Plant Archives Vol. 25, Supplement 1, 2025 pp. 1018-1032 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.138

SAFEGUARDING INSECTS AS BIO-INDICATORS OF ENVIRONMENTAL CHANGES AND POLLUTION: A REVIEW

Prasanna Malireddi[1], Mounika Jarpla[1], Patel Rajesh D.[2*], H.L. Bandhavi[1] and Desai H. R.[2]
[1]Department of Entomology, N. M. College of Agriculture, N.A.U., Navsari, Gujarat, India
[2]Navsari Agricultural University, Surat, Gujarat India
*Corresponding author E-mail: rdpatel@nau.in
(Date of Receiving : 22-07-2024; Date of Acceptance : 16-10-2024)

ABSTRACT

Bio-indicators play a pivotal role in contemporary environmental science, serving as sensitive and dynamic markers of ecosystem health since they have close contact with noxious substances that are present in the ecosystem. Bio-indicators are very valuable for evaluating impact of human activities on terrestrial, aquatic and atmosphere as they respond to various factors such as climate change, pollution, and habitat loss. This comprehensive review explores the diverse array of bio-indicators, including plant, animal microbial, plankton taxa and their utility in assessment of environmental changes. By examining the mechanisms of bio-indicator responses to diverse changes, this review paper provides insights into their applications across various domains, including air, soil and water quality monitoring. Additionally, it also discusses the advantages and challenges in utilizing insects as bio-indicators soil health assessments and ecological risk evaluations.
Keywords: Insects, Bio indicators, Pollution, Environmental changes

Introduction

Currently, various environmental changes and pollutants stand out as a significant prominent global issue. The identification and correction of these environmental changes necessitate the utilization of various tools (Zaghloul *et al.*, 2020). Throughout more than 450 million years of Earth's ever-changing climate, insects have experienced diversification *i.e.*, globally, the kingdom Animalia encompasses a total of 1,552,319 reported species, with the phylum Arthropoda accounting for approximately 80% (1,241,855 species), representing insects. In the class Insecta, the examination of threatened species across various orders indicates that Odonata has the highest count of threatened species at 702, trailed by Orthoptera with 677, Coleoptera with 368, Lepidoptera with 271, and Hymenoptera with 211, while the remaining orders each have fewer than 60 species (Raghavendra *et al.*, 2022). However, the rapidly shifting patterns of temperature and precipitation, along with several decades of other human-induced stressors like land conversion and degradation, introduce fresh challenges for these organisms (Halsch *et al.*, 2021). Insect populations are experiencing varying rates of reduction across different locations and periods. On an average, it is believed that the decline in their abundance ranges from 1-2% annually or 10-20% per decade (Dar *et al.*, 2021). Hence, there is a critical necessity to monitor environmental quality and enhance measures for preventing environmental pollution.

Changes or disturbances of the environment are often caused by human activities like ocean acidification, land use changes or any natural ecological process includes volcano eruptions and drought *etc.* is called as environmental changes (Holt and Miller, 2010).

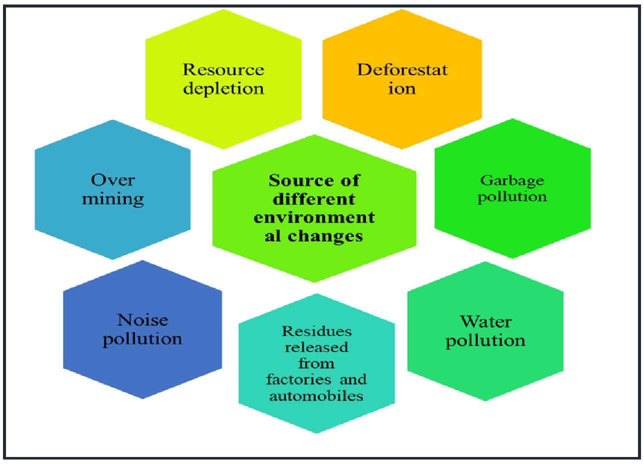


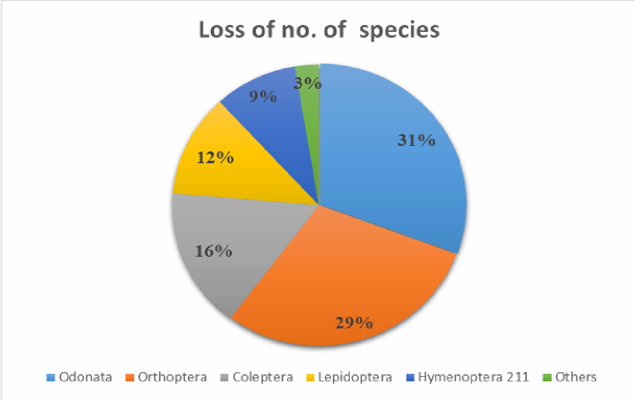
Fig. 1: Different environmental changes

Among the different changes in recent years, industrialization and urbanization have created problem of contamination of water, air and land. The pollutants generated from these changes affect the biodiversity of the environment (Findorakova *et al.*, 2017).

In nature insects play key roles in diverse processes (Metcalfe *et al.*, 2014; Noriega *et al.*, 2018) like decomposers or dung degradation (Nichols *et al.*, 2008), pollinators (Jia *et al.*, 2022), degradation of plastic (Bombelli *et al.*, 2017), medicine (Devi *et al.*, 2023), bio-control agents (Sharma *et al.*, 2019) pests, defoliators, recyclers, silk producers, and also pollution monitors (Kumar *et al.*, 2011). The potential loss of insects could have adverse impacts on entire communities. Therefore, it is crucial to possess a comprehensive understanding of how insects react to human activities. This knowledge is essential for informing conservation policies and assessing the functional outcomes of environmental changes due to human disturbances (Nicholsa *et al.*, 2007) In order to quantify these environmental changes bio-indicators can be used.

The utilization of insects as bio-indicators of environmental changes has gained significant prominence in ecological research due to the diverse and rapid responses of these organisms to alterations in their surroundings. Insects, comprising an incredibly diverse group of species, play pivotal roles in various ecosystems, making them valuable indicators of the overall health and stability of the environment. Their sensitivity to environmental shifts, coupled with their relatively short life cycles and abundance, positions them as effective and efficient indicators of ecological changes at different spatial and temporal scales.

The term "bio-indicator" refers to a species or a group of species that represents the abiotic or biotic state of the environment. It illustrates how an environmental change affects a habitat, community or ecosystem and indicates whether that change has a positive or negative influence (Parmar *et al.*, 2016), Bio-indicators are comprised of biological processes, species, or communities and serve as tools for evaluating environmental quality and tracking its fluctuations over time (Holt and miller 2010). Among different bio-indicators insects are thought to be good bio-indicators because they respond quickly to environmental stress, highly abundant, have shorter generations and are usually easily sampled and identified (Peck *et al.*, 1998). Out of 29 orders of Insecta, 10 orders *viz.*, Collembola, Ephemeroptera, Odonata, Plecoptera, Hemiptera, Lepidoptera, Trichoptera, Diptera, Coleoptera and Hymenoptera act as bio-indicators of environmental changes (Chaudhary and Saini, 2022).



(Source: Raghavendra *et al.*, 2022)

Fig. 2: Threatened species in different orders of class Insecta

Criteria for selecting bio-indicators

Prior to choosing indicator species, it is essential for the investigator to precisely outline the habitat in question and the specific issue under investigation. A comprehensive understanding of the habitat is crucial to identify potential changes that may occur within it. Therefore, a survey of both flora and fauna is required, along with an examination of physical attributes such as geology, soil types, meteorological records, and water chemistry. Once the habitat is identified, and the issue is clearly defined, the experimenter is ready to choose indicator species based on following criteria given by Han *et al.* (2015)

i. Indicator species should have well-defined classification and ecological traits
ii. They should widespread across large geographical area
iii. They should have ability to provide early warning for a changes
iv. They should have capability to differentiate between anthropogenic stress and natural stress
v. They should be important ecologically, socially and culturally
vi. Species should be easily observable, have a prolonged presence, and form gatherings with numerous individuals
vii. They should be ecologically beneficial for investigation
viii. They should exhibit distinct habitat characteristics
ix. They should be characterized by numerous independent individual groups and are minimally influenced by the size of each individual group
x. They believed to represent the response of other species

Classification of bio-indicators:

According to McGeoch (1998), bio-indicators classified into environmental, ecological and biodiversity-indicators based on their application.

1. Environmental bio-indicators

An environmental indicator refers to a species or a group of species that demonstrates predictable and easily observable responses, often quantifiable, to environmental disturbance or shifts in environmental conditions.

2. Ecological bio-indicators

An ecological indicator is a specific taxon or group of organisms that shows sensitivity to identified environmental stressors. It manifests the impact of these stress factors on the biota and serves as a representative reflection of the response observed in at least a subset of other taxa within the habitat.

3. Biodiversity bio-indicators

A biodiversity indicator comprises a set of taxa, such as genus, tribe, family or order or a specific group of species chosen from various higher taxa. It represents diversity through measures like character richness, species richness or the degree of endemism. The diversity of this selected group represents the overall diversity of other higher taxa within a habitat or a group of habitats.

Spellerberg (1991) classified environmental bio-indicators as follows :

1. Sentinels

Sentinels are responsive organisms intentionally introduced into the environment, serving either as early-warning indicators or to delineate the impact of an effluent.

2. Detectors

Detectors are naturally occurring insect species in the area of interest. They show measurable responses to environmental changes occurs in that particular area.

Example: changes in behaviour, mortality

3. Exploiters

Species whose existence serves as an indication of the likelihood of disturbance or pollution.

4. Accumulators

Organisms that absorb and store chemicals in measurable quantities are called accumulators

5. Bioassay organisms

These are the specific group of organisms employed as laboratory reagents to identify the presence of pollutants based on their toxicity.

Hammond (1994) classified bio diversity bio-indicators as follow based on their application

1. Reference group

A reference group serves as a foundation for extrapolating findings to another group with limited or incomplete data.

2. Key group

Insect group which is primarily responsible for documenting and estimating species richness in a specific area.

3. Focal group

Focal group plays a reference role but represents a subset of a larger group of interest, specifically chosen for its qualities as a predictive set.

4. Target group

Target group refers to a group that is currently under investigation or the subject of attention.

Types of bio-indicators

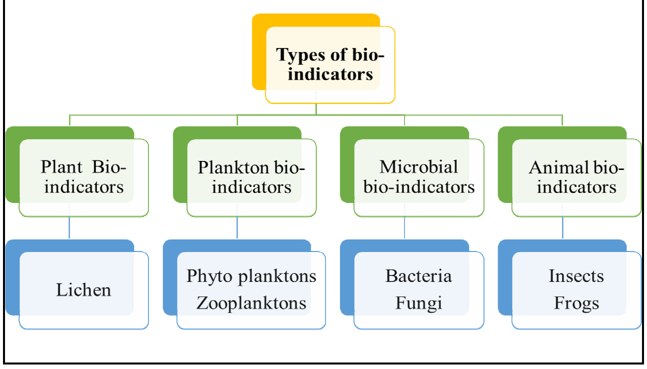


Fig. 3: Classification of bio-indicator

Plant bio-indicators

The practice of employing various wild plants as bio-indicators for monitoring pollutants present in their vicinity was dates back to the 1990s (Weinstein *et al.*, 1990). They have been extensively utilized for the detection of heavy metal and inorganic pollution (Azzazy, 2020). Additionally, Ernst (2003) has documented their effectiveness as monitors of organic pollution, attributed to their capacity to absorb contaminants from soil, water, and atmospheric deposition.

Wolffia globosa is a flowering plant that grows in mats on the surface of calm, freshwater bodies serve as a significant indicator of cadmium sensitivity and is employed for detecting cadmium contamination (Parmar *et al.*, 2016). Lichens are composite organism that arises from algae or cyanobacteria living on the tree trunks (Holt and miller 2010). The decline of lichen in forests is the indication of presence of elevated levels of sulfur dioxide (SO_2) and other pollutants from sulfur and nitrogen pollutants (Gerhardt, 2002).

Plankton bio-indicators

Planktons are the microscopic organisms residing in marine ecosystems, possess the ability to perform photosynthesis as they consists of chlorophyll. While serving as a crucial food source for numerous aquatic organisms, these tiny entities also function as indicators of the aquatic ecosystem's health (Gurjar *et al*., 2022). Changes in the species composition of phytoplanktons like *Euglena clastica, Phacus tortus,* and *Trachelon anas* are indicators of pollution in marine ecosystems (Jain *et al*., 2010). Zannatul and Muktadir (2009) stated that zooplanktons are active feders of phytoplanktons and bacterial planktons. These organisms contribute to the evaluation of contamination levels and eutrophication in aquatic environments. Examples includes *Trichotria tetrat, Alona guttata* and *Cyclips* etc.

Microbial bio-indicators

Microbes are the unicellular organisms which can be used as bio-indicators of changes in the terristrial as well as aquatic ecosystem because of their abundance and have capacity to show responses to contaminants even at low concentrations (Khatri and Tyagi, 2015). Gunatilaka *et al*. (2001) stated that detection of toxins in water can be effectively monitored through alterations in the microbial digestive system, which experiences hindrance or disruption in the presence of toxins. Bacterium like *Vogesella indigofera* demonstrates a quantitative response to heavy metals. In the absence of metal pollution, this bacterium generates a distinctive blue pigmentation and in the presence of metal pollution the pigmentation was blocked which could be serving as a significant visual indicator (Aslam *et al*. 2012). As per Dokulil (2003), blue-green algae can serve as a biological indicator to identify fluctuations in pH values across diverse ecosystems.

Animal bio-indicators

Animal indicators also play a crucial role in gauging the presence of toxins within animal tissues (Burger, 2006; Khatri and Tyagi, 2015). Zaghloul *et al.* (2020) summarized that Anura is an order of animals in the class Amphibia that includes frogs and toads are act as the bio- indicators of pollutants that are accumulated in the ecosystem. They have capacity to detoxify the pollutants that are ingest by their skin and larval gill membranes. Earthworms, essential components of soil ecosystems, can significantly contribute to the creation and breakdown of soil aggregates (Al Maliki *et al*., 2021). In the assessment of Eco toxicological risks, earthworms function as a crucial indicator for identifying potential pollutants that could harm the ecosystem. Additionally, earthworms serve as an early warning system, helping to monitor changes associated with pollution (Zaghloul *et al*., 2020).

Insect bio-indicators

Disruptions in certain species can serve as a parameter for assessing the extent of changes in a given ecosystem. Insects, being the most abundant biota in many ecosystems, are particularly susceptible to pollutants, making them reliable biological indicators for pollution in both aquatic and terrestrial environments. Given their crucial roles in various ecosystem processes, the negative impacts of insect loss extend to entire biological communities. Therefore, it is imperative to comprehensively understand insect responses to pollutants to assess the functional implications of pollution (Nichols *et al*., 2007).

Advantages of using insect bio-indicators

- To monitor the synergetic and antagonistic impacts of various pollutants on a creature.
- Early-stage diagnosis of environmental changes.
- Using insects as bio-indicators are economically viable when compared with other specialized measuring systems.
- Biological impacts on insects can be determined by analysing affected insects.
- The harmful effects of toxins on plants, as well as human beings, can be monitored
- Can be easily counted, due to their prevalence.

Characters of insects for using bio-indicators

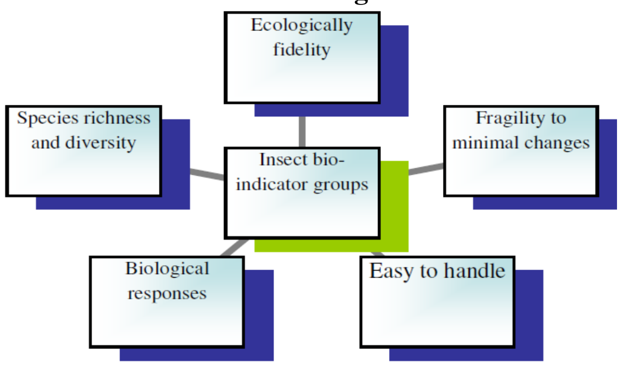


Fig. 4 : Characters of insect bio-indicators

Challenges in using insect bio-indicators

- The natural fluctuations of population must be understood
- Natural calamities may cause drastic temporary reductions in an insect population
- Effect of predators, parasitoids on insect population
- Species may be absent or inactive during certain times of the year and multiple stages in development process

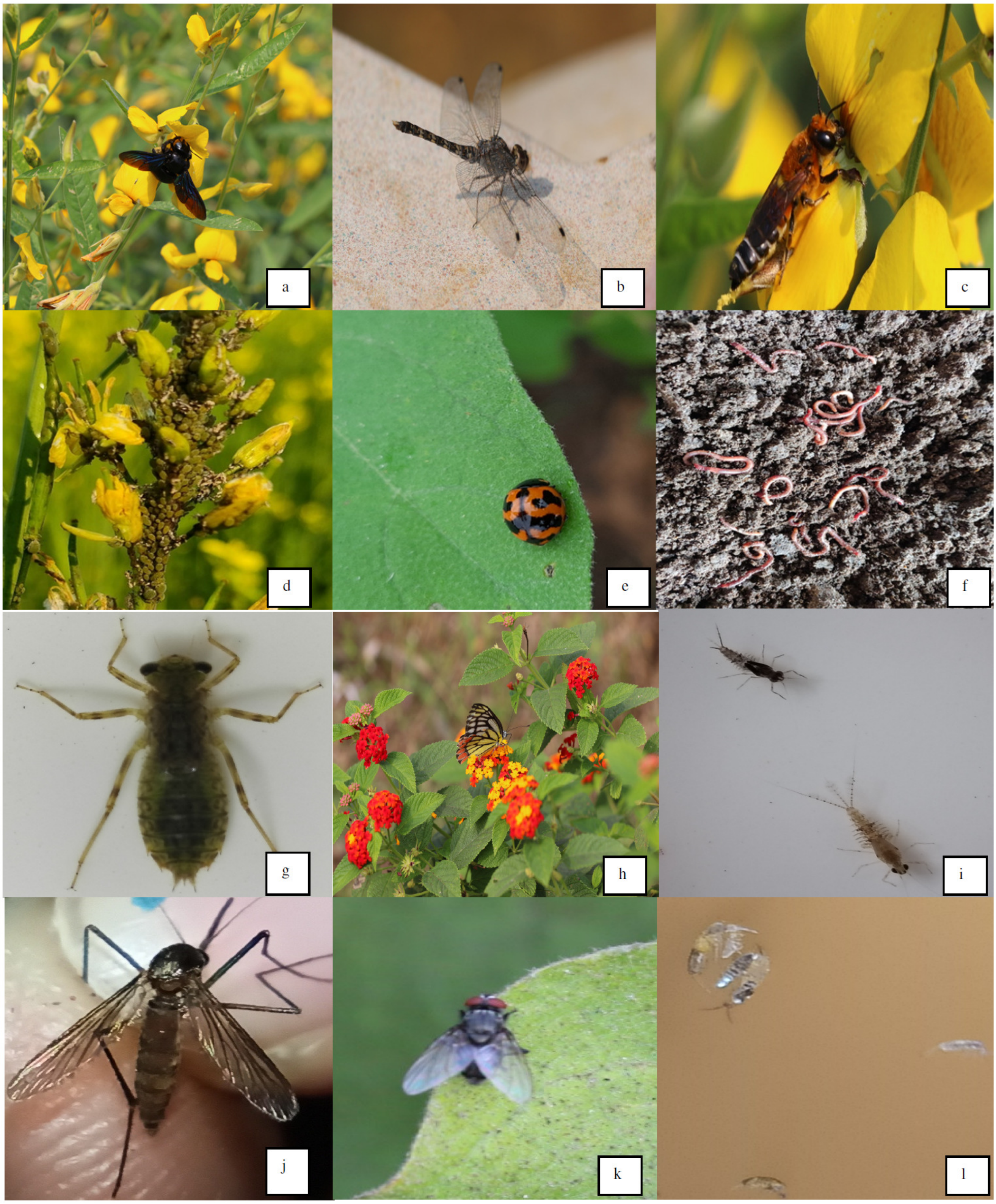


Fig. 5: Different bio-indicators

Fig. 5: Different bio-indicators: a) Bumblebee b) Dragonfly c) Honeybee d) Aphids e) Coccinellid beetle f) Earthworms g) Dragonfly naiad h) Butterfly i) Mayfly naiad j) Mosquito k) Housefly l) Springtails.

Insects as bio-indicators of water pollution

The use of insects as bioindicators of water pollution has emerged as a powerful and ecologically insightful approach in environmental monitoring. As vital components of aquatic ecosystems, insects are intricately linked to water quality and are particularly sensitive to various pollutants. Water pollution poses a pervasive threat to aquatic ecosystems, stemming from industrial discharges, agricultural runoff, urbanization, and other anthropogenic activities. Monitoring and assessing the impact of these pollutants on water bodies are critical for effective environmental management and conservation. Their life cycles, habitat preferences, and physiological responses make them valuable indicators of the health and integrity of freshwater environments. Benthic macro invertebrates, primarily composed of aquatic insects, mites, molluscs, crustaceans, and annelids, are commonly employed as key indicators in the monitoring of water systems (Bonada *et al.*, 2006).

Water striders and shore flies

Generally these insects are inhabitants of air-sea interface. This marine environment's interface remains inadequately understood, despite being a critical layer of the ocean. This interface is of paramount importance as it serves as a gateway for numerous major pollutants to enter the marine environment from the atmosphere (Duce and Hoffman, 1972).

Water striders and shore flies were observed to be influenced by abiotic factors in aquatic environments, encompassing parameters such as free carbon dioxide, dissolved oxygen, biochemical oxygen demand (BOD) and phosphate concentrations. Apart from this water strides also used as indicators of cadmium bio-monitoring. Among different genus of gerrids *Rheumatobates* have ability to accumulate cadmium in their tissues (Cheng *et al.*, 1976). *Gerris spinolae* emerges as a dependable bio-indicator in pond ecosystems, exhibiting a negative correlation with pollution. Water striders also exhibit proficiency in discerning variances in iron and manganese levels (Nummelin *et al.*, 2006). The presence of these insects in a given aquatic environment serves as a clear indicator of its health and absence of pollution. Shore flies (*Brachydeutera longipes*) belongs to order Diptera and family Ephydridae possess the potential to serve as an insect species resistant to pollution, making them indicative of the presence of pollution as they exhibit positive correlation with pollutants (Pal *et al.*, 2012).

Ephemeroptera (Mayflies)

Certain taxonomic groups, particularly Ephemeroptera, Plecoptera, and Trichoptera, collectively known as EPT taxa, have been recognized as valuable indicators of diverse environmental impacts (Carter and Resh, 2013). Ephemeroptera, or mayflies, represent a diverse order of aquatic insects found globally in freshwater environments, except for Antarctica and a few remote islands (Jacobus *et al.*, 2019). Due to their abundance, diversity, and cost-effective identification, mayflies have been extensively investigated as bioindicators in both freshwater and marine environments (Malakane *et al.*, 2020; Kamble and Nanware, 2021). Their easy collection and distinct characteristics contribute to their distinguishability from other aquatic macroinvertebrates. Global conservation concerns are noteworthy, with approximately 20% of mayfly species facing potential threats attributed to habitat degradation and loss, invasive alien species, pollution and the impacts of climate change (Jacobus *et al.*, 2019) and also water composition, water salinity, temperature, mineral water and other physico-chemical factors (Alhejoj *et al.*, 2023). Extended exposure of mayflies to low oxygen levels in water induces stress, resulting in increased mortality and subsequent population decline. The reduction in population serves as an indicator of water with low oxygen levels (Parikh *et al.*, 2020).

Trichoptera (Caddisflies)

Caddisflies, scientifically classified under the insect order Trichoptera Kirby, encompass around 15,000 described species distributed across all continents, excluding Antarctica. (Holzenthal and Thomson 2011). It is the seventh largest insect order as they stand out as the most extensive order among primary aquatic insects. Trichoptera shares close kinship with the Lepidoptera order, particularly in their dense covering of scales or hairs on the wings. Notably, the larvae of caddisflies are aquatic and adept at constructing portable cases which is called as case morphology (Holzenthal, 2009). In the context of pollution, these flies exhibit intolerance to pollution show a higher percentage in comparison to tolerant species at a given site, signifying superior water quality (Jain *et al.*, 2010).

Plecoptera (Stoneflies)

Stoneflies are a type of insect that undergo a unique life cycle, transitioning from aquatic juveniles to aerial and terrestrial adults. The adult stoneflies deposit their eggs in water, where the larvae thrive. These larvae, commonly either detritivores consuming dead vegetation or predators of other aquatic organisms, predominantly inhabit coarse substrates like boulders, cobble, and wood in swiftly flowing water. These larvae can be found in rivers and streams of various sizes, with a preference for small, shaded streams boasting cool temperatures and ample dissolved oxygen. Stoneflies absorb this essential oxygen through either gills or their skin. Their specific habitat requirements make them particularly sensitive indicators of stream quality. Although their absence does not necessarily signify pollution, the presence of stoneflies reliably points to a high-quality, minimally polluted stream (Voshell, 2002). It has been hypothesized that Stoneflies thrive exclusively in pristine or unpolluted aquatic environments, serving as indicators of water with elevated oxygen levels (Parikh *et al*., 2020).

Odonata (Dragonflies and Damselflies)

Odonates, commonly known as dragonflies and damselflies, exhibit predatory behaviour, consuming a diverse range of prey that expands in size as they mature. During their early larval stage, they predominantly feed on zooplankton, while mature larvae shift to larger macro invertebrates and occasionally small fish. Odonate larvae are commonly located in the shallows of ponds, lakes, bogs, wetlands, and still sections of streams and rivers. Some species of Odonates also inhabit swifter currents (Voshell, 2002). These are frequently suggested as reliable indicators of environmental health in aquatic ecosystems. Due to their reproductive behaviour, these insects exclusively deposit their eggs in or around freshwater, making their abundant presence in a region a strong indicator of freshwater quality (Corbet, 1999). Ponds with poor and very poor water quality harboured an abundance of Odonata species like *Zyxomma petiolatum* and *Ceriagrion cerinorubellum*, indicative of polluted water conditions. In contrast, Ponds exhibiting excellent water quality displayed the greatest diversity of Odonata species (Jacob *et al*., 2017). It was also emphasized that enhancements in water quality within aquatic bodies were evident through a rise in diversity among Odonate species and an increase in the populations of both aquatic larvae and airborne adult individuals (Catling, 2005).

Diptera (Chironomid)

Chironomid is the only the insect species having blood in their tissues due to the presence of haemoglobin. The chironomid group has been utilized as a bio-monitoring model for conducting many eco-toxicological tests because approximately half of *i.e*., 50 per cent of the macro-invertebrate fauna in aquatic ecosystems is comprised of chironomids (Michailova *et al*., 2012). Deformities in morphological parts like Antenna stand out as effective early indicators, enabling the early detection of toxic contaminants in the environment (Warwick, 1990), In certain Chironomid species there was a positive correlation between the frequencies of antenna deformities and the concentrations of Pb in the sediments (Bhattacharyay *et al*., 2005). Mouthpart deformities in chironomid larvae (Diptera) used as bio-indicator of pollution of heavy metals in the water bodies that increased mouthpart deformity incidence corresponded with increased concentration of heavy metals (Arimoro *et al*., 2018). An increase in somatic chromosome aberrations, encompassing inversions, amplifications, deletions, and deficiencies, along with a decrease in BR and NOR activity, was observed, reaching levels lower than those noted in larvae under standard conditions. Consequently, this species holds the highest probability of inducing aberrations, establishing itself as a practical model for cost-effective monitoring of the early genomic response to trace metals and other stress agents (Michailova *et al*., 2012).

Insects as bio-indicators of soil pollution

Insects play a crucial role as bioindicators of soil pollution due to their sensitivity to environmental changes. Certain insect species are particularly responsive to alterations in soil conditions, exhibiting changes in abundance, diversity, behavior, or physiological traits in response to pollution. Monitoring these insect populations provides valuable insights into the impact of soil pollutants, helping assess the overall health and quality of the soil ecosystem. Additionally, insects' relatively short life cycles and diverse ecological roles make them effective indicators for detecting both acute and chronic effects of soil pollution over time.

Collembola (Springtails)

Springtails are recognized decomposers in the soil ecosystem, residing in soil litter (Ruggiero *et al*., 2015; Verma *et al*., 2014). They contribute significantly to nutrient cycling by participating in the breakdown of plant residues, promoting the development of microflora, and impacting soil fertility by stimulating microbial activity. Their presence also restricts the activities of bacteria and fungi, mitigating potential plant diseases (Madej *et al*., 2011). Additionally, Silva *et al*. (2013) underscored their role in the food chain, serving as a nutrition source for various predators like beetles, mites, and spiders. Liu *et al*. (2018) highlighted the suitability of springtails as bio-indicators for copper concentration in soil, with their reproductive ability and adult body length thriving in varying copper concentrations which are quite higher in the soil having copper concentration of 0 mg kg^{-1} as compared to 1800 mg kg^{-1} concentration of copper.. In polluted sites, Kumar *et al.* (2011) observed that the site with the highest contamination displayed the lowest species richness, while certain pollution-resistant species flourished and dominated. Assessing soil quality index, including macro porosity, soil moisture, bulk density, pH, organic carbon content, and calcium/magnesium ratio, can be achieved by examining the morphological traits of springtails (Machado *et al.*, 2019).

Isoptera (Termites)

It was emphasized that termites play a crucial role in the functioning of tropical ecosystems, acting as primary decomposers in terrestrial environments (Da Rocha *et al*., 2010)**.** They also referred "ecosystem engineers" as capable of improving soil structure (Lavelle *et al*., in 1997) and also enhances the nutrient content (Nithyatharani *et al*., 2018). Decline in termite species richness mostly due to habitat fragmentation (Davies, 2002), land use (Attignon *et al*., 2005). Termites exhibited considerable sensitivity to environmental conditions, including both biotic and abiotic factors, which in turn influenced them as well as ecosystem processes (Bignell and Eggleton, 2000). Pribadi *et al*. (2011) identified that termite community/colony was potential to be used as a bio-indicator of the habitat disturbances based on their presence or absence. They concluded that in habitats with high level of disturbances the soil eating termites didn't exist at all.

Hymenoptera (Ants)

Previous studies suggest that ants hold promise as effective biological indicators for evaluating soil conditions and management practices in agroecosystems, providing valuable insights into crop growth and ecosystem services (Peck *et al*., 1998). Historically, ants were utilized as biological controls against California red scales, Aonidiella aurantii (Maskell) (Samways, 1981). Their capacity extends to restoring degraded ecosystems (Zaghloul *et al*., 2020) and contributing to biodiversity restoration (Underwood and Fisher, 2006). Ants, owing to their sensitivity to environmental changes and close association with soil ecosystems, are valuable bioindicators of soil pollution. Additionally, ants and their nests can serve as indicators of heavy metal contamination; ants collected from metal-polluted areas exhibited lower body mass and a lighter coloration (Skaldina *et al*., 2018). Furthermore, ants demonstrate sensitivity to disturbances in ecosystems resulting from activities like forest thinning, grazing, species invasion, forest conversion, and fragmentation, among others (Renato *et al*., 2010).

Coleoptera (Ground beetles)

Beetles emerging as the most diverse group of organisms on Earth. The estimated count of recognized beetle species ranges from 300,000 to 450,000 (Bouchard *et al*., 2017). Among which five species of beetles from the Cerambycidae, Lampyridae, Eumolpinae (formerly Chrysomelidae) and Phengodidae families were selected as excellent bioindicators due to their due to their sensitivity to environmental changes, resilience to heat, limited elevational preferences, and high abundance (Colares *et al*., 2021). The Coleoptera order has significant functions in sustaining soil quality, regulating the population of other invertebrates, influencing energy flow, and playing a role in the chemical processes associated with soil formation, as noted in the work by (Ghannem *et al*., 2017). By observing the diversity and population trends of beetle species, as well as monitoring their behaviors such as feeding habits and reproductive success, researchers can gain valuable insights into the health of the soil. Some beetle species are particularly sensitive to specific pollutants, making their presence or absence indicative of soil conditions. Additionally, studying the bioaccumulation of pollutants in beetle tissues provides a tangible measure of the extent of soil pollution.

Forest fragmentation affects dung beetles, and there is a positive correlation between the area of a fragmented habitat and the abundance and species diversity of dung beetles (Rainio and Niemela, 2003). Because of their prevalent presence in a variety of terrestrial environments, Carabid beetles (Carabidae) are commonly employed in Eco toxicological assessments. These beetles demonstrate heightened Bioaccumulation Factor (BAF) values for zinc (Zn) and copper (Cu), suggesting their efficacy in the assessment of metal pollution (Simon *et al.,* 2016). It was also showed that that body size of ground beetle (*Pterostichus oblongopunctatus* F.) measured as elytra length, significantly decreased with increasing zinc concentration in soil (Lagisz, 2008).

Insects as bio-indicators of air pollution

Hymenoptera (Paper wasp)

Paper wasps belonging to the genus *Polistes* are found globally and are commonly observed in human-made environments. These wasps are vulnerable to the risks associated with bio magnification as they occupy the highest trophic levels of food chain (Urbini *et al.*, 2006). (Maeto *et al.*, 2009) reported that these wasps have been employed as bio-indicators to assess woodland habitats in recent years. Due to their elevated trophic position, intricate biology, and limited host ranges, parasitic wasps exhibit complex and specialized habitat requirements made them reliable bio-indicators (Shaw, 2006). In 2006, Urbini and colleagues discovered that Polistes wasps have the ability to accumulate lead (Pb) in their bodies up to 36 times their own weight. This suggests that these wasps hold potential as a species for monitoring lead pollution. Furthermore, their study revealed that wasps collected from urban areas tend to exhibit higher levels of lead compared to those from rural areas.

Hemiptera (Aphids)

Aphids are commonly classified as significant sap-sucking pests affecting crops. Additionally, they have been utilized as indicators of pollution, given their ability to demonstrate an elevated population density when feeding on hosts exposed to environments characterized by high concentrations of CO_2 (Cannon, 1998).

Insects as bio-indicators of industrial pollution

Lepidoptera (Peppered moth)

The peppered moth stands as a classic example of industrial melanism, extensively researched as a bio-indicator for industrial pollution. This species is prevalent in Britain and exhibits two morphological forms: the light-coloured *Typica* and the dark-coloured *Carbonaria* moths. During the 19th century, the industrialization in Britain resulted in pollution from factories, causing tree trunks to darken due to soot and pollutants. This environmental change significantly impacted the peppered moth population (Majerus, 2009). (Kettlewell, 1995) argued that in this polluted environment, *Carbonaria*, with its dark coloration, had a selective advantage over *Typica* by avoiding bird predation through camouflage against the darkened tree trunks. This phenomenon serves as a bio-indicator, as the presence of black-coloured moths indicates the presence of industrial pollution. Heliövaara *et al.* (1989) recorded that the pupal weight, length and width of the pine beauty moth (*Panolis flammea* L.) and pine looper moth (*Bupalus piniarius* Denis and Schiffermüller) was negatively correlated with increasing concentration of industrial pollutants in their food plant and also with increasing distance from the source of pollution emission.

Insects as bio-indicators of sound pollution

Past studies indicate that certain arthropods experience disturbances from loud human-made infrastructure (Morley *et al.*, 2014). In arthropods sounds are most important part of their life, generally males are produced advertisement calls to attract opposite sex, for escaping from predators (Brehm *et al.*, 2015). Negative effects of vehicular horns, urbanization, energy extraction infrastructure and other sources suppress the advertisement calls of males (Bunkley *et al.*, 2016). They also concluded that family Cicadellidae was positively associated with background sound level, while families Mutillidae, Lycosidae and genus Pardosa negatively associated with background sounds. Environmental noise has adverse effects on the physiology and behaviour of insects. The health of ants, and likely other organisms, is negatively affected by harsh and irregular noise. On the contrary, a soft and calming noise exerts a positive influence, reducing stress and improving aspects such as social relationships, cognition, and memory in insects (Cammaerts and Cammaerts, 2018). The process of urbanization can introduce human-induced electromagnetic noise, which has the potential to interfere with the magnetic compass orientation of migratory animals (Engels *et al.*, 2014).

Insects as bio-indicators of light pollution

Excessive exposure to light disrupts the developmental cycle of numerous insects, negatively impacting their daily activity patterns or biological clock (Owens *et al.*, 2020). The proper migration of monarch butterflies relies heavily on appropriate environmental light cues and a well-functioning circadian clock. Night time light pollution (NLP) in urban areas along their migratory routes has the potential to disturb the entire migratory cycle. In these urban environments, NLP may artificially extend the perceived daytime hours for monarch butterflies, a phenomenon observed in other migratory species (Dominoni and Partecke, 2015). The continuous exposure to artificial light conditions caused by NLP can hinder the developmental processes of monarch butterflies, including eclosion behavior (Froy *et al.*, 2003). Moreover, it can disrupt the functioning of the antennal circadian clock in adult migrants, leading to inaccuracies in flight orientation during migration (Merlin *et al.*, 2009). In addition to these challenges, human-induced alterations in land use, particularly associated with urbanization, pose significant threats to the sensory environment of monarch butterflies (Kelley *et al.*, 2018).

Pollinators as bio-indicators

The dispersal of organisms and the decline of pollinators are significantly influenced by global warming (Wahengbam *et al*., 2019).

Syrphid flies

Syrphid flies, also referred to as hoverflies or flower flies, constitute a family of insects categorized under Syrphidae. These flies share a noticeable resemblance to bees and wasps but are distinctive in their capacity to hover in mid-air. Renowned for their crucial role as pollinators, syrphid flies are also beneficial in controlling aphid populations, as they prey on aphids during their larval stage**.** The extensive geographic range of these flies positions them as effective bio-indicators (Maleque *et al*., 2009). Additionally, the considerable mobility of adult flies makes them a highly suitable tool for evaluating biodiversity loss (Zheng *et al*. 2019; Sommaggio, 1999). Within various syrphid species, *Eristalis* and *Sphaerophoria* species demonstrate the ability to evaluate heavy metals such as Pb, Mn, and Cd within their bodies (Markova and Alexiev, 2002). The population densities of syrphid flies show a positive correlation with the abundance of flowers, while exhibiting a negative correlation with temperature and humidity (Sajjad *et al*., 2010).

Bumble bees

Approximately 250 bumble bee species have been documented globally, with India alone reporting 48 species to date (Saini *et al*., 2015). These bees were distinguished by the black and yellow body hairs arranged in bands over the abdomen, these bees are characterized by their long proboscis and fuzzy bodies, enhancing their efficiency as pollinators. Moreover, they exhibit a higher visitation rate to flowers per minute compared to honey bees. *B. haemorrhoidalis* is a significant bio-indicator, offering insights into the well-being and diversity of the ecosystem. This is attributed to its specialized role as a pollinator for specific flowers (Sharma *et al*., 2023). Additionally the rise in the frequency of heat waves has the potential to forecast the local extinction of bumble bee species (Soroye *et al*., 2020).

Butterflies

Monitoring butterfly populations can help scientists assess the impact of human activities, climate change, and habitat degradation on biodiversity, making butterflies essential indicators for conservation efforts and ecosystem health assessments. Butterflies have been widely employed as bio-indicators for heavy metal and environmental pollution in proximity to industrial areas, including within metropolitan regions (Da Renato *et al*., 2010). The occurrence of fire in habitats leads to a suppression of butterfly populations.

Honey bees

Honey bees serve as valuable bio-indicators, offering insights into the environmental health and overall well-being of ecosystems. Due to their foraging habits and reliance on diverse plant species for nectar and pollen, honey bees can reflect changes in floral availability, pesticide exposure, and overall habitat quality. Monitoring honey bee populations can provide important information about the impact of environmental factors, such as land use changes and pesticide applications, on pollinator health and ecosystem stability. As pollinators, honey bees play a critical role in maintaining biodiversity and supporting the reproduction of numerous plant species, making them essential indicators for assessing ecosystem health.

The honeybee (*Apis mellifera* L.) has proven to be an effective biological indicator, providing a convenient tool for environmental bio-monitoring across different scales (Porrini *et al*., 2002). Additionally, it is utilized in the monitoring of heavy metals, radioactive elements, and pesticides (Porrini *et al*., 2003). The presence of accumulated dead honeybees around hives and noticeable behavioural abnormalities serves as bio-indicators signaling significant environmental issues (Keven, 1999). Barganska *et al*. (2016) observed that honey bees (*Apis mellifera*) use two signals to indicate the chemical disruption of the environment, *i.e*., mortality (mostly due to pesticides residues) and residues detected in their bodies or bee hive products (pesticides and other contaminants like heavy metals and radionuclides).

Insects as bio-indicators for weather prediction

Insects are useful bio-indicators for predicting weather conditions. Observing their behaviors, abundance, and distribution provides valuable insights into local climate patterns. By monitoring activities like flight patterns, mating behaviors, and foraging, scientists can gather information that aids in predicting changes in weather. Certain insect species, sensitive to environmental factors influenced by weather conditions, serve as practical indicators for forecasting shifts in temperature, precipitation, and other meteorological parameters.

Table 1: Insects using for weather prediction:

Insect order	Common name	Behaviour	Predictions	Reference
Hemiptera	**Cicadas**	Singing	Onset of rainfall	Okonya and Kroschel (2013)
Hymenoptera	**Ants**	Collecting their food	Onset of rainfall	
Diptera	**House fly**	Moving in groups	Rain approaching	Alves and Barboza (2018)
Odonata	**Dragonflies**	Flight activity was low	Rain may occur on same day	
Lepidoptera	**Butterflies**	Appearance of butterflies in groups	Onset of rainfall in early	
	Army warms	Appearance	Occurrence of drought	Zuma-Netshiukhwi *et al.*, 2013
Hymenoptera	**Red ants**	Appearance	Good rains	
Isoptera	**Flying termite**	Appearance/Flight	No rain for few days	Sumi, 2018
Diptera	**Mosquito**	Appearance/abundance If suddenly disappears	Hot weather/summer season has begun Rain is imminent	
Hymenoptera	**Bees**	Busy and active: Disappearance:	Clear weather, Rainfall is imminent	
Hemiptera	**Bug spp**	Activity near river banks under stone	Beginning of winter season	Chinlampianga (2011)
Orthoptera	**Field cricket**	Bring out new soil particles from its hole during rainy season	Heavy rains or floods going to occur	

Conclusion

Insects serve as invaluable bio-indicators of environmental changes due to their sensitivity to alterations in habitat, climate, and pollution levels. Monitoring insect populations offers crucial insights into ecosystem health and can signal broader ecological shifts. By studying changes in insect abundance, diversity, and distribution, researchers can assess the impact of human activities on natural environments, identify emerging threats such as habitat loss or pollution, and inform conservation strategies and can also be used for weather prediction in some parts of country. Therefore, safeguarding insect populations is not only vital for biodiversity conservation but also essential for maintaining the balance of ecosystems and ensuring human well-being.

Acknowledgement

I am very grateful to Dr. R.D. Patel, Assistant Research Scientist and Dr. H.R. Desai, Associate Research Scientist for their intellectual suggestions and constant guidance throughout this endeavour.

References

Alhejoj, I., Hiasat, T. H., Salameh, E., Hamad, A. A. and Al Kuisi, M. (2023). Use of the Aquatic Mayfly (Insecta: Ephemeroptera) as Environmental Bio-Indicator in Jordan. *Journal homepage: http://iieta. Org /journals/ ijdne.*, **18**(1): 133-139.

Al-Maliki, S., Al-Taey, D. K. and Al-Mammori, H. Z. (2021). Earthworms and eco consequences: Considerations to soil biological indicators and plant function: A review. *Acta Ecol. Sin.*, **41**(6): 512–523.

Alves, R. R. N. and Barboza, R. R. D. (2018). Animals as ethnozooindicators of weather and climate. *In Ethnozoology*. pp. 383-420

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

Aslam, M., Verma, D. K., Dhakerya, R., Rais, S., Alam, M. and Ansari, F. (2012). Bioindicator: A Comparative Study on Uptake and Accumulation of Heavy Metals. *Research Journal of Environmental and Earth Sciences.*, **4**(12): 1060–1070.

Attignon, S. E., Lachat, T., Sinsin, B., Nagel, P. and Peveling, R. (2005). Termite assemblages in a West-African semi-deciduous forest and teak plantations. *Agriculture, ecosystems & environment*, **110**(3-4): 318-326.

Azzazy, M. F. (2020). Plant bioindicators of pollution in Sadat city, Western Nile Delta, Egypt. *PLoS One*, **15**(3): e0226315.

Barganska, Z., Slebioda, M., and Namiessnik, J. (2016). Honey bees and their products Bioindicators of environmental contamination. *Crit. Rev. Environ. Sci. Tech.*, **46**(3): 235–248. doi:10.1080/10643389.2015.1078220

Bhattacharyay, G., Sadhu, A. K., Mazumdar, A. and Chaudhuri, P. K. (2005). Antennal deformities of chironomid larvae and their use in biomonitoring of heavy metal pollutants in the river Damodar of West Bengal, India. *Environmental Monitoring and Assessment*, **108**: 67-84.

Bignell, D. E. and Eggleton, P. (2000). Termites in ecosystems. *Termites: evolution, sociality, symbioses, ecology*, pp. 363-387.

Bombelli P, Howe CJ, Bertocchini F (2017) Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella. *Curr Biol*., **27**:292–293.

Bombelli, P., Howe, C. J. and Bertocchini, F. (2017). Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella. *Current biology*, **27**(8): R292-R293.

Bonada, N., Prat, N., Resh, V. H. and Statzner, B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. *Annu. Rev. Entomol*., **51**: 495-523.

Bouchard, P., Smith, A. B., Douglas, H., Gimmel, M. L., Brunke, A. J. and Kanda, K. (2017). Biodiversity of Coleoptera. *Insect biodiversity: science and society*, pp. 337-417.

Brehm, G., Fischer, M., Gorb, S., Kleinteich, T., Kühn, B., Neubert, D. and Wurdinger, S. (2015). The unique sound production of the Death's-head hawkmoth (Acherontia Atropos (Linnaeus, 1758)) revisited. *The Science of Nature*, **102**: 1-13.

Bunkley, J. P., McClure, C. J., Kawahara, A. Y., Francis, C. D. and Barber, J. R. (2017). Anthropogenic noise changes arthropod abundances. Ecology and Evolution, **7**(9): 2977-2985.

Gunatilaka, A., Butterworth, F. M. and Gonsebatt, M. E. (2001). Biomonitors and biomarkers as indicators of environmental change 2. In *International Association for Great Lakes Research Symposium on Biomonitors and Biomarkers as Indicators of Environmental Change 2 1998: Hamilton, Ont)*. Kluwer Academic.

Cammaerts, M. C. and Cammaerts, D. (2018). Impact of environmental noise on insects physiology and ethology-a study on ants as models. *Biol. Eng. Med,*, **3**: 1-8.

Cannon, R. J. (1998). The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global change biology*, **4**(7): 785-796.

Carter, J. L. and Resh, V. H. (2013). Analytical approaches used in stream benthic macroinvertebrate biomonitoring programs of State agencies in the United States. *U.S. Geological Survey Open-File Report, 1129*, 50.

Catling, P. M. (2005). A potential for the use of dragonfly (Odonata) diversity as a bioindicator of the efficiency of sewage lagoons. *The Canadian Field-Naturalist,* **119**(2): 233-236.

Chaudhary, D. and Saini, D. K. 2022. Insects as Bio-Indicators of Environmental Change. *Vigyan Varta* **3**(2): 34-38.

Cheng, L., Alexander, G. V. and Franco, P. J. (1976). Cadmium and other heavy metals in sea-skaters: (Gerridae: *Halobates, Rheumatobates*). *Water, Air, and Soil Pollution*, **6**(1): 33-38.

Chinlampianga, M. (2011). Traditional knowledge, weather prediction and bioindicators: A case study in Mizoram, Northeastern India. *Indian J. Trad. Knowl*., **10**(1): 207-211.

Colares, C., Roza, A. S., Mermudes, J. R., Silveira, L. F., Khattar, G., Mayhew, P. J., et al. (2021). Elevational specialization and the monitoring of the effects of climate change in insects: Beetles in a Brazilian rainforest mountain. *Ecol. Indic*. **120:** 106888.

Corbet P. S. (1999) Dragonflies: Behavior and Ecology of Odonata. Comstock Publ. Assoc., Ithaca, NY. 829 p.

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

Davies, R. G. (2002) Feeding group responses of Neotropical termite assemblage to rain forest fragmentation. *Oecologia* **133**: 233-242.

Dar, S. A., Ansari, M. J., Al Naggar, Y., Hassan, S., Nighat, S., Zehra, S. B. and Hussain, B. (2021). Causes and reasons of insect decline and the way forward.

Devi, W. D., Bonysana, R., Kapesa, K., Mukherjee, P. K. and Rajashekar, Y. (2023). Edible insects: as traditional medicine for human wellness. *Future Foods*, pp.100219.

Dokulil, M. T., Markert, B. A., Breure, A. M. and Zechmeister, H. G. (2003). Bioindicators and Biomonitors. pp. 285-327.

Dominoni, D. M. and Partecke, J. (2015). Does light pollution alter daylength? A test using light loggers on free-ranging European blackbirds (Turdus merula). *Philosophical Transactions of the Royal Society B: Biological Sciences*, **370**(1667): 20140118.

Duce, R. A. and G. L. Hoffman. (1972). Trace metal measurements in the marine atmosphere and sea surface microlayer. In: Baseline studies of pollutants in the marine environment, I.D.O.E. Background Papers, Brookhaven, Conn. pp. 391-468.

Engels, S., Schneider, N. L., Lefeldt, N., Hein, C. M., Zapka, M., Michalik, A. and Mouritsen, H. (2014). Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird. *Nature*, **509**(7500): 353-356.

Ernst, W. H. O. (2003). The use of higher plants as bioindicators. In *Trace metals and other contaminants in the environment*. **6**: 423-463.

Findoráková, L., Šestinová, O. and Kováčová, M. (2017). Assessment of potential sediment contamination using screening methods (XRF, TGA/MS) taking into account principles of green chemistry, Eastern Slovakia. *Environmental Earth Sciences*, **76**(3): 1-8.

Froy, O., Gotter, A. L., Casselman, A. L. and Reppert, S. M. (2003). Illuminating the circadian clock in monarch butterfly migration. *Science*, **300**(5623): 1303-1305.

Gerhardt, A. (2002). Bioindicator species and their use in biomonitoring. *Environmental monitoring*, **1**: 77-123.

Ghannem, S., Touaylia, S. and Boumaiza, M. (2018). Beetles (Insecta: Coleoptera) as bioindicators of the assessment of environmental pollution. *Human and Ecological Risk Assessment: An International Journal*, **24**(2): 456-464.

Gurjar, P., Jhariya, S., Vyas, V. and Prakash, A. (2022). Plankton as bio-indicators to assess river health of Narmada using foldscope instrument. *Foldscope and its Applications*, 71.

Halsch, C. A., Shapiro, A. M., Fordyce, J. A., Nice, C. C., Thorne, J. H., Waetjen, D. P. and Forister, M. L. (2021). Insects and recent climate change. *Proceedings of the national academy of sciences*, **118**(2): e2002543117.

Hammond, P. M. (1994). Practical approaches to the estimation of the extent of biodiversity in speciose groups. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, **345**(1311): 119-136.

Han, Y. G., Kwon, O. and Cho, Y. (2015). A study of bioindicator selection for longterm ecological monitoring. *J. Ecol. Environ.,* **38**(1): 119–122.

Holzenthal, R. W., Morse, J. C. and Kjer, K. (2011). Order Trichoptera Kirby, 1813. In: Zhang, Z.-Q. (Ed.) Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness. Zootaxa **3148**: 209–211.

Holzenthal, R. W., Morse, J. C. and Kjer, K. (2011). Order Trichoptera Kirby, 1813. In: Zhang, Z.-Q. (Ed.) Animal biodiversity: An outline of higher-level classification and survey of taxonomic richness.

Heliövaara, K., Väisänen, R. and Kemppi, E. (1989). Change of pupal size of Panolis flammea (Lepidoptera; Noctuidae) and Bupalus piniarius (Geometridae) in response to concentration of industrial pollutants in their food plant. *Oecologia,* **79**(2): 179–183.

Holt, E. A. and Miller, S. W. (2010) Bioindicators: Using Organisms to Measure Environmental Impacts. *Nature Education Knowledge,* **3**(10):8

Jacob, S., Thomas, A. P. and Manju, E. K. (2017). Odonata (Dragonflies and Damselflies) as bio indicators of water quality. *International Journal of Innovative Research in Science, Engineering and Technology*, **6**(9): 19464-19474.

Jacobus, L. M., Macadam, C. R. and Sartori, M. (2019). Mayflies (Ephemeroptera) and their contributions to ecosystem services. *Insects*, **10**(6): 170.

Jain, A., Singh, B. N., Singh, S. P., Singh, H. B. and Singh, S. (2010). Exploring biodiversity as bioindicators for water pollution. In *National Conference on Biodiversity, Development and Poverty Alleviation,* pp. 50-56.

Jia, H., Liu, Y., Li, X., Li, H., Pan, Y., Hu, C. and Wu, K. (2022). Windborne migration amplifies insect-mediated pollination services. *Elife*, **11**: e76230.

Burger, J. (2006). Bioindicators: types, development, and use in ecological assessment and research. *Environmental Bioindicators*, **1**(1): 22-39.

Kamble, R. and Nanware, S.S. (2021). Mayfly nymphs as water pollution bioindicator. Bulletin of *Pure and Applied Sciences-Zoology*, **40**(1): 1-5.

Kelley, J. L., Chapuis, L., Davies, W. I. L. and Collin, S. P. (2018). Sensory system responses to human-induced environmental change. *Front. Ecol. Evol*., **6**:95.

Kettlewell, H. B. D. (1955). Selection experiments on industrial melanism in the Lepidoptera. *Heredity*, **9**(3): 323-342.

Kevan, P. G. (1999). Pollinators as bioindicators of the state of the environment: species, activity and diversity. In Invertebrate biodiversity as bioindicators of sustainable landscapes. pp. 373-393. *Elsevier.*

Khatri, N. and Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Front. Life Sci*., **8**(1): 23–39.

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

Lagisz, M. (2008). Changes in morphology of the Ground beetle Pterostichus oblongopunctatus Fab. (Coleoptera; carabidae) from vicinities of a zinc and lead smelter. *Environ. Toxicol. Chem*., **27** (8): 1744–1747.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P. O. W. H. and Dhillion, S. (1997). Soil function in a changing world: the role of invertebrate ecosystem engineers. *European Journal of soil biology*, **33**: 159-193.

Liu, M., Xu, J., Krogh, P. H., Song, J., Wu, L., Luo, Y. and Ke, X. (2018). Assessment of toxicity of heavy metal-contaminated soils toward Collembola in the paddy fields supported by laboratory tests. *Environ. Sci. Pollut. Res.*, **25**: 16969-16978.

Machado, J. S., Oliveira, F. L., Sants, J. C., Paulino, A. T. and Baretta, D. (2019). Morphological diversity of springtails (Hexapoda: Collembola) as soil quality bioindicators in land use systems. *Biota Neo Trop*., **19**(1): e20180610.

Madej, G., Barczyk, G. and Gdawiec, M. (2011). Evaluation of soil biological quality index (QBS-ar): Its sensitivity and usefulness in the post-mining chronosequence - Preliminary research. *Polish J. Environ. Stud*., **20**:1367-1372.

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. *J. Insect Conser*., 13, 245-257.

Majerus, M. E. (2009). Industrial melanism in the peppered moth, *Biston betularia*: an excellent teaching example of Darwinian evolution in action. Evolution: *Education and Outreach*, **2**(1): 63-74.

Malakane, K., Addo-Bediako, A. and Kekana, M. (2020). Benthic macroinvertebrates as bioindicators of water quality in the Blyde River of the Olifants river system, South Africa. *Applied Ecology and Environmental Research*, 18(1): 1621-1635.

Maleque, M. A., Maeto, K. and Ishii, H. T. (2009). Arthropods as bioindicators of sustainable forest management, with a focus on plantation forests. *Applied entomology and zoology*, **44**(1): 1-11.

Markova, E., and Alexiev, A. (2002). "Bioaccumulation of heavymetals in syrphid flies (Syrphidae, Diptera). In Study, conservation and utilisation of forest resources," in Proceedings of the Third Balkan Scientific Conference, Sofia, Bulgaria, 2-6 October 2001 (Forest Research Institute) Volume III, 151–157.

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

Merlin, C., Gegear, R. J. and Reppert, S. M. (2009). Antennal circadian clocks coordinate sun compass orientation in migratory monarch butterflies. *Science*, 325(5948): 1700-1704.

Metcalfe, D. B., Asner, G. P., Martin, R. E., Silva Espejo, J. E., Huasco, W. H., Farfán Amézquita, F. F. and Malhi, Y. (2014). Herbivory makes major contributions to ecosystem carbon and nutrient cycling in tropical forests. *Ecol. Let.*, **17**(3): 324-332.

Michailova, P., Sella, G. and Petrova, N. (2012). Chironomids (Diptera) and their salivary gland chromosomes as indicators of trace-metal genotoxicity. *Ital. J. Zool*., **79**(2): 218–230.

Morley, E. L., Jones, G. and Radford, A. N. (2014). The importance of invertebrates when considering the impacts of anthropogenic noise. *Proceedings of the Royal Society B: Biological Sciences*, **281**(1776): 20132683.

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S., Favila, M. E. and Network, T. S. R. (2008). Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. *Biological conservation*, **141**(6): 1461-1474.

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.

Nithyatharani, R. and 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.

Noriega, J. A., Hortal, J., Azcárate, F. M., Berg, M. P., Bonada, N., Briones, M. J. and Santos, A. M. (2018). Research trends in ecosystem services provided by insects. *Basic and applied ecology*, **26**: 8-23.

Nummelin, M., Lodenius, M., Tulisalo, E., Hirvonen, H. and Alanko, T. (2007). Predatory insects as bioindicators of heavy metal pollution. *Environmental Pollution*, **145**(1): 339-347.

Okonya, J. S. and Kroschel, J. (2013). Indigenous knowledge of seasonal weather forecasting: A case study in six regions of Uganda. *Agricultural Sciences*, **4**: 641–648.

Owens, A. C., Cochard, P., Durrant, J., Farnworth, B., Perkin, E. K. and Seymoure, B. (2020). Light pollution is a driver of insect declines. *Biol. Cons*., **241**: 108259. doi:10. 1016/j.biocon.2019.108259

Pal, A., Sinha, D. C. and Rastogi, N. (2012). Gerris spinolaeLethierry and Severin (Hemiptera: Gerridae) and Brachydeutera longipes Hendel (Diptera: Ephydridae): Two Effective Insect Bioindicators to Monitor Pollution in Some Tropical Freshwater Ponds under Anthropogenic Stress. *Psyche: A Journal of Entomology*, **2012**: 1-10.

Parikh, G., Rawtani, D. and 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.

Peck, S. L., Mcquaid, B. and Campbell, C. L. (1998). Using ant species (Hymenoptera: Formicidae) as a biological indicator of agroecosystem condition. *Environ. Entomol.*, **27**(5): 1102-1110.

Porrini, C., Ghini, S., Girotti, S., Sabatini, A. G., Gattavecchia, E. and Celli, G. (2002). Use of honey bees as bioindicators of environmental pollution in Italy. *Honey bees: estimating the environmental impact of chemicals*, 186-247.

Porrini, C., Sabatini, A. G., Girotti, S., Ghini, S., Medrzycki, P., Grillenzoni, F. and Celli, G. (2003). Honey bees and bee products as monitors of the environmental contamination. *Apiacta*, **38**(1): 63-70.

Pribadi, T. E. G. U. H., Raffiudin, R. I. K. A., and Harahap, I. S. (2011).Termites community as environmental bioindicators in highlands: a case study in eastern slopes of Mount Slamet, Central Java. *Biodiversitas Journal of Biological Diversity*, **12**(3): 235-240.

Raghavendra, K. V., Bhoopathi, T., Gowthami, R., Keerthi, M. C., Suroshe, S. S., Ramesh, K. B. and Chander, S. (2022). Insects: biodiversity, threat status and conservation approaches. *Current Science*, 1374-1384.

Rainio, J. and Niemela, J. (2003). Ground beetles (Coleoptera: Carabidae) as bioindicators. *Biodiv. Cons*., **12**(3): 487–506.

Renato, J., M. Rocha, J. Ribeiro, G. A. Lins, and A. Durval. (2010). Insects as indicator of environmental change and pollution: A review of appropriate species and their monitoring. *Holos Environment*, **10**(2): 250–8634. doi: 10.14295/holos.v10i2.2996.

Ruggiero, M. A., Gordon, D. P., Orrell, T. M., Bailly, N., Bourgoin, T., Brusca, R. C. and Kirk, P. M. (2015). A higher level classification of all living organisms. *PloS one*, **10**(4): e0119248.

Saini, M.S., Raina, R.H. and Ghator, H.S. 2015. Indian Bumblebees. Bishen Singh Mahendra Pal Singh, Dehradun, Uttarakhand, 247: 56-58.

Sajjad, A. and Saeed, S. H. A. F. Q. A. T. (2010). Floral host plant range of syrphid flies (Syrphidae: Diptera) under natural conditions in southern Punjab, Pakistan. *Pak. J. Bot*., **42**(2): 1187-1200.

Samways, M. J. (1981). Comparison of ant community structure (Hymenoptera: Formicidae) in citrus orchards under chemical and biological control of red scale, *Aonidiella aurantii* (Maskell) (Hemiptera: Diaspididae). *Bull. Entomol. Res.*, **71**(4): 663-670.

Sharma, A., Sandhi, R. K. and Reddy, G. V. (2019). A review of interactions between insect biological control agents and semiochemicals. *Insects*, **10**(12): 439.

Sharma, S., Sharma, G. and Joshi, N. (2023). Bumble bee, Bombus haemorrhoidalis Smith, 1852 (Apoidea: Hymenoptera)-a significant pollinator and bio-indicator species of the lower Shiwalik ranges in the Western Himalayan states of India. *This special issue includes 74 articles focusing on the following 3 major themes: Taxonomy, Biodiversity and Conservation and Biogeography. I wholeheartedly appreciate the hard work of the entire ZSI Team, coordinators of different themes, reviewers, officers and staffs of publication division for their dedication and collective team efforts, to bring out the publications on time. I also congratulate to all the authors for their articles, pub-lished in this issue,* 411.

Shaw, M. R. (2006) Habitat considerations for parasitic wasps (Hymenoptera). *J. Insect Conserv*., **10**: 117–127

Silva, R. F. D., Corassa, G. M., Bertollo, G. M., Santi, A. L. and Steffen, R. B. (2013). Fauna edáfica influenciada pelo uso de culturas e consórcios de cobertura do solo. Pesquisa agropecuária tropical, **43**: 130-137.

Simon, E., Harangi, S., Baranyai, E., Braun, M., Fábián, I., Mizser, S. and Tóthmérész, B. (2016). Distribution of toxic elements between biotic and abiotic components of terrestrial ecosystem along an urbanization gradient: Soil, leaf litter and ground beetles. *Ecol. Indic.*, **60:** 258-264. doi:10.1016/j.ecolind.2015.06.045.

Simon, E., Harangi, S., Baranyai, E., Braun, M., Fabian, I. and Mizser, S. (2016). Distribution of toxic elements between biotic and abiotic components of terrestrial ecosystem along an urbanization gradient: Soil, leaf litter and ground beetles. Ecol. Indic. 60, 258–264.

Skaldina, O., Peräniemi, S. and Sorvari, J. (2018). Ants and their nests as indicators for industrial heavy metal contamination. *Environmental Pollution*, **240:** 574-581.

Sommaggio, D. (1999). Syrphidae: Can they be used as environmental bioindicators? *Agricul. Ecosys. Environ*., **74** (1–3): 343–356.

Soroye, P., Newbold, T. and Kerr, J. (2020). Climate change contributes to widespread declines among bumble bees across continents. *Science*, **367**(6478): 685-688.

Spellerberg, I. F. (1991). Monitoring Ecological Change. Cambridge University Press, Cambridge.

Sumi, A. (2018). Ethnoecological knowledge of the Sumi tribe of Nagaland: insects as bio-indicators of weather prediction. *Int. J. Multidisci Curr. Res*., **69**(11-12): 1300-1304.

Underwood, E. C. and Fisher, B. L. (2006). The role of ants in conservation monitoring: if, when, and how. *Biol. Conser.*, **132**(2): 166-182.

Urbini, A., Sparvoli, E., & Turillazzi, S. (2006). Social paper wasps as bioindicators: a preliminary research with Polistes dominulus (Hymenoptera Vespidae) as a trace metal accumulator. Chemosphere, **64**(5): 697-703.

Verma, D., Yadav, R. K. and Kumar, M. (2014). Effect of ecological factors on population density of Collembola in Agra. *Journal of Environ. Appl. Bioresearch*, **2**(1): 25-28.

Voshell, J. R. (2002). A guide to common freshwater invertebrates of North America (No. Sirsi) i9780939923878). Granville, OH, USA: McDonald & Woodward Pub.

Wahengbam, J., Raut, A.M., Pal, S. and A. NajithaBanu (2019). Role of bumble bee in pollination. *Annals of Biology*, **35**(2): 285-289.

Warwick, W. F. (1990). The use of morphological deformities in Chironomid larvae for biological effects monitoring. *Inland Waters Dir. Sci. Publ. Ser*., **173**: 1–34.

Weinstein, L. H., Laurence, J. A., Mandl, R. H. and Waelti, K. (1990). Use of native and cultivated plants as bioindicators and biomonitors of pollution damage. *ASTM Special Technical Publication*, (1091): 117-126.

Zaghloul, A., Saber, M., Gadow, S. and Awad, F. (2020). Biological indicators for pollution detection in terrestrial and aquatic ecosystems. *Bulletin of the National Research Centre*, **44**(1): 1-11.

Zannatul, F. and Muktadir, A. K. M. (2009). A review: potentiality of zooplankton as bioindicator. *Am. J. appl. Sci.*, **6**(10): 1815-1819.

Zheng, Z., Liu, H., Wang, X., Wu, X., Chen, Y., Deng, J. and Pu, D. (2019). Development and reproduction of the hoverfly Eupeodes corollae (Diptera: Syrphidae). *Journal of Earth Sciences & Environmental Studies*, **4**(4).

Zuma-Netshiukhwi, G., Stigter, K. and Walker, S. (2013). Use of traditional weather/climate knowledge by farmers in the South-western Free State of South Africa: Agro meteorological learning by scientists. *Atmosphere*, **4**(4): 383-410.