quantitative measure that reflects how many different species there are in any provided sample area. The moderately burnt forest shows more diversity in terms of species as compared to the unburnt site. The Buzas-Gibson's evenness index shows higher evenness in unburnt sites than burnt in all forest types. While in low-burnt fires, there are very few differences in terms of various indexes. β-diversity is used for better knowledge of compositional heterogeneity between two communities, which are burnt and unburnt. The estimated cost of damage and losses of five carbon pools in all forest types studied are already presented in Tables 11 and 12.

This component of the study also summarizes the numerous ecosystem goods provided by plant species in forest fire-affected forest types. The threatened species reported from fire-prone forest types have also been generated based on field observations and published literature. It is important to study the loss just after the incidence of fire because the rain afterwards provides an opportunity for the seed bank present in the soil to re-sprout, and it will be very difficult to estimate the loss on a real-time basis. Hence, it is advised that recent fire points be used for the study and pre-monsoon conditions to be considered properly for the real-term estimation of damages.

Table-13a Matrix for the losses due to forest fire in different forest types in Uttarakhand

13a Uttarakhand

Losses of study	Forest type									
	Tropical Moist Deciduous Forests		Tropical Dry Deciduous Forests		Subtropical Pine Forests		Himalayan Moist Temperate Forests		Group TOF/Plantation	
	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt
Carbon pool (Rs./ha)	17,619 13,351- 23,339)	3,179 1,055 4,026)	* 16,276 5,362- 55,761)	8,026 (single observation)	23,332 10,130- 37,808)	5,287 (2,705 11,541)	36,126 (23,974- 42,830)	684 8,947 7,563)	22,962 (single observation)	10,020 (single observation)

For Carbon Pool: *In Uttarakhand no fire occurred in moderate severity class in Tropical Dry Deciduous Forest in 2019 hence the value taken from the same type of severity class fire occurred in Madhya Pradesh. The negative value in Sub Tropical Pine Forest and Himalayan Moist Temperate Forest in low severity class indicates the accumulation of carbon is higher in burnt areas than in unburnt areas which can be due to the negligible impact of low fire on biomass and carbon

Table-13b Matrix for the losses due to forest fire in different forest types in Madhya Pradesh

13b Madhya Pradesh

Losses of study	Forest type					
	Tropical Moist Deciduous Forests			Tropical Dry Deciduous Forests		
	Severe Burnt	Moderately Burnt	Low Burnt	Severe Burnt	Moderately Burnt	Low Burnt
Carbon pool (Rs. /ha)	21,354 19,376 23,332)	19,489 (12,572 - 26,401)	17,329 (2,514 - 27,326)	20,670 (2,884 - 72,918)	16,276 5,362 55,761	7,977 1,109 59,754

6 Chapter

ECONOMIC LOSS ASSESSMENT OF FAUNAL DIVERSITY DUE TO FOREST FIRE

*B.S. Adhikari, S. Lyngdoh,
and D. Chatterjee
WII, Dehradun*

6

6.1. INTRODUCTION

A million hectares of the world's forests are destroyed by fire each year, causing monetary losses in the form of timber and real estate as well as harm to recreational values and fatalities. The current study "Estimation of Economic losses in real term per hectare basis due to forest fire in Uttarakhand and Madhya Pradesh" was planned as a pilot study with the specific goal of estimating the economic losses brought on by forest fire to wildlife and biodiversity, timber and hydrological parameters. The responsibility of assessing the economic loss of faunal diversity due to forest fires on a per-hectare basis in Uttarakhand and Madhya Pradesh was assigned to the Wildlife Institute of India. Based on their adaptation, resilience and durability, wildlife responds to fire in different ways. Due to the loss of crucial habitat and food sources burnt in the fire, most wildlife fatalities occur after the fire has been put out. In order to develop preventive and efficient management methods for the long-term sustainability of species and protection of overall biodiversity in the landscapes, an estimated economic loss assessment is essential. The goals of WII were first to investigate how forest fires impact animals and habitats and then estimate the financial losses resulting from potential species loss or displacement. It was crucial to understand whether a species existed in areas where a fire had occurred so that losses or affected populations of species could be assessed.

Independent spatial predictions of suitable habitat distribution models were generated for every species encountered while sampling. The topography, anthropogenic, bioclimatic, Land Use Land Cover and vegetative covers utilizing Normalized difference vegetation index were chosen as the environmental and eco-geographical predictor variables because of their potential influence on habitat. After establishing a prospective habitat design, FSI Fire Scars 2019 and Forest Types data were used to anticipate the area lost to species due to forest fire in each of their respective habitat types. As part of a systematic approach, information on species density in the same forest types was acquired from several literature sources across India to estimate the approximate number of species that are adversely affected by forest fires.

Regarding monetary assessments, while Protected Areas and Zoological Parks have equivalent ecological advantages, the value of wildlife species was predicated on the conservation costs associated with ex-situ interventions on animal management, well-being,breeding, etc. However, it was impossible to calculate the actual worth of in-situ conservation in Protected Areas with reference to animals alone because no direct attributes could be used as evaluators for the value of biodiversity protection. Because wildlife conservation is a non-use value offered by the Zoos (similar to Pas), a methodology was developed based on a contingent valuation technique for calculating a minimum cost after accounting for provisioning, cultural and supporting ecosystem services. This was done for the main objective which involved computing the economic losses caused by faunal diversity.

6.2. STUDY AREA

Uttarakhand is situated in the north-western part of our country between 28°44' and 31°28' North latitudes and 77°35' and 81°01' East longitudes. Of the total geographical area (53483 km^2) of the Uttarakhand state, nearly 71% is covered with forests. Various kinds of forest types are found in the state viz. Sal, Shisham and Acacia forests in the Tropical region, Chir pine and broadleaved deciduous forests in the sub-tropical region, various kinds of Oak forests (*Quercus leucotrichophora, Q. lanata* and *Q. floribunda*), Mixed-broadleaved forest (Aesculus, Juglans and Acer) in a temperate region and Kharsu oak, Silver fir and Birch forests in the sub-alpine region.

The state of Madhya Pradesh with 45 districts covering 443000 km^2 lies between 21°17' and 26°52' N Latitude and 74°28' and 82°49' E Longitude. Twenty-five percent of the state's total land is covered by forests. Significant variances between the state's different forest types are caused by climatic variability. There are four types of forests: sub-tropical broadleaved hill forests,tropical moist forests, tropical dry forests and tropical thorn forests. Three major forest formations are discernible based on composition: teak forests, sal forests and miscellaneous forests. The western and northern parts of the state are relatively lacking in forest cover compared to the central, southern and eastern regions which are rich in composition.

Given that the faunal and floristic habitats of Binsar and Nandhaur Wildlife Sanctuary (WS) in Uttarakhand and Ratapani and Nauradehi Wildlife Sanctuary (WS) in Madhya Pradesh are similar to those of the entire state, they were chosen as state representatives to carry out the loss assessment study. Sampling in these protected areas offered an overview of species that may have been affected due to fire, allowing the computation of the corresponding loss amounts.

Binsar WS lies between 29° 30' and 29° 43' N latitudes and 79° 41' and 79° 47' E longitudes in Uttarakhand at the top of Jhandi Dhar hills, north of Almora district. The sanctuary's hilltops and slopes are covered in pure or mixed strands of chir pine,ban oak and rhododendron. It is home to animals like the leopard, barking deer, serow, rhesus monkey, jackal, pheasants, partridges, great barbets, magpies, etc. The Nandhaur WS is located in the Terai Bhabar region of the Shiwalik range and is home to a variety of animals including tigers, sloth bears, swamp deer, and elephants among others. The majority of Nandhaur's landscape is located within the Haldwani Forest Division.

Ratapani and Nauradehi WS in Madhya Pradesh contain an exceptionally rich diversity of ecologically important species. In the Raisen district of MP, Ratapani WS is home to tigers, leopards, hyenas, spotted deer, sambars, blackbuck, antelopes and other animals. Tropical dry deciduous forests, dry grasslands, teak forests and dry deciduous scrubs are the dominant types of forests found in Ratapani WS. Between latitudes 23° 5' to 23°43' N and longitudes 79° 5' to 79° 25' E, Nauradehi WS lies in Sagar, Damoh and Narsinghpur districts of MP. Tropical dry deciduous forest, being the predominant forest type in Nauradehi WS, is home to a variety of animals, including blue bulls, spotted deer, tigers, leopards, sambar, hyenas, jackals, porcupines and civets.

Fig. 24

Fire Severity map of Uttarakhand (a) and Madhya Pradesh (b)

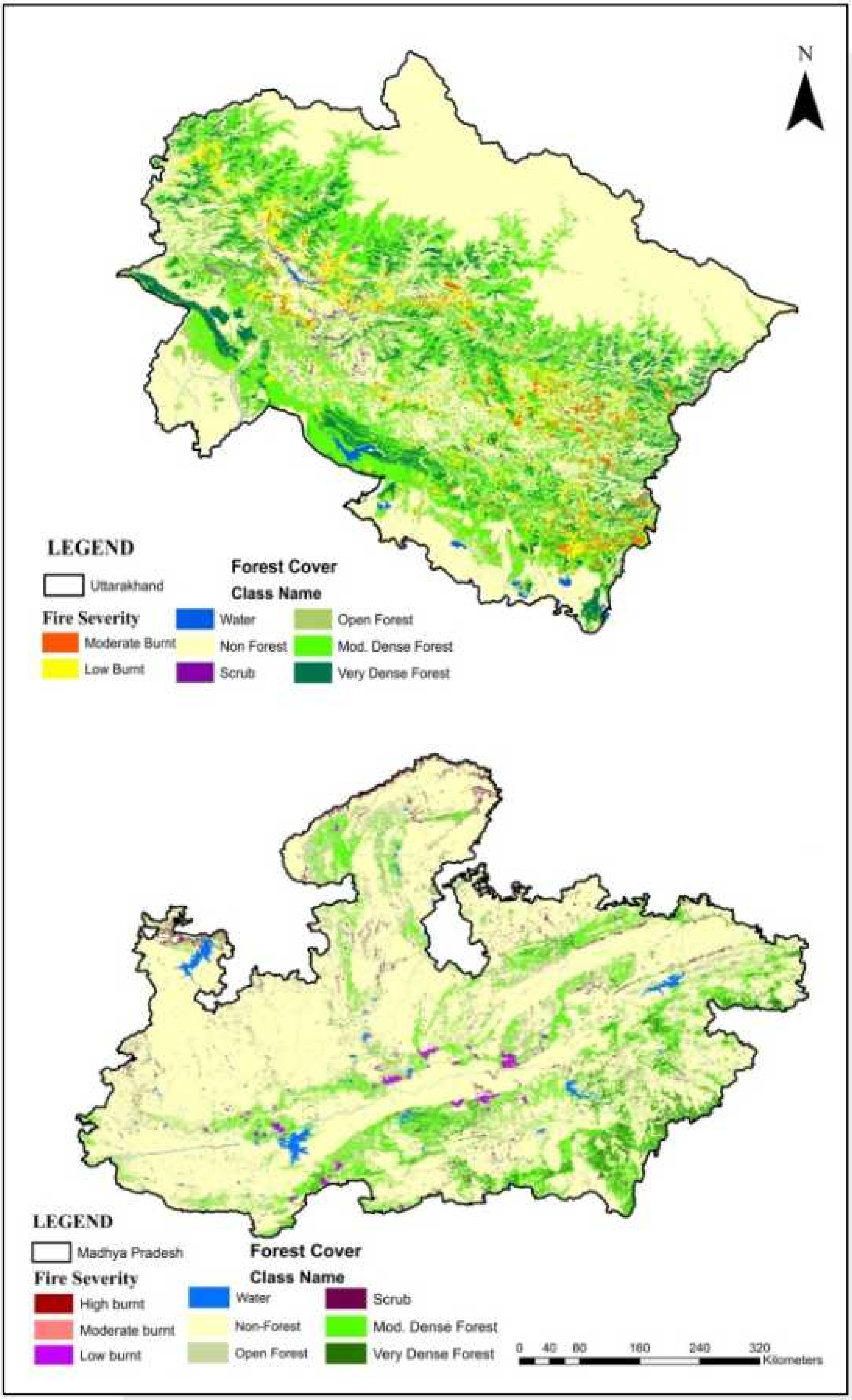


Fig. 25

Fire severity classes in representative study sites in Uttarakhand

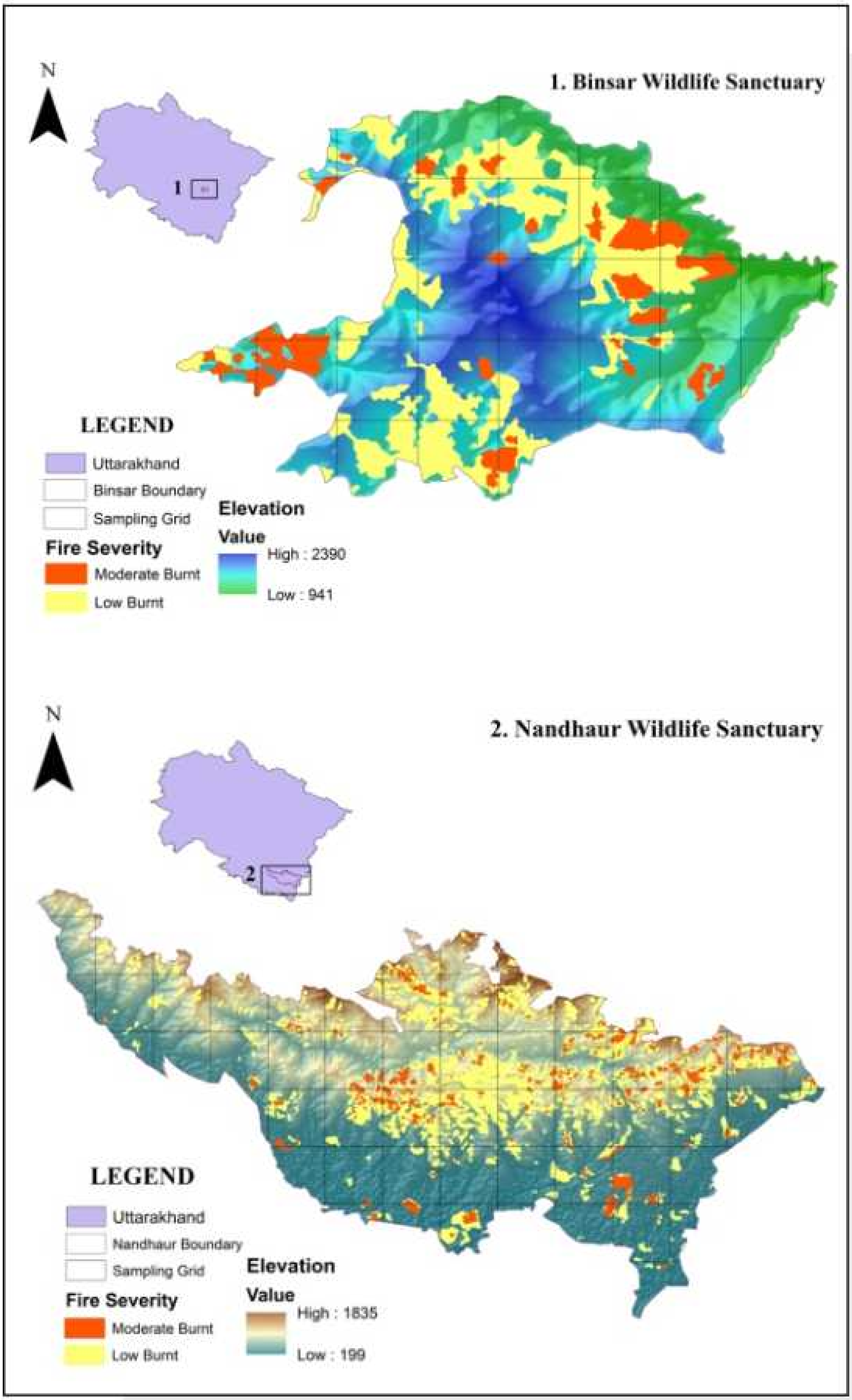
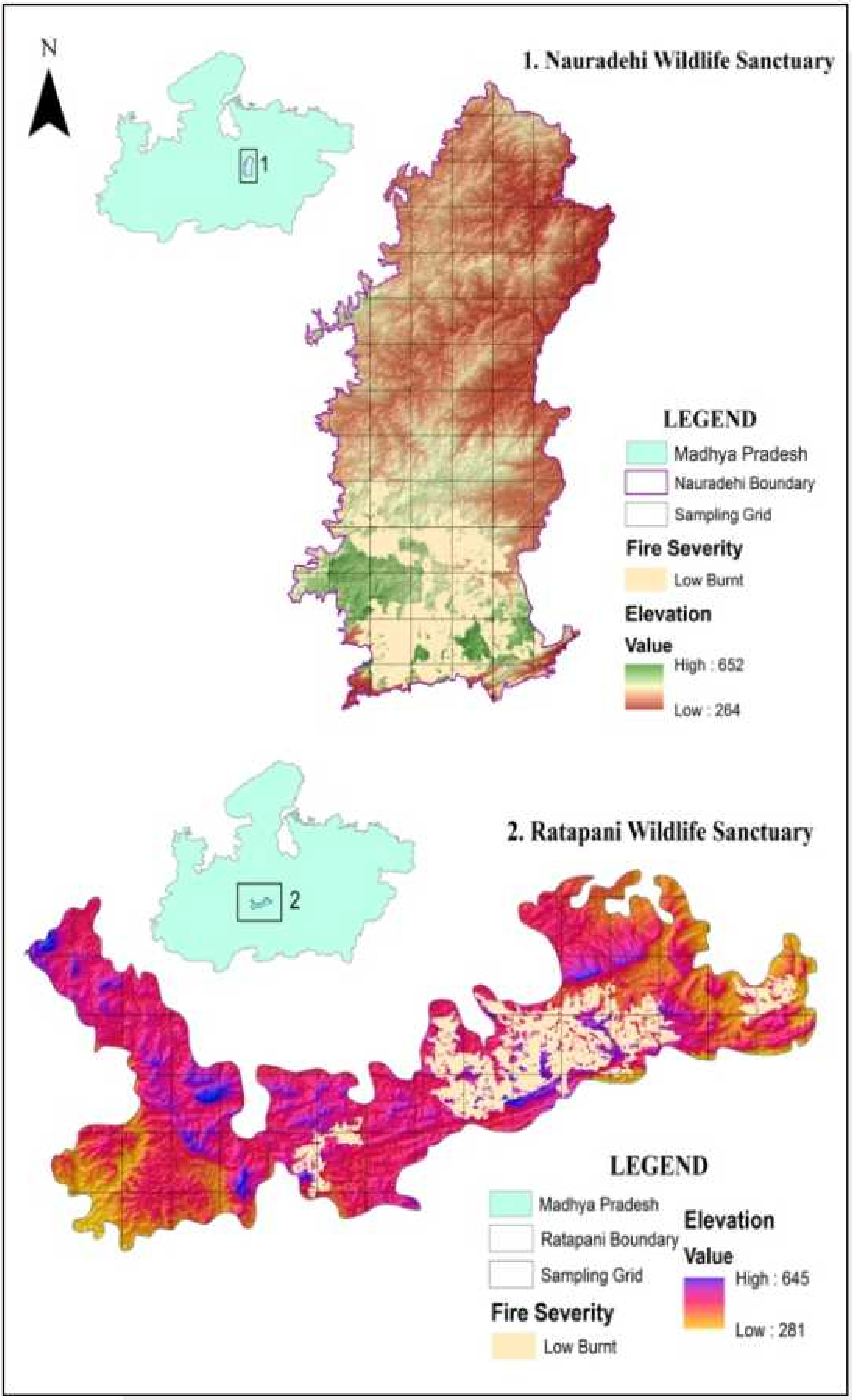


Fig. 26

Fire severity classes in representative study sites in Madhya Pradesh



6.3. METHODOLOGY

To generate geographic representations of the species' habitat distributions, field information and satellite data analytics were integrated. The representative study areas were divided into 5*5 km grids (2*2 km in the case of Binsar WS due to its small territory) to collect GPS coordinates of the faunal diversity, employing camera trapping, transect survey and sign survey. Habitat distributions of the species observed were modelled within the specific protected area using the field data points and merging them with the satellite layers of various environmental and eco-geographic parameters having a potential influence on the natural environment of the species. The geographical positions of the species were compiled according to their order such as carnivores, herbivores and omnivores, whenever the GPS coordinates of a species were insufficient to carry out the distribution modelling. With the objective of predicting the area lost to species due to forest fire in each of the particular habitat categories, fire scars provided by FSI and forest types were overlaid on the habitat design. A methodological approach was utilised that involved evaluating species density in the same forest type gathered from several literature sources across India in order to determine an approximate number of species affected by forest fires. The proportion of density in the primary (high and medium) habitat zones of species was only considered to prevent overestimating the affected individuals[1]. These individual species figures were subsequently employed to calculate the real-time economic loss due to forest fires on a per-hectare basis. The minimum care requirement of species was estimated while taking ex-situ conservation into account with the goal of calculating the economic losses to wildlife. Information on animal care and management from local zoological parks (G.B. Pant High Altitude Zoo, Nainital, Uttarakhand and Van Vihar National Park and Zoo, Bhopal, Madhya Pradesh) was retrieved with the aim of calculating the per-unit yearly expenses of species rearing. To determine the range of economic damages, similar information from the National Zoological Park in Delhi and the Arignar Anna Zoological Park in Tamil Nadu was utilised to estimate the annual cumulative rearing expenses for faunal diversity[2]. The stature, regional expansion and national significance of these parks were taken into account when choosing them. By dividing the entire cost of rearing all species present in a particular protected area (PA) by the extent of degraded habitat, the total wildlife loss in INR per hectare in each PA was calculated[3]. To calculate the variation in economic damages caused to wildlife in specific forest types, a 2-step indirect computation[4] was conducted. A systematic flowchart to help comprehend the procedure as given below:

---

[1] Proportional Density Calculation: -

Average habitat lost = (Area in species high and medium habitat potential zone) * Degraded Area/100

New Prooortional density = (Average habitat lost * Selected Density)/100.

[2] The first interval value is taken from the average financial loss of Chennai and Delhi 200s while the second interval value is determined from a nearby (state) Zoo for each forest type and fire severity.

[3] Given their adaptability and resilience in the face of a fire front,ground-dwelling animals like reptiles, amphibians and birds like the Galliformes should have their overall estimated rearing costs reduced by 25%

[4] In case of single forest type and fire type, like in Madhya Pradesh: -

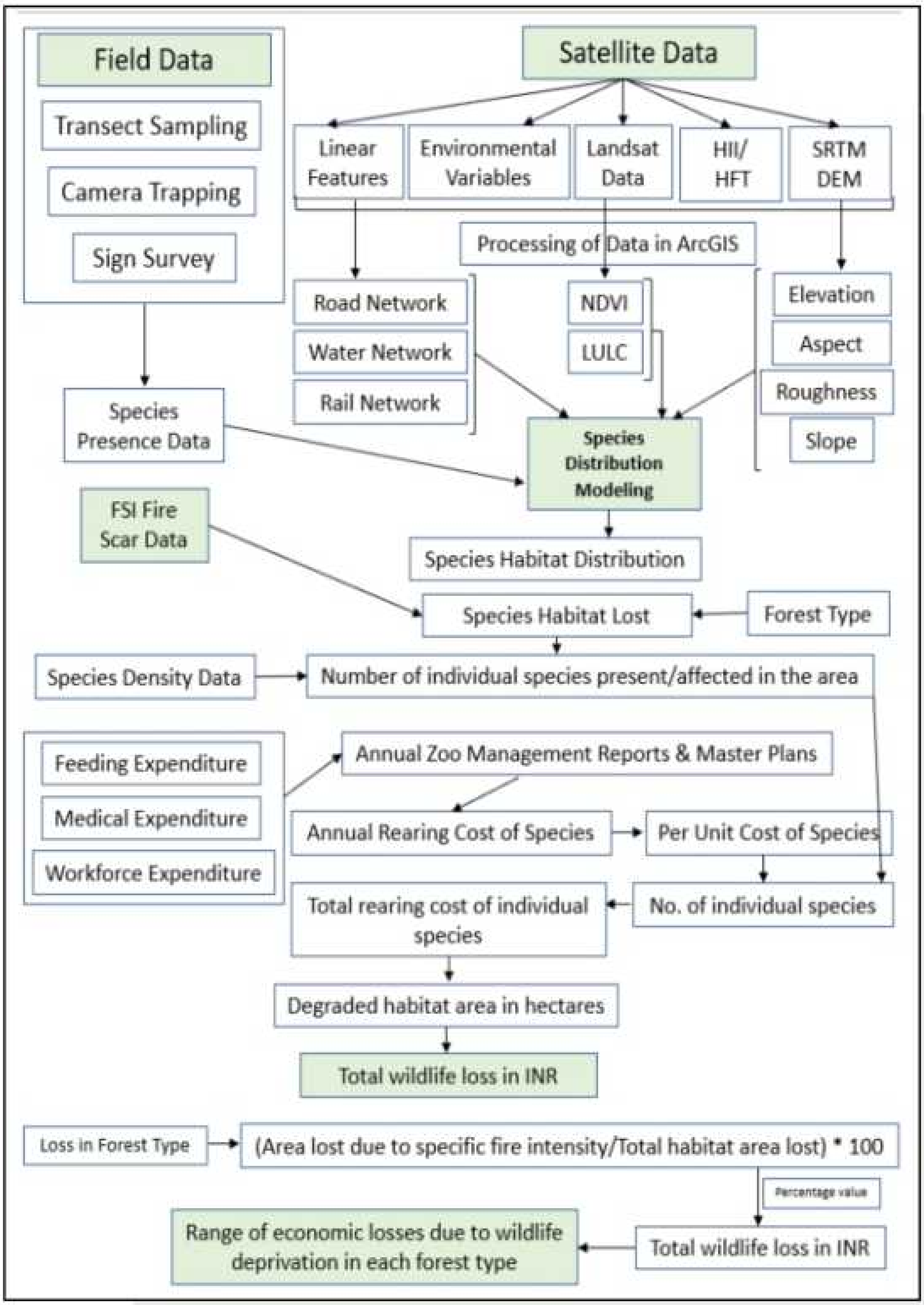
Loss = Amount incurred from wildlife loss from both selectec Protected Areas.

Due to the single forest type and fire intensity in the PAs of Madhya Pradesh, the first interval value is derived from the summation of the average values of economic losses from Chennai and Delhi Zoos and the second interval vaiue is deliver from the summation of nearby (state) Zoos.

The vegetation regeneration factor (annual mean NDVI rates) was subtracted from the base figure of tropical Crydeciduous forests (low fire severity in Ratapani and Nauradehi WS) in Madhya Pradesh in order to calculate ine monetarylosses in tropical moist deciduous forests (concerning all fire severities) and tropical dry deciduous forests (moderate anghigh severity).

Fig. 27

Methodological Flowchart



6.4. RESULTS

With the help of FSI's 2019 fire scar data for Uttarakhand and Madhya Pradesh, identification of areas impacted by fire across both protected and unprotected forests in the respective states was possible. Throughout Uttarakhand, there were a total of 4897 fire scar polygons. Under low and moderate fire severity, five prominent forest types–tropical moist temperate, tropical moist deciduous, tropical dry deciduous, subtropical pine and a small portion of plantation zones- were detected with 3467 and 1430 polygons respectively. Similar to this, two primary forest types, tropical moist deciduous forests and tropical dry deciduous forests were identified in MP with low fire severity represented by 166 polygons, moderate fire severity represented by 57 polygons and high fire severity represented by 5 polygons, for a total of 228 polygons overall. Using this information, the area damaged in each forest type at our sample sites in Uttarakhand and Madhya Pradesh for all fire severities were examined.

Table-14
Forest type and corresponding areas lost in representative study sites

State	Protected Area	Forest type	Low burnt		Moderate burnt	
			Polygon	Area lost (km^2)	Polygon	Area lost (km^2)
Uttarakahnd	Binsar Wildlife Sanctuary	Himalayan Moist temperate	7	1.6	5	1.5
		Subtropical Pine	23	14.7	18	4.3
		Tropical Dry Deciduous			1	0.08
		Total	30	16.3	24	5.8
	Nandhaur Wildlife Sanctuary	Himalayan Moist temperate	33	3.9	12	1.6
		Tropical Moist deciduous	280	105.3	106	17.15
		Tropical Dry deciduous	7	2.2	6	0.6
		Subtropical Pine	99	25.2	50	7.3
		Plantation	9	1.035	4	2.6
		Total	428	137.7	178	29.3
Madhya Pradesh	Ratapani Wildlife Sanctuary	Tropical Dry deciduous	4	106	-	-
	Nauradehi Wildlife Sanctuary	Tropical Dry deciduous	1	165	-	-

Table 14 shows that in Binsar WS, areas with low and moderate forest fire severity have respectively deteriorated by 16.3 km^2 and 5.8 km^2, with subtropical pine forests suffering the most damage. Likewise, in Nandhaur WS, the highest degradation is seen in tropical moist deciduous forests where 137.7 km^2 and 29.3 km^2 areas have been impacted due to low and moderate fire intensities, respectively. Low forest fire intensity in the tropical dry deciduous forests of Ratapani and Nauradehi WS caused the degradation of 106 km^2 and 165 km^2 of surface, respectively.

All the species reported from the representative PAs of Uttarakhand and Madhya Pradesh are represented in Table 15 in terms of their pre-fire and post-fire habitat distribution scenarios. In Uttarakhand, field surveys indicated the presence of threatened species such as the leopard, goral, tiger and Asiatic black bear. In Madhya Pradesh, four-horned antelope, sloth bears, leopards, tigers and sambars were spotted. Leopard has lost 1.5 km^2 from its high habitat zone in Binsar WS, 8.3 km^2 from its medium habitat zone, 8.1 km^2 from its low habitat zone and 3.4 km^2 from its very low habitat zone. Similar habitat damages were observed in Goral's high, medium, low and very low habitat zones, reaching 2.4 km^2, 8.2 km^2, 7.2 km^2 and 3.4 km^2, respectively. Forest fires in the Nandhaur WS also significantly destroyed the natural habitat zones of carnivorous, herbivorous and omnivorous species. The habitat of the four-horned antelope in Ratapani deteriorated to various degrees in its high, medium, low and extremely low habitat zones, reaching 11.6 km^2, 32.5 km^2, 40.7 km^2 and 20.8 km^2, respectively. Wildfires caused habitat destruction for tigers as well, primarily in their low habitat zone where 47.9 km^2 of land was lost. The habitat loss assessment findings for other species are also summarised below:

Table-15 Habitat distribution scenarios of the encountered species

Protected Area	Species (IUCN Status)	Fire regime	Habitat Zone (km²)			
			High	Medium	Low	Very Low
Uttarakhand						
Binsar WS	Leopard (V)	Before Fire	5.5	22.3	24	17.3
		After fire	1.5	8.3	8.1	3.4
	Goral (V)	Before Fire	4.5	22.9	23.1	18.5
		After fire	2.4	8.2	7.2	3.4
	Galliformes (LC)	Before Fire	3.4	13.6	20.2	31.7
		After fire	0.5	4.5	8.1	8.2
	Barking deer (LC)	Before Fire	4.8	26.1	18.9	19.1
		After fire	0.3	8.1	8.6	4.5
	Wild boar (LC)	Before Fire	1.6	19.8	24.3	23.2
		After fire	0.04		9.	6.7
	Indian crested Porcupine (LC)	Before Fire	2.7	30.8	22.6	13.1
		After Fire	0.4	10.3	9.1	1.5
	Carnivores (Tiger,Leopard) (V)	Before Fire	27.1	54.6	313.5	479.1
		After Fire	1.4	6.3	53.8	102.8
Nandhaur WS	Omnivores (Asiatic black bear,Sloth bear) (V)	Before Fire	43.9	275.6	387.8	158.7
		After Fire	9	47.5	80.6	27.1
	Herbivores (Barking deer, spotted deer, blue bull etc.) (LC)	Before Fire	22.6	65.3	119.7	662.6
		After Fire	1.2	6.5	17.3	139.2
Madhya Pradesh						
Ratapani WS	Four-horned Antelope (V)	Before Fire	58.3	119.5	263.3	328.7
		After Fire	11.6	32.5	40.7	20.8
	Sloth Bear (V)	Before Fire	45.6	96	210.7	405.2
		After Fire	9	17.7	32	46.8
	Leopard (V)	Before Fire	70.7	188.4	331.2	167.3
		After Fire	17.4	26	42.4	19.8
	Tiger (En)	Before Fire	66	192.1	326.5	172.5
		After Fire	7.4	18.2	47.9	32
	Striped Hyena (NT)	Before Fire	74.9	225.6	371.4	85.7
		After Fire	21.5	41.6	38.2	4.2
Nauradehi WS	Golden Jackal (LC)	Before Fire	87.1	169.5	386.3	608.2
		After Fire	0.7	11.8	40.6	109.1
	Blue Bull (LC)	Before Fire	100.7	232.3	423.9	494.4
		After Fire	7	17.7	39.7	97.8
	Sambar (V)	Before Fire	72.2	120	280.3	778.7
		After Fire	0.14	4.2	34.4	123.6
	Wild boar (LC)	Before Fire	107.8	235.7	423	504.7
		After Fire	7.7	16.5	37.2	101.4

As shown in Table 16, the yearly predicted cost of wildlife losses resulting from wildfires in Binsar WS is estimated to be Rs. 5872 (five thousand eight hundred seventy-two rupees only) followed by Nandhaur WS in Uttarakhand at Rs. 10048 (ten thousand forty-eight rupees only). Considering representative study sites in Madhya Pradesh, Ratapani WS is predicted to lose Rs. 3369 (three thousand three hundred sixty-nine rupees only) per hectare annually due to wildlife depletion followed by Nauradehi WS at Rs. 8148 (eight thousand one hundred forty-eight rupees only) due to forest fire.

Table-16 Rearing costs of species (per individual) and corresponding economic losses to wildlife

Protected Area	Species Class	Density (km²)	Degraded Habitat Area (km²)	Individual species affected	Per unit Rearing cost of species in INR	Total rearing cost of affected species in INR	Total wildlife loss in INR
Uttarakhand							
Binsar WS	Mammals	0.15	21.3	3	2331148.8	6993446.4	5872
	Birds	2.18		46	468432	21547873.4	
Nandhaur WS	Carnivores	0.001	164.20	1	4267761	4267761	10048
	Omnivore	0.003		1	924201	924201	
	Herbivores and Prey species	0.563		92	1284866	118207672	
	Galliformes and other birds	2.18		358	464746	166379068	
Madhya Pradesh							
Ratapani WS	Four horned Antelope	0.15	105.5	16	438364	7013824	3369
	Striped Hyena	0.01		1	452673	452673	
	Leopard	0.01		1	452673	452673	
	Sloth Bear	0.01		1	470803	470803	
	Tiger	0.01		1	452673	452673	
	Galliformes and other birds	5.6		590.8	180427	106632357	
	Reptiles	-		-	183870	183870	
Nauradehi WS	Wild boar	0.18	162.4	29	418019	12122551	8148
	Blue bull	0.87		141	260755	36766455	
	Sambar	0.02		4	260755	1043020	
	Golden Jackal	0.57		92	449419	41346548	
	Galliformes and other birds	5.6		909.4	180427	164008143	
	Reptiles	-		-	183870	183870	

Table 17 quantifies the total costs associated with rearing animals across several zoological parks to demonstrate the economic losses resulting from wildfires. In Binsar WS, the minimum loss from wildfires is Rs. 1602 (one thousand six hundred two rupees only) with a maximum loss of Rs. 5872 (five thousand eight hundred seventy-two rupees only) and an average loss of Rs. 3028 (three thousand twenty-eight rupees only). The yearly potential losses per hectare in Nandhaur WS range from Rs. 2448 (two thousand four hundred forty-eight rupees only) to Rs. 10048 (ten thousand forty-eight rupees only) with an aggregate cost of Rs. 5226 (five thousand two hundred twenty-six rupees only). In Ratapani WS, the annual probable minimal loss per hectare is Rs. 607.8 (six hundred seven rupees only) with an upper bar of Rs. 3369 (three thousand three hundred sixty-nine rupees only) and an aggregate cost of Rs. 1581 (one thousand five hundred eighty-one rupees only). The yearly potential losses per hectare in Nauradehi WS range from Rs. 5543 (five thousand five hundred forty-three rupees only) to Rs. 8148 (eight thousand one hundred forty-eight rupees only) with an aggregate cost of Rs. 6729 (six thousand seven hundred twenty-nine rupees only).

Table-17 Monetary loss computed by different zoos in INR per hectare per annum

PAs	Nearby Zoo	Chennai Zoo	Delhi Zoo	Average cost
Binsar WS	5872	1609.6	1602	3028
Nandhaur WS	10048	3183	2448	5226
Ratapani WS	3369	766	607.8	1581
Nauradehi WS	8148	6496	5543	6729

As shown in Table 18, due to low fire intensity, tropical moist deciduous forests and subtropical pine forests in Uttarakhand experienced the highest economic losses from forest fires with losses ranging from Rs. 1773.7 (one thousand seven hundred seventy-three rupees only) to Rs. 6330.0 (six thousand three hundred thirty rupees only) and Rs. 1490.3 (one thousand four hundred ninety rupees only) to Rs. 5411.8 (five thousand four hundred eleven rupees only) respectively.

As shown in Table 19, tropical dry deciduous forests in Madhya Pradesh suffered the greatest economic losses ranging from Rs. 6706.4 (six thousand seven hundred six rupees only) to Rs. 11517.0 (eleven thousand five hundred seventeen rupees only) as a result of low forest fires.

Table-18 Range of monetary losses per hectare per annum in Uttarakhand

Forest Type	Monetary Losses (INR)	
	Moderately Burnt	Low Burnt
Tropical Moist Deciduous Forests	281.6-1004.8	1773.7-6330.0
Tropical Dry Deciduous Forests	15.8-56.3	36.6-130.0
Subtropical Pine Forests	433.3-1574.1	1490.3-5411.8
Himalayan Moist Temperate Forests	134.4-489.0	180.4-653.8
Plantation	42.2-150.7	17.0-60.3

Table-19 Range of monetary losses per hectare per annum in Madhya Pradesh

Forest Type	Monetary Losses (INR)		
	Severely Burnt	Moderate Burnt	Low Burnt
Tropical Moist Deciduous Forest	5600.0-9616.7	5676.4-9748.0	5566.4-9,559.0
Tropical Dry Deciduous Forest	4171.4-7163.6	4023.8-6910.0	6706.4-11517.0

6.5. CONCLUSION

This research facilitated an assessment of the overall financial damage caused by forest fires in Uttarakhand and Madhya Pradesh. It was understood that tropical moist deciduous forests and subtropical pine forests in Uttarakhand and tropical dry deciduous forests in Madhya Pradesh experienced severe economic strain. It is advised to develop effective fire prevention strategies especially in these types of forests to conserve valuable resources that come from both wildlife and the vegetation that serves as their habitat.

20a Uttarakhand

Table-20a Matrix for the losses due to forest fire in different forest types in Uttarakhand

Losses of study	Forest type									
	Tropical Moist Deciduous Forests		Tropical Dry Deciduous Forests		Subtropical Pine Forests		Himalayan Moist Temperate Forests		Group TOF/ Plantation	
	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt	Moderately Burnt	Low Burnt
Wildlife loss	281.6 1,004.8	1773.7 6,330	15.8-56.3	36.6-130.0	433.3-1,574.1	1490.3 5,411.8	134.4-489.0	180.4 653.78	42.2-150.7	17.0-60.3

20b Madhya Pradesh

Table-20b Matrix for the losses due to forest fire in different forest types in Madhya Pradesh.

Losses of study	Forest type					
	Tropical Moist Deciduous Forests			Tropical Dry Deciduous Forests		
	Severe	Moderately	Low Burnt	Severe	Moderately	Low Burnt
Wildlife loss	5,600.0 - 9,616.7	5,676.4 - 9,748.0	5566.4 - 9,559.0	4171.4 - 7,163.6	4,023.8 - 6,910.0	6,706.4 - 11,517.0

Fig. 28

Mammals reported from Uttarakhand

Fig. 29

Mammals reported from Madhya Pradesh

7 Chapter

CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

The present study on "Estimation of economic losses in real terms per hectare basis due to forest fire in Uttarakhand and Madhya Pradesh" following the forest fires of 2019 in the identified affected polygons in Uttarakhand (42 polygons) and Madhya Pradesh (49 polygons) has been a pioneering comprehensive attempt of a team of project researchers from six various Research and Development organizations for two years. The main parameters to assess the loss due to forest fire consist of timber, non-wood forest produce, flora biodiversity, carbon sequestration, soil carbon stock, microflora and wild fauna,loss of habitat, soil, hydrology, erosion, sediment and people's dependency on forest resources covered under ecosystem services such as provisioning, supporting,regulating and cultural category. The cumulative result of forest fire losses in different forest types in Uttarakhand and Madhya Pradesh are summarised in the matrix below.

Uttarakhand

Table-21 Cumulative result of forest fire losses in different forest types in Uttarakhand

Particulars of Losses of study	Forest type									
	Tropical Moist Deciduous Forests		Tropical Dry Deciduous Forests		Subtropical Pine Forests		Himalayan Moist Temperate Forests		Group TOF/ Plantation	
	Moderately	Low Burnt	Moderately	Low Burnt	Moderately	Low Burnt	Moderately	Low Burnt	Moderately	Low Burnt
Carbon pool (ICFRE) (Rs./ha)	17,619 (13,351-23,339)	3,179 (1,055-4,026)	*16,276 (5,362-55,761)	8,026 (single observation)	23,332 (10,130-37,808)	5,287 (-Rs. 2,705-Rs. 11,541)	36,126 (23,974-42,830)	-684 (-Rs.8,947-Rs. 7,563)	22,962 (single observation)	10,020 (single observation)
Forest produce (NIHE) (Rs./ha)	46,824 (20218-1,24837)	26,915 (21270-3,2560)	1,21328 (15892-2,49614)	9595 (single observation)	2,01,633 (13653-3,52752)	1,91,905 (1,66977-2,87532)	190024 (21270-2,80164)	217537 (1,19351-3,16473)	78105 (single observation)	38868 (21270-55639)
Hydrological loss (NIH) (Rs./ha/yr)	5550.57 (942.55-8333.33)	1382.31 (111.13-2653.50)	727.81** (82.62-7055.67)	4885.41 (1382.53-8388.28)	946.73 (264.14-5438.77)	178.24 (151.93-204.55)	3063.92 (105.12-11602.43)	86.17 (52.54-119.80)	1171.48 ***	6121.66 (1140.07-11103.24)
Wildlife loss entire loss (Rs./ha)# (WII)	643.20 (281.6-1,004.8)	4052 (1773.7-6,330)	36.05 (15.8-56.3)	83.30 (36.6-130.0)	1003.70 (433.3-1,574.1)	3451.05 (1490.3-5,411.8)	311.70 (134.4-489.0)	417.10 (180.4-653.78)	96.50 (42.2-150.7)	38.65 (17.0-60.3)
Total (Rs./ha)	**70,636.77**	**35,528.31**	**1,38,367.86**	**22,589.71**	**2,26,915.43**	**2,00,821.29**	**2,29,525.62**	**2,17,356.27**	**1,02,334.98**	**55,048.31**

* In Uttarakhand no fire occurred in moderate severity class in Tropical Dry Deciduous Forest in 2019 hence the value taken from the same type of severity class fire occurred in Madhya Pradesh. The negative value in Sub Tropical Pine Forest and Himalayan Moist Temperate Forest in low severity class indicates the accumulation of carbon is higher in burnt areas than in unburnt areas which can be due to the negligible impact of low fire on biomass and carbon.

** In Uttarakhand, no polygon existed in Moderately Burnt category in Tropical Dry Deciduous Forest in 2019, hence, the value of economic loss has been placed as that of the same type of fire severity class that occurred in the similar forest type in Madhya Pradesh.

*** Only one polygon site is available for Moderately Burnt category in the forest type "Group - TOF/Plantation", therefore, the range can not be given

\# The difference of Rs. 59/- from the total combined value (Binsar WS + Nandhaur WS). The segregated values in each forest type per hectare for each fire intensity causing economic losses are due to the change in the number of pixels, while carrying out analysis of area lost due to forest fire in terms of both forest type and species habitat using the provided fire scars.

For Madhya Pradesh

Table-22 Cumulative result of forest fire losses in different forest types in Madhya Pradesh

Losses of study	Forest type					
	Tropical Moist Deciduous Forests			Tropical Dry Deciduous Forests		
	Severe	Moderately	Low Burnt	Severe	Moderately	Low Burnt
Carbon pool (ICFRE) (Rs./ ha)	Rs. 21,354 (Rs. 19,376- Rs. 23,332)	Rs.19,489 (Rs. 12,572- Rs.26,401)	Rs.17,329 (Rs.2,514- Rs.27,326)	Rs. 20,670 (Rs. 2,884- Rs. 72,918)	Rs. 16,276 (Rs. 5,362 - Rs.55,761	Rs. 7,977 (Rs. 1,109 - Rs. 59,754)
Forest produce (NIEH) (Rs./ ha)	1,15,136 (92473-136006)	96,155 (65974- 134402	83,628 (34323-136006)	1,03,348 (73170 -133526)	1,20,825 (15892 - 249614)	1,26,287 (45469 - 222663)
Hydrological loss (NIH) (Rs./ ha/yr)	768.87 (72.83 -1464.91)	132.88 (29,68 - 5450.23)	90.17 (33.95 -7177.50)	958.01 (553.10 -1388.08)	727.81 (82.62 -7055.67)	305.69 (14.96 - 6583.01)
Wildlife loss (WII) entire state (Rs./ ha)	7608.40 (5,600.0 - 9,616.7)	7712.20 (5,676.4 - 9,748.0)	7562.70 (5566.4 - 9,559.0)	5667.50 (4171.4 - 7,163.6)	5467 (4,023.8 - 6,910.0)	9111.70 (6,706.4 - 11,517.0)
Total (Rs./ ha)	1,44,867.27	1,23,489.08	1,08,609.87	1,30,643.51	1,43,295.81	1,43,681.39

7.2 RECOMMENDATIONS

The partner institutions while carrying out the studies made several recommendations based on their observations and experiences in the field along with their interactions with various stakeholders, including forest department officials and the community. The main recommendations made are enlisted as follows:

- Recent fire points should be selected for the study. Pre-monsoon conditions are to be properly considered for the real-term estimation of damages. It was difficult to locate a fire area with the combination of many variables (Slope, Aspect, Density class and Altitude). As changes were seen in different types of forests along the elevation gradients, it will be better to use elevation as one of the variables for assessment.
- The compensation to be given for the loss and damage due to forest fire must be based on forest types (Tropical Moist Deciduous Forest, Tropical Dry Deciduous Forest, Sub Tropical Pine, Himalayan Moist Temperate Forest and ToF) and severity fire classes (Severe, Moderate and Low).
- The partnering institutes should conduct an integrated spatio-temporal survey of all the parameters to quantify the ecosystem services for better economic valuation that captures ore and post-fire situations and makes the output and outcome more comparable and meaningful. The present study could not coordinate well with other partnering institutions mainly due to COVID and other logistic, administrative and financial limitations.
- Positive impacts of low to moderate intensity forest fires such as germination of certain seeds lying dormant in the soil seed bank, enhance biomass yield of certain plants,etc. need to be further researched and considered as monetary gains via vis monetary loss.
- It will be important to conduct fieldwork involving the local communities and van panchayats in order to collect data in a citizen's science approach that will also build the capacity of the real custodians of forests and lead the study results more applied. Also, the monetary value of certain species, particularly medicinal and aromatic herbs used by the local communities remains unknown and requires Stakeholder's consultation for monetary valuation. Ultimately,this process contributes to the realistic assessment of the financial loss due to forest fires.
- Implementation of habitat management initiatives that will enhance wildlife resilience and tolerance to fire incidences, which will be facilitated by delineating the zones, like buffers/corridors, allowing wildlife to escape for refuge. Preservation of critical habitats like wetlands that can serve as firebreaks and provide water at the time of distress/crunch periods.
- Formulation of suitable post-fire recovery management plans through native vegetation plantation and monitoring the recovery of wildlife populations.

REFERENCES

- **Bhatt, B.P., Singh, K., and Singh, A. (2005).** Nutritional values of some commercial edible bamboo species of the North Eastern Himalayan region, India. Journal of Bamboo and Rattan, 4(2), 111-124.
- **Costanza, R., d'Arge R., De Groot R., Farber S., Grasso M., Hannon B. and Van Den Belt M. (1997).** The value of the world's ecosystem services and natural capital. Nature, 387: 253-260.
- **Gangopadhyay, P.B. (2003).** Bamboo Resources as a Rural Livelihood Option in Madhya Pradesh,India. Paper submitted to XII World Forestry Congress, Quebec City, March 2003.
- **Goraya, G.S. and Ved, D. K. (2017).** Medicinal plants in India: an assessment of their demand and supply. National Medicinal Plants Board, Ministry of AYUSH,Government of India, New Delhi and Indian Council of Forestry Research and Education, Dehradun,100-5.
- **Haripriya, G., Sukhdev, P., Sinha, R.K. and Sanyal, S. (2005).** The value of timber, carbon, fuel wood and non-timber forest products in India's forests: Monograph 1 of the Green Accounting for Indian States Project (GAISP). Chennai (India): Green Indian States Trust.
- **Joshi, G. and Negi. G.C.S. (2011).** Quantification and valuation of forest ecosystem services in the western Himalayan region, India. International Journal of Biodiversity Science, Ecosystem Services and Management 7 (1): 2-11.
- **Kishwan, J., Pandey, R. and Dadhwal, V.K. (2012),** Emission Removal Capability of India's Forest and Tree Cover. Small-scale Forestry 11,61–72. https://doi.org/10.1007/s11842-011-9168-9.
- **Millennium Ecosystem Assessment. (2005).** Ecosystems and human well-being: findings of the scenarios working groups. Washington (DC): Island Press.
- **Mishra, R. (1968).** Ecology Work Book. Oxford and IBH Publication, New Delhi.
- **Negi, G.C.S. and Agrawal, D.K. (2006).** Measuring and valuing ecosystem services: Himalayan mountain context. Current, Science 91 (5): 573-575.
- **Pande, P. K. (2005).** Biomass and productivity in some disturbed tropical dry deciduous teak forests of Satpura plateau, Madhya Pradesh. Tropical Ecology, 46(2), 229-240.
- **Semwal, R., Tewari, A., Negi, G.C.S., Thadani, R., Phartiyal, P. (Editors and Research Contributors), Verma, M., Joshi, S., Godbole, G. and Singh, A. (Research Contributors. (2007).** Valuation of Ecosystem Services and Forest Governance: A Scoping Study from Uttarakhand. Document Published by Leadership in Environment and Development, LEAD-India, New Delhi. 125 p.
- **Singh, S.P. (2002).** Balancing the approaches of environmental conservation by considering ecosystem services as well as biodiversity. Curr. Sci. 82(11):1331–1335.
- **Singh, J.S. and Singh S.P. (1992).** Forests of the Himalaya: Structure, Function and Impact of Man. Gyanodaya Prakashan, Nainital, India. 294 pages.
- **Thakur T.K., Swamy S.L., Bijalwan A. and Dobriyal M.J. (2019).** Assessment of Biomass and net primary productivity of a dry tropical forest using geospatial technology. J. For. Res., 30: 157-17.
- The Economics of Ecosystems and Biodiversity | UNEP - UN Environment Programme (http://www.theplantlist.org/)
- **Verma M. (2000).** Himachal Pradesh forestry sector review report – economic valuation of forests of Himachal Pradesh. London (UK): International Institute of Environment and Development.

ANNEXURES

Annexure- I

Annexure I: Forest type wise losses (Rs./ha) to various forest resources due to forest fire in Uttarakhand (*Values in parentheses are the number of polygons in which the forest resources were burnt and loss was recorded)*

Polygon ID (Fire severity)	Forest types	Timber (26)	Fuel wood (25)	Fodder (38)	MAPs (15)	Wild edibles (35)	Leaf litter (42)	Regeneration (42)	Resin (28)	Total (Rs./ha)
2179 (Moderate)	HMTF	30986	3069	2100	1367	7220	3400	21000	3972	73114
2201 (Moderate)	HMTF	178336	14022	935	83	3960	3400	8000	1986	210722
4603 (Moderate)	HMTF	147288	41809	2718	0	22324	3400	5500	5958	228997
2041 (Moderate)	HMTF	102525	12120	1312	186	-375	3400	17500	3972	141015
2045 (Moderate)	HMTF	225485	58659	1312	186	-375	3400	17500	9931	316473
1238 (Moderate)	HMTF	82012	13667	1875	453	-375	3400	10000	7944	119351
2090 (Moderate)	HMTF	191876	11822	2125	19	-652.5	3400	5250	3972	218464
1867 (Moderate)	HMTF	0	0	2562	15	8864	3400	7000	0	21841
4446 (Moderate)	HMTF	225064	29858	301	0	12819	3400	4750	3972	280164
1430 (Moderate)	HMTF	0	0	301	0	12819	3400	4750	0	21270
4452 (Moderate)	HMTF	0	0	301	0	12819	3400	4750	0	21270
1518 (Moderate)	SPF	122417	35242	2687	3576	9575	3250	3500	17875	198122
1293 (Moderate)	SPF	105056	35219	2562	14426	13311	3250	19000	9931	202755
4507 (Moderate)	SPF	112267	23469	6250	1982	6576	3250	15500	9931	179225
1313 (Moderate)	SPF	0	0	-406	4492	-5692	3250	12250	0	19992
1783 (Moderate)	SPF	192010	0	1390	2176	6755	3250	4500	7944	218025
1265 (Moderate)	SPF	98801	21560	1390	2176	6755	3250	4500	11917	150349
1388 (Moderate)	SPF	178707	40391	1775	0	5230	3250	29250	11917	270520
2374 (Moderate)	SPF	122272	0	1810	0	8820	3250	18090	7944	162186
3167 (Low)	SPF	128994	19654	2443	1109	-2740	3250	5250	7944	168644
3700 (Moderate)	SPF	0	0	968	247	2188	3250	7000	0	13653
3625 (Moderate)	SPF	180121	25454	750	299	9864	3250	6750	5958	232446
3300 (Moderate)	SPF	150208	18820	1937	0	4530	3250	15750	3972	198467
3690 (Moderate)	SPF	0	45342	4000	635	9060	3250	2500	11917	76704

2655 (Low)	SPF	173408	0	4000	635	9060	3250	2500	7944	200797
3484 (Moderate)	SPF	80016	13254	1875	4138	3422	3250	3250	7944	117149
4344 (Low)	SPF	81867	17896	8937	4887	14247	3250	8000	9931	149015
4204 (Low)	SPF	0	1232	8937	4887	14247	3250	8000	1986	42539
4255 (Moderate)	SPF	288570	24974	-20	0	13250	3250	16750	5958	352752
552 (Moderate)	SPF	125929	5812	-20	0	13250	3250	16750	1986	166977
534 (Moderate)	SPF	245786	6510	-20	0	13250	3250	16750	1986	287532
548 (Moderate)	TDDF	0	0	1125	0	920	3300	4250	0	9595
336 (Moderate)	TDDF	0	0	1125	0	920	3300	4250	0	9595
397 (Moderate)	TMDF	94159	8474	1312	1120	2986	3300	11500	1986	124837
367 (Moderate)	TMDF	0	0	1312	1120	2986	3300	11500	0	20218
3884 (Low)	TMDF	0	0	1312	1120	2986	3300	11500	0	20218
3884 (Low)	TMDF	0	0	1312	1120	2986	3300	11500	0	20218
1008 (Low)	TMDF	0	0	1312	186	375	3400	17500	0	22398
4007 (Low)	TMDF	0	0	301	0	12819	3400	4750	0	21270
386 (Low)	TMDF	0	0	3456	0	8304	3300	17500	0	32560
4002 (Low)	TOF/Plantation	53709	2192	1312	1120	2986	3300	11500	1986	78105
1020 (Low)	TOF/Plantation	0	0	1468	827	13044	3300	37000	0	55639
1552 (Low)	TOF/Plantation	0	0	301	0	12819	3400	4750	0	21270

SPF= Subtropical Pine Forests; HMTF=Himalayan Moist Temperate Forests; TMDF= Tropical Moist Deciduous Forests; TDDF= Tropical Dry Deciduous Forests; TOF= Trees outside forest; Minus values denote higher monetary value of forest goods in burnt polygons.

Annexure II: Forest type wise losses (Rs./ha) to various forest resources due to forest fire in Madhya Pradesh *(Values in parentheses are the nu polygons in which the forest resources were burnt and loss was recorded)*

Polygon ID (Fire severity)	Forest type	Timber (40)	Fuel wood (38)	Fodder (47)	MAPs (43)	Wild edibles (44)	Leaf litter (47)	Regeneration (47)	Tendu patta (37)	Bamboo (20)	Total (Rs./ha)
16581 (Low)	TDDF	173209	2003	4003	2006	2735	3350	9000	4554	NA	200860
16627 (Low)	TDDF	43961	1333	4003	151	5620	3350	9000	2960	NA	70378
16470 (Moderate)	TDDF	100700	0	4003	151	5620	3350	9000	2049	NA	124873
10369 (Low)	TDDF	122960	0	1342	2678	455	3350	2750	1821	NA	135356
16455 (Moderate)	TDDF	134866	1254	1744	2956	600	3350	18000	2732	NA	165502
11563 (Moderate)	TDDF	143982	1593	2064	2586	335	3350	12750	2277	NA	168937
6993 (Moderate)	TDDF	92685	1588	671	1162	3475	3350	117000	2732	NA	222663
10013 (Moderate)	TDDF	40317	1747	671	1162	3475	3350	31750	2049	NA	84521
15522 (Low)	TDDF	0	0	1029	1498	5110	3350	31750	2732	NA	45469
6534 (Moderate)	TDDF	0	0	1029	1498	5110	3350	31750	2049	8365	53151
6865 (Moderate)	TDDF	70568	2539	960	19138	-960	3350	8250	3187	NA	107992
15762 (Moderate)	TDDF	0	0	960	2019	2810	3350	8250	5009	NA	22398
1357 (Low)	TDDF	128012	4059	1499	2019	1050	3350	2250	2277	8365	152881
1316 (Low)	TDDF	130295	3868	2139	7505	492	3350	6250	2504	8365	164768
1312 (Low)	TDDF	119169	2162	1185	271	1040	3350	14000	NA	8365	149542

1358 (Low)	TDDF	109684	5646	1957	657	35	3350	44000	NA	8365	173694
14683 (Moderate)	TDDF	154348	2497	960	1910	477	3350	4500	3415	8365	179822
14676 (Moderate)	TDDF	56170	3227	1706	316	477	3350	4750	2504	8365	80865
16720 (Low)	TDDF	137847	3805	1706	316	1910	3350	4750	2049	NA	155733
16722 (Moderate)	TDDF	114088	474	1706	316	1910	3350	4750	NA	NA	126594
16645 (Low)	TDDF	94860	1885	1706	316	-212	3350	4750	2504	NA	109371
16622 (Low)	TDDF	206620	883	1706	316	235	3350	4750	NA	NA	217860
11754 (Low)	TDDF	0	0	759	3021	235	3350	6250	2277	NA	15892
11530 (Moderate)	TDDF	33314	1593	991	6069	1205	3350	5000	NA	8365	59887
9169 (Moderate)	TDDF	41629	1352	1116	5364	82.5	3300	4500	2504	8365	68212
16311 (Moderate)	TDDF	96201	2744	1512	5364	1600	3350	4500	5464	NA	120735
16181 (Low)	TDDF	70285	2102	1462	5283	1225	3350	15750	NA	8365	107822
16068 (Low)	TDDF	50607	1532	1518	3477	795	3300	72250	2277	NA	135756
1443 (Moderate)	TDDF	36615	1173	1945	3278	600	3300	12000	2732	NA	61643
11001 (Severe)	TDDF	55171	3427	1242	4162	500	3300	21250	2960	NA	92012
11546 (Low)	TDDF	56597	1512	1091	398	835	3300	6250	3187	NA	73170
11791 (Low)	TDDF	167965	3467	1148	3250	460	3300	3000	4326	NA	186916

16860 (Low)	TDDF	230128	1743	1349	2095	700	3300	8250	2049	NA	249614
11995 (Low)	TDDF	68378	2234	1951	2941	22985	3300	26500	5237	NA	133526
4524 (Moderate)	TDDF	0	0	2133	2941	22985	3300	9500	6831	NA	47690
15203 (Low)	TMDF	111114	1856	1744	-187	600	3300	6750	2277	8365	136006
16529 (Low)	TMDF	45199	1037	1568	766	1570	3300	5750	3870	8365	71425
14057 (Moderate)	TMDF	82382	453	1204	790	2100	3300	9000	NA	8365	107594
12459 (Moderate)	TMDF	74973	910	1568	790	895	3300	9000	3643	8365	103444
12563 (Moderate)	TMDF	110505	418	1204	790	820	3300	9000	NA	8365	134402
12628 (Moderate)	TMDF	0	0	1204	2006	2250	3300	9000	3643	8365	29768
16826 (Moderate)	TMDF	85139	1254	759	3021	2330	3350	6250	3643	8365	114111
12508 (Severe)	TMDF	43366	1588	991	6069	6190	3300	6250	NA	8365	76119
10701 (Moderate)	TMDF	37028	1527	1537	-6019	3735	3300	12500	NA	8365	67992
10758 (Moderate)	TMDF	0	0	1537	-6019	6800	3300	12500	1821	8365	34323
11473 (Severe)	TMDF	91179	2451	1116	-6019	1210	3300	15750	3870	NA	118876
11576 (Moderate)	TMDF	100293	1271	1116	1354	-4887	3300	4500	1366	NA	113200

Annexure- III

Annexure III : Summary of monetary loss values for 2019 forest fire affected forests of Uttarakhand and Madhya Pradesh.

Forest products	Monetary Loss estimated in UK Forests	Monetary Loss estimated in MP Forests
Monetary loss of timber (Rs. / ha) (range & mean)	**30986**- 288570 (88085)	33314 – 230128 (82382)
Monetary loss of fuel wood (Rs. / ha) (range & mean)	1232-58659 (21220)	418-5646 (2005)
Monetary loss of ground fodder (Rs. /ha) (range & mean)	301-8937 (2154)	671-4003 (1542)
Monetary loss of MAPs (Rs. / ha) (range & mean)	15-14426 (1980)	151-19138 (2655)
Monetary loss of Wild edibles (Rs . / ha) (range & mean)	920-22324 (9091)	35-22985 (2856)
Monetary loss of Litterfall (Rs. / ha) (range & mean)	3250-3400 (3309)	3300-3350 (3328)
Monetary loss of regeneration (Rs. / ha) (range & mean)	2500-37000 (10900)	2250-117000 (14579)
Monetary loss of resin (Rs. / ha) (range & mean)	2986-17875 (6809)	NA
Monetary loss of tendu leaves (Rs. / ha) (range & mean)	NA	1366-6831 (3064)
Monetary loss of bamboo (Rs. / ha) (range & mean)	NA	8365-8365 (8365)
Total Monetary Loss due to FF (Rs/ ha range & mean)	9595- 352752 (130387)	15892-249614 (114327)
Monetary loss across Forest Types (Rs./ ha) - Himalayan Moist Tropical Forest - Sub-tropical Pine Forest - Tropical Dry Deciduous Forest - Tropical Moist Deciduous Forest - Trees Outside Forest/Plantation	 122788 170393 32586 Not Present 51671	 Not Present Not Present 121888 92271 NA