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Evaluation of the Ecosystem Health Using Biological Indicators: A Comprehensive Assessment

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Introduction:

Rising temperatures, extreme weather, higher concentrations of CO2 and other greenhouse gases (GHGs), and altered precipitation patterns pose a serious threat to the world's food supply. Global warming is a major problem that the world is currently facing. The remarkable rates of rise in sea level and air temperature demonstrate that it has reached previously unheard-of levels (Shrestha, 2019). The World Meteorological Organization (WMO) estimates that the current global temperature is one degree warmer than it was before to significant industrialization. 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 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. Carbon dioxide (CO_2), Methane (CH_4), and Nitrous oxide (N_2O) 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 50years, one of the atmosphere's well-observed changes has been the rise in atmospheric CO_2. 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. Heat infrared radiation from the Earth's surface is significantly absorbed by the atmosphere; therefore CO_2 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. 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. 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.

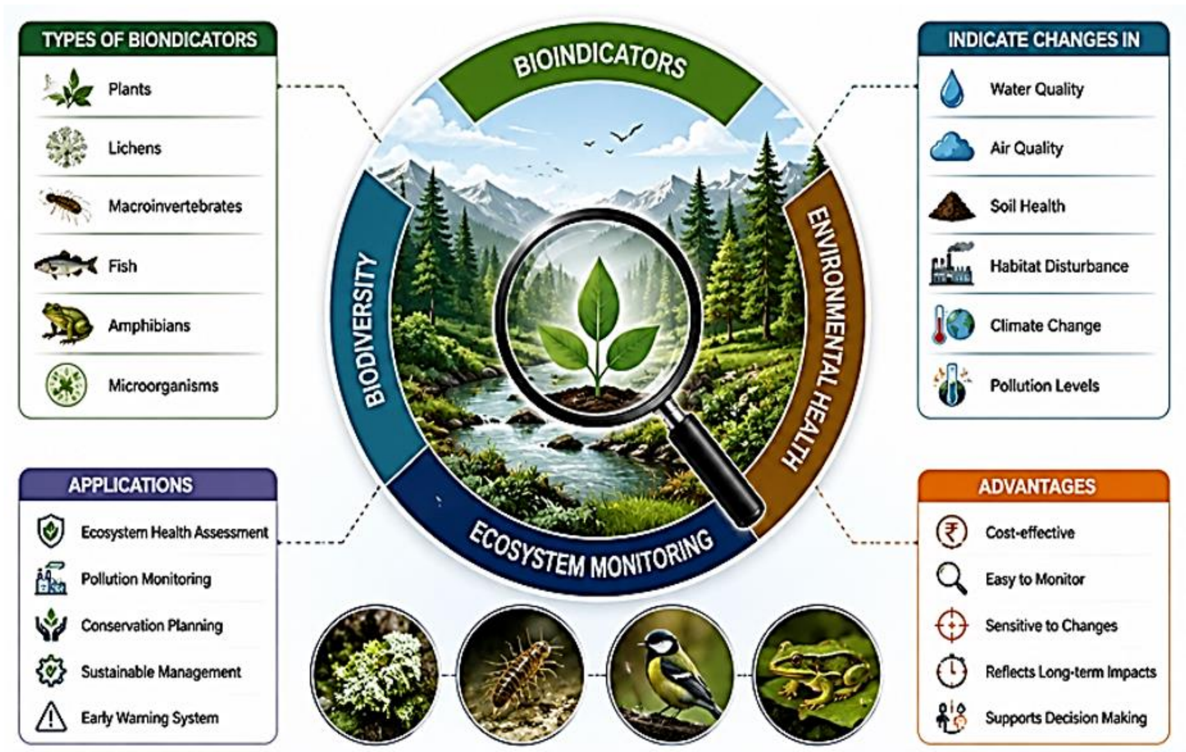
In recent decades, there has been a significant increase in awareness of detrimental environmental change worldwide. Overexploitation and habitat change are the two primary causes affecting the current state of biodiversity worldwide. It became essential to find workable ways to prevent or lessen potentially disastrous effects on biodiversity. One complementary measure that could stop the detrimental tendencies of reducing biodiversity is an agricultural environmental program (Pereira *et al.*, 2012). Environmental contamination poses a direct threat to ecosystems, hence environmental monitoring is essential to their management and forecasting. The idea of bioindication is not traditional; it has become a new concern in conservation assessment. 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. 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. Various living organisms are extremely sensitive to environmental changes that disrupt their core functions, such as metabolism, growth, and reproduction. 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.

Criteria for The Selection of Bioindicator:

Bioindicators are living organisms or biological responses that provide information about the quality and health of an ecosystem. They are widely used in environmental monitoring because they respond predictably to changes caused by pollution, habitat degradation, climate change, and other anthropogenic disturbances. The effectiveness of a bioindicator depends on several scientific criteria that ensure reliable and meaningful assessment of environmental conditions. A suitable bioindicator should possess high sensitivity to environmental changes. The organism must exhibit measurable physiological, behavioral, reproductive, or population-level responses even to slight alterations in environmental conditions. Sensitive species help detect pollution or ecological stress at an early stage before severe damage occurs. For example, lichens are highly sensitive to sulfur dioxide and heavy metal pollution, making them excellent indicators of air quality. A good indication must meet a number of criteria in order to be selected. A popular and affordable technique for detecting and tracking environmental changes is the use of bioindicators. A good bioindicator should be widely distributed over a wide geographic area, have a well-established taxonomy and ecology, be specialized to certain habitat requirements, offer early warning of change, be easy and affordable to survey, be largely independent of sample size, have a response that reflects that of other species, and be able to distinguish between cycles or trends brought on by anthropogenic stress and those brought on by natural cycles or trends. Based on domestic and global studies on the selection of bioindicators, eleven selection standards have been established (Han *et al*., 2015) *viz*.,

- Species (or species groups) with clear classification and ecology
- Species (or species groups), those are distributed in a geographically widespread area.

- Species (or species groups), those show clear habitat characteristics
- Species (or species groups), those can provide early warning for a change
- Species (or species groups), those can benefit promptly and economically from the investigation
  Species (or species groups), those are not adversely affected by the size of individual groups and have numerous independent individual groups
- Species (or species groups), those are thought to represent the response of other species.
- Species (or species groups), those are representative of the ecology change caused by the pressure of human influence
- Species (or species groups) for which research on climate change have been done
- Species (or species groups), those are easy to observe, appear for a long time and form a large group of individuals
- Species (or species groups), those are significant in terms of culture, economy, and society



Classification of Bioindicator:

A bioindicator tracks the development of biological or non-biological elements in an environment, sometimes concentrating on a living thing. It acts as a metaphor for comprehending and evaluating the state of the environment. The effects of environmental change on a species or group of species that reflect the condition of living things or inanimate items in the environment, however, can also be referred to more broadly or specifically. Similarly, it could be used to characterize organisms or groups of organisms that demonstrate the diversity of a taxonomic group in a particular region or the entire diversity (Gerhardt, 2002). There are numerous ways to classify bioindicators. divided them into three groups according to their varied backgrounds and uses: environmental, ecological, and biodiversity indicators. Pesticide resistance levels are associated with the species' overwintering range, according to a meta-analysis of global data sets. Climate change has the potential to increase this damaging species' pesticide resistance worldwide by promoting its year-round local persistence.

Table 1: Classification of Bioindicator

Type	Purpose / What it Indicates	Representative Examples
Environmental Indicators	Assess the quality of air, water, and soil; indicate pollution and environmental contamination	Lichens (air pollution), Diatoms (water quality), Earthworms (soil health), Mosses, Algae
Ecological Indicators	Reflect ecosystem structure, function, and ecological integrity	Amphibians (ecosystem health), Macroinvertebrates, Coral reefs, Mangroves, Pollinators
Biodiversity Indicators	Measure species richness, abundance, and habitat diversity	Butterflies, Birds, Bees, Vascular plants, Dragonflies
Plant Indicators	Indicate soil fertility, nutrient status, moisture, salinity, and pollution	Lichens, Mosses, Azolla, Duckweed (*Lemna* spp.), Mangroves, Hyperaccumulator plants
Animal Indicators	Monitor habitat quality, pollution, climate change, and ecosystem disturbances	Frogs, Fish, Bees, Butterflies, Earthworms, Dragonflies, Birds, Freshwater mussels

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.

Ecological Indicator: The species or group of species serves as an example of how a stressor affects a biotic system and is used to track long-term biota changes brought on by stressors, such as habitat modification, fragmentation, and climate change.

Biodiversity Indicator: A biodiversity indicator is a group of taxa (such as a genus, tribe, family, or order, or a specific group of species from a range of higher taxa) or a functional group that displays diversity (character and species richness, or level of endemism) that is representative of the diversity of other taxa in a habitat. Additionally, depending on their taxonomic status, the term "bioindicators" can refer to a variety of indications, such as microbial, plant, and animal indicators (Stewart *et al*., 2007).

Plant Indicator: Pollution still poses a hazard to health and wellbeing in the age of urbanization. The plant has a high degree of sensitivity to the identification and prediction of environmental stress. An efficient way to mitigate this issue is through biomonitoring using sensitive plant species. Lichens are disappearing from woodland regions due to increased amounts of contaminants like sulfur and nitrogen. Changes in the diversity of phytoplankton species, including *Euglena clastica*, *Phacus tortus*, and *Trachelon anas*, are indicative of pollution of marine ecosystems. *Cyanophyta* is a biological indicator of potent plankton that produces bloom patterns that demonstrate the quick eutrophication of aquatic environments (Thakur *et al*., 2013).

Animal Iindicator: Variations in a number of an organism's features have been effectively used as markers. Animal indicators help determine the amount of poisons in an animal's tissues. *Mesocyclops edax, Aheyella, Cyclops* and *Alona guttata* are zooplanktons that are zone-based markers of pollution. They serve as indicators of contaminated water, eutrophication, and water quality. Amphibians, particularly anurans like frogs and toads, are often employed as biological markers of the buildup of contaminants in a particular habitat (Zaghloul *et al*., 2020). Depending on the type of organic residues, earthworms can play a crucial role in the formation and breakdown of soil aggregates. 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 crucial roles as indicators in ecosystems. Environmental stress can be measured at multiple scales, from the individual animal to the entire invertebrate community.

Conclusion:

As ecological markers, indicator species are essential for environmental monitoring. Reliability, ecological faithfulness and fragility to minute environmental changes, ease of handling, cost-effectiveness, species richness and variety, and ease of assessing environmental changes are the main characteristics of a bioindicator. All of them belong to the class Insecta. An important sign of changes in the soil, air, and water quality is insects. The study of bioindicators in environmental contamination has recently attracted a lot of attention. Finding organisms that can accurately identify environmental disturbances and show how those disturbances impact other species or biodiversity overall is the fundamental goal of bioindicator research. These bioindicators, which alter physiologically, chemically, or behaviorally, are useful in identifying natural or man-made stress. Numerous successful indicator species have been proposed in groups such as fish, mollusks, macrophytes, crustaceans, zooplankton, microorganisms, and phytoplanktons after extensive investigation.

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