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Bioremediation Using Weeds

Springer

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ISSN 2522-8366 ISSN 2522-8374 (electronic)
Energy, Environment, and Sustainability
ISBN 978-981-33-6551-3 ISBN 978-981-33-6552-0 (eBook)
https://doi.org/10.1007/978-981-33-6552-0

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

The natural ecosystem has been negatively impacted by environmental contamination from hazardous waste products, chemical pollutants and heavy metals. These pollutants arise from both anthropogenic sources and natural sources such as hurricanes and volcanic eruptions. Bioremediation is gradually being recognized as a standard practice for the sustainable management of environment as it is more eco-friendly and low-cost remediation techniques as compared to traditional chemical and physical methods.

The International Society for Energy, Environment and Sustainability (ISEES) was founded at Indian Institute of Technology Kanpur (IIT Kanpur), India, in January 2014 with an aim to spread knowledge/awareness and catalyse research activities in the fields of energy, environment, sustainability and combustion. The society's goal is to contribute to the development of clean, affordable and secure energy resources and a sustainable environment for the society, to spread knowledge in the above-mentioned areas and to create awareness about the environmental challenges, which the world is facing today. The unique way adopted by the society was to break the conventional silos of specializations (engineering, science, environment, agriculture, biotechnology, materials, fuels, etc.) to tackle the problems related to energy, environment and sustainability in a holistic manner. This is quite evident by the participation of experts from all fields to resolve these issues. ISEES is involved in various activities such as conducting workshops, seminars and conferences in the domains of its interests. The society also recognizes the outstanding works done by the young scientists and engineers for their contributions in these fields by conferring them awards under various categories.

The Fourth International Conference on "Sustainable Energy and Environmental Challenges" (IV-SEEC) was organized under the auspices of ISEES from 27 to 29 November 2019, at NEERI, Nagpur. This conference provided a platform for discussions between eminent scientists and engineers from various countries including India, USA, China, Italy, Mexico, South Korea, Japan, Sweden, Greece, Czech Republic, Germany, Netherland and Canada. In this conference, eminent speakers from all over the world presented their views related to different aspects of energy, combustion, emissions and alternative energy resource for sustainable development and cleaner environment. The conference presented one high-voltage plenary talk by Mrs. Rashmi Urdhwareshe, Director, Automotive Research Association of India (ARAI), Pune.

The conference included 28 technical sessions on topics related to energy and environmental sustainability including 1 plenary talk, 25 keynote talks and 54 invited talks from prominent scientists, in addition to 70+ contributed talks and 80+ poster presentations by students and researchers. The technical sessions in the conference included fuels, engine technology and emissions, coal and biomass combustion/gasification, atomization and sprays, combustion and modelling, alternative energy resources, water and water and wastewater treatment, automobile and other environmental applications, environmental challenges and sustainability, nuclear energy and other environmental challenges, clean fuels and other environmental challenges, water pollution and control, biomass and biotechnology, waste to wealth, microbiology, biotechnological and other environmental applications, waste and wastewater management, cleaner technology and environment, sustainable materials and processes, energy, environment and sustainability, technologies and approaches for clean, sensors and materials for environmental, biological processes and environmental sustainability. One of the highlights of the conference was the rapid fire poster sessions in (i) engine/fuels/emissions, (ii) environment and (III) biotechnology, where 50+ students participated with great enthusiasm and won many prizes in a fiercely competitive environment. 300+ participants and speakers attended this three days' conference, where 12 ISEES books published by Springer, Singapore, under a special dedicated series "Energy, environment and sustainability" were released. This was third time in a row that such significant and high-quality outcome has been achieved by any society in India. The conference concluded with a panel discussion on "Balancing Energy Security, Environmental Impacts and Economic Considerations: Indian Perspective", where the panellists were Dr. Anjan Ray, CSIR-IIP Dehradun; Dr. R. R. Sonde, Thermax Ltd.; Prof. Avinash Kumar Agarwal, IIT Kanpur; Dr. R. Srikanth, National Institute of Advanced Studies, Bengaluru; and Dr. Rakesh Kumar, NEERI Nagpur. The panel discussion was moderated by Prof. Ashok Pandey, Chairman, ISEES. This conference laid out the roadmap for technology development, opportunities and challenges in energy, environment and sustainability domain. All these topics are very relevant for the country and the world in the present context. We acknowledge the support received from various funding agencies and organizations for the successful conduct of the Fourth ISEES Conference IV-SEEC, where these books germinated. We would therefore like to acknowledge SERB, Government of India (special thanks to Dr. Sandeep Verma, Secretary); NEERI Nagpur (special thanks to Dr. Rakesh Kumar, Director), CSIR; and our publishing partner Springer (special thanks to Swati Meherishi).

We would like to express our sincere gratitude to large number of authors from all over the world for submitting their high-quality work in a timely manner and revising it appropriately at a short notice. We would like to express our special thanks to who reviewed various chapters of this monograph and provided their valuable suggestions to improve the manuscripts.

In this monograph, core elements of multidisciplinary bioremediation practice are addressed and environmental pollutants can be effectively remediated using weeds. Chapters include recent results and more focused on current trends of introduction to potentials of weeds in bioremediation practice. We hope that the book would be of great interest to the professionals and postgraduate students involved in weed-based bioremediation or phytoremediation and environmental research.

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Introduction

Bioremediation by Weeds

Abstract Not only weeds have adversely effect on the plant productivity, humans and animals, but also many weeds have the beneficial properties and have immense potential in environmental applications as fodder generation, bioremediation, biofuel generation, industrial, soil and water conservation resources, etc. In the field of pollution control, weeds play a main role in bioremediation, with applications that include ridding environments of biological and chemical contaminants. Not very much information is available on the use of weeds for bioremediation. Therefore, this research area needs to be discussed and expanded. In the bioremediation processes, the specific uses and mechanisms of weeds include: (1) phytoextraction or phytoaccumulation; (2) phytostabilization; (3) rhizofiltration; and (4) phytovolatilization. The bioremediation potential of the weeds can be further improved by the operation of innovative approaches in bioremediation process. Overall, this book emphasizes on weed classification, different techniques for bioremediation processes using weeds to present the broad applicability of weeds in environmental management.

Keywords Weed biomass · Pollutant removal · Bioremediation · Biofuel · Environmental management

Himalayan region is recognized as one of the biodiversity hotspots of the world where Indo-Malayan, Indo-Chinese and Indian bio-geographical realms have converged. Based on the climate and soil conditions, water availability and socio-economic aspects, different agro-ecosystems are prevalent in the Himalaya. Further, this region is inhabited by various ethnic communities and their dependence on the unique entity is high. The paucity of baseline data necessitated a compilation of the catalog of weed flora. Part I of this monograph presented weed species from north-west Himalaya, a phytogeographical distinct region. It will help in better understanding the patterns of plant invasion but also for explicating the processes promoting weed invasion at local, regional or global scales.

An aquatic weed may be defined as an undesirable plant that needs some sort of action to reduce its undesirable impact on the economy, the environment, human health and amenity. Aquatic weeds are biologically adapted to grow in water different bodies and complete at least part of their life cycle in aqueous environments. The undesirable qualities of aquatic weeds usually dominate their good qualities. For example, aquatic weeds can clog waterways and can have severe ecological and economic consequences. They can obstruct irrigation and hydroelectric projects, create hazards for recreational boaters, impair shoreline properties, severely markedly light availability to other useful plants and cause aquatic animals to suffocate. Aquatic weeds can be controlled by several weed control methods like preventive weed control, cultural weed control, mechanical weed control, biological weed control, chemical weed control and weed control through their utilization for biofuel production. Nevertheless, aquatic weeds represent one of the most useful feedstocks that can be harnessed for biofuel production to minimize dependence on limited crude oil and natural gas. Biofuel production from weed biomass may play a crucial role in meeting growing energy demands. Certain aquatic plants, such as duckweeds, water hyacinth, water lettuce, water chestnuts and cattails, are excellent sources of biofuel production. Algae have 20–80% oil contents that could be converted into different types of biofuels such as biodiesel and biokerosene. Similarly, lignocellulosic biomass (LCB) from aquatic weeds represents a sustainable alternative feedstock for production of biofuel. Characteristics such as high dry matter yield, low nutrient/water requirements for growth and high cellulose contents make aquatic weeds very attractive as feedstock for biofuel production. The production of large-quantity weed biomass needs to be wisely managed and utilized for the production of biofuels. Gene technology may be used to enhance the production of oil and biofuel contents and stability of aquatic weeds.

Part II of this monograph focuses on the utilization of aquatic weeds as a possible substitute for fossil fuel and current research activities in bioconversion of aquatic weeds to biofuel. The effectiveness of wastewater treatment by aquatic weeds was summarized at laboratory and pilot scales. Aquatic weeds are capable of effective pollutant removal from polluted water and thus allow usage of the treated water for agricultural works. In addition, aquatic plants are also effective for eliminating several heavy metals like copper, iron and mercury (Cu^{2+}, Fe^{3+} and Hg^{2+}) from contaminated soil. Subsequently, after the wastewater treatment and metal removal, harvested biomass could be used as feedstock for the production of different biofuels. Therefore, the biomass of aquatic plants could be potential raw materials for the production of bio-ethanol, bio-hydrogen and bio-methane. The potential of several other feedstocks is also summarized in comparison with aquatic weeds for various biofuel production. In conclusion, aquatic weeds served as not only a potential biological agent for wastewater treatment and heavy metal removal from contaminated water and soil but also a potential feedstock for biofuel productions (Ali et al. 2020).

Parthenium hysterophorus L. is one of the most invasive weeds and belongs to the family Asteracaeae. The weed which is commonly called carrot grass, Santa Maria, Santa Maria fever few or famine weed is native to American tropics but has spread rapidly to over thirty countries across Africa, Asia and Australia. *Parthenium* weed not only causes huge loss to crop production and plant biodiversity owing to its aggressive dominance, but also has adverse effect on the health of humans and livestock. It is known to cause allergic respiratory problems, contact dermatitis, mutagenicity, allergic rhinitis, breathlessness and even diarrhoea in mammals, depending upon the climatic conditions. Several different approaches have been employed for management of the weed including mechanical such as cutting and burning; chemical such as chemical herbicides; and biological which includes leaf-feeding beetle, stem-galling moth, stem-boring weevil and fungi. However, each of these approaches has its own limitations, and therefore, integrated weed management (IWM) is considered the best option to effectively manage its spread (Pant et al. 2015). In spite of several disadvantages, the weed has the advantage of being able to grow profusely under wide range of climatic conditions and on marginal lands, thereby producing huge amount of biomass that can be pre-treated and used for developing value-added commercial products. Many innovative uses of this weed in the field of medicine, nano-medicine, bioremediation, commercial enzyme production and biofuel production have been proposed recently.

Seaweeds can be considered as potential industrial biotechnology feedstock to achieve the worldwide demand for energy and biochemical production. The higher production yield, growth rate and carbon dioxide fixation capacity of the seaweeds highlight them as a promising alternative to terrestrial crops. In addition, farming of macroalgae does not require arable land, freshwater or fertilizer, avoiding hostile impacts on food supplies. For maximum utilization of seaweed biomass into biorefinery, the bioprospecting of the novel seaweed degrading enzymes and pathways is necessary. Recent studies reported the alginate catabolism for the successful production of bio-ethanol in few micro-organisms including *Escherichia coli* and *Saccharomyces cerevisiae*. Efforts are required to uncover the metabolism of various polysaccharides for maximum utilization of the algal polysaccharides. Also, engineering of potent seaweed converting micro-organisms, discovery and isolation of novel polysaccharide degrading enzymes and their metabolic pathways is the new interesting area of research. Metabolic engineering and synthetic biology approaches have been developed to engineer micro-organisms capable of metabolizing unique sugars from seaweed biomass to produce biofuels (Prasad 2012).

The synthetic polymers have been a significant challenge to humans as these are often disposed in land and water where they will persist in all seasons leaking toxic chemicals in the environment. The rising environmental awareness is promoting researchers to develop new biodegradable material. Biopolymers are the form of polymers derived from biological sources or chemically synthesized using biological materials as substrates. Seaweeds are versatile organisms, able to produce diverse type of polymers, i.e. agar, agarose, carrageenan, alginate, ulvan, fucoidan and polyhydroxyalkanoates. Biopolymers derived from seaweed polysaccharides possess promising features as they are renewable, biodegradable, biocompatible and environment-friendly. Also, seaweed has been used as reinforcement to improve the mechanical properties of polymer composites. Various modifications have been done on seaweed biopolymer to improve the properties of the materials such as blending with other polymers, the addition of compatibilizer and reinforcement with other materials. The potential of seaweed as filler in polymer composites improves the thermal, physical and mechanical properties of the synthetic polymer matrix. The seaweed-based polymers have potential applications for drug delivery, tissue engineering, regenerative medicine, wound healing management, bioremediation, food additive, food packaging, etc.

Seaweeds, the algal forms growing in the sea, have immense potential for their possible application in food, feed and various other commercially valuable products. Utilization of seaweeds for human consumption has been reported about 1700 years ago during the Neolithic period. Initially, these were harvested by coastal population mainly for food and fodder, but later on with increased demand of seaweed-derived products seaweeds find their application in several industrial processes. Seaweed farming although very simple, but at the same time it is very sensitive w.r.t. factors like reduction in water quality, reduction in coastal nutrients and other climate changes. Industrial production of seaweeds can be successfully achieved with the help of several technological interventions. However, at ground level, optimization and efficient development of new strategies are continuously desired not only for increased biomass productivity, but also for the development of quality products of commercial importance. Besides its enormous utility in industries, seaweed farming also has few very important and significant footraces that need to be dazed to explore its potential fully. A detailed framework involving all the aspects of seaweed farming, its industrial utility and socio-economic impact has been touched in order to convert the theoretical potential of seaweeds into reality.

Weeds are undesired plants that grow in a place where they are not required. Part III is the discussion about weed utilization. However, this definition is not true for some seaweed. Weed plants are generally considered noxious or harmful for humans, animals and biodiversity. They adversely affect the native plant productivity and cause health hazards and productivity loss to agriculture and agro-forestry. In the modern globalization and climate change scenario, a number of weed plants are spreading to new places and growing in a large area across the world. Therefore, the management and utilization of weed plants are of considerable importance. Weed plant biomass has immense potential for bioenergy, biomaterials and sources of important chemicals, bioactive molecules, food, feed and nutraceutical. Various unique characteristics of different weedy plants can be utilized for the benefit of society and the environment. The property of high lignocellulose content and requirements of lesser nutrients and water for the growth of weeds can be harnessed as cheap raw material resources for the production of commercially important biochemicals. Weed biomass can act as a direct source for bioactive compounds, which can be extracted using various solvent extraction processes. Fresh biomass and residual weed biomass after biochemical extraction can also be used as raw material for microbial fermentation to produce enzymes and biochemicals such as alcohols, organic acids and bioplastic.

Invasive plants are the species that are non-native to an ecosystem and widely known as "weeds". Weeds can cause adverse economic, ecological effects, disturbance in biodiversity, extinction of indigenous plant species and the spread of human or animal diseases due to their fast growth rate, strong survival ability and fewer natural predators. Along with the pest, weeds are the main challenge to the farmers in agriculture crop production. Several methods including chemical, biological and mechanical control have been implemented for controlling the spread of weeds. However, huge weed biomass is generated globally that could create secondary pollution. Nevertheless, the weed biomass can be utilized for the production of biochar, bio-oil, syngas by pyrolysing the biomass under an oxygen-free environment. Biochar has received great attention due to varieties of applications including soil amendment to improve soil physical, chemical and biological properties, carbon sequestration, removal or immobilization of organic contaminants in soil and water. Therefore, this monograph has broadly heightened the status and potential of some terrestrial and aquatic weed plants as a source for biochemical, bioactive compounds and nutraceutical, and as a raw material for microbial fermentation to produce biochemicals and strategies to utilize the weed biomass as a feedstock for biochar preparation and its application in agriculture and environmental clean-up.

Weeds are plants that are growing where they are not desired. The weeds are responsible for various agricultural, environmental and economic losses. Weeds not only interfere with agricultural activities like crop harvesting but also are accountable for economic losses by reducing crop health, quality and yield. Weeds are also intrusive with animal feeding by causing poisoning, tainting animal products and acting as an alternative host for plant and animal pests. Besides this, they prevent the water flow by blocking the ditches and irrigation channels. Therefore, nowadays, weeds and their management are a challenging and important problem in agriculture, the environment and society. Presently, weed control is carried out by chemical methods using herbicides which are responsible for soil and water pollution. Hence, there is a need to explore alternative strategies to control invasive weeds. In recent times, biological methods have been preferred over conventional chemical methods for synthesis of nanoparticles (NPs) as they fulfil the principles of green chemistry. Plant-mediated synthesis of nanoparticles is widely used and important area of nanotechnology. The biosynthesized nanoparticles exhibited a wide range of biological activities including antibacterial, antifungal, antioxidant, larvicidal activities. Furthermore, nanoparticles were also used in textile dye degradation and wastewater remediation. Therefore, weed-based biosynthesis of nanoparticles is considered as an alternative strategy not only for the utilization of the invasive weed species but also for weed control through its harvesting and usage. The aim of this monograph provides an outline of the seaweed polysaccharide composition, different pretreatment technologies, enzyme systems for seaweed biomass conversion, native and the engineered alginate degradation pathways in micro-organisms, application in the production of biofuels, weed-mediated phytosynthesis, characterization and applications in bioremediation.

This monograph is organized into ten different chapters. Specific topics covered in the monograph include:

- Diversity, distribution and status of weed species of north-west Himalaya
- Utilization of aqueous weeds for biofuel production: current status and future prospects
- Aquatic weeds: a potential pollutant removing agent from wastewater and polluted soil and valuable biofuel feedstock
- *Parthenium hysterophorus*: weed to value
- Seaweed biomass utilization pathways in microbes and their applications in the production of biofuels
- Seaweed-based biodegradable biopolymers, composite and blends with applications
- Seaweed cultivation and its biobusiness status around the world
- Utilization of weed plants for biochemicals and bioactive compound production
- Utilization of invasive weed biomass for biochar production and its application in agriculture and environmental clean-up
- Weed biomass-based nanoparticles and their applications.

The topics are organized into three different parts: (i) general weed diversity; (ii) bioremediation; and (iii) weed utilization.

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Part I
General Weed Diversity

Chapter 1
Diversity, Distribution, and Status of Weed Species of Northwest Himalaya

Zishan Ahmad Wani, Shreekar Pant, and Virbala Sharma

1.1 Introduction

Weed is defined as 'a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation' (Zimdahl 1999). Weeds are those plants which are harmful, interfere with the agricultural operations, increase labor, add input to the cultivation, and reduce the crop yield (Sen 2000). Weeds grow in a variety of ecosystems including pastures, rangelands, and forests. There are approximately 250,000 species of plants worldwide, of those about 3% or 8000 species act as weeds (Kumari 2016). Weeds have been recognized as a problem since the beginning of agriculture and the battle against weeds is a never ending one (Tiwari et al. 2016). Weeds are believed to have been existing on the earth ever since the man started cultivating plants around 10,000 BC (Macneish 1964). The factors that create weed problems can be classified as: hydrological, habitat modification, changes in succession, disturbances, grazing, competition, diseases, hybridization, reproductive constraints, introduction, etc. (Reid 1998). Weeds differ from other plants in being more adaptive and having peculiar characteristics that make them more competitive (Dangwal et al. 2010). Most of the weeds have characteristics of enormous seed production, variety of seed dormancies, ability to grow and multiply under variable environmental conditions (Sharma et al. 2010). Some plants are naturally weedy and become a nuisance when agriculture invades the areas in which they already grow, whilst others have developed into weeds since people have started to cultivate crops

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D. Pant et al. (eds.), *Bioremediation Using Weeds*, Energy, Environment, and Sustainability, https://doi.org/10.1007/978-981-33-6552-0_1

(Swarbrick and Mercado 1987). Weeds reduce crop yield by competing for water, soil moisture, soil nutrients, sunlight, and growing space needed by crop plants. Weeds have the ability to spread rapidly and reproduce in high numbers which enables them to effectively crowd out native and endemic plant populations and establish a plant kingdom of their own within a short period of time. Weeds also act as alternate hosts for insects, bacteria, viruses, and nematodes that affect the crops badly by causing diseases (Younkin 1942). Weeds also inhibit the growth parameters of crop plants by secreting allelopathic chemicals (Oudhia and Tripathi 1998). Most of the weeds are exotic and have been introduced for various purposes like food, fodder, medicinal, ornamental, plantation, horticulture, etc., and they support farming and forestry in a big way. Introduced species became invasive when they are introduced deliberately or unintentionally outside their natural habitats into new areas where they express the capability to establish, invade, and out-compete native species (Sekar et al. 2012). These invasive species are threatening biodiversity by exerting significant impact on the native and endemic plant species or directly by altering ecosystem properties and resulting in the displacement of native communities, hence creating an imbalance in natural and agricultural ecosystems (Vitousek 1986; Kohli et al. 2004). Several exotic disturbances dramatically affect succession and lead to exotic annual communities with low native species richness (Stylinski and Allen 1999).

Most often, the term ‘weed’ is used to denote the invasive species only, but native plants have also the weed potential and can also compete with our crops. Invasive species are defined as the exotic/non-native plants that express the capability to invade or compete with native species. But a weed may be a native or an exotic species that mostly grow and compete with our crops, most of which are non-native. Thus, weeds are both native and non-native, whereas ‘invasive’ is a term related to non-native competing species only. *Artemisia roxburghiana* is regarded as a weed in Indian Himalayan Region (IHR) (Bisht 2017), but it is native to the Himalayan Region (Samant et al. 1998), so cannot be regarded as invasive as it is a native plant species. The two terms ‘weeds’ and ‘invasive species’ are often used together and are considered one and the same thing. Invasive species can be regarded as weeds, but weeds cannot be regarded as invasive. The present study presents a comprehensive database of native as well as non-native weeds of Northwest Himalayan Region (Himachal Pradesh, Uttarakhand, and Jammu and Kashmir) along with common names, life forms, range of altitude, nativity, and flowering periods and will provide the baseline information about the weeds which will serve as a manual for future weed identification.

Present findings are based on the intensive review of available information on weed species for the Northwest and West Himalaya and also the survey conducted in different parts of Uttarakhand, Himachal Pradesh, and Jammu and Kashmir. Information on various aspects like altitude, life form, flowering period, and nativity was gathered. The samples of the specimens were collected and identified with the help of local/regional floras and research papers (Osmaston 1927; Choudhery and Wadhwa 1984; Naithani 1984; Samant 1987; Singh et al. 2002). Date were compiled and analyzed for diversity, distribution pattern, and nativity.

Nativity of the species was identified following Anonymous (1883–1970), Samant et al. (1998), Samant and Pal (2003), and Dhar et al. (2002).

1.2 Species Diversity and Distribution Pattern

A total of three hundred twenty-three weeds belong to 221 genera and 72 families (Table 1.1); they are of 279 species herbs, 27 shrubs, 15 climbers, and 2 species ferns (Fig. 1.1). Among the families, Asteraceae was the dominant family (57 species) followed by Poaceae (21 species), Lamiaceae (20 species), Ranunculaceae (19 species), Fabaceae (15 species), Brassicaceae (14 species) representing maximum weed species (Fig. 1.2). Out of documented weed species, 278 species represented dicot species within 186 genera and 58 families, while 43 species represented monocots within 33 genera and 12 families and 2 species as pteridophytes within 2 genera and 2 families.

Of the total species, maximum number of species (276) occur in the altitudinal zone, 1601–2400 m, followed by (206) in zone 801–1600 m, (146) in 2101–3200, (96) in up to 800 m, (54 species) in altitudinal zone 3201–4000 m, (18 species) in 4001–4800 (18), and (04 species) above 4800 m, respectively (Fig. 1.3).

Ranunculus was the dominant genera (09 species) followed by *Veronica, Ipomoea, and Artemisia* (05 species each), and *Polygonum, Chenopodium,* and *Viola* (04 species, each).

1.2.1 Richness of Native and Non-native Species

Out of 323 plant species, 56 were native to Himalayan Region and 267 plant species were non-native or exotic (Fig. 1.4). The native species grows within an altitude range of 1000–5600 m, whereas the non-native species grows within an altitudinal range of 200–4500. Only few non-native species grows above an altitude of 4000 m. Further, the peak flowering period of the recorded weeds is between May and September.

Weeds are the undesirable plants that reduce the crop yield by competing with the crops for moisture, light, space, nutrients, etc. Weeds affect everyone in the world by reducing crop yield and quality, delaying or interfering with harvesting, interfering with animal feeding, etc. (Kraehmer and Baur 2013). There is no reliable study of worldwide damage due to weeds. However, it is estimated that loss caused by weeds has exceeded the loss from any other category of agricultural pests such as insects, nematodes, diseases, and rodents (Abouziena and Haggag 2016). Generally, weeds are invasive in nature but some weeds are native too. Invasive species cause loss of biodiversity including species extinction, changes in hydrology, and ecosystem function (Sekar 2012). Besides non-native weed species, native species also act as weeds and may cause damage to the crops or may reduce the

Table 1.1 Diversity, distribution pattern of weed plants of Northwest and West Himalayan Region

S. no.	Taxa	Family	Common name	Life form	Range of altitude (m)	Nativity	Flowering period	References
1	*Barleria cristata* L.	Acanthaceae	Bluebell Barleria	S	200–2000	Asia	March–Sept	Bisht (2017)
2	*Dicliptera bupleuroides* Nees	Acanthaceae	Roxburgh's Foldwing	H	500–2000	Asia	March–Aug	Bisht (2017)
3	*Dicliptera roxburghiana* Nees	Acanthaceae	Chinese Foldwing	H	1500–2100	Asia	July–Oct	John and Dube (1995)
4	*Justicia parviflora* Nees	Acanthaceae	Small Flowered Rungia	H	300–2000	Asia	Oct–Dec	Bisht (2017)
5	*Peristrophe speciosa* (Roxb.) Nees	Acanthaceae	Showy Foldwing	H	Up to 1600	Asia	June–Oct	Bisht (2017)
6	*Adiantum capillus-veneris* L.	Adiantaceae	Maidenhair Fern	Pt	Up to 1800	Eurasia	–	Banday et al. (2017)
7	*Sagittaria sagittifolia* L.	Alismataceae	Arrowhead	H	Up to 1800	North America Europe	July–Aug	Ganie et al. (2015)
8	*Achyranthes aspera* L.	Amaranthaceae	Chaf Flower	H	Up to 1700	North America	July–Sept	Tiwari et al. (2016)
9	*Achyranthes bidentata* Bl.	Amaranthaceae	Ox Knee	H	1500–2200	Asia	July–Sept	Bisht (2017)
10	*Aerva lanata* (L.) Juss. ex Schult	Amaranthaceae	Mountain Knotweed	H	Up to 1200	Asia and Africa	Aug–Oct	Rawat and Kharwal (2014)
11	*Alternanthera philoxeroides* (Mart.) Griseb	Amaranthaceae	Alligator Weed	H	Up to 1900	South America	July–Nov	Masoodi and Khan (2012)
12	*Alternanthera pungens* Kunth	Amaranthaceae	Khaki Weed	H	Up to 1800	South America	May–Aug	Singh and Dangwal (2014)
13	*Alternanthera sessilis* (L.) DC.	Amaranthaceae	Joy Wood	H	Up to 1500	South America	July–Sept	Dangwal et al. (2012)

(continued)