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REVIEW ARTICLE

Bioindicators and their Applications: A Comprehensive Review

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ABSTRACT: Biomarkers encompass a diverse range of living organisms, such as plants, plankton, animals, and microorganisms. Biological markers are commonly employed to assess and evaluate the environmental quality and health of ecosystems. Furthermore, these instruments serve as valuable resources for identifying instances of environmental deterioration and assessing its consequences for human civilization. Organisms are influenced by environmental determinants that contribute to environmental change. These organisms, commonly referred to as bio-indicators, serve as a crucial tool in monitoring environmental pollution and are widely recognized as one of the primary methods employed for this purpose. Bioindicators provide scientists with a comprehensive assessment of the present state of various ecosystems. By analyzing this data, scientists are allowed to exercise improved management over ecosystem conditions and subsequently address issues such as pollution and toxic substances. The primary objective of this study is to collect pertinent and extensive data for individuals seeking to acquire knowledge about bioindicators or engage in research about this field, given its substantial role within the ecosystem. The data presented herein is acquired through the examination of bioindicators in diverse ecosystems, drawing upon the research conducted by other scholars.

INTRODUCTION

Biological markers can monitor and analyze the environmental impact of different contaminants as well as biological consequences. Furthermore, they are a significant help in the quick diagnosis and prevention of the harmful effects of pesticides on plants, humans, and, in general, the environment [1]. They also have significant advantages over other measurement systems: firstly, due to the abundance of biological markers, they are easily counted and reviewed, and secondly, they are economically viable alternatives to other diagnostic systems [2]. Muller first used the term biomarker in 1980 at the National Institutes of Health in the United States (NIH). He believed that modern biological systems should be used in addition to classic global monitoring systems such as satellites and old measurement techniques [3]. In the past 20 years, biological indicators have shown that creatures are interesting and intelligent enough to examine environmental aspects. Muller called data from biomarkers one of the pillars of modern environmental monitoring [4]. An indicator should at least have the following characteristics: Taxonomic soundness, wide or cosmopolitan distribution, low mobility, well-known ecological characteristics, numerical abundance, suitability for laboratory experiments, high sensitivity to an environmental stressor, and high ability for quantification and standardization [5]. (Table 1)

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Table 1. Summary of the biological bioindicators and their applications.

Species	Origin	Biomarker	Characteristics	Reference
Spirostomum ambiguum	protozoa	evaluation of the toxicity of contaminated water to heavy metals and surfactants	cultured in non-sterile conditions	[6] [7]
colpoda steinii	protozoa	evaluation of the toxicity of contaminated soils to metals	N/A	[8]
Testate amoebae	protozoa	Analysis of health	susceptible to changes in the groundwater levels, moisture content, pH, the content of biofilm (Mg, Cu, K, P, N), and organic matter	[9]
Ciliates	protozoa	analysis of the quality of organic contaminated sediments and effluent released from the plants	short life cycle and high sensitivity to pollutants	[10]
Hymeniacidon heliophila	sponge	Bioremediation of the radionuclides, heavy metals, and PCBs	Filter-feeders exhibit various protective responses to stresses, such as heat shock proteins (HSPs), the induction of the multi-xenobiotic resistance (MXR) mechanism, and apoptotic elimination of cells.	[11] [12]
Hymeniacidon perlevis* , *H. panicea* and *H. oculata	sponge	analyzing the PAH and heavy metals	N/A	[13]
Cassiopea xamachana	cnidaria	Evaluation of the degree of water contamination with phosphate	remarkable longevity, innate immune system against harmful microorganisms	[14].
Stylophora pistillata	cnidaria	reduction of oil contamination	remarkable longevity	[15]
Leptogorgia virgulata	cnidaria	reduction of oil contamination	remarkable longevity	[16]
Planarians	Platyhelminthes	evaluate the toxic, cytotoxic, genotoxic, mutagenic, and teratogenic effects of metals, as well as the evaluation of antioxidant enzymes activity	ability to regenerate, and other characteristics such as their cosmopolitanism, ubiquity, adaptability, and their destructive nature in food chains	[17]
Terrestrial flatworm	Platyhelminthes	bioindicator for soil and forest conditions	N/A	[18]
Mollusca	lichens	Evaluation of the heavy metals	high sensitivity to air pollution and contaminants such as sulfur dioxide	[19]
Acari	arthropods	evaluation and measurement of Heavy Metals	N/A	[20]
Chilophoda	arthropods	Assessment of the quality of the earth as a bioindicator	N/A	[21]
Telodeinopus autii	arthropods	a bio-index for assessing soil	sensitive to environmental changes	[22]
Macrozoobentos Melanoides	amphipods	determination of the quality of water	N/A	[23]
Ligidium,Ligia and Trichoniscoidea	amphipods	N/A	assessment of quality of aquatic environment specially for measuring of Cu, ZN and Pb	[24]
Sigmodon hispidus	mammals	evaluation of the heavy metals and organic compounds of hydrocarbons in contaminated soils in oil	N/A	[25]
melon-headed whale	mammals	measuring the dispersion and density of trace elements such as) V, Cr, Mn, Co, Cu, Zn, Se, Rb, Sr, Mo, Ag, Cd, In, Sn, Sb, Cs, Ba, Tl, Hg, Pb, Bi	N/A	[26]
Microtus agrestisl* and *Clethrionomys glareolus	mammals	Evaluation of the concentration of fluoride accumulated in bone and tooth tissues	N/A	[27]

Biological Bioindicators and their applications

Protozoa as bioindicators

Protozoa are significant nutritional sources for eukaryotes and play a crucial role in various ecosystems, such as aquatic environments, soil, and freshwater systems. They are important contributors to the nutrient cycle and energy flow in ecosystems, benefiting microorganisms, plants, and animals. Protozoan consumption enhances nutrient uptake. Protozoans exhibit increased food consumption and respiratory rates relative to their body weight [6]. They also exhibit rapid growth and possess intricate outer membranes, which enable them to reproduce at an accelerated rate [6]. Protozoa can be influenced by factors such as groundwater levels, moisture content, pH, biofilm composition (including Mg, Cu, K, P, and N), and organic matter. The study was conducted in the soil of the Arctic Siberian region [9].

Heavy metal bioindicators

Spirostomum ambiguum is a relatively large protozoan belonging to the phylum Ciliphora. It measures approximately 2–3 mm in size, which allows for comfortable observation of its responses. This protozoan can be cultured in non-sterile conditions. The experiment conducted in the municipal waterworks and sewers of Warsaw demonstrated that *Spirostomum ambiguum* is an effective bioindicator for assessing the toxicity of heavy metals and surfactants in contaminated water [7]. In 1993, an experiment with a *colpoda steinii* species in Lee Valley and Luddington (south of England) showed that this protozoan can be used to compare the toxicity of contaminated soils to metals and to study the factors affecting the bioavailability of metals in the soil solution [8].

Bioindicators to investigate the health of soil and water

Testate amoebae are another group of aquatic protozoans that live in a free-living state. This group of protozoans also has a role in the analysis of the health of water [28].

Ciliates are commonly used as biological indicators to assess water quality due to their short life cycle and high sensitivity to pollutants. In a study conducted in southern China to enhance urban sewage treatment, it was discovered that ciliates are effective indicators for evaluating the quality of organic-contaminated sediments [10]. Additionally, ciliates can be utilized to assess the quality of effluent discharged from plants. By studying the ciliate communities in flood conditions, it is possible to determine the effectiveness of effluent treatment [29].

Sponges as bioindicators

Sponges are immobile organisms that feed by filtering water, and they can accumulate pollutants through this filtration process. This system protects against pollutants and also facilitates their release. Tense-sensitive proteins have the potential to assess pollutant stress levels before the occurrence of irreversible harm. These organisms display diverse protective responses to stress, such as the production of heat-shock proteins (HSPs), activation of the multi-xenobiotic resistance (MXR) mechanism, and elimination of cells through apoptosis [11]. Sponges can filter over 24,000 liters of water per hour, effectively removing pollutants and releasing particles ranging in size from 0.2 to 50 mm. Previous research has demonstrated that sponges possess the ability to accumulate radionuclides, heavy metals, and PCBs. Additional studies were conducted to investigate the impact of polycyclic aromatic hydrocarbons (PAH) on sponges obtained from the Pacific and North Adriatic Seas, as well as Lake Baikal [12]. The organisms studied in the sponge category across various ecosystems include *Hymeniacidon heliophila*, H. *perlevis*, H. *panicea*, H. *oculata*, *Cliona celata*, C. *viridis*, C. *rhodensis*, C. *vermifera*, C. *schmidti*, and C. *vastifica*. These sponges are highly valuable for assessing polycyclic aromatic hydrocarbon (PAH) concentrations. *Hymeniacidon perlevis, H. panicea* and *H. oculata* are the three samples of sponges that used for analyzing the measure of PAH and heavy metals in Normandy coast (France) [13].

Bioindicators to investigate the health of the ecosystem

H. *heliophila* is a voluminous and highly absorbent sponge characterized by its abundant soft texture, which is readily identifiable. The biological index of this organism is effective in assessing environments where other species are unable to thrive due to unfavorable conditions. [12].

Heavy metal bioindicators

Hymeniacidon perlevis, H. panicea and *H. oculata* are the three samples of sponges that used for analyzing the measure of PAH and heavy metals on Normandy coast (France) [13].

Bioindicators to investigate the health of water

Several sponge species, such as *Cliona celata, C. viridis, C. rhodensis, C. vermifera, C. schmidti*, and *C. vastifica*, are utilized for sedimentation purposes in Algeciras Bay. Certain species of sponges, such as *Cliona vermifera* and *C. schmidti*, have specific sediment requirements and cannot withstand precipitation exceeding 1g m^{2-1} [30].

Cnidarian as bioindicators

Cnidaria is an ancient lineage within the metazoan tree. Certain species exhibit impressive longevity, indicating the existence of a sophisticated and reliable innate immune defense mechanism capable of effectively countering repeated encounters with microbial pathogens. Emerging evidence suggests that the innate immune system of cnidarians plays a dual role, not only in eliminating harmful microorganisms but also in shaping tissue-associated microbial communities, which are vital constituents of their biology. The cnidarian holobiont provides numerous benefits to animal health through various functions. This encompasses metabolism, immune defense, development, and behavior. Changes in the normal microbiota can serve as early bioindicators of environmental change and animal disease [31]. Some of the Cnidaria that are recognized across various ecosystems are *Cassiopea xamachana, Stylophora pistillata, Leptogorgia virgulata, Sertularia marginata, Cotylorhiza tuberculate, Bunodosoma caissarum, Aiptasia pulchella*, and *Rhizostoma pulmo*.

Bioindicators to investigate the health of water

Cassiopea xamachana was utilized in Florida Bay to examine the level of phosphate water contamination [14]. The occurrence of a catastrophic oil spill in the Persian Gulf in 1991 caused significant concern among investigators. A study conducted in Eilat (Red Sea) examined the impact of oil pollution on rocky corals, revealing significant and detrimental effects on coral species. The researchers examined *Stylophora pistillata* and found that oil contamination had negative effects on their colonies, leading to increased mortality and reduced gonadal content [15]. Corals are generally highly sensitive organisms, making biochemical markers an ideal choice for studying their sensitivity [16]. Studies conducted in the Aransas Pass ship channel in Port Aransas, Texas, have demonstrated that *Leptogorgia virgulata*, a different species of coral, exhibits responses to oil pollution and its derivatives. These corals serve as reliable indicators of such pollution [16]. *Sertularia marginata* was recognized as a reliable indicator for assessing the impact of global warming in the Chafarinas Islands [32].

Bioindicators to investigate the health of water

The Mar Menor coastal lagoon is among the Mediterranean Sea's largest lagoons. *Cotylorhiza tuberculata*, a type of cnidarian found in this lagoon, is considered a reliable indicator for evaluating the presence of heavy metals. A study conducted in Rio de Janeiro, Brazil, focused on the species *Bunodosoma caissarum* and found that these organisms are effective indicators for studying artificial radioactive contamination [33]. Research conducted in Tenerife, Spain, demonstrated that *Anemonia sulcata* can serve as an effective bioindicator for evaluating δ15N density, a nitrogen isotope [34]. *Aiptasia pulchella* is commonly found in tropical and subtropical waters. This biological indicator is effective for measuring heavy metals, including lead, cadmium, cobalt, nickel, and zinc [35]. A study conducted on the North Coast of Tenerife, Canary Islands, Spain, demonstrated that *Anemonia sulcata* can serve as an effective biomarker for anthropogenic eutrophication [36]. *Rhizostoma pulmo* species serve as an indicator for assessing the levels of heavy metals in the Mediterranean coastal lagoon of southeastern Spain. The researchers analyzed the excretory materials and discovered the presence of heavy metals in the water [8].

Platyhelminthes as bioindicators

Platyhelminthes hold significance due to their phylogenetic position, regenerative capabilities, cosmopolitan distribution, adaptability, and ecological impact within food chains. Turbellaria is commonly regarded as a class encompassing various orders that inhabit diverse aquatic environments [37]. Currently, there are approximately 1,300 described freshwater species that are distributed globally. This diversity encompasses various species from the taxonomic groups Catenulida, Macrostomida, Rhabdocoela, Tricladida, Lecithoeepitheliata, and Prolecithophora, exhibiting a wide range of morphological and physiological traits. The Catenulida is a unique group of freshwater organisms, characterized by their abundance in inland waters and diverse species representation. The Continental Macrostomida comprises two families and multiple species, with Macrostomum being the largest among them. Rhabdocoela exhibits significant diversity, widespread distribution, and high abundance. Tricladida, comprising two families, exhibits a wide distribution across various regions worldwide, encompassing numerous species. Hence, it is crucial to comprehend this field to facilitate comparative biological research [38]. This study examines the ecological characteristics of planarians, specifically the terrestrial flatworm and rhizome planarians, which belong to the Platyhelminthes category. These organisms are observed in various ecosystems.

Bioindicators of a healthy ecosystem

Planarians are located in unpolluted aquatic environments, such as seas and lakes, and exhibit a broad geographical range. They also have a lot of potential as bioindicators because they are very sensitive to changes in their environment and are easy to work with [39]. Planarians are suitable for assessing the toxic, cytotoxic, genotoxic, mutagenic, and teratogenic effects of metals, as well as evaluating the activity of antioxidant enzymes [17].

Bioindicators of healthy soil

Sluys (1998) utilized various species of terrestrial flatworms (Platyhelminthes: Tricladida: Terricola) as a bioindicator to assess soil and forest conditions [18]. *Polycelis tenuis* is a species of flatworm. Five species were examined in a former zinc and lead mine. These were employed to assess the level of pollution in the mine [40]. A study conducted in the Colombo Canal examined ten species of macroinvertebrates and found that these animals can serve as effective bioindicators for assessing the health of streams and wetlands [41].

Bioindicators of healthy water

It has been found that *rhiophilous planarians*, a type of Platyhelminthes (Tricladida, Paludicola), can be used to measure heavy metal levels. A study conducted in five locations in the Netherlands and Belgium confirmed the effectiveness of this organism in assessing heavy metal contamination [40].

Nemerteans as bioindicators

Nemerteans are planktonic organisms that occupy the first trophic level in aquatic ecosystems, functioning as producers. They are commonly used as indicators of the trophic level in aquatic environments. The scarcity of trophic resources has been observed to impact the population of rotifers [42]. Some of the organisms belonging to the Platyhelminthes category, including *Lineus ruber*, *Amphiporus lactifloreus*, *Brachionus calyciflorus*, *Trichocerca cylindrica*, *Polyurthra euryptera*, *Pompholyx sulcata*, *Rotaria rotatoria*, *Filinia longiseta*, *Ascomorpha ovalis*, *Asplanchna herricki*, *Synchaeta grandis*, *Ploesoma hudsoni*, *Anuraeopsis fissa*, *Monostyla bulla*, M. *hamata*, *Ascomorpha saltans*, *Brachionus urceolaris*, *Synchaeta oblonga*, *Synchaeta okai*, *Synchaeta pectinata*, and *Synchaeta tremula*.

Heavy metal bioindicators

The utilization of nemerteans as a bioindicator was initially suggested by Butler and colleagues in 1971 and subsequently employed by McEvoy and Gibson in 1982. Nemerteans possess epidermal mucus that acts as a primary barrier against the absorption of heavy metals. The accumulation of these metals in the mucus matrix allows nemerteans to serve as effective indicators of elemental elements, even at low concentrations [43]. Marine nemerteans, such as *Lineus ruber* and

Amphiporus lactifloreus, are effective bioindicators for quantifying heavy metal concentrations, specifically lead, cadmium, and zinc [44].

Bioindicators of healthy water

In 1996, *Brachionus calyciflorus*, a type of rotifer, was employed as a bioindicator in Germany to assess and compare the water quality of upstream and downstream areas. The rotifer was investigated in the Warche and Holzwarche rivers in Germany [45]. Rotifers, such as *Trichocerca cylindrica*, *Polyurthra euryptera*, *Pompholyx sulcata*, *Rotaria rotatoria*, and *Filinia longiseta*, are effective bioindicators for heavy pollution (eutrophy) in various scientific fields. *Ascomorpha ovalis*, *Asplanchna herricki*, *Synchaeta grandis*, *Ploesoma hudsoni*, *Anuraeopsis fissa*, *Monostyla bulla*, and M. *hamata* have been identified as reliable indicators for assessing water quality [46].

Bioindicators of a healthy ecosystem

In 2009, a study was conducted in Dadian Lake, a shallow subtropical lake, to investigate the impact of temperature on two species of rotifers, namely *Polyarthra dolichoptera* and *Trichocerca pusilla* [47]. A study conducted in El Mex Bay examined several species of rotifers (*Ascomorpha saltans*, *Brachionus urceolaris*, *Synchaeta oblonga*, *Synchaeta okai*, *Synchaeta pectinata*, and *Synchaeta tremula*). The findings of this study suggest that these rotifers can serve as reliable indicators for salinity, temperature, depth, and chlorophyll concentration within the bay [48].

Nematode as bioindicators

Nematodes comprise the majority of multicellular organisms on Earth, with four out of five species belonging to this group. They are widely distributed and can be found in any environment where organic carbon is present. Nematodes exhibit a heightened susceptibility to pollutants and environmental disturbances [49]. These organisms are employed as indicators of soil health and as biomarkers in agricultural, forest, and meadow settings [50]. They serve as effective bioindicators due to their notable attributes and possess a permeable cuticle that is responsive to various contaminants. Certain nematodes have developed mechanisms to thrive in unfavorable environmental conditions and possess heat-sensitive proteins, making them susceptible to exposure to heat or metal ions [51].

Bioindicators of a healthy ecosystem

Panagrellus redivivus is recognized as a toxin concentration indicator [52]. A study conducted in Kovohuty a.s. Krompachy, a region in Slovakia known for heavy metal contamination, determined that nematodes are effective biological indicators for assessing soil pollution levels caused by heavy metals [53].

Lichens as bioindicators

Lichens are effective biological indicators due to their high sensitivity to air pollution and contaminants, such as sulfur dioxide. Lichens can exhibit various responses to pollutants, including species decline or elimination, depending on the type and severity of the pollutant [54].

Heavy metal Bioindicators

Molluscs are effective bioassays for pollutants and heavy metals, particularly in the context of lichens. Several studies have also investigated the biological effects of soil [19]. They serve as indicators of heavy metal contamination resulting from engineering activities along the Danube River [55].

Arthropods as bioindicators

Arthropods are a cost-effective and prevalent method for assessing river water quality. Aquatic arthropods are commonly employed as indicators of aquatic ecosystems. Fluctuations in population, diversity, and lifestyles within a year can serve as indicators of water pollution levels. In the realm of arthropods, the classes Insecta and Crustacea serve as valuable indicators of environmental conditions. Insect families that serve as biological indicators include Ephemeroptera, Plecoptera, Coleoptera, Diptera, and Odonata. Crustaceans such as Cladocerans, Ostracods, Decapoda, and Amphipoda are commonly employed as biological indicators. Any alteration in the abundance and diversity of species within these families is regarded as an indication of contamination [56]. Some of the organisms belonging to the Arthropods category, including Araneae, Scorpiones, Acari, Xipohosura, *Chironimus kiiensis*, C. *yavens*, *Polypedilum trigonus*, *Microchironomus* sp., *Dicrotendipes* sp., *Tanytarsus formosanus*, *Clinotanypus* sp., *Tanypus punctipennis*, *Fittkauimyia* sp., Chilophoda, and *Telodeinopus autii* [57, 58].

Bioindicators for health of ecosystem

The population of *Araneae* (spiders) based on their growth can be considered as a biological indicator, for example, the assessment of the quality of the two inside forest environments and its edge in Panama by Nephila clavipes [58]. *Scorpiones* can be bioindicators for the environment in which they live, for example, The quality of the edge of the tropical forest of northeastern Brazil is evaluated by two species of *Tityus pusillus* and *Ananteris mauryi*, with a change in their abundance and a change in their fertility [57].

Heavy metal Bioindicators

Acari, specifically Oribatida mites, have been utilized as bioindicators for assessing and quantifying the presence of heavy metals in the soils of oak forests in Romania [51]. The term "Xipohosura" refers to a specific taxonomic classification. Bioindicators for heavy metals in their living environment can include the measurement of heavy metals such as copper (Cu), zinc (Zn), iron (Fe), nickel (Ni), lead (Pb), and cadmium (Cd) in the eggs of horseshoe crabs in Malaysia (52). Insects can serve as bioindicators in their respective environments.

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Bioindicators for the health of soil

Chilophoda, specifically *Scolopendra morsitans*, is utilized as a bioindicator to evaluate the quality of the soil. It has been employed to assess the quality of soil and the presence of gelatin in the eastern region of Algeria. This assessment is based on changes observed in body weight, ovaries, and enzymatic activity [21]. *Telodeinopus autii*, a soil-dwelling organism found in African rainforests, is responsive to environmental fluctuations. Consequently, it can serve as a bio-indicator for evaluating soil conditions within its natural habitat [22].

Amphipodas as bioindicators

Amphipod communities are bioindicators for chemical elements in a wide range of aquatic environments, from freshwater to very salty water, even at the Challenger Deep's deepest points. Zooplankton typically serve as vital constituents of aquatic ecosystems, frequently functioning as mesograzers. The majority of species in the suborder Gammaridea are epibenthic, although they are occasionally found in plankton samples [61]. Hyperiidea members exclusively inhabit marine environments and are characterized by their planktonic nature. Hyperiids are often found in symbiotic relationships with gelatinous animals such as salps, medusae, siphonophores, colonial radiolarians, and ctenophores. Additionally, it is common for hyperiids to associate with gelatinous animals at certain stages of their life cycle. Fresh water and other non-marine waters support 1,900 species, which account for 20% of the overall amphipod diversity. Significant populations of endemic amphipods can be observed in Lake Baikal and the Caspian Sea basin [62]. Some of the organisms belonging to the Amphipodas category across various ecosystems are *Macrozoobentos Melanoides*, Ligidium, Ligia, Trichoniscoidea, *Aegla rostrate*, *Hyalella araucana*, *Parastacus pugnax*, and *Macrobrachium lancheteri*.

Bioindicators of healthy water

The species *Macrozoobentos melanoides* is utilized in assessing the water quality of the Krukut River in Pepok, Indonesia. An increase in the population of this species suggests an increase in water-soluble oxygen, contaminants, and suspended particles, indicating moderate water quality [23]. Ligidium, Ligia, and Trichoniscoidea are species of Isopoda commonly employed for assessing the quality of aquatic environments, particularly for measuring the levels of copper (Cu), zinc (Zn), and lead (Pb) in ponds such as Lysosomes. These species store these elements in vesicles within their hepatopancreas [24]. Ostracoda species, such as *Cyprideis torosa* found in the salt lake of Saros Bay in Turkey, serve as bioindicators for assessing salinity, water depth, and the presence of Cu and Cd metals [63].

Bioindicators for the health of the ecosystem

Metaprotella sandalensis and Turbiaria are utilized as bioindicators in coral reefs on Mauritius Island to assess the levels of nitrate, phosphate, and oxygen. High concentrations of these substances will lead to an increase in *Metaprotella sandalensis* and Turbiaria populations [64]. Another example involves the examination of *Aegla rostrate*, *Hyalella araucana*, and *Parastacus pugnax* species to evaluate the water quality of a river in Chile. The study found that variations in oxygen and temperature levels had an impact on the communities of *Aegla rostrate* and *Hyalella araucana* [65]. The Amphipoda communities on the coast of Ceuta in North Africa, specifically species such as *Phtisica marina*, *Caprella danilevskii*, *Caprella acanthifera*, and *Pseudoprotella phasma*, were studied to evaluate the environmental conditions, including high hydrodynamics and low levels of silting, dissolved organic matter, and suspension solids [66]. *Jassa marmorata* Holmes, *Ischyrocerus inexpectatus* (Ruffo), and *Phtisica marina* Slabber were also observed to serve the same purpose in Algeciras Bay, located in the Strait of Gibraltar [67].

Heavy metal bioindicators

Ligia italica is a species of isopoda found in the supralittoral zone of marine rocky coasts. It can accumulate heavy metals in its hepatopancreas, making it a useful bioindicator for assessing the aquatic environment [68]. The species *Macrobrachium lancheteri*, a type of Decapoda, is utilized in the assessment of heavy metal levels in certain rivers in Malaysia. Among these pollutants, mercury (Hg) is identified as the most toxic metal for this species [69]. The Annelida class, specifically the species *Branchiomma luctuosum*, is employed as a bioindicator to assess pollution levels in the Mediterranean ternary bay in Italy. This assessment involves the use of various indicators, such as plate count, thiosulfate, citrate, bile, and NaCl [70]. Endogeric species such as A. *limicola*, A. *rosea*, N. *caliginosus*, and O. *cyaneum* have been employed to evaluate the quality of temperate forests in Flanders, Belgium. These species are utilized to measure soil moisture, soil acidity, and nitrification levels [71].

As a type of annelida, polychaetes can adapt to their environment and deal with different types of pollution by changing the size of their populations by growing, shrinking, or multiplying, depending on the species. Consequently, polychaetes have been recognized as reliable indicators of marine pollution. Capitella capitata is the most extensively researched species due to its frequent occurrence in polluted environments characterized by high levels of organic matter. The species is the sole bioindicator recognized in Colombia based on traditional bioindication methods. Further research is needed to investigate the biological and ecological characteristics of different species of polychaetes. Additionally, laboratory bioassays should be conducted to identify which species can serve as reliable biological indicators within this country [72]. Some of the annelid organisms in various ecosystems are *Branchiomma luctuosum*, A. *limicola*, A. *rosea*, N. *caliginosus*, O. *cyaneum*, *Metaphire posthuma*, *Lampito mauritii*, *Erpobdella octoculate*, *Glassophonia complanata*, and *Limnodrilus hoffmeister* in various ecosystems.

Bioindicators for health of soil

Earthworms, specifically *Metaphire posthuma* and *Lampito mauritii* Kinberg, are utilized as bioindicators in soil environments, such as gardens and cultivated land, as well as in soil contaminated with sewage. They are employed to assess the effectiveness of heavy metals, including copper (Cu) and cadmium (Cd) [73].

Bioindicators for the health of water

Hiru denea examples include *Eepobdella leeches*, which were utilized to measure polychlorinated biphenyl levels in the Skalice river in Czechia [74]. Some other oligochaetes that belong to the genus Hirudinea are *Erpobdella octoculata*, *Glassophonia complanata*, and *Limnodrilus hoffmeister*. These are often used to check for organic matter in Anchar Lake that contains oxygen (O_2), phosphorus (P), nitrogen (N), and carbon dioxide (CO_2). The abundance of these worms' communities is expected to increase when these substances are present in the water [75].

Gnathostomata refers to a group of vertebrates characterized by the presence of jaws. Gnathostomes encompass around 60,000 species, accounting for 99% of extant vertebrates, which includes humans. Living gnathostomes possess several key features, including opposing jaws, true teeth (although some species have lost this trait), paired appendages (such as pectoral and pelvic fins, arms, legs, wings, etc.), and horizontal structures. These appendages are composed of elastomeric elastin proteins [76]. The inner ear's semicircular canal, as well as physiological and cellular anatomical features like the myelin sheath of neurons and the adaptive immune system, which includes discrete lymphoid organs such as the spleen and thymus [77], utilize V (D) J recombination to generate antigen recognition sites instead of genetic recombination in variable lymphocyte receptor genes [78]. Some of the various organisms belonging to the Gnathostomata category across different ecosystems are *Rhynchocypris oxycephalus*, *Galaxias occidentalis*, *Nannoperca vittate*, *Nannatherina balstoni*, *Mugil curema*, *Carrasius gibelio*, *Callorhinchus capensis*, *Rhinobatos annulatus*, *Rhinobatus blochii*, *Oncorhynchus gorbuscha*, O. *keta*, O. *tshawytscha*, and O. *nerka*.

Bioindicators for the health of water

Rhynchocypris oxycephalus, a cold-water fish, is utilized as a bioassay for studying climate change in Southeast Asian waters [China] [79]. *Galaxias occidentalis, Nannoperca vittata*, and *Nannatherina balstoni* were employed as bioindicators for salinity in the Blackwood River, located in Southwest Australia [80]. Another bioindicator used in the same location was the *Pouched lamprey* (Geotria australis) [81]. *Mugil curema* is utilized as a bioindicator in northeastern Brazil to evaluate water pollution resulting from untreated industrial and municipal wastewater [82]. The *Carrasius gibelio* species was employed as a biological marker to assess industrial pollutants and industrial wastewater in three water basins located in southern Bulgaria. This species was utilized in a study examining mercury contamination in Gulf water, specifically in Ambon Bay. The presence of dark red and black colors in the water indicates the presence of mercury [83].

Bioindicators for health of Heavy metals

Heavy metal levels were checked in the tissues of *Callorhinchus capensis*, *Rhinobatos annulatus*, and *Rhinobatus blochii* sharks in the Persian Gulf and Saldenha Bay of Africa in 2013. These findings were then compared to the parasitic indices observed in 2016 [84]. *Schroederichthys chilensis* was employed as a species for assessing heavy metal concentrations, including Cd, Zn, Cu, Pb, and Hg, in the Persian Gulf [85]. *Carcharhinus dussumieri* was utilized as a bioindicator to assess the presence of various heavy metals, such as manganese (Mn), copper (Cu), mercury (Hg), iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), and magnesium (Mg), in the Persian Gulf and Iskenderun Bay [86]. *Carcharhius limbatus* and *Rhizoprionodo terraenovae* can be considered bioindicators of the aquatic environment in the Gulf of Mexico, specifically in northeast Florida. Dianoxagellat causes neurotoxicity, leading to death [87]. An additional instance of Actinoterygii is *Cyprinus carpio*, found in Karakaya Dam Lake in eastern Turkey. Also,

the liver of C. *carpio* was analyzed for the activity of glutathione S-transferase, carboxylesterase, lactate dehydrogenase, acid phosphatase, and aspartate amino transferase [88]. *Gambusia affinis* is a species commonly used as a bioindicator for pesticide contamination, specifically organic chlorine and lindane, in the southwestern Istrian peninsula of Croatia. An additional instance pertains to the impact of chemical pollution on the species *Schroederichthys chilensis* in the Lenga region of Chile [89]. Total tin and butyltin compounds like MBT and TBT were found in the liver of *Katsuwonus pelamis* fish caught off the coasts of Japan, Brazil, and the North Pacific. Consequently, this fish species can serve as an indicator for the presence of these compounds [90]. PBDE compounds accumulate in the muscle tissue of this fish [91]. Organochlorine pesticides (OCPs) like HCH and DDT have been detected in the Southern Hemisphere and the Pacific Ocean. These chemicals have been identified in species such as *Oncorhynchus gorbuscha*, O. *keta*, O. *tshawytscha*, and O. *nerka* near the Kuril Islands, as well as in the Bering Sea and the Sea of Okhotsk [92]. Despite the widespread endorsement of amphibians as effective biological indicators, there is limited evidence supporting their superiority over other taxa in measuring biodiversity or habitat quality [93]. Some of the various organisms belonging to the amphibian category are *Ascaphus truei*, *Dicamptodon tenebrosus*, *Rhyacotriton variegutus*, *Tompoterna cryptotis*, *Pelophylax ridibundus*, *Pseudepidalea viridis*, *Plethodon cinereus*, *Rana pipiens*, *Pelophylax ridibundus*, and *Pseudepidalea viridis*.

Bioindicators for health of water

The impact of fine sediment on three amphibian species, namely *Ascaphus truei*, *Dicamptodon tenebrosus*, and *Rhyacotriton variegutus*, within California's Redwood National Park were reported [94]. An amphibian species serves as a bioindicator for ecosystem health in the national parks of Awash and Shalla Lake in Ethiopia [95]. A type of amphibian called *Tompoterna cryptotis* is used to test pesticides in Somaliland (Hargeisa), especially organochlorines (like dieldrin and BHC isomers) and organophosphates (like fenitrothion and malathion) [96]. Pelophylax ridibundus and Pseudepidalea viridis, two species of amphibians, are utilized in southern Bulgaria to evaluate the levels of nitrite nitrogen, suspended solids, and industrial pollutants such as coal dust, sulfates, and heavy metals [97]. *Plethodon cinereus* is a North American amphibian species commonly used as a bioindicator to assess forest quality. It is also employed for assessing mercury levels in forests in North America [98].

Bioindicators for health of Heavy metals

Rana pipiens is utilized as a species for assessing the acute toxicity of herbicides, specifically atrazine and alachlor, in the northern leopard frog [35]. *Pelophylax ridibundus* and *Pseudepidalea viridis* are amphibian species utilized in southern Bulgaria to evaluate the levels of nitrite nitrogen, suspended solids, and industrial pollutants such as coal dust, sulfates, and heavy metals [97]. Reptiles are a group of animals characterized by their scaly skin, cold-blooded metabolism. Reptiles are commonly defined as organisms belonging to the group Reptilia, which is a paraphyletic assemblage that includes all sauropsids except birds [99]. Living reptiles comprise turtles, crocodilians, squamates (reptiles and snakes), and rhynchocephalians (tuatara). As of March 2022, the Reptile Database includes approximately 11,700 species. In the traditional Linnaean classification system, avian species are classified as a distinct class separate from reptiles. Crocodilians are phylogenetically closer to avian species than to other extant reptiles. Consequently, contemporary cladistic classification systems include birds within the taxonomic group Reptilia, thereby reclassifying the term as a clade. Some cladistic definitions exclude the term "reptile" and instead use the clade Sauropsida, which includes all amniotes that are more closely related to modern reptiles than to mammals. The study of traditional reptile orders, often in conjunction with the examination of contemporary amphibians, is referred to as herpetology. Proto-reptiles, believed to be the earliest reptiles, emerged approximately 312 million years ago during the Carboniferous period. These reptiles evolved from advanced reptiliomorph tetrapods and gradually adapted to terrestrial environments. Hylonomus, a small reptile resembling a lizard, is the earliest known eureptile with a punctual nature. Based on hereditary and fossil evidence, it is suggested that the two major lineages of reptiles, Archosauromorpha (including crocodilians, birds, and their relatives) and Lepidosauromorpha (including reptiles and their relatives), diverged towards the end of the Permian period [100]. Some of the reptile species that are found across various ecosystems are P. *catenifer*, C. *viridis*, and *Podarcis sicula*.

Bioindicators for health of ecosystem

In a 1971 study conducted on snakes at the native Pawnee farm in northeastern Colorado, various snake species, including P. *catenifer* and C. *viridis*, were examined to assess the impact of herbicides, organophosphates, and lead. The study revealed that both male and female snakes had small quantities of chlorine hydrochloride in their fatty tissues, as well as low levels of lead in their livers. This property renders it suitable for organic pollutants [101]. A study conducted in Val d'Agri, southern Italy, examined the ecological effects of toxicology on the *Podarcis sicula* (wall lizard). The study assessed the activities of cytochrome P450 1A1 (EROD & BPMO), AchE, bile metabolites (PAH), and pollution levels (PAH and trace elements) in the Italian wall lizard. However, the findings indicated that this particular animal species demonstrated superior efficacy in evaluating the presence of carcinogenic PAH and its metabolites in bile, making it a viable bioindicator [102].

Birds as a bioindicator

Birds inhabit diverse habitats. Certain bird species exhibit generalist behavior, while others display specialization in terms of their habitat preferences or dietary requirements [103]. Within a given area, such as a forest, avian species exhibit varying habitat preferences. Some species forage within the forest, while others prefer the understory or open areas. Forest birds have diverse feeding habits, including insectivory, frugivory, and nectarivory. Waterfowl engage in feeding behaviors such as fishing, herbivory, and predation, or kleptoparasitism. The grassland harbors a high population density of avian species. Birds of prey have a specialization in hunting mammals or other birds, whereas lizards specialize in hunting snakes [104]. Birds are susceptible to predation by various mammalian predators. Birds can be infected by a diverse range of parasites, both internal (endoparasites) and external (ectoparasites). Some of these parasites have evolved and adapted to be transmitted from parent birds to their offspring [105]. Some of the investigated bird species so far are cattle egret (*Eudocimus albus*), common eider (*Somateria mollissima*), thick-billed murre (*Cepphus gruylle*), Leach's storm-petrel (*Oceanodroma leucorhoa*), northern goshawk (*Accipiter gentilis*), Eurasian magpie (*Pica pica*), red-faced cormorant (*Larus schistisagus*), crested auklet (*Aethia cristatella*), least auklet (*Aethia pusilla*), northern fulmar (*Fulmarus glacialis*), fork-tailed storm-petrel (*Oceanodroma furcata*), scaly-throated foliage-gleaner (*Sclerurus scansor*), rufous-bellied thrush (*Mionectes rufiventris*), long-tailed manakin (*Chiroxiphia caudata*), summer tanager (*Habia rubica*), red-breasted merganser (*Mergus serrator*), and black-necked grebe and great crested grebe.

Bioindicators for health of Heavy metals

A study conducted on cattle egrets (*Bubulcus ibis*) revealed that the levels of heavy metals in their habitat exceed the standards established by the Environmental Protection Agency (EPA). Consequently, these metals have been found to accumulate in the eggs of the species as well as influence their behavior. The heavy metals mentioned are lead, cadmium, chromium, cobalt, silver, and nickel [106]. *Eudocimus albus* serves as a bioindicator for assessing mercury levels in wetland environments during periods of precipitation in Florida. *Somateria mollissima*, *Cepphus gruylle*, *Alca torda*, and *Oceanodroma leucorhoa* are utilized as bioindicators for measuring mercury (Hg) levels in the Gulf of Maine. *Accipiter gentiliss* and *Pica pica* are avian species utilized for the detection of Pb, Cd, and Hg in German environmental specimen bank regions. Organochlorine pesticides (OCPs) like HCH and DDT are detected in the Southern Hemisphere and Pacific Ocean. These OCPs are identified in various species, such as *Larus schistisagus*, *Aethia cristatella*, *Aethia pusilla*, *Fulmarus glacialis*, and *Oceanodroma furcata*. These species are found near Kuril Island, the Bering Sea, and the Sea of Okhotsk [92].

Bioindicators for health of ecosystem

Bird feathers can serve as an indicator for assessing pollutants, including microfilters, microplastics, and sustainable organic pollutants [107]. A wading bird is a type of bird that is adapted to foraging in shallow water and is typically found near wetlands or bodies of water. The bird's fillings are reliable indicators for measuring mercury pollution in the environment [108]. A study conducted in a mountainous region of Rio de Janeiro examined forest fragmentation in passerine birds. The study found that the tested species (*Sclerurus scansor*, *Mionectes rufiventris*, *Chiroxiphia caudata*, and *Habia rubica*) did not exhibit a preference for specific areas of the forest for their habitat. This suggests that biological indicators are suitable for assessing the effects of forest fragmentation on these bird species [109]. *Accipiter gentilis* and *Pica pica* are bird species utilized to detect atmospheric pollution in specific regions of the German Environmental Specimen Bank [110].

Bioindicators for health of water

Mergus serrator, black-necked grebe (*Podiceps nigricollis*), and great crested grebe (*Podiceps cristatus*) are species found in the Marmenor in the Mediterranean Sea. These species serve as bioindicators, meaning their presence and abundance can provide insights into the environmental conditions of the ecosystem. It has been observed that an increase in the population of these species is associated with an increase in jellyfish numbers and nitrogen loading. Additionally, *Mergus serrator* has been found to hurt fish populations, which can have long-term implications for fishing activities [111].

Mammals as bioindicators

Mammals possess mammary glands for milk production, a neocortical brain region, fur or hair, and three middle ear ossicles. These characteristics distinguish mammals from reptiles and birds, their ancestral species that diverged during the Carboniferous period over 300 million years ago. Approximately 6,400 extant mammal species have been identified and classified into 29 distinct groups [101]. Mammals represent the sole extant constituents of the Synapsida. This panel, along with Sauropsida (reptiles and birds), comprises the broader taxonomic group known as Amniota. The initial synapsids were the sphenacodonts, which encompassed the renowned Dimetrodon. Synapsids, previously misclassified as reptiles such as pelycosaurs, are non-mammalian synapsids. These synapsids, also known as local mammals or protomammals, were divided into various groups. They eventually evolved into mammals during the Middle Permian period. Mammals evolved from cynodonts, a highly developed group of therapsids, during the late Triassic to early Jurassic periods. The emergence of modern mammals occurred during the Paleogene and Neogene periods of the Cenozoic era, following the extinction of non-avian dinosaurs. Since 66 million years ago, mammals have become the predominant terrestrial group and continue to thrive today [112]. The placental group encompasses the majority of mammals, including six orders that are particularly diverse in terms of species. The three most populous orders in terms of species are rodents, including mice, rats, porcupines, voles, capybaras, and other rodents; Chiroptera, which encompasses bats; and Soricomorpha, consisting of moles, shrews, and solenodons. The following three major orders, depending on the biological classification system employed, are as follows: primates (monkeys, apes, and lemurs), Cetartiodactyla (whales and even-toed ungulates), and Carnivora (cats, dogs, weasels, bears, seals, and related species) [113]. In 2006, a total of 5416 mammal species were identified worldwide. The specimens are categorized into 1,229 groups, 153 families, and 29 orders [113]. The International Union for Conservation of Nature (IUCN) conducted the Global Mammal Assessment of the IUCN Red List in 2008, which identified a total of 5,488 species. A 2018 study in the Journal of Mammalogy reported a total of 6,495 known mammal species, with 96 of them being recently extinct [101]. Some of the examined organisms are dairy cattle, *Chionomys nivalis*, *Ochotona princeps*, *Napeozapus insignis*, *Blarina brevicuda*, *Peromyscus leucopus*, P. *maniculatus*, *Clethrionomys glaperi*, *Microtus pinetorum*, *Sorex cinereus*, *Napeozapus insignis*, C. *gupperi*, P. *maniculatus*, P. *leucopus*, B. *brevicauda*, *Sigmodon hispidus*, and *Erinaceus europaeus*.

Bioindicators for the health of ecosystem

Two separate studies conducted in different regions examined milk samples obtained from dairy cattle. The findings suggest that milk obtained from cows in rural environments is free from contamination and considered to be entirely healthy. Conversely, milk obtained from cows in industrial environments was found to be contaminated. The performance involves juggling and the use of harmful substances. Contamination has been found to impact the lactation of cattle [114]. *Chionomys nivalis*, a species found in the mountains of Bulgaria, is utilized as an indicator of environmental quality in alpine ecosystems [115]. *Ochotona princeps* is a species used to evaluate environmental and climate changes. It is also studied to understand the impact of surface ice loss on glucocorticoid metabolites in the Rocky Mountains [116]. The distribution and nutritional patterns of small mammals in the New England Forest are indicative of the local climate and the dispersal of vegetation and animal species in the region. In areas with plants, the species *Napeozapus insignis* and *Blarina brevicuda* are more common, while the species *Peromyscus leucopus* and P. *maniculatus* are less common. N. *insignis* and *Clethrionomys glaperi* species are found in specific habitats. Wet and Microtus pinetorum, *Sorex cinereus*, and *Napeozapus insignis* species have the narrowest habitat, while C. *gupperi*, P. *maniculatus*, P. *leucopus*, and B. *brevicauda* species have the largest extent of habitat [25].

Bioindicators for the health of water

A study conducted in Ontario, Canada, demonstrated that small mammals, specifically mice and voles, serve as effective biological indicators to manage sustainable forests. The *Sigmodon hispidus* species from three contaminated sites and a reference center in the shipping company reported to assess the presence of heavy metals and organic compounds, specifically hydrocarbons, in soils contaminated by oil refineries [25].

Bioindicators for the health of Heavy metals

A study conducted at Ehime University in Japan examined the melon-headed whale (*Peponocephala electra*) and found that these animals have favorable indicators for assessing the distribution and concentration of various trace elements, including V, Cr, Mn, Co, Cu, Zn, Se, Rb, Sr, Mo, Ag, Cd, In, Sn, Sb, Cs, Ba, Tl, Hg, Pb, and Bi [26]. *Erinaceus europaeus*, *Martes foina*, and *Vulpes vulpes* are utilized as bioindicators for heavy metals (Cr, Cd, Pb, and Hg) in the Urbino-Pesaro and Maech areas in central Italy. *Antechinus stuartii*, *Rattus norvegicus*, and *Rattus rattus* hair species have been utilized as bioindicators to assess the presence of heavy metals (Cu, Pb, Cd, and Zn) in terrestrial ecosystems in Australia [117]. *Apodemus sylraticus*, *Clethrionomys glareolus*, and *Sorex araneus* species are utilized as bioindicators in an acidic sandy soil environment contaminated with metallic lead (Pb) pellets. These pellets are known to accumulate in the kidney, liver, and bone tissue [118]. The species *Myodes glareolus* and *Apodemus flavicollis* are used as bioindicators for heavy metals, specifically mercury (Hg), cadmium (Cd), and lead (Pb), in various regions of Slovenia. These metals have been detected in the tissues of these species [119]. *Ursus arctos*, *Canis lupus*, *Lynx lynx*, and *Canis aureus* have been employed as bioindicators to evaluate the presence of heavy metals, including Pb, Cd, Zn, Cu, Se, Fe, Tl, Ca, and Co, in Croatia [120]. *Eptesicus fuscus*, *Myotis grisescens*, *Myotis myotis*, and *Pipistrellus pipistrellus* species have been employed as bioindicators to evaluate the presence of heavy metals (such as As, Cd, Cr, Co, Cu, Hg, Mn, Ni, Pb, Sn, and Tl) in North America and Europe [121]. *Peponocephala electra* was employed as a bioindicator to assess the presence of various heavy metals (Cd, Ag, Mo, Sr, Rb, Se, Zn, Cu, Co, Mn, Cr, V, Bi, Pb, Hg, Tl, Ba, Cs, Sb, Sn, and In) in the es-Bank of Ehime University, Japan [26]. *Crocidura russula* and *Mus spretus*, are utilized to detect the presence of heavy metals such as copper (Cu), cadmium (Cd), and nickel (Ni) in the Preguicha mine and iron (Fe), lead (Pb), mercury (Hg), selenium (Se), and molybdenum (Mo) in the Alrusel mine. Additionally, in Algeria, exposure to heavy metals, specifically lead (Pb) and zinc (Zn), along with metallothioneins, leads to liver alterations in *Mus spretus* [122]. *Medocus apodemus sylvaticus*, a species of rodent, was utilized as a biological indicator to assess the presence of heavy metals (Cn, Cr, Cd, Zn, Pb, Ni, Mn, Pd, Pt, Rh, and PGEs) in agricultural and urban soils within the Suburban Basin of Modena, located in northern Italy [123].

Bioindicators for the health of the ecosystem

Organochlorine compounds, such as lindane, HCB, toxaphene, DDT, and their byproducts, were found in marine mammals' blubber from the northern hemisphere [124]. Animals that live in the western and southern

Pacific, like *Peponcephara electra*, have high levels of PCB, DDT, HCH, hexachlorocyclohexanes, and lagenorhynchus obliquidens. These substances are recognized as bioindicators [124]. *Pontoporia blainvillei*, a species found in Brazil, was utilized as a biomarker for pyrethroids. No toxicity was detected in adult specimens, and it appears that decomposition occurred [125]. The disposal of waste from Garraf landfill in the NE Srain region produces toxins that consist of heavy metals and chemicals. These toxins have been found to cause liver and kidney damage, as well as histopathological changes, in wood mouse (*Apodemus sylvaticus*) and insectivorous (*Crocidura russula*) species [126]. The species *Microtus agrestis* and *Clethrionomys glareolus* are employed to assess fluoride concentrations in bone and tooth tissues. These species are found in grasslands affected by fluoride mineral resources, specifically in fluorspar tailing areas in northeast England and rural regions of Northumberland [27]. Organochlorine pesticides (OCPs), including HCH and DDT, have been detected in the southern hemisphere and Pacific Ocean. The species *Odobenus rosmarus* and *Eschrichtius robustus* have found these substances in the area around Kuril Island, as well as in the Bering Sea and the Sea of Okhotsk [92]. A study was conducted to examine the impact of sunlight, UV filters, and the concentration of octocrylene on Pontoporia blainrillei, a species found along the coast of Brazil. This investigation also explored the potential of *Pontoporia blainrillei* as a bioindicator [127].

CONCLUSIONS

This article aims to comprehensively investigate and analyze various living organisms capable of serving as bioindicators. The study encompasses a range of organisms, starting with the simplest forms and progressing towards the most intricate ones. While additional research on this matter exists, significant and extensive studies have been carried out. We conducted a comprehensive study of various taxonomic groups in diverse ecological settings, encompassing both aquatic and terrestrial environments. Additionally, we investigated the impact of heavy metal contamination on these organisms. Notably, our findings revealed that all studied organisms possess the potential to serve as bioindicators in some capacity. The selection of an organism for evaluation is determined by various parameters, such as the organism's accessibility, sensitivity, and suitability for evaluation and testing. To assess the degree of toxicity, using a pollution-sensitive organism that resides at greater depths in a lake is a more convenient and cost-effective approach compared to employing an organism with a shallower biological flora and lower sensitivity. The various parameters and unique considerations within a series of ecosystems enhance the specificity of organism selection and facilitate more comprehensive study outcomes. Studying these cases is crucial for identifying effective solutions to combat pollutants and expediting our research progress. This article aims to provide a summary of key indicators used to evaluate the quality of aquatic and terrestrial ecosystems, as well as the performance and response of organisms within these ecosystems. This study aims to provide a comprehensive understanding of these organisms and their effectiveness in advancing research.

Conflict of interests

The authors declare no competing financial and non-financial conflict of interest.

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