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Review

A Review of Plant Bioindicators in Wetlands

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Abstract

With the increasing human population, the protection of water resources is becoming a critical issue. Wetlands are one of the most important water resources, helping assimilate pollutants. Hence, the ecosystem integrity of wetlands is important. Plant bioindicators with phytoremediation (physiologically removing pollutants from the ecosystem by plants) capacity can be very helpful in this regard. Based on the current literature, this study specifically aims to overview plant bioindicators with phytoremediation ability. A systemic literature review (SLR) method was used to find a detailed overview of the most relevant research. A total of 70 plants were identified as bioindicators. Out of all the indicator plants, *Phragmites australis*, *Sorghum saccharatum, Lepidium sativum, Sinapis alba, Apium nodiflorum, Arundo donax, Bolboschoenus maritimus, Juncus acutus, Nasturtium officinale*, *Typha angustifolia* and *Typha domingensis* was identified as the most studied bioindicator plants. The literature review revealed that these plant bioindicators had treatment impacts on metals, nutrients, urban runoffs and wastewater. According to studies, the roots of these plant bioindicators are primarily for absorbing pollutants, which is a specific physiological property of phytoremediation. Hence, the study concluded that for specific waste materials this set of plant bioindicators can be strong contenders for understanding wetland ecosystem integrity and their physiological mechanisms of phytoremediation can provide a blueprint for developing "bioindicators" for wetlands.

Keywords

Bioindicators; phytoremediation; wetlands; pollutants; *Phragmites; Sorghum; Sinapis; Lepidium; Apium, Typha*

1. Introduction

Protecting water resources is crucially important with the increasing population. Wetlands are one of the chief global water resources working as nature's kidneys [1]. Wetlands have the ability to absorb pollutants known as their self-purification property [2]. Maintaining the ecosystem integrity of wetlands thus is very important to maintain the quality of aquatic ecosystems overall. Bioindicators (such as - macroinvertebrates, microbes, plankton, plants, etc.) are very helpful for this purpose [3]. Bioindicators identify signals across many temporal and spatial scales and create a consolidated assessment of the environmental impacts of ecosystem stresses [4, 5]. As the bioindicator identifies signals of ecosystem stress, they are also affected by the stress [6]. These species are often tolerant to stress factors [6]. Understanding the physiological mechanisms (for example possible uptake of the pollutants by the indicators in their body tissues) of how these stresses (like pollutants) affect the bioindicators, will be insightful as this information can build a blueprint for constructing bioindicators for future use. A good bioindicator should have a measurable response to stress [6]. If the fate of the pollutants or the stress factor in the bioindicator is known, then the quality or the capacity of the bioindicator for the specific pollutant can be understood.

Specific plants can be useful to understand the health of a wetland ecosystem. On the other hand, they are also widely known for reducing pollutants in ecosystems by assimilating those in their tissues by the property of phytoremediation [7]. This Phytoremediation is enabled by specific physiology such as the absorption of pollutants in the plant roots or shoots [7]. Hence, in light of the existing literature review, this study aims to provide an overview of plant bioindicators capable of detecting and consequently alleviating stress (such as metals, nutrients, urban runoffs, wastewater, or water quality parameters indicative of pollution) in wetlands.

2. Materials and Methods

For identifying the relevant literature, a systemic literature review (SLR) method was used. The SLR method has been used in a wide range of studies [8-10]. The SLR method in this study analyzed the "Web of Science" database [11]. This Web of Science database comprises several other databases and provides comprehensive literature on the topic of interest. Articles published in Web of Science undergo a well-defined editorial process to maintain the quality and impact factor of the concerned journal [11].

During the article search process, "plant sediment bioindicators" under the "documents" section of the Web of Science database was searched, yielding 121 peer-reviewed articles. The search was done within the "Web of Science Core Collection" and "All" editions. To find more relevant indicators in the wetland ecosystem the search was further narrowed to “plant wetland sediment bioindicators”, which yielded 29 of the most relevant peer-reviewed articles.

Based on these 29 articles, a detailed review of plant wetland bioindicators was created. Some articles were not accepted to incompatibility with the aim of this study. The articles that were selected, were mostly based on plant bioindicators that have been used in wetland ecosystems and have given a clear indication of toxic stresses (such as heavy metals). These peer-reviewed articles were chosen from several geographic locations across the planet to show the effectiveness of the plant bioindicators across a spatial scale. The dates of these articles were purposefully chosen from 1986 to 2022 to review the effectiveness of the plant bioindicators on a temporal scale.

3. Results

With the SLR method, 70 plant species were identified as wetland bioindicators (Table 1). Out of the 70, 11 species - *Phragmites australis*, *Sorghum saccharatum, Lepidium sativum, Sinapis alba, Apium nodiflorum, Arundo donax, Bolboschoenus maritimus, Juncus acutus, Nasturtium officinale*, *Typha angustifolia* and *Typha domingensis* was identified as the most studied plant bioindicators of the wetland ecosystem (Table 1). Within the articles selected for the study, the species *Phragmites australis* was detected to be used in seven research articles, followed by *Sorghum saccharatum, Lepidium sativum, Sinapis alba, Typha domingensis* in three. However, two studies enlisted the remaining each of most studied plant bioindicators (Table 1).

Table 1 A summary of bioindicator plants with the types of waste treated in wetlands with reference articles.

	A. Metals only	**Indicator plants**	**Reference**
1	Cd, Cu, Pb and Zn	*Phragmites australis*, *Typha capensis* and *Spartina maritima*	[12]
2	As, Cd, Cr, Cu, Hg Mn, Ni, Pb, and Zn	*Alisma plantago-aquatica, Apium nodiflorum, Arundo donax, Bolboschoenus maritimus, Carex cuprina, Cyperus longus, Eichhornia crassipes, Epilobium hirsutum, Equisetum arvense, Juncus acutus, Juncus maritimus, Lemna minor, Lemna gibba, Nasturtium officinale, Paspalum paspaloides, Phragmites australis, Typha angustifolia, Typha domingensis, Typha latifolia* and *Veronica anagallis-aquatica*	[13]
3	Cd, Cu, Cr, Co, Fe, Pb, Zn, and Mn	*Lantana camara, Bignonia gracilis, Abutilon indicum, Adiantum caudatum Malvestrum coromandilianum, Parthenium hysterophorus, Ageratum conyzoids, Anagalis arvensis, Sida acuta, Prosopis juliflora, Cannabis sativa, Achyranthus aspera*	[14]
4	As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn	*Posidonia oceanica, Cymodocea nodosa, Phragmites australis, Arundo donax,*	[15]

		Typha domingensis, Apium nodiflorum, and *Nasturtium officinale*	
5	Zn, V, Pb, Ni, Mn, Fe, Co Cu, Cr, Cd, As, Al	*Phragmites australis*	[16]
6	Cd, Cr, Cu, Ni, Pb, Zn, and As	*Oenanthe* sp.*, Juncus* sp.*, Typha* sp.*, Callitriche* sp.*1*, and *Callitriche* sp.*2*	[17]
7	Pb and Hg	*Sorghum saccharatum, Lepidium sativum* and *Sinapis alba*	[18]
	B. Urban Runoff	**Indicator plants**	**Reference**
8	Urban runoff	*Phragmites australis*	[19]
	C. Water quality parameters indicative of pollution	**Indicator plants**	**Reference**
9	Water: Water Depth, pH, EC, NO_3^-, NH_4^+, PO_4^{3-}, Cl^-, SO_4^- Sediment: water content, pH, HCO_3-, CO_3^{2-}, EC, K_2O, P_2O_5, Cl-	*Bolboschoenus glaucus, Bolboschoenus maritimus, Carex riparia, Eleocharis palustris, Phalaris arundinacea, Phragmites australis, Potamogeton lucens, Scirpus lacustris, Scirpus lacustris* ssp*. Tabernaemontani, Sparganium erectum, Stachys palustris, Typha angustifolia, Typha latifolia, Xanthium strumarium* ssp*. italicum*	[20]
	D. Metals and nutrients	**Indicator plants**	**Reference**
10	Cr, Cu, Ni, Pb, Zn and TP	*Typha domingensis* Pers - TP in leaves and roots, Cu, Pb and Zn in roots; *Eichhornia crassipes* (Mart.) Solms. - TP in leaves and roots, Pb, Zn in roots; *Alternanthera philoxeroides* (Mart.) Griseb. - TP in leaves and roots, Cu, Pb, Zn in roots; *Pistia stratiotes* L.- TP in leaves and roots, Cu, Pb and Zn in roots	[21]
11	Nitrate-Nitrite, Phosphate, Cd, Cu, Pb, and Zn	*Sorghum saccharatum, Lepidium sativum* and *Sinapis alba*	[22]
	E. Wastewater	**Indicator plants**	**Reference**
10	Municipal and Agricultural wastewater with high BOD, COD, fecal coliform, nitrogen, phosphorus, and metals	*Phragmites nana, Canna lily, Spartina patens, Cyperus papyrus, Cyperus alopecuroides, Bacopa monnieri, Hydroctyle vulgaris, Litrum salicaria, Schoenoplectus vallidus, Juncus acutus, Iris pseudoacorus*, *Iris louisiana*	[23]
11	Wastewater with pesticides	*Sorghum saccharatum, Lepidium sativum* and *Sinapis alba*	[24]
	F. Nutrients only	**Indicator plants**	**Reference**
12	Nitrogen, Phosphorus and COD	*Phragmites australis*	[25]

The most studied plant bioindicators were then categorized based on trapping pollutants i.e., metals, nutrients, urban runoffs, metals and nutrients, and wastewater (Figure 1 and Table 1). *Phragmites australis* was observed to successfully trap all these types of pollutants; *Sorghum saccharatum, Lepidium sativum,* and *Sinapis alba* were observed to trap metals, nutrients, and wastewater; *Typha angustifolia* and *Bolboschoenus maritimus* trapped metals and reduce the water quality parameters indicative of pollution; *Typha domingensis* trapped metals and nutrients; *Juncus acutus* was observed to trap metals and wastewater; whereas *Apium nodiflorum, Arundo donax,* and *Nasturtium officinale* treated metals only (Figure 1 and Table 1).

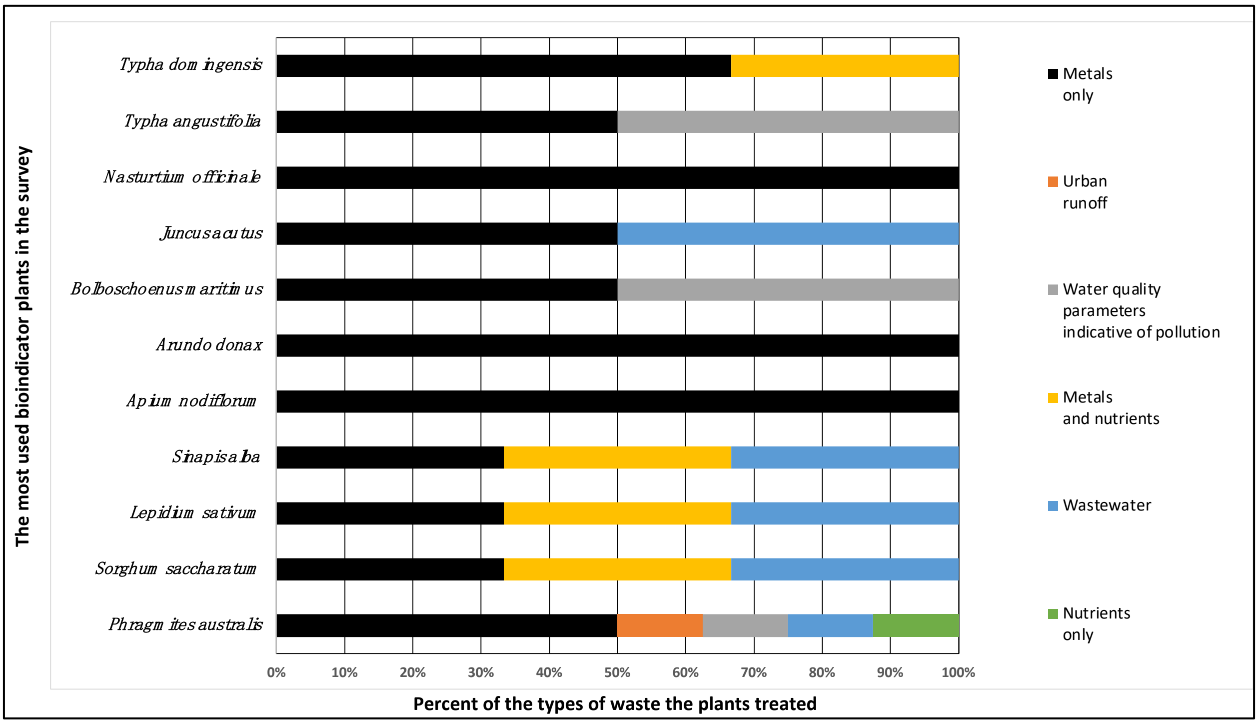

Figure 1 Percent of the types of waste materials treated by the most used bioindicator plants found in the survey. According to EPA 2003, the urban runoff type of waste is composed of nutrients, metals, organic pollutants like oil and grease, and pesticides.

4. Discussion

This study aims to provide a literature overview of plants capable of detecting and consequently reducing ecological stress or pollutants (such as metals, nutrients, urban runoffs, wastewater, or water quality parameters indicative of pollution) in wetlands.

Out of all the 70 plants reviewed, *Phragmites australis*, *Sorghum saccharatum, Lepidium sativum, Sinapis alba, Apium nodiflorum, Arundo donax, Bolboschoenus maritimus, Juncus acutus, Nasturtium officinale*, *Typha angustifolia* and *Typha domingensis* was observed to be the most studied plant bioindicators. These bioindicators provided a consolidated assessment of the environmental impacts of ecosystem stresses like metals, nutrients, urban runoffs, wastewater, or water quality parameters indicative of pollution [4, 5].

Pollutants from human activities reduce biodiversity and deteriorate human health. Even low levels of pollutants can impose risk by accumulating pollutants at higher trophic levels, called as biomagnification [7]. Pollutants like metals (such as As, Cd, Hg, Pb, Ni, Cr) are widely known for bioaccumulation [7, 26]. Some metals like Fe, Zn, Cu, Co are micronutrients of plants but can be toxic at higher concentrations as well [27]. There are very specific physiological mechanisms present in plants through which plants can uptake the pollutants inside the body tissues via roots [7]. Plants usually uptake metals (such as: Cd, Hg, Pb, Ni, Cr) by specific channel proteins (transporters) that are located at the plasma membrane of root cells [7]. However, few other plasma membrane transporters (for example - phosphorus-transporters) can contribute to the uptake of non-essential metals like As (as AsO_3). On the other hand, organic pollutants (for example herbicides) are absorbed into plant roots by a simple diffusion mechanism [7, 28]. Direct chemical (such as organic or inorganic pollutants) uptake via roots depends upon the chemical concentration in the soil and the rate of transpiration of a plant [29]. Plants also have reportedly been observed for uptaking inorganic pollutants such as TN (Total nitrogen), NH^+_4 (Ammonia nitrogen), and TP (Total Phosphorus) via roots increasing the COD (Chemical Oxygen Demand) [30, 31].

The literature review reflected that *Phragmites australis* was the most common aquatic plant used as a bioindicator with the ability to absorb a wide range of waste materials (metals, nutrients, urban runoffs, metals and nutrients, and wastewater). For example, *Phragmites australis* physiologically take up metals in the roots with an increase in biomass [32-34]. Studies have reported Cr, Cd, Cu, Co, Fe, Pb, Mn, Ni, and Zn accumulation in the roots and translocation of Cd and Pb in the leaves [35, 36] of *Phragmites australis*. The order of metal accumulation among *Phragmites australis* body parts is highest in roots followed by leaves and stems [37-40]. Other than metal removal from waste materials, *Phragmites australis* also has the ability to remove substances including dyes, pesticides, pharmaceuticals products, and illicit drugs [41-43]. According to literature, microorganisms in the rhizosphere roots of *Phragmites australis* can remove organics like phenolic compounds [40, 44, 45]. Overall, the genus *Phragmites* is one of the most effective plants in removing pollutants from wetlands [46].

For the other plant bioindicators, the literature review revealed metals to be assimilating in shoots and roots of *Aruno donax and Nasturtium officinale* indicating their strong phytoremediation potential [47, 48]. Although some studies observed *Nasturtium officinale* to have a threshold for uptake of metals such as Pb, Cd and As [49].

For *Typha domingensis,* the literature review observed metals are absorbed in the roots and leaves of [21, 50]. These studies revealed for nutrients though an increase in the root cross-sectional areas of *Typha domingensis* [21].

In the literature, *Typha augustifolia* and *Bolboschoenus maritimus* was observed to be good bioindicator of pollution physiological properties such as relatively deep water, slightly acid water, and sediments with low EC (electroconductivity) values, poor in SO_4^{2-} and K_2O [20]. *Typha augustifolia* was also found to be a metal assimilator in roots and leaves [51]. The literature revealed *Juncus acutus* to be an indicator, physiologically taking up metals in the roots [52, 53] and improving overall water quality conditions in wetlands [23]. Studies have found metal being taken up specifically in the roots and other tissues [13, 15] of *Apium nodiflorum* and *Bolboschoenus maritimus* as well.

Studies showed among *Sorghum saccharatum, Lepidium sativum* and *Sinapis alba*, the indicator plant *Sorghum Saccharum has* the highest amount of plant sensitivity when exposed to pollutants such as metals and nutrients [18, 22, 54]. These studies observed lower stem growth inhibition (or growth facilitation) when exposed to phosphate, nitrate-nitrite in *Sorghum saccharatum, Lepidium sativum* and *Sinapis alba* [18, 22]. Significant lower root growth inhibition (or growth facilitation) was seen when exposed to Pb. Implying Pb assimilating in the roots of *Sorghum saccharatum, Lepidium sativum* and *Sinapis alba* according to the literature [18, 22]. Other studies also observed metals like Cd, Zn, Pb, Cu and Fe up taken in *Sinapis alba* roots [55].

Hence, in this study, it was clearly observed that the most used plant bioindicators according to the literature review can detect several pollutants like metals, nutrients, urban runoffs, metals and nutrients, and wastewater. Furthermore, the study identified distinct physiological mechanisms of phytoremediation in these plant bioindicators which could be further investigated to understand the fate of the pollutants in plant tissues. The fate of these pollutants could be used to build a blueprint to develop plant bioindicators for wetland ecosystems.

5. Conclusions

This study identified a set of widely used plants (*Phragmites australis*, *Sorghum saccharatum, Lepidium sativum, Sinapis alba, Apium nodiflorum, Arundo donax, Bolboschoenus maritimus, Juncus acutus, Nasturtium officinale*, *Typha angustifolia,* and *Typha domingensis) as* bioindicators of wetland ecosystem health, based on the literature-survey. These plants absorbed and thus reduce a wide range of pollutants through specific physiological mechanisms of phytoremediation via roots, stems, and leaves. Hence, these plants not only can be bioindicator candidates helping to understand the ecosystem integrity of wetlands, but their physiological mechanisms of phytoremediation can help to construct a future blueprint for constructing bioindicators for wetlands.

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Author Contributions

Subhomita Ghosh Roy performed the conceptualization, research, data collection, data analysis, manuscript draft preparation, writing, reviewing, and manuscript edits.

Competing Interests

The author declares no competing interest.

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