Review Article

INSECTS AS ECOLOGICAL INDICATORS: A REVIEW

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

Keywords: Bioindicators, ecosystem, taxa, disturbances, managements.

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). 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.

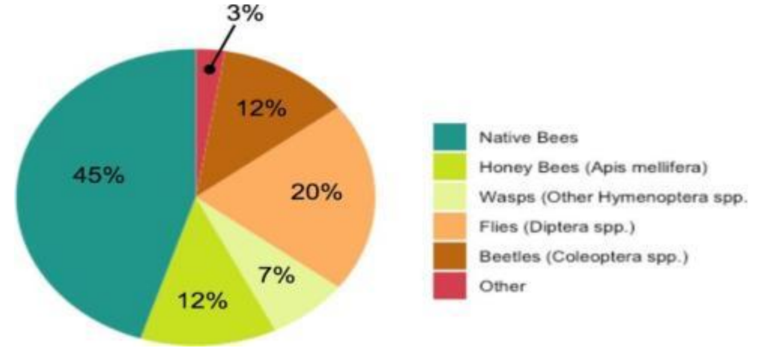

Fig.1. Percentage of pollinating insects contributed by different taxonomic group (Source: Graham et al.,2021)

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.

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.

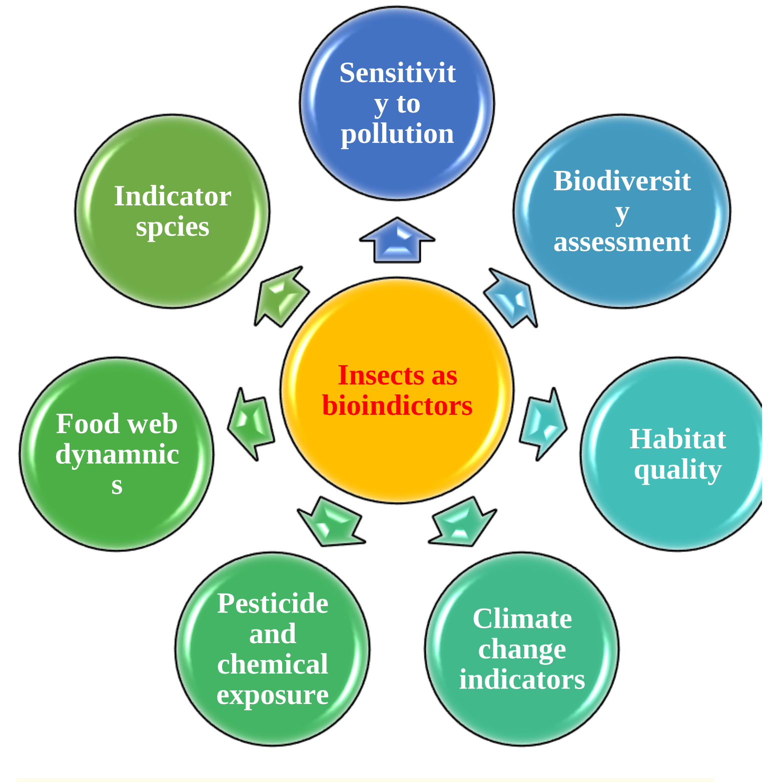

Fig.2. Insect group characteristics as bio-indicators

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.

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.

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.

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.

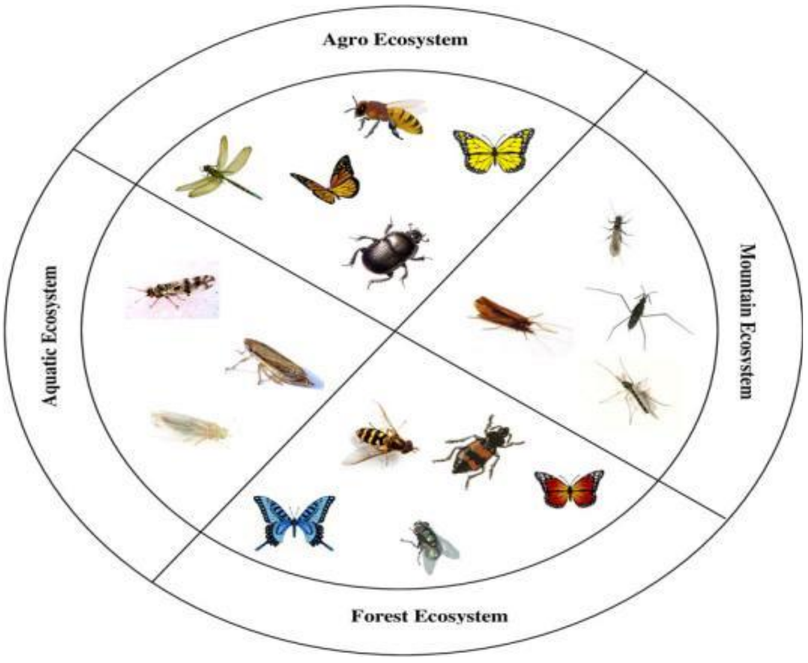

Fig.3. Insects as bio-indicators of different ecosystems (Source: Chaudhary et al.,2023).

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).

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* and *Dorymyrmex bureni*, 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.

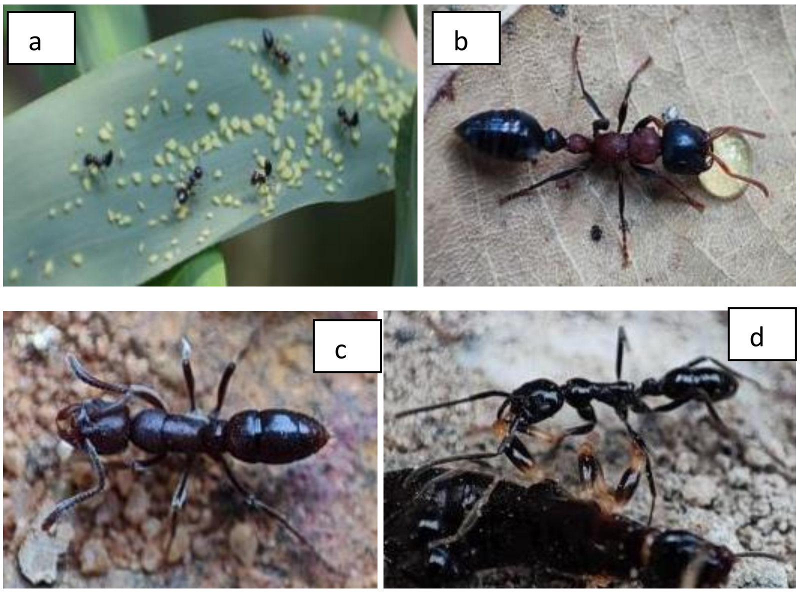

Fig.4. Different species of ants act as bio-indicators (a) (b) *Tetraponera rufonigra* (c) *Bothroponera* sp. (d) *Leptogenys* sp. (Photo credit: Ashirwad Tripathy).

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).

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,

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

Epipaschiinae, Lymantriidae, and Anthelidae) (Kitching et al., 2000). Grand ditches butterfly (*Euthalia patala*) 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, 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).

Recently, study on Lycaenidae family butterfly, Pale Grass Blue (*Zizeeria maha*) 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 E 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). Hirowatari et al. (2007) demonstrated that three generalist butterfly species—*Melanitis leda*, *Charaxes bernardus*, and *Danaus genutia*—could be used as disturbance indicators after fire in Southeast Asia's tropical rain forests.

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 &b) *Coccinella septempunctata*; (c) *Chilocorus infernalis* (d) *Aceraius grandis* (e) dung beetle (Photo credit: 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).

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 oblongopunctatus* (ground beetle) 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* and *Calathus*, were the first insects to inhabit burned *Quercus pyrenaica* 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* (Audino et al., 2014; Samad et al., 2015). *Blaps polycresta* 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). Carabid beetles, *Parallelomorphus laevigatus,* 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* [Cryptophagidae] and *Corticaria rubripes* [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*, *Oxysternon palaemon*, and *Sulcophaneus menelas*, although small-sized tunnelers *Onthophagus appendiculatus* 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*, 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).

Flies

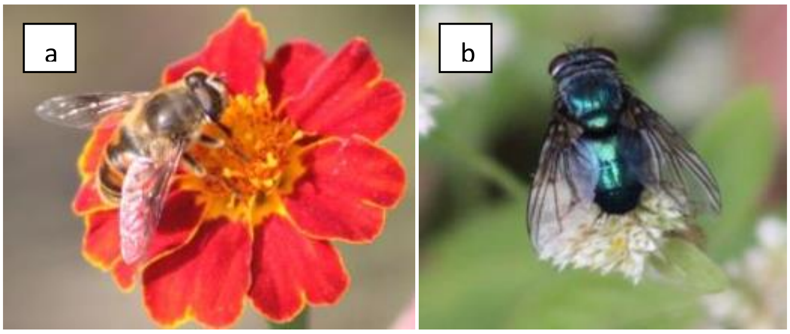

Fig.7. Diptera order as an bio-indicators

Gchironomidae, Syrphidae, Calliphoridae and Drosophilidae are among the few families employed as bioindicators (Langraf et al., 2017). *Drosophila mealnogestar*, a model organism for genetics 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). 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.

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).

Fig.8. Odonata order as an bio-indicators

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

Fig.9. Grasshopper

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 *Trigonidium caledonica* (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).

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 soil. 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

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

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).

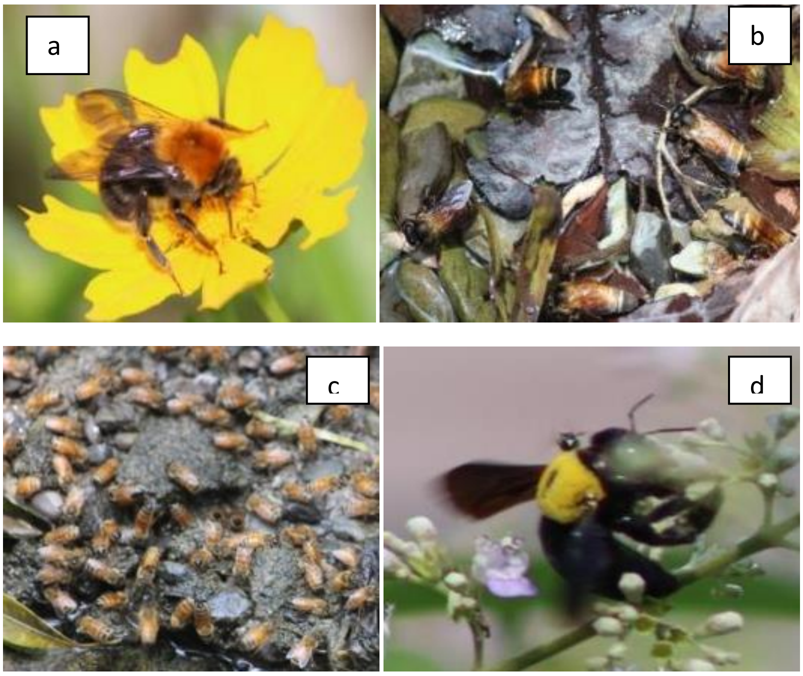

Fig.11. Hymenoptera order as an bio-indicators (a) (b) *Apis dorsata* (d) (c) *Apis cerana* (d) *Xylocopa* sp. (Photo credit: Shweta Bisht)

Effects of forest management practices on insects

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* 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.

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.

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