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Utilization of Bioindicators in Environmental Biomonitoring: A Comprehensive Review

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Abstrak: Biomonitoring lingkungan merupakan cabang ilmu terkini dalam ilmu lingkungan modern. Konsep tersebut memungkinkan pemantauan kualitas lingkungan dengan melibatkan penggunaan organisme sebagai ukuran tingkat kontaminasi. Tinjauan komprehensif ini menampilkan kemajuan terkini dalam bidang ilmu lingkungan dengan penekanan pada metodologi inovatif, terobosan teknologi, dan implikasinya terhadap pemahaman dan pengelolaan lingkungan. Kajian tersebut membahas tentang jenis-jenis bioindikator yang telah digunakan dan manfaatnya masing-masing. Pemantauan cepat terhadap kualitas lingkungan melalui biomonitoring membantu membekali pembuat kebijakan dan pemangku kepentingan dengan data penting dan memfasilitasi pengambilan keputusan berbasis bukti. Penelitian lebih lanjut dalam bidang ini diperlukan karena dapat menjadi alternatif yang layak untuk pemantauan lingkungan yang cepat, murah dan praktis.

Kata Kunci: Biomonitoring, Kualitas, Lingkungan

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Abstract: *Environmental biomonitoring is the latest branch of science in modern environmental science. The concept allows the monitoring of environmental quality by involving the use of organisms as a measure of contamination levels. This comprehensive review showcases the latest advances in the field of environmental science with emphasis on innovative methodologies, technological breakthroughs and implications for environmental understanding and management. The review discusses the types of bioindicators that have been used and their respective benefits. Rapid monitoring of environmental quality through biomonitoring helps equip policy makers and stakeholders with critical data and facilitates evidence-based decision making. Further research in this field is needed as it can be a feasible alternative to rapid, low-cost and practical environmental monitoring.*

Keywords: *Biomonitoring, Quality, Environment*

Introduction

Environmental biomonitoring is the practice of using living organisms as determinants of environmental quality. This study began to be recognised around 2 centuries ago in the 1800s and became part of modern environmental science. In the Americas, this science first developed in 1887. Meanwhile, in Europe, it was first discovered in the 1900s by two scientists who first alluded to the concept with the term "biological indicators of pollution" . In addition, this concept is also studied in toxicology as a health risk assessment tool. Where biomonitoring can be categorised into 2, depending on the object being monitored, the level of exposure to the toxicant or the level of effect of the toxicant. Various research

related to bioindicators continue to emerge and develop from various scientific fields with various approaches. In this article, research from various sources is discussed and analysed, especially the latest methodologies, revolutionary technological breakthroughs, and broad implications of bioindicators for managing and protecting the changing environment.

Different bioindicator utilisation and approaches imply different implementation methods. To better understand the concept of bioindicators, a classification or categorisation of bioindicator types is carried out. In general, bioindicators can be categorised according to their taxonomy into plant, animal, microbial and planktonic. Organisms that may serve as bioindicators are highly sensitive to environmental changes that affect the main functions of life such as metabolism, growth and reproduction. The application of bioindicators, which can be useful in many ways, is also narrowed down to its function as an environmental indicator that limits the focus of bioindicator applications as a monitor of changes in environmental quality. Assessment of environmental quality is limited to several environmental components such as water, air and soil. The urgency of research on the topic of bioindicators is particularly necessary given the condition of biodiversity, which has experienced a drastic decline in the last few decades.

The purpose of this review is to assist the reader by explaining the basic concepts that underpin the importance of biomonitoring in monitoring environmental health. The review explains the important role of biomarkers, translating the response of organisms to environmental stresses, providing an early warning system for abnormalities that may go unnoticed. In addition, this review also highlights the pragmatic importance of environmental biomonitoring. This information and understanding can be useful to policy makers, conservationists, and stakeholders to encourage sustainable practices. Cross-disciplinary cooperation between the scientific and policy realms emphasizes the crucial role played by environmental biomonitoring.

Methodology

This research was conducted in two stages. The first stage is a literature review which is a search process accompanied by in-depth analysis that also evaluates similar studies that discuss relevant topics. The journals used were taken from ScienceDirect, JSTOR, Taylor and Francis, Springer, ACS Publication, Sinta and Wiley using the keywords "Bioindicators for environment", "Bioindicators for Environmental Monitoring" and "Bioindicators Review". The second stage is data analysis of the collected research articles. The analysis method used is comparative descriptive qualitative method. The purpose of comparative qualitative research is to search and find similarities and differences in phenomena. The results of the analysis are then presented in diagrams to improve readability.

Result

A total of 23 literature studies on the use of various bioindicators to determine environmental quality were collected. These 23 studies analysed the types of bioindicators

used and the variables measured using different bioindicators. Analyses of these 23 pieces of literature are provided in Table 1.

Table 1: Research on Bioindicators

No	Name of the Researcher	Year	Research Title	Class (Kingdom) of Bioindicators	Measured Variable	Reference
1	Burger et al.	2012	Selenium: Mercury Molar Ratios in Freshwater Fish from Tennessee: Individual, Species and Geographical Variations have Implications for Management	*Pisces* (*Animalia*)	Hg Contamination	[7]
2	Moncheva et al.	2011	Rapana Venosa as bioindicator of Environmental Pollution	*Gastropoda* (*Animalia*)	River Pollution	[8]
3	Montuelle et al.	2009	The periphyton as a multimetric bioindicator for assessing the impact of land use on rivers: an overview of the Arteries-Morcilla Experimental Watershed (France)	Mixture of *algae* and *cyanobacteria* (*Protista dan Bacteria*)	River Pollution	[9]
4	Pollet, I. and Bendell-Young, L. I	2000	Amphibians as Indicators of Wetland Quality in Wetlands Formed from Oil Sands Effluent	*Amphibia* (*Animalia*)	Wetland Quality	[10]
5	James A. Kushlan	1993	Colonial Waterbirds as Bioindicators of Environmental Change	*Aves* (*Animalia*)	Toxic Element Contamination	[11]
6	Zannatul Ferdous	2009	A Review: Potentiality of Zooplankton as Bioinidicator	*Diatoms* (*Protista*)	River Quality	[12]

	and A.K.M. Muktadir					
7	Aslan et al.	2013	Evaluation of Lichens as Bio-indicators of Metal Pollution.	*Lichen* (*Fungal*)	Metals Pollution	[13]
8	Reynolds, J.W.	2001	The Earthworms of South Carolina	*Clitellata* (*Animalia*)	Soil Pollution	[14]
9	Russo, D. and Jones, G.	2015	Bats as bioindicators: An Introduction	*Mammalia* (*Animalia*)	Light Pollution	[15]
10	Bogan, A.E.	1993	Freshwater bivalve extinctions (Mollusca: Unionoida): A search for causes. American Zoologist	*Bivalvia* (*Animalia*)	River Pollution	[16]
11	Utami, S. and Fajar, E.	2021	Exploration of Aquatic Macroinvertebrates as a Bioindicator of Water Quality in Nogosari River, Pacitan Energy	*Insecta (Animalia)*	River Quality	[17]
12	Pupitasari, R., Purbonegoro, T., and Putri, D., I.	2018	Short Time Effect of Cadmium and Copper on Java Medaka (Oryzias Javanicus) as Bioindicator for Ecotoxicological Studies	*Actinopterygii (Animalia)*	Heavy Metals Contamination	[18]
13	Prihastanti, E., Hastuti. E.D., Setiari, N., and Haryati. S.	2023	Determination of proline content and NPK resorption of mangrove leaves as adaptive bioindicators of environmental change	*Malpighiales (Plantae)*	Nutrient Reabsoption Capability	[19]

14	Oliveira, R. C. D., dkk	2016	Bee Pollen as a Bioindicator of Environmental Pesticide Contamination	*Insecta (Animalia)*	Pesticide Contamination	[20]
15	Macali, A. and Bergami, E.	2020	Jellyfish as innovative bioindicator for plastic pollution	*Scyphozoa (Animalia)*	Soil Pollution	[21]
16	Ueno et al.	2004	Global Pollution Monitoring of Polybrominated Diphenyl Ethers Using Skipjack Tuna as a Biondicator	*Actinopterygii (Animalia)*	Plastic Contamination	[22]
17	Herrera-Duenas et al.	2014	Oxidative Stress of House Sparrow as bioindicator of Urban Pollution	*Aves (Animalia)*	Urban Air Pollution	[23]
18	Li, Y., Wu, J., Chen, H., & Chen, J.	2005	Nematodes as Biological	*Adenophorea (Animalia)*	Soil Quality	[24]
19	Biase et al.	2022	Use of Lichen to Evaluate the Impact of Post-Earthquake Reconstruction Activities on Air Quality: A Case Study from the City of L'Aquila	*Fungal*	Air Pollution	[25]
20	Miller et al.	1996	Evaluating Ozone Air Pollution Effects on Pines int the Western United States	*Conifers (Plantae)*	Air Pollution (Ozone)	[26]
21	Dahlgaard, H.	1981	Bioindicators for monitoring radioactive pollution of the marine environment	*Bivalvia (Animalia)*	Air Pollution (Radioactive)	[27]

22	Rainio, J. and Niemela, J.	2003	Ground Beetles (Coleoptera: Carabidae) as bioindicators	*Insecta (Animalia)*	Forest Damage	[28]
23	Marin, R.	2023	Benthic foraminifera as bioindicators of coral reef health	*Granuloreticulosa (Protista)*	Shellfish Reef Health	[29]

Analysis of the 23 studies on the use of bioindicators showed the use of different classes of bioindicators. However, in this review article each bioindicator is grouped again based on its kingdom. The results of the data show the most use of bioindicators from the *Animalia* (69.50%) kingdom. Meanwhile, the least use of bioindicators came from the kingdom of *Bacteria* (2.20%). This analysis is also consistent with previous studies.

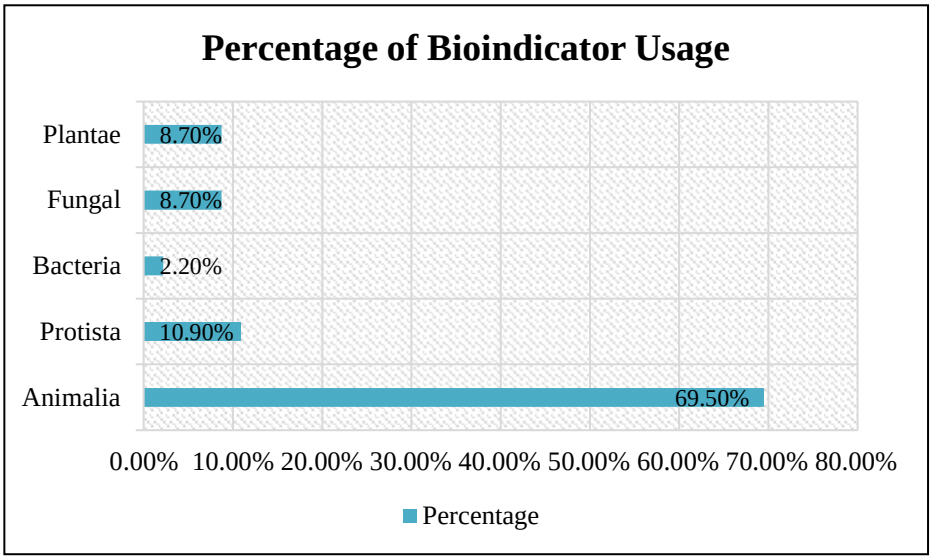

Figure 1. Percentage of Bioindicator Usage by Kingdom

The prevalence of research on bioindicators from the Animalia kingdom compared to those from other kingdoms can be attributed to several factors. The main reason lies in the practicality of using bioindicators from the animal kingdom. Firstly, animals are often more visible and mobile than plants, fungi or microorganisms. Therefore, they are easier to observe and monitor. Secondly, the *Animalia* kingdom includes a wide variety of species, including vertebrates and invertebrates, which are often more accessible and well-studied than other kingdoms such as *Fungi* and *Plantae*. This abundance of species provides researchers with a wide array of potential bioindicators, which makes it possible to conduct comprehensive studies on their use in environmental monitoring. In addition, the high biodiversity within the Animalia kingdom, which includes 90% of identifiable animal species, offers a rich source of potential bioindicators for assessing environmental health

Furthermore, the abundance of research using animal bioindicators is supported by its relevance and its accuracy in environmental quality measurement. The evolutionary conservation of certain traits and genetic sequences within the kingdom Animalia has facilitated research on bioindicators. Studies have shown strong evolutionary conservation of k-mer composition and correlation contributions between introns and intergenic regions of Animalia genomes, indicating a degree of genetic stability that could make them reliable candidates for bioindicators. The conserved nature of certain genetic elements within the kingdom Animalia suggests that bioindicators from this kingdom may show consistent responses to environmental stressors, making them valuable for environmental health assessment. In addition, bioindicators from the Animalia kingdom interact with diverse aspects of ecosystems such as air, water and soil through various natural processes such as respiration, seed dispersal and pollination, nutrient cycling, decomposition, trophic interactions and symbiosis, making them relevant for providing information on overall ecosystem health and function. Although, animal bioindicators are frequently used in related studies, it is essential to recognize the more accurate capability of other bioindicators from other kingdoms to measure certain environment condition, as illustrated in the table above.

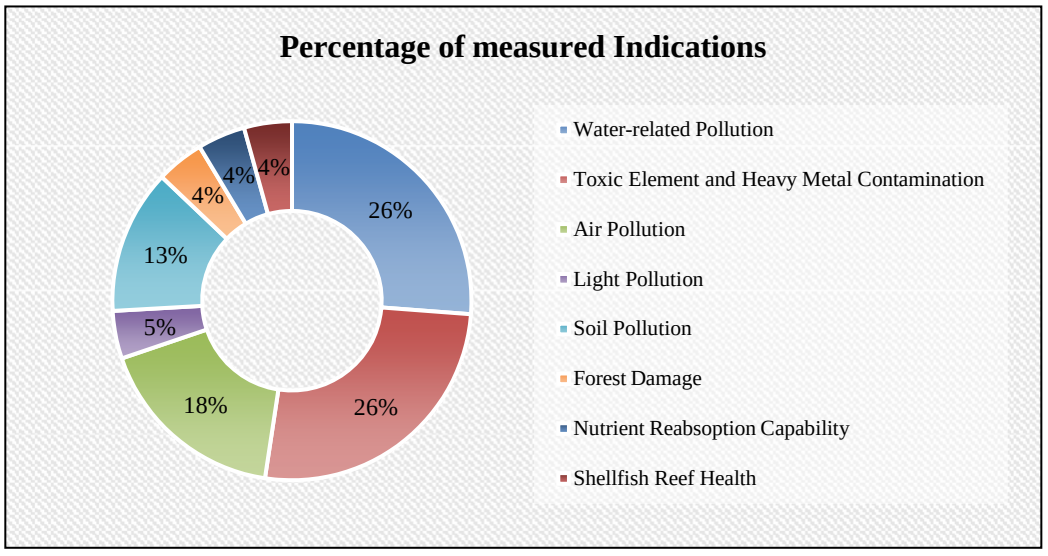

Figure 2. Percentage of measured Indications

The use of bioindicators can be beneficial in time-constrained situations. However, to increase the accuracy of research with bioindicators, it would be better if other methods are also used. If the frequency of sampling is limited, it is likely that many important data will be lost. In addition, there is also the possibility of repetition that will produce different outputs and the possibility of death if the exposure received exceeds the organism's capacity.

In addition to the type of bioindicator, the indication being measured is also explained. Most measure pollution of different components. Others measure the level of contamination. The advantage of plant bioindicators is their immobile location while the

advantage of animal bioindicators is their ability to give fairly accurate results on some environmental components through the analysis of substances that enter the tissue [36].

Discussion

Based on the review, it can be observed that bioindicators from different classes and kingdoms are used. Many things can influence the creation of such conditions, particularly, in the context of research on bioindicators in the fields of monitoring and analysing data related to environmental quality and health. There are several potentially contributing variables to the trend in the number of uses of each bioindicator. The first is the methodology that causes and requires the generalization of results, albeit indirectly. The responses of species to each other are diverse and can be contradictory, however, in studies involving bioindicators, the response of a species is considered the same for a particular type of stimulus. Meanwhile, almost all groups of land animals have been used as indicators. Then, there is also the theory that suggests many bioindicator selections in studies involving bioindicators are based on subjective personal preferences.

Research involving bioindicators has a well-established history in assessing environmental health. However, conventional approaches in this field come with limitations, often associated with reduced accuracy. Despite these constraints, the utilization of bioindicators as indicators of environmental health carries promising advantages that fuel ongoing research in this domain. Furthermore, the contemporary landscape of scientific advancements, characterized by modernization and digitalization, provides substantial support for the progression of research utilizing bioindicators. In light of these considerations, the subsequent discussion presents a SWOT analysis of the use of bioindicators in measuring environmental health and quality.

Table 2: SWOT Analysis of the Utilization of Bioindicators for measuring environmental health and quality

Strength	• Holistic Understanding • Cost-Effective Monitoring • Sensitive to Changes • Long-Term Monitoring Potential [43]	• Complex Interpretation [44] • Species-Specific Responses • Limited Spatial Resolution [45] • Limited Applicability [46]	**Weaknesses**
Opportunities	• Advancements in Molecular Biology [47] • Integration with other Monitoring Methods [48] • Education and Awareness [49]	• Human Impact on Bioindicators [50] • Climate Change Effects [51] • Technological Limitations [52]	**Threats**

Conclusion

Based on the findings, it is evident that biological indicators, or bioindicators, present a compelling alternative for assessing health and environmental quality due to their heightened cost-effectiveness, accessibility, and practicality. While various bioindicators, primarily from the *Animalia* kingdom, have been extensively utilized, there is a pressing need to explore alternative types to enhance the scope of measurable indicators, especially with the advancement on sciences and technology that could be integrated to create a more meaningful and accurate interpretation.

The utilization of bioindicators extends valuable benefits to governmental bodies and policymakers, serving as an efficient early warning system, facilitating site-specific assessments, and fostering increased community involvement. Beyond these immediate advantages, the incorporation of bioindicators indirectly contributes to the realization of sustainability goals. By supplying essential information for informed resource management and conservation initiatives, bioindicators play a pivotal role in promoting responsible environmental practices and advancing the broader concept of sustainability.

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