Ecological Engineering 138 (2019) 28–37

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Review

Managing environmental contamination through phytoremediation by invasive plants: A review

K. Prabakaran[a,1], Jian Li[a,1], A. Anandkumar[a], Zhanrui Leng[a], Chris B. Zou[b], Daolin Du[a,*]

[a] *Institute of Environment and Ecology, School of the Environment and Safety Engineering, Jiangsu University, Zhenjiang 212013, China*
[b] *Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, OK 74078, USA*

ARTICLE INFO

Keywords:
Invasive plants
Tolerance
Phytoremediation
Contaminant remediation
Sustainable management

ABSTRACT

Environmental degradation by contaminants is a serious concern in the developing world. The remediation strategies to overcome the problem of environmental degradation should be assorted for its ecological impacts. Phytoremediation is a green technology for the removal of pollutants from various environmental compartments by employing green plants. An ideal phytoremediation plant candidate should possess some characteristic features such as exhibiting stronger growth traits with high biomass, unpalatable nature, exuberant root system, hyper accumulation of target contaminants accompanied with stress tolerance attributes. The growth of natural vegetation is prevented by the barren and uncongenial conditions prevailing in the contaminated sites, but however invasive plants are capable of establishing themselves on those sites due to their opportunistic incursive nature. Since, it is hard to eradicate an invasive species once after their establishment in a new habitat or ecosystem, they can possibly be controlled by sustainable management through the way of exploiting them in contaminant remediation, thus phytoremediation. Therefore, it is of foremost requisite to determine the ability of invasive species in offering various ecologically viable services including contaminant remediation through scientific exploration. In this review, the implications of using invasive plants in contaminant remediation with accompanying challenges and scopes involved are discussed with the available volume of literatures in contaminant remediation using plants, especially the invasive plants.

1. Introduction

The plants which are capable undergoing proficient proliferation outside their native boundary are called invasive plants (Richardson et al., 2000; Daehler, 2003) which has been introduced to an environment where it is non-native, or exotic, and whose introduction causes environmental or economic damage or harm to human health (IUCN, 2012). Increasing anthropogenic activities generate soil disturbances which prefers the growth of competitive invasive plant species at the compromise of natives (Hess et al., 2019). Although the concept of plant invasion across continents dates back to several millennia, it is believed that the global travel by humans after the 16th century, hastened the intercontinental movement of the species to a greater extent (Middleton, 2019). When compared to native plants, invasive plants are probably taller and are capable of demonstrating more prominence in growth, competitive ability, or fecundity (Daehler, 2003; Thébaud and Simberloff, 2001). The free intercontinental movement of species created a “New Pangea” and this aggressive species invasion to new continents is causing the world’s flora to become more and more homogeneous (Middleton, 2019). Thus, invasive plants are known to attain high abundance to influence biodiversity and degrade ecosystem function (Ehrenfeld, 2010; Wei et al., 2018).

Invasive plant species are capable encompassing wide physiological niches and special functional attributes and is quickly acquainted to altering environmental conditions (Wan and Wang, 2018). This intrinsic ability of invasive plants enhances them to flourish even in non-native habitats which in turn constricts the living spaces of native species (Catford, 2012; Hellmann, 2008; Lowe, 2000; Pyšek, 2012; Rejmánek, 2015). Intentionally alien plants were introduced to offer various ecosystem services such as fodder, fuel-wood, medicines, fruits, shade and aesthetic appeal. However, despite offering these services, some of these plant species are capable of intruding into the surrounding natural areas, thereby causing disruption and alterations of ecosystem functions, reducing native biodiversity, and negatively impacts local economies and human well-being (Jeschke et al., 2014; Le Maitre, 2011; Pejchar and Mooney, 2009; Potgieter et al., 2019).

* Corresponding author.
E-mail address: daolindu@163.com (D. Du).
[1] The authors contributed equally to this work.

https://doi.org/10.1016/j.ecoleng.2019.07.002
Received 18 March 2019; Received in revised form 24 June 2019; Accepted 4 July 2019
Available online 16 July 2019
0925-8574/

During expansion, there are also several evidenced instances that invasive plants can undergo rapid adaptive evolution. In the United States around 100 million acres are an abode to invasive plants and it is expanding at a rate of 14 million acres every year (Zimdahl and Brown, 2018). The Invasive plants were supposed to be causing severe threats to cropland, rangeland, aquatic and wildland habitats (Mullin, 2000). Considering the threat posed by invasive plants, the European Union, from January 2016, amended a law that to keep crop, breed, transport, sell, exchange, or deliberately or unintentionally release 14 non-native invasive plants is a punishable offense (Zimdahl and Brown, 2018).

China is one among the largest territories and mega diversity (Liu and Diamond, 2005; Liu, et al., 2003; Xu et al., 2008). In the case of plant introductions, however, a minor faction has escaped into the natural areas and impacts the ecosystem by creating several problems that include competition for resources, hybridization, increased sedimentation and alterations in nutrient, geochemical and hydrological cycles. As China is expanding its international trade activities, unintentional introductions are now increasing that may pose severe threats as they are unknown and unexpected. Xu, Qiang (Xu et al., 2012), presented a comprehensive list of Invasive Alien Species (IAS) in China, which includes 265 plants, out of which 252 terrestrial, 7 freshwater and 6 marine plant species. Of the total 265 invasive plant species about 180 species (67.9%) were intentionally introduced for various beneficial purposes. Almost half of all IAS (51.1%) was invaded from North and South America, 18.3% from Europe, 17.3% from Asia (excluding China), 7.2% from Africa, 1.8% from Oceania, and the source of the left 4.3% IAS remains unknown. About 48% of the invasive plants were accidentally released in China, including 25% being brought in via contaminated seed mixes, such as animal feed, 326 agricultural crops, oil plants, and green provenders (Gao et al., 2018).

In an inspection of imported materials contained in 349 ships from 30 countries between 1986 and 1990, about 200 species of alien weeds have been found. Weeds and poisonous grass species have outspread at the cost of high-quality grass species over as around 90% of China's grasslands (Diamond, 2005). Similarly, the perennial salt marsh grass *Spartina alterniflora* is native to the Atlantic and Gulf coasts of North America (Wan et al., 2009). The inherent capability of the plant to undergo rapid adaptive evolution in genotypes or exhibiting phenotypic plasticity makes the plant a dreadful invader (Lee, 2002; Richards et al., 2006). In the present scenario, *S. alterniflora* has colonized estuaries and coastal salt marshes across globe, causing severe impacts on the local ecosystems (Feng et al., 2017; Ma et al., 2014; Strong and Ayres, 2016). Primarily, *S. alterniflora* was introduced to China in 1979 through the concept of Ecol. Eng. to control erosion, soil amelioration, dike protection, seaward expansion of land, etc. (An, 2007; Hong-Xia et al., 2008). As a result of continuous grafting and natural dispersal, this plant species has spread to an extent making China the world's most prominent *Spartina* invaded region (Li et al., 2009; Strong and Ayres, 2013; Zheng et al., 2018). This plant is categorized on the first published list of the sixteen invasive plants by the State Environmental Protection Administration of China in 2003 (Wang et al., 2006). Over the past few decades, these plants are found to be vulnerable to the mangrove ecosystems of China. For instance the Zhangjiang Mangrove Estuary was invaded by *S. alterniflora* in the 1990 s. From then on, the area was rapidly occupied by *S. alterniflora* and the total area of invasion was found to be escalated from 57.94 ha to 116.11 ha (Gao et al., 2019; Liu et al., 2017; Zhang et al., 2017).

Another important invasive weed, *Alternanthera philoxerides*, commonly known as alligator weed, is an aquatic and clonal weedy species native to South America (Buckingham, 1996), and can co-exists abundantly in natural habitats all over the world (Ding et al., 2007). Currently, *A. philoxeroides* is found to be spreading over a wide range of temperate, tropical and subtropical areas throughout the world, including USA, Australia, India and China, over large latitudinal gradients (Lu et al., 2013; Wu et al., 2017). In the 1930s, this plant was being introduced in China as a forage crop (Dong et al., 2001), and at present it extends its habitat in major parts of south China and represents itself as one of the worst invader and is one of the 12 most harmful invasive species in China (Nan et al., 2013; Xu and Ye, 2003; Li and Xie, 2002). It acquires a strong inherent reproductive capability that it can emerge from even small fragments and can readily proliferate in new environments (Martin, 2001). It can adapt well to diverse environmental conditions due to its great phenotypic and morphological plasticity (Pan et al., 2006).

However, there exists certain concern that claims that the possible extents of danger by invasive species are exaggerated beyond the actual truth. For instance, in the United States, over the past 200 years about 50,000 non-native species were introduced. The list includes 5000 plant species and around only 675 species (14%) were considered to be invasive and, nevertheless, these introduced plants contributed to 98% of the productive crops grown in the US food system in 1998 (Chafe, 2005; Pimentel et al., 2000). A few among the 5000 introduced exotic plants escapes to the natural systems and turn to establish further, exhibiting themselves as pests and becomes a threat to agriculture or local biodiversity (Zimdahl and Brown, 2018). A comparative analysis of the invasive histories of species introduced into China and the USA demonstrates that it takes around 100 years for an exotic species to become an invasive species (Gao et al., 2018). For the case of British animals and plants, just about only 1 in 1000 introduced species have become pests (Williamson and Fitter, 1996). Therefore, in spite of their legitimate and watchful concerns invasive plants are rarely troublesome. In fact the invasive plants are capable of exhibiting stronger growth traits even in lands degraded by contaminants, and consequently can be utilized for contaminant remediation. In this review, an attempt was made to implicate the use of invasive plants in contaminant remediation by providing an understanding of the current status and the future direction of contaminant remediation using plants, especially the invasive plants.

2. Environmental contamination in China

The per capita cultivable land area of China is less than half of the world average and that of arable water is about one quarter of the world average (UNESCO, 2012). Thus, the country cannot spare any more available land or water as a result of increasing pollution (Lu et al., 2015). At present, soil pollution in China is the most wide and severe problem in the world. Understanding this, since 2006, the Chinese government has introduced a series of action plans in order to implement strategies to control, prevent and remediate soil pollution. The national soil pollution survey of China has taken 8 years and incurred a cost of around 161 million US dollars and the survey report published in 2014 indicated that about 16.1% of arable land is polluted with inorganic pollutants, particularly, Cd, Hg, As, Pb and Cr (MEP, 2014) causing the greatest risk to food safety in China (MEP&MLR, 2014). About 10.18% of arable soil was polluted by heavy metals and consequently resulted in a 13.86% reduction of grain production in China (Zhang et al., 2015). In 2007, according to the estimates of the Ministry of Land and Resource in China, the country suffered an economic loss of about 3.2 billion dollars as a result of farmland metal pollution (Gui-chun et al., 2009).

Since the founding of new China to 2012, the country marks an increased heavy metal emissions by 30 times (Tian et al., 2015). Apart from heavy metals elevated concentrations of organic pollutants such as organochlorine pesticides (OCPs), poly-aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and phthalate esters (PAEs), are also a threat to the agricultural soils across China and there is a need for the imperative management strategies and integrated cost effective remediation technologies to reclaim the polluted agricultural lands (Sun et al., 2018). Apart from environmental damage, water scarcity, and inappropriate use of pesticides, the most crucial factor affecting the food safety are chemical pollutants and hence, there is a need for integrating food safety policies with soil and water pollution management policies in China (Lu et al., 2015). Environmental management strategies in China are very challenging due to the rapid socio-economical advancement and the furtherance of these challenges will drive the country's environmental management in future (Duan, 2016). In 2014, the Chinese Central Government has announced major policies in the area of pollution control and remediation (Han et al., 2016). Furthermore, in order to implement the policies regarding soil pollution prevention and control on a legal flight, the country has introduced the People's Republic of China soil pollution prevention and control law in 2017 (Zhang et al., 2018).

3. Phytoremediation – Concepts and applications

The remediation strategies to overcome the problems of environmental degradation should be percolated for its ecological impacts. The removal of environmental pollutants from contaminated soil, sediments, sludge and water by employing green plants is termed as phytoremediation. This is a green technology, which is efficient in remediating a variety of environmental pollutants. Plant rhizosphere interactions with contaminants, are the key factor in phytoremediation technologies. Plants take up the metals from the rhizosphere as follows: Heavy metal mobilization in soil and subsequent uptake by plant roots, translocation of the accumulated metals from roots to aerial tissues followed by sequestration of the metals in plant tissues and tolerance. The uses of plants in contamination remediation have been tested since the 1970s, and in the 1980s the governmental and commercial sectors started recognizing the concept of phytoremediation (Liu et al., 2018). Gradually this technology has been widely explored over the years and there are over 100 soil heavy metal remediation pilot/field projects using the phytoremediation technology have been reported (USEPA, 2016). Based on the applicability, phytoremediation techniques are subdivided into different classes (Ali et al., 2013; Khalid, 2017; Mahar, 2016; Rezania et al., 2016; Yadav et al., 2018), which are:

i) Phytoextraction

Involves the use of plant roots to uptake contaminants from the soil and subsequent translocation of contaminants to the aerial parts of the plant where it gets accumulated followed by the biomass harvest for safe disposal of accumulated contaminants.

ii) Phytovolatilization

Plants uptake of contaminants from the soil and the subsequent conversion and release of toxic contaminants to less toxic vapours into the atmosphere through transpiration process of the plants.

iii) Phytofiltration

The use of plants biomass to filter out pollutants from contaminated water systems.

iv) Phytostabilization

The process of employing plants to stabilize pollutants by reducing their mobility and bioavailability thereby preventing their migration into the nearby environments and food chain.

v) Phytodegradation

The process through which plants uptake organic xenobiotics followed by the degradation with the help of enzymes.

vi) Rhizodegradation

The process of enhanced biodegradation of pollutants associated with the mediation of rhizosphere microbes.

Phytoremediation is found to be a promising remediation technology for a number of environmental pollutants in China, including heavy metals (Mahar, 2016; Gao et al., 2015; Ding et al., 2018; Chen et al., 2004; Wang et al., 2015; Li et al., 2019), organic contaminants such as PAHs, TPHs, PCBs, OCPs, pthalic acid esters, etc. (Ma et al., 2012; He et al., 2015; Ye et al., 2014; Teng et al., 2010; Wei and Pan, 2010; Xiao et al., 2015; Feng et al., 2017), and radionuclides (Tang and Willey, 2003; Wang et al., 2012, 2018; Yan, 2016; Huang et al., 2017). Recently, Gong, Zhao (Gong et al., 2018) presented an overview of the recent developments and knowledge on the general principles, technical progress and effectiveness of the field scale key remediation techniques for metal contamination and emphasized that although physical and chemical remediation methods are applied on field scale, they are known to cause environmental degradation and secondary pollution issues coupled with high cost and labour. However, bio-remediation methods, particularly phytoremediation techniques are environmentally friendly, safe, least destructive, and cost-efficient. When compared to the conventional techniques, phytoremediation techniques offers the benefit of economic feasibility (Tang et al, 2016).

An experiment to determine the cost benefits of a two-year phytoremediation project for soil contaminated with arsenic, cadmium and lead, demonstrates the method be cost efficient and the benefits of phytoremediation will countervail the project costs in less than seven years (Wan et al., 2016). Results from the field trials of phytoremediation in China are promising as arsenic contaminated soil in Hunan and Guangxi Province have been successfully remediated *by Pteris vittata* with accompanying costs as low as $3.08 per m^3 of contaminated soil (Xie et al., 2010). It is evident from the literature survey that phytoremediation of soil contaminants is becoming popular in recent years. For instance, the Chinese National Scientific Foundation Council has sanctioned 155 related research projects between 2000 and 2013. As discussed earlier, Cd being the deadly heavy metal contaminant of agricultural soils, most of the sanctioned projects were aspired for revealing the detailed potential remediation mechanisms of uptake, transfer and accumulation of Cd by hyper-accumulators as well as the genes involved (Zhang et al., 2014). Apparently, until 2014, the State Intellectual Property Office of China authorised around 60 invention patents out of the total 126 invention patents which primarily focused on phytoremediation of cadmium enriched soils (Yao-mei, 2013).

4. The mechanism of contaminant uptake and accumulation by invasive plants

Invasive plants are usually hyperaccumulaters which are capable of accumulating pollutants beyond their metabolic needs with concentrations ranging upto thousands of ppm (Keeran et al., 2019; Rai, 2008; Fernando et al., 2016; Ting et al., 2018). The different non-mutually exclusive hypotheses available in the literature describe hyperaccumulators as plants possessing increased tolerance against pollutants, resistance against herbivores and pathogens, drought tolerance and allelopathy (Boyd and Martens, 1992). As a matter of fact, invasive plants are known to demonstrate all the desirable characters of hyperaccumulators: increased tolerance to pollutants (Michalet, 2017; Yang et al., 2007), protection against herbivores or pathogens (Mangla and Callaway, 2008; Joshi and Vrieling, 2005), drought tolerance (Turner et al., 2017; Filippou et al., 2014), and allelopathy (Bibi and Abu-Dieyeh, 2016; Chengxu et al., 2011). A database called PHYTOREM compiled by the environment biotechnology applications division of Environment Canada, have listed some of the invasive plants are capable of accumulating four or more metals individually and some of which was recorded to exhibit the highest accumulated values of heavy metals (McIntyre, 2003).

Hyperaccumulators exhibits a much greater potential in taking up heavy metals from the soil; a faster and effective translocation of metals from root to above ground aerial parts, and a remarkable potential to detoxify and sequester of accumulated heavy metals (Verbruggen et al., 2009; Yang et al., 2005; Rascio and Navari-Izzo, 2011). Trace elements in the environment have been taken up by the plants through the processes of absorption, transport and translocation. Transporters mediate the uptake of metal ions in plants and some of the identified transporters include ZIP1-4, ZNT1, IRT1, COPT1, AtVramp1/3/4 and LCT1 on the plasma membrane-cytosol interface; ZAT, ABC type, AtMRP, HMT1, CAX2 and RAN1 (Shah and Nongkynrih, 2007). Chelators impart the detoxification of accumulated metals by buffering cytosolic metal concentrations, whereas chaperones specifically disseminate metal ions to organelles and metal requiring proteins. Two cysteine-rich peptides, the metallothioneins (MTs) and phytochelatins (PCs) were found to play a notable role in the sequestration of thio – reactive metals (Meagher, 2000).

The tolerance of plants to pollutants is the key prerequisite mechanism of plants for phytoremediation (Ali et al., 2013; Clemens, 2001; Jabeen et al., 2009; Singh et al., 2019; Tong et al., 2004). Cell wall binding followed by the active transport of metal ions into the vacuole and chelation through the triggering of metal-binding peptides and the formation of metallocomplex are the key mechanisms governing the heavy metal tolerance in plants (Mejáre and Bülow, 2001; Memon and Schröder, 2009). Chelation of metals by low molecular-weight proteins such as metallothioneins and the phytochelatins were found to be the key mechanism of metal detoxification observed in plants (Memon and Schröder, 2009). Heavy metal-binding molecules, such as phytochelatins, amino acids, glutathione, and metallothionein plays a important role in mitigating the metal toxicity by forming metal chelate complexes (Ali et al., 2013; Singh et al., 2019). Hyperaccumulators mitigate the toxicity due to the high concentrations of heavy metals by storing it in the vacuoles of large epidermal cells as they are the organells with low metabolic activity and hence major metabolic activities cannot be inhibited (Ali et al., 2013; Leitenmaier and Küpper, 2011). In this way, the hyperaccumulators manage to keep the metal levels in the mesophyll cells and cytoplasm within the safe limits, thereby protecting the activities of important enzymes and photosynthesis from heavy metal toxicity (Leitenmaier and Küpper, 2011). Despite, effective detoxification of metal ions occurs through the segregation of these metal chelate complexes into the subcellular location through transporters (Leitenmaier and Küpper, 2013).

Transmembrane transporter proteins comprising of proton pumps, cotransporters, antitransporters, and channels present in the plasma membrane are involved in ion uptake and translocation (Singh et al., 2019; Hall and Williams, 2003). Infact, hyperacculators are ascertained to have exhibit an elevated expression of transporter genes when compared to that of non accumulators (Leitenmaier and Küpper, 2011; Pence et al., 2000; Verbruggen et al., 2009). In the case of organic pollutants a family of ATP-binding cassette (ABC) transporters called the glutathione-S-conjugate pump discerns the oxidized diglutathione (GS-SG), glutathione conjugates of organics, conjugates of diverse high-molecular-weight toxic organic xenobiotics, and peptide-metal complexes such as phytochelatins (Lu et al., 1998; Tommasini et al., 1998). Herbicides and endogenous organic compounds are transported out of cells or accumulated into vacuoles (Li et al., 1997; Lu et al., 1997) for their subsequent chemical degradation and mineralization into harmless biological compounds (Meagher, 2000).

5. The use of invasive plants in phytoremediation – Challenges and scopes

Plants employed for the purpose of phytoremediation should possess some specific characteristic features such as rapid growth with high biomass, unpalatable nature, exuberant root system and hyper accumulation of target contaminants accompanied with stress tolerant attributes to a wide range of environmental parameters. Alas, many plants are incapable to survive in contaminated sites due to the toxic effects of pollutants present and, this makes invasive plants, the better candidates for phytoremediation. Biological invasions are an ecosystem level problem in restoration. Non-native exotic species hinder the restoration of many natural areas and impacts ecological changes that may be irreversible and thus forbidding successful restoration (Doren et al., 2009). However, there exists certain management strategies and conceptual ecological models through which this problem can be overruled (Doren et al., 2009; Doren et al., 2009; D'antonio, C. and L.A. Meyerson, 2002). In fact, it becomes possible to improve the reclamation of degraded site with non-invasive native and economic species when the site is ameliorated to some extent by invasive species in the large-scale ecosystem restoration programs (Pandey, 2012).

Zimdahl and Brown (Zimdahl and Brown, 2018), suggested that amidst few exceptions, attempts to eradicate invasive species are a waste of money, labor and effort as invasive species are opportunists and it can be controlled to some extent and cannot be eradicated fully. The desirable management option for invasive species will not be its eradication (Bonanno, 2016) and that will not necessarily ensure the restoration of ecosystems to their pre-invasive status (Rodewald et al., 2015). Invasive species can also be beneficial and in many cases, the likely benefits of invasive species are under-reported (Bonanno, 2016; Chapman, 2016). There are also instances where invasive plants were found to have contributed positively to economical, social and ecological services (Wagh and Jain, 2018; Richardson and Van Wilgen, 2004; Le Maitre et al., 2000). Understanding the economic use of invasive plants can be an effective approach to control their proliferation. The risk of invasiveness while using exotic plants for biofuel production can be undermined by the use of global databases and screening tools for distinguishing high-risk species, the design and constellation of plantations to reduce spread risk, and the use of biological control to reduce invasiveness (Richardson and Blanchard, 2011). Similar management strategies can be adopted while choosing exotic plants for phytoremediation.

Furthermore, this is not a problem of recent times as species invasions dates back to historic times and therefore it is necessary to implement holistic assessments appropriate for management strategies and decision-making, by understanding the positive and negative impacts of appropriating uncontrolled invasions compared to controlled introductions (Chapman, 2016). Integration of scientific knowledge with decision-making related to eco-restoration of problematic environments would greatly benefit from the perceptivities that species which come up spontaneously should respond to assisted spontaneous restoration (Pandey, 2013). Perhaps the best management strategy for invasive species is to find them some efficient usage such as phytoremediation. Invasive plants based phytoremediation is getting popular these days, due to its environmentally friendly and cost-effectiveness for removal of potentially toxic elements from soils (Yousaf et al., 2018).

Many invasive plants were investigated for the purpose of phytoremediation, some of which were given in Table 1. Among the investigated plants, *Eichhornia crassipes* also known as water hyacinth, attracts special attention among researchers. It is very difficult to eradicate this notorious weed (Patel, 2012), however, its ability to uptake contaminants has given a conceivable management route for its use in phytoremediation (Rezania et al., 2015). The resilience of this plant to a wide range of climatic conditions and its possession of a high biomass turnover within a single growing season, associated with its inherent tolerance to elevated concentrations of organic and inorganic water contaminants, makes this worst weed, the most widely tested plants for phytoremediation (Ting et al., 2018; Rezania et al., 2015; Mishra and Maiti, 2017; Newete et al., 2016). Recently Goswami and Das (Goswami and Das, 2018), demonstrated that *E. crassipes* successfully removes 55–57% of Cu from test water and the efficacy of the phytoremediation was established by catfish bioassay evidencing the edible part of fish reared in remediated water had Cu within FAO recommended levels. In a one year long phytoremediation study on a

Table 1
Invasive plants employed for phytoremediation technologies.

Invasive Plant(s)	Contaminant(s)	Process	Medium	Country	References
Eichhornia crassipes	Ag, Cd, Cr, Cu, Hg, Ni, Pb, and Zn	Phytofiltration	Water	Nigeria	Odjegba and Fasidi, 2007
	Nitrogen	Phytofiltration	Water	USA	Fox et al., 2008
	Fe, Mn, As, Au, Cu, Hg, U and Zn	Phytofiltartion	Water	South Africa	Newete et al., 2016
Typha latifolia	Al, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn	Phytoextraction	Soil	Italy	Bonanno and Cirelli, 2017
	Zn, Mn, Cu, Pb, Cd, Cr and Ni	Phytoextraction	Soil	India	Pandey et al., 2014
Phragmites australis, Typha latifolia	Boron	Phytofiltration	Effluent	Turkey	Türker et al., 2013
Phragmites australis	Benzimidazole anthelmintics	Phytodegradation	Culture medium	Czech Republic	Podlipná et al., 2013
Arundo donax	Se	Phytoextraction	Soil	Hungary, USA and Spain Ecotypes	Domokos-Szabolcsy et al., 2018
	Improved pH, EC, OC, microbial counts and soil enzyme activities and uptake Cd, Pb, Co, Ni and Fe	Phytoextraction	Bauxite-derived red mud	Hungary	Alshaal et al., 2013
	Cd and Zn	Phytofiltartion	Water	Slovakia	Dürešová et al., 2014
Chromolaena odorata	Crude oil and Cd, Ni, Zn	Phytoextraction	Soil	South Africa	Atagana, 2011
Ipomoea carnea	Cd, Pb, Cu, Cr,Mn and Ni	Phytoextraction	Fly ash deposits	India	Pandey, 2012
Ipomoea aquatica	Pb	Phytofiltration	Water	India	Bedabati Chanu and Gupta, 2016
Amaranthus spinosus	Cu, Zn, Cr, Pb and Cd	Phytoextraction	Soil	India	Chinmayee et al., 2012
Agrostis capillaries	Multi-metal contaminants	Rhizodegradation	Soil	Germany	Langella et al., 2014
Elodea canadensis	Co	Phytofiltration	Water	Romania	Mosoarca et al., 2018
Egeria densa	Se	Phytofiltration	Effluent	India	Ohlbaum et al., 2018
Hydrocharis morsus-ranae	Co, Cu, Hg, K, Mn, and Ni.	Phytofiltartion	Water	Poland	Polechońska and Samecka-Cymerman, 2016
Myriophyllumaquaticum	nutrients and organic matter	Phytofiltration	Water	Brazil	Souza et al., 2013
Tithonia diversifolia	Zn and Pb	Phytoextraction	Soil	NIgeria	Adesodun et al., 2010
Pistia stratiotes	Ag nanoparticles	Phytofiltration	Water	USA	Hanks et al., 2015
Pluchea indica	^{40}K and ^{262}Ra, and Pb	Phytostabilisation	Soil	Thailand	Kaewtubtim et al., 2018
Spartina densiflora	Co	Phytostabilisation	Soil	Spain	Cambrollé et al., 2011
Spartina alterniflora	Cr, Cu, Pb, Fe and Zn	Phytoextraction	Soil	USA	Salla et al., 2011
Alternanthera philoxeroides	Textile dye	Phytodegradation	Effluents	India	Rane et al., 2015

polluted river, it was found that the water hyacinth reduces ammoniacal nitrogen from 5.2 mg/L to 3.5 mg/L, equivalent to 48.6% of contaminant removal efficiency (Wang et al., 2011). Another study using water hyacinth in a polluted river of 5000 m^2 with 90% of water hyacinths' coverage accomplished a higher ammoniacal nitrogen removal efficiency of 86.5% (Hu et al., 2012).

Another invasive aquatic macrophyte *Pistia stratiotes*, also known as water lettuce was also widely recognized for its hyperaccumulative capability of various organic and inorganic contaminants. Also these plants were found to be efficient in reducing silver nanoparticles and silver ions from contaminated wastewaters to lower levels than the WHO's maximum contamination limit (Hanks et al., 2015). A phytofiltration lagoon with *P. stratiotes* is very viable within the biorefinery for providing biomass year-round and for treating the polluted water very effectively (Olguín, 2017). A laboratory experiment to elucidate the phytoremediation efficiency of waste water toxicity using *E. crassipes* and *P. stratiotes* demonstrated a reduction of 58.87% of ammonium, 50.04% of PO_4^{3-}, 82.45% of COD and 84.91% of BOD. In addition, the metal contents in treated wastewater after 15 days of experiment marked a percent reduction of 97.56% for *E. crassipes* and 93.51% for *P. stratiotes* tanks. Further, the study ascertained that *E. Crassipes* has higher remediation potential than *P. stratriotes* with the effluents treated by *E. Crassipes* sustains the survival of fish beyond 24 h of exposure (Victor et al., 2016).

Arundo donax, also known as giant reed is a noxious invasive weed and its utilitarian role in phytoremediation aspect is being investigated widely (Fernando et al., 2016; Nassi o Di Nasso et al., 2013; Fiorentino et al., 2010). Giant reed is found to be promising crop for the phytoremediation of potentially toxic elements (Fiorentino et al., 2017) including selenium and it can be used in the phytoremedition of problematic Se-rich soils in China and USA (El-Ramady, 2015). In a laboratory experiment, *A. Donax* was found to be tolerant against higher concentrations of arsenic. It was found that, in addition to bioaccumulation, the plant volatilizes 7.2 – 22% of arsenic in concentrations ranging from 300 to 1000 μg L^{-1} and this intrinsic capability of *A. donax* can be utilised to remediate and restore arsenic contaminated soils (Mirza, 2011). Similarly *A. donax* were examined for its phytoextraction efficiency in As contaminated synthetic wastewater and was found to tolerate upto 600 μg L^{-1} and hence the plant can be exploited to treat As contaminated waters (Mirza, 2010). The extent of tolerance demonstrated by *A. donax* to a range of contaminants could be used to exploit contaminated sites for biomass production for energy purposes (Papazoglou, 2007). Thus, invasive plants have the potential to be used as bioenergy crops simultaneously while remediating contaminated sites. Nevertheless invasive plants can also be explored in the management of problematic environments. For instance fly ash deposits originating from coal based thermal power plants are one such concern worldwide. Uncongenial conditions prevailing in fly ash basins prevent the natural colonization of flora, but however invasive plants are capable of exhibiting spontaneous growth in such sites. It was found that invasive plants such as *Typha latifolia*, *Ipomoea carnea* and *Ricinus communis* exhibits tolerance to such stress conditions and proved to be the potential candidates of phytoremediation of Flyash deposits (Pandey, 2012, 2013, Pandey et al., 2014).

Some of the major studies in China that deals invasive plants for the purpose of phytoremediation are given in Table 2. In China, the use of water hyacinth and water lettuce for phytoremediation of water bodies gained significant importance. A combination of both these macrophytes was recommended for the phytoremediation of domestic sewages contaminated by nitrogen and phosphorous (Qin et al., 2016). Water hyacinth could serve as an efficient, economical and ecological alternative for the phytoremediation of agro-industrial wastewater polluted with pesticides (Xia and Ma, 2006). The environmental performance and the economic feasibility of using water hyacinth to produce biogas coupled with their phytoremediation efficiency to reduce simultaneous nutrient stock in eutrophic water bodies was found to be applicable (Wang and Calderon, 2012). The invasive bioenergy crop *Riccinus communis* has great potential for the phytoremediation of soils co-contaminated by DDTs and Cd (Huang et al., 2011). Phytoremediation through three invasive aquatic plants *viz., Eichhornia*

Table 2
Invasive plants employed for phytoremediation technologies in China.

Invasive Plant(s)	Contaminant(s)	Process	Medium	References
Alternanthera philoxeroides	Cd	Phytoextraction	Soil	Li et al., 2018
Ambrosia artemisiifolia	As, Cd, Cr, Cu, Mn, Ni, Pb, V, and Zn	Phytoextraction	Soil	Yousaf et al., 2018
Arundo donax	As and Pb	Phytoextraction	Soil	Liu et al., 2017
**Ageratum conyzoides, Bidens pilosa, Senecio scandens, Imperata cylindrical, Buddleja davidii*	Cd, Pb and Zn	Phytoextraction	Soil	Zhu et al., 2018
Chromolaena odorata, Bidens pilosa and *Praxelis clematidea*	Cd	Phytoextraction	Soil	Wei et al., 2018
Eichornia crassipes and *Pistia stratiotes*	N and P	Phytofiltration	water	Qin et al., 2016
Phragmites australis	U, Th, Ba and Pb	Phytoextraction	Soil	Li et al., 2011
Polygonum perfoliatum	Mn	Phytoextraction	Soil	Liu et al., 2010
Eichhornia crassipes	Ethion	Phytofiltration	Water	Xia and Ma, 2006
Eichornia crassipes, Pistia stratiotes and *Myriophyllum spicatum*	Nutrients	Phytofiltration	Water	Lu et al., 2018
Spartina alterniflora	Cu, Zn, Pb, and Cr	Phytostabilization	Sediment	Zhang et al., 2019

crassipes, *Pistia stratiotes*, *Myriophyllum spicatum* was found to be a promising technology for in situ remediation of severely polluted rural rivers in developing countries, including China (Lu et al., 2018). In an experiment to remediate of two commonly used pesticides by exotic wetland plants *viz.,* Typha *latifolia, Phragmites australis, Iris pseudacorus,* it was found that the plants are capable of metabolising the pesticides after uptake (Lv, 2016). The invasive weed *Alternanthera philoxeroides* can be used for the phytoremediation of Cd in their invaded water bodies (Li et al., 2018).

Invasive plants are managed through three different categories of, containment, reduction or nuisance control and eradication (Hussner, 2017). However, the invasive species are hard to eradicate once after their establishment in a new habitat or ecosystem nevertheless, either prevent them from getting a foothold or learn to live with them (Chen et al., 2016). Therefore, the advantages of invasive plants should be taken into account rather than their disadvantages so that they can be properly controlled through exploitation with the way of sustainable development (Lu and Zhang, 2013). For instance, the water hyacinth, *Eichhornia crassipes*, is an extremely problematic aquatic weed for its unpleasant growth in water bodies. However, its inherent tendency of absorbing nutrients has made this weed a fascinating candidate in phytoremediation of watersheds, through which the weed can be sustainable managed in combination with herbicidal control, integrated biological control and also by curbing nutrient supply to control its growth. In addition to waste water treatment, this plant can add up to offering useful by-products such as animal and fish feed, power plant energy (briquette), ethanol, biogas, composting and fiber board making (Rezania et al., 2015). The major drawback in the phytoremediation technology is the time span required to achieve an effective result and it can be made an economically sustainable option by possibly harvesting additional benefits such as bioenergy production and phytomining (Harris et al., 2009; Licht and Isebrands, 2005; Vocciante et al., 2019).

It is to be noted that owing to their invasive nature, both water hyacinth and water lettuce should be confined within the remediation system for their ample utilisation of pollutant scavenging ability without bestowing undue environmental impacts. As invasive plants are opportunistic in nature, they produce more biomass than non-invasive plants. The number and biomass of water hyacinth can double in 6 to 15 days under optimal conditions (Lindsey and Hirt, 1999). Proper and complete utilisation approach on a large scale basis can be a viable option for the control of water hyacinth. Being a biomass source of cellulose and hemicellulose the plant can be utilized to develop value added by-products. The water content and a favourable C/N ratio marks this macrophyte an ample source to produce biogas through anaerobic digestion (O'Sullivan, 2010; Singhal and Rai, 2003). It can provide an appropriate gas yield of around $0.34\,m^3\,kg^{-1}$ total solid, much higher than that of other agricultural residuals (Huang and Fang, 1999). The biogas produced contains 60% methane content, which can be utilized as fossil fuel in boilers. The resultant leftover slurry contains high N, P and K content, which can be utilised for agricultural purposes (Verma et al., 2007). The biomass of macrophytes such as *Eichhornia* sp., *Typha* sp. and *A. donax* constitutes lignin (10–25%), hemicelluloses (20–30%), cellulose (30–50%), hydrogen (5%), lipids, and mineral matter, thereby characterising themselves as a viable option for bioenergy, and other bio-products in addition to phytoremediation (Dipu et al., 2011; Bhattacharya and Kumar, 2010). Owing to its competitive bioethanol yield over other agronomic energy crops, *A. donax* demonstrates more energy output and can be considered a potential alternative for biorefineries using poplar or similar hardwood feedstock's (Bura et al., 2012; Nsanganwimana et al., 2014). The production of electricity from invasive plant biomass is financially feasible in South Africa, as determined by the net present value (NPV) of up to US$2.7 million, compared to diesel generators which have negative NPV of up to -US$2.3 million (Stafford and Blignaut, 2017).

In China, the beneficial role of invasive plants in various aspects including contaminant remediation is evolving and its needs further development through scientific exploration. The invasive *Spartina alterniflora* has got high carbon storage abilities and exhibit significant ecological function for the carbon cycle and carbon sink in China's ocean ecosystem (Liao, 2007). Furthermore, *S. alterniflora* is also proposed as a bioenergy crop complying with the strategic goal of China's bioenergy industry (Lu and Zhang, 2013). Although the expansion of the invasive *Spartina alterniflora* in the salt marshes affects the native flora, total salt marsh area extent will increase due to its fast expansion, suggesting that the distribution and extent of invasive species are of great importance to understand its effects on local ecosystems (Gu, 2018). Accumulation and output of heavy metals by the invasive plant *Spartina alterniflora* in a coastal salt marsh of northern Jiangsu Province, China was studied and found that the plant exhibits temporary storage of heavy metals and can be used for phytomining of metals, but however, the output of heavy metals released by *S. alterniflora* to the environment cannot be ignored, that *S. alterniflora* may be considered a source of metal contaminants and therefore it becomes essential to consider the balance between metal absorption and export, while choosing a plant for phytoremediation (Chen et al., 2018). Recently, Wei, Huang (Wei et al., 2018), determined the possibility of using three invasive plant species *viz., Chromolaena odorata*, *Bidens pilosa* and *Praxelis clematidea* and recommended that the examined plants were potential candidates for soil Cd phytoremediation due to their high accumulative capacity and advantageous growth and tolerance traits. However, the authors also suggested that certain preventive field management strategies should be adopted such as the early harvest of plants before they produce seeds in order to prevent their outspread to the untargeted neighboring areas. Due to their inherent adaptability even in harsh environments, such as degraded lands, invasive plants will serve as potential candidates to remove contaminants. Therefore, instead of considering their disadvantages, invasive plant species with relatively stronger growth traits can be used for sustainable contaminant remediation with suitable field management strategies.

6. Conclusion

Biological invasions are a widely discussed topic over many decades. Although there exists concerns regarding the role of invasive species in altering ecosystem functions and making the world's flora more homogenous, there are many instances in which invasive plants are certainly found to be useful as most of the invasive plants are intentionally introduced to offer various agricultural and horticultural services. In addition, invasive plants are opportunists and cannot be eradicated completely once after its establishment in a naturalized environment. Therefore, it is of foremost requisite to determine its ability in offering ecologically viable services for the achievement of holistic ecosystem management in coexisting environmental settings. Phytoremediation of contaminants using invasive plants is found to be a promising option as invasive plants are generally tolerant to a wide variety of stress attributes and can flourish even in lands degraded by a variety of pollutants. It is evident from the literature survey that most of the contamination remediation experiments using invasive plants are found to be successful and therefore invasive plants can be used as potential candidates for phytoremediation. It is also agreed that the use of invasive plants should not be approached passively and appropriate management strategies are necessarily practiced to avoid undue range extension of invasive plants to the untargeted neighboring areas.

Declaration of Competing Interest

None.

Acknowledgements

This work was supported by the State Key Research Development Program of China (2017YFC1200100), the National Natural Science Foundation of China (31570414, 31770446, 31800429), the Natural Science Foundation of Jiangsu Province (BK20170540), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), the Jiangsu Collaborative Innovation Center of Technology and Material of Water Treatment, Study Abroad Scholarship of Jiangsu University and the post doctoral fellowship (209319) awarded by Jiangsu University, Zhenjiang, China.

References

Adesodun, J.K., Atayese, M.O., Agbaje, T., Osadiaye, B.A., Mafe, O., Soretire, A.A., 2010. Phytoremediation potentials of sunflowers (Tithonia diversifolia and Helianthus annuus) for metals in soils contaminated with zinc and lead nitrates. Water Air Soil Pollut. 207 (1–4), 195–201.
Ali, H., Khan, E., Sajad, M.A., 2013. Phytoremediation of heavy metals—Concepts and applications. Chemosphere 91 (7), 869–881.
Alshaal, T., Domokos-Szabolcsy, É., Márton, L., Czakó, M., Kátai, J., Balogh, P., Elhawat, N., El-Ramady, H., Fári, M., 2013. Phytoremediation of bauxite-derived red mud by giant reed. Environ. Chem. Lett. 11 (3), 295–302.
An, S., et al., 2007. Spartina invasion in China: implications for invasive species management and future research. Weed Res. 47 (3), 183–191.
Atagana, H.I., 2011. Bioremediation of co-contamination of crude oil and heavy metals in soil by phytoremediation using Chromolaena odorata (L) King & HE Robinson. Water Air Soil Pollut. 215 (1–4), 261–271.
Bedabati Chanu, L., Gupta, A., 2016. Phytoremediation of lead using Ipomoea aquatica Forsk. in hydroponic solution. Chemosphere 156, 407–411.
Bhattacharya, A., Kumar, P., 2010. Water hyacinth as a potential biofuel crop. Electronic J. Environ. Agric. Food Chem. 9 (1), 112–122.
QScience Proceedings 2016 (4), 20. https://doi.org/10.5339/qproc.2016.qulss.20.
Bonanno, G., 2016. Alien species: to remove or not to remove? That is the question. Environ. Sci. Policy 59, 67–73.
Bonanno, G., Cirelli, G.L., 2017. Comparative analysis of element concentrations and translocation in three wetland congener plants: Typha domingensis, Typha latifolia and Typha angustifolia. Ecotoxicol. Environ. Saf. 143, 92–101.
Boyd, R., Martens, S., 1992. The raison d'être for metal hyperaccumulation by plants. The vegetation of ultramafic (serpentine) soils, pp. 279-289.
Buckingham, G.R., 1996. Biological control of alligatorweed, Alternanthera philoxeroides, the world's first aquatic weed success story. Castanea 232–243.
Bura, R., Ewanick, S., Gustafson, R., 2012. Assessment of Arundo donax (giant reed) as feedstock for conversion to ethanol. Tappi J. 11 (4), 59–66.
Cambrollé, J., Mateos-Naranjo, E., Redondo-Gómez, S., Luque, T., Figueroa, M., 2011. The role of two Spartina species in phytostabilization and bioaccumulation of Co, Cr, and Ni in the Tinto–Odiel estuary (SW Spain). Hydrobiologia 671 (1), 95.
Catford, J.A., et al., 2012. Quantifying levels of biological invasion: towards the objective classification of invaded and invasible ecosystems. Glob. Change Biol. 18 (1), 44–62.
Chafe, Z., 2005. Bioinvasions. State of the world 2005: redefining global security. WW Norton and Company, New York.
Chapman, P.M., 2016. Benefits of Invasive Species. Mar. Pollut. Bull. 107 (1), 1–2.
Chen, C., et al., 2016. Invasions by alien plant species of the agro-pastoral ecotone in northern China: species-specific and environmental determinants. J. Nature Conserv. 34, 133–144.
Chen, Y., Shen, Z., Li, X., 2004. The use of vetiver grass (Vetiveria zizanioides) in the phytoremediation of soils contaminated with heavy metals. Appl. Geochem. 19 (10), 1553–1565.
Chen, L., et al., 2018. Accumulation and Output of Heavy Metals by the Invasive Plant Spartina alterniflora in a Coastal Salt Marsh. Pedosphere 28 (6), 884–894.
Chengxu, W., et al., 2011. Review on allelopathy of exotic invasive plants. Procedia Eng. 18, 240–246.
Chinmayee, M.D., Mahesh, B., Pradesh, S., Mini, I., Swapna, T., 2012. The assessment of phytoremediation potential of invasive weed Amaranthus spinosus L. Appl. Biochem. Biotechnol. 167 (6), 1550–1559.
Clemens, S., 2001. Developing tools for phytoremediation: towards a molecular understanding of plant metal tolerance and accumulation. Int. J. Occup. Med. Environ. Health 14 (3), 235–239.
Daehler, C.C., 2003. Performance Comparisons of Co-Occurring Native and Alien Invasive Plants: Implications for Conservation and Restoration. Annu. Rev. Ecol. Evol. Syst. 34 (1), 183–211.
D'antonio, C., Meyerson, L.A., 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restor. Ecol. 10 (4), 703–713.
Diamond, J., 2005. Collapse: How societies choose to fail or succeed. Penguin.
Ding, B., et al., 2007. Physiological responses of Alternanthera philoxeroides (Mart.) Griseb leaves to cadmium stress. Environ. Pollut. 147 (3), 800–803.
Ding, K., et al., 2018. Phytoremediation of Heavy Metal-Contaminated Soil in Southern China. In: Twenty Years of Research and Development on Soil Pollution and Remediation in China, pp. 375–387.
Dipu, S., Kumar, A.A., Thanga, V.S.G., 2011. Phytoremediation of dairy effluent by constructed wetland technology. Environmentalist 31 (3), 263–278.
Domokos-Szabolcsy, É., Fári, M., Márton, L., Czakó, M., Veres, S., Elhawat, N., Antal, G., El-Ramady, H., Zsíros, O., Garab, G., 2018. Selenate tolerance and selenium hyperaccumulation in the monocot giant reed (Arundo donax), a biomass crop plant with phytoremediation potential. Environ. Sci. Pollut. Res. 25 (31), 31368–31380.
Dong, W.Q.Y., Cui, Y., Liu, X., 2001. Instances of soil and crop heavy metal contamination in China. Soil Sediment Contam. 10 (5), 497–510.
Doren, R.F., Richards, J.H., Volin, J.C., 2009. A conceptual ecological model to facilitate understanding the role of invasive species in large-scale ecosystem restoration. Ecol. Indicators 9 (6), S150–S160.
Doren, R.F., Volin, J.C., Richards, J.H., 2009. Invasive exotic plant indicators for ecosystem restoration: an example from the Everglades restoration program. Ecol. Indicators 9 (6), S29–S36.
Duan, Q., et al., 2016. Distribution of heavy metal pollution in surface soil samples in China: a graphical review. Bull. Environ. Contam. Toxicol. 97 (3), 303–309.
Dürešová, Z., Šunovská, A., Horník, M., Pipíška, M., Gubišová, M., Gubiš, J., Hostin, S., 2014. Rhizofiltration potential of Arundo donax for cadmium and zinc removal from contaminated wastewater. Chem. Pap. 68 (11), 1452–1462.
Ehrenfeld, J.G., 2010. Ecosystem Consequences of Biological Invasions. Annu. Rev. Ecol. Evol. Syst. 41 (1), 59–80.
El-Ramady, H.R., et al., 2015. Giant reed for selenium phytoremediation under changing climate. Environ. Chem. Lett. 13 (4), 359–380.
Feng, J., et al., 2017. Effects of short-term invasion of Spartina alterniflora and the subsequent restoration of native mangroves on the soil organic carbon, nitrogen and phosphorus stock. Chemosphere 184, 774–783.
Feng, N.-X., et al., 2017. Efficient phytoremediation of organic contaminants in soils using plant–endophyte partnerships. Sci. Total Environ. 583, 352–368.
Fernando, A.L., et al., 2016. Chapter 4 - Giant Reed (Arundo donax L.): A Multipurpose Crop Bridging Phytoremediation with Sustainable Bioeconomy. In: Prasad, M.N.V. (Ed.), Bioremediation and Bioeconomy. Elsevier, pp. 77–95.
Filippou, P., et al., 2014. Proline and reactive oxygen/nitrogen species metabolism is involved in the tolerant response of the invasive plant species Ailanthus altissima to drought and salinity. Environ. Exp. Bot. 97, 1–10.
Fiorentino, N., et al., 2010. Biomass accumulation and heavy metal uptake of giant reed on a polluted soil in Southern Italy. J. Biotechnol. 150, 261.
Fiorentino, N., et al., 2017. Giant reed growth and effects on soil biological fertility in assisted phytoremediation of an industrial polluted soil. Sci. Total Environ. 575, 1375–1383.
Fox, L., Struik, P., Appleton, B., Rule, J., 2008. Nitrogen phytoremediation by water hyacinth (Eichhornia crassipes (Mart.) Solms). Water Air Soil Pollut. 194 (1–4), 199–207.
Gao, J., et al., 2015. Cadmium removal capability and growth characteristics of Iris sibirica in subsurface vertical flow constructed wetlands. Ecol. Eng. 84, 443–450.
Gao, L., et al., 2018. General laws of biological invasion based on the sampling of invasive plants in China and the United States. Global Ecol. Conserv. 16, e00448.
Gao, G.-F., et al., 2019. Spartina alterniflora invasion alters soil bacterial communities and enhances soil N2O emissions by stimulating soil denitrification in mangrove wetland. Sci. Total Environ. 653, 231–240.
Gong, Y., Zhao, D., Wang, Q., 2018. An overview of field-scale studies on remediation of soil contaminated with heavy metals and metalloids: technical progress over the last decade. Water Res. 147, 440–460.

Goswami, S., Das, S., 2018. Eichhornia crassipes mediated copper phytoremediation and its success using catfish bioassay. Chemosphere 210, 440–448.
Gu, J., et al., 2018. Losses of salt marsh in China: Trends, threats and management. Estuar. Coast. Shelf Sci. 214, 98–109.
Gui-chun, L., Jian-jun, Q., Chang-bin, Y., 2009. Study on Calculating Losses of Cropland Degradation. Chinese Agric. Sci. Bull. 3, 051.
Hall, J., Williams, L.E., 2003. Transition metal transporters in plants. J. Exp. Bot. 54 (393), 2601–2613.
Han, D., Currell, M.J., Cao, G., 2016. Deep challenges for China's war on water pollution. Environ. Pollut. 218, 1222–1233.
Hanks, N.A., Caruso, J.A., Zhang, P., 2015. Assessing Pistia stratiotes for phytoremediation of silver nanoparticles and Ag(I) contaminated waters. J. Environ. Manage. 164, 41–45.
Harris, A., et al., 2009. Indicative assessment of the feasibility of Ni and Au phytomining in Australia. J. Cleaner Prod. 17 (2), 194–200.
He, L., et al., 2015. Contamination and remediation of phthalic acid esters in agricultural soils in China: a review. Agron. Sustainable Dev. 35 (2), 519–534.
Hellmann, J.J., et al., 2008. Five Potential Consequences of Climate Change for Invasive Species. Conserv. Biol. 22 (3), 534–543.
Hess, M.C.M., Mesléard, F., Buisson, E., 2019. Priority effects: Emerging principles for invasive plant species management. Ecol. Eng. 127, 48–57.
Hong-Xia, Z., et al., 2008. Effect of an alien species Spartina alterniflora Loisel on biogeochemical processes of intertidal ecosystem in the Jiangsu coastal region, China. Pedosphere 18 (1), 77–85.
Hu, C., Ou, Y., Zhang, D., Zhang, H., Yan, C., Zhao, Y., Zheng, Z., 2012. Phytoremediation of the polluted Waigang River and general survey on variation of phytoplankton population. Environmental Science and Pollution Research 4168–4175. https://doi.org/10.1007/s11356-012-0931-z.
Huang, H., Fang, R., 1999. Study on anaerobic treatment of SCR processing wastewater and water hyacinth. China biogas 17 (4) 7–9, 17.
Huang, H., et al., 2011. The phytoremediation potential of bioenergy crop Ricinus communis for DDTs and cadmium co-contaminated soil. Bioresour. Technol. 102 (23), 11034–11038.
Environ Sci Pollut Res 24 (3), 2996–3005. https://doi.org/10.1007/s11356-016-8037-7.
Hussner, A., et al., 2017. Management and control methods of invasive alien freshwater aquatic plants: a review. Aquat. Bot. 136, 112–137.
IUCN, 2012. International Union for Conservation of Nature and Natural Resources.
Jabeen, R., Ahmad, A., Iqbal, M., 2009. Phytoremediation of heavy metals: physiological and molecular mechanisms. The Botanical Review 75 (4), 339–364.
Jeschke, J.M., et al., 2014. Defining the Impact of Non-Native Species. Conserv. Biol. 28 (5), 1188–1194.
Joshi, J., Vrieling, K., 2005. The enemy release and EICA hypothesis revisited: incorporating the fundamental difference between specialist and generalist herbivores. Ecol. Lett. 8 (7), 704–714.
Kaewtubtim, P., Meeinkuirt, W., Seepom, S., Pichtel, J., 2018. Phytomanagement of radionuclides and heavy metals in mangrove sediments of Pattani Bay, Thailand using Avicennia marina and Pluchea indica. Mar. Pollut. Bull. 127, 320–333.
Keeran, Nisha Surendran, Balasundaram, Usha, Govindan, Ganesan, Parida, Ajay Kumar, 2019. In: Transgenic Plant Technology for Remediation of Toxic Metals and Metalloids. Elsevier, pp. 381–393. https://doi.org/10.1016/B978-0-12-814389-6.00018-3.
Khalid, S., et al., 2017. A comparison of technologies for remediation of heavy metal contaminated soils. J. Geochem. Explor. 182, 247–268.
Langella, F., Grawunder, A., Stark, R., Weist, A., Merten, D., Haferburg, G., Büchel, G., Kothe, E., 2014. Microbially assisted phytoremediation approaches for two multi-element contaminated sites. Environ. Sci. Pollut. Res. 21 (11), 6845–6858.
Le Maitre, D.C., et al., 2011. Impacts of invasive Australian acacias: implications for management and restoration. Divers. Distrib. 17 (5), 1015–1029.
Le Maitre, D.C., Versfeld, D., Chapman, R., 2000. Impact of invading alien plants on surface water resources in South Africa: A preliminary assessment.
Lee, C.E., 2002. Evolutionary genetics of invasive species. Trends Ecol. Evol. 17 (8), 386–391.
Leitenmaier, B., Küpper, H., 2011. Cadmium uptake and sequestration kinetics in individual leaf cell protoplasts of the Cd/Zn hyperaccumulator Thlaspi caerulescens. Plant, Cell Environ. 34 (2), 208–219.
Leitenmaier, B., Küpper, H., 2013. Compartmentation and complexation of metals in hyperaccumulator plants. Front. Plant Sci. 4, 374.
Li, Z., Xie, Y., 2002. Invasive alien species in China. Beijing: China Forestry Publishing House 1 (3), 54.
Li, Z.-S., et al., 1997. Vacuolar uptake of the phytoalexin medicarpin by the glutathione conjugate pump. Phytochemistry 45 (4), 689–693.
Li, B., et al., 2009. Spartina alterniflora invasions in the Yangtze River estuary, China: an overview of current status and ecosystem effects. Ecol. Eng. 35 (4), 511–520.
Li, G.-y., Hu, N., Ding, D.-x., Zheng, J.-f., Liu, Y.-l., Wang, Y.-d., Nie, X.-q., 2011. Screening of plant species for phytoremediation of uranium, thorium, barium, nickel, strontium and lead contaminated soils from a uranium mill tailings repository in South China. Bull. Environ. Contam. Toxicol. 86 (6), 646–652.
Li, J., Du, Z., Zou, C.B., Dai, Z., Du, D., Yan, C., 2018. The mutual restraint effect between the expansion of Alternanthera philoxeroides (Mart.) Griseb and cadmium mobility in aquatic environment. Ecotoxicol. Environ. Saf. 148, 237–243.
Li, X., et al., 2019. Optimization of combined phytoremediation for heavy metal contaminated mine tailings by a field-scale orthogonal experiment. Ecotoxicol. Environ. Saf. 168, 1–8.
Liao, C., et al., 2007. Invasion of Spartina alterniflora enhanced ecosystem carbon and nitrogen stocks in the Yangtze Estuary, China. Ecosystems 10 (8), 1351–1361.
Licht, L.A., Isebrands, J., 2005. Linking phytoremediated pollutant removal to biomass economic opportunities. Biomass Bioenergy 28 (2), 203–218.
Lindsey, K., Hirt, H.-M., 1999. *Use water hyacinth.* A Practical Hanbook of uses for the Water Hyacinth from Across the World. Anamed: Winnenden 114.
Liu, J., Diamond, J., 2005. China's environment in a globalizing world. Nature 435 (7046), 1179.
Liu, J., et al., 2003. Protecting China's biodiversity. American Association for the Advancement of Science.
Liu, P., Tang, X., Gong, C., Xu, G., 2010. Manganese tolerance and accumulation in six Mn hyperaccumulators or accumulators. Plant Soil 335 (1–2), 385–395.
Liu, Y.-N., Guo, Z.-H., Xiao, X.-Y., Wang, S., Jiang, Z.-C., Zeng, P., 2017. Phytostabilisation potential of giant reed for metals contaminated soil modified with complex organic fertiliser and fly ash: A field experiment. Sci. Total Environ. 576, 292–302.
Liu, M., et al., 2017. Monitoring the invasion of spartina alterniflora using multi-source high-resolution imagery in the Zhangjiang Estuary, China. Remote Sensing 9 (6), 539.
Liu, L., et al., 2018. Remediation techniques for heavy metal-contaminated soils: principles and applicability. Sci. Total Environ. 633, 206–219.
Lowe, S., et al., 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Invasive Species Vol. 12.
Lu, Y.-P., Li, Z.-S., Rea, P.A., 1997. AtMRP1 gene of Arabidopsis encodes a glutathione S-conjugate pump: isolation and functional definition of a plant ATP-binding cassette transporter gene. Proc. Natl. Acad. Sci. 94 (15), 8243–8248.
Lu, Y.-P., et al., 1998. AtMRP2, an Arabidopsis ATP binding cassette transporter able to transport glutathione S-conjugates and chlorophyll catabolites: functional comparisons with AtMRP1. Plant Cell 10 (2), 267–282.
Lu, X., et al., 2013. Climate warming affects biological invasions by shifting interactions of plants and herbivores. Glob. Change Biol. 19 (8), 2339–2347.
Lu, Y., et al., 2015. Impacts of soil and water pollution on food safety and health risks in China. Environ. Int. 77, 5–15.
Lu, B., Xu, Z., Li, J., Chai, X., 2018. Removal of water nutrients by different aquatic plant species: An alternative way to remediate polluted rural rivers. Ecol. Eng. 110, 18–26.
Ma, T., et al., 2012. Removal of phthalic esters from contaminated soil using different cropping systems: a field study. Eur. J. Soil Biol. 50, 76–82.
Ma, Z., et al., 2014. Effects of invasive cordgrass on presence of marsh grassbird in an area where it is not native. Conserv. Biol. 28 (1), 150–158.
Mangla, S., Callaway, R.M., 2008. Exotic invasive plant accumulates native soil pathogens which inhibit native plants. J. Ecol. 96 (1), 58–67.
Mahar, A., et al., 2016. Challenges and opportunities in the phytoremediation of heavy metals contaminated soils: a review. Ecotoxicol. Environ. Saf. 126, 111–121.
Martin, A.C., 2001. Weeds. Macmillan.
McIntyre, T., 2003. Phytoremediation of heavy metals from soils, in Phytoremediation Springer, 97–123.
Meagher, R.B., 2000. Phytoremediation of toxic elemental and organic pollutants. Curr. Opin. Plant Biol. 3 (2), 153–162.
Mejáre, M., Bülow, L., 2001. Metal-binding proteins and peptides in bioremediation and phytoremediation of heavy metals. Trends Biotechnol. 19 (2), 67–73.
Memon, A.R., Schröder, P., 2009. Implications of metal accumulation mechanisms to phytoremediation. Environ. Sci. Pollut. Res. 16 (2), 162–175.
MEP, 2014. Ministry of Environmental Protection of the People's Republic of China. Q&A for Nationwide Soil Pollution Survey Report.
MEP&MLR, 2014. Ministry of Environment Protection and Ministry of Land Resources of the People's Republic of China. Nationwide Soil Pollution Survey Report.
Michalet, S., et al., 2017. Tolerance of Japanese knotweed s. l. to soil artificial polymetallic pollution: early metabolic responses and performance during vegetative multiplication. Environ. Sci. Pollut. Res. 24 (26), 20897–20907.
Middleton, Beth A., 2019. In: Encyclopedia of Ecology. Elsevier, pp. 431–440. https://doi.org/10.1016/B978-0-12-409548-9.11175-3.
Mishra, S., Maiti, A., 2017. The efficiency of Eichhornia crassipes in the removal of organic and inorganic pollutants from wastewater: a review. Environ. Sci. Pollut. Res. 24 (9), 7921–7937.
Mirza, N., et al., 2011. Ecological restoration of arsenic contaminated soil by Arundo donax L. Ecol. Eng. 37 (12), 1949–1956.
Mosoarca, G., Vancea, C., Popa, S., Boran, S., 2018. Adsorption, bioaccumulation and kinetics parameters of the phytoremediation of cobalt from wastewater using elodea canadensis. Bull. Environ. Contam. Toxicol. 100 (5), 733–739.
Mullin, B.H., 2000. Invasive plant species.
Nan, H., et al., 2013. Screening of native hyperaccumulators at the Huayuan River contaminated by heavy metals. Biorem. J. 17 (1), 21–29.
Nassi o Di Nasso, N., Roncucci, N., Bonari, E., 2013. Seasonal Dynamics of Aboveground and Belowground Biomass and Nutrient Accumulation and Remobilization in Giant Reed (Arundo donax L.): A Three-Year Study on Marginal Land. BioEnergy Res. 6 (2), 725–736.
Newete, S.W., Erasmus, B.F., Weiersbye, I.M., Byrne, M.J., 2016. Sequestration of precious and pollutant metals in biomass of cultured water hyacinth (Eichhornia crassipes). Environ. Sci. Pollut. Res. 23 (20), 20805–20818.
Nsanganwimana, F., et al., 2014. Arundo donax L., a Candidate for Phytomanaging Water and Soils Contaminated by Trace Elements and Producing Plant-Based Feedstock. A Review. Int. J. Phytorem. 16 (10), 982–1017.
Odjegba, V.J., Fasidi, I.O., 2007. Phytoremediation of heavy metals by Eichhornia crassipes. The Environmentalist 27 (3), 349–355.
Ohlbaum, M., Wadgaonkar, S.L., van Bruggen, J.J.A., Nancharaiah, Y.V., Lens, P.N.L., 2018. Phytoremediation of seleniferous soil leachate using the aquatic plants Lemna minor and Egeria densa. Ecol. Eng. 120, 321–328.
Mirza, N., et al., 2010. Phytoremediation potential of Arundo donax in arsenic-contaminated synthetic wastewater. Bioresour. Technol. 101 (15), 5815–5819.
Lv, T., et al., 2016. Phytoremediation of imazalil and tebuconazole by four emergent

wetland plant species in hydroponic medium. Chemosphere 148, 459–466.
Lu, J., Zhang, Y., 2013. Spatial distribution of an invasive plant Spartina alterniflora and its potential as biofuels in China. Ecol. Eng. 52, 175–181.
Singhal, V., Rai, J., 2003. Biogas production from water hyacinth and channel grass used for phytoremediation of industrial effluents. Bioresour. Technol. 86 (3), 221–225.
Olguín, E.J., et al., 2017. Year-round phytofiltration lagoon assessment using Pistia stratiotes within a pilot-plant scale biorefinery. Sci. Total Environ. 592, 326–333.
O'Sullivan, C., et al., 2010. Anaerobic digestion of harvested aquatic weeds: water hyacinth (Eichhornia crassipes), cabomba (Cabomba Caroliniana) and salvinia (Salvinia molesta). Ecol. Eng. 36 (10), 1459–1468.
Pan, X., et al., 2006. The influence of abiotic stress and phenotypic plasticity on the distribution of invasive Alternanthera philoxeroides along a riparian zone. Acta Oecologica 30 (3), 333–341.
Pandey, V.C., 2012. Invasive species based efficient green technology for phytoremediation of fly ash deposits. J. Geochem. Explor. 123, 13–18.
Pandey, V.C., 2013. Suitability of Ricinus communis L. cultivation for phytoremediation of fly ash disposal sites. Ecol. Eng. 57, 336–341.
Pandey, V.C., Singh, N., Singh, R.P., Singh, D.P., 2014. Rhizoremediation potential of spontaneously grown Typha latifolia on fly ash basins: Study from the field. Ecol. Eng. 71, 722–727.
Papazoglou, E.G., 2007. Arundo donax L. stress tolerance under irrigation with heavy metal aqueous solutions. Desalination 211 (1), 304–313.
Patel, S., 2012. Threats, management and envisaged utilizations of aquatic weed Eichhornia crassipes: an overview. Rev. Environ. Sci. Bio/Technol. 11 (3), 249–259.
Pejchar, L., Mooney, H.A., 2009. Invasive species, ecosystem services and human well-being. Trends Ecol. Evol. 24 (9), 497–504.
Pence, N.S., et al., 2000. The molecular physiology of heavy metal transport in the Zn/Cd hyperaccumulator Thlaspi caerulescens. Proc. Natl. Acad. Sci. 97 (9), 4956–4960.
Pimentel, D., et al., 2000. Environmental and economic costs of nonindigenous species in the United States. Bioscience 50 (1), 53–65.
Podlipná, R., Skálová, L, Seidlová, H., Szotáková, B., Kubíček, V., Stuchlíková, L., Jirásko, R., Vaněk, T., Vokřál, I., 2013. Biotransformation of benzimidazole anthelmintics in reed (Phragmites australis) as a potential tool for their detoxification in environment. Bioresour. Technol. 144, 216–224.
Polechońska, L., Samecka-Cymerman, A., 2016. Bioaccumulation of macro-and trace elements by European frogbit (Hydrocharis morsus-ranae L.) in relation to environmental pollution. Environ. Sci. Pollut. Res. 23 (4), 3469–3480.
Potgieter, L.J., et al., 2019. Perceptions of impact: Invasive alien plants in the urban environment. J. Environ. Manage. 229, 76–87.
Pyšek, P., et al., 2012. A global assessment of invasive plant impacts on resident species, communities and ecosystems: the interaction of impact measures, invading species' traits and environment. Glob. Change Biol. 18 (5), 1725–1737.
Qin, H., Zhang, Z., Liu, M., Liu, H., Wang, Y., Wen, X., Zhang, Y., Yan, S., 2016. Site test of phytoremediation of an open pond contaminated with domestic sewage using water hyacinth and water lettuce. Ecol. Eng. 95, 753–762.
Rai, P.K., 2008. Phytoremediation of Hg and Cd from industrial effluents using an aquatic free floating macrophyte Azolla pinnata. Int. J. Phytorem. 10 (5), 430–439.
Rane, N.R., Chandanshive, V.V., Watharkar, A.D., Khandare, R.V., Patil, T.S., Pawar, P.K., Govindwar, S.P., 2015. Phytoremediation of sulfonated Remazol Red dye and textile effluents by Alternanthera philoxeroides: An anatomical, enzymatic and pilot scale study. Water. Res. 83, 271–281.
Rascio, N., Navari-Izzo, F., 2011. Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? Plant Sci. 180 (2), 169–181.
Rejmánek, M., 2015. Global trends in plant naturalization. Nature 525, 39.
Rezania, S., et al., 2015. Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. J. Environ. Manage. 163, 125–133.
Rezania, S., et al., 2016. Comprehensive review on phytotechnology: heavy metals removal by diverse aquatic plants species from wastewater. J. Hazard. Mater. 318, 587–599.
Richards, C.L., et al., 2006. Jack of all trades, master of some? On the role of phenotypic plasticity in plant invasions. Ecol. Lett. 9 (8), 981–993.
Richardson, D.M., Blanchard, R., 2011. Learning from our mistakes: minimizing problems with invasive biofuel plants. Curr. Opin. Environ. Sustain. 3 (1–2), 36–42.
Richardson, D.M., Van Wilgen, B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts?: working for water. S. Afr. J. Sci. 100 (1–2), 45–52.
Richardson, D.M., et al., 2000. Naturalization and invasion of alien plants: concepts and definitions. Divers. Distrib. 6 (2), 93–107.
Rodewald, A.D., et al., 2015. Does removal of invasives restore ecological networks? An experimental approach. Biol. Invasions 17 (7), 2139–2146.
Salla, V., Hardaway, C.J., Sneddon, J., 2011. Preliminary investigation of Spartina alterniflora for phytoextraction of selected heavy metals in soils from Southwest Louisiana. Microchem. J. 97 (2), 207–212.
Shah, K., Nongkynrih, J., 2007. Metal hyperaccumulation and bioremediation. Biol. Plant. 51 (4), 618–634.
Singh, R., et al., 2019. Adaption Mechanisms in Plants Under Heavy Metal Stress Conditions During Phytoremediation. In: Phytomanagement of Polluted Sites. Elsevier, pp. 329–360.
Souza, F.A., Dziedzic, M., Cubas, S.A., Maranho, L.T., 2013. Restoration of polluted waters by phytoremediation using Myriophyllum aquaticum (Vell.) Verdc., Haloragaceae. J. Environ. Manage. 120, 5–9.
Stafford, W., Blignaut, J., 2017. Reducing landscape restoration costs: feasibility of generating electricity from invasive alien plant biomass on the Agulhas Plain, South Africa. Ecosyst. Serv. 27, 224–231.
Strong, D.R., Ayres, D.R., 2013. Ecological and evolutionary misadventures of Spartina. Annu. Rev. Ecol. Evol. Syst. 44, 389–410.
Sun, J., et al., 2018. Organic contamination and remediation in the agricultural soils of China: a critical review. Sci. Total Environ. 615, 724–740.
Tang, S., Willey, N.J., 2003. Uptake of 134 Cs by four species from the Asteraceae and two varieties from the Chenopodiaceae grown in two types of Chinese soil. Plant Soil 250 (1), 75–81.
Tang, X., et al., 2016. Review of remediation practices regarding cadmium-enriched farmland soil with particular reference to China. J. Environ. Manage. 181, 646–662.
Teng, Y., et al., 2010. Influence of arbuscular mycorrhiza and rhizobium on phytoremediation by alfalfa of an agricultural soil contaminated with weathered PCBs: a field study. Int. J. Phytorem. 12 (5), 516–533.
Thébaud, C., Simberloff, D., 2001. Are Plants Really Larger in Their Introduced Ranges? Am. Nat. 157 (2), 231–236.
Tian, H., et al., 2015. Quantitative assessment of atmospheric emissions of toxic heavy metals from anthropogenic sources in China: historical trend, spatial distribution, uncertainties, and control policies. Atmos. Chem. Phys. 15 (17), 10127–10147.
Ting, W.H.T., et al., 2018. Application of water hyacinth (Eichhornia crassipes) for phytoremediation of ammoniacal nitrogen: a review. J. Water Process Eng. 22, 239–249.
Tommasini, R., et al., 1998. An ABC-transporter of Arabidopsis thaliana has both glutathione-conjugate and chlorophyll catabolite transport activity. Plant J. 13 (6), 773–780.
Tong, Y.-P., Kneer, R., Zhu, Y.-G., 2004. Vacuolar compartmentalization: a second-generation approach to engineering plants for phytoremediation. Trends Plant Sci. 9 (1), 7–9.
Turner, K.G., Nurkowski, K.A., Rieseberg, L.H., 2017. Gene expression and drought response in an invasive thistle. Biol. Invasions 19 (3), 875–893.
Türker, O.C., Böcük, H., Yakar, A., 2013. The phytoremediation ability of a polyculture constructed wetland to treat boron from mine effluent. J. Hazard. Mater. 252–253, 132–141.
UNESCO, 2012. The Fourth United Nations World Water Development Report: Managing Water under Risk and Uncertainty (WWDR4). UNESCO, Marseilles.
USEPA, 2016. Phytotechnology Project Profiles. U.S. Environmental Protection Agency, Washington, DC. 2016.
Verbruggen, N., Hermans, C., Schat, H., 2009. Mechanisms to cope with arsenic or cadmium excess in plants. Curr. Opin. Plant Biol. 12 (3), 364–372.
Verbruggen, N., Hermans, C., Schat, H., 2009. Molecular mechanisms of metal hyperaccumulation in plants. New Phytol. 181 (4), 759–776.
Verma, V., Singh, Y., Rai, J., 2007. Biogas production from plant biomass used for phytoremediation of industrial wastes. Bioresour. Technol. 98 (8), 1664–1669.
Victor, K.K., et al., 2016. Phytoremediation of wastewater toxicity using water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes). Int. J. Phytorem. 18 (10), 949–955.
Vocciante, M., et al., 2019. Enhancements in phytoremediation technology: environmental assessment including different options of biomass disposal and comparison with a consolidated approach. J. Environ. Manage. 237, 560–568.
Wagh, V.V., Jain, A.K., 2018. Status of ethnobotanical invasive plants in western Madhya Pradesh, India. South African J. Botany 114, 171–180.
Wan, J.-Z., Wang, C.-J., 2018. Expansion risk of invasive plants in regions of high plant diversity: a global assessment using 36 species. Ecol. Inf. 46, 8–18.
Wan, S., et al., 2009. The positive and negative effects of exotic Spartina alterniflora in China. Ecol. Eng. 35 (4), 444–452.
Wan, X., Lei, M., Chen, T., 2016. Cost–benefit calculation of phytoremediation technology for heavy-metal-contaminated soil. Sci. Total Environ. 563–564, 796–802.
Wang, Z., Calderon, M.M., 2012. Environmental and economic analysis of application of water hyacinth for eutrophic water treatment coupled with biogas production. J. Environ. Manage. 110, 246–253.
Wang, Q., et al., 2006. Invasive Spartina alterniflora: biology, ecology and management. Acta Phytotaxonomica Sinica 44 (5), 559–588.
Wang, H., Zhang, H., Cai, G., 2011. An application of phytoremediation to river pollution remediation. Procedia Environmental Sciences 1904–1907. https://doi.org/10.1016/j.proenv.2011.09.298.
Wang, D., et al., 2012. The uptake of Cs and Sr from soil to radish (Raphanus sativus L.)- potential for phytoextraction and remediation of contaminated soils. J. Environ. Radioact. 110, 78–83.
Wang, W.-H., et al., 2015. Research Progress on Phytoremediation of Soil Contaminated by Heavy Metals.
Wang, W.-H., et al., 2018. Ramie (Boehmeria nivea)'s uranium bioconcentration and tolerance attributes. J. Environ. Radioact. 184–185, 152–157.
Wei, S., Pan, S., 2010. Phytoremediation for soils contaminated by phenanthrene and pyrene with multiple plant species. J. Soils Sediments 10 (5), 886–894.
Wei, H., Huang, M., Quan, G., Zhang, J., Liu, Z., Ma, R., 2018. Turn bane into a boon: Application of invasive plant species to remedy soil cadmium contamination. Chemosphere 210, 1013–1020.
Williamson, M., Fitter, A., 1996. The varying success of invaders. Ecology 77 (6), 1661–1666.
Wu, H., Ismail, M., Ding, J., 2017. Global warming increases the interspecific competitiveness of the invasive plant alligator weed, Alternanthera philoxeroides. Sci. Total Environ. 575, 1415–1422.
Xia, H., Ma, X., 2006. Phytoremediation of ethion by water hyacinth (Eichhornia crassipes) from water. Bioresour. Technol. 97 (8), 1050–1054.
Xiao, N., et al., 2015. Efficiency of five ornamental plant species in the phytoremediation of polycyclic aromatic hydrocarbon (PAH)-contaminated soil. Ecol. Eng. 75, 384–391.
Xie, J., et al., 2010. Phytoremediation of soil co-contaminated with arsenic, lead, zinc and copper using Pteris vittata L.: a field study. Acta Sci Circumst 30, 165–171.

Xu, R., Ye, W., 2003. Biological invasion-theory and practice. Science Press, Beijing.
Xu, H., et al., 2008. Biodiversity congruence and conservation strategies: a national test. AIBS Bulletin 58 (7), 632–639.
Xu, H., et al., 2012. An inventory of invasive alien species in China. NeoBiota 15, 1.
Yadav, K.K., et al., 2018. Mechanistic understanding and holistic approach of phytoremediation: a review on application and future prospects. Ecol. Eng. 120, 274–298.
Yan, X., 2016. Uptake of radionuclide thorium by twelve native plants grown in uranium mill tailings soils from south part of China. Nucl. Eng. Des. 304, 80–83.
Yang, X., et al., 2005. Molecular mechanisms of heavy metal hyperaccumulation and phytoremediation. J. Trace Elem. Med Biol. 18 (4), 339–353.
Yang, R.-Y., et al., 2007. Invasive and non-invasive plants differ in response to soil heavy metal lead contamination. Botanical Stud. 48 (4), 453–458.
Yao-mei, W., 2013. Patent bibliometric analysis on the remediation tech niques of soil heavy metal pollution. Ecol. Environ. Sci. 22 (5), 901–904.
Ye, M., et al., 2014. Evaluation of enhanced soil washing process and phytoremediation with maize oil, carboxymethyl-β-cyclodextrin, and vetiver grass for the recovery of organochlorine pesticides and heavy metals from a pesticide factory site. J. Environ. Manage. 141, 161–168.
Yousaf, B., Liu, G., Abbas, Q., Ali, M.U., Wang, R., Ahmed, R., Wang, C., Al-Wabel, M.I., Usman, A.R.A., 2018. Operational control on environmental safety of potentially toxic elements during thermal conversion of metal-accumulator invasive ragweed to biochar. Journal of Cleaner Production 195, 458–469.
Zhang, B.J., Luo, L.G., Wei, Y.H., Nie, G.X., Zhang, X.X., 2014. Research fields analysis to reply the soil cadmium contamination projects supported by National Natural Science Foundation of China. Chinese J. Tropical Agric. 34 (1), 98–102.
Zhang, X., et al., 2015. Impact of Soil Heavy Metal Pollution on Food Safety in China. PLoS ONE 10 (8), e0135182.
Zhang, X., et al., 2018. Spatial distribution of metal pollution of soils of Chinese provincial capital cities. Sci. Total Environ. 643, 1502–1513.
Zhang, D., et al., 2017. Introduction and Spread of an Exotic Plant, Spartina alterniflora, Along Coastal Marshes of China. Wetlands 37 (6), 1181–1193.
Zhang, Q., Yan, Z., Li, X., Xu, Y., Sun, X., Liang, Q., 2019. Formation of iron plaque in the roots of Spartina alterniflora and its effect on the immobilization of wastewater-borne pollutants. Ecotoxicol. Environ. Saf. 168, 212–220.
Zheng, S., Shao, D., Sun, T., 2018. Productivity of invasive saltmarsh plant Spartina alterniflora along the coast of China: a meta-analysis. Ecol. Eng. 117, 104–110.
Zhu, G., Xiao, H., Guo, Q., Song, B., Zheng, G., Zhang, Z., Zhao, J., Okoli, C.P., 2018. Heavy metal contents and enrichment characteristics of dominant plants in wasteland of the downstream of a lead-zinc mining area in Guangxi, Southwest China. Ecotoxicol. Environ. Saf. 151, 266–271.
Zimdahl, Robert L., Brown, Cynthia S., 2018. In: Fundamentals of Weed Science. Elsevier, pp. 209–252. https://doi.org/10.1016/B978-0-12-811143-7.00008-1.