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# Insects as bioindicator: A hidden gem for environmental monitoring

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Environmental contamination research has been quite interesting in bioindicators recently. The basic objective of bioindicator research is to find species that can reliably detect environmental disturbances and demonstrate how those disturbances affect other species or biodiversity as a whole. Since they frequently come into contact with the harmful substances found in soil, water, and air, insects are particularly valuable for evaluating how human activities affect the terrestrial ecosystem, the aquatic system, and the atmosphere. In this review article, we've emphasized the use of insects as a resource for assessing contaminants and monitoring environmental contamination. Insects have been our main focus since they are key indicators of changes in soil, water, and air quality. The majority of insects, including beetles, ants, honey bees, and butterflies are employed in this study as biological indicators since they are sensitive to even the slightest environmental changes and are also used to monitor different environmental toxins.

## KEYWORDS

insects, monitoring, climate change, environmental pollutants, ecosystem, bioindicator

## 1 Introduction

Global food production is in grave danger as a result of rising temperatures, climatic extremities, increased CO<sub>2</sub> and other greenhouse gas concentrations (GHGs), as well as changed precipitation patterns (Shrestha, 2019). Today's world is dealing with the significant issue of global warming. It has reached unprecedented levels, as indicated by the incredible rates of increase in the air temperature and sea level (Field et al., 2014). According to the World Meteorological Organization (WMO), the world is currently about one degree warmer than it was before heavy industrialization. According to the Intergovernmental Panel on Climate Change (Field et al., 2014; IPCC, 2022), each of the past three decades has gotten warmer, with the 2000s being the warmest. The Earth may warm by 1.4°C–5.8°C over the next century, according to a variety of global climate models and development scenarios

(Pachauri and Reisinger, 2007). Greenhouse gas concentrations have dramatically increased during the past two centuries when compared to the pre-industrial era, which is a primary contributor to global warming (Rogelj et al., 2018). Carbon dioxide (CO<sub>2</sub>), Methane (CH<sub>4</sub>), and Nitrous oxide (N<sub>2</sub>O) are produced in the atmosphere as a result of the most prevalent anthropogenic activities, such as burning fossil fuels and altering land use (Yoro and Daramola, 2020). Over the past 50 years, one of the atmosphere's well-observed changes has been the rise in atmospheric CO<sub>2</sub> (Prentice et al., 2001). Its atmospheric concentration has drastically increased to 416 ppm from 280 ppm reported for the pre-industrial period and is expected to double in 2,100 (Pachauri and Reisinger, 2007; Anonymous, 2023). Heat infrared radiation from the Earth's surface is significantly absorbed by the atmosphere; therefore CO<sub>2</sub> is classified as a greenhouse gas. In proportion to the quantity of atmospheric gasses that absorb thermal infrared radiation from the Earth's surface, more radiation is discharged from the atmosphere towards the surface of the planet (Mahlman, 1997). Since there is more energy available for sensible and latent heat flow, the long-wave balance at the Earth's surface is less negative. The amount of energy available for heat flux increases, which raises the temperature of the air (Streck, 2005). Extreme weather and climatic phenomena have been observed to shift since the middle of the 20th century. There have been other changes that have been connected to 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 rise in frequency and severity in some areas (Field et al., 2014). Even though the speed and complexity of global change pose a significant challenge for ecology, this fact does not exclude taking action to address the fundamental causes of global change (Yang et al., 2021).

Detrimental environmental change across the world has received much more attention in recent decades. The two main factors influencing the current state of global biodiversity are habitat change and overexploitation. Finding practical methods for averting or minimizing potentially catastrophic consequences on biodiversity became necessary. An agricultural environmental scheme is a complementary tool that which could reverse the negative trends of declining biodiversity (Pereira et al., 2012). Ecosystems are directly challenged by environmental contamination, making environmental monitoring a necessary component of their management and prediction. The concept of bioindication is not a conventional one; it has been turned into an emerging issue related to conservation assessment. The term "bioindicator" refers to a species or a group of species that represents the abiotic or biotic state of the environment. It illustrates how environmental change affects a habitat, community, or ecosystem and indicates whether that change has a positive or negative influence (Parmar et al., 2016). Various living organisms are extremely sensitive to environmental changes that disrupt their core functions, such as metabolism, growth, and reproduction (David, 1989). Owens et al. (2020) concluded how artificial lights can be tuned to reduce their impact on susceptible populations. Artificial light at night is unique among anthropogenic habitat disturbances in that it is fairly easy to upgrade, and leaves behind no residual effects. Moreover, recognition of the ways in which artificial light at night affects insects can help conservationists to



reduce or eliminate one of the major drivers of insect declines. Contrary to other putative causes of insect decreases, such as habitat loss, chemical and light pollution, and nutrient dilution, these factors may be common in surviving natural areas (Welti et al., 2020). Sánchez-Bayo and 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. Bioindicators are frequently utilized as markers for biological parameters, taxonomic variety, or natural change.

Arthropods turn out the most successful among all invertebrates despite their survival during the Cretaceous and Permian mass extinctions. They are the principle players functioning in the ecosystem processes (Kim, 1993). The most prevalent animal in all types of ecosystems, insects can be utilized to detect the impact of alterations in the environment. Taxonomic, behavioural, and environmental studies eventually are necessary to monitor the changes in biodiversity and its inevitable implications. To assess environmental change, biomonitors and bioindicators are essential components. When evaluating the environment, bioindicators can be used to estimate the quality of changes occurring while biomonitors are employed to gather quantitative data on the environment's quality. Therefore, it is necessary to use insects as a bioindicator to assess the quality of environmental changes. This review paper aims to provide a summary of the major insect bioindicator groups of different ecosystems and their role.

## 2 Criteria for the selection of bioindicator

To preserve biodiversity, healthy ecosystems must be maintained. Since ecosystems are so complex, using indicator taxa to assess ecosystem health is highly imperative. Ecosystem

health, biodiversity levels, target taxa status, endemism levels, and resource availability have all been evaluated using indicator taxa (Faith and Walker, 1996). The prerequisites for the indicator's selection are flexible and heavily influenced by the investigation's targets, such as the indicator for a study of an area's biological variety, the indicator for habitat loss, the indicator for climate change, and the indicator for a polluted area. To choose a decent indicator, it must satisfy a wide range of requirements. The use of bioindicators is a common and economical method for identifying and monitoring environmental changes. A good bioindicator should have well-established taxonomy and ecology, be widespread across a large geographic area, be specialized to certain habitat requirements, provide early warning of change, be simple and cost-effective to survey, be largely independent of sample size, have a response that reflects that of other species, and be able to differentiate between trends or cycles caused by anthropogenic stress and those triggered by natural cycles or trends (Noss, 1990). The major criteria for the selection of bioindicators are shown in Figure 1.

Based on domestic and global studies on the selection of bioindicators, eleven selection standards have been established (Han et al., 2015) viz.

- i. Species (or species groups) with clear classification and ecology
- ii. Species (or species groups), those are distributed in a geographically widespread area.
- iii. Species (or species groups), those show clear habitat characteristics
- iv. Species (or species groups), those can provide early warning for a 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 for a long time and form a large group of individuals
- xi. Species (or species groups), those are significant in terms of culture, economy, and society

Moreover, there are 19 selection criteria can be categorized into four main groups: baseline information, location information, niche and life history attributes, and others (Hilty and Merenlender, 2000).

### 3 Classification of bioindicator

A bioindicator, which in certain contexts focuses on a living entity, monitors the progress of biological or non-biological factors in an environment. It serves as a representation to understand and assess the ecosystem's health status. However, it also refers more broadly or specifically to the impacts of environmental change on a species or group of species that represent the state of living forms or

inanimate objects in the environment. Likewise, it could be used to describe living entities or group of living things that illustrate the diversity of a taxonomic group in a specific area or the whole diversity (Gerhardt, 2002). Bioindicators 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. The meta-analysis of global data sets reveals that pesticide resistance levels are linked to the species overwintering range. By facilitating local persistence all year round, climate change can promote and expand pesticide resistance of this destructive species globally (Ma et al., 2021).

#### 3.1 Environmental indicator

A species or group of species that respond well to environmental disturbances or a change in the status of the environment in predictable ways that can be easily observed and quantified is known as an environmental indicator. It is used to detect changes in the environment.

#### 3.2 Ecological indicator

The species or group of species demonstrates the impact of a stressor on a biotic system and is used to monitor long-term stressor-induced change on biota (including habitat alteration, fragmentation and climate change).

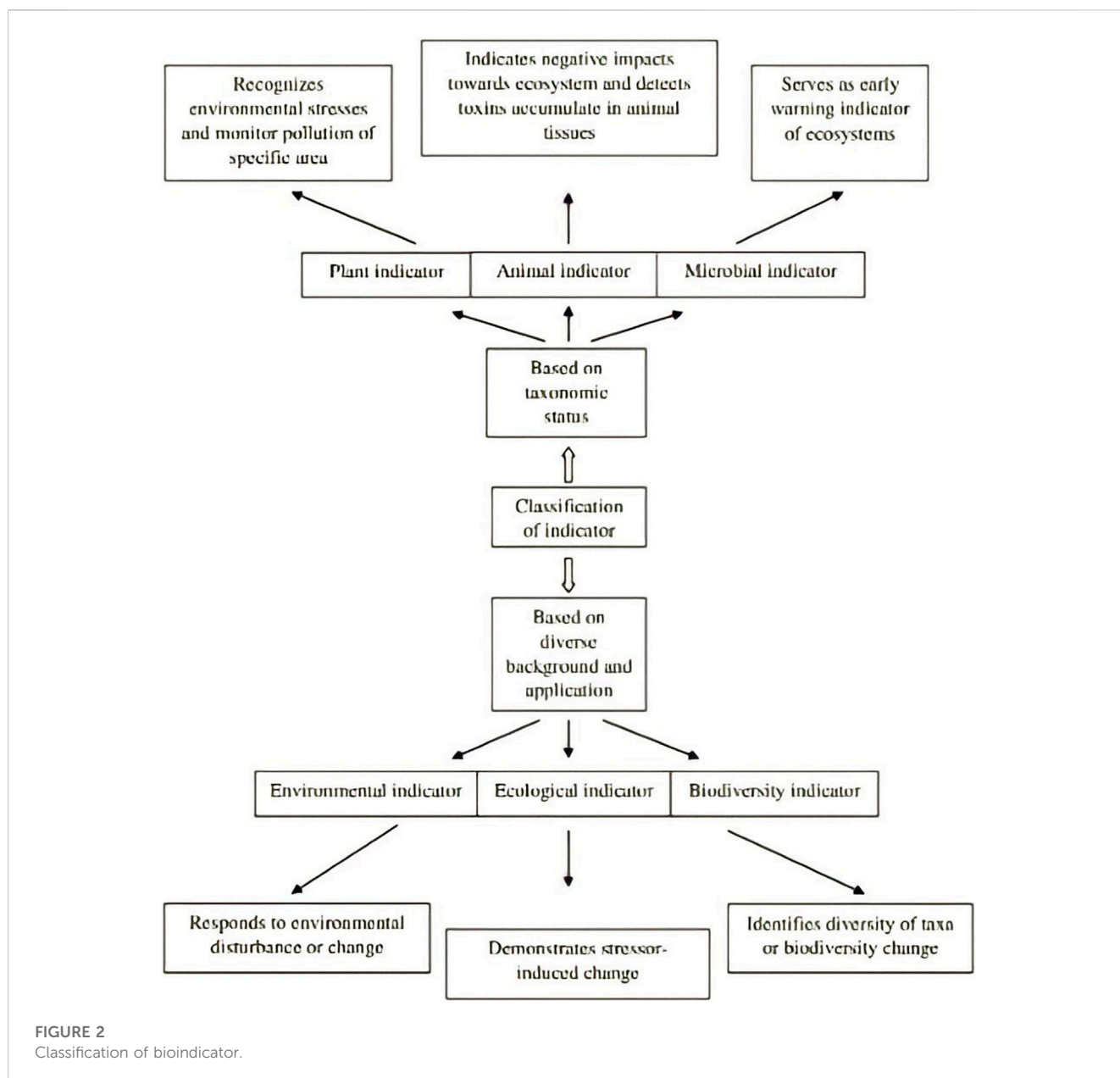
#### 3.3 Biodiversity indicator

A group of taxa (such as a genus, tribe, family, or order, or a particular group of species from a range of higher taxa) or a functional group that exhibits diversity (character and species richness, or level of endemism) that is reflective of the diversity of other taxa in a habitat is referred to as a biodiversity indicator (Mc Geoch, 1998; Stewart et al., 2007).

Also, the term bioindicators can mean different types of indicators, including plant, animal, and microbial indicators according to their taxonomic status (Figure 2).

#### 3.4 Plant indicator

In the era of urbanization, pollution continues to threaten health and welfare. The Plant shows high sensitivity to environmental stress recognition and prediction. Biomonitoring with sensitive plant species performs an effective means of attenuating this problem. Increased levels of pollutants like sulphur and nitrogen are responsible for the disappearance of lichens from forest areas (Holt and Miller, 2010). Marine ecosystem contamination is indicated by alterations in the diversity of phytoplankton species, such as *Euglena clastica*, *Phacus tortus*, and *Trachelon anas* (Jain et al., 2010). *Cyanophyta* is a biological indicator of powerful plankton that shows the rapid eutrophication of aquatic habitats through the production of bloom patterns (Thakur et al., 2013). The impact of air pollutants can be interpreted by calculating Air



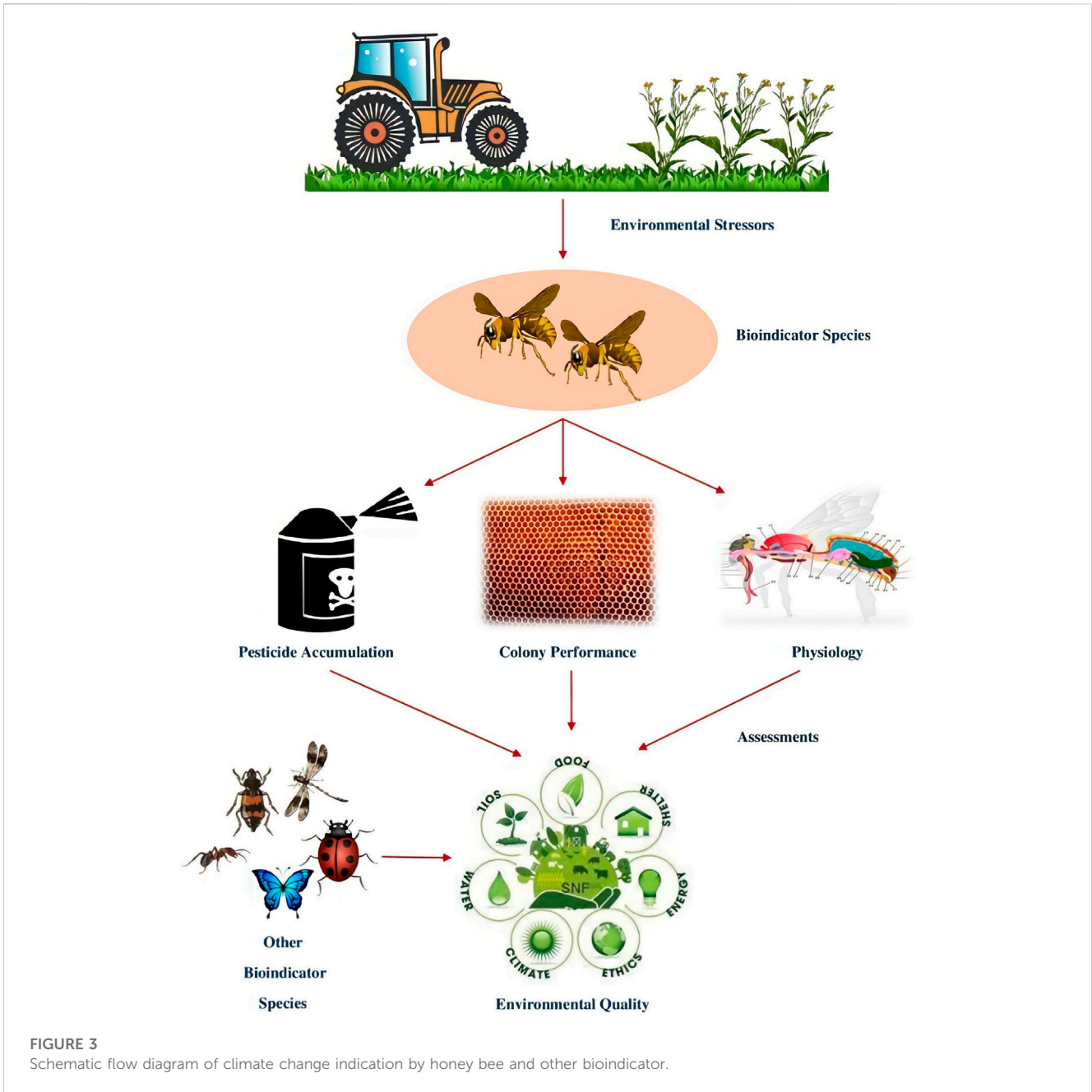
Pollution Tolerance Index (APTI) using biochemical parameters of plants like total chlorophyll content, ascorbic acid content, relative water content, and pH value (Singare and Talpade, 2013). The Guava cultivar “Paluma” can potentially be used as a bioindicator of phytotoxic ozone levels in the tropical region (Furlan et al., 2007). Auto fluorescence analyses of the secretory cells of vegetative tissues or microspores are suitable objects for ozone (O<sub>3</sub>) monitoring and could early indicate damage by stress factors (Roshchina and Roshchina, 2003).

### 3.5 Animal indicator

Changes in a number of an organism’s characteristics have been successfully employed as indicators. Animal indicators

assist in determining the level of toxins present in an animal’s tissues (Khatri and Tyagi, 2015). Zooplanktons that are zone-based indicators of pollution include *Alona guttata*, *Mesocyclops edax*, Cyclops, and Aheyella (Jain et al., 2010; Hosmani, 2014). They are used to indicate water quality, eutrophication, and contaminated water. Amphibians, notably anurans, which include frogs and toads, are frequently used as biological indicators of contaminant accumulation in a specific ecosystem (Zaghloul et al., 2020). Earthworms, a key soil system species, can play a vital role in the formation and decomposition of soil aggregates, according to the kind of organic residues (Al-Maliki et al., 2021). Earthworms are more sensitive to temperature changes as a bioindicator of soil quality than the effects of moisture content. Invertebrates are also reliable bioindicators; insects play vital





roles as indicators in ecosystems. Environmental stress can be assessed at several scales, from the individual animal to the entire invertebrate community.

### 3.6 Microbial indicator

Microorganisms are potentially used as indicator species to detect environmental pressures when exposed to environmental perturbations. They exhibit high sensitivity towards environmental change. Changes in the physiological system of microbes like the development of stress protein (Khatri and Tyagi, 2015) or alterations in the digestive system help to detect the presence of toxins in water (Uttaḥ et al., 2008). A group of

eukaryotic microbes, Foraminifera is used for coral reef monitoring (Hallock et al., 2003). Assessment of coral reef health through biofilms coupled with Autonomous Reef Monitoring Structures (ARMS) tools are also employed (Roitman et al., 2018). Bacterial orders such as the opitulales, chitinophagales, cytophagales and saccharimonadales may act as bioindicators of high P or nutrient-rich locations (Mason et al., 2020). Molds, including *Trichoderma* sp., *Exophiala* sp., *Stachybotrys* sp., *Aspergillus fumigatus*, *A. versicolor*, *A. niger*, *Phialophora* sp., *Fusarium* sp., *Ulocladium* sp., *Penicillium* sp., *Candida albicans*, and certain yeasts are frequently used as biological indicators for contaminants. According to (Dokulil, 2003) blue-green algae may be used as a biological indicator for detecting pH value variations in various ecosystems.

## 4 Insects used as a bioindicator of climate change

One of the most important contemporary ecological issues is how the consequences of climate change on living things affect them. These consequences are pervasive and frequently negative (Wilson et al., 2007; Bellard et al., 2012; Grimm et al., 2013; Menéndez et al., 2014; Sheldon, 2019). Various other studies have demonstrated that climate can have both direct and indirect effects on species interactions, range, abundance, and phenology. It also affects on the structure and dynamics of ecosystems, biodiversity, and the constitution of biological communities. According to numerous reports, animals may migrate northward in response to climate change based on their physiological tolerances to temperature (Parmesan, 1996; Root et al., 2003; Menéndez, 2007; Menéndez et al., 2014; Sheldon, 2019). Different ecological processes, as well as the biology and ecology of species, are being impacted by climate change. As a result, choosing a bioindicator to track these consequences becomes essential, even if choosing the right species is quite challenging. In this regard, some researchers have suggested criteria for choosing species (Groot et al., 1995). Also, they have been cited as effective bioindicators of climate change (Menéndez, 2007; Gerlach et al., 2013) as the climate has a direct impact on their survival, reproduction, and development (Figure 3 (Bale et al., 2002)).

Contrary to other living things, insects frequently have shortened life cycles, and they are represented at many different trophic levels, where they play significant roles in ecosystem function levels. However, it is crucial to comprehend the current elevation distribution and other ecological characteristics of the local insect populations to monitor the consequences of climate change in mountains. Among insects, beetles (Coleoptera) stand out as the most diversified known living species among the 300,000–450,000 recognized species (Bouchard et al., 2017). They may be easily sampled using a variety of approaches and have already been suggested as bioindicators in various contexts (Gerlach et al., 2013; Oliveira et al., 2014). The most vulnerable species to extinction due to climate change are those found in mountains and those confined to high latitudes. As a result of global warming, the cold-adapted species will be compelled to ascend to higher latitudes. Some of the species might someday reach the end of their range and go extinct. The decline of a species can happen over many hundreds of years and is difficult to identify. Between 1970 and 1999, there was a significant shift in the diversity of butterfly species in Britain (Menéndez et al., 2006). As an example, during two seasons of artificial warming, the isotomid *Cryptopygus antarcticus* experienced a population loss, which led to a decrease in the overall abundance of the order Collembola in the lichen community. The effects of temperature increases of 1°C–2°C will have effects comparable in magnitude to the climate change currently observed in the Antarctic region. *Gamasellus racovitzai* (Trouessart), a mesostigmatid predatory mite, significantly decreased, and the overall number of prostigmata significantly increased (Bokhorst et al., 2008). In the United Kingdom, a lot of beetles, butterflies, dragonflies, grasshoppers, and aquatic bugs have migrated north and to higher altitudes (Hickling et al., 2006). Studied by (Colares

et al., 2021) five Coleopteran species from the family Cerambycidae, Eumolpinae (Chrysomelidae), Lampyridae, and Phengodidae families were chosen as ideal bioindicators because of their heat tolerance, narrow elevational ranges, and abundance. The smallest elevation range belongs to the family Eumolpinae and Lampyridae. Utilizing abundant species (or groups of species) with constricted elevation ranges as bioindicators can help to monitor the effects of climate change on the biota and determine how species are adapting through time. According to their findings, imidacloprid residues may be extremely hazardous to non-target insects in the environment, even in areas far from the agro ecosystem where the herbicides were used (Wang et al., 2022). Their findings showed that the Scarabaeinae fauna of *Itatiaia* is incredibly diverse, with wide fluctuations in richness and abundance along the elevation gradient and notable phenological shifts at the community level related to seasonal climate variations (Araújo et al., 2022).

The class Insecta includes many potential representatives that can be utilized as environmental bioindicators since they possess a higher structural and functional organization level, highly complex morphology, physiology, well-developed sense organs, complex behavior, and are characterized by a greater diversity of species. As a result, they can be more precise, quicker, and more flexible to reflect disturbances in their environment, as xenobiotics may reach the organisms *via* air, water, or soil. Utilizing bioindicators is a cutting-edge approach for detecting several forms of environmental mismanagement, such as contamination, high-input farming that degrades soil health, improper waste disposal, and pollution. The significance of insects as bioindicators in supporting human policy decisions for conservation and assessing the functional effects of human disturbance on ecosystems is acknowledged globally, but we ignore this in India, hence it is highlighted here (Table 1). Coleoptera, Diptera, Hymenoptera, Isoptera, Lepidoptera, and Hemiptera are examples of orders that may serve as indicators of changes in microclimate, foraging behavior and nesting places, reduced food availability due to the use of agrochemicals, and interactions with other species (Figure 4).

To determine how climate change will affect IPM programs necessitates an understanding of how changes in relevant abiotic factors will affect insect pheromonal communication is described in Table 2. Minor alteration in temperature, relative humidity, CO<sub>2</sub> and O<sub>3</sub> concentrations, wind currents, and average annual precipitation could change in insect behavior which will create consequences for agricultural productivity (Sharma and Singla, 2021). Insect pheromone production could be impacted by rising atmospheric CO<sub>2</sub> levels. The production of secondary metabolites is impacted by variations in CO<sub>2</sub> concentrations in plants (Ode et al., 2014). Escape behavior of aphids could be affected due to increasing CO<sub>2</sub> concentration by limiting the acetylcholinesterase enzymatic activity, which is related to neural transmission of alarm pheromone perception (Boullis et al., 2016).

There are three ways that ectotherms might adapt to climate change: plasticity, local adaptations, or both. They can modify their phenology to adapt to new seasonal climate patterns or change their geographic distribution to match their current thermal preferences (Walther et al., 2002; Parmesan and Yohe, 2003).

TABLE 1 Bioindicators for specific variables in terrestrial and aquatic habitats.

| Group  | Biomonitoring                          | Habitat     | References                        |
|--|--|-------------|-----------------------------------|
| (O) Diptera- (F) Chironomidae                | pH/Acidification                       | Aquatic     | Mousavi (2002)                    |
|  | Nitrogen and Phosphorus                | Aquatic     | Brodersen and Lindegaard (1997)   |
|  | Heavy metals                           | Aquatic     | Arimoro et al. (2018)             |
| (F) Syrphidae                                | Heavy metals                           | Terrestrial | Anna et al. (2021)                |
| (O)Diptera- (F) Sarcophagidae                | Heavy metal (e.g., asbestos)           | Terrestrial | Bartosova et al. (1997)           |
| (O) Collembola-                              | Air pollution/Acid deposition          | Terrestrial | Steiner (1995)                    |
|  | Nitrogen Input                         | Terrestrial | Kopeszki (1997)                   |
|  | Pesticides                             | Terrestrial | Frampton and Van Den Brink (2007) |
|  | Contaminated soil                      | Terrestrial | Liu et al. (2018)                 |
| (O) Odonata-                                 | Pesticides                             | Aquatic     | Braby and Williams (2015)         |
|  | Heavy metals                           | Aquatic     | Nummelin et al. (2007)            |
|  | Habitat disturbances                   | Aquatic     | Shafie et al. (2017)              |
| (O) Trichoptera-                             | Heavy metals                           | Aquatic     | Aizawa et al. (1994)              |
|  | Coal mine runoff                       | Aquatic     | Fernandez-alaez et al. (2002)     |
|  | Water pollution                        | Aquatic     | Lindenmayer et al. (2000)         |
| (O) Hymenoptera- (F) Formicidae              | Degraded and reforested areas recovery | Terrestrial | Srivastava et al. (2017)          |
|  | Heavy metals                           | Terrestrial | Nummelin et al. (2007)            |
| (O) Hymenoptera- (F) Apidae                  | Pesticides                             | Terrestrial | Burgio et al. (2015)              |
|  | Composite index                        | Terrestrial | Schweiger et al. (2005)           |
|  | Crop diversity                         | Terrestrial | Hendrickx et al. (2007)           |
|  | Heavy metals                           | Terrestrial | Porrini et al. (2003)             |
|  | Radionuclides                          | Terrestrial | Porrini et al. (2003)             |
| (O) Coleoptera- (F) Carabidae                | Habitat alteration                     | Terrestrial | Rainio and Niemela (2003)         |
|  | Heavy metal                            | Terrestrial | Lagisz (2008)                     |
|  | Crop diversity                         | Terrestrial | Schweiger et al. (2005)           |
| (F) Staphylinidae                            | Changes in agricultural techniques     | Terrestrial | Bohac (1999)                      |
| (O) Lepidoptera- (F) Geometridae & Noctuidae | Heavy metals                           | Terrestrial | Heliövaara and Väisänen (1990)    |
| (O) Hemiptera- (F) Gerridae                  | Heavy metals(e.g., Cd)                 | Aquatic     | Jardine et al. (2005)             |
| (O) Neuroptera- (F) Myrmeleontidae           | Heavy metals                           | Terrestrial | Nummelin et al. (2007)            |
| (O) Blattodea-                               | Soil ecosystem                         | Terrestrial | Duran-Bautista et al. (2020)      |

Each of these actions has an impact on the population and community levels as well as the evolution of species (Blanckenhorn, 2018). If insects can intermittently boost their cold tolerance, such as by fast cold-hardening, quiescence, a immediate behavioral response may enable them to deal with warmer and more fluctuating winter temperatures (Owen et al., 2013). The parasitoid *Anaphes nitens* (Hymenoptera: Mymaridae) undergoes winter quiescence in mild-winter regions of N-E Spain instead of displaying genuine diapause to adapt the duration of dormancy to the winter time temperatures (Santolamazza-Carbone et al., 2009).

## 5 Bioindicator insect groups to monitor environmental changes

### 5.1 Beetles as bioindicator

Coleopterans are considered as potential bioindicators and mainly belong to the group Carabidae, Staphylinidae, and Curculionidae. The most popular insect utilized in environmental biomonitoring is the ground beetle, especially for evaluating environmental pollutants and forest management (Ghannem et al., 2018). They are collected by using pitfall traps from the



**FIGURE 4**  
Major bioindicator insects. (A) Beetle, (B) Chironomid, (C) Ant, (D) Bee, (E) Butterfly, (F) Termite, (G) Springtail, (H) Dragonfly.

**TABLE 2** Climate change interactions with pheromonal communication.

| Concerning insect                          | Climate change   | Impact   | References                   |
|--|--|--|------------------------------|
| Male beewolf, <i>Philanthus triangulum</i> | Increase of 5°C temperature during larval rearing                            | adult male produces more pheromonal secretions   | Roeser-Mueller et al. (2010) |
| Female moth, <i>Striacosta ablicosta</i>   | Increase in the temperature difference between the photophase and scotophase | Calling behavior is greatly affected   | Mozūraitis and Būda (2006)   |
| Ladybird larvae                            | Increasing temperature   | Deposit more longchain hydrocarbons and employed as oviposition deterrent pheromone                        | Sentis et al. (2015)         |
| <i>Drosophila melanogaster</i>             | Temporary ozone fumigation at concentration between 40 and 120 ppb           | Lose their biological activity   | Arndt (1995)                 |
| Male moth <i>Caloptilia fraxinella</i>     | Elevated temperature condition   | Altered male pheromone responsiveness  | Lemmen and Evenden (2015)    |
| Springtail <i>Orchesella cincta</i>        | Heat stress (35.2°C)   | In male, heat exposure alters the spermatophore pheromone biosynthesis pathway and changes its composition | Zizzari et al. (2017)        |



region of chronic heavy metal pollution, which has resulted in an accumulation of various heavy metals in the soil. Multiple morphological traits are assessed to monitor heavy metal pollution like elytra length, body size, etc. (Lagisz, 2008). The toxic effect of copper has resulted in changes in the locomotory behaviour of adult carabids and a high degree of larval mortality. It is believed to be that behavioural changes are associated with copper exposure during larval development (Bayley et al., 1995). With research on *Pterostichus oblongopunctatus* (Simon et al., 2016), observed high BAF (Bioaccumulation factor) values for Copper (Cu) and Zinc (Zn) indicating that this species is preferable in metal contamination assessment. Additionally, it has been demonstrated by (Conti et al., 2017) that the carabid sp. *Parallelomorpha laevigatus* is a reliable indicator of toxic substances. In forests or on farms, scarabaeid beetles have a tremendous amount of potential as environmental indicators (Niemela et al., 1993). Dung beetles are likewise affected by forest fragmentation, and their abundance and species richness are positively correlated with the size of the fragments (Rainio and Niemela, 2003). To evaluate the genotoxic effects of herbicides on non-target soil-dwelling species, *Harpalus rufipes* provides early warning signs (Cavaliere et al., 2019).

## 5.2 Lepidopterans as bioindicator

Butterflies are significant bioindicators on account of their sensitivity towards the slightest alteration in environmental factors. They have been extensively used as heavy metal and environmental pollution bioindicators that are close to industrial states and even inside metropolitan regions (Da Renato et al., 2010). Butterflies are very sensitive to climatic variables. The temperature has a significant impact on butterfly range shifts, oviposition sites, egg-laying rates, larval development, and survival rates (Sharma and Sharma, 2017). Pupal size of Noctuidae and Geometridae species changes with levels of industrial air pollutants (Heliövaara et al., 1989). According to (Kyerematen et al., 2018), different environmental stressors in Sierra Leone's wetlands affect butterfly communities, and the higher the stress, the lesser the diversity of butterflies in a specified place. According to the estimates, the above observation is the consequence of significant environmental stresses in the Sierra Leone River Estuary (SLRE), including mining, agricultural, and factory pollution. The results further show that Mamunta Mayosso Wildlife Sanctuary (MMWS) is made up of a mosaic of several vegetation patches which supports higher diversity of butterfly species. This study also reveals that anthropogenic activities have a deleterious impact on butterfly diversity. Moths have been utilized as bioindicators to monitor the recovery of vegetation following environmental stress (Kumar et al., 2015). Arctiinae, Catocalinae, Heliolithinae, Noctuidae, Hermeniidae, and Phycitinae are some moth families/subfamilies that respond positively to disturbances, while Ennominae, Geometrinae, Lymantriidae, Epipaschiinae, and Anthelidae respond negatively (David, 1989). Kozlov et al. (2022) also noted that the overall abundance of Lepidoptera (moths and butterflies) did not alter along the pollution gradient. The life history characteristics of each species were linked to how it responded to pollution. Insect ability to withstand heavy metals varies widely. Despite the global

decline in pollinators, little is understood about how heavy metals affect insects. According to Skaldina and Sorvari (2019), the heavy metal pollution alters the morphology and physiology of insect pests including aphids and butterfly larvae.

## 5.3 Ants as bioindicator

Ants are ubiquitous in almost all the trophic levels of the web, food chains, and other ecological functions. They are used as a good bioindicator group for various types of pollution (Kaspari and Majer, 2000; Andersen et al., 2002) including soil-heavy metal contamination (Gramigni et al., 2013; Khan et al., 2017), aerial phthalate pollution (Lenoir et al., 2014) and land rehabilitation (Khan et al., 2017). Red wood ant *Formica lugubris* accumulates heavy metals such as Aluminum (Al), Cadmium (Cd), Cobalt (Co), Copper (Cu), Iron (Fe), Nickel (Ni), Lead (Pb), and Zinc (Zn) both in worker ant bodies and nest material (Skaldina et al., 2018). Ants are increasingly being used as bioindicators to monitor ecosystem health conditions (Akhila and Keshamma, 2022). The ant fauna also somewhat reflects the other invertebrate taxa found in a region (Majer, 1983). Ants are frequently employed as efficient disturbance bioindicators for restoring biodiversity and managing ecosystems (Underwood and Fisher, 2006) because of their ecological relevance (Tibcherani et al., 2018) and sensitivity to ecosystem disruption brought on by species invasion, grazing, thinning of the forest, conversion of the forest, fragmentation of the forest, and other disturbances (Da Renato et al., 2010).

## 5.4 Bees as bioindicator

Social insects can consume pollutants while foraging and then pass them on to the larvae or mix them into the materials used to build their nests. Pollutants in bees can also wind up in food that has been kept, such as honey or bee bread (Feldhaar and Otti, 2020). Honey bees are reliable and efficient biological indicators because they exhibit environmental chemical impairment due to a high rate of mortality and intercept particles suspended in air or flowers. They were incredibly effective in ground surveys due to their high mobility. Honey bees are used to monitor pesticides, heavy metals, and radionuclides (Porrini et al., 2003). Studied by (Di Fiore et al., 2022) the concentrations of different elements viz., Beryllium (Be), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), Lead (Pb), Copper (Cu), and Vanadium (V) in urban and rural areas. Later, they concluded that the honeybee can accumulate environmental pollutants and provide data on the progression of environmental pollution across time and space. Honey bees use two signals to indicate the chemical disruption of the environment, i.e., mortality (mostly due to pesticide residues) and residues detected in their bodies or bee hive products (pesticides and other contaminants like heavy metals and radionuclides), that can be determined employing appropriate laboratory analysis (Barganska et al., 2016). There is a possibility that the honey bee colony will absorb pesticides in layers which represents the yearly treatment strategy throughout the colony's territory because of its diverse range of feeding preferences and extended foraging season. Careful pesticide content monitoring can reveal variations in the

persistence of agrochemicals in particular hive compartments (Quigley et al., 2019). When compared to colonies that were taken in less disturbed habitats, those that were obtained in heavily anthropogenic areas show more asymmetry. Indeed, morphological characteristics can also reveal the habitat quality (Nunes et al., 2015). Cunningham et al. (2022) stated that the pollinator European honey bee, *Apis mellifera* exposed to pollutants and diseases while foraging they bring these things back to their hives where they may be identified and used as biomonitoring. Polluted substance is found in bees and their hive components such as honey, wax, and stored pollen, as well as heavy metals, air pollution, pesticides, and plant diseases. Honey bees are also used as indicators on new dangers like climate change and antibiotic resistance.

## 5.5 Parasitic wasps as bioindicator

Recently, parasitic wasps have been employed as bioindicators for habitats in woodlands (Hilszczanski et al., 2005). On a landscape scale, the parasitoids were more prevalent in habitats of mixed woodlands with a variety of species than in coniferous woodlands. The parasitoid assemblage was more strongly influenced by forest type and deadwood attributes, indicating that it is essential to maintain the diversity of deadwood habitats for parasitoid conservation. Due to their high trophic position, complex biology, and restricted host ranges, parasitic wasps are intricate and highly specialized (Maleque et al., 2009). Aculeate wasps can accurately quantify the variety of all arthropod species in an ecosystem, both social and solitary wasp species, and some social wasp species have also been found to be reliable indicators of heavy metal contamination (Brock et al., 2021).

## 5.6 Chironomids as bioindicator

Chironomids have been used as a biomonitoring model for ecotoxicological tests. Antennal deformities serve as great early warning indicators for the detection of toxic contaminants in the environment (Warwick, 1990). Both somatic aberrations (deletions, inversions, and deficiencies) and functional abnormalities (reduction in the amount of BRC, BRB, and the NOR activity) caused by trace-metal contamination can be easily recognized and utilized as reliable markers of genotoxicity (Michailova et al., 2012). Mouthparts deformities of chironomids are also observed under elevated metal concentrations (Arimoro et al., 2018). The family Chironomidae has the potential to be a bioindicator of changes in aquatic ecosystems on a global scale due to their species richness, including the indirect effects of drought (Cañedo-Argüelles et al., 2016).

## 5.7 Syrphid flies as bioindicator

Syrphid flies are a strong bioindicator of landscape-level forest management practices due to their widespread geographic distribution (Maleque et al., 2009). *Eristalis* spp. and *Sphaerophoria* spp. accumulate heavy metals like Mn, Pb, and Cd

of the industrial region in their body (Markova and Alexiev, 2002). Additionally, due to their high adult mobility, flies are the best tool to assess the biodiversity of landscapes (Sommaggio, 1999).

## 5.8 EPT taxa as bioindicator

Ephemeroptera, Plecoptera, and Trichoptera (EPT), more commonly referred to as mayflies, stoneflies, and caddisflies are great bioindicators of good water quality. Mayflies are sensitive to oxygen depletion in flowing water. Stoneflies indicate highly oxygenated water and caddisflies are sensitive to water pollution and used as bioindicators of water purity (Parikh et al., 2020). Caddisflies and mayflies being abundant in waters subject to little toxic stress, it has been hypothesized that the relative numbers of caddisflies, and mayflies may indicate various degrees of heavy-metal stress (Winner et al., 1980).

## 5.9 Dragonflies as bioindicator

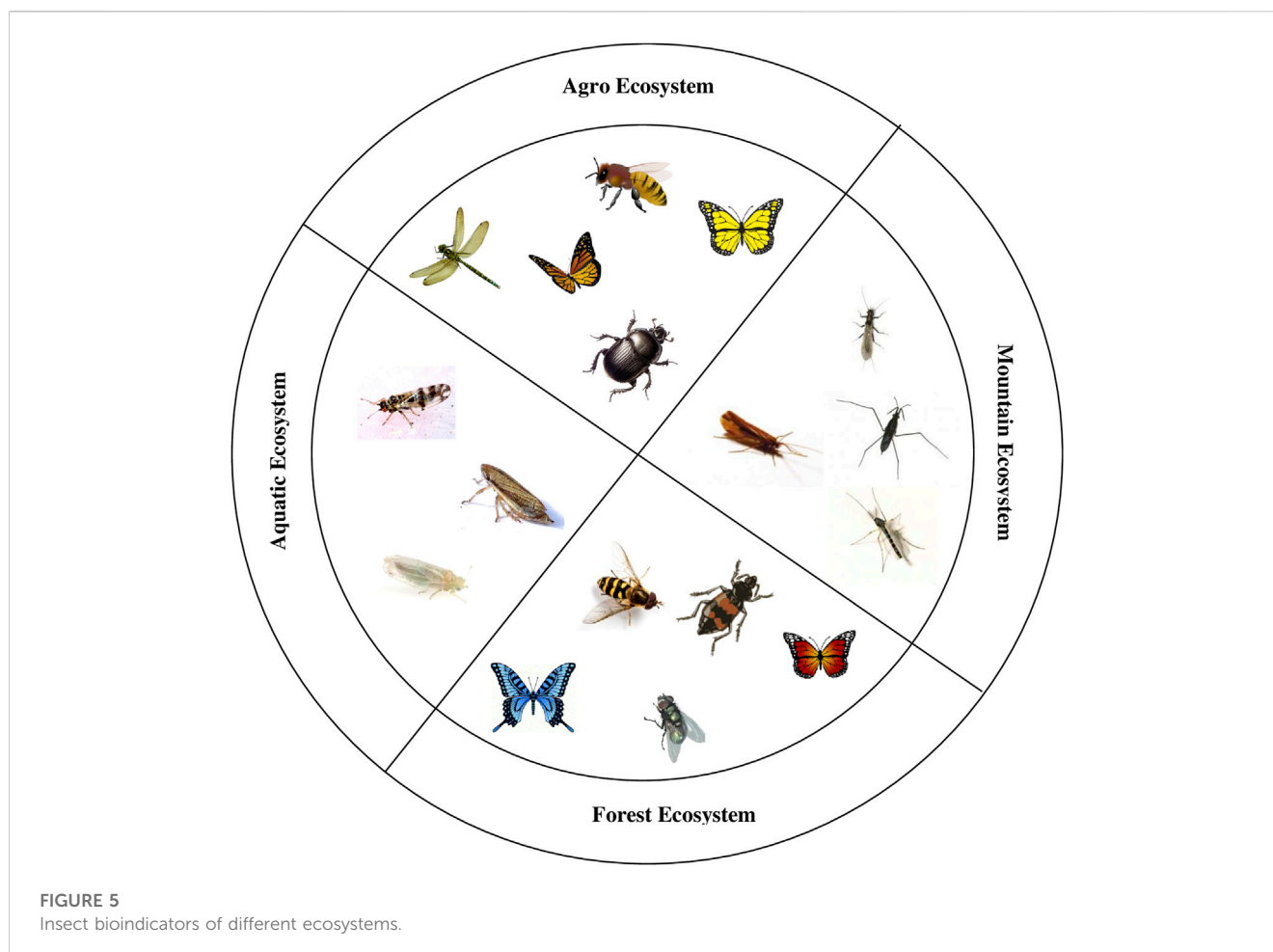
The most reliable ecological indicator in riparian and aquatic environments is thought to be dragonflies. They respond sensitively to habitat disturbance and heavy metal deposition, particularly in lakes and flooded drainage areas (Shafie et al., 2017). Their presence in any aquatic body indicates that it is synthetic pollution-free (Azam et al., 2015).

## 5.10 Termites as bioindicator

Termites are “ecosystem engineers”, which act as bioindicators of soil fertility through the determination of soil physico chemical parameters of termite mound soil in comparison with chemically fertilized soil (Nithyatharani and Kavitha, 2018). Termites also show indicator capacity for soil ecosystem services such as chemical fertility, hydrological functions, macro-aggregation, and biodiversity (Duran-Bautista et al., 2020). Termites accumulated high amounts of heavy metals such as Ca, Mg, Al, Fe, Zn, Cu, Mn, Be, Ba, Pb, Cr, V, Ni, and Cd. Alajmi et al. (2019) investigated and recorded a significant direct relationship between the presence of termites on the concentrations of Al, Cu, Zn, Be, Cd, Mn, Ca, Mg, Pb, V, and Mo, while, a significant indirect correlation existed for Ba, Cr, Ni, Co, and Fe.

## 5.11 Springtails as bioindicator

Springtails are abundant soil arthropods which are very sensitive to changes in the soil properties and the impact of anthropogenic activities. The decline in springtail species richness reflects soil water acidity brought on by organic pollutants and wastes, pesticide use in agricultural soils, and heavy metal pollution (Rusek, 1998). The QBS-adapt index, which measures the soil's biological quality in response to seasonal changes, is a sensitive tool for distinguishing between various land use patterns for different seasons. The QBS-adapt index can be determined by the morphological traits of springtails (Machado et al., 2019).



## 5.12 Minor insect groups as bioindicator

Aphids are indications of pollution even though surge in population density while feeding on hosts that are exposed to environments with high CO<sub>2</sub> concentrations (Zaghloul et al., 2020). Also, Nepidae, Corixidae, Notonectidae, Gerridae, Belostomatidae, Veliidae, and Mesoveliidae are hemipteran insect families that serve as bioindicators used to assess the water quality (John and Polhemus, 2008). Gerridae family members were used to monitor different iron and manganese concentrations, however, it seems that they behaved less well enough for nickel and lead (Nummelin et al., 2007).

## 6 Insect as bioindicators of different ecosystems

The major bioindicator insects in different ecosystems are depicted in Figure 5.

### 6.1 Insect as bioindicators of agricultural ecosystem

Changing consumer demand, the need for higher production, and climate change are all exerting strain on agricultural

landscapes. Environmentally significant creatures that inhabit agricultural land and its surroundings will be impacted by decisions made about land management. Agricultural landscape quality changes can be detected and followed over time and space using honey bees as bioindicators (Quigley et al., 2019). Agro-ecosystems are primarily performed as both providers and consumers of ecological services including carbon sequestration, soil conditioning, decomposition of organic matter, nutrient recycling, predation, pollination, support biodiversity, and cultural services. Intensive chemical input has subjected to serious degradation of these services. Monoculture provides an optimum environment for the growing population of herbivorous insects. Insect pollinators include hundreds of solitary bee species, bumble bees, flies, beetles, and butterflies, mainly hymenoptera communities that are common for pollination in agricultural areas. Furthermore, predatory insects such as some beetles, true bugs, lacewings, flies, midges, and wasps contribute to crucial ecosystem functions by acting as biocontrol agents. Moreover, through interacting with the soil, insects play a crucial role in enhancing agricultural soil. Dung beetle increases nitrogen, phosphorus, potassium, calcium, and magnesium or total protein content in the soil which elevates the crop yield in relation to chemicals (De Groot et al., 2002). Bioturbation agents, like ants, play a major role in bioindication due to their greater diversity in agro-ecosystem. The activity of terrestrial decomposer termites boosts infiltration

potential, which results in water retention and improved productivity.

## 6.2 Insect bioindicators of forest ecosystem

Bioindicators are a potentially useful tool for Sustainable Forest Management (SFM). An increase or decrease in the population of insect species may indicate significant changes in the ecosystem. The predominance of houseflies and mosquitoes indicates unhygienic environmental conditions. Butterflies are regarded as reliable ecological indicators and are tolerant to changes in topography and moisture. Butterflies are a sign of healthy environmental conditions (Weiss et al., 1988). Due to the intensive competition for resources, which prevents the predominance of a few dominating species, areas that are either cultivated or heavily forested with a diverse range of plant species demonstrated significant insect species diversity and higher ecological stability (Da Rocha et al., 2010). An extensive study of the consequences of forest fragmentation has been conducted utilizing a variety of arthropod indicator species. For example, (Fujita et al., 2008) revealed that urban forest remnants' richness in carabid species increased with the rise in fragment area but remained largely constant with the increase in isolation distance from major forests. Dung beetles are likewise more affected by forest fragmentation, and their number and species richness were positively associated with the extent of the fragments (Feer and Hingrat, 2005). Syrphid flies are the best tool for assessing landscape-level biodiversity due to their great adult mobility and species richness (Maleque et al., 2009). Furthermore, climate change will have a significant impact on increasing frequency, and severity of non-indigenous invasive insect species in forest ecosystem. Invasive species are introduced beyond their native regions to a completely new region of less or no natural enemies and capable of causing vast invasion owing to their great dispersal and adaptation ability. Invasion of insect species is a serious threat like emerald ash borer (*Agrilus planipennis*) causes severe destruction of ash trees (Herms and Mc Cullough, 2014), balsam wooly adegid (*Adelges tsuga*) infestation resulting in death of hemlock tree species (Havill et al., 2011), spread of gypsy moth (*Lymantria dispar*) causes *Quercus sp.* mortality (Davidson et al., 1999), and Asian long horned beetle (*Anoplophora glabripennis*) is responsible for the death of hardwood species of *Acer*, *Salix*, *Aesculus*, etc. (Dodds and Orwig, 2011) across the forests of eastern N. America.

## 6.3 Insect bioindicators of aquatic ecosystem

Ephemeroptera, Plecoptera, Trichoptera, and Diptera (EPT&D) are aquatic invertebrate insect species that are extremely sensitive to changes in water quality and are only able to survive in streams with very little pollution, cool temperatures, and well-oxygenated waters. *Baetis* and *Paraleptophlebia* (Ephemeroptera), and Chironomidae (Diptera) exhibit a considerable rise in abundance, and therefore density, immediately after an anthropogenic disturbance (Relyea et al., 2000). Insects are less typically utilized as biological indicators of metal contamination, despite species of the genus *Halobates* being suited to detect Cd and Hg (Nummelin et al., 2007). There are

several benefits of using aquatic insects to biomonitor the health of aquatic ecosystems. One of these is the potential for detecting changes in water quality, both during sampling and changes that have occurred, as a result of these species' largely sedentary lifestyles and extended life spans (Wahizatul et al., 2018).

## 6.4 Insect bioindicators of mountain ecosystem

In alpine regions, anthropogenic environmental degradation is still prevalent. According to their specific environmental tolerances, invertebrate communities are dispersed along with these sharp altitudinal gradients, and they respond accordingly when environmental conditions change. Only a few reliable invertebrate biomonitoring systems, particularly those which focus on terrestrial invertebrates, are regularly and extensively employed to track the changes in the mountain environment. *Neophilaenus lineatus*, a species of spittlebug, responds to shifting mean temperatures by exhibiting fast, often yearly changes in their upper altitudinal limit. *Craspedolepta schwarzi*, a species found at high elevations, may become extinct if suitable alpine habitats disappear. *C. nebulosa* and *C. subpunctata*, two lower-altitude species, may be anticipated to demonstrate an upward extension of their overlapping ranges, however, *C. nebulosa* always inhabits an elevation that is slightly higher than *C. subpunctata* (Hodkinson and Bird, 1998).

## 7 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. The class Insecta has all of them. Insect serves as a crucial indication of changes in the quality of the soil, the air, and the water. Although it can be difficult to choose a particular indication and then recognize it, as well as the relationship between the indicators and their specialized uses, these modifications have an impact on many species' physiological characteristics and abundance. This insect will be highly useful in the future as an indicator species because we can use it to detect pollution in the soil, water, and air. By doing so, we will be able to prevent habitat loss and reduce pollution in the future.

## Author contributions

SC and VKD initiated and wrote the manuscript. All the authors reviewed the manuscript, contributed to consulting references, and agreed for publication.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.



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