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Insects as Ecological Indicators: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Insects are universal components of ecosystems, and their roles in maintaining ecological balance are multifaceted. They also show a sensitive response to environmental health. Abundance, diversity, and behaviour of insects are sensitive to changes in their environment, rendering them an invaluable indication of ecosystem health. The life cycles of these insects are fast, and they are sensitive to changes in the environment; hence, they become forerunners of disturbance, thus showing changes in the ecosystem before noticeable effects on larger organisms occur. For example, changes in insect populations may indicate changes in the climate, land use, level of pollution, and habitat quality. Terrestrial and aquatic habitats use insects as bio indicators, since different taxa respond to different stressors. While aquatic insects, such as mayflies and stoneflies, are an indication of the health of freshwater ecosystems, terrestrial ones—butterflies, beetles, moths, bees, etc.—indicate habitat fragmentation, pesticide exposure, and climate change impacts. It is through the power of their ecological importance and using advances in technology that these

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researchers have the potential to leverage this complex world of insects to protect biodiversity forlong-lasting care. This review article focuses on the priority of insects as a beneficiary for monitoring environmental pollution and assessing pollutants.

Keywords: Bioindicators; Insects; ecosystem; taxa; disturbances; managements.

1. INTRODUCTION

“Currently, the world is dealing with the significant issue of global warming. It has reached unprecedented levels, as indicated by the incredible rates of increase in air temperature and sea level” (Field et al. 2014). “Greenhouse gas concentrations have dramatically increased during the past two centuries compared with the pre-industrial era, which is a primary contributor to global warming” (Rogelj et al., 2018). “Other changes have been associated with anthropogenic impacts, such as a decrease in cold temperature extremes, increased warm temperature extremes, faster rates of sea level rise, and more frequent heavy precipitation events have all been observed in several areas. Weather extremities, such as heat waves and prolonged periods of extreme precipitation, are predicted to increase in frequency and severity in some areas” (Field et al., 2014). The two main factors that influence the current state of global biodiversity are habitat change and overexploitation.

“Biological processes, species, or communities are examples of bioindicators, which are used to evaluate the state of the environment and how it changes over time. Natural stressors like drought and late spring freezing are frequently blamed for environmental changes, as are manmade disturbances like pollution and changes in land use. Nonetheless, the main subject of bioindicator study is anthropogenic stresses. It has been mostly since the 1960s that bioindicators have been developed and used widely” (Holt & Miller, 2011). It is highly problematic to utilize bioindicators (McGeoch, 1998) to represent broader biodiversity responses (Lawton et al., 1998; Barlow et al., 2007) since biological responses to a disturbance might differ significantly among taxa (Barlow et al., 2007; Filgueiras et al., 2019).

Although environmental contamination poses a direct threat to ecosystems, environmental monitoring is essential to both managing and forecasting ecosystem health. The idea of bio-indication is not traditional; it is now a developing problem associated with conservation evaluation. A species or a collection of species that symbolizes the biotic or abiotic condition of the ecosystem is referred to as a "bioindicator." It shows how changes in the environment impact a community, ecosystem, or habitat and indicates whether such changes have a good or negative impact (Parmar et al., 2016; Chowdhury et al.,2023). Many living things are very sensitive to changes in their surroundings that interfere with their basic processes, including growth, metabolism, and reproduction (David, 1989). According to Lindenmayerr et al. (2000), the use of indicator species is a significant and practical technique for establishing sustainable agreement when evaluating the impacts of both natural and man-made disturbances in forests.

Artificial light at night is unique among anthropogenic habitat disturbances in that it is fairly easy to upgrade and leaves no residual effects behind. Moreover, recognizing the ways in which artificial light at night affects insects can help conservationists to reduce or eliminate one of the major drivers of insect decline. In contrast to other putative causes of insects, such as habitat loss, chemical and light pollution, and nutrient dilution, these factors may be common in surviving natural areas (Welti et al., 2020). Sanchez-Bayoand Wyckhuys (2019) demonstrates significant rates of decline that within the next several decades could result in the extinction of 40% of all insect species worldwide.

Arthropods, despite surviving the Cretaceous and Permian mass extinctions, were the most successful of all the invertebrates. The most common species in all types of ecosystems, insects, can be utilized to measure the effects of environmental changes. Numerous ecological processes are attributed to insects, and their extinction could have detrimental consequences for the ecosystem as a whole. Because of their ecological peculiarities, which provide information about the characteristics of the environment in which they exist or about the evolution of this environment under the influence of certain practices, insects are used as bioindicators to detect changes in the environment and the presence of pollution (Djamel et al., 2022). It is estimated that 65% of all flowering plants and some seed plants (e.g. cycads and pines) require insects for pollination.

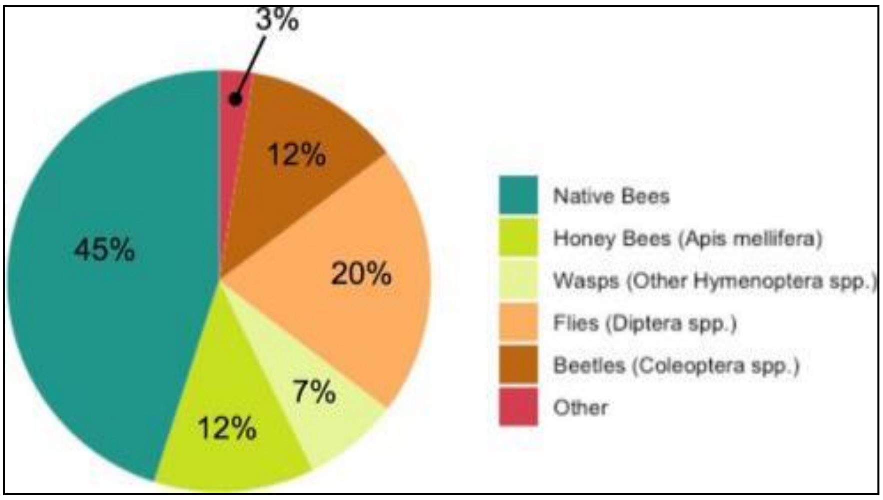

Fig. 1. Percentage of pollinating insects contributed by different taxonomic group (Source: Graham et al.,2021)

2. METHODS

This review was conducted following a systematic approach aimed at gathering, appraising, and synthesizing existing literature on the role of insects as ecological indicators. Based on this scope, the review aimed to explore how insects could serve as indicators of environmental health and biodiversity in different habitats, such as forests, aquatic systems, and agricultural landscapes. A comprehensive literature search was conducted through academic databases, including Google Scholar, Biological Abstract, HAL, Qeios, Research Gate, Scielo, and SSRN along with peer-reviewed articles, books, and review papers published during the last 20 years. Studies relevant to this discussion were identified in line with predefined inclusion criteria that emphasized peer-reviewed publications, case studies, and reviews discussing the roles of insects as ecological indicators, especially over the last two decades. In the process, studies unrelated to ecological monitoring or lacking rigorous peer review were excluded. The selected articles were critically appraised to evaluate their methodological rigor, relevance to different ecosystems, and consistency in findings. Data were extracted on the insect groups commonly employed as indicators, such as beetles, butterflies, moths, bees, dragonflies, dragonflies, grasshoppers, termites and ants, the monitored environmental parameters, including habitat quality, pollution, and climate change, and the geographical and ecological context of the studies.

3. SELECTED STUDIES

3.1 Why Insects Used as Biological Indicators

Insects occupy a vast range of niches and can be found in nearly every terrestrial and freshwater habitat. Moreover, they are frequently found in large quantities. Due to their small size and short life cycles, insects make excellent subjects for laboratory testing, which can be done in conjunction with monitoring experiments. These two facts mean that there are insect species available to serve as indicators in almost every ecological situation (Mahanta et al., 2023). There are several reasons for using insects as biological indicators.

1. **Sensitivity to Environmental Changes**: Insects are highly responsive to environmental changes, including changes in temperature, humidity, pollution levels, and habitat quality. As a result, their populations and diversity can serve as early indicators of environmental disturbance.
2. **Diverse and Abundant:** Insects constitute a vast and diverse group of organisms, with an estimated millions of species. Their abundance and diversity make them suitable for monitoring different ecosystems and their responses to various environmental factors.
3. **Short Life Cycles:** Many insect species have relatively short life cycles, allowing for rapid responses to environmental changes.

This enables scientists to observe and measure shifts in insect populations over relatively short time frames, providing timely information about ecosystem health.

4. **Position in the Food Web:** Insects often occupy key positions in food webs, serving as prey for various other organisms. Changes in insect populations can have cascading effects on other species, making them useful indicators of broader ecological changes.
5. **Specificity to Habitat Types:** Different insect species are adapted to specific habitats and environmental conditions. Monitoring the presence or absence of certain indicator species can reveal the quality of a particular habitat and the impact of environmental changes on that habitat.
6. **Ease of Sampling:** Insects are relatively easy to sample and identify, and there are standardized methods for collecting and studying them. This makes it practical and cost-effective to use insects for monitoring purposes over large geographic areas.
7. **Response to Pollution:** Some insect species are particularly sensitive to pollution. Changes in their abundance or diversity can signal pollution events, making them valuable indicators of water, air, or soil quality.
8. **Education and Public Awareness:** Insects are easily observable and accessible, making them suitable for educational programs. Their use as biological indicators can raise public awareness about environmental issues and the importance of conservation.

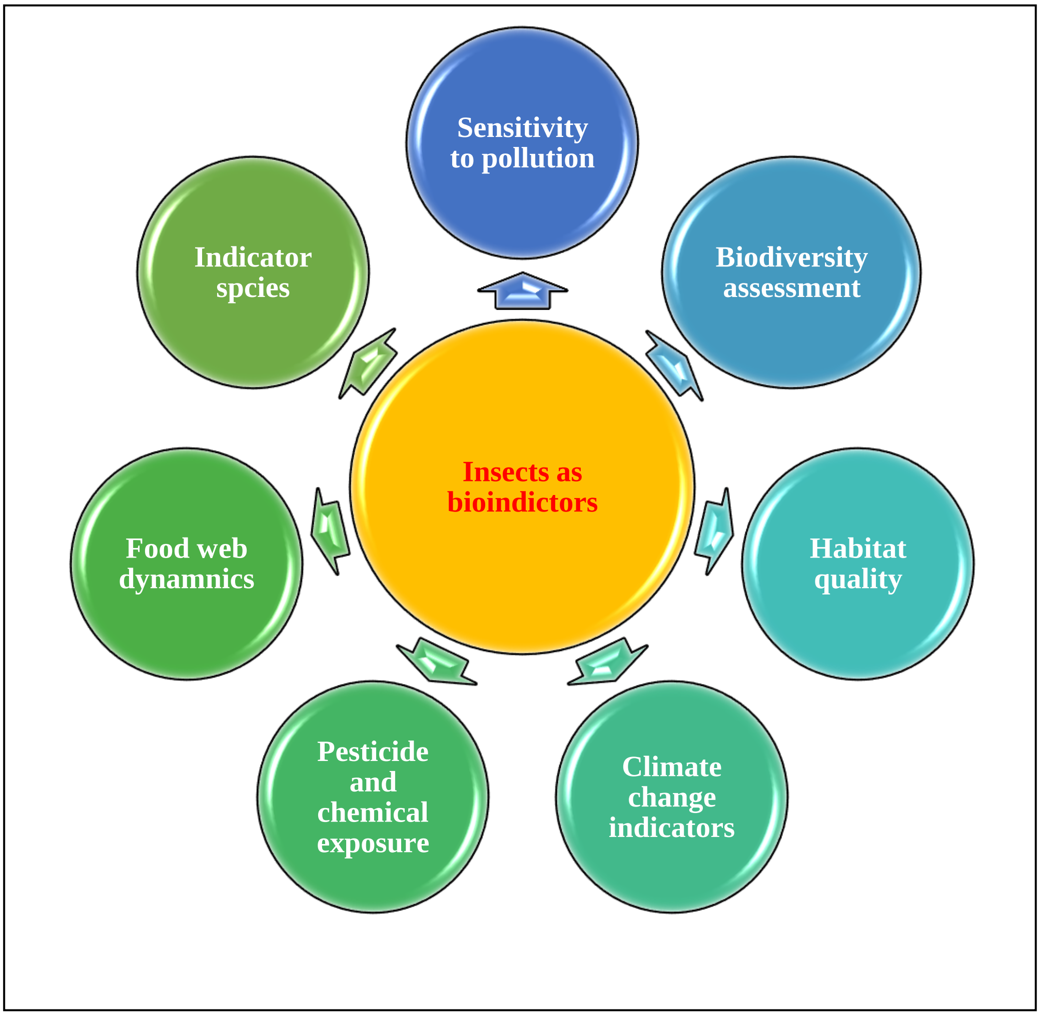

Fig. 2. Insect group characteristics as bio-indicators

3.2 Criteria for selection of bio indicator

According to Noss (1990), an ideal bio-indicator should possess a well-defined taxonomy and ecology, be broadly distributed over a sizable geographic area, be specific to particular habitat requirements, offer early warning of changes, be easy and inexpensive to survey, be largely independent of sample size, and be able to distinguish between cycles or trends brought on by natural cycles or trends and those brought on by anthropogenic stress. Eleven criteria for bioindicator selection have been developed, drawing from both national and international research (Han et al., 2015).

I. Species (or species groups) with clear classification and ecology.
II. Species (or species groups), those are distributed in geographically widespread area.
III. Species (or species groups), those show clear habitat characteristics.
IV. Species (or species groups), those can provide early warning flora change.
V. Species (or species groups), those can benefit promptly and economically from the investigation.
VI. Species (or species groups), those are not adversely affected by the size of individual groups and have numerous independent individual groups.
VII. Species (or species groups), those are thought to represent the response of other species.
VIII. Species (or species groups), those are representative of the ecology change caused by the pressure of human influence.
IX. Species (or species groups) for which research on climate change have been done.
X. Species (or species groups), those are easy to observe, appear flora long time and form a large group of individuals.
XI. Species (or species groups), those are significant in terms of culture, economy, and society.

3.3 Classification of bio-indicators

Bio indicators can be categorized in a variety of ways (Mc Geoch, 1998) classified them into three categories: environmental, ecological, and biodiversity indicators based on diverse background and application. Insects can be classified as bio-indicators based on various criteria, including their sensitivity to environmental changes, habitat preferences, and ecological roles.

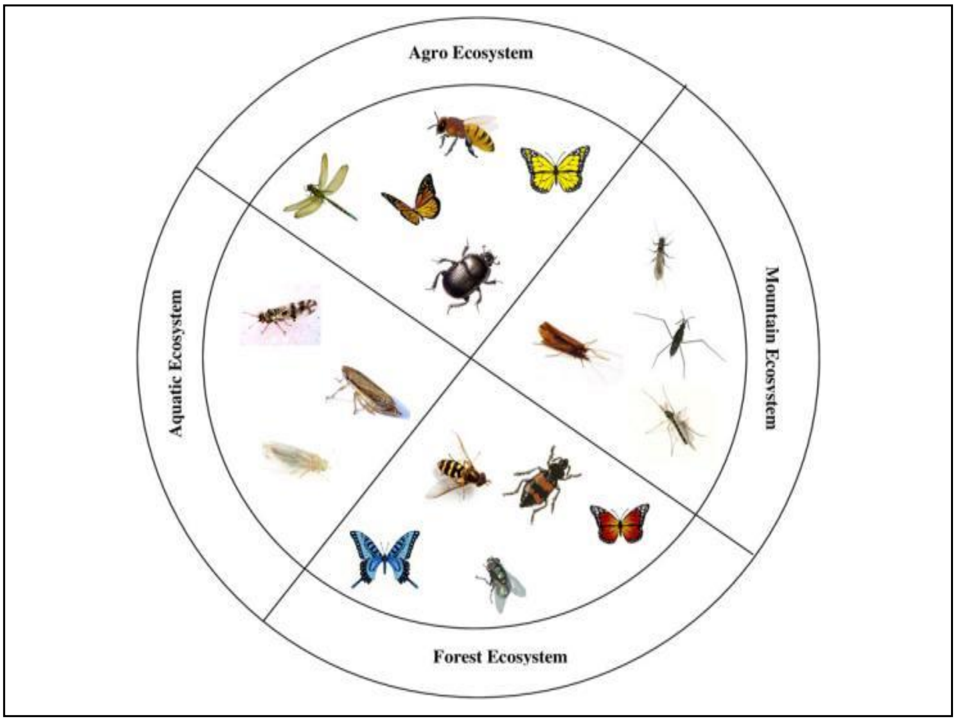

Fig. 3. Insects as bio-indicators of different ecosystems (Source: Chaudhary et al.,2023).

3.4 Bio-indicators Insect Groups

Arthropods are good bioindicators of ecosystem change and habitat modification because of their small body size, short generation period (Kremen et al., 1993), high sensitivity to temperature and moisture changes (Schowalter et al., 2003), and ability to provide ecological services (Longcore, 2003). These qualities make arthropods useful indicators of the quality of forest management practices (Samways 1994; New 1995, 1998; Progar and Schowalter 2002; Maleque et al. 2006). Butterflies, moths, bees, dragonflies, and ladybugs are indicators of different plant ecosystems. Monitoring the presence or absence of a specific insect species on specific plants can provide insight about the plant community's health and diversity.

3.5 Ants as Bio-indicators

Ants have been widely used as effective disturbance bioindicators for ecosystem management due to their eco-functional importance (Gauld and Bolton, 1988) and high sensitivity to ecosystem disturbances caused by forest thinning, grazing, species invasion, forest fires, forest conversion, forest fragmentation, and other forms of disturbance (Carvalho and Vasconcelos, 1999; Vasconcelos et al., 2000; Maeto and Sato, 2004; Sinclair and New, 2004; Stephens and Wagner, 2006; Del Toro,.I.,2012; Philpott et al.,2010).

Ants have been utilized to measure a variety of environmental consequences, including fire, deforestation and logging, agricultural intensification, mining, and urbanization (Underwood & Fisher, 2006; Philphott et al., 2006). *Camponotus atriceps* (Smith, F. 1858) (Hymenoptera : Formicidae) and *Dorymyrmex bureni*, (Trager, 1988) (Hymenoptera : Formicidae) two ant species that prevail in forest and harvest areas, were employed in a study conducted in Brazil to evaluate heavy metal levels. Researchers discovered that because ants absorb more agrochemicals from agriculture than forests, they are good bio-indicators of heavy metal contamination.

Ground-foraging ants were utilized to monitor the forest's health. The inherent unpredictable nature of the behavior is directly related to the ant fauna (Toro et al., 2012; Hodkisnson and Jackson, 2005; Bohac, 1999). Ants are particularly vulnerable to activities that could imperil their range, such as mining, logging, ire, and agriculture (Andersen et al. 2006, Silva et al. 2009, Vasconcelose et al., 2000).

A positive association has been identified between total ant population and tree density. This shows that trees have an essential role in ant nesting (Frizzo and Vasconcelos, 2013), food production (Arnan et al., 2007), and microclimate adjustment (Perfecto and Vandermeer, 1996). The response of specialized predators suggests that trees serve as an important source of prey for ants. Ant colonies emphasize the importance of plant structure, particularly trees' role in providing wildlife with food and nesting locations (Frizzo and Vasconcelos, 2013; Neilly et al., 2018).

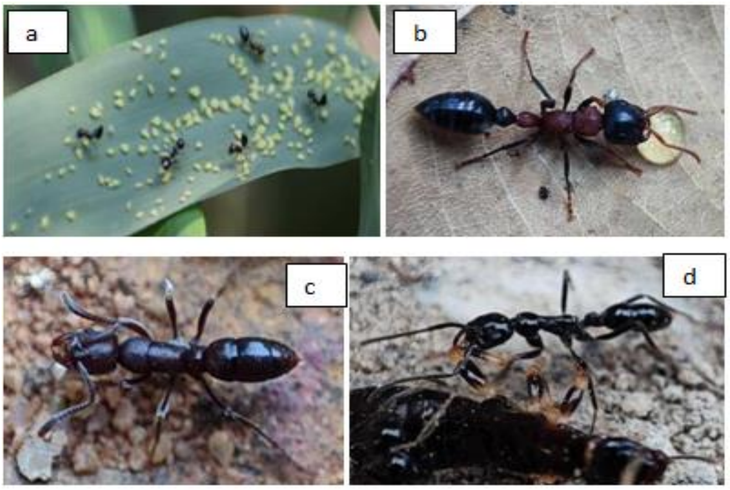

Fig. 4. Different species of ants act as bio-indicators (b) *Tetraponera rufonigra* (c) *Bothroponera* sp. (d) *Leptogenys* sp. (Photo Source: Ashirwad Tripathy)

3.6 Butterflies & Moths as Bio-indictors

Butterflies and moths are two of the most attractive and recognized insects in the Lepidoptera group. The abundance of vascular plant species, nectar plant species, and herbaceous plant species all correlate with the abundance of butterfly species (Niemela and Baur, 1998; Grill et al., 2005; Kitahara et al., 2008). There are moth families and subfamilies that respond positively to disturbances (e.g., Arctiinae, Catocalinae, Heliothinae, Noctuinae, Hermeniidae, and Phycitinae) and those that respond negatively (e.g., Ennominae, Geometrinae, Epipaschiinae, Lymantriidae, and Anthelidae) (Kitching et al., 2000). Grand ditches butterfly *Euthalia patala* (Kollar, 1844) (Lepidoptera: Nymphaidae) is one of the important indicators species of Himalayan moist temperate ban oak forests in India's Western Himalayan area.

When compared to naturally occurring dense forests, thinned and burned, and wildfire (disturbed woods) have a greater diversity of butterflies. Butterfly populations have been found to be higher in disturbed woods, as they are known to interact the most during disturbances. As a result, butterflies are regarded as one of the most reliable ecological markers of climate change. Because of their strong associations with environmental qualities such as sunny weather, meadows, hilly terrain, forest boundaries, and an abundance of herbaceous plants, they are frequently used as indicators of healthy ecosystems. Butterfly species are most abundant at lower altitudes, indicating that they can be utilized as indicators of altitudinal and other environmental changes (Kumar et al., 2011).

Fig. 5. Lepidoptera order as an bio-indicators: Butterflies: (a) Grand Dutches (b) Vagrant (c) Western courtier (d) Grey pansy (e) Orange oakleaf; Moths: (f) greater death head moth (g) dark owlet moth (h) tussock moth (i) Small sphinx moth (Photo clicked by Gaurav Chand Ramola & Lekhendra Sahu)

Recently, study on Lycaenidae family butterfly, Pale Grass Blue (*Pseudozizeeria maha* (Kollar, 1844) (Lepidoptera: Lycaenidae) was conducted in Japan, identifying this species as a valuable biological indicator for detecting changes in the human environment following the Fukushima nuclear accident (Hiyama & Otaki, 2020). The nuclear disaster was found to have reduced the species richness and biodiversity of this butterfly (Lie et al.,1992; Kaplan et al., 1997). The presence of iron, copper, nickel, cadmium, and other fertilizer-related elements was investigated using pupae from various Noctuidae and Geometridae species, the Eriocraniidae population, the length of the cycle, and the mortality rate of newly hatched larvae from butterflies (Family Nymphalidae), which feed on plants exposed to elevated carbon dioxide concentrations (Da Rocha et al. 2010).

Monitoring butterfly diversity and abundance may aid in understanding the structure and function of ecosystems at the landscape scale. Semi-natural habitat patches found in plantation woodlands maintain a high level of butterfly diversity. Butterflies, which are typically found in old-growth forests, forest edges, and semi-natural grassland habitats, underscore the importance of habitat preservation in maintaining regional biodiversity (Kitahara, 2004; Halder et al., 2008; Bergman et al.,2008; Sharma & Sharma, 2017). Hirowatari et al. (2007) demonstrated that three generalist butterfly species—*Melanitis leda* (Linnaeus, 1758) (Lepidoptera: Nyphalidae), *Charaxes bernardus* (Fabricius,1793) (Lepidoptera: Nyphalidae) and *Danaus genutia* (Cramer, 1779) (Lepidoptera: Nyphalidae) could be used as disturbance indicators after fire in Southeast Asia's tropical rain forests.

3.7 Beetles as Bio-Indicators

Given their wide range of habitats on land, beetles have gained interest as biological markers of environmental pollutants (Zodl and Wittmann, 2003). While they forage for plants and dirt on the soil's surface, beetles are able to absorb hazardous substances as part of their underground biological cycle, which includes rest, shelter, egg-laying, embryonic development, and hibernation. These have been regarded as good bioindicators because of their broad distribution, ease of sampling, ability for bioaccumulation, and diet, which includes carnivorous, phytophagous, or saprophagous organisms (Berger and Dallinger 1993).

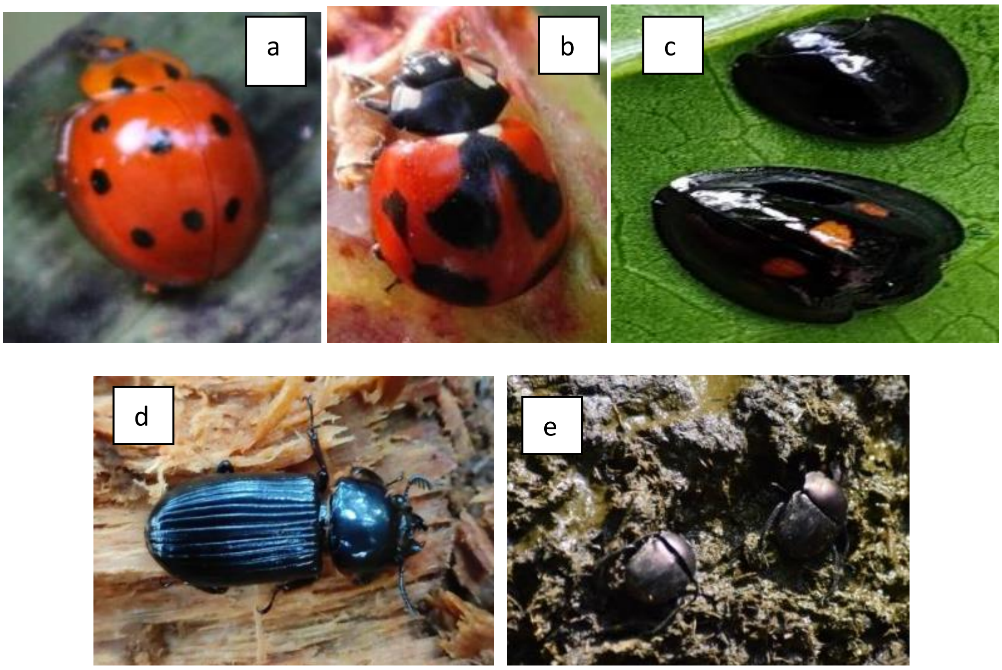

Fig. 6. Coleoptera order as an bio-indicators; (a) *Coccinella septempunctata* (b) *Coccinella* spp. (c) *Chilocorus infernalis* (d) *Aceraius grandis* (e) *Scarabaeus* spp. (dung beetle) (Photo Source: Ashirwad Tripathy).

Carabid beetles are one of the best arthropod groups for examining the ecological implications of diverse anthropogenic impacts on soil ecosystems due to their taxonomy, ecological uniqueness, abundance, and susceptibility to human disturbance (Leovei and Sunderland, 1996). Several studies have employed changes in carabid variety, dominance, abundance, sex ratio, and other factors as bio monitors. Carabids, also known as ground beetles, are commonly used as indicators of ecosystem change in temperate area grassland and boreal forest environments because they are inexpensive to sample (Rainio and Niemela, 2003; Talarico et al.,2014).

As a result, they may receive monetary compensation for their employment. Cercambycid beetles are connected with blossoming plants, coarse woody debris, and ancient oak trees—that is, old-growth forest remnants within a matrix of conifer plantations (Ohsawa, 2004, 2007, 2008; Muller et al., 2008). *Pterostichus oblongopunctatu* (Fabricius, 1787)(Coleoptera: Carabidae) investigations (Simon et al., 2016) indicated high BAF (Bioaccumulation factor) values for zinc (Zn) and copper (Cu), indicating that this species is recommended in metal pollution evaluation in ecosystems (Rainio and Niemela, 2003).Garcia Tejero et al. (2013) found that carabids, particularly from the genera *Steropus* Dejean (Coleoptera: Carabidae) and *Calathus* Bonelli, 1810 (Coleoptera: Carabidae), were the first insects to inhabit burned *Quercus pyrenaica* (Willd) (Fagaceae) woods in Spain. Because they eat mostly organic stuff, these pyrophilous insects thrive from fire. They also have various characteristics that make them suitable for use as indicator taxa, allowing researchers to measure the consequences of disturbances on ecosystems and habitat changes. According to Beaudry et al. (1997), the dramatic effect of fire may lead certain species to disappear while others, such as fire-attractive *Amara* sp. and *Harpalus* sp., arise.

Ground beetles serve as a bio indicator of heavy metal accumulation. An experiment was conducted to investigate heavy metal absorption in soil, by using beetle, *Oulema gallaeciana* (Heyden,1870) (Coleoptera: Chrysomelidae) (Audino et al., 2014; Samad et al., 2015). *Blaps polycresta*Tschinkel 1975 (Coleoptera: Tenebrionidae) is a type of beetle that exhibits ultra structure changes in ovarian tissues. Copper, zinc, cadmium, and lead are the most commonly discovered metals in ovarian tissues (Shonouda and Osman, 2018; Lövei et al.,1996). Carabid beetles, *Parallelomorphus laevigatus* Fabricius, 1792 (Coleoptera: Carabidae), are utilized to detect soil metal pollution in the environment (Shonouda & Osman, 2018; Sorenson et al., 2009). Many ground beetle species rely on coarse woody debris for overwintering, ovipositioning, and larval development (Goulet, 1974; Thiele, 1977; Buddle et al., 2000). The use of heavy machinery during logging compacts the soil layer and crushes and disrupts rock and coarse woody debris material, resulting in the loss of paths through the litter layer as well as surface hiding and hunting areas (Pearce & Lisa, 2005).

Tiger beetles are also employed as good bio indicators because of their stable taxonomy, ease of monitoring, and variety of species. Furthermore, the distribution and diversity of these beetles can be linked to other taxa (Souza et al.,2010; Bokl et al.,2015). Dung beetles are also useful bioindicators of forest disturbance and biodiversity loss. A study was undertaken in Tanzania to investigate the species diversity, functional diversity, and composition of Scarab beetles (Bokl et al., 2015; Coelho et al., 2009).Maeto et al. (2002) compared longicorn beetle assemblages in Japan's old-growth forests (120 years with no history of clearing), second-growth forests (30 - 70 years), and conifer plantations and found that *Pidonia* spp. and some other saproxylic species were unique to old-growth forests and suggested that they were good indicators of forest recovery after cutting. Ramola and Singh (2022) studied the relationship between Cerambyciid borer infestation and human-induced biotic interferences causing mortality of kharsu (*Quercus semecarpifolia*) oak trees in Garhwal, Western Himalaya, India and found that how anthropogenic factor are responsible for the outbreak of borer infestation and on what criteria forest area can be categorized as disturbed and undisturbed forest.

Wikars and Schimmel (2001) investigated the impact of fire intensity on soil arthropods (such as *Atomaria pulchra* Erichson, 1846 [Cryptophagidae] and *Corticaria rubripes* Mannerheim, 1844 [Lathridiidae] in both cut and uncut pine forests in central Sweden. They found that arthropod mortality was proportional to the fraction of organic soil burnt. Martikainen et al. (1999) found that mature managed forests (over 120 years old) and old-growth forests (over 160 years old) in southern Finland have a greater diversity of scolytid beetles (13,557 bark-beetle individuals belonging to 30 species). Carabid assemblages are strongly impacted by vegetation types (Niemelä, 2001). Fujita et al. (2008) observed that the carabid species richness of urban forest remnants rose with fragment area but remained more or less constant with increasing isolation distance from major woods. Landscape patterns that support a variety of vegetation types have a significant impact on carabid assemblages.

The species richness and number of dung beetles are positively correlated with the area of the fragments, and they are also susceptible to forest fragmentation (Feer and Hingrat, 2005). Estrada and Coates-Estrada (2002) found that dung beetle populations declined gradually from continuous forest to farmland forest, with 56% collected in continuous forest, 29% in mosaic habitat, and 15% in forest fragment habitat. Dung beetles in tropical rainforests and dry forests can act as bioindicators of habitat changes caused by fragmentation (Andresen, 2005, 2008; Davis and Philips, 2005). Their abundance decreases with the intensity of the modification and the degree of remoteness from main woods (Nichols et al. 2007). Changes in cow density are likely to have an indirect and direct impact on dung beetles. Increased cattle equal more manure, which gives bugs with additional feeding options. Previous study showed that dung availability influences the species composition and abundance of dung beetles (Lobo et al., 2006; Tonelli et al., 2017). Cattle density was shown to be negatively connected with the abundances of large-sized tunnelers *Dichotomius glaucus* (Harold, 1869) (Coleoptera: Scarabaeidae), *Oxysternon palaemon* Castelnau, 1840 (Coleoptera: Scarabaeidae) and *Sulcophaneus menelas* Castelnau, 1840 (Coleoptera: Scarabaeidae) although small-sized tunnelers *Onthophagus appendiculatus* (Coleoptera: Scarabaeidae) exhibited a positive correlation (Carvalho et al., 2020). Almeida and Louzada (2009) describe all of these species as coprophagous. Louzada et al. (2010) observed a negative association between the number of small-sized roller dung beetles and grass cover, indicating that dense grass prevents dung rolling.

According to Holliday (1991, 1992), beetles which live in fire-affected areas have excellent flight dispersal ability. During the 11-year experiment, they noticed that the percentage of brachypterous (flightless) species in the burned areas increased. This pattern appeared to continue until conifers eventually dominated the area. According to Niemela et al. (1993), the variety of ground beetles was found to be lower in a forest landscape that had been fragmented during 30 years of logging than in woods that were on the edge of the active logging zone but still had mature stands connected to continuous old forest. Some of the larger species associated with later stages of decay, such as the cerambycid genus *Toxeutes* found in Eucalyptus logs in southeast and eastern Australia, would be excellent candidates for old-growth indicator species in this microhabitat. Kleinevoss et al. (1996) proposed effective markers for coarse woody debris microhabitats for stag beetle and cerambycid species. *Lordithon speciosus* (Erichson, 1839) (Coleoptera: Staphylinidae), a beetle found in Finland's boreal forests, could serve as an old-growth indicator species for the dead standing tree microhabitat (Kaila et al. 1997).

3.8 Flies

Gchironomidae, Syrphidae, Calliphoridae and Drosophilidae are among the few families employed as bioindicators (Langraf et al., 2017; Sommaggio, 1999). *Drosophila mealnogestar* Meigen, 1830 (Diptera: Drosophilidae) amodel organism for genetics

Fig. 7. Diptera order as a bio-indicator (Photo source: Ankita Singh Sajwan)

and forensic studies, has the ability to act as a bio indicator in open situations. Dipterans have the potential to degrade habitat and cause forest disturbance. Chironomidae larvae can be utilized to detect trophic changes in urban reservoirs (Osman et al., 2015; Arimoro et al., 2018). Sueyoshi et al. (2003) found that syrphid flies responded differently in young secondary forests, mixed forests, and old-growth forests and suggested that syrphid flies could be useful bioindicators for measuring biodiversity in various wooded habitats. Syrphid flies' variety increases quickly after clear-cutting but decreases with stand age (Maeto et al, 2009). Because of their high adult mobility, flies are the ideal tool for assessing biodiversity at the landscape scale.

3.9 Dragonflies

Dragonflies can effectively determine the health of wetlands. According to Gardon (2023), the presence of multiple dragonfly species in a wetland indicates high water quality, as dragonflies require clean water for larval development. They are regarded as the best ecological indicators in aquatic and riparian environments. They respond quickly and sensitively when heavy metals accumulate. Dragonflies are thought to be most vulnerable to habitat disruption, particularly in lakes and flooded drainage areas. Their presence in any water body demonstrates that it is free of synthetic pollution, and they are an excellent indication of the health of both terrestrial and aquatic ecosystems (Parikh et al., 2021).

3.10 Grasshopper

Orthopterans, which include grasshoppers and crickets, have been utilized as ecological indicators to detect environmental changes. Crickets have tremendous potential as bioindicators in the endangered tropics due to their high level of diversification and endemism (Cigliano et al., 2020), abundance, and local ecological specializations (Desutter-Grandcolas, 1995, 1997). Cricket abundances were highest in forested habitats (i.e., forest and reforest) (Anso et al.,2021), indicating that these habitats provide the best trade-off between food resources (Barberena-Arias & Aide, 2003; Williams et al., 2008), predator protection (Brouwers & Newton, 2009), and favorable moisture conditions. Some cricket species were previously recognized as potential indicators of an ecological stage, such as *Caledonica trigonidium* (Orthoptera: Grylloidea)(cricket) formerly characterized as living the forest understory and singing on low plants with a distinctive and recognizable low-frequency song (Desutter-grandcolas et al., 2016).

Fig. 8. Odonata order as an bio-indicators (Photo source: Gaurav Chand Ramola)

Fig. 9. Grasshopper (Photo source: Gaurav Chand Ramola)

3.11 Termites

Termites are a typical type of insects that act as a bioindicator of soil fertility. Termites have an important role in nutrient transfer, acetogenesis, methanogenesis, and nitrogen fixation in soilLisha et al.,2020). The texture and fertility of the mound soil alter as a result of erosion. Termites' digestive processes have been altered and adapted to enhance pH, oxygen, and hydrogen—all of which are essential for modifying the chemical and physical composition of soil (Leonard and Rajot 2001). Termites gathered significant levels of heavy metals such as Ca, Mg, Al, Fe, Zn, Cu, Mn, Be, Ba, Pb, Cr, V, Ni, and Cd. Alajmi et al. (2019) examined and found a substantial direct association between the presence of termites (Nithyatharani et al.,2018).

3.12 Bees

Bees can adapt to a variety of environmental conditions and collect a wide range of air components. As a result, honeybees are regarded as bioindicators and biomonitoring agents for environmental quality. Honeybees are excellent biological indicators because they are widely spread and sensitive to environmental changes across many square kilometers away from the hives. According to Parikh et al. (2020), their primary goal is to monitor environmental toxicity caused by pesticides, heavy metals, and radioactive chemicals. Bees that generate honey employ two ways to convey the chemical disruption of their environment: first, by dying (mainly from pesticide residues); second, by leaving residues in their bodies or products that come from their colonies (pesticides) other contaminants like heavy metals and radionuclides), which can be identified through appropriate laboratory testing (Barganska et al. 2016).

3.13 Effects of Forest Management Practices on Insects diversity

Bioindicators could be an effective tool for Sustainable Forest Management (SFM). An increase or reduction in insect population could signify substantial changes in the ecology. Clear-cutting has typically resulted in the replacement of forest specialist species with open-habitat species, which reduces arthropod diversity and ecosystem functioning (Siira-Pietikäinen et al., 2003; Pawson et al., 2006; Nichols et al., 2007). Clear-cutting deciduous forests in temperate climes, on the other hand, produces temporary grasslands and young forests, increasing butterfly diversity and richness (Inoue, 2003).

Selective cutting, line thinning, and green tree retention harvesting have all been described as environmentally beneficial silvicultural approaches (Phillips et al., 2006; Jacobs et al., 2007; Maleque et al., 2007a). Line-thinned plots promote increased biomass and species diversity of understory vegetation, as well as insect abundance, in *Cryptomeria* D.Don (Cuppressales :Cupressaceae) plantations in Japan (Maleque et al., 2006b, 2007a, b; Ishii et al., 2008). An abundance of natural enemies can also serve as a functional bioindicator for the ecosystem. The functional interactions between parasitoids and herbivorous hosts are heavily influenced by host population, distribution, and host habitat-related characteristics such vegetation structure and herbivorous insect foraging areas (Meiners and Obermaier, 2003). Davis (2000) discovered that in a lowland diptocarp forest in Malaysian Borneo, reduced-impact thinning promoted a more diverse dung beetle assemblage than conventional thinning. Thinning and prescribed-burning stands had a more diverse species composition than unmanaged stands and single-thinned stands. Villa-Castillo and Wagner (2002) demonstrated that single-thinned stands did not vary from uncontrolled stands in terms of species assemblages. Martikainen et al. (2006) demonstrated that, in compared to non-harvesting forests, green tree retention harvesting boosted food, shelter, and breeding grounds, resulting in increased carabid species diversity. Although faunal convergence achieves equilibrium roughly 30 years after wildfires and harvesting, Buddle et al. (2000) reported that most web-building spider species re-colonize faster in stands damaged by harvest than in stands disrupted by fire.

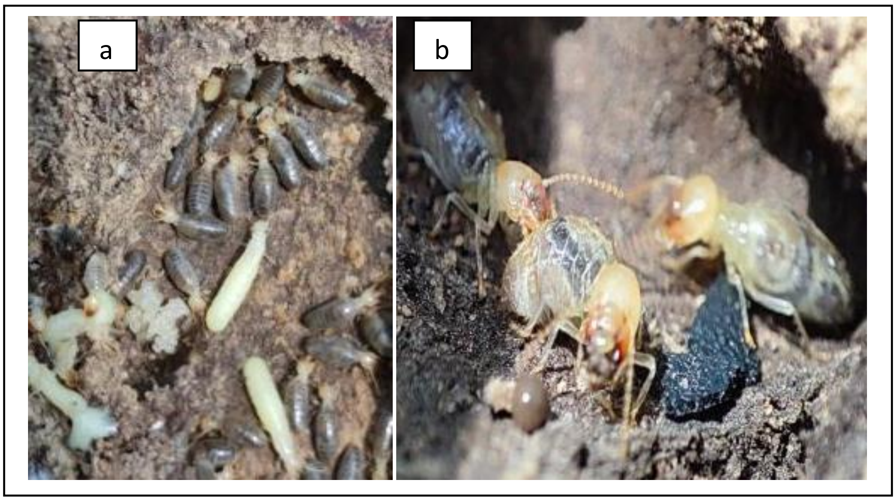

Fig. 10. Isoptera order as an bio-indicators (a) *Angulitermes* sp. (Photo Source: Ashirwad Tripathy)

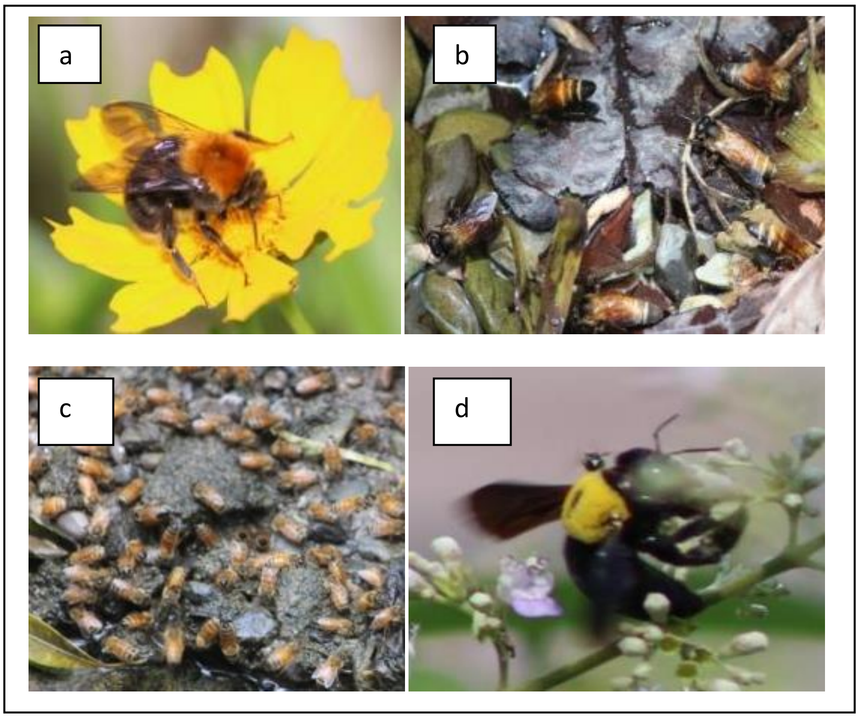

Fig. 11. Hymenoptera order as an bio-indicators (a) *Bombus festivus* (b) *Apis dorsata* (c) *Apis cerana* (d) *Xylocopa* sp. (Photo Source: Shweta Bisht)

4. CONCLUSION

For environmental monitoring, indicator species are crucial as ecological indicators. The primary attributes and traits of a bioindicator include dependability, ecological faithfulness and fragility to tiny environmental changes, ease of handling, cost-effectiveness, species richness and variety, and ease of assessing environmental changes. Insects, with their abundance, diversity, and sensitivity to environmental changes, offer invaluable insights into the health of our ecosystems. As bioindicators, they serve as early warning systems, helping scientists and policymakers monitor and address environmental challenges, from pollution and climate change to habitat degradation. As we continue to grapple with the consequences of human activities on the natural world, the tiny creatures buzzing around our gardens and streams remind us that the health of our planet is interconnected with the well-being of even its smallest inhabitants.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Alajmi, R., Abdel-Gaber, R., & AlOtaibi, N. (2019). Characterization of the *12S rRNA*gene sequences of the harvester termite *Anacanthotermes ochraceus* (Blattodea: Hodotermitidae) and its role as a bioindicator of heavy metal accumulation risks in Saudi Arabia. *Insects*, *10*(2), 51.

Almeida, S. D. S., & Louzada, J. N. (2009). Estrutura da comunidade de *Scarabaeinae* (Scarabaeidae: Coleoptera) em fitofisionomias do Cerrado e sua importância para a conservação. *Neotrop.Entomol.*,*38*, 32–43.

Andersen, A. N., Hertog, T., & Woinarski, J. C. Z. (2006). Long-term fire exclusion and ant community structure in an Australian tropical savanna: Congruence with vegetation succession. *J Biogeogr*, *33*, 823–832.

Andresen, E. (2005). Effects of season and vegetation type on community organization of dung beetles in a tropical dry forest. *Biotropica*, *37*, 291–300.

Andresen, E. (2008). Dung beetle assemblages in primary forest and disturbed habitats in a tropical dry forest landscape in western Mexico. *Journal of Insect Conservation*, *12*, 639–650.

Anso, J., Gasc, A., Bourguet, E., Desutter-Grandcolas, L., & Jourdan, H. (2022).Crickets as indicators of ecological succession in tropical systems, New Caledonia.*Biotropica*, *54*(5), 1270–1284.

Arimoro, F. O., Auta, Y. I., Odume, O. N., Keke, U. N., & Mohammed, A. Z. (2018). Mouthpart deformities in *Chironomidae* (Diptera) as bioindicators of heavy metals pollution in Shiroro Lake, Niger State, Nigeria.*Ecotoxicology and Environmental Safety*, *149*, 96–100.

Arnan, X., Rodrigo, A., & Retana, J. (2007).Uncoupling the effects of shade and food resources of vegetation on Mediterranean ants: An experimental approach at the community level.*Ecography*, *30*(2), 161–172.

Audino, L. D., Louzada, J., & Comita, L. (2014). Dung beetles as indicators of tropical forest restoration success: Is it possible to recover species and functional diversity? *Biological Conservation*, *169*, 248–257.

Barberena-Arias, M., & Aide, T. (2003).Species diversity and trophic composition of litter insects during plant secondary succession.*Caribbean Journal of Science*, *39*, 161–169.

Barganska, Z., Slebioda, M., & Namiessnik, J. (2016). Honey bees and their products as bioindicators of environmental contamination. *Crit. Rev. Environ. Sci. Tech.*, *46*(3), 235–248.

Barlow, J., Gardner, T. A., Araujo, I. S., Ávila-Pires, T. C., Bonaldo, A. B., Costa, J. E., & Peres, C. A. (2007). Quantifying the biodiversity value of tropical primary, secondary, and plantation forests.*Proceedings of the National Academy of Sciences*, *104*(47), 18555–18560.

Beaudry, S., Duchesne, L. C., & Cote, B. (1997).Short-term effects of three forestry practices on carabid assemblages in a jack pine forest.*Can. J. For. Res.*, *27*, 2065–2071.

Berger, B., & Dallinger, R. (1993).Terrestrial snails as quantitative indicators of environmental metal pollution. *Environmental Monitoring and Assessment*, *25*, 65–84.

Bergman, K., Ask, L., Askling, J., Ignell, H., Wahlman, H., & Milberg, P. (2008). Importance of boreal grasslands in Sweden for butterfly diversity and effects of local and landscape habitat factors.*Biodivers.Conserv.*,*17*, 139–153.

Bohac, J. (1999). Staphylinid beetles as bioindicators. *Agriculture, Ecosystems & Environment*, *74*(1–3), 357–372.

Brouwers, N. C., & Newton, A. C. (2009). Habitat requirements for the conservation of wood cricket (*Nemobius sylvestris*) (Orthoptera: Gryllidae) on the Isle of Wight, UK. *Journal of Insect Conservation*, *13*, 529–541.

Buddle, C. M., Spence, J. R., & Langor, D. W. (2000).Succession of boreal forest spider assemblages following wildfire and harvesting.*Ecography*, *23*, 424–436.

Carvalho, K. S., & Vasconcelos, H. L. (1999).Forest fragmentation in central Amazonia and its effects on litter-dwelling ants.*Biol. Conserv.*, *91*, 151–157.

Carvalho, R. L., Andersen, A. N., Anjos, D. V., Pacheco, R., Chagas, L., & Vasconcelos, H. L. (2020). Understanding what bioindicators are actually indicating: Linking disturbance responses to ecological traits of dung beetles and ants. *Ecological Indicators*, *108*, 105764.

Chowdhury, S., Dubey, V. K., Choudhury, S., Das, A., Jeengar, D., Sujatha, B., Kumar, A., Kumar, N., Semwal, A., & Kumar, V. (2023). Insects as bioindicators: A hidden gem for environmental monitoring. *Frontiers in Environmental Science*, *11*, 1146052. https://doi.org/10.3389/fenvs.2023.1146052

Cigliano, M. M., Braun, H., Eades, D. C., & Otte, D. (2020).*Orthoptera species file* (Version 5.0/5.0). http://Orthoptera.SpeciesFile.org.

Coelho, M.S., Fernandes, G.W., Santos, J.C., and Delabie, J.H.C. (2009). Ants (Hymenoptera: Formicidae) as bioindicators of land restoration in a Brazilian Atlantic Forest fragment. *Sociobiology, 54*(1), 51.

Da Rocha, J. R. M., De Almeida, J. R., Lins, G. A., & Durval, A. (2010). Insects as indicators of environmental change and pollution: A review of appropriate species and their monitoring. *Holos Environment*, *10*(2), 250–262.

David, T. (1989).Bio-indicators in air pollution research.In *Biological markers of air pollution stress and damage in forests* (pp. 73–80). Washington, DC: National Academies Press.

Davis, A. J. (2000). Does reduced-impact logging help preserve biodiversity in tropical rainforests? A case study from Borneo using dung beetles (Coleoptera: Scarabaeoidea) as indicators. *Environ. Entomol.*,*29*, 467–475.

Davis, A. L. V., & Philips, T. K. (2005). Effect of deforestation on a southwest Ghana dung beetle assemblage (Coleoptera: Scarabaeidae) at the periphery of Ankasa Conservation Area. *Environ. Entomol.*,*34*, 1081–1088.

Del Toro,.I., R. R., Ribbons, R., & Pelini, S. L. (2012). The little things that run the world revisited: A review of ant-mediated ecosystem services and disservices (Hymenoptera: Formicidae). *Myrmecological News*, *17*, 133–146.

Desutter-Grandcolas, L. (1995). Toward the knowledge of the evolutionary biology of the phalangopsid crickets (Orthoptera: Grylloidea: Phalangopsidae): Data, questions, and evolutionary scenarios. *Journal of Orthoptera Research*, *4*, 163–175.

Desutter-Grandcolas, L. (1997). Le peuplement de grillons (Orthoptères, Grylloidae) des sous-bois forestiers du Col d'Amieu (Nouvelle-Calédonie). I. Etude du peuplement. *Mémoire du Muséum National d'Histoire Naturelle*, *171*, 125–135.

Desutter-Grandcolas, L., Anso, J., & Jourdan, H. (2016). Crickets of New Caledonia (Insecta, Orthoptera, Grylloidea): A key to genera, with diagnoses of extant genera and descriptions of new taxa. *Zoosystema*, *38*, 405–452.

Djamel, B., Abdelkader, R., Abdelghani, B., & Lotfi, M. (2022).Evaluating insects as bioindicators of the wetland environment quality (arid region of Algeria).*Vegetation Index and Dynamics*, *321*.

El Bokl, M. M., Semida, F.M., Abdel-Dayem, M.S., and Surtasi, E.I. (2015). Ant (Hymenoptera: Formicidae) diversity and bioindicators in the lands with different anthropogenic activities in new Damietta, Egypt. *International Journal of Entomological Research, 3*(2), 35-46.

El-Samad, L. M., Mokhamer, E., Osman, W., Ali, A., & Shonouda, M. L. (2015). The ground beetle, *Blaps polycresta* (Coleoptera:

Tenebrionidae) as bioindicator of heavy metals soil pollution. *Journal of Advanced Biology*, *7*, 1153–1160.

Estrada, A., & Coates-Estrada, R. (2002). Dung beetles in continuous forest, forest fragments, and in an agricultural mosaic habitat island at Los Tuxtlas, Mexico. *Biodivers.Conserv.*,*11*, 1903–1918.

Feer, F., & Hingrat, Y. (2005).Effects of forest fragmentation on a dung beetle community in French Guiana.*Conservation Biology*, *19*(4), 1103–1112.

Field, C. B., & Barros, V. R. (Eds.). (2014). *Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects*. Cambridge University Press.

Filgueiras, B. K., Melo, D. H., Andersen, A. N., Tabarelli, M., & Leal, I. R. (2019). Cross-taxon congruence in insect responses to fragmentation of Brazilian Atlantic forest.*Ecological Indicators*, *98*, 523–530.

Frizzo, T. L., & Vasconcelos, H. L. (2013). The potential role of scattered trees for ant conservation in an agriculturally dominated neotropical landscape. *Biotropica*, *45*(5), 644–651.

Fujita, A., Maeto, K., Kagawa, Y., & Ito, N. (2008). Effects of forest fragmentation on species richness and composition of ground beetles (Coleoptera: Carabidae and Brachinidae) in urban landscapes. *Entomological Science*, *11*, 39–48.

García-Tejero, S., Taboada, Á., Tárrega, R., Salgado, J., & Marcos, E. (2013). Differential responses of ecosystem components to a low-intensity fire in a Mediterranean forest: A three-year case study. *Community Ecology*, *14*(1), 110–120.

Gauld, I., & Bolton, B. (Eds.).(1988). *The Hymenoptera* (pp. xi+-332).

Goulet, H. (1974). Biology and relationships of *Pterostichus adstrictus* Eschscholtz and *Pterostichus pensylvanicus* Leconte (Coleoptera: Carabidae). *Quaestiones Entomologicae*, *10*, 3–33.

Grill, A., Knoflach, B., Cleary, D. F. R., & Kati, V. (2005). Butterfly, spider, and plant communities in different land-use types in Sardinia, Italy.*Biodiversity and Conservation*, *14*, 1281–1300.

Halder, I. V., Barbaro, L., Corcket, E., & Jactel, H. (2008). Importance of seminatural habitats for the conservation of butterfly communities in landscapes dominated by pine plantations.*Biodiversity and Conservation*, *17*, 1149–1169.

Han, Y. G., Kwon, O., & Cho, Y. (2015).A study of bioindicator selection for long-term ecological monitoring.*Journal of Ecology and Environment*, *38*(1), 119–122.

Hirowatari, T., Makihara, H., & Sugiarto.(2007). Effects of fires on butterfly assemblages in lowland dipterocarp forest in East Kalimantan.*Entomological Science*, *10*, 113–127.

Hiyama, A., & Otaki, J. M. (2020). Dispersibility of the pale grass blue butterfly *Zizeeri amaha* (Lepidoptera: Lycaenidae) revealed by one-individual tracking in the field: Quantitative comparisons between subspecies and between sexes. *Insects*, *11*(2), 122.

Holliday, N. J. (1991). Species responses of carabid beetles (Coleoptera: Carabidae) during post-fire regeneration of boreal forest. *Canadian Entomologist*, *123*, 1369–1389.

Holliday, N. J. (1992). The carabid fauna (Coleoptera: Carabidae) during post-fire regeneration of boreal forest: Properties and dynamics of species assemblages. *Canadian Journal of Zoology*, *70*, 4400–4452.

Holt, E. A., & Miller, S. W. (2011). Bioindicators: Using organisms to measure. *Nature*, *3*, 8–13.

Inoue, T. (2003). Chronosequential change in a butterfly community after clear-cutting of deciduous forests in a cool temperate region of central Japan. *Entomological Science*, *6*, 151–163.

Ishii, H. T., Tanabe, S., & Hiura, T. (2004).Exploring the relationships among canopy structure, stand productivity and biodiversity of temperate forest ecosystems.*Forest Science*, *50*, 342–355.

Jacobs, J. M., Spence, J. R., & Langor, D. W. (2007). Variable retention harvest of white spruce stands and saproxylic beetle assemblages.*Canadian Journal of Forest Research*, *37*, 1631–1642.

Kaila, L., Martikainen, P., & Punttila, P. (1997). Dead trees left in clear-cuts benefit saproxylic Coleoptera adapted to natural disturbances in boreal forest. *Biodiversity and Conservation*, *6*, 1–18.

Kaplan, M. I., Limoli, C. L., & Morgan, W. F. (1997). Perpetuating radiation-induced chromosomal instability.*Radiation Oncology Investigations*, *5*, 124–128.

Kitahara, M. (2004).Butterfly community composition and conservation in and around a primary woodland of Mount Fuji, central Japan.*Biodiversity and Conservation*, *13*, 917–942.

Kitahara, M., Yumoto, M., & Kobayashi, T. (2008).Relationship of butterfly diversity with nectar plant species richness in and around the Aokigahara primary woodland of Mount Fuji, central Japan.*Biodiversity and Conservation*, *17*, 2713–2734.

Kitching, R. L., Orr, A. G., Thalib, L., Mitchell, H., Hopkins, M. S., & Graham, A. W. (2000). Moth assemblages as indicators of environmental quality in remnants of upland Australian rain forest. *Journal of Applied Ecology*, *37*, 284–297.

Kleinevoss, K., Topp, W., & Bohac, J. (1996).Buchen-TotholzimWirtschaftswaldals lebensraum fürxylobionteInsekten [Dead beech wood in the commercial forest as habitat for xylobiont insects].*Zeitschrift für Ökologie und Naturschutz*, *5*, 85–95. (In German).

Kremen, C., Colwell, R. K., Erwin, T. L., Murphy, D. D., Noss, R. A., & Sanjayan, M. A. (1993). Terrestrial arthropod assemblages: Their use in conservation planning. *Conservation Biology*, 796–808.

Kumar, S., Joshi, P. C., Nath, P., Awasthi, S., Singh, V. K., & Mansotra, D. K. (2011).Insects as bio-indicators of environmental pollution.*International Journal of Environment and All Science*, *1*, 2454–5198.

Langraf, K., Petrovicova, S., David, M., Ábelova, M., & Schlarmannova, J. (2017). Body volume in ground beetles (Carabidae) reflects biotope disturbance. *Folia Oecologica*, *44*(2), 114–120.

Lawton, J. H., Bignell, D. E., Bolton, B., Bloemers, G. F., Eggleton, P., Hammond, P. M., & Watt, A. D. (1998). Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature*, *391*(6662), 72–76.

Leonard, J., & Rajot, J. L. (2001). Influence of termites on runoff and infiltration: Quantification and analysis. *Geoderma*, *104*, 17–40.

Lindenmayer, D. B., Margules, C. R., & Botkin, D. B. (2000). Indicators of biodiversity for ecologically sustainable forest management.*Conservation Biology*, *14*(4), 941–950.

Lisha, J. M., Vijay, S., Bhaskaran, V., & Vinoth, R. (2020). Insects as pollution indicators of environment.*Agriallis*, *2*(8), 8–13.

Lobo, J. M., Hortal, J., & Cabrero-Sañudo, F. J. (2006).Regional and local influence of grazing activity on the diversity of a semi-arid dung beetle community.*Diversity and Distributions*, *12*, 111–123.

Longcore, T. (2003). Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, USA). *Restoration Ecology, 11*(4), 397-409.

Louzada, J., Lima, A.P., Matavelli, R., Zambaldi, L., and Barlow, J. (2010). Community structure of dung beetles in Amazonian savannas: role of fire disturbance, vegetation and landscape structure. *Landscape Ecology, 25*, 631–641.

Lövei, G.L., and Sunderland, K.D. (1996). Ecology and behaviour of ground beetles (Coleoptera: Carabidae). *Annual Review of Entomology, 41*(1), 231-256.

Maeto, K., and Sato, S. (2004). Impacts of forestry on ant species richness and composition in warm-temperate forests of Japan.*Forest Ecology and Management, 187*, 213–223.

Maeto, K., Noerdjito, W.A., Belokobylskij, S.A., and Fukuyama, K. (2009).Recovery of species diversity and composition of braconid parasitic wasps after reforestation of degraded grasslands in lowland East Kalimantan.*Journal of Insect Conservation*.

Maeto, K., Sato, S., and Miyata, H. (2002). Species diversity of longicorn beetles in humid warm-temperate forests: the impact of forest management practices on old-growth forest species in southwestern Japan. *Biodiversity & Conservation, 11*, 1919-1937.

Mahanta, D.K., Samal, I., Komal, J., Bhoi, T.K., Majhi, P.K., and Ahmad, M.A. (2023). Understanding anthropogenic climate change, its consequences on insect pests, and techniques in forecasting and monitoring pest dynamics: a contemporary scenario. In *Climate change and insect biodiversity* (pp. 44-67).CRC Press.

Maleque, M.A., Ishii, H.T., and Maeto, K. (2006).The use of arthropods as indicators of ecosystem integrity in forest management.*Journal of Forestry, 104*, 113–117.

Maleque, M.A., Ishii, H.T., Maeto, K., and Taniguchi, S. (2006a). Management of insect biodiversity by line thinning in Japanese cedar (*Cryptomeria japonica*) plantations, central Japan.*Eurasian Journal of Forest Research, 9*(1), 29–36.

Martikainen, P., Kouki, J., and Heikkala, O. (2006). The effects of green tree retention and subsequent prescribed burning on ground beetles (Coleoptera: Carabidae) in boreal pine-dominated forests. *Ecography, 29*, 659–670.

Martikainen, P., Siitonen, J., Kaila, L., Punttila, P., and Rauh, J. (1999). Bark beetles (Coleoptera, Scolytidae) and associated beetle species in mature managed and old-growth boreal forests in southern Finland. *Forest Ecology and Management, 116*(1-3), 233-245.

McGeoch, M.A. (1998). The selection, testing and application of terrestrial insects as bioindicators.*Biological Reviews, 73*(2), 181-201.

Meiners, T., and Obermaier, E. (2003). Hide and seek on two spatial scales—vegetation structure effects herbivore oviposition and egg parasitism. *Basic and Applied Ecology, 5*, 87–94.

Müller, J., Bubler, H., and Kneib, T. (2008). Saproxylic beetle assemblages related to silvicultural management intensity and stand structures in a beech forest in southern Germany. *Journal of Insect Conservation, 12*, 107–124.

Neilly, H., O'Reagain, P., Vanderwal, J., and Schwarzkopf, L. (2018). Profitable and sustainable cattle grazing strategies support reptiles in tropical savannah rangeland. *Rangeland Ecology & Management, 71*(2), 205-212.

Nichols, E., Larsen, T., Spector, S., Davis, A.L., Escobar, F., Favila, M., and Network, T.S.R. (2007). Global dung beetle response to tropical forest modification and fragmentation: a quantitative literature review and meta-analysis. *Biological Conservation, 137*(1), 1-19.

Niemelä, J., and Baur, B. (1998). Threatened species in a vanishing habitat: plants and invertebrates in calcareous grasslands in the Swiss Jura mountains. *Biodiversity and Conservation, 7*, 1407–1416.

Niemelä, J., Langor, D.W., and Spence, J.R. (1993). Effects of clear-cut harvesting on boreal ground-beetle assemblages (Coleoptera: Carabidae) in western Canada. *Conservation Biology, 7*(3), 551–561.

Niemelä, J., Spence, J. R., Langor, D., Haila, Y., & Tukia, H. (1993). Logging and boreal ground-beetle assemblages on two continents: Implications for conservation. *Conservation Biology*, *7*(4), 818–828.

Niemelä, J.A.R.I. (2001). Carabid beetles (Coleoptera: Carabidae) and habitat fragmentation: a review. *European Journal of Entomology, 98*(2), 127-132.

Nithyatharani, R., & Kavitha, U. S. (2018).Termite soil as bio-indicator of soil fertility.*International Journal for Research in Applied Science and Engineering Technology*, *6*(1), 659–661.

Noss, R. F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. *Conservation Biology*, *4*(4), 355–364.

Ohsawa, M. (2004).Species richness of *Cerambycidae* in larch plantations and natural broad-leaved forests of the central mountainous region of Japan.*Forest Ecology and Management*, *189*, 375–385.

Ohsawa, M. (2007).The role of isolated old oak trees in maintaining beetle diversity within larch plantations in the central mountainous region of Japan.*Forest Ecology and Management*, *250*, 215–226.

Ohsawa, M. (2008). Different effects of coarse woody material on the species diversity of three saproxylic beetle families (*Cerambycidae*, *Melandryidae*, and *Curculionidae*). *Ecology Research*, *23*, 11–20.

Osman, W., El-Samad, L. M., Mokhamer, E. H., El-Touhamy, A., & Shonouda, M. (2015). Ecological, morphological, and histological studies on *Blaps polycresta* (*Coleoptera*: *Tenebrionidae*) as biomonitors of cadmium soil pollution. *Environmental Science and Pollution Research*, *22*(18), 14104–14115.

Parikh, G., Rawtani, D., & Khatri, N. (2021).Insects as an indicator for environmental pollution.*Environmental Claims Journal*, *33*(2), 161–181.

Parmar, T. K., Rawtani, D., & Agrawal, Y. K. (2016). Bioindicators: The natural indicator of environmental pollution. *Frontiers in Life Science*, *9*(2), 110–118.

Pawson, S. M., Brockerhoff, E. G., Norton, D. A., & Didham, R. K. (2006). Clear-fell harvest impacts on biodiversity: Past research and the search for harvest size thresholds. *Canadian Journal of Forest Research*, *36*, 1035–1046.

Pearce, J. L., & Venier, L. A. (2006). The use of ground beetles (*Coleoptera*: *Carabidae*) and spiders (*Araneae*) as bioindicators of sustainable forest management: A review. *Ecological Indicators*, *6*(4), 780–793.

Perfecto, I., & Vandermeer, J. (1996).Microclimatic changes and the indirect loss of ant diversity in a tropical agroecosystem.*Oecologia*, *108*, 577–582.

Phillips, I. D., Cobb, T. P., Spence, J. R., & Brigham, R. M. (2006). Salvage logging, edge effects, and carabid beetles: Connections to conservation and sustainable forest management. *Environmental Entomology*, *35*, 950–957.

Philpott, S. M., Perfecto, I., Armbrecht, I., & Parr, C. L. (2010). Ant diversity and function in disturbed and changing habitats. In L. Lach, C. L. Parr, & K. L. Abbott (Eds.), *Ant ecology* (pp. 137–156). Oxford University Press.

Progar, R. A., & Schowalter, T. D. (2002).Canopy arthropod assemblages along a precipitation and latitudinal gradient among *Douglas-fir* (*Pseudotsuga menziesii*) forests in the Pacific Northwest of the United States.*Ecography*, *25*, 129–138.

Rainio, J., & Niemelä, J. (2003). Ground beetles (*Coleoptera*: *Carabidae*) as bioindicators. *Biodiversity and Conservation*, *12*(3), 487–506.

Ramola, G. C., & Singh, A. P. (2022). Relationship between *Cerambycid* borer (*Insecta*: *Coleoptera*) infestation and human-induced biotic interferences causing mortality of *kharsu* (*Quercus semecarpifolia* Smith in Rees) oak trees in Garhwal, Western Himalaya, India. *Current Science*, 327–332.

Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., & Tavoni, M. (2018). Scenarios towards limiting global mean temperature increase below 1.5 °C. *Nature Climate Change*, *8*(4), 325–332.

Samways, M. J. (1994). *Insect conservation biology*.Chapman and Hall.

Sánchez-Bayo, F., & Wyckhuys, K. A. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation*, *232*, 8–27.

Schowalter, T. D., Zhang, Y. L., & Rykken, J. J. (2003). Litter invertebrate responses to variable density thinning in western Washington forest. *Ecological Applications*, *13*(5), 1204–1211.

Sharma, M., & Sharma, N. (2017). Suitability of butterflies as indicators of ecosystem condition: A comparison of butterfly diversity across four habitats in Gir Wildlife Sanctuary. *International Journal of Advanced Research in Biological Sciences*, *4*(3), 43–53.

Shonouda, M., and Osman, W. (2018). Ultrastructural alterations in sperm formation of the beetle, *Blaps polycresta* (Coleoptera: Tenebrionidae) as a biomonitor of heavy metal soil pollution. *Environmental Science and Pollution Research*, 1–11.

Siira-Pietikäinen, A., Haimi, J., & Siitonen, J. (2003).Short-term responses of soil microarthropod community to clear felling and alternative forest regeneration methods.*Forest Ecology and Management*, *172*, 339–353.

Silva, P. S. D., Bieber, A. G. D., Leal, I. R., Wirth, R., & Tabarelli, M. (2009). Decreasing abundance of leaf-cutting ants across a chronosequence of advancing Atlantic forest regeneration.*Journal of Tropical Ecology*, *25*, 223–227.

Sinclair, J. E., & New, T. R. (2004). Pine plantations in southeastern Australia support highly impoverished ant assemblages (*Hymenoptera*: *Formicidae*). *Journal of Insect Conservation*, *8*, 277–286.

Sommaggio, D. (1999). Syrphidae: Can they be used as environmental bioindicators? *Agriculture, Ecosystems & Environment*, *74*, 343–356.

Sorensen, M.A., Parker, D.R., and Trumble, J.T. (2009). Effects of pollutant accumulation by the invasive weed saltcedar (*Tamarix ramosissima*) on the biological control agent *Diorhabda elongata* (Coleoptera: Chrysomelidae). *Environmental Pollution, 157*(2), 384-391.

Souza, M. M. de, Louzada, J., Eduardo Serráo, J., and Cola Zanuncio, J. (2010). Social wasps (Hymenoptera: Vespidae) as indicators of conservation degree of riparian forests in Southeast Brazil. *Sociobiology, 56*(2), 387.

Stephens, S. S., & Wagner, M. R. (2006). Using ground foraging ant (*Hymenoptera*: *Formicidae*) functional groups as bioindicators of forest health in northern Arizona ponderosa pine forests. *Forest Ecology and Management*, *225*, 43–52.

Sueyoshi, M., Maeto, K., Makihara, H., Makino, S., & Iwai, T. (2003). Changes in dipteran assemblages with secondary succession of temperate deciduous forests following clear-cutting.*Bulletin of the FFPRI*, *2*, 171–191.

Talarico, F., Brandmayr, P., Giulianini, P. G., Ietto, F., Naccarato, A., Perrotta, E., & Giglio, A. (2014).Effects of metal pollution on survival and physiological responses in *Carabus* (*Chaetocarabus*) *lefebvrei* (Coleoptera, Carabidae).*European Journal of Soil Biology*, *61*, 80–89.

Thiele, H. U. (1977). *Carabid beetles in their environments: A study on habitat selection and adaptations in physiology and behaviour*. Springer-Verlag.

Tonelli, M., Verdu, J. R., & Zunino, M. (2017).Effects of grazing intensity and the use of veterinary medical products on dung beetle biodiversity in the sub-mountainous landscape of Central Italy.*PeerJ*, *5*, e2780.

Underwood, E. C., & Fisher, B. L. (2006). The role of ants in conservation monitoring: If, when, and how. *Biological Conservation*, *132*(2), 166–182.

Underwood, E. C., & Fisher, B. L. (2006). The role of ants in conservation monitoring: If, when, and how. *Biological Conservation*, *132*, 166–182.

Vasconcelos, H. L., Vilhena, J. M. S., & Caliri, G. J. A. (2000).Responses of ants to selective logging of a central Amazonian forest.*Journal of Applied Ecology*, *37*, 508–515.

Vasconcelos, H. L., Vilhena, J. M. S., Magnusson, W. E., & Albernaz, A. L. K. N. (2006). Long-term effects of forest fragmentation on Amazonian ant communities.*Journal of Biogeography*, *33*, 1348–1356.

Villa-Castillo, J., & Wagner, M. R. (2002). Ground beetle (*Coleoptera*: *Carabidae*) species assemblage as an indicator of forest condition in northern Arizona ponderosa pine forests. *Environmental Entomology*, *31*, 242–252.

Welti, E. A., Roeder, K. A., de Beurs, K. M., Joern, A., & Kaspari, M. (2020). Nutrient dilution and climate cycles underlie declines in a dominant insect herbivore. *Proceedings of the National Academy of Sciences*, *117*(13), 7271–7275.

Wikars, L. O., & Schimmel, J. (2001). Immediate effects of fire-severity on soil invertebrates in cut and uncut pine forests. *Forest Ecology and Management*, *141*(3), 189–200.

Williams, B. K., Rittenhouse, T. A., & Semlitsch, R. D. (2008). Leaf litter input mediates tadpole performance across forest canopy treatments. *Oecologia*, *155*, 377–384.

Zodl, B., & Wittmann, K. J. (2003).Effects of sampling, preparation and defecation on metal concentrations in selected invertebrates at urban sites.*Chemosphere*, *52*(7), 1095–1103.

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