Macrothink Institute™

Journal of Environment and Ecology
ISSN 2157-6092
2024, Vol. 15, No. 1

Exploring Soil Invertebrate Responses to Forest Fires in Margalla Hills National Park (MHNP), Islamabad: An Inquiry into Survival Strategies beneath the Ash

Kiran Sahar (Corresponding author)

Hagler Bailly Pakistan, Islamabad, Pakistan

Islamabad Wildlife Management Board, Ministry of Climate Change and Environmental Coordination, Islamabad Pakistan

E-mail: kiransahar151@gmail.com

Shahzad Aslam

Department of Zoology, Islamabad College for Boys G-6/3 Islamabad, Pakistan

Sakhawat Ali

Islamabad Wildlife Management Board, Ministry of Climate Change and Environmental Coordination, Islamabad Pakistan

Ahmar Riaz

Islamabad Wildlife Management Board, Ministry of Climate Change and Environmental Coordination, Islamabad Pakistan

Ghulam Murtaza

Hagler Bailly Pakistan, Islamabad, Pakistan

Zahid Baig Mirza

Islamabad Wildlife Management Board, Ministry of Climate Change and Environmental Coordination, Islamabad Pakistan

Received: June 17, 2024   Accepted: July 15, 2024   Published: November 29, 2024

doi:10.5296/jee.v15i1.21987   URL: https://doi.org/10.5296/jee.v15i1.21987

Abstract

A study was conducted to investigate the impact of forest fires on soil invertebrate diversity in the Margalla Hills National Park (MHNP) near Islamabad (33°40 – 33°44 N, 72°55 – 73°20 E), situated in the Murree foothills within an elevation range of 450m to 1500m. The study area experiences a fire season from early April to mid-July annually, resulting in significant biodiversity loss. Data were collected from June 2023 to December 2023, primarily focusing on elevation ranging from 548.64 to 1219.2 m. Eight sampling sites were selected, including Shahdara Top, Ratta Hottar, Kanthla Top, Talharr Top, Trail-3 & Trail-5 Connector, Jabbri, Chera Di Gali, and Saidpur in the study area. During the fire season (April-June), a survey was conducted to compare burnt and unburned areas, revealing that abundant soil invertebrates were also observed in the burnt sites. This occurrence was attributed to the migration of predatory soil invertebrates from unburned areas, where they fed on dead insects. A total of 1211 specimens representing 57 different taxa were recorded, with 302 specimens from 33 taxa in the burnt area and 909 specimens from 57 taxa in the unburned area. The species diversity index was 2.88 for the burnt area, classified as 'Not good'. In contrast, the unburned area exhibited a species diversity index of 3.54, classified as 'Good.' Similarly, species evenness was higher in the unburned area. Post-fire season surveys (referred as Winter Season) revealed a significant decline in soil biodiversity, attributed to Alien Invasive Plant Species (AIPS), soil compaction, and dormancy of invertebrates, creating unfavorable habitats for soil biota. A comparison of diversity between summer and winter seasons in the eight sampling sites with burnt areas showed variations in the sites with Trail 3 and 5 Connector exhibiting the highest diversity in summer and Chera Di Gali ranking highest in winter due to dormancy stages of invertebrates of the order Coleoptera, Geophilida and Scolopendromorpha. Common orders observed in burnt sites included Aranea, Coleoptera, Dictyoptera, Gastropods, Hemiptera, Homoptera, Hymenoptera, and Orthoptera. In contrast, unburned sites showed abundance in orders like Aranea, Coleoptera, Diptera, Geophilida, Gastropods, Hemiptera, Homoptera, Haplotaxids, Lepidopterans, Scolopendromorpha, and Zygentoma. Certain species occurred in both burnt and unburned sites, belonging to orders including Aranea, Dictyoptera, Diptera, Gastropods, Geophilida, Hemiptera, Hymenoptera, Isoptera, and Orthoptera. Forest fires limit data collection for invertebrates, plant biodiversity, and macrofauna. Effective conservation and management of soil invertebrate species in MHNP, Islamabad, require immediate and comprehensive preventive measures by relevant authorities such as IWMB and CDA Islamabad.

Keywords: Forest fire, burnt sites, soil invertebrates, MHNP Islamabad

1. Introduction

Forest fire is a tremendous natural disaster that disrupts most terrestrial biomes (Robinne & Secretariat, 2021). It wipes out both flora and soil in forests (Bowman et al., 2011; Thompson et al., 2009). Forest fire is a destructive process that creates toxic damage, and can change plant configuration, composition, diversity, depletion of biomass, and organic matter hunters (Abe et al., 2000). Forest fires are almost always intentionally started by people (Frost, 1996), such as livestock owners trying to encourage a green flush for their animals, rodent hunters, people building firebreaks around their homesteads, people clearing land for farming, etc. (Ajayi & Kwesiga, 2003; Certini, 2005; Greenslade, 1997; Raj et al., 2020). Making charcoal or smoking out beehives in the woods (Piearce, 1986). The harm caused by repeated uncontrolled burns to flora and soil is commonly acknowledged (Certini, 2005; White, 1983).

Controlled and prescribed fires are the two major types of forest fire (HYVÄRINEN et al., 2009). There are three impacts of fire; short-term, medium-term, and long-term or permanent (Ribeiro-Kumara et al., 2020; Sileshi & Mafongoya, 2006). A forest fire has severe effects on the physical, chemical, biological, and mineralogical properties of soil (Certini, 2005), including loss or deduction of structure and soil organic matter, decreased porosity, and increased pH (Raj et al., 2020). The impact of damage on the soil caused by forest fire depends on various factors; the intensity of the fire, the quantity of humidity, and the type of organic matter acting as fuel (Parsons et al., 2010). The impact of fire on the soil is masked by the more lucid impact on the flora and fauna of the area (Kraus & Goldammer, 2007). The organic matter found in soil can easily catch fire and undergo fast combustion that alters several characteristics of soil (Bot & Benites, 2005; Verma & Jayakumar, 2012). Invertebrates, despite their significant ecological role, are given less attention by conservationists than large animals like mammals and birds or the diversity of forest plants (Frost, 1996; Kraus & Goldammer, 2007; Krebs et al., 2010).

Invertebrates help in maintaining ecological processes in equilibrium; recycling nutrients by decomposing organic matter, pollination, seed dispersal, uplifting soil texture, and being an integral part of the food web (Bot & Benites, 2005; New et al., 2010). Recent research demonstrates a strong relationship between soil invertebrates and key soil processes such as carbon mineralization, the development of complex organic material, nitrogen fixation, and denitrification, all of which are crucial factors in determining plant growth (Bignnell & Eggleton, 2000; Lavelle et al., 2003). Some invertebrates, like termites and earthworms, play crucial roles in determining the structure of the soil, preserving its fertility, and creating the landscape (Bignnell & Eggleton, 2000; John & Moshe, 1994). The soil in terrestrial food webs provides food for a variety of predatory invertebrates and vertebrates, invertebrates are also significant participants. They also act as herbivores which in turn leads to fresh floristic growth (New et al., 2010). Plans for managing fire that preserve plant species diversity and types of vegetation may not necessarily preserve invertebrate diversity, because invertebrates integrate abiotic variables more finely than plants do (Cho et al., 1995). The loss of species is likely to be caused by both excessively frequent fires and a complete lack of fire, and the ideal time between burns will vary depending on the community type (Gill, 1997). For instance, lack of fire may limit the above-ground floristic variety and have an impact on invertebrates that depend on early successional plants for food or shelter (Lunt & Morgan, 2002). Inversely, fire may destroy invertebrate habitats like well-rotted logs, deep leaf litter, moss, and humus, which may take at least 20 years to regenerate fully (Greenslade & Smith, 2010; Lacey, 1973).

Pakistan's forest cover accounts for approximately 5.2% of its geographical area (GoP, 2015; Qasim, 2022). Forest fires have become a major environmental disaster in this country in recent years as a result of climate change and increased human economic activity (Krebs et al., 2010; Schoennagel et al., 2004; Shah et al., 2021; Tariq et al., 2021). They have destroyed many natural resources, degraded the soil, and polluted the air. Every year, from early April to mid-July, which is the annual dry season, deliberate forest fires occur in the Margalla Hills National Park (MHNP), associated with Islamabad, the country's capital (Shah et al., 2021; Tariq et al., 2021). A substantial portion of Margalla Hills National Park (MHNP) Islamabad experiences more fires due to prolonged dry weather, exceptionally high temperatures, and changing human activity in land use. These fires in addition to the burning of the trees, bushes, and grasses, inflict colossal damage to the ecology of the area. This study was designed to estimate the ecological damage done by forest fires to the invertebrates' ecosystems above and within the soil in MHNP, Islamabad.

2. Method

2.1 Study Area

The study was carried out in the Margalla Hills National Park (MHNP) and selected eight sampling sites affected by forest fires: Shahdara Top, Ratta Hottar, Kanthla Top, Talharr Top, Trail-3 & Trail-5 Connector, Jabbri, Chera Di Gali, and Saidpur (Figure 1).

The MHNP spans 15,883 hectares and is located along the northeastern border of Islamabad. Situated at N 33° 44' 25.5", E 73° 03' 15.3", the Margalla Hills represent the westernmost extension of the Indo-Himalayan ecosystem. Surrounding the MHNP are over 30 settlements with a total population of around 70,000 individuals. Notably, Nurpur is the largest settlement with over 15,000 residents, followed by Chauntra with 12,000 people, and several other settlements with approximately 9,000 inhabitants each (Anwar & Chapman, 2000; Fatima et al., 2021). The major threats to the park include encroachments, woodcutting and grazing, wildfires, invasive plant species, and an increasing number of visitors (Fatima et al., 2021). In 2021, a total of 189.0422 acres were damaged across various locations within the park. Similarly, in 2022, a total of 45.425 acres were affected, indicating a continued threat to the park's biodiversity and ecological balance due to forest fires (Mahmood & Ali, 2022).

The MHNP features rugged terrain with elevations ranging from 456 to 1580 meters, characterized by southerly-oriented hills and various valleys (Anwar & Chapman, 2000; Aslam et al., 2024). The climate is sub-tropical semi-arid, experiencing two rainy seasons within the monsoon belt, with winters from January to March and summers from July to September. The average annual rainfall is 1900 mm. Average temperatures range from -3.9 °C to 46.6°C (Anwar & Chapman, 2000; Fatima et al., 2021; Tahir & Asim, 2018). The MHNP is differentiated into different types of habitats identified based on *Google Earth™* satellite imagery of 2023. The most abundant habitat type in the study area was Dense Forest, making up 66.3%, followed by Built up Area 14.7%, Sparse Forest 12.7%, Water Body 3.6%, Agricultural Land 2.4%, and Bare Ground 0.3% (Figure 3). These habitats comprised of *Olea-Acacia*, *Acacia-Carissa*, *Olea-Carissa*, *Myrisine-Dodonea*, and *Pinus-Quercus* plant community. This vegetation also supports diverse wildlife, including 250 bird species, 38 mammal species, and at least 13 herpetofauna species (Ahmed et al., 2023; Anwar & Chapman, 2000; Aslam et al., 2024).

Journal of Environment and Ecology
ISSN 2157-6092
2024, Vol. 15, No. 1

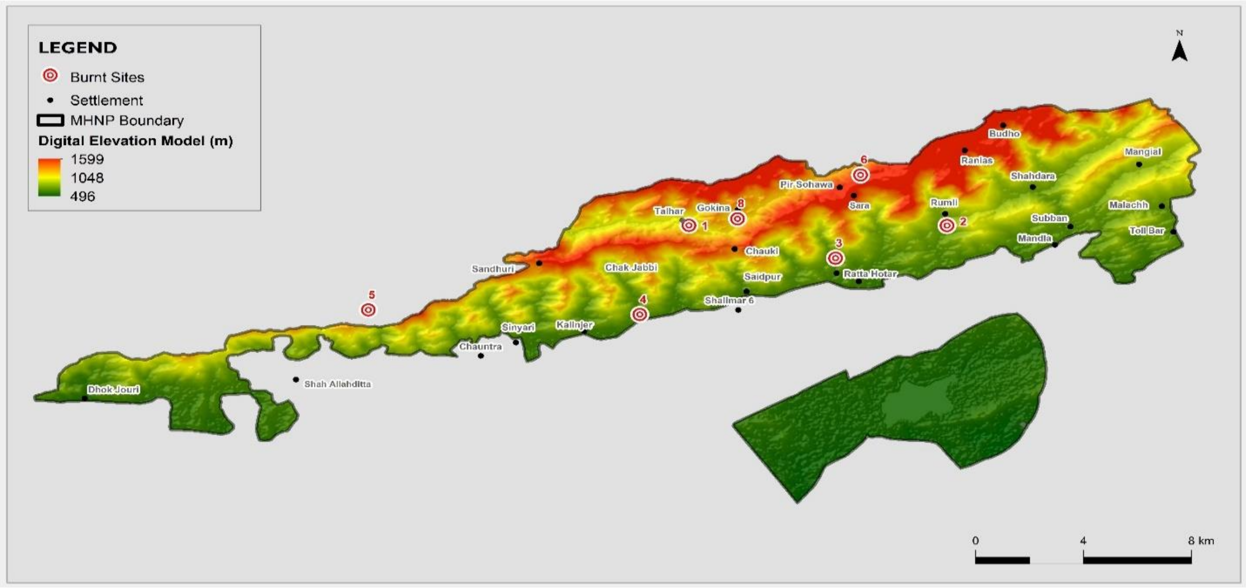


Figure 1. Map of the study area with sampling locations of burnt sites and adjacent unburnt sites.

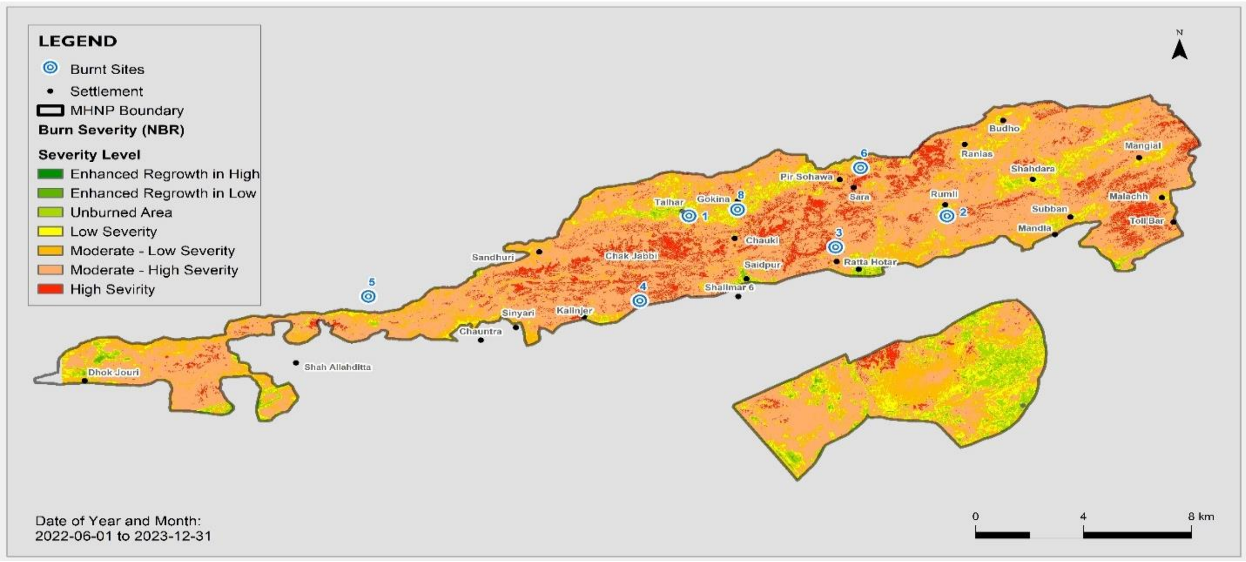
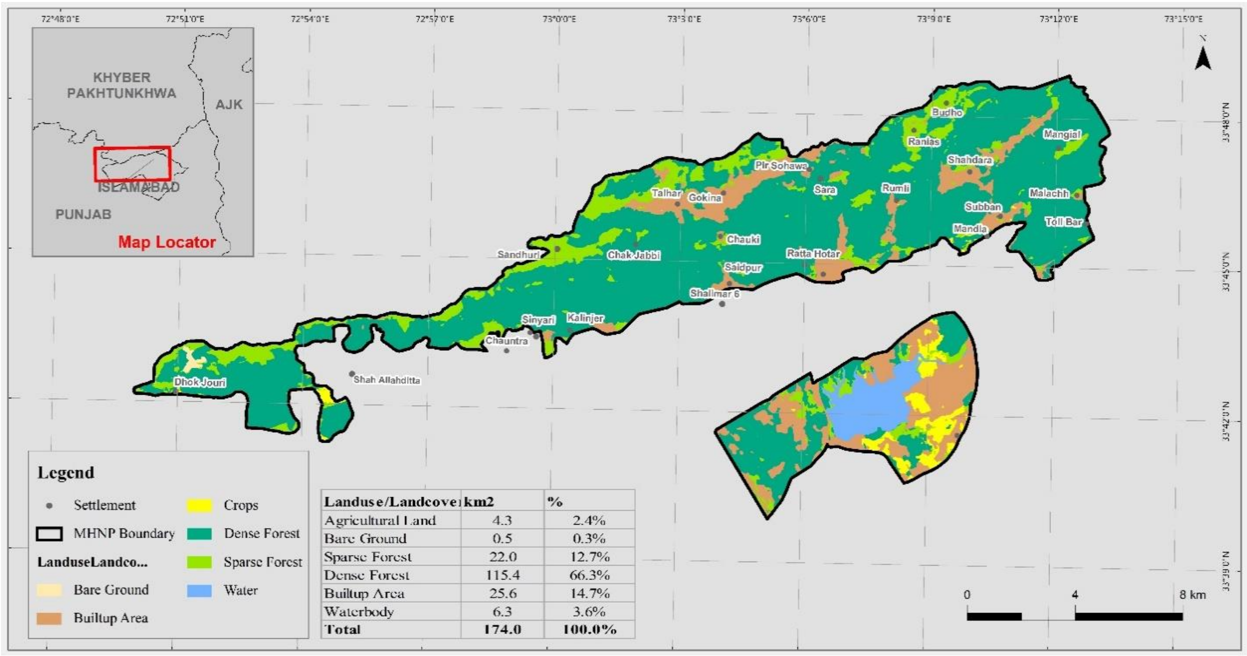


Figure 2. Map of Normalized Burn Ratio (NBR) of forest fires in MHNP. It is calculated to effectively identify and assess the extent and severity of burnt areas due to forest fires. The Normalized Burn Ratio (NBR) is an index that uses the differences in the way healthy green vegetation and burnt vegetation reflect light to find burnt areas. It is calculated using the following Sentinel-2 bands: Near Infrared/Band 8 and Shortwave Infrared/Band 12. NBR returns values between -1 and 1. Healthy green vegetation will have a high NBR value while burnt vegetation will have a low value. Areas of dry, brown vegetation or bare soil will also return lower NBR values than green vegetation. In the context of MHNP, NBR provides essential data to support conservation and fire management efforts in high severity areas, ensuring the protection and restoration of this valuable natural area.



Landuse/Landcover	km2	%
Agricultural Land	4.3	2.4%
Bare Ground	0.5	0.3%
Sparse Forest	22.0	12.7%
Dense Forest	115.4	66.3%
Builtup Area	25.6	14.7%
Waterbody	6.3	3.6%
Total	**174.0**	**100.0%**

Figure 3. Map of Habitat types exiting in MHNP.

2.2 Methodology

The various steps used to collect, store, process, analyze, and infer the results were carried out in the following order: s*ampling and specimen processing*, Collection and Identification of Specimens, Measures and Covariates, and Data Analysis.

2.2.1 Sampling and specimen processing

Sampling of invertebrates was carried out on both burnt and unburnt sites from June 2023 to December 2023. A 100 m transect line was used into equally spaced intervals (e.g., 20 m intervals). At predetermined intervals along the transect, standardized-size (e.g., 1x1 m²) quadrats were placed randomly on the ground surface.

2.2.2 Collection and Identification of Specimens

In the study, a combination of sampling techniques was utilized to capture a diverse range of invertebrate taxa. Hand collection was employed, involving the direct collection of invertebrates by hand using forceps. Soil samples were obtained, and they were processed using sieves with a mesh size of 4 mm. The soil was also excavated from various locations within the study site. The depth of soil excavation varied depending on the target invertebrate taxa, with deeper samples (30 cm) often taken for centipedes, millipedes, and beetles. Sweep netting was also utilized to capture flying insects and those resting on vegetation (Doğramaci et al., 2011).

2.2.3 Measures and Covariates

Berlese funnels were used for sampling soil-dwelling invertebrates, such as mites, springtails, and beetle larvae. These funnels were set up with specific apparatus, including 30.5 cm diameter funnels, 35.6 cm height, 4–6 mm mesh screens, and 25 W tungsten filament lamps. The invertebrates collected in Berlese funnels were deposited into Ehrlen-Meyer flasks containing 70% alcohol over three days. Specimens were sorted into different vials and pinned for preservation (Sabu et al., 2011). The preserved specimens were identified using a dissection microscope in the Pakistan Museum of Natural History (PMNH) laboratory in Islamabad. Additionally, a literature review was conducted to assist in the identification process.

2.2.4 Data Analysis

The diversity of sampled soil invertebrates was assessed using the Shannon Diversity Index (SDI) and visualized through box-whisker plots generated in program R. The Shannon-Wiener Index (H') is a widely used metric for measuring species diversity within a community. The calculation of this index follows the formula described by (Clarke & Warwick, 2001):

$$H' = -[\Sigma Pi(lnP \quad \text{(Clarke \& Warwick, 2001)}$$

Where:

H´ = Diversity Index;

Pi = Proportion of each species within the sample (calculated as the number of individuals of a species divided by the total number of individuals

lnPi = Natural logarithm of the proportion Pi

The Shannon-Wiener Index values range from 1.5 to 3.5. Values above 3 indicate stable environmental conditions, whereas lower values suggest reduced diversity, often indicative of ecological stress or disturbance. To further understand the distribution of species within the communities, we calculated the Pielou Evenness Index (PEI). This index measures how evenly individuals are distributed among the different species in a community (Dinesh et al., 2018; Zhang et al., 2012).

The formula for calculating the Pielou Evenness Index is:

$$E = 1 - H'/\ln(S)$$

Where,

H′ = Observed value of Shannon Index

S = Total number of species observed in the community

A PEI value closer to 1 indicates that species are evenly distributed, whereas lower values signify dominance by a few species, suggesting a less stable community structure.

To analyze the differences in species richness among the eight burnt sites, we employed one-way ANOVA. This statistical test allows us to determine if there are significant differences in the mean species richness across the different sites. The results of the ANOVA elucidate the impact of fire on soil invertebrate communities, providing a clearer understanding of ecological consequences following disturbance.

3. Results

A total of 57 taxa belonging to 15 orders were identified from the eight study sites, which included Aranea, Coleoptera, Dermaptera, Dictyoptera, Diptera, Geophilida (Gastropods Basommatophora and Scolopendrmorpha), Haplotaxids, Homoptera, Hymenoptera, Hemiptera, Isoptera, Lepidoptera, Orthoptera, Stylommatophora, Zygentoma (Table 1).

3.1 Specimen Collection and Abundance

In total, 1211 specimens were collected from both burnt and unburnt sites. The results showed a lower relative abundance in the burnt area, with 302 specimens representing 33 taxa, compared to 909 specimens from 57 taxa in the unburnt area during the post-fire season. The highest relative abundance in unburnt areas was observed at Shahdara Top (130 specimens), followed by Trail 3 & 5 Connector (127 specimens) and Ratta Hotar (126 specimens). Conversely, the burnt area at Jabbri near Gokina village showed the lowest relative abundance, with 28 specimens (Table 2).

3.2 Species Richness and Diversity

The unburnt areas at Trail 3 & 5 Connector showed the species' highest richness, with 22 different taxa. This was followed by unburnt areas at Chera Di Gali and Ratta Hotar, each with 19 taxa. Burnt areas at Kanthala Top and Jabbri near Gokina village showed the lowest richness, with only six and four taxa, respectively.

The Shannon diversity index (H) indicated significant differences between the burnt and unburnt areas. The unburnt areas displayed greater species diversity, suggesting that the fire caused extensive damage to the soil fauna in the burnt areas. Interestingly, the burnt areas were dominated by predator species such as ants, spiders, and beetles, which likely preyed on weakened or fire-affected species (Table 2).

3.3 Post-Fire Habitat Characteristics

Unburnt areas supported a higher abundance of soil fauna, largely due to favorable conditions such as dense vegetation and leaf litter. These conditions provided shade, reduced direct sunlight, and offered protection from predators, fostering a conducive environment for soil invertebrates. Additionally, the migration of flying insects to unburnt areas following the fire further contributed to increased abundance. Conversely, the burnt areas exhibited harsh conditions that were less favorable for soil fauna survival. Reduced food sources, increased soil compaction, and exposure to direct sunlight were key factors contributing to the lower abundance in these regions. The evenness index (E) on burnt and unburnt areas revealed no significant difference. This is because the distribution of species in both areas was relatively high. The evenness index was influenced by the food chain, which means the longer the food chain, the higher the evenness index. The soil fauna evenness index value shows a value less than 1 which means that the distribution of individual abundance at each point was uneven. Equity refers to how the abundance of species (number of individuals) is evenly distributed within a community.

3.4 Winter Season Observations

The resampling of soil invertebrates during the winter season identified 13 taxa including *Geophillus falvus, Paropeas achatinaceum, Clubiona corticalis*, *Scolopendra sp.*, *Dysdercus koenigii*, *Plocamostethus planiusculus*, *Cydnus atrrimus*, *Platy labia major Dohrn*, *Camponotus sp* and *Coptotermes gestori* along with three new species *Allopeas clavulinum*, *Scolopendra morsitan* and *Cyrtophora cicatrosa*. The grubs were collected at a depth of 15 cm (Table 3). Insects during this period were observed in a resting state, reflecting their adaptation to extreme cold temperatures. These species employ strategies such as diapause, huddling, and producing cryoprotectants to survive harsh winter conditions. The study showed that postfire environments affect the biodiversity of various soil-dwelling and arboreal invertebrates. It was noted that species like beetles and ants increased in number, while other species were negatively impacted in the postfire sites. Specifically, it discusses how species that burrow into the soil, such as certain ticks and walking sticks, survive fire events by remaining underground. In our case, the high diversity of *Geophillus falvus* and *Scolopendra morsitan* were observed which exhibited adaptations like diapause or sheltering underground to survive postfire conditions (van Mantgem et al., 2015). Despite these survival mechanisms, the overall diversity and abundance of soil invertebrates in the burnt areas remained extremely low during winter, influenced by the post-fire environmental changes.

Table 1. Identified specimens from burnt and unburnt sites in MHNP.

No	*Order*	*Family*	*Species*
1	Hemiptera	Cydnidae	*Cydnus aterrimus*
		Phrrhocoridae	*Dysdercus koenigii, Dysdercus cingulatus*
		Lygaeidae	*Lygaeus militaris Fabricius*
		Pentatomoidae	*Alcaeorrhynchus grandis*
		Cixiidae	*Nilaparvata lugens stal*
2	Coleoptera	Scarabaeidae	*Holotrichia serata, Cyclocephala lurida, Cotini nitida*
		Chrysomelidae	*Chrysochus auratyus, Zygograma bicolorata*
		Cetoniidae	*Glycyphana stolata*
		Carabidae	*Plocamostethus planiusculus, Calathus.sp,*
		Elateridae	*Scarites.sp*
		Coccinellidae	*Ampedua nigrinus, Agrypnus.sp*
		Buprestidae	*Coccinella septempunctata*
		Cerambycidae	*Chalcophora angulicolis*
		Staphylinidae	*Dorysthenes indicus*
			Erichsonius.sp
3	Orthoptera	Gryllidae	*Gryllus bimaculatus*
		Acrididae	*Acrotylus.sp*
4	Dictyoptera	Blattellidae	*Blattella germanica*
		Ectobiidae	*Blattella vaga*
5	Diptera	Asilidae	*Diogmites neoternatus*

		Rhagionidae	*Bactocera dorsalis*
6	Homoptera	Cicadidae	*Purana tigrine*
7	Hymenoptera	Formacidae	*Camponotus.sp*
8	Aranea	Araneidae Thomicidae Clubionidae	Cyrtophora *cicatrosa* *Coriarachne depressa, Ozyptila trux* *Clubiona latreille, Clubiona corticalis, Clubiona diversa, Clubiona frisia*
9	(Gastropods) Basommatophora Stylommatophora	Achatinidae Bradybaenidae	*Paropeas achatinaceum, Allopeas clavulinum* *Bradybaena similaris*
10	Dermaptera	Carcinophoridae	*Platy labia major Dohrn*
11	Geophilida Scolopendromorpha	Geophilidae Scolopendridae	*Geophilus falvus* *Scolopendra.sp, Scolopendra morsitan*
12	Lepidoptera	Erebidae	*Amsacta.sp*
13	Isoptera	Termitidae	*Odontotermes obesus, Coptotermes gestori*
14	Zygentoma (Sliver fish)	Lepismatidae	*Lepisma saccharina*
15	Haplotaxids	Lumbricidae Megascolecidae	*Lumbricus terrestris* *Pontodrilus perrier,*

Table 2. Abundance and richness of invertebrates in burnt and unburnt areas in post-fire season.

Taxa	*Post Fire Season*																*Total*	*Total Burnt Area*	*Total Unburnt Area*
	Said Pur Village		*Chera Di Gali*		*Opposite to Monal Restaurant*		*Trail 3 & 5 Connector*		*Kanthala Top*		*Ratta Hotar*		*Shahdara Top*		*Jabbri near Gokina village*				
	Burnt Area	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*			
Acrotylus sp.	-	-	-	-	-	-	2	5	-	-	-	-	2	5	3	7	24	7	17
Agrypnus sp.	-	-	-	-	-	-	-	-	-	-	-	6	-	-	-	-	6	0	6
Alcaeorrhynchus grandis	0	5	-	4	-	6	-	12	-	-	-	-	-	-	-	-	27	0	27
Ampedus nigrinus	-	-	3	5	-	-	-	-	-	-	-	5	-	8	-	-	21	3	18
Bactrocera dorsalis	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	6	10	0	10
Blattella germanica	3	6	0	8	0	12	-	-	-	8	6	7	-	-	6	10	66	15	51
Blattella vaga	-	-	-	-	-	-	-	6	6	6	-	-	6	9	-	-	33	12	21
Bradybaena achatinaceum	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	0	1
Bradybaena similaris	-	1	-	-	-	-	-	-	3	4	-	-	-	-	-	5	13	3	10
Bug immature	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1

Taxa	*Post Fire Season*																*Total*	*Total Burnt Area*	*Total Unburnt Area*
	Said Pur Village		*Chera Di Gali*		*Opposite to Monal Restaurant*		*Trail 3 & 5 Connector*		*Kanthala Top*		*Ratta Hotar*		*Shahdara Top*		*Jabbri near Gokina village*				
	Burnt Area	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*			
nymph																			
Calathus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	3	0	3
Camponotus sp.	-	-	-	-	-	-	18	6	0	10	-	-	8	12	-	-	54	26	28
Caterpillar	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-	-	8	0	8
Chalcophora angulicollis	-	-	-	5	-	-	-	8	-	-	-	-	-	-	-	-	13	0	13
Chrysomelidae auratus	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	6	0	6
Clubiona corticalis	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	2	0	2
Clubiona diversa	-	-	3	5	-	1	-	-	-	-	-	-	-	-	2	6	17	5	12
Clubiona frisia	-	-	-	-	1	2	3	4	-	-	-	-	-	-	-	-	10	4	6
Clubiona latreille	1	3	-	-	-	-	-	-	-	2	-	-	-	-	-	-	6	1	5
Coccinellidae septempunctata	-	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-	6	0	6
Coptotermes gestori	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	0	10
Coriarachne depressa	-	2	-	-	-	-	2	5	-	-	-	-	2	3	0	5	19	4	15
Cotinis nitida	1	2	3	5	-	-	-	-	-	-	-	5	-	-	-	-	16	4	12
Cyclocephala lurida	4	7	-	-	-	-	-	-	-	-	-	6	-	-	-	-	17	4	13
Cydnus aterrimus	6	21	0	6	1	10	3	10	0	18	-	-	6	8	6	16	111	22	89
Diogmites neoternatus	-	-	3	5	-	-	-	-	-	-	-	-	-	-	2	6	16	5	11
Dorysthenes indicus	-	-	0	9	-	-	-	-	-	-	-	-	-	-	-	-	9	0	9
Dysdercus cingulatus	-	-	-	5	-	-	-	9	-	-	-	-	-	-	-	5	19	0	19
Dysdercus koenigii	-	-	-	6	-	-	7	5	-	-	-	-	-	-	-	3	21	7	14
Erichsonius	1	5	-	-	-	-	6	8	2	4	2	4	-	-	-	-	32	11	21

Taxa	*Post Fire Season*																*Total*	*Total Burnt Area*	*Total Unburnt Area*
	Said Pur Village		*Chera Di Gali*		*Opposite to Monal Restaurant*		*Trail 3 & 5 Connector*		*Kanthala Top*		*Ratta Hotar*		*Shahdara Top*		*Jabbri near Gokina village*				
	Burnt Area	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*			
sp.																			
Family Tettigoniidae (nymph)	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	0	1
Geophilus flavus	3	7	-	-	1	8	2	5	-	8	-	5	3	7	-	8	57	9	48
Glycyphana stolata	-	-	1	6	-	-	-	-	-	-	-	-	-	-	-	-	7	1	6
Grubs	-	-	2	5	-	7	-	-	-	-	-	-	-	-	-	-	14	2	12
Gryllus bimaculatus	2	12	2	10	-	8	8	10	5	8	-	-	8	12	-	-	85	25	60
Holotrichia serata	-	-	-	5	4	20	-	-	-	-	-	-	-	10	-	-	39	4	35
Immature nymph	-	-	-	1	-	-	-	-	-	10	-	-	-	-	-	-	11	0	11
Lygaeus militaris	-	-	-	3	-	-	-	3	-	5	-	-	-	-	-	-	11	0	11
Lepisma saccharina	-	6	-	-	-	-	-	-	-	6	-	-	-	-	-	-	12	0	12
Lioponera longitarsus	15	15	6	8	16	18	-	-	20	20	5	15	10	20	-	-	168	72	96
Lumbricus terrestris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	0	3
Moth larvae	-	-	2	10	-	-	-	-	-	-	-	-	-	-	-		12	2	10
Moth pupa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	0	1
Odontotermes obesus	-	12	-	-	-	-	9	20	-	-	-	-	-	-	8	15	64	17	47
Ozyptila trux	2	2	-	-	-	-	2	3	-	-	2	3	-	-	-	-	14	6	8
Paropeas achatinaceum	-	-	-	-	2	2	-	-	7	6	-	-	6	7	-	-	30	15	15
Pigmy grasshopper	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	6	1	5
Platylabia major Dohrn	-	8	-	-	-	-	-	-	-	5	-	-	-	-	-	-	13	0	13
Plocamostethus planiusculus	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	7	0	7

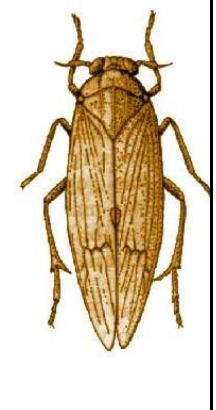
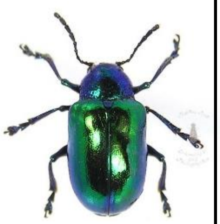
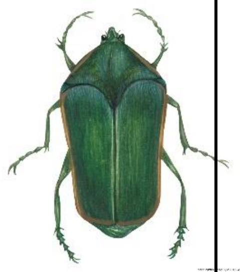
Taxa	*Post Fire Season*																*Total*	*Total Burnt Area*	*Total Unburnt Area*
	Said Pur Village		*Chera Di Gali*		*Opposite to Monal Restaurant*		*Trail 3 & 5 Connector*		*Kanthala Top*		*Ratta Hotar*		*Shahdara Top*		*Jabbri near Gokina village*				
	Burnt Area	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*	*Burnt Area*	*Unburnt Area*			
Pontodrilus perrier	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	0	3
Purana tigrina	-	-	2	6	-	-	-	2	-	-	-	-	-	-	-	3	13	2	11
Scarites sp.	-	-	-	-	-	1	5	8	-	-	-	-	-	-	-	-	14	5	9
Scolopendra cingulatus	-	-	-	-	1	8	-	-	-	-	-	-	-	-	-	-	9	1	8
Scolopendra.sp	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	2	0	2
Snail Shell	-	-	-	-	5	6	-	-	-	-	-	-	-	-	-	-	11	5	6
Subfamily Copiphorinae	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	1	0
Subfamily Oedipodinae (nymph)	-	-	-	-	1	4	-	-	-	-	-	-	-	-	-	-	5	1	4
True Bug Immature nymph	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	0	1
Abundance	**38**	**124**	**27**	**119**	**33**	**126**	**67**	**130**	**43**	**127**	**15**	**56**	**51**	**120**	**28**	**107**	**1211**	**302**	**909**
Richness	**10**	**17**	**10**	**22**	**10**	**19**	**12**	**19**	**6**	**16**	**4**	**9**	**9**	**15**	**7**	**17**	**57**	**33**	**57**

Table 3. Abundance and Richness of Specimens in Winter Season.

Survey Sites	*Burnt*		*Unburnt*	
	H	*E*	*H*	*E*
Said Pur Village	1.89	0.52	2.59	0.54
Chera Di Galli	2.187	0.66	2.57	0.58
Opposite to Monal	1.62	0.47	2.4	0.51
Trail 3 and 5 connectors	2.22	0.53	2.75	3.39
Kanthala Top	1.51	0.4	2.62	0.54
Ratta Hotar	1.48	0.52	2.21	0.54
Shahdara Top	2.1	0.54	2.65	0.55
Jabbri	1.89	0.54	2.54	0.57

H represents “species diversity” and E represents “species evenness.”

Journal of Environment and Ecology
ISSN 2157-6092
2024, Vol. 15, No. 1

				
Nilaparvata ***lugens stal***	*Holotrichia* ***serrata***	*Chalcophora* ***angulicolis***	*Plocamostethus* ***planiusculus***	*Ampedus* ***nigrinus***
				
Cyclocephala ***lurida***	*Cydanus* ***aterrimus***	*Chrysochus* ***auratus***	*Cotinis* ***nitida***	*Glycyphana* ***stolata***
				
Lepisma ***saccharina***	*Lioponera* ***longitarsus***	*Odontotermes* ***obesus***	*Zygogramma* ***bicolorata***	*Lygaeus* ***militaris Fabricius***
				
Clubiona ***frisia***	*Gryllus* ***bimaculatus***	*Platy labia* ***majora Dohrn***	*Cyrtophora* ***cicatrosa***	*Coptotermes* ***gestroi***
				
Lumbricus ***terrestris***	*Bactrocera* ***dorsalis***	*Diogmites* ***neoternatus***	*Dysdercus* ***cingulatus***	*Dysdercus* ***koenigii***

Journal of Environment and Ecology
ISSN 2157-6092
2024, Vol. 15, No. 1

				
Clubiona ***latreille***	*Clubiona* ***diversa***	*Ozyptila* ***trux***	*Geophilus* ***flavus***	*Scolopendra* ***cingulata***
				
Paropeas achatinaceum	*Bradybaena* ***similaris***	*Allopeas* ***clavulinum***	*Blattella* ***germanica***	*Blattella vaga*

			
Purana ***tigrina***	*Coccinella* ***septempuncta ta***	*Alcaeorrhynch us* ***grandis***	*Coriarachne* ***depressa***

Figure 4. Preserved specimens and identification at Pakistan Museum. Web images of species collected from the burnt sites as most of them were not intact carcasses which could not photographed.

3.5 Comparative Analysis of Burnt and Unburnt Sites of MHNP:

This study focuses on soil invertebrate diversity and abundance across different sampling sites in MHNP, comparing areas affected by fire with those that remain unburnt. In each site, specimens from various invertebrate orders were collected and analyzed for species richness and abundance. Burnt sites, particularly in areas of intense fire activity, exhibited no stable declines in both parameters.

3.5.1. Said Pur Village

Nine different invertebrate orders were collected, with higher species diversity of Aranea (spiders), Dictyoptera (cockroaches), Hymenoptera (ants and bees), and Orthoptera (grasshoppers) observed in the burnt area (Table 2). The damage caused by fire was evident, particularly in Gastropods (snails), as several burnt snail shells were collected. The unburnt site recorded a higher overall abundance of 124 individuals compared to 38 in the burnt site. The species richness was 17 in the unburnt area versus 10 in the burnt area. (Figure 2a).

3.5.2. Chera Di Galli

The Orders Aranea, Coleoptera, Diptera, Geophilida, Hemiptera, Hymenoptera, and Orthoptera were collected from this sampling site (Table 2). The order Coleoptera and Hemiptera species diversity was more in that region. The similar species of both sites were Hemipterans. A comparison between unburnt (119) and burnt sites (27) showed a higher abundance of soil invertebrates in the former region than in the second one (Figure 2b). The species richness of the unburnt site was 22 than that of the burnt site 10 in the sampling region.

3.5.3. Opposite to Monal

The orders Aranea, Gastropoda, Hymenoptera, and Orthoptera were found in similar abundance at both the burnt and unburnt sites. However, orders such as Coleoptera, Geophilida, Lepidoptera, and Scolopendromorpha were only observed in the unburnt site (Table 2). A comparison revealed a significantly higher abundance of soil invertebrates (Figure 2c) at the unburnt site (126 individuals) compared to the burnt site (33 individuals). Additionally, species richness was greater in the unburnt site, with 19 species compared to 10 in the burnt area.

3.5.4. Trail 3 and 5 Connector

The orders Aranea, Coleoptera, Hemiptera, Homoptera, Hymenoptera, Isoptera, and Orthoptera were found at both the burnt and unburnt sites (Table 2). While Hymenoptera, Isoptera, and Orthoptera were equally abundant at both sites, the numbers of Aranea, Coleoptera, Hemiptera, and Homoptera were higher in the unburnt site. Overall, the unburnt site had a greater abundance (Figure 2d) of soil invertebrates (130 individuals) compared to the burnt site (67 individuals), with higher species richness as well, showing 19 species in the unburnt area versus 12 in the burnt area.

3.5.5. Kanthala Top

At Kanthala Top, the orders Aranea, Coleoptera, Dictyoptera, Gastropods, Hemiptera, Hymenoptera, and Orthoptera were observed in higher numbers (Table 2). Burnt snail shells at the site indicated that the forest fire severely impacted the snail population. While Hymenoptera, Orthoptera, and Dictyoptera were present in similar numbers at both sites, the other orders were more abundant at the unburnt site. A comparison revealed a significantly higher abundance (Figure 2e) of soil invertebrates in the unburnt site (127 individuals) compared to the burnt site (43 individuals). Species richness was also higher at the unburnt site, with 16 species compared to 6 at the burnt site.

3.5.6. Ratta Hotar

The Hymenoptera and Orthoptera species were observed at both the burnt and unburnt sites, while some species from the orders Aranea, Coleoptera, and Hemiptera were present in adjacent burnt areas. The biodiversity loss was severe, as indicated by the diversity index (Table 2). A comparison of relative abundance (Figure 2f) showed significantly more soil invertebrates in the unburnt site (56) compared to the burnt site (15). The species richness was also higher at the unburnt site (9 species) compared to the burnt site (4 species).

3.5.7. Shahdara Top:

The orders Aranea, Dictyoptera, Diptera, Gastropods, Geophilida, Hemiptera, Hymenoptera, and Orthoptera were observed (Table 2) at this site. The burnt site showed a rich diversity of Aranea (spiders) and Geophilida (centipedes), with predators feeding on weak and burnt prey. Burnt snail shells indicated the forest fire's impact on the mollusk population. Coleoptera, Diptera, and Hemiptera species were more abundant at the unburnt site, with Dipterans playing key ecological roles as scavengers, predators, and pollinators. Overall, soil invertebrate abundance (Figure 2g) was higher in the unburnt site (120) compared to the burnt site (51), with a species richness of 15 at the unburnt site versus 9 at the burnt site.

3.5.8. Jabbri

In the sampled region, the orders Aranea, Archaeognatha/Microcoryphia, Coleoptera, Dictyoptera, Diptera, Haplotaxids, Hemiptera, Homoptera, Isoptera, Orthoptera, and Zygentoma were identified (Table 2). Species from orders Aranea, Dictyoptera, Diptera, Hemiptera, Isoptera, and Orthoptera were found at both burnt and unburnt sites, while Coleoptera, Homoptera, Haplotaxids, and Zygentoma were unique to unburnt sites. The unburnt site showed a significantly higher abundance (107 invertebrates) compared to the burnt site (28), (Figure 2b) with greater species richness at the unburnt site (17 species) versus the burnt site (7 species).

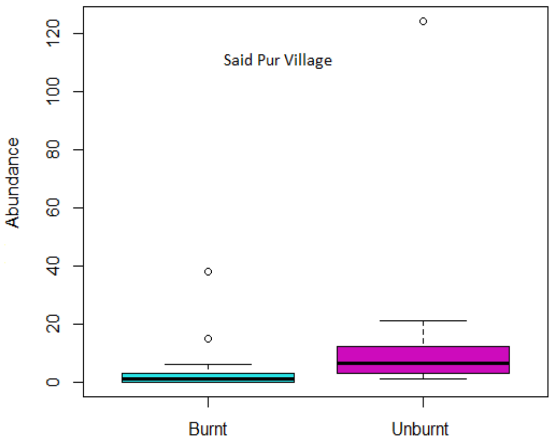


Figure 2 (a).

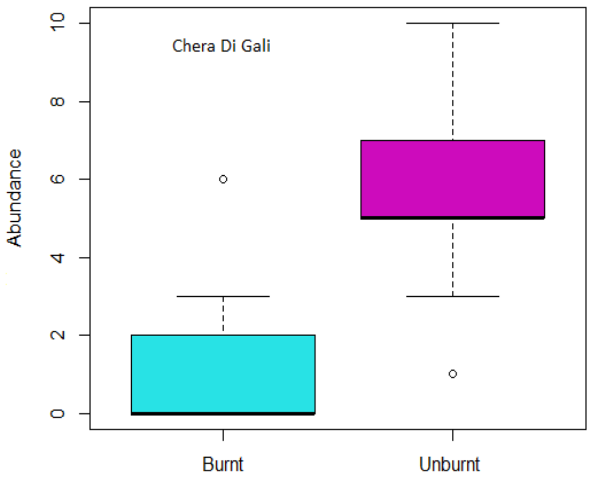


Figure 2(b).

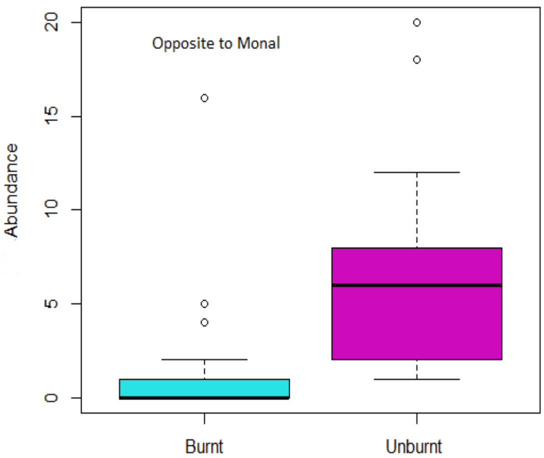


Figure 2(c)

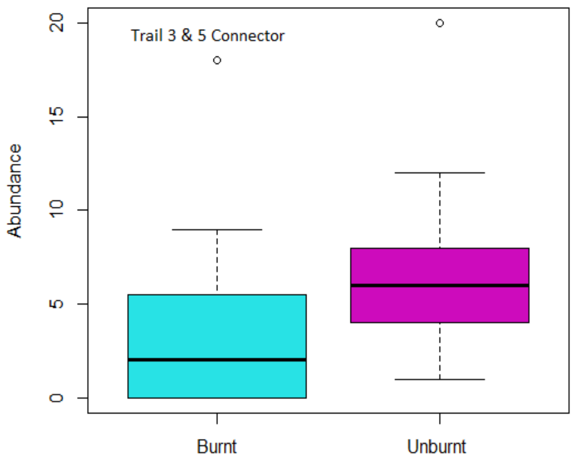


Figure 2(d)

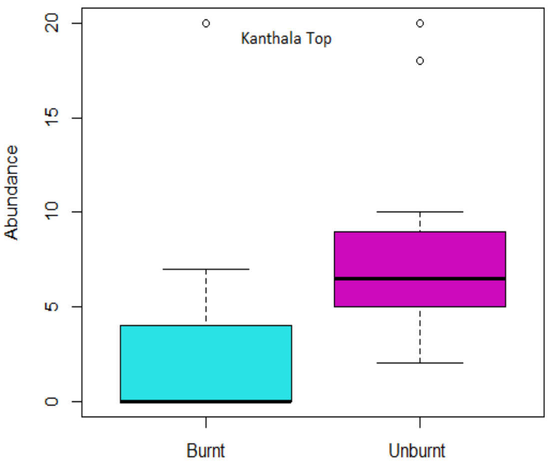


Figure 2(e)

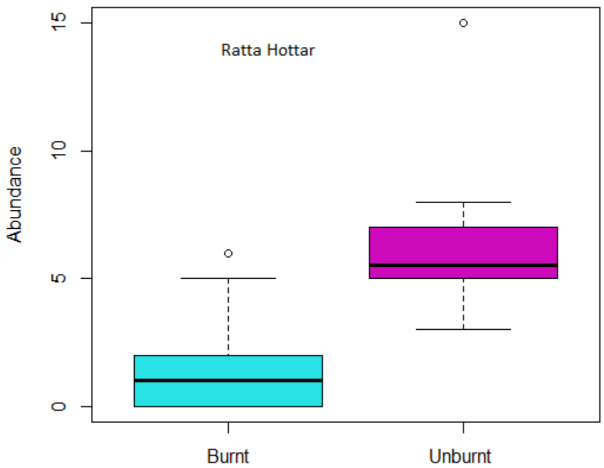


Figure 2(f)

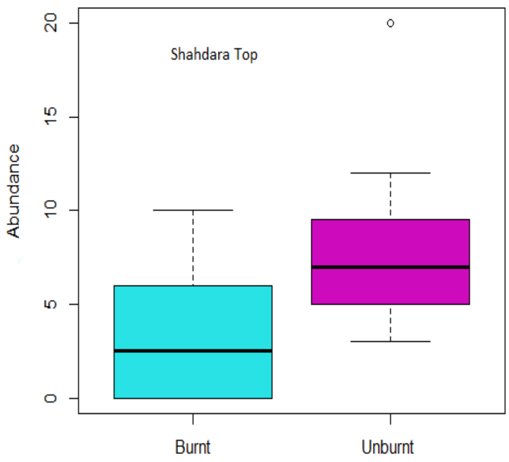


Figure 2(g)

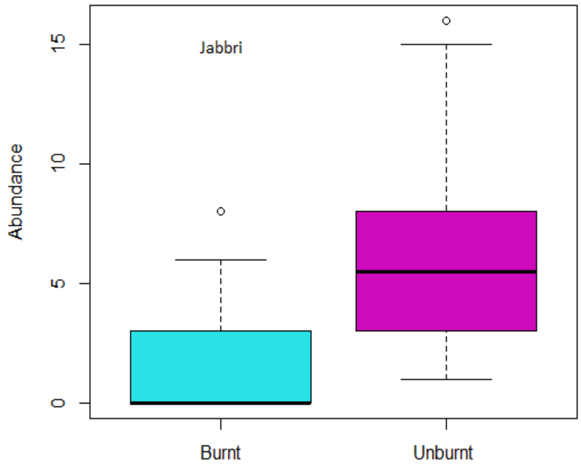


Figure 2(h)

Figure 3. A comparison of relative abundance in both burnt-unburnt sites using whisker boxes plots. The short whisker horizontal lines show maximum and minimum values, the lower and upper horizontal lines of the box show 1st and 3rd quartiles while a horizontal line inside the box illustrates median value. The tiny circles correspond to the outliers. In the case of burnt sites, poor and rich abundance is shown by Saidpur village and Shahdara top site respectively while for unburnt sites the same statistics were depicted by Ratta Hotar village and Jabri site.

4. Discussion

We identified a total of 57 taxa belonging to 15 orders, including Aranea, Coleoptera, Dictyoptera, Diptera, Hemiptera, Hymenoptera, Orthoptera, Zygentoma, and others. A total of 1211 specimens were collected from both burnt and unburnt sites, with the unburnt sites showing a significantly higher abundance (909 specimens of 57 taxa) compared to the burnt sites (302 specimens of 33 taxa) during the post-fire season. The unburnt area at Shahdara Top had the highest relative abundance, while the burnt areas near Jabbri recorded the lowest (Table 2).

The Margalla Hills National Park encompasses two major ecosystems studied: above ground, within, and below the soil. The above-ground ecosystem includes both abiotic factors and flora that contribute to its structure and function. Nocturnal insects inhabiting this environment were observed under stones, pinecones, bark of trees, leaf litter, and in mountain crevices. Species identified include *Dysdercus koenigii, Dysdercus cingulatus, Lygaeus militaris Fabricius, Purana tigrina, Zygograma bicolorata, Gryllus bimaculatus, Acrotylus.sp, Blattella germanica, Blattella vaga, Coriarachne depressa, Ozyptila trux, Clubiona latreille, Paropeas achatinaceum, Bradybaena similaris, Allopeas clavulinum,* and *Lepisma saccharina*.The below-ground ecosystem is enhanced by mycorrhizal associations and plant roots, which provide essential nutrients to sustain the subterranean biodiversity. These interactions play a critical role in nutrient cycling, soil health, and supporting the biodiversity that thrives within the soil.

The forest fires caused extensive damage to the area's flora and fauna, significantly affecting the ecosystem. The absence of a buffer zone in the Margalla Hills National Park allowed nearby communities to exploit park resources, leading to unauthorized construction and overuse of natural resources. This resulted in habitat destruction, which has contributed to the reduced biodiversity observed in the study. The findings from this study indicate that forest fires have destructive impacts on ecosystems at physical, biological, ecological, and environmental levels. A comparison between burnt and adjacent unburnt sites revealed a significant decrease in the richness and evenness of soil invertebrates in the areas affected by fire leading to soil compaction, organic matter loss, and reduced moisture retention, negatively impacting soil fauna. However, species that live in deeper soil layers or migrate to unaffected areas can survive and recolonize over time. Post-fire recovery processes, such as vegetation regrowth, are crucial for restoring soil fauna diversity and abundance (Neary, 2019). Disturbances, like fire, can significantly disrupt community dynamics by reducing species richness and abundance in the short term. However, such disturbances also open up opportunities for species to colonize new areas and allow ecosystems to undergo natural succession. The post-fire recovery of soil invertebrates follows this pattern, with species gradually recolonizing once habitat conditions improve and stabilize (Sousa, 1984).

The species that survived but were less numerous, primarily predators, were found at the burnt sites. Several factors contributed to this: firstly, the post-fire survey began several days after the outbreak of forest fires, allowing invertebrates time to adapt to the altered environment. Secondly, the prey-predator relationship led predators to consume weakened prey, resulting in the predominance of predators such as spiders, crickets, cosmopolitan cockroaches, and below-ground invertebrates like centipedes and beetle larvae at the burnt sites. Thirdly, a key factor in fire propagation in the Margalla Hills is the abundance of pine trees. Pine needles, which contain highly inflammable compounds, contribute significantly to the spread of fire. Research conducted by Singh et al. (2022) shows that pine trees, despite being fire-resistant, act as ignition sources due to the explosive nature of their needles. This aligns with our observations, as the burnt areas in the park have a higher concentration of pine trees, making them more vulnerable to fire outbreaks. While pine needles contribute to fire spread, they also protect the topsoil by forming a layer of ash that preserves soil from erosion and aids in moisture retention. This, in turn, supports the survival of topsoil-dwelling insects, even after fires. However, leaf litter plays a significant role in propagating fires, leading to a decline in herbivorous species like snails, earthworms, beetles, bugs, crickets, and cockroaches. Snails and crickets were particularly affected (Fischer, 2021; Singh et al., 2022).

Moretti and Legg (2009) showed that soil invertebrates with specific traits, such as high mobility and the ability to feed on multiple food sources, are more likely to survive and recover quickly after fire events. In contrast, species with limited mobility or specialized feeding habits tend to suffer more significant declines. The study provides evidence that post-fire recovery is driven by a combination of species' functional traits and habitat conditions, such as the availability of food and shelter in unburned areas. Interestingly, ants and termites exhibited increased abundance in the burnt areas. Both species are predators capable of withstanding low to moderate fire intensities. Ants, which nest underground, were observed carrying termite larvae back to their colonies. Termites also thrived in low-intensity fire areas, utilizing debris and charred wood for survival. In burnt sites recovery can occur within a similar 1 to

2-year timeframe. This resilience is largely attributed to the ability of certain species to migrate from unaffected areas or survive in deeper soil layers (Andersen et al., 2014). Studies by (Sholikha et al., 2018) found that soil invertebrates like centipedes, millipedes, and ground beetles can recover within 1 to 2 years after a fire. This recovery is facilitated by survival strategies, including migration to deeper soil layers or nearby unburned areas. Wet environments tend to experience faster recovery due to better moisture retention and vegetation regrowth. In our case, the same species was observed in burnt areas during post-fire.

A noticeable pattern was observed where species migrated from burnt areas to adjacent unburnt sites, seeking shelter and food. This explains the higher abundance of herbivorous insects in unburnt areas, where plant life is more abundant. Surprisingly, the overall environmental impacts of forest fires were detrimental, temporarily disrupting soil fauna and ecological linkages by eroding habitats. While some predators, like those from the orders Aranea, Hymenoptera, Orthoptera, and Dictyoptera, were more abundant in burnt sites, similar taxa were also present in unburnt areas. Species richness in unburnt areas was higher, although irregularities in species distribution suggested movement between burnt and unburnt sites.

These findings align with and contrast with previous studies; (Vasconcelos et al., 2009) observed lower ant species richness in fire-affected sites, although the taxonomic composition remained consistent. This aligns with the increased ant populations observed in the burnt areas of this study. (Yekwayo et al., 2018) found that species like ants, cockroaches, and bugs showed fire resistance, with consistent richness in both burnt and unburnt sites. This supports the idea that certain species are adapted to withstand fire.

Wildfires could increase ground beetle diversity by reorganizing habitats (Sasal et al., 2010). However, in this study, ground beetle diversity was higher in unburnt sites, potentially due to the limited timeframe of the research. Studies (Larsen & Work, 2003) on Carabidae (ground beetles) suggest that while fire may initially reduce arthropod abundance due to direct heat mortality, species activity could be positively influenced by alterations in vegetation structure rather than negatively impacted directly by fire (Liu, 2019). Forest fires also had a significant impact on gastropods. Mollusk species, closely associated with leaf litter and grass, are particularly vulnerable to direct heat mortality. Habitat destruction from fires disrupts their ability to find food and shelter, leading to population declines.

Forest fires significantly affect the diversity of soil invertebrates and disrupt the ecological roles of species within the trophic pyramid, leading to disturbances in nutrient and energy flow. The fires create opportunities for predators to prey on weakened or burnt organisms. Species from various orders, such as Aranea and Orthoptera, showed increased abundance in burnt areas, while some species migrated to adjacent unburnt areas for protection. These findings highlight the temporary alterations in habitat, species structures, and ecological dynamics caused by forest fires, while also showcasing the adaptability of certain species to environmental changes (Haddad & Tewksbury, 2005; Levine, 2020).

Furthermore, soil invertebrates play a crucial role in nutrient cycling, soil structure maintenance, and ecosystem productivity. Long-term disruptions in their populations could lead to broader ecological consequences, such as reduced soil fertility and slower vegetation recovery. The balance of predator-prey relationships, as seen with species like ants and spiders dominating burnt areas, may shift permanently, affecting other fauna reliant on soil ecosystems. (Peters, 2005) discussed that fire alters soil and vegetation dynamics, and the long-term consequences for soil organisms, including the impacts on biodiversity and community structure. The study emphasizes that while recovery is possible, the composition of the community may change over time.

Margalla Hills experience significant temperature fluctuations, with average maximum and minimum temperatures of 33.3°C and 19.5°C, respectively. The extreme temperatures, which reach highs of 42°C in May and June and drop below zero in December and January (Jabeen et al., 2009), have a pronounced effect on the survival of poikilothermic insects. These insects, which cannot regulate their body temperature, are particularly vulnerable to seasonal variations. To cope with these conditions, some insects have developed adaptive strategies such as migration, diapause, and the production of antifreeze compounds that allow them to survive harsh winter conditions. Seasonal variations in temperature, light, moisture, and resource availability are closely tied to the life history of these insects, influencing their development, activity, and reproduction (Bale & Hayward, 2010; Larson et al., 2019).

Insects employ various strategies to overwinter, such as creating safe habitats. For instance, stink bugs and Asian lady beetles seek shelter, while many flies rely on huddling mechanisms to survive. Despite these strategies, most insects perish during winter, with only larvae, nymphs, eggs, and pupal stages surviving the season's extreme cold (Ward et al., 2020). Post-fire studies reveal a decline in species diversity within the Margalla Hills National Park. The winter season survey found that only a few species, such as *Geophilus flavus*, *Scolopendra cingulata*, and *Scolopendra morsitans*, remained abundant after the fire, suggesting that forest fires significantly affect the local invertebrate population

During the winter season sampling, several habitat modifications were observed, including changes in vegetation composition. Alien invasive plant species, such as Common Lantana *Lantana camara*, Carrot Grass *Parthenium hysterophorus*, and Paper Mulberry *Broussonetia papyrifera*, had colonized burnt areas. The presence of these invasive species led to soil compaction, which hindered the survival of soil-dependent invertebrate species. As a result, only arthropods, orthopterans, and dipterans were found to dominate the burnt sites. According to Schlau (2022) wildfires can facilitate invasive species and alter plant-soil interactions through physical and chemical soil changes.

In the short term, forest fires lead to significant reductions in soil invertebrate diversity and abundance, as shown in our findings, with only a few taxa surviving in burnt areas. These survivors rely on adaptation strategies like migrating to deeper soil layers or nearby unaffected regions. However, long-term recovery depends heavily on factors such as soil fertility, vegetation regrowth, and climatic conditions post-fire. For example, invasive species often capitalize on these disturbed environments, potentially hindering the natural recovery of native species over the long term. As our study mentions, the altered conditions (e.g., soil compaction, loss of organic matter, reduced moisture) from fires can persist, which may affect the recolonization rates and long-term survival of sensitive species.

These findings align with the ecological theory that fire serves as a disturbance that resets successional stages. Over the long term, the recovery of soil invertebrates will depend on the regeneration of plant cover and the restoration of organic material, which provides essential food and shelter for these species. Studies by Sousa (1984) and Sholikha et al. (2018) suggest that while short-term recolonization is possible, the establishment of a stable and diverse invertebrate community could take longer, especially if invasive species alter habitat conditions. The potential shift in species composition in favor of more opportunistic or invasive species may lead to long-term changes in ecosystem dynamics.

Similarly, the study in the high Andean region of Peru found that forest fires influenced soil chemical properties, particularly in areas with *Pinus* plantations (Schlau, 2022), even though physical properties remained stable (Gonzáles et al., 2024). Both studies emphasize how wildfires disrupt ecosystems, leading to changes in vegetation and soil dynamics, and highlight the need for targeted restoration efforts. In our study, this could involve post-fire interventions such as seeding native "fire follower" species to restore plant-soil balance and limit further invasive spread, complementing findings from the Peruvian study regarding post-fire recovery strategies. Forest fires significantly impact soil invertebrate diversity and abundance, as evidenced by the drastic reduction in species richness and abundance in burnt areas. However, soil invertebrates exhibit resilience, with some recolonizing affected areas over time. The recovery process, while gradual, demonstrates the adaptability of soil invertebrates to post-fire environments, suggesting that ecosystems can eventually regain balance after such disturbances. In conclusion, while our findings show a promising recovery of soil invertebrates within 1 to 2 years, long-term implications suggest potential shifts in species composition and ecosystem processes, which could alter soil community dynamics and ecosystem functions for years to come. Monitoring these impacts beyond the short recovery period is crucial for understanding the full ecological consequences of fire disturbances.

5. Conclusion

The same taxa were collected from both sites, but the burnt sites' diversity index significantly decreased compared to unburned areas. The movement of arthropods and loss of species from burnt areas ultimately disturbed the abundance and evenness of unburned sites. Hence, the soil arthropod population is affected by fires, but it is more vulnerable than the gastropod population. It also altered the arthropods' habitat and species' traits and provided opportunities to adapt to new environments. Consequently, the forest fire negatively impacted nutrient flow, porosity of the soil, water cycle, weather conditions, and prey-predator relationship and allowed the invasion of non-native plant species in the affected areas in MHNP. It is clear that forest fires in the MHNP significantly disrupt soil fauna and the ecosystem's balance. However, habitat recovery is expected within two years, with fire-follower species aiding the restoration of native plant species in the MHNP.

Acknowledgments

We are highly thankful to Dr. Mishqatullah, Associate Curator, Pakistan Museum of Natural History (PMNH), Islamabad for his undoubtful promise in taxonomic work on specimens collected from the burnt sites of the study area.

Authors contributions

Zahid Baig Mirza (ZBM) conceived this research idea and supervised the study. Sakhawat Ali (SA) provided logistic support to the study area. Kiran Sahar (KS), Shahzad Aslam (SA), and Ahmar Riaz (AR) conducted the field study by collecting the samples. Ghulam Murtaza (GM) developed the study area. Kiran Sahar (KS) wrote the initial manuscript and carried out statistical data analysis. Shahzad Aslam (SA) edited and finalized the manuscript.

Funding

This study was sponsored by a small grant released from the scientific committee of the Islamabad Wildlife Management Board (IWMB), Ministry of Climate Change and Environmental Coordination, Islamabad Pakistan.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Macrothink Institute.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

References

Abe, T., Bignell, D. E., & Higashi, M. (2000). *Termites: evolution, sociality, symbioses, ecology*. Springer Science & Business Media.

Ahmed, H., Jallat, H., Hussain, E., Saqib, N. U., Saqib, Z., Khokhar, M. F., & Khan, W. R. (2023). Quantitative assessment of deforestation and forest degradation in Margalla Hills National Park (MHNP): employing landsat data and socio-economic survey. *Forests*, *14*(2), 201-2010. https://doi.org/https://doi.org/10.3390/f14020201

Ajayi, O., & Kwesiga, F. (2003). Implications of local policies and institutions on the adoption of improved fallows in eastern Zambia. *Agroforestry systems*, *59*(3), 327-336. https://doi.org/https://doi.org/10.1023/B:AGFO.0000005233.32309.e4

Andersen, A. N., Ribbons, R. R., Pettit, M., & Parr, C. L. (2014). Burning for biodiversity: highly resilient ant communities respond only to strongly contrasting fire regimes in A ustralia's seasonal tropics. *Journal of Applied Ecology*, *51*(5), 1406-1413.

Anwar, M., & Chapman, J. A. (2000). Distribution and population status of grey goral, in the Margalla Hills National Park (MHNP), Islamabad. Pak. *Pakistan Journal of Agriculture Research*, *16*(2), 20-32. https://doi.org/https://www.cabi.org/GARA/FullTextPDF/2009/20093351049.pdf

Aslam, S., A.R., K., Ashraf, M. I., Jameel, M. A., & Sahar, K. (2024). Food Preference of Rhesus Monkey (Macaca mulatta) in the Margalla Hills National Park, Islamabad, Pakistan. *Pakistan Journal of Zoology*, *56*(3), 1249-1262. https://doi.org/https://dx.doi.org/10.17582/journal.pjz/20210724200757

Bale, J., & Hayward, S. (2010). Insect overwintering in a changing climate. *Journal of Experimental Biology*, *213*(6), 980-994. https://doi.org/https://doi.org/10.1242/jeb.037911

Bignnell, D. E., & Eggleton, P. (2000). In: Abe T., Bignell D.E. and Higashi M. (eds), Termites: Evolution, Sociality, Symbiosis, Ecology. In *Termites in ecosystems* (pp. 363-287). Kluwer Academic Publisher.

Bot, A., & Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production*. Food & Agriculture Org.

Bowman, D. M., Balch, J., Artaxo, P., Bond, W. J., Cochrane, M. A., D'antonio, C. M., DeFries, R., Johnston, F. H., Keeley, J. E., & Krawchuk, M. A. (2011). The human dimension of fire regimes on Earth. *Journal of biogeography*, *38*(12), 2223-2236. https://doi.org/https://doi.org/10.1111/j.1365-2699.2011.02595.

Certini, G. (2005). Effects of fire on properties of forest soils: a review. *Oecologia*, *143*, 1-10. https://doi.org/https://doi.org/10.1007/s00442-004-1788-8

Cho, G., George, A., Stoutjeskijk, R., & Longmore, R. (1995). *Jervis Bay. Kowari 5*. Australian Nature Conservation Agency Publication, Canberra.

Clarke, K. R., & Warwick, R. (2001). Change in marine communities. *An approach to statistical analysis and interpretation*, *2*, 1-68.

Dinesh, G., Ramesh, P., Chitra, N., & Sugumaran, M. (2018). Ecology of birds and insects in organic and conventional (In-organic) rice ecosystem. *International Journal of Current Microbiology and Applied Sciences*, *7*(4), 1769-1779. https://doi.org/https://doi.org/10.20546/ijcmas.2018.704.201

Doğramaci, M., DeBano, S. J., Kimoto, C., & Wooster, D. E. (2011). A backpack-mounted suction apparatus for collecting arthropods from various habitats and vegetation. *Entomologia Experimentalis et Applicata*, *139*(1). https://doi.org/https://doi:10.1111/j.1570-7458.2011.01099.x

Fatima, H., Mahmood, T., Hennelly, L. M., Farooq, M., Akrim, F., & Nadeem, M. S. (2021). Spatial distribution and dietary niche breadth of leopard cats (Prionailurus bengalensis) inhabiting Margalla Hills National Park, Pakistan. *Zoological Studies*, *60*. https://doi.org/https://doi.org/10.6620%2FZS.2021.60-34

Fischer, C. J., & O'Neill, K. M. . (2021). Effects of prescribed fire on soil invertebrate diversity and community structure in a southeastern US pine forest. , . *Fire Ecology*, *17*(1), 1-17.

Frost, P. (1996). *The ecology of miombo woodlands* (Vol. 266).

Gill, A. M. (1997). Eucalypts and fires: interdependent or independent. *Eucalypt ecology: individuals to ecosystems*, 151-167.

Gonzáles, H., Ocaña, C. L., Cubas, J. A., Vega-Nieva, D. J., Ruíz, M., Santos, A., & Barboza, E. (2024). Impact of forest fire severity on soil physical and chemical properties in pine and scrub forests in high Andean zones of Peru. *Trees, Forests and People*, *18*, 100659.

GoP. (2015). *Government of Pakistan, M/O of climate change, Islamabad. Year book 2015–16. Islamabad, Pakistan.*

Greenslade, P. (1997). Short term effects of a prescribed burn on invertebrates in grassy woodland in south-eastern Australia. *Memoirs of the Museum of Victoria*, *56*(2), 305-312. https://doi.org/https://doi.org/10.24199/j.mmv.1997.56.18

Greenslade, P., & Smith, D. (2010). Short term effects of wild fire on invertebrates in coastal heathland in southeastern Australia. *Pacific conservation biology*, *16*(2), 123-132. https://doi.org/https://doi.org/10.1071/PC100123

Haddad, N. M., & Tewksbury, J. J. (2005). Low-quality habitat corridors as movement conduits for two butterfly species. *Ecological Applications*, *15*(1), 250-257.

HYVÄRINEN, E., Kouki, J., & Martikainen, P. (2009). Prescribed fires and retention trees help to conserve beetle diversity in managed boreal forests despite their transient negative effects on some beetle groups. *Insect Conservation and Diversity*, *2*(2), 93-105. https://doi.org/https://doi.org/10.1111/j.1752-4598.2009.00048.x

Jabeen, A., Khan, M. A., Ahmad, M., Zafar, M., & Ahmad, F. (2009). Indigenous uses of economically important flora of Margallah hills national park, Islamabad, Pakistan. *African Journal of Biotechnology*, *8*(5).

John, L., & Moshe, S. (1994). Organisms as ecosystem engineers. *Oikos*, *69*(3), 373-386.

Kraus, D., & Goldammer, J. G. (2007). Fire regimes and ecosystems: an overview of fire ecology in tropical ecosystems. Forest fires in India–workshop proceedings (ed. Schmerbeck, J., Hiremath, A. and Ravichandran, C.). ATREE, Bangalore, India and Institute of Silviculture, Freiburg, Germany,

Krebs, P., Pezzatti, G. B., Mazzoleni, S., Talbot, L. M., & Conedera, M. (2010). Fire regime: history and definition of a key concept in disturbance ecology. *Theory in Biosciences*, *129*, 53-69. https://doi.org/https://doi.org/10.1007/s12064-010-0082-z

Lacey, C. J. (1973). Silvicultural characteristics of White Cypress Pine.

Larsen, K. J., & Work, T. W. (2003). Differences in ground beetles (Coleoptera: Carabidae) of original and reconstructed tallgrass prairies in northeastern Iowa, USA, and impact of 3-year spring burn cycles. *Journal of Insect Conservation*, *7*, 153-166. https://doi.org/https://doi.org/10.1023/A:1027309101653

Larson, E. L., Tinghitella, R. M., & Taylor, S. A. (2019). Insect hybridization and climate change. *Frontiers in Ecology and Evolution*, *7*, 348. https://doi.org/https://doi.org/10.3389/fevo.2019.00348

Lavelle, P., Senapati, B., & Barros, E. (2003). Soil macrofauna. In: Schroth G. and Sinclair F.L. (eds), . In *Trees, Crops and Soil Fertility: Concepts and Research Methods* (pp. 303-323). CAB International.

Levine, A. L., & Tietje, W. . (2020). Post-fire recovery of soil invertebrate communities in an eastern Mediterranean ecosystem. . *Ecological Research*, *5*(5), 3850-3860.

Liu, C., & Xia, Y. (2019). Impact of fire on soil arthropods and their implications for ecosystem functioning., . *Applied Soil Ecology*, *135*, 90-96.

Lunt, I., & Morgan, J. (2002). *The role of fire regimes in temperate lowland grasslands of southeastern Australia* (J. E. W. R. A. Bradstock, A. M. Gill, Ed.).

Mahmood, T., & Ali, S. (2022). *COMPARATIVE REPORT ON FIRE INCIDENT REPORT IN MARGALLAH HILLS NATIONAL PARK, ISLAMABAD.* .

Moretti, M., & Legg, C. (2009). Combining plant and animal traits to assess community functional responses to disturbance. *Ecography*, *32*(2), 299-309.

Neary, D. G. (2019). Forest soil disturbance: Implications of factors contributing to the wildland fire nexus. *Soil Science Society of America Journal*, *83*, S228-S243.

New, T., Yen, A., Sands, D., Greenslade, P., Neville, P., York, A., & Collett, N. (2010). Planned fires and invertebrate conservation in south east Australia. *Journal of Insect Conservation*, *14*, 567-574. https://doi.org/https://DOI 10,1007/S10891–010–9284–4

Parsons, A., Robichaud, P. R., Lewis, S. A., Napper, C., & Clark, J. T. (2010). *Field guide for mapping post-fire soil burn severity* (Vol. 243). Citeseer.

Peters, R. H. (2005). *The Role of Fire in the Structure and Dynamics of Terrestrial Ecosystems. Cambridge University Press.* Cambridge University Press.

Piearce, G. (1986). *How to save the Zambezi teak forests* (Unasylva (FAO), Issue. f. a. A. O. o. U. States.

Qasim, M. (2022). *Forest Biomass and Land Cover Change Assessment of the Margalla Hills National Park in Pakistan Using a Remote Sensing Based Approach*

Raj, A., Jhariya, M., Yadav, D., & Banerjee, A. (2020). Forests for Resource Management and Environmental Protection. In *Environmental and sustainable development through forestry and other resources* (pp. 1-24). Apple Academic Press.

Ribeiro-Kumara, C., Pumpanen, J., Heinonsalo, J., Metslaid, M., Orumaa, A., Jõgiste, K., Berninger, F., & Köster, K. (2020). Long-term effects of forest fires on soil greenhouse gas emissions and extracellular enzyme activities in a hemiboreal forest. *Science of the Total Environment*, *718*, 135291. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.135291.

Robinne, F.-N., & Secretariat, F. (2021). Impacts of disasters on forests, in particular forest fires. *UNFFS Background paper*.

Sabu, T., Vinod, K., Latha, M., Nithya, S., & Boby, J. (2011). Cloud forest dung beetles (Coleoptera: Scarabaeinae) in the Western Ghats, a global biodiversity hotspot in southwestern India. *Tropical Conservation Science*, *4*(1), 12-24. https://doi.org/https://doi.org/10.1177/194008291100400103

Sasal, Y., Raffaele, E., & Farji-Brener, A. G. (2010). Succession of ground-dwelling beetle assemblages after fire in three habitat types in the Andean forest of NW Patagonia, Argentina. *Journal of Insect Science*, *10*(1), 37. https://doi.org/https://doi.org/10.1673/031.010.3701

Schlau, B. M. (2022). Wildfire disturbance affects species interactions of a harmful invasive annual in second year of post-fire vegetative recovery. *Biological Invasions*, *24*(2), 373-383.

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience*, *54*(7), 661-676. https://doi.org/https://doi.org/10.1641/0006-3568(2004)054[0661:TIOFFA]2.0.CO;2

Shah, A., Ali, K., & Nizami, S. M. (2021). Four decadal urban land degradation in Pakistan a case study of capital city islamabad during 1979–2019. *Environmental and Sustainability Indicators*, *10*, 100108. https://doi.org/https://doi.org/10.1016/j.indic.2021.100108

Sholikha, M., Salmah, S., Hamidah, S., & , & Hidayat, T. (2018). . Recovery of soil invertebrates after forest fire in Central Kalimantan, Indonesia. Biodiversitas Journal of Biological Diversity, . *19*(5), 1537-1544.

Sileshi, G., & Mafongoya, P. (2006). The short-term impact of forest fire on soil invertebrates in the miombo. *Biodiversity & Conservation*, *15*(10), 3153-3160. https://doi.org/ https://doi.org/10.1007/s10531-005-5411-z

Singh, R. D., Gumber, S., Joshi, H., & Singh, S. P. (2022). Allocation to tree bark in pine and oak species in fire affected mixed forests across the Northern Hemisphere. *Forest Ecology and Management*, *509*, 120081. https://doi.org/https://doi.org/10.1016/j.foreco.2022.120081

Sousa, W. P. (1984). The role of disturbance in natural communities. *Annual review of ecology and systematics*, *15*, 353-391.

Tahir, Z., & Asim, M. (2018). Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review. *Renewable and Sustainable Energy Reviews*, *81*, 2839-2861. https://doi.org/https://doi.org/10.1016/j.rser.2017.06.090

Tariq, A., Shu, H., Siddiqui, S., Mousa, B., Munir, I., Nasri, A., Waqas, H., Lu, L., & Baqa, M. F. (2021). Forest fire monitoring using spatial-statistical and Geo-spatial analysis of factors determining forest fire in Margalla Hills, Islamabad, Pakistan. *Geomatics, Natural Hazards and Risk*, *12*(1), 1212-1233. https://doi.org/https://doi.org/10.1080/19475705.2021.1920477

Thompson, I., Mackey, B., McNulty, S., & Mosseler, A. (2009). Forest resilience, biodiversity, and climate change. A synthesis of the biodiversity/resilience/stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series,

van Mantgem, E. F., Keeley, J. E., & Witter, M. (2015). Faunal responses to fire in chaparral and sage scrub in California, USA. *Fire Ecology*, *11*, 128-148.

Vasconcelos, H. L., Pacheco, R., Silva, R. C., Vasconcelos, P. B., Lopes, C. T., Costa, A. N., & Bruna, E. M. (2009). Dynamics of the leaf-litter arthropod fauna following fire in a neotropical woodland savanna. *PloS one*, *4*(11), e7762. https://doi.org/https://doi.org/10.1371/journal.pone.0007762

Verma, S., & Jayakumar, S. (2012). Impact of forest fire on physical, chemical and biological properties of soil: A review. *proceedings of the International Academy of Ecology and Environmental Sciences*, *2*(3), 168.

Ward, S. F., Eidson, E. L., Kees, A. M., Venette, R. C., & Aukema, B. H. (2020). Allopatric populations of the invasive larch casebearer differ in cold tolerance and phenology. *Ecological Entomology*, *45*(1).

White, F. (1983). *The vegetation of Africa* (Vol. 20).

Yekwayo, I., Pryke, J. S., Gaigher, R., & Samways, M. J. (2018). Only multi-taxon studies show the full range of arthropod responses to fire. *PloS one*, *13*(4), e0195414. https://doi.org/https://doi.org/10.1371/journal.pone.0195414

Zhang, H., John, R., Peng, Z., Yuan, J., Chu, C., Du, G., & Zhou, S. (2012). The relationship between species richness and evenness in plant communities along a successional gradient: a study from sub-alpine meadows of the Eastern Qinghai-Tibetan Plateau, China. *PloS one*, *7*(11), e49024. https://doi.org/https://doi.org/10.1371/journal.pone.0049024