

Predatory insects as bioindicators of environmental pollution

ABSTRACT

Industrialization, urbanization and agricultural activities have significantly contributed to environmental pollution which impacts soil, air and water as well as the health of plants, animals and humans. Despite the importance of addressing pollution, conventional techniques such as chemical sampling and laboratory analysis still pose difficulties in fully determining its range. Employing species that interact with soil, air and water may serve as a reliable indicator of pollution levels in the environment and its impact on overall biodiversity. This paper highlights the use of predatory insects as a bioindicator since they occupy higher trophic levels in ecosystems, their health and population dynamics reflects the bioaccumulation of pollutants. This study utilizes several insects, including predatory beetles, ants and dragonflies as biological indicators of pollution due to their sensitivity to the slightest changes in the environment and also in monitoring various environmental contaminants.

Keywords: Bioindicator, environmental pollution, environment, industrialization, urbanization, predatory insects, ecosystem, monitoring

1. INTRODUCTION

The average global temperature is ~~believed~~ ~~thought~~ to ~~increase~~ ~~be~~ ~~rising~~ as a result of both natural and human activities. Environmentalists and scientists have ~~been~~ ~~warned~~ ~~ing~~ for decades that the current use of Earth's resources is unsustainable. ~~Currently,~~ ~~G~~lobal warming poses a hazard to human ~~health~~ ~~survival~~. The ~~E~~arth is experiencing rising temperatures as a result of carbon emissions produced by human economic activities. This will impact ~~the~~ temperature globally in ~~a~~ geographically diverse manner and over extended periods. Within span of ten years duration, 2023 was recorded as the hottest year with an average temperature of 1.45°C (World Meteorological Organization, 2024). At global warming of 1.5°C, 4% of vertebrates, 6% of insects, and 8% of plants from 1,05,000 species examined are expected to reduce more than half of their geographic range (Intergovernmental Panel for Climate Change, 2018). The average global temperature was 14°C in 1960 and increased to 18°C by 2020 (Kabir et al., 2023). IPCC has predicted that by the year 2100, the average global temperature would increase from 2 to 6°C, primarily owing to the emission of carbon dioxide resulting from the ~~usage~~ of fossil fuels (Singh & Singh, 2008b). If rise in the global mean temperatures is more than 2 to 3 °C over pre-industrial levels, then 20 to 30 percent of the plant and animal species that have been evaluated until now would probably be at higher risk of ~~becoming~~ ~~going~~ extinct (Fischlin et al., 2007).

Environmental pollution is the presence of ~~any~~ ~~environmental~~ pollutants (solid, liquid, or gaseous substances) in the environment (Environment Protection Act, 1986). Approximately 70 per cent of ~~the~~ total air pollution is attributed to vehicular emissions. In the next few years, ~~contribution of~~ ~~India's~~ ~~contribution~~ to global carbon emissions is predicted to rise ~~due~~ ~~owing~~ to rising urbanization, transition to commercial fuels, increased use of vehicles, and persistent ~~tee~~ usage of inefficient coal-fired power plants (Singh & Singh, 2008a). ~~The~~ IPCC has reported ~~an~~ increase in greenhouse gases, ~~which is~~ primarily due to ~~an~~ increase in global average temperature since the mid-20th century. Human activities, such as the use of fossil fuels, have mostly contributed to climate change by increasing the concentration of greenhouse gases in the

atmosphere (Hegerl et al., 2007). This increased in greenhouse gas (GHG) concentrations has ve led to environmental warming of the environment. Increased carbon dioxide in the atmosphere, higher temperatures, shifting precipitation and transpiration patterns, increasing frequency of extreme events, and changing pest, weed, and pathogen stresses are some offew the ways that climate change will affect agriculture and food production globally (Easterling et al., 2007). Anthropogenic activities such aslike deforestation and urbanization, are responsible for the loss of biodiversity, whichthat negatively impacts ecosystems, and the changes in climate are attributed to rising sea levels, frequent rains, extreme heat waves, decreasing snow cover, melting glaciers, and ocean acidification (Singh & Singh, 2008). It is also estimated that climate change might be the primary cause of global decline in biodiversity after 2050.

There has beenis a rapid increase in greenhouse gas concentrations over the past 200 years in comparedison withto the pre-industrial period (Rogelj et al., 2018). Common anthropogenic activities, such as fossil fuel combustion and changes in land use, produce carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), which account for 79.70%, 11%, and 6% of greenhouse gas emissions, respectively (Yoro & Daramola, 2020). It is vital to find feasible solutions, to prevent and reduce the disastrous effects on biodiversity. The agricultural environment scheme is an alternative strategy that caneould stop the downward trend in biodiversity losses (Pereira et al., 2012). BecauseSinee environmental pollution posesoffers a direct threat to ecosystems, environmental monitoring is essential forto both managing and forecasting these systems. A bioindicator can be used fortuitously used, as it is described as a species or a group of species that illustrates biotic or abiotic conditions of the ecosystem. It shows how a habitat, community, or ecosystem is affectedimpaeted by environmental change and indicates whether those changes have a beneficial or detrimental effect (Parmar et al., 2016). They are useful becausesinee they offer perceptions ofinto the state of the environment without requiring advanced tools or measurements (Landres et al., 1988). An effective bioindicator will provides information regarding toxins and exposure levels, with reports asserting that employing a biomonitoring agent is the most effective method for assessment (David, 1989; Khatri & Tyagi, 2014).

2. TYPES OF BIOINDICATOR

Bioindicators provide specific insights into environmental health and, making arethem valuable tools for conservation, pollution control, and ecosystem management. Bioindicators refers to a group of species that acting as a representatives of the natural state of the environment, taking into account both biotic and abiotic changes to the habitat. There are different types of bioindicators, based on their taxonomic status and diverse backgrounds.

2.1 Based on taxonomic status

a) Animal indicator

Animals have specific habitat and dietary requirements thatwhich makes them sensitive to particular pollutants or habitat alterations, which helping toin determineing specific environmental stressors. The D detrimental effects on the environment occurs through variations in population density. Toxin levels in animalthe tissues of animal can be determined usingascertained with the help of animal indicators (Khatri & Tyagi, 2014). Frogs are the bioindicators of freshwater and terrestrial habitats, therefore, any alteration in theirits habitat, also affects the population of frog population. Zooplankton species thatwhich serve as zonal indicators of pollution include, *Alona guttata*, *Mesocyclops edax*, *Cyclops* and *Aheyella* (Ramchandra et al., 2006; Pradhan et al., 2008). Invertebrates, including insects, are importantsignificant

bioindicators. Insects, ~~particularly especially~~ predatory insects, occupy ~~ies~~ higher trophic levels ~~and~~, often integrate the cumulative effects of environmental changes over larger spatial and temporal scales, thereby providing a more comprehensive picture of ecosystem health. As a bioindicator of soil quality, earthworms are more responsive to temperature fluctuations than to ~~changes in~~ moisture content ~~changes~~. Depending on the type of organic residues, earthworms ~~may might~~ be crucial ~~for to~~ the development and breakdown of soil aggregates (Al-Maliki et al., 2021).

b) Microbial indicator

Microbial indicators provide significant cues ~~for environmental about~~ changes ~~in the~~ environment. Certain microbes ~~that~~ produce stress proteins when exposed to benzene and cadmium pollutants can be ~~used exploited~~ as early warning indicators (Khatri & Tyagi, 2014). Changes in the ~~microbial~~ digestive system ~~of microbes~~ indicate the presence of toxins in water. These alterations may also cause variations in the quantity of light ~~generated by that~~ the bacteria generate (Arora, 1966; Uttah et al., 2008). Blue-green algae may serve as a biological indicator for identifying ~~pH-value~~ fluctuations ~~in pH~~ in diverse habitats (Dokulil, 2003).

c) Plant indicator

In forests, lichens respond to ecological shifts, such as modifications to ~~the~~ climate, air quality, and forest structure. The rise in sulphur dioxide (SO₂) levels has led to ~~the~~ disappearance of lichens in ~~the~~ forests (Holt & Miller, 2011; Khatri & Tyagi, 2014). In the tropical region, “Paluma,” a Guava cultivar, may be employed as a bioindicator of phytotoxic ozone levels (Furlan et al., 2007). Recently, water pollution has ~~become been~~ a major issue ~~owing due~~ to urbanization and industrialization (Burger, 2006). Changes in the diversity of plants ~~determines~~ ~~the~~ water quality, hence acting as plant ~~bioindicators bioindicator~~. ~~The d~~ Diversity of phytoplanktons, *viz.*, *Euglena clastica*, *Phacus tortus*, and *Trachelon anas* are phytoplanktons indicates contamination of marine ecosystems (Phillips & Rainbow, 1993; Jain et al., 2010). *Wolffia globosa* ~~is serves as an~~ ~~important significant~~ indicator of ~~C deadmium~~ pollution. *Cyanophyta*, ~~known as~~ a biological indicator of potent plankton, demonstrates ~~rapid quick~~ eutrophication by generating bloom patterns in aquatic environments (Thakur et al., 2013).

Bioindicators are also classified based on ~~their~~ diverse backgrounds and applications, ~~such namely as~~, biodiversity indicators, ecological indicators, and environmental indicators (McGeoch, 1998).

2.2 Based on diverse background and application

a) Biodiversity indicator

~~The A~~ species richness of ~~the~~ community ~~was~~ indicated by the species richness of an indicator taxon. When selecting and designing a reserve or choosing ~~an~~ area for giving status as ~~a~~ conservation area, insects are employed as biodiversity indicators to emphasize areas that have ~~the~~ maximum overall diversity (Lees, 1996).

b) Ecological indicator

This ~~is a~~ species or ~~a~~ group of species ~~that~~ reacts to environmental disturbances or alterations (*viz.*, detectors, sentinels, accumulators, bioassay organisms, and exploiters) in a predictable manner.

c) Environmental indicator

~~The~~ Species that ~~are~~ is vulnerable to several pressures, such as pollution and habitat fragmentation ~~are~~, is called environmental indicators.

3. Criteria for selecting an effective bioindicator

Bioindicators ~~essentially~~ monitors the environment by providing data on the conditions of ~~the~~ natural environment over time. Not every organism or biological reactions ~~is~~ are equally suitable for all environmental conditions. ~~Thus,~~ ~~thus~~ choosing an effective bioindicator is crucial ~~for~~ obtaining accurate and useful data. The criteria for selecting an indicator are negotiable and ~~are~~ greatly impacted by the objectives of the study viz., indicators for biodiversity assessment, habitat degradation, climate change, and pollution levels. To select an appropriate indicator, ~~it must fulfill~~ a broad range of criteria ~~must be met~~. The indicator should be effective, ~~and~~ economical, and mostly unaffected by ~~the~~ sample size. It should be sensitive enough to provide early warnings and ~~capable of distinguishing~~ between naturally occurring cycles and those caused by anthropogenic stressors. Additionally, it should allow ~~for~~ constant monitoring across a broad spectrum of stresses (Noss, 1990). ~~The~~ Criteria of selection ~~criteria~~ for ~~the~~ biological agents ~~are~~ is shown ~~represented~~ in Fig.1.

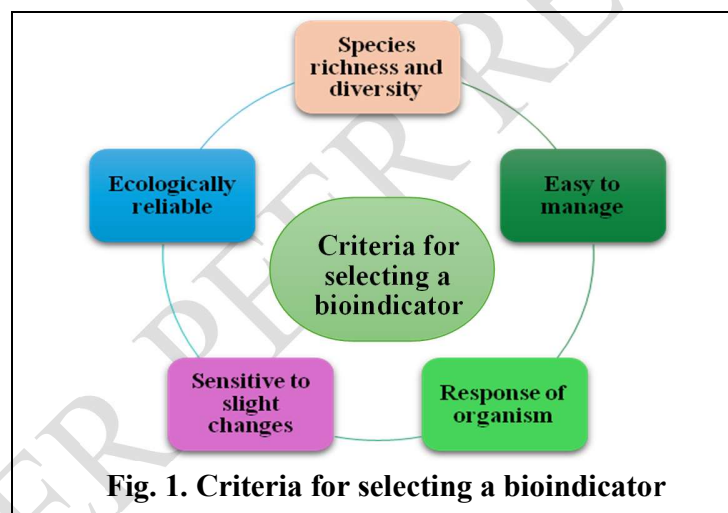


Fig. 1. Criteria for selecting a bioindicator

It should be easily sorted and sampled, simple to maintain in a laboratory, ~~should~~ provide plenty of autecological information, ~~should~~ have slight variation in genetics and function, ~~and should~~ be rapidly capable of building up pollutants (Hellawell, 1986). Bioindicators should be present in abundance, any alterations in the species should be detected using remote sensing, provide a clear response, such as to either disappear or become less prevalent, to alter or mutate, to replace or to get replaced through other species, ~~and~~ should be non-target species ~~when in case~~ pesticides are being monitored (Jenkins, 1971).

The bioindicator species should be easily recognized taxonomically, ~~and~~ have access to taxonomic knowledge, ~~and~~ should play a role in ~~the~~ environment or agriculture, representing all main functional guilds, ~~and~~ trophic levels, and numerous host-specific characteristics (Stork, 1994). They should ~~be representing~~ both related and unrelated taxa and ~~be should~~ spread across a variety of habitats (Pearson & Cassola, 1992; Faith & Walker, 1996). Eleven selection criteria for bioindicators ~~were have been~~ devised based on domestic and global studies (Han et al., 2015).

In ~~apart from~~ addition ~~this~~, the ~~19~~nineteen selection criteria ~~were~~have been divided into four categories: ~~including~~, location information, baseline information, niche, and life history attributes (Hilty & Merenlender, 2000).

4. Predatory insects as bioindicators of diverse pollution types

Predatory insects provide an early warning of ecosystem disturbances ~~owing due~~ to their high sensitivity to pollutants. Monitoring their populations shows the broader ecological impacts of chemical and biological contaminants. This makes them ~~a~~cost-effective and reliable tools ~~s~~ for assessing and managing environmental health across diverse habitats. Various bioindicators ~~of the~~ roles of predatory insects ~~roles~~ are discussed ~~beas~~ follows.:

4.1 Ants

Ants are eusocial insects ~~that belong~~ing to ~~the family~~ Formicidae ~~family~~. Ants are an essential component of any monitoring system; ~~becauseas~~ they are prevalent, ecologically significant, and simple to gather. They are required to monitor adverse changes in soil quality and ~~can~~provide early warnings (Underwood & Fisher, 2006). Anthropogenic activity affects the size, type, and distribution of ~~the~~ ant nests. ~~The n~~Nest of *Lasius niger* ~~isare~~ the most ~~prevalent~~prevelant and has ~~a~~ greater percentage of underground nests ~~s~~ near industrial pollutants (Blinova & Dobrydina, 2019). Worker ants of *Formica lugubris* ~~has~~es fewerless melanized heads ~~s~~ in contaminated areas (Skaldina et al., 2018). Therefore, they contribute ~~toin~~ ecosystem health ~~byas~~ they absorb~~ing~~ and potentially mitigat~~inge~~ phthalate pollution in their ~~en~~vironment (Lenior et al., 2014).

4.2 Beetles

Beetles belonging to ~~the~~ family Carabidae are predatory ~~and~~soil dwellings; hence, ~~they~~ are used to monitor soil pollution. They represent ~~a~~ broad group of organisms that differ ~~both~~ taxonomically and ecologically. Beetles are distinguished from other insects by the presence of rigid forewings that protect ~~the~~membranous hind wings. They are employed in field research to identify environmental toxins ~~and~~as well as for metal biomonitoring. In *Pterostichus oblongopunctatus*, ~~the~~elytra length and hindwing length decreases near ~~the~~ zinc and lead smelter (Lagisz, 2008). *Carabus lefebvrei* is useful ~~forin~~ assessing arsenic and mercury levels in the environment ~~because~~due ~~of~~to its high bioaccumulation factor. Similarly, in *Chlaenius olivieri*, the bioaccumulation factor (BAF) was in the range ~~of~~, cadmium (9.89) > copper (0.92) > nickel (0.89) > zinc (0.18) near ~~the~~ textile factory, which reduced the growth rate, body size, ~~and~~declined the reproductive success, ~~and~~as well as the survival rate when compared to the control site that was distant from ~~the~~ textile factory (Ghannem et al., 2016). *Parallelomorphus laevigatus* accumulates~~d~~ high levels of different elements, specifically arsenic, cadmium, chromium, lead, nickel, and mercury (Conti et al., 2017).

Predatory aquatic beetles provide ~~a~~ reliable indication of trace elements. Aquatic beetles belonging to ~~the~~ famili~~iesy~~ Dytiscidae, Hydrophilidae, and Gyrinidae are good indicators of water pollution (Sarikar & Vijaykumar, 2022). These are effective indicators ~~for~~to monitor~~ing~~ the rate of metal buildup in aquatic invertebrates, thus rendering them useful for discriminating between impacted and unimpacted ~~environments~~surroundings (Burghelea et al., 2011). Tiger beetles are regarded as ~~the~~canaries ~~offer~~ for the environment. They are used as habitat thermometers ~~to~~ measur~~ing~~ the health of ~~athe~~ habitat (Pearson & Pearson, 2014). Oil spills near ~~the~~ seashore have reduced populations ~~s~~ of ~~the n~~Northe-Eastern beach tiger beetle, *Cicindela dorsalis dorsalis*. These existed on ~~the~~sandy beaches from Virginia to Massachusetts, and ~~are~~ currently, ~~it is~~ restricted to the beaches of ~~the~~Chesapeake Bay and Massachusetts (U.S. Fish and Wildlife Service, 1994).

Predatory beetles can also be used as bioindicators ~~offer~~ pesticide ~~contamination~~ ~~pollution~~. Pesticides may have indirect effects on natural enemies, producing lethal and sub-lethal effects. Various physiological and behavioural changes ~~may~~ ~~might~~ occur ~~with~~ ~~upon~~ ~~utilizing~~ ~~pesticide~~ ~~use~~ ~~pesticides~~. ~~However,~~ ~~they~~ are indirectly harmed by pesticides. Their number may decline as a result of changes in ~~the~~ resources (honeydew, host plant quality) or decreased prey availability, which suggests the use of an effective pesticide (Duso et al., 2020; Bordini et al., 2021). Adult emergence, fecundity, and fertility of the parental generation in *Coccinella septempunctata* ~~were~~ reduced by thiamethoxam at doses of $0.1 \times LC_{10}$ (0.053 mg L⁻¹) and LC_{10} (0.53 mg L⁻¹) (Jiang et al., 2019).

4.3 Damselflies

Damselflies belong to ~~the~~ order Odonata, whose nymphs ~~are~~ called ~~as~~ naiads ~~and~~, spend their whole ~~lives~~ ~~life~~ in water. ~~The~~ ~~D~~ damselfly naiads are sensitive to pH, movement, and depth of water. Any fluctuation in their numbers indicates pollution in aquatic ecosystems (Sarikar & Vijaykumar, 2022).

4.4 Dragonflies

Dragonflies are regarded as “Guardians of the watershed” (Clausnitzer & Jödicke, 2004). They lay eggs in or close to freshwater; hence, their number ~~at~~ ~~in~~ a particular location is ~~a~~ reliable indicator of ~~habitat~~ ~~the~~ quality ~~of~~ ~~habitat~~. They ~~harnessed~~ ~~to~~ ~~assess~~ ~~ed~~ the status of the water quality based on ~~the~~ biotic indices, consequently proving them ~~to~~ ~~as~~ ~~been~~ effective biological indicators (Sarikar & Vijaykumar, 2022). At a particular temperature and pressure, the behavior, metabolism, and survival of larvae are ~~known~~ ~~to~~ ~~be~~ influenced by dissolved oxygen levels (Corbet, 1999). ~~The~~ ~~D~~ dissolved methylmercury concentrations in dragonfly larvae serve as valuable indicators in aquatic environments (Jeremiason et al., 2016). They are ~~effective~~ ~~good~~ ~~at~~ ~~in~~ detecting significant differences in iron, nickel, and manganese (Nummelin et al., 2007).

4.5 Fireflies

The disappearance and declining population of fireflies indicates light pollution (Hagen et al., 2015). The bioluminescent flashing and mating success in both, *Photinus pyralis* (predator of *Photuris versicolor*) and *P. versicolor* (prey species) ~~were~~, significantly reduced in light-polluted areas (Firebaugh & Haynes, 2018).

4.6 Syrphid flies

Syrphid flies belonging to ~~the~~ order Diptera and family Syrphidae, are significant ~~for~~ ~~in~~ evaluating the biological diversity of ~~their~~ surroundings because of their rapid adult mobility (Sommaggio, 1999). *Eristalis* spp. and *Sphaerophoria* spp. capture heavy metals, such as manganese, lead, and cadmium, in their bodies from the industrial zone (Markova & Alexiev, 2001).

4.7 Water striders

Water striders belong to ~~the~~ order Coleoptera and family Gerridae. They are ~~known~~ ~~as~~ ~~called~~ water striders ~~because~~ ~~offer~~ their ability to walk on water. They ~~are~~ ~~known~~ ~~to~~ accumulate high concentrations of heavy metals ~~in~~ ~~near~~ industrial areas (Nummelin et al., 1998; Jardine et al., 2005;

Nummelin et al., 2007). These are useful bioindicators for assessing water quality (Sarikar & Vijaykumar, 2022).

Other predatory insects as bioindicators in different habitats are represented in table 1.

Table 1. Predatory insects as bioindicators in different habitats

Order	Family	Habitat	Indicates	References
Coleoptera	Carabidae	Terrestrial	Crop diversity	(Schweiger et al., 2005)
			Heavy metal	(Lagisz, 2008)
			Destruction of habitat	(Rainio & Niemela, 2003)
	Staphylinidae	Terrestrial	Alteration in agricultural methods	(Bohac, 1999)
Diptera	Syrphidae	Terrestrial	Heavy metals	(Anna et al., 2021)
Hemiptera	Anthocoridae (<i>Orius sauteri</i>)	Terrestrial	Pesticides (e.g., Acetamiprid, imidacloprid)	(Lin et al., 2020)
	Gerridae	Aquatic	Heavy metals	(Jardine et al., 2005)
Hymenoptera	Formicidae	Terrestrial	Heavy metals	(Nummelin et al., 2007)
			Recovery of degraded and reforested areas	(Srivastava et al., 2017)
	Vespidae (<i>Polistes dominulus</i>)	Terrestrial	Heavy metals (e.g., Pb)	(Urbini et al., 2006)
Neuroptera	Myrmeleontidae	Terrestrial	Heavy metals	(Nummelin et al., 2007)
Odonata		Aquatic	Heavy metals	(Nummelin et al., 2007)
			Pesticides	(Braby & Williams, 2015)
			Disturbances in habitat	(Shafie et al., 2017)

5. Conclusion

Predatory insects are versatile bioindicators that are effective in across both agricultural and urban habitats. As higher trophic-level organisms, they are highly sensitive to environmental contaminants, and changes in their populations provide early warnings of ecological disturbances.

Although [the](#) initial monitoring costs may be high, the valuable data they provide can guide interventions to prevent habitat degradation and mitigate pollution, supporting sustainable ecosystem management.

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