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Sustainable Development, Volume 8

Floristic Diversity
Biology and Conservation

Edited by Gopal Shukla, Jahangir A. Bhat, Sumit Chakravarty, Adel W. Almutairi and Mei Li

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IntechOpen Book Series

Sustainable Development

Volume 8

Aims and Scope of the Series

Transforming our World: the 2030 Agenda for Sustainable Development endorsed by United Nations and 193 Member States, came into effect on Jan 1, 2016, to guide decision making and actions to the year 2030 and beyond. Central to this Agenda are 17 Goals, 169 associated targets and over 230 indicators that are reviewed annually. The vision envisaged in the implementation of the SDGs is centered on the five Ps: People, Planet, Prosperity, Peace and Partnership. This call for renewed focused efforts ensure we have a safe and healthy planet for current and future generations.

This Series focuses on covering research and applied research involving the five Ps through the following topics:

1. Sustainable Economy and Fair Society that relates to SDG 1 on No Poverty, SDG 2 on Zero Hunger, SDG 8 on Decent Work and Economic Growth, SDG 10 on Reduced Inequalities, SDG 12 on Responsible Consumption and Production, and SDG 17 Partnership for the Goals

2. Health and Wellbeing focusing on SDG 3 on Good Health and Wellbeing and SDG 6 on Clean Water and Sanitation

3. Inclusivity and Social Equality involving SDG 4 on Quality Education, SDG 5 on Gender Equality, and SDG 16 on Peace, Justice and Strong Institutions

4. Climate Change and Environmental Sustainability comprising SDG 13 on Climate Action, SDG 14 on Life Below Water, and SDG 15 on Life on Land

5. Urban Planning and Environmental Management embracing SDG 7 on Affordable Clean Energy, SDG 9 on Industry, Innovation and Infrastructure, and SDG 11 on Sustainable Cities and Communities.

The series also seeks to support the use of cross cutting SDGs, as many of the goals listed above, targets and indicators are all interconnected to impact our lives and the decisions we make on a daily basis, making them impossible to tie to a single topic.

Meet the Series Editor

Usha Iyer-Raniga is a professor in the School of Property and Construction Management at RMIT University. Usha co-leads the One Planet Network's Sustainable Buildings and Construction Programme (SBC), a United Nations 10 Year Framework of Programmes on Sustainable Consumption and Production (UN 10FYP SCP) aligned with Sustainable Development Goal 12. The work also directly impacts SDG 11 on Sustainable Cities and Communities. She completed her undergraduate degree as an architect before obtaining her Masters degree from Canada and her Doctorate in Australia. Usha has been a keynote speaker as well as an invited speaker at national and international conferences, seminars and workshops. Her teaching experience includes teaching in Asian countries. She has advised Austrade, APEC, national, state and local governments. She serves as a reviewer and a member of the scientific committee for national and international refereed journals and refereed conferences. She is on the editorial board for refereed journals and has worked on Special Issues. Usha has served and continues to serve on the Boards of several not-for-profit organisations and she has also served as panel judge for a number of awards including the Premiers Sustainability Award in Victoria and the International Green Gown Awards. Usha has published over 100 publications, including research and consulting reports. Her publications cover a wide range of scientific and technical research publications that include edited books, book chapters, refereed journals, refereed conference papers and reports for local, state and federal government clients. She has also produced podcasts for various organisations and participated in media interviews. She has received state, national and international funding worth over USD $25 million. Usha has been awarded the Quarterly Franklin Membership by London Journals Press (UK). Her biography has been included in the Marquis Who's Who in the World® 2018, 2016 (33rd Edition), along with approximately 55,000 of the most accomplished men and women from around the world, including luminaries as U.N. Secretary-General Ban Ki-moon. In 2017, Usha was awarded the Marquis Who's Who Lifetime Achiever Award.

Meet the Volume Editors

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Preface

In the vibrant tapestry of life on Earth, there exists a realm of remarkable beauty and complexity—the world of plants. Plants, with their myriad forms, colors, and functions, have fascinated humanity for centuries. They are the foundation of terrestrial ecosystems, providing oxygen, sustenance, and shelter to countless organisms. Yet, the intricate web of plant life is facing unprecedented challenges in the modern age. *Floristic Diversity – Biology and Conservation* is an exploration into the captivating world of plant ecology and aquatic ecology. This book is the culmination of the collective efforts of passionate researchers, each dedicated to unraveling the mysteries of our planet's flora and aquatic ecosystems. In these pages, we delve into diverse topics that span arid deserts, bustling urban centers, pristine forests, and aquatic landscapes.

Our journey begins with a groundbreaking methodology, the Floristic-Holistic Method, designed to reevaluate floristic diversity, conservation, and ecosystem protection in arid, semi-arid, and sub-humid regions. From there, we traverse the globe, from the urban jungles of Beijing, China, to the fringe areas of Jaldapara National Park in the Indian sub-Himalayan region, exploring the intricate relationships between biodiversity and human communities. The Western Himalayas come alive as we adopt a pluralistic approach to biodiversity conservation, embracing the traditions and customs of indigenous people. Traditional ecological customary law emerges as a beacon of hope for the conservation and sustainability of our precious biodiversity.

Turning our gaze to aquatic ecosystems, we journey to Indonesia's peatland areas, where we advocate for sustainable development and the protection of aquatic biodiversity. Mesopotamia, particularly the Kurdistan region of Iraq, becomes the backdrop for our exploration of the environmental impact of aquatic lower plants. Intriguingly, we discover the potential of aquatic plants as nature's own filtration systems, capable of removing pesticides from wastewater, a crucial step towards a cleaner and healthier environment. Lastly, we tackle the invasive water hyacinth, an environmental challenge that demands innovative management solutions and presents new opportunities.

Floristic Diversity – Biology and Conservation is a testament to the shared vision of our co-editors and contributors—a vision of a world where the rich tapestry of plant life, both on land and in water, thrives and endures. It is a call to action, an invitation to join us on this enlightening journey of discovery, conservation, and appreciation for the remarkable diversity of life that surrounds us. We hope this book inspires you to explore the intricate beauty of our planet's flora and aquatic ecosystems and encourages you to become stewards of our natural world. Together, we can ensure that future generations inherit a world where biodiversity flourishes and the wonders of nature continue to captivate our hearts and minds.

With gratitude for your interest in the preservation of our planet's natural heritage.

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Section 1

Plant Ecology

Chapter 1

The Floristic-Holistic Method for Arid, Semiarid, and Subhumid Areas: A Tool for the Revaluation of Floristic Diversity, Conservation, and Protection of the Ecosystem

Cynthia Cristina González, Antonella M. Lista, Cristian Silva, Mauricio Alejandro Joffe, Gastón Ezequiel Ponce, Patricia Lorena Simón and Magdalena Llorens

Abstract

The valorization of methods for comprehensive data collection is one of the fundamental tools to establish concrete bases and is applicable to lines of work in conservation, preservation, and protection of ecosystems. During the last 20 years, from the Botany Laboratory and Herbarium Trelew, we have valued the Floristic-Holistic Method that we have been adapting, for flora surveys. Method is intensively used in some Argentine provinces of arid, semiarid, and subhumid zones of the South American Arid Diagonal (Santa Cruz, Chubut, Río Negro, Neuquén, Mendoza, and arid islands of the Patagonian Atlantic coast). This revaluation focuses its importance on not only providing information on ecological parameters (bare soil, topsoil, living plant cover, and dead plant cover), richness, equitability, and floristic diversity, but also on status, conservation, botanical types, biological forms, adaptations, plant density, percentages of protected species, potential invasions of exotic species, forage productivity, and animal receptivity. The information is comprehensive and adaptable to different situations, applicable to different plant associations, types of terrain, and landscape units (open and closed mount, shrubby steppes, subshrubs, grasses, wastelands, rocky fields, peladales, and all kinds of modified areas). The method thus holistically conceptualizes ecosystem goods and services, allowing their study at different scales.

Keywords: flora, method, south American arid diagonal, grasslands, mount, steppe

1. Introduction

The natural grasslands of the arid and semiarid zones are nonarable land due to climatic, edaphic, or topographic limitations, which are covered by native and/or naturalized vegetation. They can be used as fodder for domestic and wild livestock, as well as to extract water and wood, and for recreational purposes [1]. Likewise, a characteristic of the natural grasslands of Argentine Patagonia (as well as much of the South American Arid Diagonal) is that different biological forms coexist (shrubs, subshrubs, herbaceous eudicots, and grasses) [2–4]. In these ecosystems, it is necessary to use an ecological evaluation method that considers the different biological forms that make up that plant community and that allows differentiating the forms present regardless of whether they are foragers or not, and whether they are present in all seasons of the year or not. That is, the method must reflect the comprehensive diversity present in the area, beyond the uses assigned to each of the species that make up the identified diversity indices (such as wild herbivory or livestock).

Starting in 1995, the Herbarium Trelew work team, referred in the following sections as HTW, used a variety of methods in the field for the flora censuses carried out, according to specific work requirements. Then, starting in 2002, the Pastoral Value Method [2–4], known in the following sections as PVM, is integrated into the methodologies to calculate the ecological parameters considering results and data obtained from the structure of the vegetation, forage productivity, and livestock receptivity.

From 2005 to 2009, it was adapted by the HTW work team gradually the way in which the data were collected based on: the need to generate specific data for the different lines of work that made up the HTW (research, project development, education, professional training, university training, and environmental services), the characteristics of arid and semiarid zones, the floristic composition observed, the field experience by the work staff, the observations in the floristic interactions, and the bases of conservation and preservation to be considered on the identified vegetation units and landscape units. The PVM was thus transformed into a post for obtaining and assessing new results and new horizons of botanical interpretation, expanding data collection not only to considerations of vegetation structure, forage productivity, and animal receptivity, but also to considerations of the type holistic ones related to plant ecology and eco-physiology for arid, semiarid, and subhumid zones. There is a change in the observation for data collection, moving from an exclusive livestock and productive approach to a multidisciplinary botanical, biological, ecological, physiological, and environmental approach, thus considering a new conservationist and protectionist point of view of the environments to evaluate.

In the PVM, the observations focus on the recording, which plants are available for livestock consumption, not only if they are young branches but also the height of the grazing animal and annual plants are not considered in the survey. On the other hand, in the Floristic-Holistic Method, called in the next sections as FHM, the entire flora is surveyed, regardless of the height of the plants or whether it is a young or old branch, focusing the observation mainly on the data of plants considering the presence and if they are alive. Starting in 2010, the FHM began to take hold, which is used to date in the active lines of work of the Botany Laboratory and HTW.

Since the 1990s, by the HTW work team, the published qualitative and quantitative methods have been adapted based on the experimental requirements with the aim of obtaining a modified method that has a conservationist and protectionist vision of the flora of the surveyed sites. It was also sought that the exposed method be useful to different types of applications in the field and diverse scopes in different areas of science. In this way, a method is obtained that considers and groups several methods in a complete way, feasible for application and analysis, applicable in terrestrial ecosystems for arid, semiarid, and subhumid zones, taking into account the visualization and understanding requirements of existing ecological dynamics and relationships to consider when making decisions on conservation, protection, planning, and management, which allow sustainable use of ecosystem goods and services in a systemic and holistic way. It is intended to express the path traveled both in field work and in office work in the last two decades by the HTW, based on the integration of qualitative and quantitative methods used historically, as they were adapted based on the experimental requirements, in view of the creation of the Floristic-Holistic Method that points toward a conservationist and protectionist vision of the flora of the surveyed sites.

2. Environmental characterization of census areas

Argentina's Arid Diagonal is defined by climatic-geographical aspects as an arid strip of latitudinal distribution that includes cold deserts (high Andean and Patagonian) and warm ones on the eastern Andean slope in the shadow of rains. The typification of mesic-aridic soils in the high Andes and Patagonia and thermo-aridic in low Andean pockets and plains and the phytogeographic and syntaxonomic diversity give it an identity that differentiates it from the rest of the dry areas of the world. These aspects also allow Arid Diagonal to be granted the condition of bio-climate entity [5].

Argentina's Arid Diagonal [5] (**Figure 1**) is defined as referring exclusively to the distribution in Argentina of the South American Arid Diagonal. It extends through 17° latitude between 27° and 44°S, south of 45°S (**Figure 1**), and precipitation is from the Pacific and occurs throughout the year. From the particularities, it is characterized by two climatic regimes: Tropical to the north and Mediterranean to the south of 35°S and in the high mountain range, determined by the influence of the anticyclones of the Atlantic and the Pacific, by the climate of mesic-aridic soil in the high Andes and Patagonia and thermal-aridic in the foothills and plains. On the other hand, Diagonal Árida Argentina includes six associated phytogeographic regions: Altoandina, Puna, Payunia, Patagonia, Cardonal, and Mount [5]. By relating the regimes to the soils and the phytogeographic regions present, the cold and warm deserts that comprise it can be recognized: cold deserts (Altoandino, Puna, Payunia, and Patagonia) and hot deserts (Cardonal and Mount).

3. Materials and methods

Floristic surveys were carried out with various methods along different sectors of Argentina's Arid Diagonal, perfecting this method from 1344 transects, with 260,000 base data that will later be expanded to other derived data and a sampling effort of 403,200 steps (403.2 kilometers) surveyed. This distance was covered on foot, lowering a rod every three steps to take a census of all the flora present. The set of transects represents the environmental evaluation of the flora of the regions over two decades, integrating 21 years of sampling (between 2001 and 2022).

Considering the geographical distribution of the transects, 181 correspond to transects carried out in the province of Santa Cruz, 780 in Chubut, 23 in Río Negro, and 360 in Mendoza. Taking into account the geographical positions of each transect, results from census areas belonging to the high Andean, puna, payunia, patagonia, cardonal, and mount regions were included for the evaluation of the method [5]. Specifically for the bioclimatic zones raised within the South American Arid Diagonal

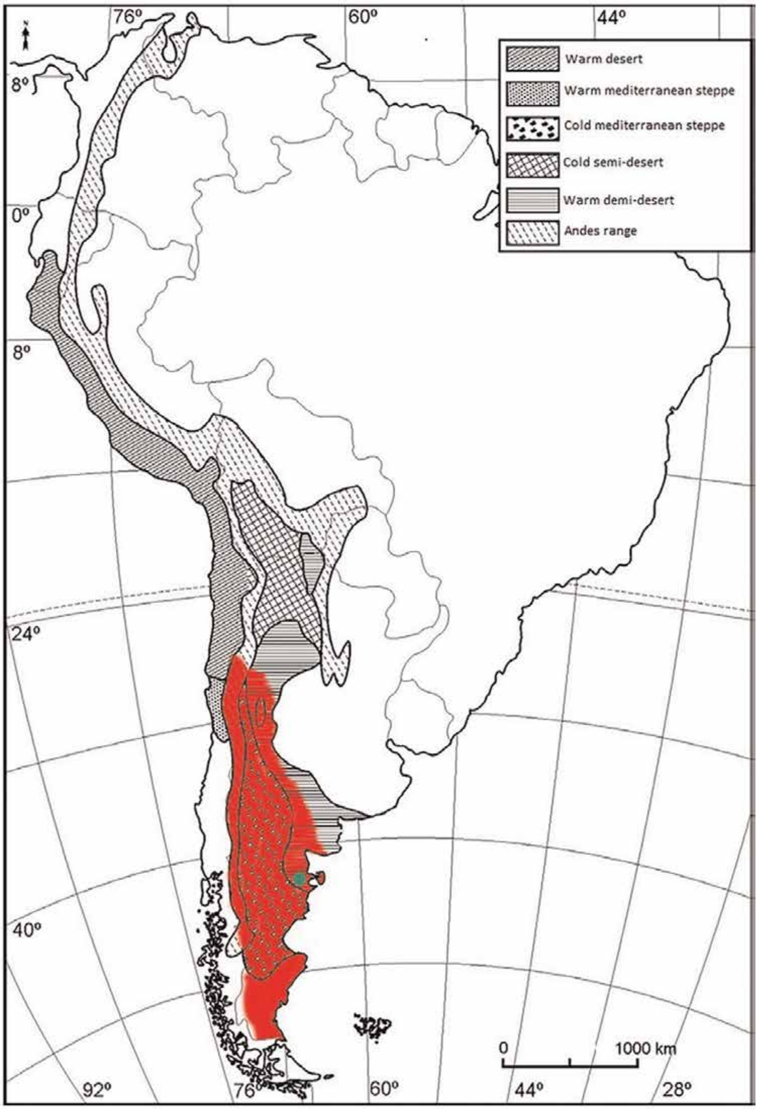

Figure 1.
Distribution of rainfall and physiognomies in the area of the South American Arid Diagonal. Taken from [5]. In red, areas where flora censuses were carried out with the proposed method. The green dot indicates a simultaneous census area with the Floristic-Holistic Method (FHM) and the Pastoral Value Method (PVM).

[5], 555 transects belonging to the cold Mediterranean steppe, 545 to warm semideserts, and 158 to the Andean range are recognized (**Figure 1** and **Table 1**). Considering hot and cold environments of the total number of transects, 545 correspond to hot desert transects and 713 to cold deserts.

It is worth mentioning that the method was applied in different ecological areas, such as:

- In the province of Santa Cruz, 161 transects were considered in the central plateau area, 7 in the humid Magellanic steppe area, 8 in the dry Magellanic steppe area, and 26 in the "Mata Negra" scrub area.

Ecological areas according to INTA	Phytogeographic areas	Bioclimatic entity of the South American arid diagonal	Usage factor (UF-%)
South Mount	Mount	Warm semidesert	25–35
North mount	Mount	Warm semidesert	30–50
Coast	Patagonia and mount	In warm semidesert and Cold Mediterranean steppe	25–35
Steppe (Saws and Central Plateaus)	Patagonia and payunia	Cold Mediterranean steppe	25–35
Steppe (Saws and Western Plateaus)	Patagonia and payunia	Cold Mediterranean steppe	30–50
Gramineous steppe (Pre-mountain range)	Puna, patagonia and high Andean	Andes range	40–60

Table 1.
Use factor in the different ecological areas, phytogeographic areas, or bioclimatic entities surveyed.

- In the province of Chubut, 259 transects were considered in the mount area, 499 in the steppe, six in the pre-mountain range area, and three in the Andean forest area.
- In the province of Río Negro, 23 transects are considered that corresponds entirely to the mount area.
- In the province of Mendoza, 151 transects from the Andean area, 61 from the steppe area, and 92 from the mount area were evaluated.

For the development of the method, different situations were taken and it came to be taken as the most powerful and relevant method to evaluate the flora, including plants, fungi, lichens, and macroalgae (such as macroalgae of the genus *Chara,* very common in pond areas in semideserts) in different situations. We have tested the use of the method for studies of general plant biodiversity, for comparison between different landscape units and for comparison of the same landscape unit throughout the different seasons of the year (spring, summer, autumn, and winter) or throughout of several years, to calculate the receptivity of domestic and/or wild animals, to evaluate the degrees of degradation over the years, or the passive or active ecological restoration of land, to know the degree of conservation of an area, to assess the loss of diversity/productivity/receptivity of flood-prone areas where dams or weirs will be built or where the water course will be diverted, in areas that have suffered clearing, fires or changes in land use, including for opening to livestock or agricultural barrier or road diversions, industrial effluent impacts, and for monitoring loss of native species and/or biological invasions concrete and/or potential, and for mining studies, for evaluation of studies of direct and indirect impacts of various kinds, for studies of ethnobotanical uses, etc. In all cases, the method has proven to be the most powerful for comprehensive assessments of the flora.

4. Description of the floristic-holistic method (FHM)

This proposal combines several types of sampling in a single comprehensive methodology. This method combines the point intercept line with the Point Centered Quadrants Method [6] and the Pastoral Value Method (PVM) [2–4].

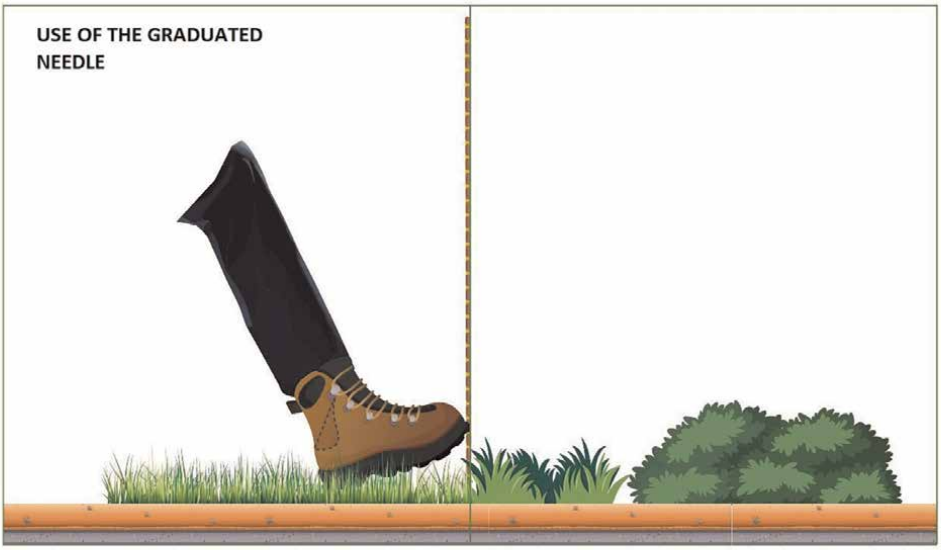

Figure 2.
Location and use of the metal needle. Modified from [2, 3].

For data collection in the field, the types of environments must be recognized, classifying the vegetation by its physiognomy and by the dominant aspects, highlighting those that make the greatest contribution to the total coverage.

The Floristic-Holistic Method (FHM) consists of randomly locating the first point of the transect, and the rest of the points are located on an imaginary line at a fixed distance. Each transect had 100 equidistant points, whose distance was equal to 3 paces (1 pace = 1 meter). To ensure a good census of vegetation, data collection is avoided near fences, roads, or areas disturbed by the passage of vehicles, or in patches that are not representative of the vegetation.

To perform the reading, a metal needle 1 m long and 5 mm in diameter is used. The needle is stuck in the ground at the height of the toe of the shoe (**Figure 2**) and vegetation records are taken along the needle, noting suitable forms for it.

To place the needle at each point, you look at the reference point, thus avoiding choosing where to place it.

All living plants are taken as the focus of observation, regardless of whether they are forage, ephemeral, or annual. Thus:

- If a live plant or branch is touched directly (regardless of whether or not it is accessible to herbivores), the number of touches observed circled should be noted. A touch is considered to be one or more contacts of the live portions that occur for every 1 cm of the needle, if the contacts occupy 2 cm, they are considered 2 touches, and so on (**Figure 3**). The presence and the number of touches, if it is alive, are relieved.

- If the species or part contacted is dead, an "X" surrounded by a circle should be noted and it is considered dead standing (**Figure 4**).

Due to the superposition of different biological forms in the vertical structure, one or more plant species can be recorded in the same reading.

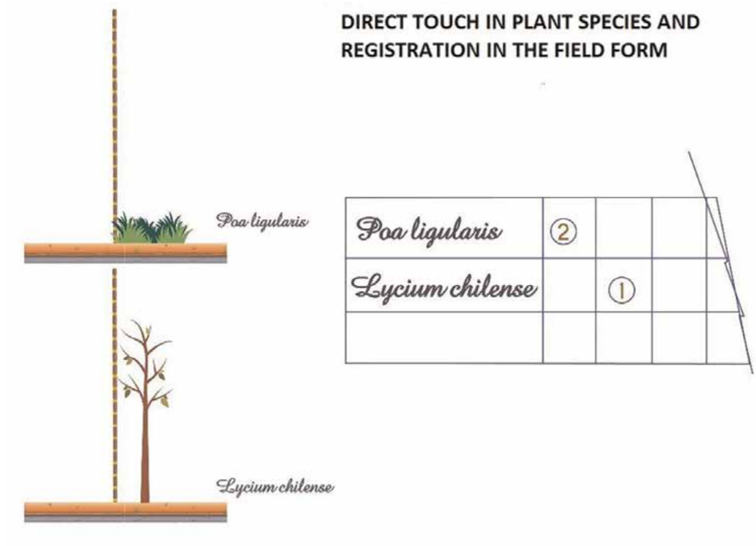

Figure 3.
Direct touch on perennial plant and a living portion of the plant. Modified from [2, 3].

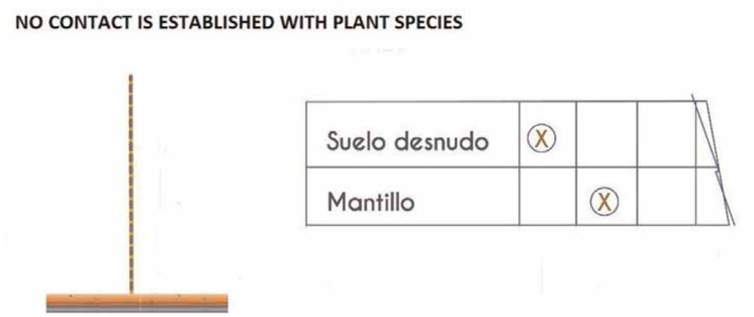

Figure 4.
Direct contact of bare soil, mulch, rock, or erosion pavement. Modified from [2, 3].

- If there is no direct contact with living plant species along the needle. And in the event that the direct contact of the needle is bare soil, topsoil (dead or decomposing plant material on the surface), rock (rocky outcrops or large clasts), or erosion pavement (high percentage of stones of different surface sizes), it is recorded with an "X" surrounded by a circle. Then, the closest plant in the four quadrants is observed, which one is noted (without circling the number of touches, since the touch is indirect) (**Figure 5**). The indirect touch is relieved only on living plants.

From the information obtained in each transect, the attributes of the soil and vegetation are summarized:

Bare or unvegetated ground: Sum of points where the needle directly touched bare ground, rock, topsoil, and other surface soil attributes.

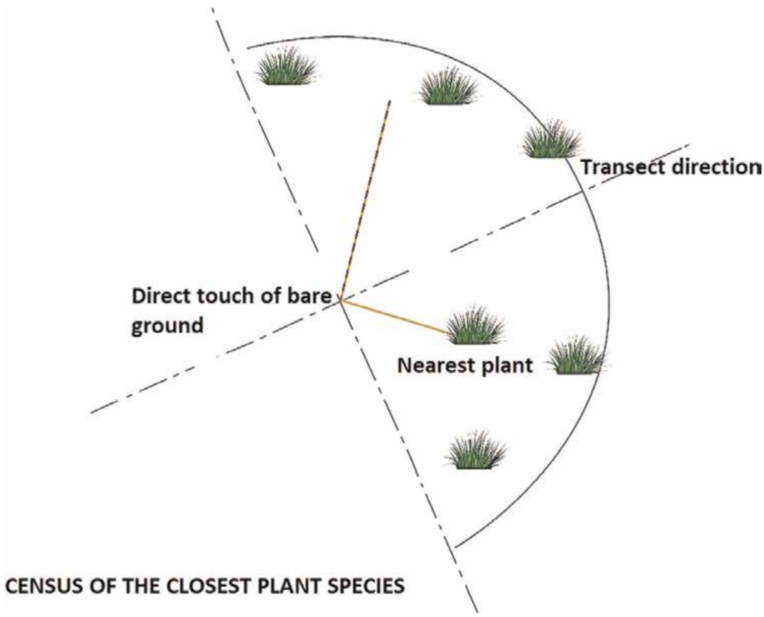

Figure 5.
When the needle touch bare soil, mulch, rock, or erosional pavement, the closest species of the four quadrants is counted. Modified from [2, 3].

Dead plant material: Sum of points where the needle directly touched a dead plant in a living position or pieces of dead branches not incorporated into the soil.

Litter: Sum of points where the needle directly touched mulch or decomposing dead plant material incorporated into the soil (broken branches, leaves, seeds, remains of flowers, and fruits).

Coverage by species (CoSp): Number of points in which a species has been found (the closest plants are not included). Since the points are 100, the coverage can be expressed as a percentage. To facilitate its computation, the mark or number of touches of directly touched plants is circled on the spreadsheet.

Total relative plant cover (TRPC): Sum of the cover (Co) of plant species. It would be the number of points where the rod directly touched a living plant (closest plants are not included). Since the points are 100, the coverage can be expressed as a percentage. To facilitate its computation, the mark or number of touches of directly touched plants is circled on the spreadsheet.

Total absolute plant cover (TAPC): Sum of all the covers of the species.

Specific plant coverage (SPC—touches by species): Total number of contacts of the rod with a species (the number of touches that has been recorded for each species (direct touch) is added). Percentage expression of the relationship between the number of touches made to a species (TSp) and that of total touches (TT) made to all the species registered in the 100 sampled points: SPC = (TSp x 100)/TT.

For this point, it is recommended to follow the updated names of the species according to the catalog of vascular plants of the southern cone [7].

Cover by biological forms (CBF): Percentage of total cover or by species that correspond to the different biological forms (shrubs, herbs, grasses, trees, succulents, and thallophytes).

Cover by biological types: Percentage of total cover corresponding to the type of plant according to the classification of the large groups of plants (Bryophyta, Lycophyta, Monilophyta, Gymnosperms (Gnetophyta, Coniferophyta), angiosperms (Monocotyledons, Eudicots, Basal Angiosperms, Magnolides), fungi (Mucoromycota, Ascomycota, Basidiomycota, etc.), lichens.

With respect to monocotyledons, they can be grouped into gramineous and non-gramineous monocots. As for lichens, the species itself, their growth form (crustaceans, foliose, and fruticulous), the type of thallus (homogeneous or heterogeneous structure), and/or the substrate in which they live (saxicolous, terrestrial, etc.) can be considered as corticultural, follicultural, or zoobiotic.

Coverage by biological status: Percentage of total coverage or by species that corresponds to the different types of status in plants (native nonendemic, endemic, introduced non-feral, native feral). At this point, the IUCN red list of treated species (https://www.iucnredlist.org/) and checklist of CITES species (https://checklist.cites.org/#/en) can be considered, as well as legislation national. In the case of Argentina, we used resolution 84/2010 (red list of endemic species of Argentina—https://www.argentina.gob.ar/normativa/nacional/resoluci%C3%B3n-84-2010-165,374) and resolution 109/2021 (list of invasive, potentially invasive, and cryptogenic exotic species—https://www.argentina.gob.ar/normativa/nacional/resoluci%C3%B3n-109-2021-348,718), both resolutions of the Ministry of Environment and Control of Sustainable Development of the Nation.

Coverage by biotype or type of life: Percentage of total coverage or by species that corresponds to the different types of plants (annuals, biennials, perennials, and multiennials).

Coverage by botanical families: Percentage of total coverage or by species that corresponds to the different botanical families (Alliaceae, Apiaceae, Asteraceae, Cactaceae, Fabaceae, Poaceae, and so on).

Coverage Raunkiaer biological forms: Percentage of total coverage or by species that correspond to the different life forms according to Raunkiaer [8]. This classification is based on the position of the shoot buds, and this is an adaptive character because growth depends on the buds once the adverse season is over. Five main categories are distinguished in this classification:

1. Therophytes or annual plants: Spend the adverse period in the seed stage.

2. Hydrophytes: Shoot buds in the water (they can be floating or fixed in the mud).

3. Geophytes or cryptophytes: Vegetative buds are below ground level.

4. Hemicryptophytes: Vegetative buds are found at surface level.

5. Camephytes plants whose vegetative buds are found in the aerial parts, but below 25 cm in height.

6. Phanerophytes: Plants with vegetative buds located in the aerial part above 25 cm in height. In addition, the Phanerophytes, according to their height are divided into nanophanerophytes (plants up to 2 meters high), microphanerophytes (plants between 2 and 8 meters high), mesophanerophytes (plants from 8 to 30 meters high) and megaphanerophytes (plants more 30 meters high).

7. Epiphytes: Plants that live on other plants.

They can also be quantified according to adaptation (xerophytes, mesophytes, hydrophytes, and so on) and organ modifications (plants with rhizomes, tubers, bulbs, foliar thorns, cauline thorns, napiform roots, and so on).

Plant-specific density: Number of plants per hectare. Number of times a plant appears every 100 direct hits on a 100 meters transect. It is calculated from the number of plants recorded in the transect and considering the length of each transect (100 meters).

Shanon-Weaver Diversity Index: It is calculated from the proportions (p_i) of each species (i) in the total sample of individuals. It is calculated using the following formula: $H = -\Sigma p_i \log_e p_i$. Where H is the logarithmic measure of diversity, and p_i = proportion of individuals of species i with respect to the total number of individuals (i.e., the relative abundance of species i). It can be said that the Shannon diversity index measures (the reciprocal of) the probability of selecting all the species in the proportion that they exist in the population; that is, it measures the probability that a sample selected at random from an infinitely contains exactly n_1 individuals of species 1, n_2 of species 2, ... and n_s individuals of species S [9–11].

The diversity value (H) generally varies between 1.5 and 3.5 and rarely exceeds 4.5 [12]. It is worth mentioning that the maximum diversity ($H_{max} = \ln S$) is reached when all species are equally present. On the other hand, the value of H is bounded between 0 and ln(s), which tends to zero in communities with little diversity and is equal to the logarithm of the species richness in communities with maximum equality [13].

Equity: It allows knowing the degree of regularity with which individuals are distributed among species. It is calculated using the following formula: $E = H/\ln S$.

Where H is the diversity index and S is the number of species (specific richness). Evenness approaches zero when one species dominates all others in the community and approaches 1 when all species share similar abundances [13].

Wealth: Number of recorded species.

Species Quality index (SQI): Specific quality index that has been assigned to each species as a result of the evaluation of its degree of acceptability by livestock, the period in which it is used, and its nutritional value (in Ref. to [2, 3]). But many other species surveyed by our HTW team based on more than 25 years of field observation in different areas with different conditions and different levels of degradation are also recorded. **Table 2** presents a list of species with their SQI.

Pastoral Value (PV): The value of the pastoral value determines the amount of forage available at the livestock level. It is calculated based on its floristic composition, and the quality and quantity of the species that compose it (in the census considering only living plants and those of forage value).

The following formula was used: $PV = (0.2 \times \Sigma (Tsp \times SSI) \times TAPC)/TT$.

where TSp = Touches per species, SQI = Specific Quality Index, TAPC = Total absolute plant cover, TT = Total Touches. The constant 0.2 is used to keep the range of pastoral values between 0 and 100. Note: Once the census calculations have been carried out, the pastoral values (PV) are obtained per transect carried out. Subsequently, the average PV (PVp) is calculated for each surveyed environment.

Use Factor (UF): The concept of use factor corresponds to the percentage of available forage that can be grazed by livestock to allow sustainable production over time. This factor varies with the type of vegetation in each area, the climatic conditions, and the vigor of the most important forage plant species. These values for each environment were developed by researchers from the National Institute of Agricultural Technology (INTA Trelew, Chubut, Argentina), according to what was

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Herb	Rosaceae	*Acaena spp.*	3	Bush	Zygophyllaceae	*Larrea spp.*	0
Bush	Verbenaceae	*Acantholippia seriphioides*	2	Herb	Fabaceae	*Lathyrus magellanicus*	2
Bush	Asteraceae	*Acanthostyles bunifolius*	2	Herb	Malvaceae	*Lecanophora sp.*	3
Herb	Fabaceae	*Adesmia aff philips*	0	Herb	Brassicaceae	*Lepidium spp.*	2
Bush	Fabaceae	*Adesmia boronioides*	0	Grass	Poaceae	*Leptochloa crinita*	3
Herb	Fabaceae	*Adesmia capitellata*	2	Herb	Asteraceae	*Leuceria achillaefolia*	1
Herb	Fabaceae	*Adesmia corymbosa*	2	Bush	Loranthaceae	*Ligaria cuneifolia*	0
Herb	Fabaceae	*Adesmia gutullifera*	0	Grass	Poaceae	*Lolium perenne*	1
Herb	Fabaceae	*Adesmia longipes*	2	Bush	Solanaceae	*Lycium ameghinoi*	1
Herb	Fabaceae	*Adesmia lotoides*	2	Bush	Solanaceae	*Lycium chilense*	5
Herb	Fabaceae	*Adesmia quadripinnata*	1	Bush	Solanaceae	*Lycium gillesianum*	3
Herb	Fabaceae	*Adesmia retrofracta*	3	Bush	Solanaceae	*Lycium tenuispinosum*	2
Bush	Fabaceae	*Adesmia trijuga*	3	Succulent	Cactaceae	*Maihuenia patagonica*	0
Herb	Fabaceae	*Adesmia villosa*	2	Succulent	Cactaceae	*Maihueniopsis darwinii*	0
Bush	Fabaceae	*Adesmia volckmanii*	3	Herb	Malvaceae	*Malvella leprosa*	2
Grass	Poaceae	*Agropyron spp.*	2	Herb	Fabaceae	*Medicago lupulina*	1
Grass	Poaceae	*Agrostis spp*	5	Herb	Fabaceae	*Medicago sativa*	3
Grass	Poaceae	*Alopecus magellanicus*	1	Herb	Oleaceae	*Menodora decemfida*	1
Grass	Poaceae	*Ammophila arenaria*	0	Bush	Oleaceae	*Menodora robusta*	1
Herb	Primulaceae	*Anagallis alternifolia*	1	Herb	Loasaceae	*Mentzelia albecens*	3
Bush	Fabaceae	*Anarthrophyllum desideratum*	1	Herb	Loasaceae	*Mentzelia parvifolia*	0
Bush	Fabaceae	*Anarthrophyllum rigidum*	3	Bush	Polygalaceae	*Moninna dyctiocarpa*	3
Grass	Poaceae	*Aristida mendocina*	5	Bush	Plantaginaceae	*Monthea aphylla*	0
Grass	Poaceae	*Aristida spegazzinii*	0	Grass	Poaceae	*Muhlembergia asperifolia*	0

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Herb	schoepfiaceae	*Arjona spp.*	2	Bush	Verbenaceae	*Mulguraea aspera*	5
Grass	Poaceae	*Arrehenatherum elatius*	1	Bush	Verbenaceae	*Mulguraea ligustrina*	5
Herb	Fabaceae	*Astragalus spp.*	0	Bush	Verbenaceae	*Mulguraea scoparia*	3
Bush	Amaranthaceae	*Atriplex spp.*	3	Bush	Verbenaceae	*Mulguraea tridens*	3
Bush	Apiaceae	*Azorella caespitosa*	1	Herb	Bryophyta	*Mosses*	0
Bush	Apiaceae	*Azorella microphylla*	0	Bush	Asteraceae	*Mutisia retrorsa*	0
Bush	Apiaceae	*Azorella prolifera*	2	Bush	Asteraceae	*Nardophyllum bryoides*	0
Bush	Apiaceae	*Azorella monantha*	0	Bush	Asteraceae	*Nardophyllum chiliotrichioides*	1
Bush	Asteraceae	*Baccharis darwinii*	3				
Bush	Asteraceae	*Baccharis divaricata*	3	Grass	Poaceae	*Nasella spp.*	3
Bush	Asteraceae	*Baccharis salicifolia*	2	Bush	Asteraceae	*Nassauvia aculeata*	1
Bush	Asteraceae	*Baccharis spartioides*	0	Bush	Asteraceae	*Nassauvia axillaris*	1
Herb	Asteraceae	*Baccharis tenella*	2	Bush	Asteraceae	*Nassauvia glomerulosa*	2
Bush	Berberidaceae	*Berberis microphylla*	1	Bush	Asteraceae	*Nassauvia ulicina*	0
Herb	Calyceraceae	*Boopis anthemioides*	2	Grass	Poaceae	*Nassella longiglumis*	4
Bush	Nyctaginaceae	*Bougainvillea spinosa*	0	Grass	Poaceae	*Nassella tenuis*	2
Bush	Asteraceae	*Brachiclados caespitosa*	2	Grass	Poaceae	*N. tenuissima*	0
Bush	Asteraceae	*Brachyclados lyciodes*	2	Herb	Brassicaceae	*Nasturtium officinale*	3
Bush	Asteraceae	*Brachyclados megalantus*	2	Herb	Solanaceae	*Nicotiana spp.*	1
Bush	Polygalaceae	*Bredemeyera microphylla*	4	Herb	Amaryllidaceae	*Notoscordum gracile*	1
Grass	Poaceae	*Briza reniformes*	0	Herb	Onagraceae	*Oenothera spp.*	0
Grass	Poaceae	*Bromus brevis*	2	Herb	Iridaceae	*Olsynium spp.*	2
Grass	Poaceae	*Bromus catharticus*	5	Herb	Oxalidaceae	*Oxalis compacta*	1

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Grass	Poaceae	*Bromus setifolius*	3	Grass	Poaceae	*Panicum urvilleanum*	1
Grass	Poaceae	*Bromus unioloides*	3	Grass	Poaceae	*Pappostipa ameghinoi*	1
Bush	Scrophulariaceae	*Buddleja spp.*	4	Grass	Poaceae	*Pappostipa chrysophylla*	1
Herb	Loasaceae	*Caiophora pulchella*	0	Grass	Poaceae	*Pappostipa humilis*	0
Herb	Portulacaceae	*Calandrinia affinis*	2	Grass	Poaceae	*Pappostipa ibari*	3
Herb	Calceolariaceae	*Calceolaria spp.*	2	Grass	Poaceae	*Pappostipa major*	0
Thallophyte	Teleochistaceae	*Caloplaca sp.*	0	Grass	Poaceae	*Pappostipa psilantha*	3
Herb	Calyceraceae	*Calycera spinulosa*	2	Grass	Poaceae	*Pappostipa speciosa*	2
Herb	Brassicaceae	*Cardamine cordata*	3	Bush	Fabaceae	*Parkinsonia precox*	3
Herb	Asteraceae	*Carduus thoermeri*	1	Thallophyte	Parmeliaceae	*Lichens*	0
Herb	Cyperaceae	*Carex argentina*	1	Succulent	Cactaceae	*Parodia submammulosa*	0
Herb	Cyperaceae	*Carex gayana*	2	Bush	Caryophyllaceae	*Paronichya chilensis*	0
Herb	Cyperaceae	*Carex subantártica*	1	Herb	Asteraceae	*Parthenium hysterophorus*	1
Herb	Caryophyllaceae	*Cerastium arvense*	3	Herb	Asteraceae	*Perezia recurvata*	1
Bush	Asteraceae	*Chuquiraga aurea*	1	Bush	Ericaceae	*Pernettya mucronata*	0
Bush	Asteraceae	*Chuquiraga avellanedae*	2	Herb	Boraginaceae	*Phacelia spp.*	2
Bush	Asteraceae	*Chuquiraga erinacea sp. erinacea*	2	Bush	Apocynaceae	*Philibertia candolleana*	1
Bush	Asteraceae	*Chuquiraga erinacea sp. Hystrix*	2	Grass	Poaceae	*Phleum pratense*	2
Bush	Asteraceae	*Chuquiraga rosulata*	2	Grass	Poaceae	*Phragmites australis*	0
Herb	Asteraceae	*Cirsium vulgare*	0	Herb	Brassicaceae	*Physaria mendocina*	2
Bush	Ranunculaceae	*Clematis montevidensis*	4	Herb	Loasaceae	*Pinnasa bergii*	2
Bush	Euphorbiaceae	*Coliguaja integerrima*	0	Grass	Poaceae	*Piptochaetium napostense*	5
Bush	Rhamnaceae	*Colletia spinosissima*	1	Herb	Plantaginaceae	*Plantago patagonica*	1
Bush	Rhamnaceae	*Condalia microphylla*	0	Herb	Plantaginaceae	*Plantago sp.*	3

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Herb	Convolvulaceae	*Convolvulus arvensis*	4	Bush	Lythraceae	*Pleurophora patagonica*	3
Herb	Poaceae	*Cortaderia spp*	0	Grass	Poaceae	*Poa holciformis*	0
Bush	Malvaceae	*Corynabutylon bicolor*	2	Grass	Poaceae	*Poa lanuginosa*	3
Herb	Boraginaceae	*Cryptantha globulifera*	1	Grass	Poaceae	*Poa ligularis*	5
Bush	Asteraceae	*Cyclolepis genistoides*	1	Grass	Poaceae	*Poa pratensis*	3
Herb	Cyperaceae	*Cyperus sp.*	2	Grass	Poaceae	*Poa spiciformis*	5
Grass	Poaceae	*Dactylis glomerata*	3	Grass	Poaceae	*Polypogom australis*	0
succulents	cacti	*Denmozoa rhodacantha*	0	Grass	Poaceae	*Polypogon monspeliensis*	4
Grass	Poaceae	*Deschampsia flexuosa*	2	Herb	Portulacaceae	*Portulaca spp.*	3
Herb	Brassicaceae	*Descurainia pimpinelifolia*	2	Bush	Fabaceae	*Prosopidastrum angusticarpum*	1
Herb	Brassicaceae	*Diplotaxis tenuifolia*	3	Bush	Fabaceae	*Prosopidastrum globosum*	3
Bush	Rhamnaceae	*Discaria articulata*	0	Bush	Fabaceae	*Prosopidastrum striatum*	3
Grass	Poaceae	*Distichlis spp.*	1	Bush	Fabaceae	*Prosopis alpatacus*	2
Succulents	Cactaceae	*Echinopsis leucantha*	0	Bush	Fabaceae	*Prosopis denudans*	2
Herb	Cyperaceae	*Eleocharis pseudoalbibracteata*	4	Bush	Fabaceae	*Prosopis flexuosa*	0
Bush	Ephedraceae	*Ephedra chilensis*	3	Bush	Fabaceae	*Prosopis strombulifera*	2
Bush	Ephedraceae	*Ephedra ocherata*	3	Bush	Asteraceae	*Proustia cuneifolia*	3
Bush	Ephedraceae	*Ephedra triandra*	0	Bush	Asteraceae	*Pseudognaphalium vira vira*	4
Herb	Equisetaceae	*Equisetum bogotense*	2	Herb	Asteraceae	*Psyla tenella*	0
Herb	Equisetaceae	*Equisetum giganteum*	2	Herb	Ranunculaceae	*Ranunculus peduncularis*	1
Grass	Poaceae	*Eremium erianthus*	5	Bush	Rhamnaceae	*Retanilla patagonica*	2
Herb	Geraniaceae	*Erodium cicutarium*	5	Herb	Polygonaceae	*Rumex acetosella*	0
Herb	Phrymaceae	*Erythrante lutea*	1	Grass	Poaceae	*Rytidosperma spp.*	5
Bush	Asteraceae	*Eupatorium bunifolium*	3	Bush	Amaranthaceae	*Salicornia ambigua*	0

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Bush	Asteraceae	*Eupatorium patens*	3	Bush	Amaranthaceae	*Salsola kali*	1
Bush	Euphorbiaceae	*Euphorbia collina*	0	Bush	Lamiaceae	*Salvia cuspidata*	5
Herb	Convolvulaceae	*Evolvulus sericeus*	0	Bush	Amaranthaceae	*Sarcocornia spp.*	1
Bush	Solanaceae	*Fabiana denudata*	2	Bush	Anacardiaceae	*Schinus johnstonii*	1
Bush	Solanaceae	*Fabiana patagonica*	1	Bush	Anacardiaceae	*Schinus marchandii*	1
Bush	Solanaceae	*Fabiana peckii*	1	Bush	Anacardiaceae	*Schinus roigii*	1
Grass	Poaceae	*Festuca argentina*	0				
Grass	Poaceae	*Festuca arundinacea*	2	Bush	Asteraceae	*Senecio albibracteata*	1
Grass	Poaceae	*Festuca australis*	3	Bush	Asteraceae	*Senecio filaginoides*	0
Grass	Poaceae	*Festuca kurtziana*	1	Bush	Asteraceae	*Senecio spp.*	1
Grass	Poaceae	*Festuca magellanica*	1	Bush	Fabaceae	*Senna aphylla*	2
Grass	Poaceae	*Festuca pallescens*	2	Grass	Poaceae	*Setaria spp.*	4
Grass	Poaceae	*Festuca pyrogea*	1	Herb	iridaceae	*Sisyrinchium spp.*	2
Bush	Frankeniaceae	*Franquenia patagonica*	1	Herb	Solanaceae	*Solanum sarrachioides*	1
Herb	Rubiaceae	*Galium richardianum*	2	Herb	Asteraceae	*Sonchus oleraceus*	5
Herb	Fabaceae	*Glycirrhyza astragalina*	0	Herb	Malvaceae	*Sphaeralcea miniata*	2
Bush	Asteraceae	*Pentaphorus glutinosus*	0	Herb	Malvaceae	*Sphaeralcea sp.*	3
Bush	Asteraceae	*Grindelia spp.*	0	Grass	Poaceae	*Sporobolus rigens*	0
Bush	Asteraceae	*Gutierrezia solbriggi*	3	Bush	Euphorbiaceae	*Stillingia patagonica*	0
Herb	Amaryllidaceae	*Habranthus jamesonii*	2	Bush	Amaranthaceae	*Suaeda divaricata*	0
Herb	Ranunculaceae	*Halerpestes cymbalaria*	1	Herb	Brassicaceae	*Sysimbrium altissimum*	2
Bush	Asteraceae	*Haplopappus pectinatus*	0	Herb	Asteraceae	*Tagetes mendocina*	3
Herb	Fabaceae	*Hoffmannseggia spp*	3	Tree	Tamaricaceae	*Tamarix ramossisima*	3

Biological form	Botanical family	Name	IE	Biological form	Botanical family	Name	IE
Grass	Poaceae	*Hordeum comosus*	3	Herb	Asteraceae	*Taraxacum officinale*	2
Grass	Poaceae	*Hordeum hallophylum*	2	Bush	Asteraceae	*Tessaria absinthioides*	1
Herb	Asteraceae	*Hyalis argentea*	0	Bush	Rosaceae	*Tetraglochin alatum*	1
Herb	Apiaceae	*Hydrocotyle ranunculoides*	2	Bush	Rosaceae	*Tetraglochin ameghinoi*	2
Herb	Asteraceae	*Hypochaeris chilensis*	2	Bush	Rosaceae	*Tetraglochin caespitosum*	2
Herb	Asteraceae	*Hypochaeris sp.*	1	Grass	Poaceae	*Trichloris crinita*	4
Herb	Asteraceae	*Hysterionica jasionoides*	2	Herb	Asteraceae	*Trichocline sinuata*	0
Grass	Poaceae	*Jarava ambigua*	0	Herb	Fabaceae	*Trifolium repens*	1
Grass	Poaceae	*Jarava neaei*	2	Grass	Poaceae	*Trisetum longiglume*	1
Grass	Poaceae	*Jarava psylantha*	3	Grass	Poaceae	*Trisetum spicatum*	1
Herb	Juncaceae	*Juncus spp.*	2	Herb	Amaryllidaceae	*Tristagma patagonica*	2
Bush	Verbenaceae	*Junellia chritmifolia*	3	Herb	Asteraceae	*Tymophylla pentachaeta*	1
Bush	Verbenaceae	*Junellia connatibracteata*	1	Tree	Fabaceae	*Vachellia caven*	3
Bush	Verbenaceae	*Junellia minutifolia*	1	Herb	Valerianaceae	*Valerian spp.*	2
Bush	Verbenaceae	*Junellia seriphioides*	1	Herb	Scrophulariaceae	*Verbascum thapsus*	4
Bush	Verbenaceae	*Junellia spisa*	1	Herb	Plantaginaceae	*Veronica anagallis-aquatica*	3
Bush	Verbenaceae	*Junellia thymifolia*	2	Herb	Fabaceae	*Vicia nigricans*	2
Grass	Poaceae	*Koeleria sp.*	1	Herb	Asteraceae	*Xanthium spinosum*	0
Herb	Asteraceae	*Lactuca serriola*	4	Herb	Amaryllidaceae	*Zephyranthes gillesiana*	2
Bush	Zygophyllaceae	*Larrea ameghinoi*	1	Bush	Fabaceae	*Zuccagnia punctata*	0

Table 2.
Specific Quality Index (SQI) of the most common species in the surveyed areas.

Ecological areas	Forage availability (Kg Dry Matter/hectare)
South mount	13.30 × PV
North mount	15 × PV
Coast	12.26 × PV
Steppe (Saws and Central Plateaus)	14.05 × PV.
Steppe (Saws and Western Plateaus)	9.58 × PV
Gramineous steppe (Pre mountain range)	9.16 × PV

Table 3.
Forage availability in the different ecological areas. To see the equivalence in phytogeographic areas or bioclimatic entities, see ***Table 1****.*

established in similar environments in other parts of the world [14], and the evaluation of different productive situations in different environments [2–4], see **Table 1**.

Receptivity Estimate: It is calculated from the determination of the forage productivity and the intensity or degree of use, which is called the Use Factor (UF) of each ecological area [15]. The INTA Trelew carried out censuses with forage harvest in different ecological areas, from which it determined different linear regression models of the forage availability of herbaceous and 20% woody forage (FAHWF 20%) [2–4], See **Table 3**.

Recommended load: For the analysis, the measured pastoral value is used to estimate forage availability, and to determine the recommended load, the corresponding Use Factor (UF) of the same was calculated and the forage to be hypothetically consumed by the cattle is computed and divided by 300 kilos of dry matter per year (KgMS/year), which consumes 1 Ovine Livestock Unit (OLU or UGO in Spanish by “Unidad Ganadera Ovina”), which corresponds to a capon of the Merino breed of 40 kg of live weight. On the other hand, you can take the Equivalent Patagonic Sheep (EPS or EOP in spanish by “Equivalente Oveja Patagónico”), which corresponds to the average annual requirements of a Corriedale sheep of 49 kg of live weight at service, sheared in September. That gestates and weans a live 20 kg lamb at 100 days of lactation. This corresponds to 2.79 mega calories of metabolizable energy per day [16]. Then, it is possible to estimate the stocking rate in other categories [2, 3], be they sheep (dry sheep, breeding sheep, lamb, ram, etc.), cattle (bull, dry cow, breeding cow, heifer, calf, etc.), goats (castrón, dry goat, breeding goat, goating, etc.), horses (horse, filly, dry mare, breeding mare), rabbit, hare, etc. (**Table 4**). It is also possible to calculate the stocking rate considering the square league, which is a measure widely used in some regions by farmers. It is important to remember that 1 square league is equal to 2330.99 hectares.

Vegetation map: These data must be accompanied by a satellite image, in order to calculate the number of hectares occupied by each environment and thus have the animal load data. Normally, the processing and analysis of available satellite images are carried out in the office. Based on the electromagnetic radiation reflected and emitted by all the elements present on the earth’s surface, it is possible to obtain a map of plant forms present in a region, which is obtained from the conceptual classification of the environmental variability present, which can be measured in a satellite image by combining bands of different wavelengths.

The way in which each of the elements reflects or emits radiation has to do with its particular characteristics (chemical composition, surface roughness, moisture

Category	Olu (or Ugo)	Category	Olu (or Ugo)
Capon	1	Breeding cow (400 kg)	12
breeding sheep	1.2	Dry cow	9
Sheep (Milk tooth—2 teeth)	0.73	Heifer (1st service)	11
Lamb (2 teeth–4 teeth)	1	Bull (600 kg)	11
Sheep (Baby tooth—2 teeth)	0.85	Calf (150–250 kg)	5.5
Lamb (2 teeth–4 teeth)	1.15	Calf (250–350 kg)	7.2
ram in maintenance	1.15	Dry goat	0.8
ram in service	1.5	Breeding goat	1.1
Sheep (first gestation period)	0.92	Goating, cabrilla, or kid	0.4
Sheep (second gestation period)	1.1	Castron or castrated goat	1.25
Dry sheep	0.83	Equines. Studs	15

Table 4.
Livestock equivalences according to categories and species, taken from [2–4].

content, reflective properties, etc.); this behavior is unique for each coverage type and is called a spectral signature.

Sentinel T19HEB images, etc. can be used. Images with low cloudiness should be chosen. A combination of false-color composite (FCC) can be made of bands 11-8-4, and the area of the image that will be of interest should be cropped. Then, through exhaustive visual analysis of a variety of compositions and spectral features of the image, the information that allows the best discrimination of the categories of interest is selected. In short, the image must be analyzed using combinations of bands based on the spectral behavior of the vegetation. In this way, through the application of unsupervised and supervised digital classification techniques, the first map of plant formations is generated.

Finally, it is important to note that the classification of the multispectral image implies categorizing the reflectances present in the image in statistical terms. This involves reducing the measurement scale of a continuous variable (reflectances) to a nominal or categorical scale (classes of information), that is, transforming the original image into another image whose pixels no longer reflect values of electromagnetic energy or physical variables (such as radiance or reflectance), but categories or classes of information (types of vegetation).

5. Comparison between the floristic-holistic method and the pastoral value method

To analyze how much the data obtained with the FHM deviate from the data obtained with the PVM [2, 3], five field transects were carried out with each method. To avoid census errors, both methods were performed on each transect line at the same time and they were recorded on separate forms (**Figure 6**). The surveys were carried out in 2015, in a mount area that bio-climatically corresponds to the warm semidesert in Ref. [5] (**Figure 1**: Green Point). They were carried out in the "El Moro" livestock establishment, Telsen Department, Province of Chubut, and 120 km north of

Figure 6.
Field survey. Observe the data collection with two spreadsheets at the same time (each spreadsheet corresponds to each one of the methods).

the city of Trelew and is accessed by provincial route N°. 8 (**Figure 1**. Green point). The area is between 30 and 50 meters above sea level and is characterized by having average rainfall that averages 150 mm per year. Winds prevail from the west sector, sometimes reaching speeds greater than 80 km per hour. The average annual temperature is 13–14°C [17].

The "El Moro" establishment is located in the biogeographical province of Austral Mount. It is characterized by the constant presence of the "Jarillas," shrubs belonging to the Zigofiláceas family. The Zygophyllaceae species with the greatest representation in the study area are the "Jarilla" *Larrea divaricata* and the "Jarilla fine" *Larrea nitida,* as well as the "Jarilla creeping" *Larrea ameghinoi.* These plants reach one or two meters in height, or less (in very windswept areas), and grow scattered, leaving clearings where herbs develop at the right times. Among the shrubs that grow associated with Jarillas, the "Alpataco" *Prosopis alpataco*, the "Mata sebo" *Monttea aphylla*, the "Monte negro" *Bougainvillea spinosa*, the "Pichana" *Senna aphylla*, and the "Chirriadora" *Chuquiraga erinacea ssp hystrix,* among others. Other important components of the Austral Mount are they are the representatives of the family Cactaceae, the grasses, and other herbaceous plants.

According to the censuses carried out, both methods showed the same values of bare soil (average 43.8%), plant cover (26.6%), dead plant material (standing dead) 21.2%, and litter 8.4%. Analyzing the biological forms, it was observed that herbs were found between 3.5 and 4.2%, grasses between 16 and 18.5%, respectively, shrubs between 73 and 76.8%, and cacti between 13.5 and 4.5% (**Table 2**). Regarding the comparison of both methods, it can be observed that the differences are slight, but a

Biological form	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)
Herbs	3.55	4.24	0.69
Grasses	16.03	18.52	2.49
Shrubbery	76.87	73.16	−3.72
Cacti	3.55	4.55	1.00

Table 5.
Comparison of biological forms in both methods.

tendency to overestimate grasses (difference of 2.49%) and underestimate shrubs (difference of 3.72%) is observed in the PVM (see **Table 5**).

Analyzing forms and biological types together, a slight difference was observed between both methods (**Table 1**). For all forms, it was observed that the percentage was less than 0.5% between both methods, except in perennial grasses, where the percentage was 1.61% higher in PVM, and in shrubs, which was 3.87% lower in PVM (see **Table 6**).

On the other hand, the status showed that native species ranged between 51.3 and 55.3%, endemic species between 35.7 and 38.6%, and introduced species between 8.9 and 10%. Comparing both methods, a difference between 1 and 4% was observed between both methods (see **Table 7**). Recording the greatest differences between native species is probably due to the fact that in this category "native species" has the highest number of registered species compared with "endemic species" and "introduced species."

Form and biological type	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)
Annual herbs	1.84	2.20	0.36
Annual grasses	6.96	7.85	0.88
Perennial Herbs	1.71	2.04	0.33
Perennial grasses	9.07	10.68	1.61
Shrubbery	76.08	72.21	−3.87
Subshrubs	0.79	0.94	0.15
Cacti and succulents	3.55	4.08	0.53

Table 6.
Comparison of forms and biological types in both methods.

Status	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)
Native plants	55.32	51.33	−3.99
Endemic plants	35.74	38.62	2.88
Introduced plants	8.94	10.05	1.11

Table 7.
Comparison of the status of both methods.

Taxonomic type	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)
Eudicots	83.84	81.32	−2.52
Monocots	16.16	18.68	2.52

Table 8.
Comparison of taxonomic type in both methods.

Analyzing the taxonomic type, it was observed that eudicots range between 81.3 and 83.8%, and monocots between 16.1 and 18.6% (see **Table 8**). Comparing both methods, it is observed that the PVM would be overestimating monocots by 2.5% and underestimating eudicots by 2.5%. It is precisely the same trend that has been observed above, a slight tendency to underestimate shrubs (eudicots) and overestimate grasses (monocotyledons).

Nineteen botanical families were registered. For the taxonomic identification of the plants, the names of the families accepted in the catalog of vascular plants of the southern cone [7] were used. The traditional designations for the names of the families: Compositae, Cruciferae, Gramineae, Leguminosae, and Umbelliferae have been replaced by those accepted in more recent publications [18] as Asteraceae, Brassicaceae, Poaceae, Fabaceae, and Apiaceae, respectively.

The analysis of the botanical families showed that there is a dominance of 5–6 families (Zygophyllaceae, Poaceae, Solanaceae, Verbenaceae, Fabaceae, Amaranthaceae) over the rest of the families, but that dominance is different if it is analyzed by a method or on the other (See **Table 9**).

The MFH analysis showed a dominance of the families Zygophyllaceae and Solanaceae (both with 18.79%). Then, Poaceae (16.03%), Fabaceae (13.93%), Verbenaceae (12.22%), Chenopodiaceae (8.41%), Cactaceae (3.55%), Asteraceae (2.5%), and Geraniaceae (1.45%) and the rest of the families represented in less than 1%. The MVP analysis showed a dominance of the Poaceae family (18.52%), along with Solanaceae (16.48%), Verbenaceae and Zygophyllaceae (both 14.44%), Fabaceae (13.65), Chenopodiaceae (8.95%), Cactaceae (4.08%), Asteraceae (2.67%), Geraniaceae (1.57%), Anacardiaceae (1, 26), and the rest of the families represented in less than 1%.

On the other hand, comparing both methods, it was observed that most of the botanical families they show a difference of less than 0.5%. But comparing the values of the differences, it was recorded that this difference is 2.2–2.4% higher in the families Poaceae and Verbenaceae for the MVP and 2.3% lower in Solanaceae, and 4.35% lower in Zygophyllaceae for the MVP (**Table 8**). These differences may be due to the fact that in the census of the PVM the presence of Zygophyllaceae would be underestimated due to the fact that the number of touches is not counted, but rather it is only registered with an "X" as a non-forage. Regarding the Solanaceae family, it could be slightly underestimated with the PVM because the needle touched non-forage portions of it. And finally, again a slight tendency to overestimate grasses (Poaceae) and some species of Verbenaceae is observed.

The diversity index (Shanon-Weaver) was similar in both methods (FHM 1.05, and PVM 0.99), showing a percentage difference of 0.06. Plant density showed different values in both methods. The FHM calculation resulted in 3420 plants/ha, and the MVP showed 3100 plants/ha. The difference of both methods is 320 plants/ha. This difference is quite significant and may be due to the number of touches each plant has.

Identified families	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)
Poaceae	16.03	18.52	2.49
Verbenaceae	12.22	14.44	2.22
Amaranthaceae	8.41	8.95	0.54
Cactaceae	3.55	4.08	0.53
Anacardiaceae	0.91	1.26	0.35
Loasaceae	0.13	0.31	0.18
Asteraceae	2.50	2.67	0.17
Rosaceae	0.66	0.78	0.12
Geraniaceae	1.45	1.57	0.12
Apiaceae	0.53	0.63	0.10
Caryophyllaceae	0.53	0.63	0.10
Plantaginaceae	0.13	0.16	0.03
Cyperaceae	0.13	0.16	0.03
Calyceraceae	0.13	0.16	0.03
Boraginaceae	0.13	0.16	0.03
Nyctaginaceae	1.05	0.94	−0.11
Fabaceae	13.93	13.65	−0.28
Solanaceae	18.79	16.48	−2.31
Zygophyllaceae	18.79	14.44	−4.35

Table 9.
Comparison of botanical families in both methods.

It is worth mentioning that in the VPM 637 total touches were recorded (direct forage touches + indirect forage touches + the touches corresponding to the direct and indirect “Xs”). On the other hand, in the MFH, 761 total touches were recorded (direct touches + indirect touches).

The analysis of forage availability and pastoral value, by the MVP, revealed the following data: The pastoral value ranged between 3.3 and 11.72 (average 5.78), and the average forage availability of 76.85 Kg dry matter/hectare. Showing a usable forage availability (with a use factor of 30%) of 23.06 Kg dry matter/hectare, this value would be giving a stocking rate of 0.08 OLU/ha or 0.04 EPS/ha. This would be equivalent to 200 capons per league or 400 sheep per league.

On the other hand, the MFH showed a pastoral value that ranged between 3.7 and 15.3 (average 9.27), and the average forage availability was 140.69 Kg dry matter/hectare. The usable forage availability (with a use factor of 30%) of 42.21 Kg dry matter/hectare. This last value would give a stocking rate of 0.14 OLU or 0.08 EPS/ha.

Comparing both methods, an important difference between the methods is observed (see **Table 9**). The pastoral value calculated by the FHM shows a value higher than that calculated by the PVM (37.6% higher), and the estimate of forage availability and stocking rate shows a value 45.3% higher than that calculated by the

Forage parameters	Floristic-holistic method (FHM)	Pastoral value method (PVM)	Difference (FHM-PVM)	Difference (FHM-PVM) expressed in %
Pastoral value	9.27	5.78	3.49	37.64
Forage availability (kg dm/ha)	140.69	76.85	63.84	45.38
Usable forage availability (use factor 30%)	42.21	23.06	19.15	45.38
Ovine livestock unit (Olu)	0.14	0.08	0.06	45.38
Equivalent patagonic sheep (Eps)	0.08	0.04	0.04	45.38

Table 10.
Comparison of pastoral value, forage availability, and stocking rate for both methods.

PVM (see **Table 10**). These differences will lie in the way of recording the data by both methods. In the FHM, all touches are recorded, while in the PVM, all forage touches are recorded but not all non-forage touches.

In nature, domestic grazers coexist with the natives and they all have different ways of feeding, some cut, others browse, uproot, rough, etc., and they also select what they most want and consume at different heights. Anyone would assume that the larger the animal, it could graze at higher altitudes, but this is not always the case in nature, there are many medium-sized and small-sized grazers and/or browsers that graze at high altitudes, as can be seen in small- and medium-sized rodents (guinea pigs, tuco-tucos, mice, hares, rabbits, and maras), and various species of birds, lizards, etc., which can be seen at the top of the bushes consuming flowers, fruits, and leaves (**Figures 7–11**), but also in the very intricate interior of the bushes, both sites are inaccessible to domestic livestock, but are inaccessible to many species of wildlife.

On the other hand, branches and thorns of shrubs were observed, non-forage parts by MVP, heavily browsed, debarked, and in some cases cut (**Figure 10**) by rodents. It is worth mentioning that the cutting of rodent branches is recognized because it is always a bevel cut. The most heavily barked shrubs were those of *Bougainvillea, Condalia, Lycium, Prosopis, Prosopidastrum,* and *Schinus species.* Despite long hours of observation and on numerous occasions, we were unable to determine whether this bark is consumed by rodents or they only perform this action to wear down and sharpen their teeth. But it is important to note that this action of debarking branches occurs more intensely in times of great drought and when there is not much forage supply and living flora. It is worth mentioning that in MVP, the person in charge of carrying out the sampling is the one who decides if the plant and/or part of the plant is edible or not, and if it is accessible or not for livestock. Therefore, in the FHM, by surveying everything that is alive, regardless of whether it is forage or not, this bias is avoided. The diversity of plant species in the arid and semiarid zones of Patagonia is crucial to cushion the effects of drought on the functioning of ecosystems [19]. Among the most important conclusions, they observed that ecosystems with a greater diversity of plant species are more likely to have species that are more tolerant to drought and, in addition, can make more efficient use of available resources due to the complementarity and synergistic interactions between the species.

Figure 7.
Detail of debarked branches at the base of the Prosopidastrum striatum *trunks.*

6. Virtues, advantages, and scope of the floristic-holistic method (FHM)

Among the most representative virtues of the FHM we can mention the following: it is a simple, practical method applicable to different types of land and low cost, and does not have negative effects on the ecosystem since it is not required to harvest materials or alter the feet of the species, and also combines quantitative and qualitative characters.

Figure 8.
Detail of bevel-cut twigs typical of rodents in Prosopidastrum striatum. *Note in the figure that they are upper branches, and are at a height of about 1 meter.*

Figure 9.
*Intensely browsed and debarked spines of alpataco (*Prosopis alpataco*). Notice rodent droppings on the floor.*

Figure 10.
*General view of Mata Amarilla (*Anarthrophyllum rigidum*—Family Fabaceae) heavily browsed.*

Whatever the application of interest and the type of environment to survey, it is necessary to have at least one experienced botanist with extensive knowledge of the flora. If necessary, field support technicians must also be prepared to assist in data collection and registration. As for office work, its planning and management are important, given that data analysis is long and complex, also requiring a prepared and trained team.

Based on its structure and work methodology, the method allows comparing a great diversity of biological, ecological, and environmental situations. For example, when it is necessary to carry out studies of general plant biodiversity (**Figure 12**), floristic composition (**Figure 13**), for comparison between different

Figure 11.
*Detail of bevel cut (*Anarthrophyllum rigidum*—Family Fabaceae) evidencing browsing by rodents (in this case it is rabbits).*

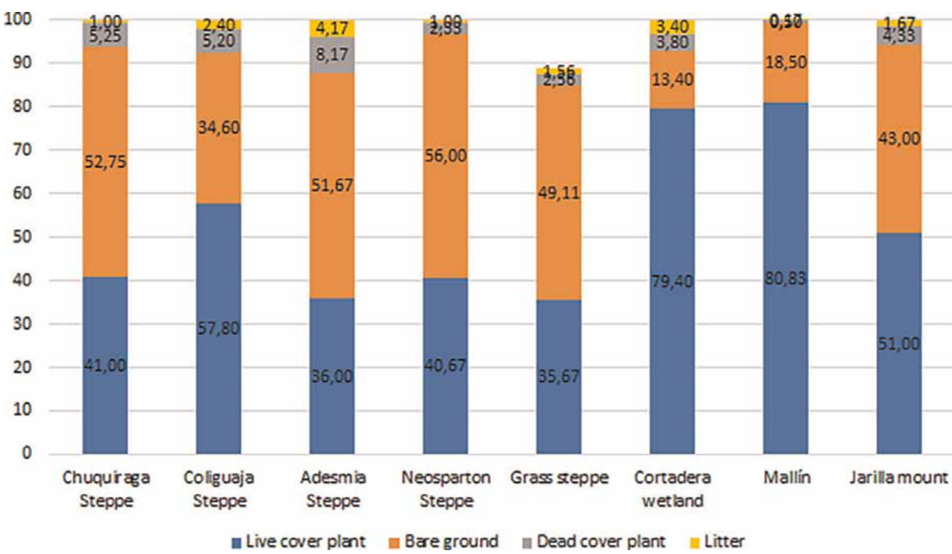

Figure 12.
Main ecological parameters in different environments of the cold Mediterranean steppe of Chubut. Values are expressed in percentages. Summer sampling 2012.

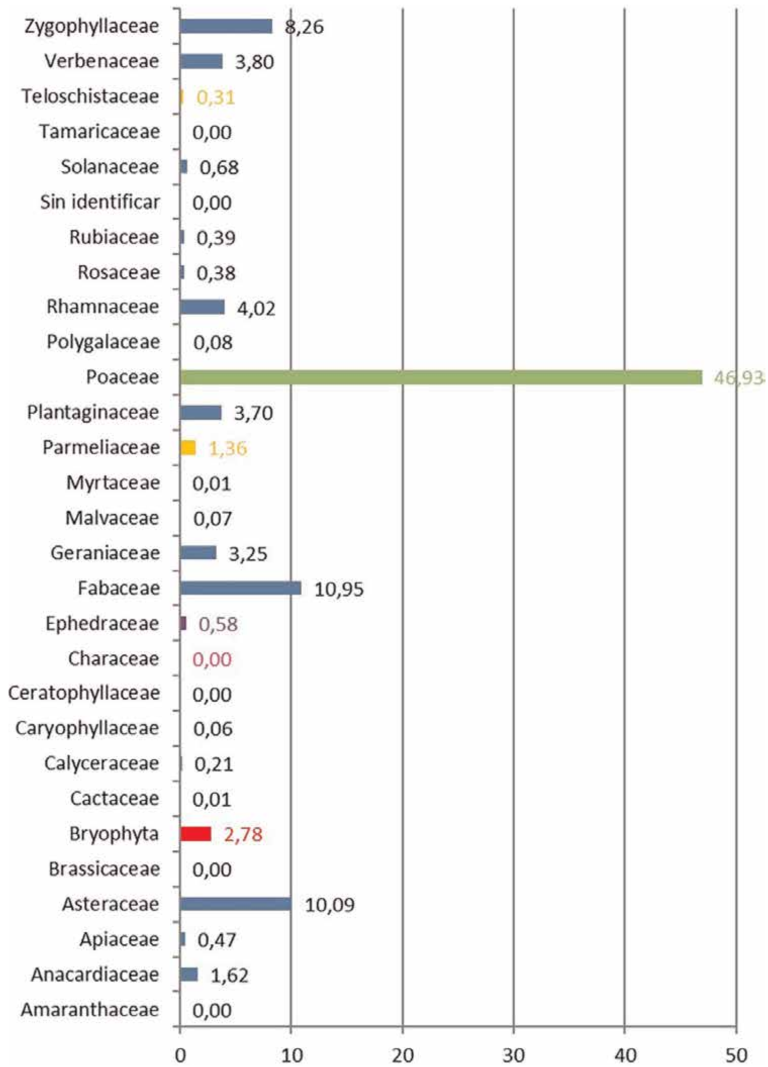

Figure 13.
Floristic composition by botanical families (%) for a baseline of a wind farm (renewable energies). Eudicotyledonous families in blue, monocots (Poaceae) in green, gymnosperms (Ephedraceae) in violet, lichenized fungi (Parmeliaceae and Teloschistaceae) in orange, and mosses (Bryaceae) in red. Mount environment in the warm semidesert, Province of Río Negro. Fall 2019 sampling.

landscape units (**Figure 14**), for comparison of the same landscape unit along the different seasons of the year (spring, summer, autumn, and winter—**Figure 15**) or over several years (**Figures 16–19**).

Data collection also applies to calculate the receptivity of domestic and/or wild animals (**Figure 17**), to assess the degrees of degradation over the years, or the passive or active ecological restoration of land (**Figures 18** and **19**), also to know the degree of conservation of an area, also to evaluate the loss of diversity/productivity/receptivity of flood-prone areas where dams or weirs will be built or where the watercourse will be diverted, and also in areas that suffered volcanism (**Figure 16**), fires (**Figure 18**), and/or clearing (**Figure 19**).

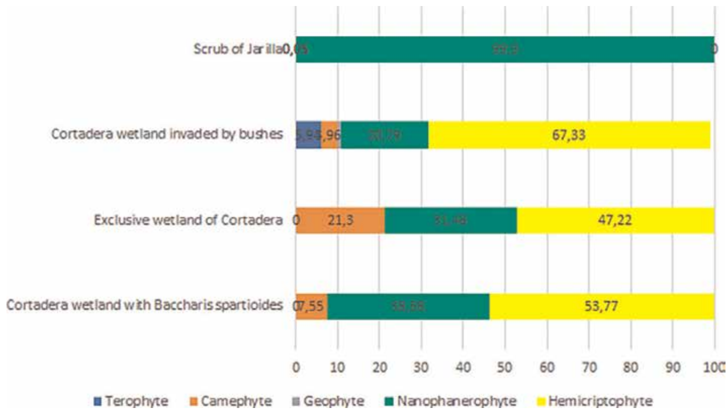

Figure 14.
Raunkiaer adaptive strategies, in different environments surveyed in the mount (warm semidesert) and high steppe (Andean range) of the province of Mendoza. 2019 Winter Samplings.

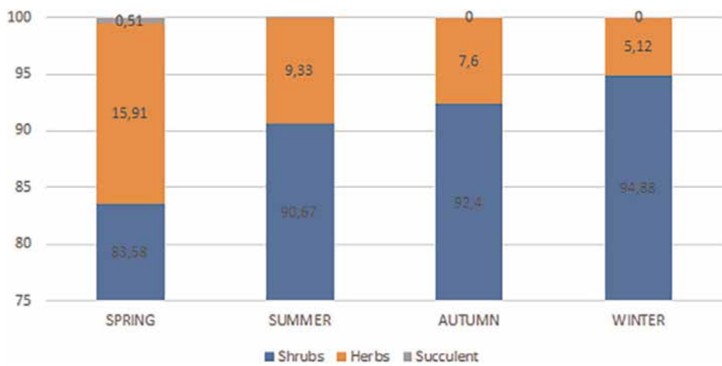

Figure 15.
Biological forms of the Neosparton steppe environment, which corresponds to the warm semidesert of Mendoza, expressed as a percentage. Samplings 2019.

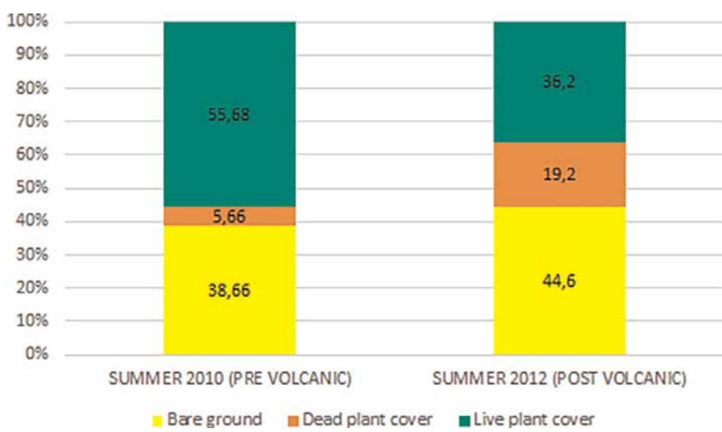

Figure 16.
Variation of biological forms in response to a volcanism event in the Mediterranean steppe of Chubut. Samplings at summer 2010 and 2012.

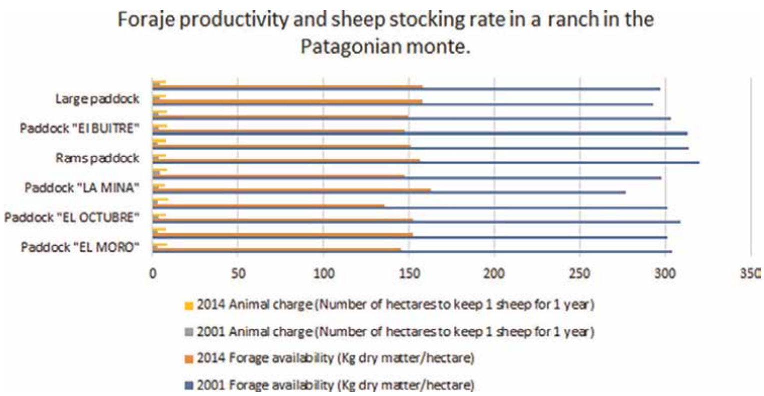

Figure 17.
Forage availability (in kilos of dry matter per hectare) and stocking rate (in sheep livestock units per hectare (OLU/ha)). Sampling in 2001 and 2014 for a stay in Mount Chubutense (warm semidesert). Related to an extensive impact activity (extensive livestock use). The names correspond to the denomination of the registered tables.

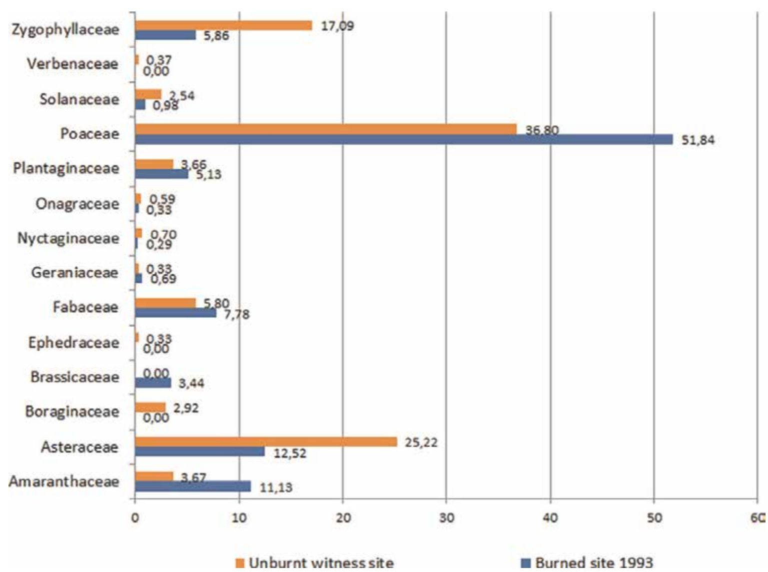

Figure 18.
Botanical families were identified in a burned site with 21 years of passive ecological restoration in comparison with a neighboring non-burned area (reference ecosystem). Samplings 2014 for a forest area (warm semidesert) of Chubut.

Applies to calculate changes in land use include for opening to livestock or agricultural barrier or road diversions, impacts of industrial effluents (**Figure 20**), and for monitoring the loss of native species and/or specific biological invasions and/or potential, for mining studies, for evaluation studies of direct and indirect impacts of various kinds, for studies of ethnobotanical uses (**Figure 21**), etc. As seen in the results presented, the FHM also allows:

- The visualization of all existing biological forms (**Figures 12–15**), valuing plant ecological relationships and recognizing in turn interactions with the fauna

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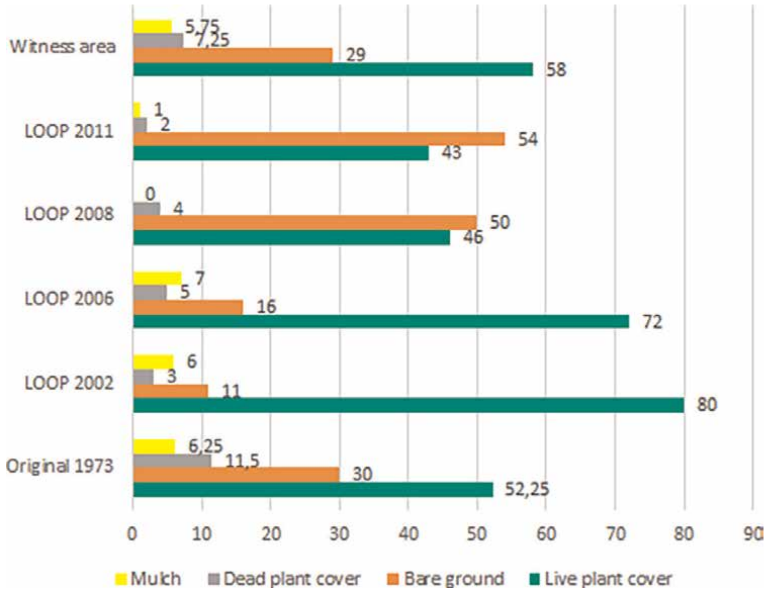

Figure 19.
Percentage representation of the ecological parameters recorded for an area of cold Mediterranean steppe in the province of Santa Cruz with a chronological comparison of 38 years to monitor a passive restoration process on a punctual disturbance due to intensive impact activity (gas pipeline). The trunk area (1973) corresponds to the initial clearing for the work of a gas pipeline, the following loops of different years, which correspond to new clearings to expand the capacity of the gas pipeline, and the witness area is a neighboring area where there was never any clearing.

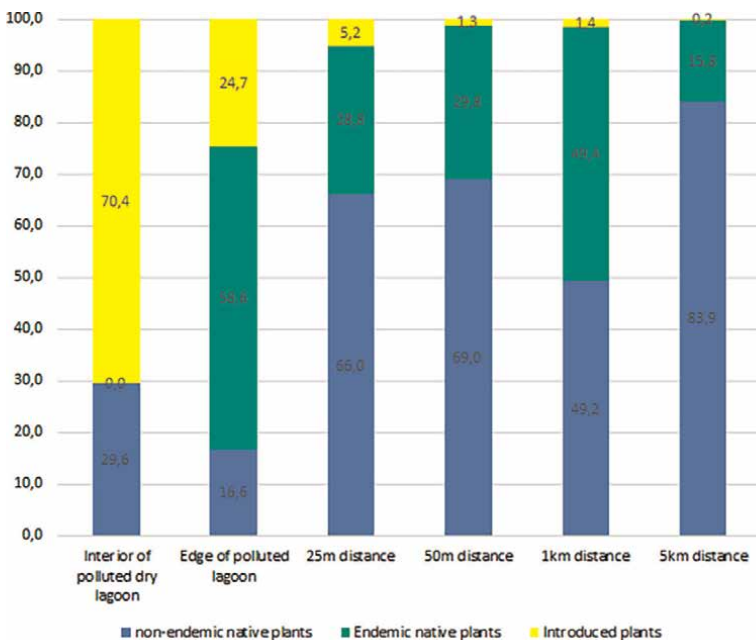

Figure 20.
Status in (%) of the surveyed plants according to a gradient of environmental contamination by industrial effluents with heavy metals. Border corresponds to the area of maximum contamination, then 25 meters, 50 meters, and the control at 5 km (reference ecosystem). Samplings 2014, 2015, and 2016 correspond to a forest area (warm semidesert), the province of Chubut. Note that in the area of greatest contamination there is a greater proportion of introduced species.

present in the sites surveyed, such as habitat use, use of biological corridors, herbivore, parasitism, symbiotic relationships, among others.

- To present the comprehensive plant stratification of the different phytogeographic units that make up the South American Arid Diagonal (**Figures 12–15**).

- Obtain specific data on ranges of environmental parameters that influence the distribution of species, being able to obtain, for example, data on the distribution of species, genus, family, and order by minimum and maximum height (in meters above sea level). The analysis for other parameters is applicable according to the tools used in the field, and it is possible to add to each transect, in addition to the geographic positioning data, values of relative humidity, ambient humidity, and incidence of solar radiation, among others (**Figures 12–18**).

- Analyze the status of areas of the direct and indirect impact regarding possible atmospheric contamination, infiltration into the ground, the presence of contaminants in receiving bodies (soil and/or water), and bioaccumulation of heavy metals, among others, in comparison with reference ecosystems (**Figure 20**).

- Obtain comparative data between disturbed areas and impacts and reference ecosystems (sites belonging to the phytogeographic units without disturbances or with minor impacts, which keep the ecological parameters of the bibliography stable) and carry out an analysis considering the time factor, being able to diagram, plan, and program prevention and mitigation measures for different types of impacts (regardless of their intensity, frequency, durability, or scale) (**Figures 16–19** and **20**).

- Obtain specific data for progress studies, analysis of desertification processes, clearing, and post-fire damage, thus obtaining a concrete database for decision-making, environmental management plans, and monitoring and contingency plans in a clear practical way applicable to the field (**Figures 16–21**).

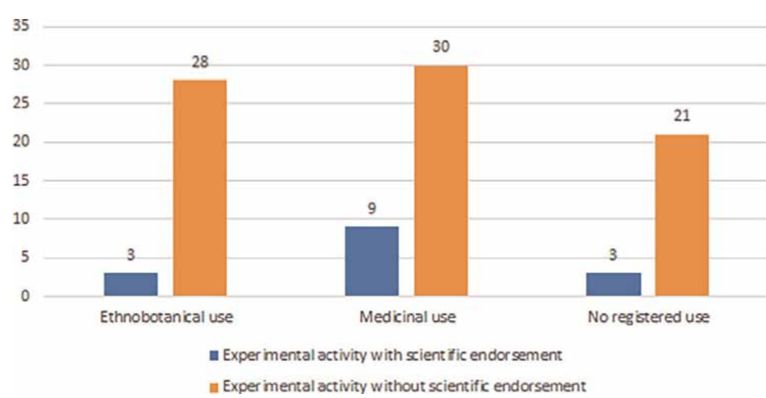

Figure 21.
Analysis of uses of plants based on data on plant cover, associated botanical uses, medicinal and others with and without scientific verification. Samplings 2013, 2014, and 2015, in Paso de Indios, cold Mediterranean steppe of Chubut.

- Work on territories subjected to anthropogenic activities with intensive impacts (1st, 2nd, and 3rd category mining, conventional and non-conventional oil extraction, renewable energy generation, and distribution of electricity and gas) as well as anthropogenic activities with extensive impacts (sheep, goat, horse and cattle farming, and agriculture including monocultures) (**Figures 17** and **19**).

- Carry out monitoring of the state of conservation and preservation of ecosystems, both applied to the conservation of species (in relation to their uses as ecosystem goods and services) and applied to the preservation of species (in relation to the intrinsic value of each species) (**Figures 12–15**, **17** and **19**).

- Obtain sociocultural assessments of the ecosystem goods and services related to the flora of a particular site (**Figure 21**).

- It provides the state, productive, and extractivist sectors with the necessary tools to revalue the flora that makes up a fundamental link for the conservation and preservation of the South American Arid Diagonal (**Figures 16–19**).

- The identification of biological and environmental indicators advances in invasive/exotic/introduced species, advances in adventitious species, and advances in naturalized species (**Figures 13**, **14**, and **20**).

- Establish the diagram (since it allows evaluating the reference ecosystem), planning (since it allows evaluating the progress situation), and progress and results (since it allows analyzing the results after the first reproductive season, first flowering season, first seed bank generation station, and its temporary advances) for remediation, rehabilitation, and ecological restoration work, given the plasticity in data collection (**Figures 13–16** and **17**).

- The analysis of compost composition and biological crusts, deepening the knowledge of seed banks (**Figure 13**).

- Evaluate the productivity of cultivation areas of both native flora and productive species (**Figure 17**).

- The analysis of the state of conservation and preservation of fresh and saline mallines, key areas for productivity, water balance, and biodiversity of Argentina's Arid Diagonal, being also sites highly impacted by oil, mining, and livestock activities (**Figures 14**, **17**, and **19**).

- Assess the recovery of biodiversity comprehensively with respect to the reference ecosystems (**Figures 14** and **16–21**).

- Evaluate the response based on obtaining ecological parameters in relation to tolerance gradients against stress situations, fundamentally against water stress.

- It offers the technician in the field the possibility of adapting the data collection according to the stated requirement, it allows the collection of data in different topographies of the land, thus favoring fieldwork. In turn, the data collection structure favors teamwork for cabinet determinations (**Figures 16–21**).

- The generation of specific databases on the current state of the flora of the surveyed environments, being able to generate scientific dissemination material, scientific communications, environmental education work at all educational and social levels, community work, analysis work economic sociocultural for Latin America (**Figures 16–21**).

- The generation of databases in vulnerable rural areas with scarce resources for environmental management and policy that require knowledge of their ecosystem goods and services by virtue of their sustainable use (**Figures 16–21**).

- The consideration and staging for the different actors involved in the academic, political, economic, social, institutional, and cultural spheres of the role of the flora in the environments to be studied, thus considering the environmental commitments through treaties, agreements, and agendas that Argentina assumes worldwide in consideration of the environmental situation, in relation to the objectives of sustainable development and the problems to be faced with respect to climate change.

- The generation of direct and indirect jobs, as well as the training, education, and improvement of the technical team, promotes the condition of inter and multidisciplinary teams.

- Promote community production, participation, and intervention projects, thus favoring the environmental commitment of rural communities and urban communities in relation to the flora of the places they inhabit.

- The conservation, restoration, and study of fragile ecosystems, favoring the development of planning and territorial ordering, are fundamental in the fulfillment and application of the current environmental policies of the country.

7. Conclusions

1. The methodology proposed by the FHM allows comprehensive data collection that provides multidisciplinary tools for the characterization of the plant ecology of the South American Arid Diagonal.

2. The advantages of FHM over other qualitative and quantitative methods for biological and environmental characterization have been demonstrated in the last two decades through fieldwork by the HTW team.

3. The application of the FHM in different landscape units and vegetation units allows us to offer concrete prevention, planning, and mitigation responses to the current environmental problems of the South American Arid Diagonal.

4. The methodological characteristics of the FHM allow this method to be replicated in the South American Arid Diagonal as well as in other arid, semiarid, and subhumid areas of the world.

5. The dynamics of the FHM allow the concrete formation of work groups both in the field and in the office, promoting and strengthening training and scientific unity.

6. The dynamics of the FHM allow scientific dissemination and community work as tools in raising awareness and environmental policies at a social, cultural, and economic level.

7. The presentation of the FHM to the global scientific community constitutes a tool for the comprehensive and holistic assessment of our plant ecosystems.

8. Final considerations

The valorization of the Floristic-Holistic Method stands out not only for the contributions and scope of the method, but also as a basic method against the main environmental problems, related to problems associated with the South American Arid Diagonal. Some of the problems are soil loss, water deficit, changes in use, clearing, affectation of native forests, conservation of protected natural areas, urban and rural planning, land use planning, zoning, environmental impact assessment processes and strategic environmental assessment, clearing, overgrazing, overlapping land use, loss of native vegetation, modifications in heterogeneous vegetation, affectation, and conservation of flora species protected by national and international regulations. As mentioned before, the Floristic-Holistic Method allows the environmental management of the ecosystem goods and services of the territories, the importance of international conventions and treaties, the international and national flora protection regulations, and the sustainable development goals (SDGs), within which is, among others, the conservation of ecosystems, as one of the fundamental aspects on which to develop science, technology, and lines of research.

Considering the 21 years of data collection, the results are encouraging. The Floristic-Holistic Method allows establishing new horizons (in terms of considerations and scope) for phyto-ecological field studies for arid, semiarid, and subhumid zones. Methods that guarantee the sustainable use of ecosystem goods and services, that allow environmental planning and evaluation in different types of territories, that minimize and mitigate possible impacts, and that favor technical scientific knowledge and development considering the zonal human resource are key tools for an environmental development that considers all the actors involved.

Concrete, applicable, and practical databases also favor decision-making, the sociopolitical cultural context of Latin America, policies, plans, and programs by the states, which integrate scientific and technical visions together with the needs of an environment, which consider the human actor as the main positive and negative modifier, as well as a generator of new paths, with a holistic horizon and sustainable in the vision of our environment.

General objectives

- Introduce the Floristic-Holistic Method to the global scientific community.

- To propose this methodology as an integral method to evaluate floristic biodiversity, ecological parameters, and eco-physiological parameters applicable to different types of landscape units, environment units, and vegetation units in arid, semiarid, and subhumid zones.

Particular objectives

- Explain in detail how the Floristic-Holistic Method is applied as a methodology in the field.
- Explain the application of the method in different types of environments, landscapes, and plant physiognomies.
- Explain the importance of comprehensive methods for the biological and environmental analysis of our ecosystems.
- Explain the usefulness of the Floristic-Holistic Method in the Argentine Arid Diagonal, and the importance of environmental characterizations in arid, semiarid, and subhumid zones in the post of their conservation and preservation.
- Explain how to calculate from the Floristic-Holistic Method, the common ecological parameters (bare soil, live and dead plant cover, litter, diversity index, evenness, specific richness, and plant density).
- Explain how the FHM allows evaluating the floristic composition detailing the botanical families, biological forms, types of life, and the classic and non-classical botanical types, such as macroalgae, lichenized, and non-lichenized fungi.
- Explain how the FHM evaluates through status and how it allows considering the protection of species at the international (IUCN and CITES) and national levels.
- Explain how the FHM allows to evaluate the eco-physiological aspects that other methodologies do not allow to contemplate in the data registry.
- Explain how it is also possible through the FHM to calculate the forage availability, the pastoral value, and how it also allows estimating the livestock receptivity of a region.
- Compare the Floristic-Holistic Method with the Pastoral Value Method, evaluating its comprehensive characterization in comparison with the utilitarian characterizations of other methodologies.
- Evaluate the advantages and disadvantages of the method based on the analysis of the results obtained in the last two decades of field implementation of the FHM.

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Chapter 2

Assessment of Urban Biodiversity: A Case Study of Beijing City, China

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Abstract

Habitat loss is the most important factor affecting biodiversity. Beijing is an international metropolis with rich biodiversity. With the development of urbanization, biodiversity has been affected to a certain extent in Beijing City. We investigated plant communities in three green land types, parks, residential areas, and roads along an urbanization gradient in the Beijing urban area (inner 6th ring road). Species composition, similarity index, and diversity of plants in urban areas were calculated. The results showed 536 species, belonging to 103 families, and 319 genera in the Beijing urban area. Among them, there were 361 native species and 175 imported species. Eighty species were imported from abroad and 95 species from inland, namely 14.9% and 17.7% of the total species, respectively. The species richness and diversity of trees and shrubs first increased and then decreased along the urbanization gradients, with the decreasing trend from the inner 2nd ring road and the increasing trend from the 3rd–4th ring road. No significant difference was found along the urbanization gradient for herbaceous plants. There were no significant differences in species evenness along the urbanization gradient.

Keywords: urbanization, green land types, plant, community, homogenization, species richness

1. Introduction

City is a complex ecosystem including nature and society [1]. Different functional areas in the city are embedded with each other to form a complex system, which supports the city's demand for huge logistics, energy flow, information flow, and other flows. It also determines that the city has special habitat characteristics, such as obvious gradient change of environmental factors, apparent reduction of natural habitat areas, habitat fragmentation, and fragile ecosystem [2]. Urban biodiversity is not only the fundamental condition of urban survival but also the basis of human survival. At the same time, it has ecological, cultural, and esthetic values [3]. The protection and maintenance of urban biodiversity is the foundation of urban healthy development, the premise of improving the function of urban ecosystem and meeting the needs of human survival. Urban green space is an artificially constructed plant community, which affects the living environment of citizens, but it is disturbed by human activities to a great extent. Therefore, the protection of biodiversity in the city is extremely important and difficult simultaneously.

Urbanization is considered to be one of the main drivers of environmental change, which has a significant impact on the attributes of biological and abiotic ecosystems all over the world [4–7]. Driven by the tide of economic globalization and the requirements of improving people's living standards, the level of urbanization will be further improved. At the global scale, a widely used dataset for projecting the global urbanization level by 2050 is the national-scale 5-year-interval World Urbanization Prospects (WUP) data released by the Population Division of the Department of Economic and Social Affairs of the United Nations (UNPD) [8]. According to WUP, the world urbanization rate will reach 68.4% by 2050 [9]. Well-managed urbanization processes can help maximize the benefits of economic agglomeration while reducing environmental degradation and other potential adverse impacts [10, 11]. However, rapid urbanization will also bring many negative effects. For example, the urban expanded, which often grows faster than parks or reservations [12–14]. Among them, the impact of urbanization on biodiversity is the focus of attention and one of the hotspots in current ecological research [15]. Urban expansion leads to habitat fragmentation and invasion of alien species, thus reducing professional species and increasing common generalist species. This process is defined as biological homogenization [13, 16, 17]. Urbanization leads to the decrease of biodiversity. The invasion of alien species and the reduction of local species caused by urbanization lead to the homogenization of urban organisms [13, 17–19], and the homogenization of urban plants is also prominent [20]. Plants are the basis of all life and development, providing habitats for animals and microorganisms.

Plant diversity is the foundation of urban ecosystem stability and the guarantee of urban sustainable development. It plays an indispensable role in the stability and function of urban ecosystem. Plant diversity under the influence of urbanization is the basis and hotspot of current urban biological ecosystem research [21]. The research on urban plant diversity began in the 1840s in Germany, Britain, and other European countries, and in the 1980s and 1990s there were extensive studies in various developed countries [22–26]. In developing countries, urbanization often has two characteristics: First, the natural ecosystem is replaced by artificial buildings; second, the natural soil is replaced by the green space dominated by exotic ornamental plants, which has a great impact on biodiversity [27]. China has a relatively late cognition of urban plant diversity, and there are few studies. Since 2000, there have been studies on plant diversity in Zunhua, Shanghai, and other cities in China [28–31]. Beijing, which has developed rapidly urbanization, also has a certain research foundation [32, 33], including research on plant diversity in parks [34–36], research on plant diversity in residential green spaces [37], and research on exotic plants in residential green spaces [38]. However, there are relatively few studies on the impact of urbanization on plant diversity under different urban green space types [39, 40], and there is a lack of research on the impact of urbanization gradient on plant distribution.

2. Research area and survey method

Beijing is the capital of China and the ancient capital of many dynasties in history. It is located in the north of North China Plain (39°28′–41°05'N, 115°25′–117°30′E), with a width of 160 km from east to west, a length of 176 km from north to south, and a total area of 16410.54km^2, under the jurisdiction of 16 municipal districts. It is adjacent to Tianjin and surrounded by Hebei Province together with Tianjin, bordering

Yanshan Mountain and Inner Mongolia Plateau in the north, Huang-Huai-Hai Plain in the south, Taihang Mountain and Shanxi Plateau in the west, and Songliao Plain in the northeast. It is generally divided into three geomorphic units: western mountain, northern mountain, and southeast plain. Beijing has a typical warm temperate semi-humid continental monsoon climate, with an annual average temperature of 12.77°C (1978–2013) and an average annual precipitation of 548.86 mm (1978–2013). Though affected by the terrain, climate, soil, and other conditions, Beijing is rich in natural vegetation types, showing regular vertical distribution and transitional alternation. The main zonal vegetation is the warm temperate deciduous broad-leaved forest and the distribution of temperate coniferous forest. However, as an international metropolis, there are few natural communities in the urban area, and there are relatively many kinds of artificially planted plants.

The plant communities of three main types of green space in the parks, streets, and residential areas in each ring of the built-up area in Beijing are selected. Mechanical point method is used to conduct sample point survey within the 6th ring of the built-up area in Beijing. The lines are drawn from the center to the east, west, south, and north (i.e., "two axes"—along the east-west axis of Chang'an Street and the north-south axis perpendicular to it), and select appropriate parks, streets, and residential areas in four directions to conduct plant diversity surveys (three sample points were selected for different green space types within the 2nd ring). A total of 19 parks, 19 residential areas, and 19 streets were selected. A total of 57 transects were investigated in the street, and 114 arbor quadrats, 456 shrub quadrats, and 456 herb quadrats were surveyed in parks and residential areas.

The overall situation of the park green space, residential green space, and street green space in the selected sample points is inspected, and the types of plants, life forms, and whether they are introduced species appearing in the green space were recorded. Among them, all plant species in the park green space and residential green space were recorded, and 100 m transect was selected for each street to record all plant species. According to the method recommended by Fang et al. [41], three tree quadrats of 10 m × 10 m were selected in each park green space and residential green space, and four 5 m × 5 m shrub quadrats and four 1 m × 1 m herb quadrats were selected from each tree quadrat (shrub and herb quadrats were selected from tree quadrats, respectively).

3. Species composition of Beijing City

A total of 536 species of plants belonging to 319 genera and 103 families were investigated in the built-up area of Beijing.

From the perspective of family composition, among the 103 families, Compositae is the family with the largest number of species, including 56 species, followed by Rosaceae with 46 species, Gramineae and Leguminosae with 39 and 37 species, respectively. More than 89% of the families contain less than 10 species, and families with less than 5 species account for 69.9%, including 40 families with 1 species. There are 32 families including 2~4 species, and only 11 families including more than 10 species.

In terms of genus composition, among the 319 genera surveyed, *Prunus* and *Artemisia* contain more than 10 species, *Populus, Polygonum*, and *Chenopodium* contain more than 5 species, while 314 genera such as *Rosa*, *Salix*, *Dendranthema* contained less than 5 species, accounting for 98% of the total, of which 217 genera contain only 1 species, accounting for 68% of the total genera, 91 genera with 2~4 species, accounting for 28.5% of the total genera, and 11 genera with more than 5 species, accounting for only 3.5% of the total genera.

In terms of frequency, *Sophora japonica* has the highest frequency of arbors in all quadrats of urban green space plants in Beijing, up to 0.59, followed by *Sabina chinensis*, which is 0.32. *Buxus megistophylla* had the highest frequency of shrub occurrence, which is 0.46, and *Punica granatum* was 0.06. *Setaria viridis*, the most common herb, is 0.2, followed by *Viola philippica*, which was 0.19.

4. Species richness within each loop of Beijing City

The number of plant species distributed within the 2nd ring is the least, with 218 species (**Table 1**). Among them, there are 66 species of plants in the streets in the 2nd ring, 189 species in the park, and 159 species in the residential area. There are 371 species in the 5th to 6th ring, which is significantly higher than other rings. Among them, the number of plant species in the park is the largest, reaching 299 species. There is little difference in the distribution of plant species in other rings, namely 243 species in the 2nd to 3rd ring, 259 species in the 3rd to 4th ring, and 261 species

Ring road	Green type	Richness of species	The proportion
Inside the 2nd ring	Street	66	40.7%
	Park	189	
	Residential	159	
	Total	218	
2nd to 3rd ring	Street	80	45.3%
	Park	192	
	Residential	146	
	Total	243	
3rd to 4th ring	Street	87	48.3%
	Park	208	
	Residential	173	
	Total	259	
4th to 5th ring	Street	76	48.7%
	Park	199	
	Residential	193	
	Total	261	
5th to 6th ring	Street	72	69.2%
	Park	299	
	Residential	171	
	Total	371	

Table 1.
The number of species and the proportion of the total number of species in each ring under different types of green space.

in 4th to 5th ring. Among the 536 species distributed in the urban area of Beijing, 114 species are only distributed in one ring, accounting for 21.3% of the total number of species surveyed, belonging to rare distribution; 266 species are distributed in 2rd to 4th rings, account for 49.6% of the total surveyed species and belong to dispersive species; and 156 species of plants are distributed in the 5 loops, accounting for 29.1% of the surveyed total species, belonging to widely distributed species.

5. Introduced species

Among the 536 plant species surveyed in the urban area of Beijing, 175 species are introduced species, accounting for 32.6% of the total, including 95 domestically introduced species and 80 foreign introduced species. Trees and shrubs account for a large proportion of the introduced species. Among them, 41 species of arbors are introduced domestically, accounting for 37.6% of the total arbor species, 16 species of arbors are introduced abroad, accounting for 14.7% of the total arbor species. The proportion of shrubs introduced from China is 33.6%, and that from abroad is 14.1%. In the survey, there are 253 native herbaceous species, accounting for 79.1% of the total herbaceous species, and the total number of introduced herbaceous plants is only 20.9%.

The number of introduced species in different rings in Beijing urban area is unevenly distributed, of which 99 species are introduced in the 2nd ring, accounting for 45.4% of the total number of species in the 2nd ring. Outside the 2nd ring, with the increase of urbanization gradient, the number of introduced species showed a gradual increase trend. There are 90 introduced species from the 2nd ring to the 3rd ring, accounting for 37% of the total species. There are 100 introduced species from the 3rd ring to the 4th ring, accounting for 38.6% of the total species. There are 108 introduced species from the 4th ring to the 5th ring, accounting for 41.4% of the total species. There are 129 species introduced from the 5th ring to the 6th ring, accounting for 34.8% of the total species.

6. Similarity index and diversity index

The similarity indices of street green space and park green space between the 3rd to 4th ring and the 4th to 5th ring are the highest, which are 0.50 and 0.52, respectively, indicating that the species composition of the streets and parks in the two loops is the most similar (**Table 2**). The similarity index between the 2nd to 3rd ring and the 4th to 5th ring in the green space in the residential area is the highest, which is 0.48. The three types of green space with the lowest similarity index among the rings are different. On the whole, the similarity indexes between the street green space and the park green space from the 3rd to 4th ring and other rings are relatively high, reaching an average of 0.47 and 0.45, respectively, indicating that the species composition similarity between the street green space and the park green space from the 3rd to 4th ring and the corresponding green space types of other rings is high. The similarity index between park green space and residential green space from the 5th to 6th ring and other rings is relatively low, with an average of 0.35 and 0.39, respectively, indicating that some species of park green space and residential green space from the 5th to 6th ring are less distributed in the corresponding green space types in other rings.

The plant richness indexes of different life forms change differently with the outward expansion of the city. The richness indexes of trees and shrubs show a trend

	Jaccard indexes	2nd to 3rd ring	3rd to 4th ring	4th to 5th ring	5th to 6th ring
Street	Inside the 2nd ring	0.36	0.45	0.38	0.39
	2nd to 3rd ring		0.47	0.40	0.43
	3rd to 4th ring			0.50	0.45
	4th to 5th ring				0.44
Park	Inside the 2nd ring	0.40	0.38	0.41	0.27
	2nd to 3rd ring		0.51	0.45	0.34
	3rd to 4th ring			0.52	0.39
	4th to 5th ring				0.40
Residential	Inside the 2nd ring	0.47	0.42	0.46	0.40
	2nd to 3rd ring		0.44	0.48	0.42
	3rd to 4th ring			0.44	0.38
	4th to 5th ring				0.35

Table 2.
The similarity index between the various rings under different types of green space.

of decreasing first and then increasing, while the richness indexes of herbs gradually increase with the increase of urbanization gradients. Among the plants of different life forms, herbs are the most abundant. The herb richness index of the 3rd to 4th ring is the highest, reaching 0.89, and that of the 2nd ring is the lowest, which is 0.83. The shrub richness was the lowest, and the shrub richness index was only 0.18 in the 2nd ring, which was relatively high. Trees are slightly higher than shrubs, and the tree richness index in the 3rd to 4th ring is the lowest, which is 0.40, and the highest in the 2nd ring is 0.71.

With the increase of urbanization gradient, the diversity index of trees and shrubs shows a trend of decreasing first and then increasing, while the diversity index of herbs has no obvious change law with the change of urbanization gradient. Among them, the species diversity of herb is the largest, the 5th to 6th ring with the highest herb index reach 0.98, and the lowest 4th to 5th ring also reach 0.86. The second is arbor, the highest diversity index is 0.60 in the 5th to 6th ring, and the lowest diversity index is 0.29 in the 3rd to 4th ring. The diversity of shrubs is the lowest. The lowest shrub index in the 4th to 5th ring is only 0.04, and the highest shrub index in the 2nd ring is only 0.16.

With the increase of urbanization gradient, the species evenness of trees, shrubs, and herbs has no obvious change. Among them, the species evenness of shrub is the lowest, with an average of 0.12, the highest within the 2nd ring is 0.19, and the lowest in the 4th to 5th ring is only 0.05. The evenness of arbor and herb is relatively high, with average values of 0.50 and 0.58, respectively. The highest evenness of arbor is 0.57 in the 2nd ring, and the highest evenness of herb is 0.64 in the 2nd to 3rd ring.

Due to the change of green space types, the species diversity index (richness, diversity, and evenness) of shrubs shows significant difference ($P < 0.05$), and the other species diversity indexes do not show significant difference. With the changes of

Species diversity indices	*T*-test	Impact factor	
		Green type	Ring road
Margalef's indexes of tree	*F*	0.000**	2.154
	P	0.984	0.376
Shannon's indexes of tree	*F*	0.093	2.970
	P	0.762	0.610
Pielou's indexes of tree	*F*	1.030	1.101
	P	0.317	0.243
Margalef's indexes of shrub	*F*	4.939	25.407
	P	0.032*	0.054
Shannon's indexes of shrub	*F*	7.635	38.461
	P	0.009**	0.324
Pielou's indexes of shrub	*F*	8.475	51.018
	P	0.006**	0.519
Margalef's indexes of the herb	*F*	0.001**	0.968
	P	0.971	0.578
Shannon's indexes of the herb	*F*	0.034 *	0.333
	P	0.855	0.571
Pielou's indexes of the herb	*F*	0.133	0.728
	P	0.718	0.335

Table 3.
The ANOVA analysis between species diversity indices and impact factor.

different loops, there was no significant difference in species diversity index (richness and diversity) ($P > 0.05$). Pearson's correlation analysis between species diversity index and various influencing factors is listed in **Table 3**. Shrub richness is significantly correlated with green space types at the level of 0.05. Shrub diversity index and evenness index were significantly correlated with green space types at the level of 0.01. There was no significant correlation between the species diversity indexes in each loop.

7. Species and environmental factors

The species distribution of different green space types is greatly affected by human factors, so this study only ranks the species distribution in different loops. Because there are many species, only the species with relatively high frequency are shown in the ranking chart. The canonical correspondence analysis (CCA) results of species-environment clearly show the distribution of species in different loops and the average value of relative occurrence frequency. In the tree species environment CCA ranking diagram, the characteristic value of axis1 is 0.411 and the characteristic value of axis2 is 0.255. The two axes show a high correlation between species and environmental factors, which are 0.795 and 0.777, respectively. The interpretation rates of the two axes can reach 42.0% and 68.1%, respectively. The distribution and occurrence frequencies of different tree species in the 2nd ring and the 5th to 6th ring are not different, but the occurrence frequencies in other rings are significantly different. For example, the average value of occurrence frequency of ash tree in each ring is in the order of: 3rd to 4th ring >2nd to 3rd ring > inside the 2nd ring >5th to 6th ring >4th to 5th ring, while the average value of occurrence frequency of juniper tree in each ring is in the order of: inside the 2nd ring >5th to 6th ring >4th to 5th ring >3rd to 4th ring >2nd to 3rd ring. The characteristic values of axis1 and axis2 in the shrub species-environment CCA ordination diagram are 0.328 and 0.255, respectively. The correlation between species and environmental factors shown in the two axes is relatively high, 0.769 and 0.670, respectively. The interpretation rates of the two axes are 33.6% and 59.7%, respectively. The frequency of occurrence of most shrub species in the 4th to 5th ring is relatively low. Among them, *Buxus megistophylla*, *Buxus sinica*, *Prunus cerasifera*, and *Lonicera maackii* have the lowest distribution frequency in the 4th to 5th ring, while the highest frequency is in the 5th to 6th ring. The average frequency of occurrence in the 2nd ring, the 2nd to 3rd ring, and the 3rd to 4th ring is not much different. The characteristic values of axis1 and axis2 in the herbaceous species environment CCA ordination diagram are 0.206 and 0.156, respectively. The correlation between the species and environmental factors shown in the two axes is also relatively high, which are 0.750 and 0.753, respectively. The interpretation rates of the two axes are 36.3% and 63.8%, respectively. The species of herbaceous plants are significantly more than trees and shrubs, and they are highly concentrated in each ring. Most herbaceous plants have the highest occurrence frequency inside the 2nd ring and in the 5th to 6th ring. Among them, plants such as *Eleusine indica*, *Digitaria sanguinalis*, *Ophiopogon japonicus,* and *Viola philippica* have a higher frequency inside the 2nd ring and in the 5th to 6th ring, and they are distributed in all other rings with little difference in their frequency.

Relevant studies [17–19] show that the high-intensity human interference, invasion of alien species, and reduction of native species caused by urbanization have led to the homogenization of species distribution. This study found that the similarity index of urban green space plants in Beijing is high, indicating that the cultivation and allocation of urban green space plants in Beijing are greatly affected by human activities, especially the species of trees and shrubs on the streets are relatively single, which makes the urban plants tend to be homogeneous. On the issue of protecting urban plant diversity, the first principle to be followed is to respect nature and maintain and protect urban plant diversity guided by respect for nature. According to international excellent experience, the goal of urban biodiversity protection is to introduce nature and forests into cities. The area of green space in the city is small, and the core of protecting urban plant diversity is to use limited green space, scientifically and reasonably carry out ecological allocation, and maintain and restore urban biodiversity. In the early stage of urban development planning, precious plants and areas with high biodiversity value should be protected in a key way, and in garden design, both ornamental value and ecological benefits should be used, native species should be encouraged, exotic species should be introduced reasonably, corresponding plants should be selected and configured under different environmental conditions according to local conditions, species with different ornamental values (fruits, leaves, branches, flowers, etc.) should be configured reasonably, and shade-tolerant ground cover plants should be used scientifically to increase urban plant diversity. Grass germplasm resources are an important part of biodiversity [42] and have the characteristics of strong adaptability, low maintenance and management costs, and unique ornamental value [43, 44], especially ornamental grasses, which play an extremely important role in urban landscape design. In the urban area of Beijing, most native species have extremely high ornamental value and are natural ground cover plants. The application and rational allocation of native species in urban green space plants can reflect the regional characteristics and urban personality of the city and can also reflect the local characteristics of urban landscaping in the region. It will also promote the harmonious coexistence between man and nature and achieve a symbiotic and co-prosperous relationship.

The richness and diversity index of urban plants also change with the degree of urbanization. At present, due to different research sites or methods, there are two main trends of the impact of urbanization on urban plant diversity: one is that plant diversity increases with the strengthening of urbanization [45] and the other is that the plant richness increases along the change from urban area to urban-rural fringe to suburb [26, 46]. McKinney [47] found in the summary of the research on the impact of urbanization on species richness that 65% of the plant research results show that with the slow improvement of urbanization level, the plant species richness continues to increase. However, in this study, within a certain range, the plant richness and diversity index decreased with the increase of urbanization gradient and then showed a gradually increasing trend with the development of the city. Different from previous studies [36], in this study, the richness index of shrubs is lower than that of trees, which may be due to the fact that trees are the main body of artificial green space, shrubs are used in combination, and less species are selected. It is found that the plant diversity index inside the 2nd ring is slightly higher than that in the 2nd to 3rd ring, which may because the landscaping construction inside the 2nd ring pays attention to the introduction and allocation of shrubs and herbs, which makes the diversity of trees, shrubs, and grasses inside the 2nd ring relatively high. Previous studies have shown that woody plant richness in residential areas and parks is higher than that of other land use types [48]. This survey found that the species diversity index of shrubs is more significantly affected by green space types.

The difference of quadrat species diversity index with the change of environmental factors is not significant, but the distribution of species is greatly affected by environmental factors. CCA ranking analysis shows that the average value of distribution and occurrence frequency of plant species in each loop is different, which may be because the microclimate formed in different environments is more suitable for the survival of some species, or because different soil environments affect the distribution of species [49]. It may also because different urban construction areas have different urban landscape design schemes.

Research has shown that urbanization leads to the increase of alien species, while the diversity of native species decreases [29, 45, 50, 51]. The number of introduced species of urban plants in Beijing shows a gradually increasing trend outside the 2nd ring. The main reason may be that in the later urban construction, the introduction and cultivation of exotic garden plants have been gradually increased. At the same time, it shows that more and more attention is paid to the introduction of alien species in urban construction to achieve better plant configuration and ornamental effect, but the introduction of alien species will ignore the phenomenon of native species.

At the beginning of urban development and after it develops to a certain extent, the richness and diversity index of urban plants increase. In urban construction, not only must foreign species be introduced for the design and configuration of garden plants, but more attention must be paid to the selection of local species, that appropriately increase the types and quantity of shrubs and the types of turfgrass. If not necessary, avoid using a large area of single turfgrass, which can not only make the tree, shrub, and grass form a close-to-natural multilayer green space community structure but also give full play to its ecological benefits to the greatest extent and make the urban biodiversity play its value [52].

Beijing has a wide geographical scope and a huge number of green areas. Because the survey objects are some sample points in the urban artificial green space, the number and area of the selected sample points are limited, so the results of plant species, family and genus distribution, biological diversity characteristics, and other aspects of research are not comprehensive enough. If you want to have a more accurate and in-depth study on the plant diversity of Beijing's urban green space, it is necessary to comprehensively investigate all plant communities in the city and establish a complete Beijing urban green space biodiversity monitoring system to monitor the dynamic changes of urban biodiversity for a long time, so as to provide services for the protection of biodiversity in Beijing.

8. Conclusion

1. A total of 536 species of plants belonging to 319 genera and 103 families were investigated within the 6th ring in Beijing. Among them, Compositae, Rosaceae, Gramineae, and Leguminosae are many families, while Plum and Artemisia are many genera. Among the 536 plant species investigated, 175 are introduced species, of which 95 are domestic introduced species, accounting for 17.7% of the total, and 80 are foreign introduced species, accounting for 14.9% of the total.

2. There is high similarity of green space plants in Beijing urban area. The similarity index of street green space and park green space is the highest between the 3rd to 4th ring and the 4th to 5th ring, reaching 0.50 and 0.52, respectively. The highest similarity index of residential green space is between the 3rd to 4th ring and the 4th to 5th ring, with an index of 0.48.

3. With the increase of urbanization gradient, the species richness and species diversity index of trees and shrubs in urban green space plants shows a trend of first decreasing and then increasing, while the change rule of herbs is not obvious. The evenness of plant species has no obvious change with the increase of urbanization gradient.

4. The distribution and occurrence frequency of different plants in each ring are different. Some arbor species appear in the 2nd ring and the 5th to the 6th ring at the same time, and the average value of the occurrence frequency in the two rings is not different. The frequency of most shrub species in the 4th to 5th ring is relatively low, and the species of herbs are significantly higher than those of trees and shrubs and have a high concentration distribution in each ring.

9. Prospect

Practice has proved that there are many factors affecting urban development and biodiversity change. The city itself is a huge complex ecosystem, and the social, economic, and natural environment of different cities are quite different. In addition, the terrain, climate, hydrology, and soil conditions of cities are diverse, so the impact of urban development on biodiversity is completely different [2]. In the future, the impact of urbanization on biodiversity can be considered from the following aspects:

1. Using a geo-detector model to determine the impact strength of certain urbanization factors that affect urban biodiversity. For example, Li et al. [53] used the geographic detector model to determine the influence intensity of urbanization factors on tree diversity in Beijing. The results showed that the influence intensity of the influence factors was in the following order: land use type > forest canopy patch size > population density > impervious surface scale > distance from city center. The interactions among the factors are nonlinearly enhanced, indicating that urban tree diversity depends not only on the properties of a single factor but also on the spatial interactions among multiple factors.

2. Studying the impact of urban heat island effect on ecological interaction under climate change [54]. In urban heat islands, warmer temperatures may negatively affect the abundance, phenology, physiology, and behavior of species, including pollinators, herbivores, natural enemies, and urban pioneers, affect the evolution of pathogen virulence, and affecting reciprocal and antagonistic ecological interactions in cities [55–58].

3. Studying the quantitative relationship between urbanization intensity and biodiversity diversity. For example, Zhao et al. [59] used the percentage of total impervious surface area (PTIA) as an indicator of urbanization intensity, showing that PTIA is the main predictor of plant diversity variability in Wuhan urban areas and establishing a threshold for plant diversity.

4. Research on urban biodiversity conservation. Liu et al. [60] proposed that university campuses are valuable resources for urban biodiversity research and protection. Therefore, university campuses with high biodiversity can be protected and used as valuable resources for biodiversity education, research, and protection; Huang Chunwei and other researchers [61] found that the habitat loss caused by cities to biodiversity mostly occurs in countries with low political stability and regulatory quality, which can link land governance with the threat of urbanization to biodiversity.

The research of Fuller and others [62] shows that there is a clear link between biodiversity and the social benefits of urban nature. Therefore, the theoretical knowledge of urban biodiversity conservation is actively applied to buffer the damage to biodiversity caused by urbanization. It will also be the main content of future research.

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Chapter 3

Non-Timber Forest Products: Diversity, Utilization, and Dependency in Fringe Areas of Jaldapara National Park in Indian Sub-Himalayan Region

Lakpa Doma Lepcha, Biplov Ch. Sarkar, Gopal Shukla and Sumit Chakravarty

Abstract

Non-timber forest products (NTFPs) greatly contribute to livelihood, development, and poverty alleviation across the tropics. We also assumed that the fringe communities inhabiting Jaldapara National Park (JNP) of Indian eastern sub-Himalayan region largely rely on the NTFPs for their livelihood due to its remote and isolated location with no physical infrastructure and facilities. Multistage sampling technique was used for the study. The sample size was 205 households selected randomly from a sample frame of 10 villages. Descriptive statistics was employed to analyze and summarize the data. A total of 146 NTFP species was documented. The communities relied on their NTFP collection/harvest for food, medicine, firewood, fodder, and other socio-cultural items for household use and cash income. The documented species were further categorized into plant, fish, fungus, and insect. The relative frequency of citation (RFC), value ranged from 0.2 to 0.96 for all categories of NTFPs with average 0.78. Income from NTFPs contributed on an average 45% of the total annual household income of the households. NTFPs provided a natural insurance to households especially during the periods of scarcity. Focused interventions with technical and financial support are recommended to uplift the livelihood of the communities in JNP.

Keywords: forest fringe community, NTFP, livelihood, sustainable development, eastern Himalayas

1. Introduction

Any biological products and services collected mainly from forests and other associated tree-based land use systems are known as non-timber forest products

(NTFPs) [1–4]. Most of the rural and indigenous communities residing in and around forests rely for their livelihood on NTFPs socioeconomically and culturally [2, 3, 5–14]. Non-timber forest products (NTFPs) along with the tradition of plants-based knowledge is distributed among the vast number of indigenous and rural communities [15, 16]. NTFPs provide natural insurance against hunger and malnutrition during scarcity and even during famines [5]. NTFPs are thus vital for the social development of the indigenous/forest fringe and rural communities [17]. In spite of the "right of ownership, i.e., access to collect, use and dispose of minor forest produce by the 'Forest Rights Act, 2006'" to the indigenous communities dependent on forest or forest dwellers, they still remain underprivileged and impoverished [18]. Having potential to address poverty, sustainable development, and tropical forest conservation without competing with agricultural activity, NTFPs is now receiving more academic and policy attention [2, 3, 19, 20].

The dependency of the indigenous forest and rural people on NTFP continues today because of their poor economic conditions and non-empowerment toward socioeconomic development [21] through its use in food, medicine, fiber, fuelwood and sale [2–4]. Plant and animal resources and their value as NTFPs are rich among the ethno-cultural groups [22, 23], but potentialities of many of these resources and valuable plants are yet to be explored [2, 3]. Unfortunately, till now, there are no serious efforts either to document the NTFP resources or to analyze their utilization and socioeconomic aspects [5]. Additionally, due to deforestation, modernization, unsustainable development, and ignorance of younger generation toward NTFPs, the traditional knowledge associated with them and their utilization is gradually eroding through acculturation and the loss of plant biodiversity [24–26]. Awareness, research, and education are needed to protect this diminishing knowledge of NTFPs and conserve bioresources for the benefit of our future generations [27].

Dependence on NTFP collection and utilization is still a crucial livelihood strategy for forest dwellers in the Terai foothills of eastern Himalayas in West Bengal [11, 24, 28–31]. Unfortunately, now the traditional knowledge associated with NTFPs in these regions is found mostly confined to the older generation of these communities, which is consequently in the verge of extinction [24]. Hence, identifying and documenting the diversity of NTFP resources with their utilization is important to conserve and manage these resources sustainably while also being helpful for restoration and preservation of their associated traditional knowledge [25, 26, 32–34]. More importantly, promoting the NTFPs-based activities has now become a crucial policy action of any developmental strategy for uplifting and empowering the rural and indigenous communities [35]. Such documentation will provide baseline data and information for conservation and sustainable utilization of the NTFP resources. Additionally, these documentations will be a proper testimony from specialists, which will also popularize the NTFPs to be introduced into the present-day farming systems and also get acceptance for utilization by the urban population [25, 26, 35, 36]. Therefore, the present study was conducted in the forest fringe villages in the Terai region of West Bengal with the following objectives:

- Documentation/enlistment of NTFPs used by forest fringe communities.

- Traditional uses and utilization pattern of NTFPs by these communities.

2. Methods and materials

2.1 Study area

JNP is a part of Himalayan Biodiversity Hotspot [15]. It is situated on the foothills of the eastern Himalayas, India [37]. The park is mainly savannah, containing giant grasses along with mixed deciduous, wet monsoon, tropical moist deciduous, tropical semievergreen, and riverine forests [38]. The region is subtropical, receiving average annual rainfall of 250–300 cm from south–west monsoon of which 80% is received from June to August. The summer and winter temperatures are mild with 34°C as the highest in the month of May, while the lowest temperature is 7.5°C in the month of January. The study area as measured by GPS (Germin- 72) was between 25^0 $58^{'}$ N and 27^0 $45^{'}$ N latitudes and 89^0 08′ E and 89^0 55′ E longitudes with an elevation of 47 m above mean sea level.

The forest is inhabited by divergent Indo-Mongoloid communities of Mech, Ravas, Totos, Uraons, Tamang, Toppo, Lepcha, Rajbangsi, and Mundas, making it bioculturally diverse with varied socioeconomic conditions. These indigenous people are permanently settled in and around the national park. Each indigenous community has its own distinct culture and beliefs (www.alipuarduar.gov.in). The primary livelihood activity of these communities is subsistence farming and NTFP collection. Their standing crop is frequently decimated by wild elephants. Further, the habitations are remotely located and isolated with no physical infrastructure and facilities like limited accessibility by good roads, making the whole area underdeveloped. The inhabitants of the area thus depend on NTFPs to meet their income and daily needs. The forest resources are locally managed by Forest Protection Committees under the Joint Forest Management Scheme controlled by the State Forest Department [39].

2.2 Sampling procedure

Multistage sampling procedures were applied in this study. JNP and the villages were selected purposively, while the respondents were selected randomly. The selection of the study area was purposive because it is a national park important for its rhinoceros conservation and inhabited by the indigenous communities depending on it for NTFP resources. The villages were located in the designated forest area and are termed as forest villages. The Indian Forest Act permits the inhabitants of these villages access and resource use rights over the collection of NTFPs from the park as the country is a signatory of the United Nation Convention on Biological Diversity of 1992 [40]. Major ten villages located in and around the national park that has more than 50 households were also selected purposively and from the each village; one tenth of the total households (205) were randomly selected [3].

2.3 Data collection

The data were collected from the sampled households by the lead author assisted by a trained enumerator with the help APRE-tested structured questionnaire through personal interviews and focus group discussions (FGD) guided by a checklist of questions [41–43]. The questionnaire was pretested for elimination, addition, and alteration with non-sample respondents of the study area. In pretesting, care was taken not to include respondents who were selected as sample for final interview. On the basis of experiences in pretesting, appropriate changes in the construction of item and their sequence were made. Prior to starting the interviews, a few days were devoted in each selected village to establish rapport with the respondents. The questionnaire was administered to the respondent in the local language, and the responses were recorded in English. On the basis of the objectives of study, the questionnaire was designed with two sections. The first section was on socioeconomic attributes of the respondents like literacy, occupation, and total monthly household income, while the second section was on the collection and utilization including processing of NTFPs, value of NTFPs consumed and sold by the households, and contribution of NTFPs to total monthly household income.

Occupation indicates the economic activity of a household and thus is a source of income. We hypothesized that as our study villages are remotely located and isolated with no or very little basic infrastructure facilities, there will be limited or no livelihood options except dependency on forest resources or subsistence farming as was also reported in earlier studies [44]. The limitations of our study area mentioned above also led us to hypothesize that the inhabitants will be mostly illiterate and thus will have no other livelihood options except for relying on subsistence farming or on forest resources. Studies have shown that education results in lesser dependency on forest or farming activity and more inclination toward alternative employment opportunities [45]. Our last hypothesis was that the study area would have very low or marginal total household monthly income because of illiteracy and limited livelihood options rendering the inhabitants with no other livelihood options other than to depend on subsistence farming and NTFP collection from the forest [46].

Generally, the head of the household was taken as the respondent. The society of the study area is patriarchal, so the husband is the head of the family. In case when the husband is absent, the wife, eldest son, or the daughter was interviewed on behalf of the head. A total of 10 FGDs were conducted, one in each selected village. There were about 15–20 participants in the discussions, which included the village chief, senior citizens of the village, some prominent NTFP collectors, members of Forest protection committee, and representatives of the State Forest Department. The information gathered from these discussions supplemented the household surveys, which were finally used for interpretations of the results.

2.4 Data analysis

Data collected were statistically analyzed using a descriptive technique (frequency, percent and bar chart). We classified our respondents as literates and illiterates. According to Indian standards, a person who has only basic "3Rs" knowledge, that is, can read and write his/her name and can perform simple arithmetic, is literate and otherwise not. Literacy of the respondents is expressed as per cent of the total respondents. Monthly total household income is calculated as the sum total of income a household was earning from different sources (if any). Generally, the total household income (THI) is the summation of agricultural (AI), nonagricultural (NAI), and forest income (FI) or THI = AI + NAI + FI [5]. The households were classified as low-, medium-, and high-income group [47] based on their total monthly household income and then expressed as per cent of the total respondents. USD to Indian rupee exchange rate during the study period was USD1 = INR60.

2.5 Relative frequency of citation (RFC)

Relative frequency of citation (RFC) implies in this study to finding out the most collected NTFPs by the forest fringe people [48]. The RFC value is "0" when no one refers to the plant as being useful and "1" when all the participants refer to the plant as being useful. RFC is calculated as

$$\text{RFC} = \frac{FC}{N}$$

Where "FC" denotes the number of participants who mention the collection and use of the species, and N denotes the total number of participants.

3. Results

3.1 Socioeconomic attributes

The main occupation of the indigenous communities of the sampled villages in and around JNP is subsistence farming and collecting/harvesting NTFPs supplemented with some temporary activities like daily paid manual labor or petty business. According to our classification made on the basis of total monthly household income, there were only two income groups. Almost all the respondents, that is, 95.33%, were in the low-income group living on USD 2–10 daily, and the rest were in the medium-income group living on 10–20 USD daily. The contribution of NTFP toward the total monthly household income varied widely in the range of 1–70% with an average of 45%. Around 60% of the respondents in the study area were literate, had spent at least two years in formal education, and had a tendency to search for an alternate occupation other than farming or collecting NTFP.

3.2 NTFPs diversity/richness

Documented NTFPs were listed as plant, fungus, and animal origin. A total of 146 NTFP species representing 126 genera and 76 families were documented, which were used by the indigenous communities of JNP (**Figure 1**; **Table 1**). Of these documented species, 95 were collected from the wild, 24 were cultivated, and 27 were either collected from the wild or cultivated (**Table 1**). Out of these documented NTFP species, 125 were plants, 14 animals, and seven fungi. Among the plants, trees dominated the list with 70 species, followed by herbs with 32 species, shrubs with 16 species, and climbers the least with seven species. Fishes with 13 species dominated the list of animals with one species of honeybee. Family *Fabaceae* among plants dominated the list with six species and six genera followed by *Euphorbiaceae* and *Malvaceae* each with five genera and five species. In animals, family *Cyprinidae* dominated with five genera and five species. In fungus, *Pleurotaceae* and *Lyophyllaceae* dominated with two species each.

Sn- scientific name; Vn- vernacular name; F- family; Lf- life form (C- climber; Fi- fish; Fu- fungus; H- herb; I- insect; S- shrub; T- tree); Is- IUCN status (DD-Data deficient; NA-Not yet assessed; LC-Least concern); Toc- time of collection (Whole year- Wy); Pu- part used (B- bark; Br- branch; Ds- dry seed; Fl-flower; Fr-fruit;

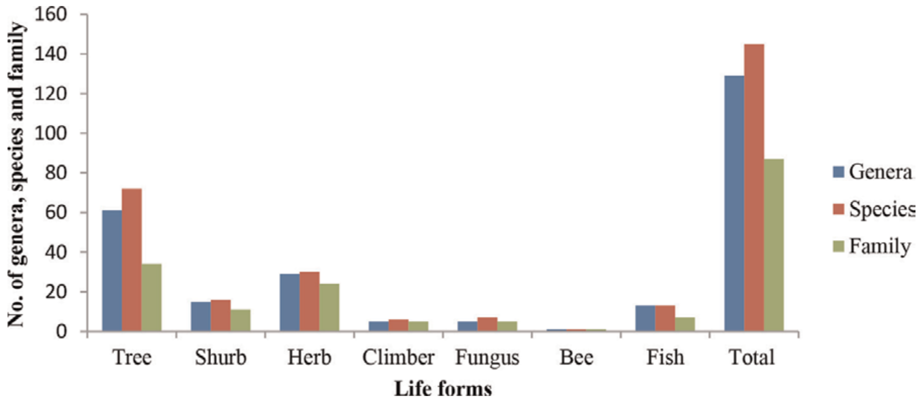

Figure 1.
NTFP diversity/richness used by fringe communities of JNP.

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
Animal origin- fish					
1	*Channastriatus* (Bloch) *Sole*; Channidae	NA	Wy	Cooked and consumed	0.73
2	*Catlacatla* (F. Hamilton) *Katlay*; Cyprinidae	NA	Wy	Cooked and consumed	0.94
3	*Cirrhinusmrigala* (Hamilton) *Mrigal*; Cyprinidae	LC	Wy	Cooked and consumed	0.94
4	*Clariasbatrachus* (L.) *Magur*; Clariidae	LC	Wy	Cooked and consumed	0.76
5	*Garragotyla* (Gray.) *Buduna*; Cyprinidae	LC	Wy	Cooked and consumed	0.86
6	*Gudusiachapra* (F. Hamilton) *Chipla*; Clupeidae	LC	Wy	Cooked and consumed	0.87
7	*Heterepneutesfossiles* (Bloch) *Sangri*; Heteropneustidae	LC	Wy	Cooked and consumed	0.94
8	*Penaeusmonodon* *Chingri*; Clupeidae	NA	Wy	Cooked and consumed	0.94
9	*Labeo rohita* F. Hamilton *Rahu*; Cyprinidae	LC	Wy	Cooked and consumed	0.94
10	*Mystusvittatus* (Bloch) *Tangra*; Bagridae	LC	Wy	Cooked and consumed	0.92
11	*Psilorhynchussucatio* (Ham.) *Chepti*; Psilorhynchidae	LC	Wy	Cooked and consumed	0.91
12	*Pethiaticto* (Hamilton) *Punti*; Cyprinidae	LC	Wy	Cooked and consumed	0.88

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
13	*Rita rita* (Ham.) *Rita*; Bagridae	LC	Wy	Cooked and consumed	0.93
			Animal origin- insect		
14	*Trigona Sp.* *Putka*; Apidae	—	Sep-Jan/ Ho	Cooked and consumed as medicine.	0.92
			Plant origin- climber		
15	*Coccinia grandis* (L.) Voigt *Telakucha*; Cucurbitaceae	NA	May-Aug/ L, Fr	Cooked as vegetable	0.82
16	*Cissusrepanda* Vahl. *Panilahara*; Vitaceae	NA	Wy/Tw	Whole plant is used to make rope and as fodder.	0.88
17	*Dioscorea bulbifera* L. *Githa*; Dioscoreaceae	NA	Wy/B, L	Dried powder of tuber is applied to cure ulcer and cooked as vegetable.	0.73
18	*Dioscorea pentaphylla* L. *Bhegur*; Dioscoreaceae	NA	Jun-Jan/ Rh	Extract is applied on infected portion to cure boil and cooked as vegetable.	0.73
19	*Momordicadioica* Roxb. Ex willd. *Ban karela*; Cucurbitaceae	NA	May-Jul/ Fr, R	Fruits cooked as vegetable and also consumed to cure stomach disorder. Leaf extract administered orally (250 ml) twice a day for two days during fever.	0.72
20	*Piper thomsonii* Linn. *Pipla*; Piperaceae	NA	Nov-Mar/ Fr	Fruits are boiled in water with salt. This mixture is consumed to cure cough & cold.	0.96
21	*Plumbagozeylanica* L. *Chita*; Plumbaginaceae	NA	Wy/L, R, B	Leaf extracts are mixed with rice for making rice beer. Rhizomes are crushed and boiled and consumed empty stomach during early morning to treat fever.	0.71
Plant origin- herb					
22	*Achyranthusarpera* L. *Apang*; Amaranthaceae	NA	Jan-Dec/R, Sd	Root powder mixed with black salt or root and seed crushed together and consumed with water to get relief from indigestion and dysentery.	0.44
23	*Ageratum conyzoides* L. *Bhusuri*; Asteraceae	NA	Wy/L	Fresh leaf extracts are applied on cut and wound and bandaged to stop bleeding and for healing.	0.82
24	*Artemisia vulgaris* L. *Titepate*; Asteraceae	NA	Wy/L, Fl, R	Leaves, flowers, and roots are crushed together with fresh water and consumed to control dysentery.	0.20
25	*Asparagus racemosus* Willd. *Satamuli*; Asparagaceae	NA	Jan-Dec/Fl, R	Dried root powder is consumed to get relief from diabetes and dysentery. Leaves are eaten to get relief from fever.	0.60
26	*Bambusa bamboos* (L.) Voss *Bans*; Poaceae	NA	Wy/Wp	Used for fencing and making small bridge and ladder.	0.83
27	*Bambusa vulgaris* Schrad ex J.C Wendl. *Baans*; Poaceae	NA	Wy/Ys, L, St	Young and tender shoots are cooked as vegetable and processed as pickle. Leaves are used as fodder and clumps as fencing.	0.09
28	*Basella alba* L. *Pui sag*; Basellaceae	NA	May-Jul/L	Decoction of root relieves vomiting. Tender twigs are used as vegetables.	0.22

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
29	*Bryophyllumpinnatum* (Lam.) Oken *Partharkurchi*; Crassulaceae	NA	Wy/L, Wp	Leaf paste is applied on burnt skin and on swelling for relief. Whole plant is used for decoration.	0.10
30	*Calamusrotang* L. *Bet*; Palmae	NA	Oct-Jan/ L, Fr	Leaves are used for home decoration, and fruits are edible.	0.49
31	*Cardamine hirsute* L. *Simrayo sag*; Brassicaceae	NA	Oct-Feb/L	Leaves with small twigs are cooked and used as vegetable	0.16
32	*Cassia tora* L. *Chakunda*; Caesalpiniaceae	NA	Jul-Dec/ L, Sd	Leaf extract is applied against rashes and allergies. Seeds are consumed to get relief against cough and cold.	0.61
33	*Centellaasiatica* Linn. *Gortapre*; Apiaceae	LC	Jan-Dec/L	Leaves are consumed as vegetables, which also ease body pain and fever. Leaf extract in water solution is also administered orally during early morning in empty stomach to heal wounds.	0.48
34	*Chenopodium album* L. *Bethusaag*; Chenopodiaceae	NA	Sep-Jan/ L	Tender leaves are cooked as vegetable.	0.35
35	*Cissusquadrangularis* L. *Harjora*; Vitaceae	NA	Jan-Dec/Wp	The plant is grinded and fried in mustard oil along with onion and then applied and messaged to get relief from fracture.	0.40
36	*Colocasia esculenta* (L.) Schott *Ban-Kuchu*; Araceae	LC	May-Aug/ Rh	Cooked as vegetable.	0.19
37	*Cynodondactylon* (L.) *Dubbaghass*; Poaceae	NA	Jan-Dec/Sh	Shoot extract is applied externally to cure skin disease and taken orally to cure vomiting and leprosy. Entire plant is fed to cattle for increasing lactation.	0.19
38	*Cyprus rotundus* L. *Mutha*; Poaceae	LC	Jun-Nov/Rh	Powdered and administered orally against dysentery, fever, and ulcer.	0.46
39	*Daturametel* L. *Dhutra*; Solanaceae	NA	Wy/L, Fl, Sd	Flowers and fruits are offered during religious ceremony. Mixture of leaf and seed is used to treat asthma, cold, and cough.	0.12
40	*Dendrocalamus strictus* (Roxb.) Nees *Male bans*; Poaceae	NA	Wy/Wp	Leaves are used as fodder for goat. Clumps are used as pole.	0.84
41	*Desmodiumgangeticum* (L.) DC *Salpani*; Fabaceae	NA	Sep-Dec/ Wp	Plant extract is consumed to get relief from rheumatism. Root is fed to post-labor woman.	0.53
42	*Dichroafebrifuga* Lour *Vasak* Hydrangeaceae	NA	Wy/L, R	Root extract consumed to control cough & cold. Fresh leaf and root exudates are consumed to control vomiting and blood pressure.	0.35
43	*Diplazium- esculentum* (Retz.) Sw. *Dhenkisaag*; Athyriaceae	LC	Apr-Oct/ Ys, L	Tender leaves are used as vegetable and whole plant as fodder.	0.96
44	*Drymariavillosa* Cham &Schlecht *Abijalo*; Caryophyllaceae	NA	Dec-Feb/L	Whole plant is consumed to cure jaundice and cold.	0.36

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
45	*Euphorbia thymifolia* Linn. *Dhudiya*; Euphorbiaceae	NA	Wy/Br	Leaf and tender stem decoction is consumed to treat cystitis and kidney problems.	0.38
46	*Ficuscunia* Buch. -Ham. Ex Roxb. *Khaniyun*; Moraceae	NA	May-Nov/ Wp	Used as green fodder.	0.70
47	*Fumaria indica* Pugsley *Ban dhania*; Fumariaceae	NA	Mar-Jul/ L	Leaves are used as spice.	0.41
48	*Hedyotisscandens* Roxb. *Koaru*;Rubiaceae	NA	May-Aug/L	Tender leaves with twigs are cooked as vegetable.	0.18
49	*Lycopodiumclavatum* L. *Nagbeal*; Lycopodiaceae	NA	Wy/R, L	Young root and leaves are consumed to treat sexual disorder and also used for decoration.	0.82
50	*Phyllanthus fraternus* G.L Webster *Bhuiamala*; Phyllanthaceae	NA	Wy/Wp	Plant extract is externally applied to cure skin infections. Plant exudates are externally applied on sores and ulcers or mixed with oil to cure conjunctivitis	0.17
51	*Saussurealappa* C. B. Clarke *Kur*; Compositae	NA	Wy/R, Fl	Dried roots are powdered with black pepper and administered orally to cure asthma, cold and cough. Flowers are used during religious ceremony.	0.40
52	*Solanum nigrum* L. *Kakmachi*; Solanaceae	NA	Wy/Fl, Fr, Sh	Animal feed, leaves with flower are cooked as vegetable and ripe fruits as dessert.	0.51
53	*Vernoniacinerea* (L) Less. *Chotokuksima*; Asteraceae	NA	Wy/Wp	Fever, hiccups, nerve disorders, kidney disease, and stomach discomfort.	0.26
			Plant origin- shrub		
54	*Abroma augusta* (L.) L. f. *UlatKambal*; Sterculiaceae	NA	Jan-Dec/R, L	Root powder is used to control urine infection. Leaf extract is useful for diabetes.	0.04
55	*Ageratina Adenophora* (Spreng.) R. King & H. Rob. *Banmara*; Asteraceae	NA	Wy/L	Leaves soaked in water for bathing to cure skin infection.	0.14
56	*Capsicum annum* L. *Jeray chili*; Solanaceae	NA	Apr-Jul/ Fr	Used as spice.	0.02
57	*Cinchona officinalis* L. *Cinchona*; Rubiaceae	NA	Wy/B, R	Root and bark decoction is orally administered against malaria and dysentery. Bark is also used as spice.	0.86
58	*Dendrocnide sinuate* (Blume) Chew *Moringe*; Urticaceae	NA	Apr-Oct/Ys	Young shoot cooked as vegetable.	0.31
59	*Lantana camara* L. *Ban-tulshi*; Verbenaceae	NA	Wy/Sh	Leaf extract is applied on ring worm and administered orally to get relief from cold and cough. Used as fencing and fuel wood.	0.27
60	*Melastomamalabathricum* L. *Dantrangi*; Melastomataceae	NA	Aug-Feb/Fl, L	Consumed to cure cholera, diarrhea, fever and dysentery.	0.10
61	*Meyna spinosa* Roxb. Ex Link *Kalomaney*; Rubiaceae	NA	May-Jun/L, Tu, Fr	Fruit are used as vegetable. Tuber and leaves are consumed to cure boil, dysentery and indigestion.	0.21

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
62	*Mussaendatreutleri* Stapf. *Tamba*; Rubiaceae	NA	Wy/Ys	Cooked as vegetable.	0.85
63	*Rauvolfiaserpentina* (L.) Kurz. *Sarpagandha*; Apocynaceae	NA	Oct-May/R, L	Half teaspoon root and leaf powder is consumed thrice a day to get relief from hypertension and control blood pressure. Root extract is taken orally to cure jaundice.	0.16
64	*Sida cordifolia* Wight &Arnott *Berela*; Malvaceae	NA	Wy/Wp	Consumed as energy vitalizer.	0.10
65	*Sidafallax* L. *Sida*; Malvaceae	NA	Wy/Br	Used as fuel wood.	0.12
66	*Tetracerasarmentosa* (L.) Vahl *Rikang*; Dilleniaceae	NA	Wy/R	Consumed to control diarrhea. Paste is applied to get relief from burn. Extract is applied to cure mouth ulcers.	0.35
67	*Urticadioica* L. *Sisnoo*; Urticaceae	LC	Wy/L, Fl, Ys	Cooked as vegetable.	0.66
68	*Vitexheterophylla* Roxb. *Panchpattay*; Lamiaceae	NA	Wy/L	Used as fodder.	0.51
69	*Vitexnegundo* L. *Nisinda*; Verbenaceae	NA	Wy/Wp	Consumed during morning to cure rheumatism and fever.	0.36
Plant origin- tree					
70	*Acacia catechu* (L. f) Wild. *Khayer*; Mimosaceae	NA	Wy/Br, Hw, B	Branches and twigs are used for fuel wood. Heartwood is processed as *Khatta* and consumed with betel leaf to cure indigestion. Bark powder is consumed to cure rheumatism.	0.30
71	*Aeglemarmelos* (L.) Corr. *Bel*; Rutaceae	NA	Dec-May/ Fr, L	Pulp is used to make health drink as body coolant during summer and to cure dysentery. Leaves are used during religious ceremony.	0.29
72	*Aglaiahiernii* Visal. Ramach *Lali*; Meliaceae	NA	Mar-May/ Br, Ds, L	Branches are used as fuel wood. Dry seeds are decorative. Fresh leaves used as fodder during summer.	0.30
73	*Albizia lebbeck* (L.) Benth. *Siris*; Mimosaceae	NA	Jan-Dec/Br, Sd, B, L	Seed powder is administered orally to get relief from pile and body pain. Bark is boiled and extract is consumed orally to control cold. Leaves are used a fodder and twigs as fuel wood.	0.41
74	*Alstoniascholaris* (L.) R. Br. *Chhatian*; Apocynaceae	NA	Jan-Dec/B	Bark paste is applied to cure skin disease. One tea spoon of bark extract is administered orally during early morning once a day to in empty stomach to cure jaundice and get rid of stomach worms.	0.32
75	*Amoorarohituk* (Roxb.) Wight &Arn. *Lasuney*; Meliaceae	NA	Wy/Br	Twigs are used as fuel wood.	0.55
76	*Anthocephalus cadamba* (Roxb.) Wight &Arn. *Kadam*; Rubiaceae	NA	Wy/Br	Twigs are used as fuel wood and to make agriculture implements. Fresh leaves are used as fodder.	0.16

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
77	*Artocarpus chama* Buch-Ham. Ex. Wall *Latore*; Moraceae	NA	Jan-Dec/L	Fresh leaves are used as goat fodder during lean period.	0.21
78	*Artocarpus heterophyllus* Lam. *Kanthal*; Moraceae	NA	Jan-Dec/Fr, L Lt	Fruit consumed as dessert and processed to pickle. Leaf is goat fodder, and latex is used as gum.	0.89
79	*Artocarpus lakoocha* Buch-Ham *Bore*; Moraceae	NA	Jul-Dec/ Fr, L, B	Fruits consumed as dessert. Leaf and bark are used against skin disease.	0.29
80	*Azadirachta indica* A. Juss. *Neem*; Meliaceae	LC	Apr-Dec/L, Sd, B	Fried leaves are consumed to cure mouth ulcers mouth. Leaves are boiled in water for bathing to cure small pox. Leaf extract is consumed orally to cure pneumonia and also used as appetizer. Twigs are used as tooth brush.	0.40
81	*Baccaureasapida* (Roxb.) Mull. Arg. *Latka*; Euphorbiaceae	NA	Jul- Sep/ Fr	Fruit are eaten as dessert.	0.91
82	*Bauhinia malabarica* Roxb. *Tanki*; Fabaceae	NA	Wy/L, F, Sh	Leaves are boiled and cooled solution is consumed daily to get relief from stomach pain. Fresh leaves are used as fodder. Flowers are cooked as vegetable. Branches are used as fuel wood.	0.72
83	*Bauhinia purpurea* L. *Devakanchan*; Caesalpiniaceae	NA	Wy/L, Fl, B, R	Leaf is boiled and solution is consumed to control jaundice. Bark paste is applied to heal wounds. Flower is used as vegetable and for decoration. Root paste is consumed to control ulcer.	0.76
84	*Bauhinia variegata* (L.) Benth. *Raktokanchan*; Caesalpiniaceae	LC	Jan-Dec/Fl, B, R	Decoction of bark and root is applied to cure mouth ulcer and skin disease. Flowers are used as vegetable.	0.69
85	*Beischimedia roxburghii* Nees. *Tarsing*; Lauraceae	NA	Wy/L	Leaves are used as fodder during lean season.	0.80
86	*Bombax ceiba* L. *Simul*; Bombacaceae	NA	Wy/Br, Fr, R, Sd,	Roots extract is consumed to treat diarrhea. Twigs are used as fuel wood. Seed and fruit floss is used to make pillow and blanket.	0.90
87	*Bridelia- retusa* (L.) A. Juss. *Gayo*; Euphorbiaceae	NA	May-Nov/L	Fresh leaves and small twigs are used as fodder.	0.76
88	*Buteamonosperma* (Lam.) O. Kuntze *Palash*; Papilionaceae	NA	Wy/B, Sd, L, Fl	Flower and leaf infusion is orally administered against diarrhea. Seed powder is consumed to kill stomach worms.	0.21
89	*Careya arborea* Roxb. *Kumbhi*; Lecythidaceae	NA	May-Dec/ Fr, L, B, Fl	Bark extract is consumed in empty stomach to cure dysentery. Flowers are used for decoration and branches are used as fuel wood.	0.61
90	*Cassia fistula* L. *Bandarlathi*; Caesalpiniaceae	NA	Wy/Fr, Fl, R, B	Dried Fruit and fresh flower are used to decorate the household. Root and bark are used to control asthma, fever, and cold &	0.20

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
				cough. Root is also used to control skin disease.	
91	*Castanopsis indica* (Roxb. exLindl.) A. DC *Kattus*; Fagaceae	NA	Wy/Sd, L, Br	Fruits & seed are cooked as vegetables and also to control blood pressure. Leaf paste in solution form is consumed to cure gastric problems. Twigs are used as fuel wood.	0.83
92	*Chukrasiatabularis* Juss. *Chikrashi*; Meliaceae	LC	Jun-Jan/ Br	Branches are used as fuel wood, agriculture implements, and for construction purposes.	0.18
93	*Cinnamomum camphora* (L.) J. Presl *Dalchini*; Lauraceae	NA	Wy/B, R, Tw	Dried bark is used for aroma in tea or hot water. Dried barks or leaves are consumed for stomach disorder and diabetes and to check reduced body weight. Root is burnt with fuel wood to repel mosquito.	0.21
94	*Cinnamomum tamala* (Ham.) Nees & Eberm. *Tejpata*; Lauraceae	NA	Jan-Dec/L, B	Leaf and bark is consumed with food to control hypertension and diarrhea.	0.21
95	*Dalbergia sissoo* Roxb. Ex DC *Sissoo*; Fabaceae	NA	Wy/L, Br	Leaves are used as fodder and branches as fuel wood and handles of agricultural implements.	0.40
96	*Delonixregia* (Hook.) Raf *Gulmohar*; Caesalpiniaceae	NA	Dec-Feb/P	Dried pods are used to decorate home.	0.44
97	*Dillenia indica* L. *Chalta*; Dilleniaceae	NA	Jan-Feb/ Fr, L	Leaves and fruits are elephant feed. Raw fruits are processed to pickle.	0.41
98	*Dilleniapentagyna* Roxb. *Tantari*; Dilleniaceae	NA	Sep-Nov/L	Leaves are used as fodder, decoration, and making plates.	0.50
99	*Elaeocarpussikkimensis* Roxb. *Bandarey*; Elaeocarpaceae	NA	Wy/Br	Braches are used as fuel wood.	0.53
100	*Elaeocarpus sphaericus* (Gaertn.) K. Schum. *Rudraksh*; Elaeocarpaceae	NA	May-Jul/Fr, Sd	Fruit and seed are consumed to control blood pressure and diabetes.	0.19
101	*Emblica officinalis* Gaerth *Amlakhi*; Euphorbiaceae	NA	Aug-Feb/Fr	Ripe fruits are consumed as dessert and with sugar to get relief from cold and stomach pain. Fruits are also processed to make pickle and candy.	0.84
102	*Erythrinastricta* Roxb. *Faledo*; Fabaceae	NA	Wy/L, B	Bark paste is consumed to cure liver problems, fever, and rheumatism.	0.55
103	*Ficuselastica* Roxb. *Laberay*; Moraceae	NA	Jun-Oct/L, Lt	Fresh leaves are used as goat fodder. Fruit latex is used in making gum.	0.23
104	*Ficusracemosa* L.f *Dumri*; Moraceae	NA	Fr, L	Leaves are used to cure mouth disease of domestic animals and as fodder. Ripe fruits are used as dessert.	0.19
105	*Ficus religiosa* L. *Peepal*; Moraceae	NA	May-Nov/ L, Wp	Sacred and religious plant.	0.22
106	*Garungapinnata* Roxb. *Dabdebay*; Burseraceae	NA	Sep-Dec/L, Fr	Used as fodder	0.28

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
107	*Gmelina arborea* Roxb. *Ghamari*; Verbenaceae	NA	May-Oct/L, R, Fr	Used as fodder during summer.	0.24
108	*Lagerstroemia parviflora* L. *Jarul*; Lythraceae	LC	Wy/Br, Sh, F, Fr	Small branches are used as fuel wood and to make handles of agriculture equipment. Flowers are used for decoration.	0.60
109	*Litsea monopetala* (Roxb.) Pers. *Kutmero*; Lauraceae	NA	Wy/B, R, Tw	Leaves cure arthritis. Bark and root powder is applied externally against bruises and pains. Tender twigs with leaves are used as fodder.	0.55
110	*Mallotus philipensis* (Lam.) Muell. Arg *Sindure*; Euphorbiaceae; T	NA	Jun-Sep/L	Used as fodder.	0.18
111	*Mangifera indica* L. *Aam*; Anacardiaceae	DD	Wy/Fr, Br, L	Ripe fruits are consumed as dessert, and raw fruits are processed to pickle and drinks. Leaf is sacred. Branches are used for agri. Implements and as fuel wood.	0.58
112	*Magnolia pterocarpa* Roxb. *Patpatay*; Magnoliaceae	DD	Wy/L, Br	Fodder and fuel wood.	0.46
113	*Michelia champaca* L. *Champ*; Magnoliaceae	LC	May-Dec/L, Sd, Fl	Leaf and seed are consumed to control fiver and eye disease; fuel wood; flowers are used for decoration.	0.51
114	*Murrayakoenigii* (L.) Sprengel *Karipata*; Rutaceae	NA	Wy/L	Leaf extract is consumed to control black fever and diarrhea. Leaves are used as spice and aroma or consumed in empty stomach to cure gastroenteritis.	0.14
115	*Oroxylum indicum* (L.) Benth. *Totola*; Bignoniaceae	NA	Nov-Feb/Fl, Sd, Fr, B	Bark is boiled with sugar, and the solution is consumed thrice a day to control jaundice. Flowers are cooked as vegetable to maintain blood pressure and also used as house decoration.	0.74
116	*Phanera variegata* (L.) Benth *Koinar*; Fabaceae	NA	Wy/Fr, Br	Bark and fruits are consumed to treat diarrhea and indigestion.	0.30
117	*Pongamiapinnata* L. *Karanj*; Fabaceae	LC	May-Jun/ Br, F	As tooth brush to cure dental pain and small ones as fuel wood.	0.25
118	*Premnabengalensis* C.B. Clarke *Gidary*; Lamiaceae	NA	Wy/L	Used as fodder.	0.33
119	*Pterospermumacerifolium* (L.) Wild *Parari*; Sterculiaceae	NA	Oct-Nov/L, Br	Used as fodder and fuel wood.	0.64
120	*Pterygotaalata* (Roxb.) R. Br *Narkeli*; Sterculiaceae	NA	Jan-Mar/Fr, L	Fruits with leaves are used for decoration.	0.72
121	*Sapindus rarak* DC. *Ritha*; Sapindaceae	NA	Oct-Dec/Fr	Used as soap and shampoo.	0.60
122	*Schimawallichii* (DC.) Korth. *Chilaune*; Theaceae	LC	Wy/Br, B	Branches as firewood and bark for dyeing and treating urine infection.	0.53

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
123	*Schleicheraoleosa* (Lour.) Oken *Kusum*; Sapindaceae	NA	Apr-May/ Br, Fr	Ripe fruits are consumed as desserts, and branches are used as fuel wood.	0.77
124	*Shorea robusta* Gaertn. f. *Sal*; Diterocarpaceae	LC	Apr-Oct/Br, L, Rs, S	Bark powder is applied on burns; leaves are used in plate-making; flower, bark, and leaves are used during festivities, and branches are used as fuel wood.	0.19
125	*Spondias mangifera* Willd. *Amara*; Anacardiaceae	NA	Apr-Jun/Fr	Fruits are used as vegetable and processed to make chutneys and pickles.	0.57
126	*Sterculiavillosa* Smith *Odal*; Sterculiaceae	NA	Feb-Mar/Fr, Fl	Used for decoration.	0.81
127	*Syzygium cumini* (L.) Skeels *Jam*; Myrtaceae	NA	Jul-Dec/ Fr, Sd, L, B	Branches are used as fuel wood, fruits as dessert, and leaves as goat fodder. Seed powder mixed with table salt is consumed with water to control indigestion and dysentery.	0.63
128	*Tectona grandis* L.f. *Shegun*; Lamiaceae	NA	Wy/Br, L	Construction, furniture, agriculture equipment. Branch and leaves are used as fuel wood.	0.55
129	*Tremaorientalis* (L.) Biume *Kuail*; Ulmaceae	LC	Wy/L	Used as fodder.	0.15
130	*Terminaliachebula* Retz. *Harra*; Combretaceae	NA	Jan-Mar/Br, L, Fr, Sd	Fruits, seed extract, and flowers are consumed with water against cold and cough. Flowers vegetable, branches, fuel wood and leaves fodder.	0.86
131	*Terminaliaalata* Roth. *Panisaj*; Combretaceae	NA	May-Jul/Fr	Fruit are used for house decoration during marriage.	0.16
132	*Terminaliaarjuna* (Roxb.) Wight &Arn *Arjun*; Combretaceae	NA	Wy/B, Br, L	Bark extract in water solution is consumed to cure heart problem and powder to control diabetes. Leaves and branches are used as fuel wood.	0.14
133	*Terminalia belerica* Roxb. *Barra*; Combretaceae	NA	Wy/Br, L, Fr, Sd	Fruits and seed are used consumed to cure cough and stomach ailments. Leaves are used as fodder and branches as fuel wood.	0.88
134	*Terminaliapaniculata* Roth *Kainjal*; Combretaceae	NA	Wy/L, B	Bark and leaf decoction controls diabetes. Leaves are fodder.	0.19
135	*Tetramelesnudiflora* R.Br *Maina*; Tetramelaceae	LC	Wy/Br	Used as fuel wood and handles for agriculture implements.	0.12
136	*Tinospora cordifolia* (Willd) *Gulancha*; Menispermaceae	NA	Wy/B, Sh, L	Roots in water solution after overnight soaking are consumed empty stomach in early morning to cure diabetes and stomach pain.	0.89
137	*Toonaciliata* Roem. *Toon*; Meliaceae	LC	Wy/L, Fr	Hut construction, furniture, fuel wood, & agriculture equipment.	0.33
138	*Trewianudiflora* L. *Pitali*; Euphorbiaceae	NA	Wy/Br, L	Shoot and leaf decoction controls excessive bile and leaf paste applied on wounds. Leaves are fodder and branches are collected for fuel wood.	0.24

Sl. No.	Sn/Vn/F/Lf	Is	Toc/Pu	Mou	RFC
139	*Ziziphus- mauritiana Lam.* *Kul*; Rhamnaceae	NA	Jan-Mar/Fr, L,	Leaf is goat fodder. Fruit and seed with salt control vomiting.	0.96
			Fungus		
140	*Pleurotusostreatus* (Jacq.) P. Kumm. *Chamray Chew*; Pleurotaceae	NA	Jun-Sep/Mu	Consumed as vegetable and processed to pickle.	0.94
141	*Pleurotus* sp. *Kaney*; Pleurotaceae	—	Jun-Sep/Mu	Consumed as vegetable	0.86
142	*Armillariamellea* (Vahl) P. Kumm. *Cheplay chew*; Phylsalacriaceae	NA	Jul-Nov/Mu	Boiled mushroom is consumed directly.	0.74
143	*Cantharelluscibarius* Fr. *Girolle*; Cantharellaceae	NA	Jul-Oct/ Mu	Consumed as vegetable and processed to pickle and snacks.	0.78
144	*Lentinussquarrosulus* Mont. *Kath chattu*; Polyporaceae	NA	Jun-Nov/ Mu	Consumed as vegetable.	0.73
145	*Termitomycesclypeatus* R. Heim *Kalunge Chew*; Lyophyllaceae	NA	Jun-Sep/ Mu	Consumed as vegetable.	0.64
146	*Termitomycesmammiformis* R. Heim *Jauri Chew*; Lyophyllaceae	NA	Jun-Sep/ Mu	Consumed as vegetable and processed to pickle.	0.80

Table 1.
Utilization pattern of NTFP species in JNP.

Ho- honey; Hw-Hardwood; L-leaf; Lt-latex; Mu- mushroom; P- pod; R- root; Rh- rhizome; Rs- resin; Sd- seed; Sh-shoot; St-stem; Tu-Tuber; Tw-twigs; Wp- whole plant; Ys- young shoot); Mou- mode of utilization; RFC- Relative Frequency citation.

3.3 Relative frequency citation

The RFC value ranged from 0.2 to 0.96 for all categories of NTFPs with an average of 0.78. In overall categories, the NTFP species collected most were *Piper thomsonii*, *Diplazium esculatum*, and *Ziziphus mauritiana*. All most all of the respondents (96%) cited these species. This is because these plant species have higher sale value in the local market. Among the 13 fish species, the RFC value ranged from 0.73 to 0.94 and the most collected fish species were *Heterepneutesfossiles, Penaeus monodon,* and *Labeorohita*and *Catla- catla* (0.94) and the least collected species was *Channa strictus* (0.73). Among fungus, the value ranged from 0.64 to 0.94 and the most collected species was *Pleurotusostreatus* and and the least was *Termitomycesclypeatus*, while the RFC value for single species of Bee *Trigona Sp.* was 0.92 (**Figure 2**).

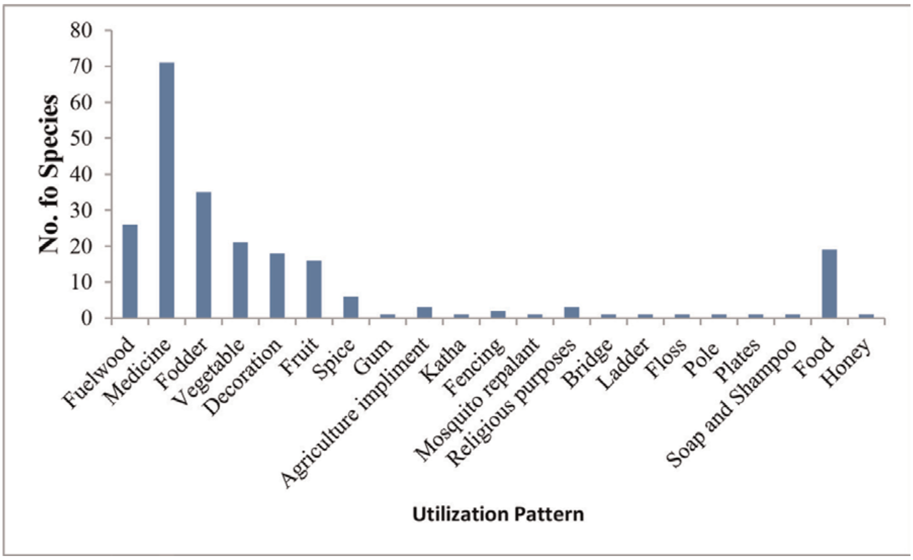

Figure 2.
Mode of NTFP use.

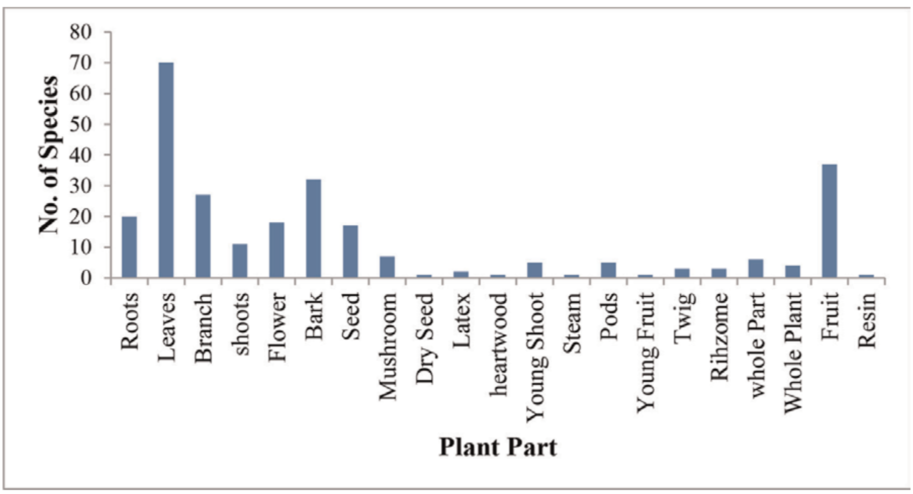

Figure 3.
Plant parts used.

3.4 Parts used, harvesting pattern, and time

Plant parts of NTFPs used by the indigenous communities of JNP and their mode of harvesting and utilization pattern are presented in **Table 1** and **Figure 3**. It was recorded that leaves/foliage were the most used plant part harvested/collected from 70 species, followed by fruits of 36 species, branches of 30 species, barks of 23 species, roots and rhizomes of 21 species, flowers of 17 species, seeds of 16 species, and shoots, twigs, and tender stem of 10 species. Latex and resin were extracted from three plant species. More than 60% of the documented NTFP species were collected or harvested throughout the year, and prominent among these is fuel wood. About 25% species were collected or harvested during the rainy season, which include fodder, wild vegetable, medicinal plants, mushroom, honey, and fish. Fourteen species were collected or harvested during winter season, and the rest of the species were collected or harvested during the summer season. Generally, leaves were harvested during the profuse growth period of plant, that is, rainy season, which included fodder and leafy vegetable.

3.5 Utilization

The various uses of the NTFP species are for medicine, food, fruit, vegetables, spice, fodder, fuel wood, decoration/craft, fencing, and religious purposes as well as for construction, agriculture implements, soap/shampoo, rope, furniture, plate, and mosquito repellent (**Table 1** and **Figure 4**). The maximum number of species were documented with single use (75 species), and *Mangifera indica* is used for six purposes.

3.6 Medicine

Of the total documented NTFPs, 73 species were used for ethnomedicinal purposes, and among these species, 28 species were solely used for medicinal purpose (**Table 1**). The important species used as medicine are *Acacia catechu, Azadirachta indica, Aegle marmelos, Artocarpus lakoocha, Bauhinia malabarica, Bauhinia purpurea, Bombax ceiba, Castanopsis indica, Oroxylum indicum, Syzygium cuminii, Terminalia chebula, Terminalia bellerica, Trewianudiflora, and Ziziphus mauritiana*, which are usually administered against bleeding, urine infection, indigestion/stomach disorder, diarrhea/dysentery, diabetes, ulcer, gastroenteritis, rheumatism, fever, control body temperature, skin disease, allergy, stomach pain, jaundice, cuts/wound, could, cough, vomiting, nausea, and blood pressure. *Azadirachta indica*was is used round the year for treating various diseases like eye infection, allergy, and skin infection and also used as tooth stick. *Oroxylum indicum* is also used round the year to control jaundice and blood pressure.

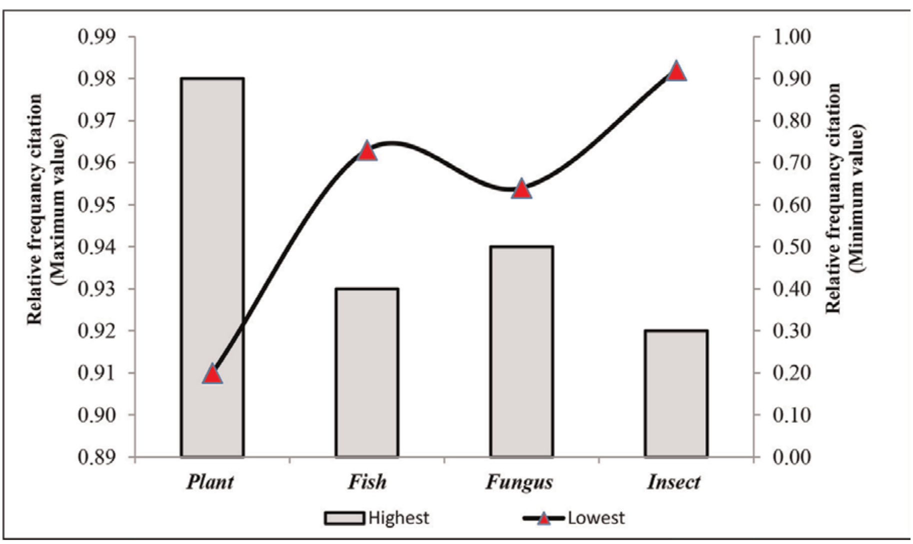

Figure 4.
Relative frequency citation (RFC) value.

The indigenous communities of JNP were rich in ethnopharmacological knowledge to properly use NTFPs. A total of 49 diseases/ailments were cured with the help of locally available plant resources. Fever, cough, and cold were documented as the most common disease suffered by the community. For remedy, the community used 12 different plant species. Another common disease was dysentery, and 10 plant species were used for its treatment. Skin and stomach problems were treated with eight and seven species, respectively. Diabetes, vomiting, and diarrhea were treated with five species each, while four species each were used for treating indigestion, mouth ulcer, rheumatism, and blood pressure. Similarly, three species each were used to treat asthma and allergy, while two species each were used as remedy for urine infection, jaundice, kidney problem, heart problem, eye problem, and burns. Treatment of cut and wound, snake bite, fracture, swelling/pain, body pain, arthritis, pneumonia, loss of appetite, liver aliments, stomach worm, cholera, gastroenteritis, ring worm, boil, sexual disorder, hypertension, conjunctivitis, tooth pain, small pox, reducing weight, leprosy, bleeding control, cystitis, hiccup, and nerve disorder was done by using only one plant species. Young twigs of *Azadirachta indica* and *Pongamia pinnata* are used for dental care. Honey secreted by *Trigona* spp. is mixed with black pepper powder and consumed for relief against cold and cough. Even mouth disease of domestic animals was documented to be treated, and *Ficus racemosa* was used for it.

Proper selection of species, parts, as well as preparation and administration methods was very important in traditional healthcare systems. Generally, fresh part of the plant is used for the preparation of medicine except for the underground parts, which were used in dried form. Ethnomedicinal formulations were administered both externally (skin, nasal, eye, and dental) and internally as oral doses. Most of the preparations were a mixture of different plant species, and in a few cases, only one plant species was used. Different parts of a single species were also used to cure different diseases. Almost all plant parts were used to prepare different medicinal formulations: roots, rhizomes, tubers, bark, leaves, flowers, fruits, seeds, young shoots, whole plants, and gum and latex. Doses of these preparations were not standardized but administered on the basis of age, physical appearance, and intensity of the illness. Children were usually administered with smaller doses than adults. The course of frequency of treatment is decided by the type of disease and its severity. The majority of formulations were prepared as juice followed by paste and decoction. The mode of preparation included juice, paste, decoction, powder, infusion, and chewing raw plant parts. The administration of the therapy is done as a raw, dried form in small pieces or powder, solution, or mixed with water/milk/honey and paste/lotion. Roots and rhizomes were preferred to prepare traditional remedies.

3.7 Food and nutrition

Many plant-, animal- and fungus-based NTFPs were collected by the indigenous communities from JNP for food and nutrition (**Table 1**). Plant-based resources used for food and nutrition was represented by 42 species. Animal-based resources used for food were represented by fish with 13 species and a honey bee species. Fruiting bodies of seven species of fungus were also used as food. Among the plant resources, more than 50% of the species were used as vegetable and fruits. Honey and fungus collected were mostly used for food and medicine purposes. All the mushrooms were used for culinary purposes and sometimes as snacks and added value to pickle as well. Fish supplements protein in the diets of the collectors. Leaves/foliage, root, rhizome, tuber, fruit, and flower/inflorescence of the plants were collected from the forest and either cooked or consumed fresh. The communities were collecting these plant resources round the year or when available. Fruits are also consumed ripe as dessert or as vegetable and also processed as pickle or chutney. Herbs are generally consumed as leafy vegetables. Some tubers, rhizomes, pods, and fruits are also consumed as vegetable. Edible plants are generally important for both humans and domestic animals during the time of scarcity.

The indigenous communities of JNP were collecting different type of wild edible and cultivated fruits from the forest for both self-consumption and sale for cash income. The community collects fruits of 17 species for food, vegetable, and spice and also add value to products like pickles (**Table 1**). The maximum amount of fruits collected were consumed directly either raw or ripe. Fruits of *Artocarpus hetrophyllus* were either used as vegetable and pickle or consumed ripe. Fruits of *Mangifera indica* were also consumed as both ripe and raw after preparation of chutney. Fruits of *Syzygium cuminii*, *Baccaureasapida, Aegle* marmelos, and *Artocarpus lakoocha* were consumed as ripe only, whereas *Ziziphus mauritiana* and *Dillenia indica* were used for the preparation of pickle or "*chutney*".

Wild vegetables were collected for self-consumption and also sold in the local market to earn cash income. A total of 26 NTFP species were used as vegetable (**Table 1**). Among these, 19 were plants and seven mushrooms. NTFPs for vegetable purpose were daily collected for household needs. Leafy parts of the species were mostly preferred by the communities as vegetable and collected round the year from the forest. Some of the common species used as vegetable for both home consumption and sale were *Diplazium esculentum*, *Basella alba*, *Mussaendatreutleri*, and *Colocasia esculenta*. Rhizome and tender shoots of the *Colocasia* and *Basella* were collected during the rainy season for self-consumption, and a bulk of the amount was sold at the local market. Flower of *Mussaendatreutleri* is used for culinary purposes and consumed with rice. This cuisine is locally known as "*Mocha*" and consumed for supplementing the iron deficiency. Tender upper leafy part of *Chenopodium album* is cooked as vegetable and consumed with "*chapatti*" during winter season. Young shoots of *Bambusa vulgaris* were either consumed as vegetable or processed as pickle.

Products from six species of plants were used as spices or aroma for the preparation of locally made pickles for either self-consumption or sale (**Table 1**). These species are *Capsicum annum*, *Cinchona officinalis*, *Cinnamomum camphora*, *Cinnamomum tamala*, *Flumaria indica*, *and Murrayakoenigii*. Leaves of *C. tamala* and bark of *C. camphora* are used for making black tea and also used with rice. Leaves of *M. koenigii* were used for aroma and as condiment. Fish and mushroom were collected for both self-consumption and sale. Fishes like *Cirrhinamrigala*, *Labeorohita*, *Mystusvittatus*, and *Puntius ticto* were caught from the river, ponds, and other perennial water sources round the year except *Catlacatla*, which is caught during the rainy season only. The species is costly and used generally during ceremonial occasions. The fringe communities are highly dependent on these fishes for nutrition and energy along with cash income from sale in the local market. Seven types of mushrooms were also collected from the forest during the rainy season to prepare different culinary items for consumption with rice.

3.8 Animal feed

Plant leaves/foliage, fern, herb, and leaves of shrubs are collected from the forest as a supplement to the conventional fodder for domestic animals, and for this purpose, 36 plant species were used (**Table 1**). Some of the preferred species as fodder were *Artocarpus*, *Ficus*, and *Dillenia sp*. as these species are available almost round the year. Leaves of *Ziziphus mauritiana* and *Syzygium cuminii* were also used as fodder, especially for goat. Leaves and foliage were mainly collected as fodder during summer and winter seasons when there is acute shortage of normal fodder. Fruits of *Dillenia indica* were also collected as feed for animals.

3.9 Other uses

The inhabitants of JNP largely depend for their domestic energy consumption on fuel wood collection from the forest, and they mainly use dead and dried wood of 26 species collected from the forest (**Table 1**). Apart from using it as domestic energy, firewood is sold in the local market and is a major contributor in the household income. The maximum consumption of firewood was documented during winter and rainy seasons as compared to during summer season. The area experiences cold temperature during the winter season, which necessitates firewood burning for heat. The firewood species preferred were *Albizia lebbeck*, *Anthocephalus cadamba*, *Pongamia pinnata*, *Schima wallichii*, *Lagerstroemia parviflora*, and *Mangifera indica* as compared to other documented species. Dried leaves of *Tectona grandis* are also collected during summer and used as fuel.

The fringe communities also make different types of craft and decorative items from the plant resources for decorating houses during festival, marriages, and other traditional rituals. Eighteen plant species were listed that were in use for this purpose (**Table 1**). The decorative or craft items were also sold in the local market for earning money. Some of the common species for this purpose are *Cassia fistula*, *Delonix regia*, *Oroxylum indicum*, and *Sterculia villosa*. Leaves, foliage, flowers, fruits, and twigs of six plant species were used for religious purposes (**Table 1**). Leaves of *Aegle Marmelos* and *Mangifera indica* were sacred and used as offering to God during rituals. Fruits of *Datura metal*, *Saussurealappa* flower, and seeds of *Elaeocarpus sphaericus* were also used while performing a religious ritual. *Ficus religiosa* is considered sacred by the fringe community. Three plant species were used to fence the homestead for protection against stray animals (**Table 1**). *Bambusa vulgaris* and *Bambusa bamboos* and *Lantana camara* were used for fencing around the animal shed and in crop fields. Bamboo thatching is also commonly used for fencing the house and animal shed.

NTFPs were also used for other purposes like agricultural implements, construction work (bridge, house, and animal shed), furniture, flosses, gum, honey, katha, ladder, pole, mosquito repellent, plate, rope, soap, and shampoo (**Table 1**). The branches of *Tetramelesnudiflora* and *Anthocephalus kadamba* were used for making small agricultural implements (handle of spade, plow). *Shorea robusta* is used for furniture and house construction, while its dried leaves are burned as mosquito repellent. Its leaves are also used for making plates. Small root pieces of *C. camphora* are also burned along with firewood as mosquito repellent. B*ambusa bamboos* and *Dendrocalamus strictus* are used for making ladder and construction of small temporary bridge. Twigs of *Cissus repanda* are used for making rope, heart wood of *Acacia catechu* for katha, and leaves of *Dilleniapentagyna* for plate, *Ficus elastica* for gum, *Bombax ceiba* for floss (floss of *Bombax* is locally known as "*Tula*"), and *Sapindus rarak* for soap and shampoo.

4. Discussions

4.1 Socioeconomic attributes

Socioeconomic profiling of forest-dependent communities helps in understanding their dependency on NTFP resources [2, 3, 13, 49, 50]. The settlement of the villages is in the designated forest area of JNP for past many generations with marginal land holding granted to the settlers in recognition of their traditional right to natural resources by the Forest Department. The villagers do not have any additional land to till except for the land around homestead where subsistence farming is practiced, that is, homegarden agroforestry. Rural livelihood is linked to socioeconomic characteristics of households as well as physical factors [51, 52]. Literacy level of the respondents indicates their progressiveness [3], and more than half of the respondents in this study were literates, ranging from illiterates to graduates. The total monthly income of the households surveyed in the study varied from INR ₹ 1000 to ₹ 30,000. The contribution of NTFP toward household income also varied widely from 1–70%.This is because the households earn income from NTFPs after their household needs are fulfilled [3, 53]. Similar variations in income from NTFPs were also reported by many earlier studies [21, 54–56]. Earnings from NTFPs vary from region to region [57, 58] depending on ecological settings, income level, and caste/community [59]. The entire household also had alternate income options. A majority of the households were engaged in daily paid manual labor and as vendors. NTFPs ensure year-round income to the households, and thus, the reliance of the households is more on them than on other livelihood options. This indicates that NTFPs are satisfying multiple needs of food, shelter, medicines, fibers, energy, and cultural artifacts and thus supporting the well-being of the indigenous people of JNP [2, 3, 39, 60].

Due to the availability of limited livelihood options to earn for a decent living and low development in the study area, the indigenous communities living in and around JNP were collecting NTFPs from the forest to meet their daily needs though their cash income varied widely from NTFPs. The cash income from NTFP sale is highly skewed because only the NTFPs that remain unused after satisfying their needs are subjected to sale in the local market and very less to the traders or vendors. It was reported that 43 NTFP species were sold by the fringe communities of JNP but in unprocessed form [3] and thus were undervalued, fetching only the collection charges of NTFPs to the collectors [3, 56]. Deprived of the fair prices of their product, the community is forced to spend more time on its collection, leading to unsustainable harvesting [61]. An absence of fair price mechanism and regulated market links in JNP was reported to be the cause of deprival of fair prices of NTFPs to its fringe communities [3].

Moreover, remoteness and absence of good roads make it very rare to approach the study area by the traders/vendors from outside for trading NTFPs. Several other studies though had also reported a wider range (10–60%) in the contribution of NTFPs to the total household income but ascertained that NTFPs do ensure a permanent source of income year-round [3, 62]. Distribution, collection, and contribution in household economy of these NTFPs vary from region to region and forest to forest due to change in locality factors including sociocultural domains [1]. Studies have also indicated that due to poorly developed market network, transportation absence of quality assurance, price-fixing mechanism and processing, most of the NTFPs are consumed in household to satisfy daily needs [63]. It is reported that the more isolated and remotely located the area is, the higher is the contribution of NTFPs to noncash income [5]. The economic, livelihood, and ecological benefits of NTFPs can only be realized when their collectors are benefitted fully [5, 12, 13, 17].

4.2 Relative frequency of citation (RFC)

The relative frequency of citation (RFC) indicates that most cited species were collected abundantly in their respective season for the household consumption or marketing. Several studies suggested that a marketing of NTFPs leads to their competitive exploitation, followed by biological degradation [3, 64, 65]. Therefore, to study the diversity of NTFPs, the time of collection, utilization, and marketing channel are pivotal for the sustainability.

4.3 NTFP diversity

Documentation of 146 NTFP species indicates that the JNP is a rich reservoir of NTFP species of immense potential for human well-being. This documentation of NTFP species from JNP may play a pivotal role in the utilization and conservation of this natural wealth. Further studies on phytochemical principles including extraction of different active constituents on a scientific scale will lead to the recognition and preservation of the NTFP species unknown to the outer world. Among the enlisted 146 NTFP species, 116 were not assessed or not evaluated, 26 species falls under least concern and two species were under data deficit category in the IUCN priority list of species, [66]. Enlisting the species compared with the IUCN priority list indicates the status of the population of a particular species in an area. Such documentation will ensure future conservation of these species in the wild through their sustainable utilization and promote their domestication. The IUCN status of the JNP NTFP species warrants more vigorous and systematic research to gather accurate and complete information on the population status of the species in the area for their sustainable management and conservation for their continuous exploitation.

The ethnobotanical plant species that were documented as cultivated (24 species) or both cultivated and wild (27 species) were actually been planted by the respondents in their home garden, and it was found during the survey that almost all the respondents were maintaining a home garden contributing to the conservation of the species they were using. Indigenous people of JNP domesticating/cultivating ethnobotanical plants in their home gardens clearly indicate the community consciousness on the conservation values of these ethnobotanical species. This means that the inhabitants of JNP have switched to sustainable harnessing their valuable natural resource through domestication of some valuable wild species and leaving these species intact in the wild. There is a need to plant and domesticate the NTFP species of JNP through formulating local missions supporting indigenous strategies of food security. Similar report on home gardens maintaining rich biodiversity of ethnobotanical plants was also reported in earlier studies [11, 67]. There is relevance of man-made environments as a prominent source of ethnobotanical plants for both indigenous and non-indigenous agricultural societies for their conservation [68]. Home gardens serve as refuge for legacy species, with forces of family tradition and bonds that promote knowledge transmission and conservation [67, 69].

4.4 Plant part use/harvesting time

Most of the species were harvested year-round, while those used as fruits, vegetables, and fodder were harvested during the rainy season. Destructive harvesting was done in case of whole plants, roots, tubers, and rhizomes. Harvesting bark and seeds was also destructive as this can affect the survival of the plants. Harvesting patterns of leaves or foliage, root, rhizomes, and tubers indicate their possibility of vulnerability for becoming endangered and ultimately extinction [11]. Earlier studies also documented similar time of harvest or collection of NTFPs [4, 13]. The uses of various plant parts of these documented NTFP species in traditional uses were similarly reported by many workers [29, 70]. Genetic biodiversity of NTFP species gets threatened or vulnerable because of destructive harvesting techniques mainly done for commercial exploitation along with other causes like grazing, loss of habitat, and unmonitored trade [71]. NTFPs are freely harvested by users either for their own use or for trade [72]. The harvesting of these multiple-use species can put them under threat [73] but can also lead to better chances for their conservation [74], especially through home gardens.

4.5 Utilization

The acquaintance of forest flora and fauna and their importance are rich among the indigenous communities as they are traditionally integrated in the traditional lifestyle of these people, and this traditional knowledge system was accumulated and passed on from one generation to the other orally [4]. NTFPs collected were of multipurpose nature and were mostly used to supplement daily food and nutritional and health requirements of the households and domestic animals as well [1, 13, 24, 28–30, 50, 75–77 27]. There is much documentation of use ethnobotanical plants other than medicines and food [70, 71, 78].

Generally, NTFPs collected were consumed fresh either as food or for treating ailments traditionally [79] except for underground parts, which when used for medicinal purposes were dried [80]. Rarely the collected NTFPs were value added with exceptions for domestic consumptions that too very crudely [4, 81, 82]. Using roots and rhizomes to prepare traditional medicinal formulations has an advantage that these underground organs generally contain high concentrations of bioactive compounds [83]. Many studies also have made such observations [5, 12]. Proper selection of species, parts, as well as preparation and administration methods was very important in traditional healthcare systems [29, 30, 77].

Identification, documentation, collection/extraction, and conservation of indigenous traditional knowledge about the plants are very essential to be used in the near future for the ever-increasing population to ensure food and nutritional security [84]. No new food, particularly the wild food, will be accepted by the urban population without proper testimony from specialists. It will be no wonder if some plants used by the indigenous community as food may on analysis prove rich in nutrition. Others however may come out to poorer or even nutritionally almost useless. But that too would not minimize the utility of recording whatever information can be gathered on the botanical folklore of these fast-disappearing cultures [5].

Information generated from this study will be helpful to understand the human–forest relationship in terms of livelihood options and scheduling sustainable harvest procedures for the indigenous communities and thereby increasing their participation in the conservation and sustainable management of these natural resources [14, 84]. Such documentation will also aid in the preservation of traditional conservation practices and framing management strategies, whereas utilization pattern can be helpful in transferring the traditional knowledge to younger generations and appreciating its value for human welfare and thus conservation of these ethnobotanical plant species. However, for the development of indigenous people and to conserve their knowledge under intellectual property right, a vast effort is needed [85].

Revitalizing the principles of traditional and religious practices where modern conservation programs could integrate traditional knowledge systems of indigenous communities into their conservation and management activities of natural resources is needed [86]. Ethnobotanical studies have reported resource management by the local people utilizing the principles of traditional knowledge in light of today's modern conservation principles [25–27, 87]. Institutional intervention was recommended to protect the rights and empower the JNP fringe community to access information on policy, market, and value addition of their products with capacity-building, financial, and infrastructural support [3]. Additionally, such missions will rejuvenate the sociocultural heritage and traditional food market circuits of JNP, which will conserve and replenish the NTFP resource to uplift the socioeconomic status and livelihood of indigenous communities at JNP [87–91].

5. Conclusion

The indigenous fringe communities of JNP with their traditional lifestyle relied on NTFPs for their daily subsistence needs and also for permanent source of cash income. The sale of NTFP was contributing 45% on an average to the total annual household income. NTFPs also provided a safety net particularly during the periods of scarcity and filled the gap of food deficit, especially when their subsistence standing crops were destroyed by wild elephants. We documented 146 NTFP species from our study area. In this list, 95 were wild, 24 were cultivated, and 27 species were both wild and cultivated. Some wild plant species were also grown in home gardens, thus aiding the conservation of these species. However, there is very less or no information available for these documented species as 116 species were not assessed or not evaluated, 26 were least concern, and two species were under the data deficit category in the IUCN priority list of species. More research is required to update information on the population status of these NTFP species. Systematic accounting the volume of NTFPs collected/harvested along with cash and noncash income should be initiated. Policies supporting *ex situ* conservation programs through capacity building the communities with improved cultivation techniques of commercially viable NTFP species and value addition of NTFP products will enhance their income and relieve pressure from the forest. Storage, grading, processing, and value addition through linking with existing development schemes should be created or promoted. Institutional intervention is required to empower the communities with information on policy, finance, markets, and products to enable them to trade NTFPs with better returns. Diversification of livelihood options along with education, skill, and basic infrastructure development is also recommended.

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Authorship contribution

Lakpa D. Lepcha: Data collection, analysis of data, and writing first draft; Gopal Shukla: Conceptualization of study and finalizing the draft MS; Biplov Ch. Sarkar: Data Collection and analysis; and Sumit Chakravarty: Conceptualization of study and final editing of MS.

Data availability

All the data are included in the paper.

Conflict of interest

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work presented in this paper.

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Chapter 4

Biodiversity Conservation of Western Himalayas: A Pluralistic Approach

Mast Ram Dhiman and Girish P. Muthanarasimha

Abstract

The conservation of biodiversity has been a matter of serious concern all over the world. Regions of the world with rapidly changing land use and economies require transdisciplinary focus to adequately address today's challenges for conservation, local livelihoods, and development. Himalayan ecosystem sustainability is vital for the employment of approximately 1.3 billion people in Asia. The Indian Himalayan Region (IHR) are special for their natural geological wealth, forest, flora, fauna and biodiversity, snow, ice and water bodies, traditional knowledge, and mountain agriculture. It is now widely accepted that the rich and diverse Himalayan ecosystem is fragile. The regions are predominantly populated by local societies. Live in biodiversity wealthy regions of the country, the neighboring mountainous communities are dependent upon biodiversity for meeting their livelihood security. Hence, sustaining biodiversity in the mountain region also means defending the benefit of the people. Recognition of the Himalayas as one of 34 global biodiversity hotspots aptly reflects its wide-ranging ecological significance. Societies across the world have had long-standing traditions of using and caring for nature, but the formal, mainstream, and largely western 'conservation movement' is only about 120 years old. Biocultural approaches to conservation represent a synthesis of theory across multiple fields linked to biodiversity conservation, including social-ecological systems thinking, commons theory, bio-cultural diversity and heritage, indigenous natural resource management and traditional ecological knowledge, and different models of participatory and people-centered conservation. This synthesis points to the potential for pluralistic, partnership-based, and dynamic approaches to guide conservation processes.

Keywords: Western Himalaya, diversity, conservation, pluralistic, biodiversity loss

1. Introduction

The conservation of biodiversity has been a matter of serious concern all over the world. Regions of the world with rapidly changing land use and economies require transdisciplinary focus to adequately address today's challenges for conservation, local livelihoods, and development. Himalayan ecosystem sustainability is vital for the employment of approximately 1.3 billion people in Asia. The Indian Himalayan

Region (IHR) are special for their natural geological wealth, forest, flora, fauna and biodiversity, snow, ice and water bodies, traditional knowledge, and mountain agriculture. It is now widely accepted that the rich and diverse Himalayan ecosystem is fragile. The perennial rivers of north India depend heavily upon the sustainability of glaciers and the ecosystem of the Himalayan region. As defined in the Convention on Biological Diversity, biodiversity encompasses the variety and variability of life forms, ecosystems, and ecological processes, at all levels of biological organization, and is the foundation of human survival and economic well-being [1]. The popularity of the biodiversity concept rests on the fact that its three-tiered definition (diversity within species, between species, and of ecosystems) provides a 'big tent' that encompasses a variety of interests within the modern conservation movement.

Forests cover around 30% of the earth's surface and besides being the reservoirs of biologically rich and genetically diverse ecosystems also provide a wide range of services that include healthy soils, clean drinking water, climate regulation, and recreational and esthetic benefits [2]. About 410 million people are reported to be dependent on forests for subsistence and income and around 1.6 billion depend on forest goods and services [3]. Ever-increasing demands on forest ecosystem goods and services are increasing pressure on the natural resources of forests and making them more vulnerable. Ever increasing human population combined with unsustainable resource use, poor management, and limited investment in conservation further contribute to their vulnerability [4].

The biodiversity of mountain regions has been studied by scientists for a long period which suggests that they are a rich repository of biodiversity [5, 6]. The Himalayan forest landscape is a provider of a wide range of goods and ecosystem services to its inhabitants and downstream communities [7]. In the Himalayan regions, the altitude range (800–6000 m) particularly plays a major role in the distribution of different species and these species found at each altitude have their own importance in sustaining other associated flora and fauna. This interdependency of species with other various communities in the high altitudes has a significant role in maintaining the biodiversity of these areas. The IHR is a mega hot spot of biological diversity. The IHR supports vast natural diversity, consisting of 18,440 plant species, including 1748 and 675 species of medicinal importance and wild edibles, respectively. However, the Himalayan ecosystem is recognized as one of the most vulnerable ecosystems to the consequences of climate change and anthropogenic disturbances [8]. Most of the published literature adopts a singular approach to biodiversity, scientifically justified without reflecting on the indications of the central metrics which are available for equity and social justice in preservation practice. In this chapter, we take into account the role of conservation science, the definitions and concepts it employs, and their effects on conservation policy and practice. We contemplate some of the challenges and opportunities that would reveal in exploring a pluralistic perspective on biodiversity conservation.

2. Importance of IHR biodiversity

Forests support life for more than 70% of terrestrial biodiversity; regulate water cycles, sustain soil quality, and reduce the threat of natural disasters like floods and landslides, as well as directly and indirectly sustaining the livelihoods of >1.6 billion people on the globe [9]. IHR is continuously deteriorating despite its crucial importance in maintaining the ecosystem, as the value of ecosystems to human welfare is still underestimated. The high Himalayan ranges and glaciers cover most of the northern parts of the Western Himalayan region of Indian sub-continents. Whereas, the adjoining lower reaches are under forest land use that occupies about 2/3rd of the landscape. The mountainous parts of the region are gifted with rich biodiversity having tree species from sub-tropical to alpine zones. The commonly collected NTFPs from these forests include a variety of wild edibles, medicinal, and aromatic plants such as pine resin, lichens, moss, wild mushrooms, fruits, and flowers and these also provide income and employment to its inhabitants through forest-based activities [10]. In India, Western Himalayas is one of the two important diversity hotspots, the other being the Western Ghats [11] and is unique because of the different geomorphic conditions, changing thermal regimes, and fast water current. The Himalayan Mountains are important sources of water to the Indo-Gangetic plains through the perennial glacier-fed rivers. The value of ecosystem services provided by the Himalayan forests was estimated to be $1150/ha annually.

The Himalayan region is known for the diversity and richness of its medicinal plants and it harbors a large number of ethnic communities, each with a distinct culture and traditional knowledge system [12]. IHR has been reported to house 8000 angiosperms, 44 gymnosperms, and 600 pteridophyte species [13], and of these, 1748 species fall under various traditional and modern therapeutic uses. The highest number (701) of medicinal and aromatic plant species (MAPs) have been reported from the Uttarakhand region [14, 15]. Among different biogeographic provinces, nearly 643 species of medicinal and aromatic plants are known from Himachal Pradesh and 701 from Uttarakhand in Western Himalayas. Nearly 26% of known MAPs are native to the Himalayan region while another 6% share their nativity with Himalayan and adjoining areas [15]. India has emerged as a strong destination in the herbal sector with 8.13% of the global share and 22% growth, which is highest in the world [16]. MAPs have been used for decades and serve both as a source of income and affordable healthcare in many developing countries [17]. Today, more than 90% of plant species used in the pharmaceutical industry are harvested from the wild, many of these come from the subalpine and alpine regions of the Himalayas. Depletion and loss of medicinal plant diversity and its knowledge base may have significant impacts on human health and livelihood [11]. Hence, protection of the genetic pool of this valuable wealth in nature is urgently required for long-run sustainability and making it available for future generations.

These are also used by pharmaceutical companies for developing herbal medicine and used for the synthesis of new molecules [18] which has directly increased their demand and also promoted their illegal collection from the wild. In the Western Himalayas, around 30% trade of MAPs operated from alpine areas, and 90–95% material is collected from wild habitats through destructive practices [19] and their population declined considerably.

3. Present status of biodiversity in IHR

The Indian Himalayan Region lies between 27°–38° N Latitudes and 72°–89° E Longitudes which covers about an area of 419,873 km^2 (nearly 18% of India) with >2800 km long and 220–300 km wide. The altitude ranges from 200 to >8000 m above mean sea level. Indian Himalayan region includes the parts of Trans, North-west, West, Central, and East Himalaya, and ranges from Arunachal Pradesh to Jammu and Kashmir and Ladakh Union Territories and rising to an altitude of more than

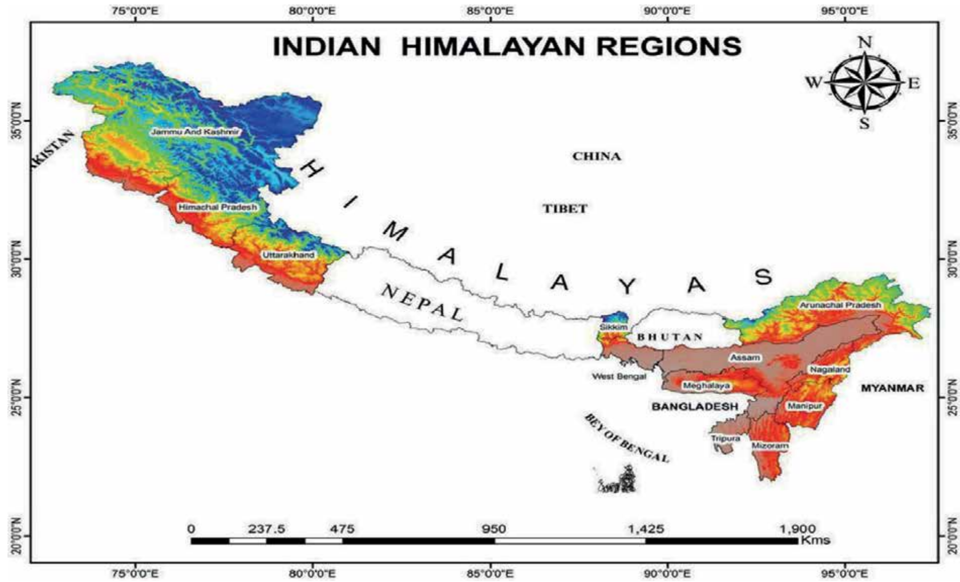

Figure 1.
Location map of the Indian Himalayan region.

8000 m AMSL (**Figure 1**). The IHR support three bio-geographic zones namely Trans Himalaya, The Himalaya, and North-East India and eight biogeographic provinces including Ladakh Mountains, Tibetan Plateau, Northwest, West, Central & East Himalaya, Brahmaputra valley, and North East Hills. The IHR is very well known for its representative, natural, unique, and socio-economically important biodiversity [15] and is designated as one of the biodiversity hot spots [20]. The richness of the biological diversity is mainly due to its unique climatic conditions, topography, and diverse habitats. The rich plant diversity has been utilized by the natives in various forms such as medicine, food (edible), fuel, fodder, making agricultural tools, house building, small scale enterprises (i.e., basket, mat, hat, kilta, *etc*.), and religious ceremonies [21].

4. Plant biodiversity in IHR

In angiosperms, about 10,452 species belong to 2302 genera and 232 families and in gymnosperms, 51 species belong to 20 genera and 8 families are reported from the IHR, Nepal and Bhutan [22]. About 3160 species of vascular plants in the Himalayan region are endemic. The IHR represents 18,940 species of plants, among these 8500 species (40% endemics) characterized by angiosperms; 44 (15.91% endemics) by gymnosperms, 600 (25% endemics) of pteridophytes; 1737 (32.53% endemics) of bryophytes; 1159 (11.22% endemics) of lichens and 6900 (27.39% endemics) of fungi. In angiosperms overall, 6745 species of 225 families, belonging to 1768 genera have been noticed from the Trans, North West, and Western Himalayas. Among that, 604 were tree species, 1049 shrubs and herbs are 5092 [21]. About 3984 species of angiosperms and 21 species of gymnosperms are reported from Arunachal Pradesh; From Assam, 3010 species of angiosperms and 7 species of gymnosperms; In Manipur, 2376 angiosperms species and 5 of gymnosperms; from Meghalaya, angiosperms 1886 and 6 species in gymnosperms; 2141 angiosperms and 6 of gymnosperms from Mizoram;

In Nagaland, 2431 angiosperms and 9 of gymnosperms species; 1463 species in angiosperms and 13 of gymnosperms from Tripura, and 4458 species of angiosperms from Sikkim were recorded [23].

The gymnosperms group is represented by the families Cupressaceae, Cycadaceae, Ephedraceae, Ginkgoaceae, Pinaceae, Podocarpaceae, Taxaceae, and Taxodiaceae in the IHR [22]. The angiosperms are the biggest collection of plant species and consist of the families Acanthaceae, Apiaceae, Asteraceae, Brassicaceae, Fabaceae, Euphorbiaceae, Lamiaceae, Liliaceae, Orchidaceae, Poaceae, Polygonaceae, Rosaceae, Rubiaceae, Scrophulariaceae, etc. Some monotypic families represented only by single species are Actinidiaceae, Adoxaceae, Casuarinaceae, Biebersteiniaceae, Calycanthaceae, Cannaceae, Caricaceae, Ceratophyllaceae, Circaesteraceae, Clusiaceae, Coriariaceae, Daphniphyllaceae, Datiscaceae, Dipterocarpaceae, Droseraceae, Hippuridaceae, Icacinaceae, Iteaceae, Lardizabalaceae, Leeaceae, Marantaceae, Martyniaceae, Melianthaceae, Moringaceae, Myricaceae, Ochnaceae, Paeoniaceae, Platanaceae, Plumbaginaceae, Podophyllaceae, Podostemaceae, Proteaceae, Punicaceae, Rhizophoraceae, Saurauiaceae, Sonneratiaceae, Saururaceae, Sphenocleaceae, Stylidiaceae, Torricelliaceae, Trillidiaceae, Tropaeolaceae, Zannichelliaceae, etc. The dominating genera in Trans, North West, and West Himalaya are, *Carex, Taraxacum*, *Potentilla*, *Astragalus*, *Saxifraga*, *Cotoneaster, Artemisia*, *Cyperus, Polygonum, Corydalis, Berberis, Euphorbia, Silene, Poa, Primula, Pedicularis, Nepeta, Impatiens, Ranunculus, Persicaria, Veronica, Allium, Rubus, Ficus,* etc. [21].

In medicinal plants, a total of 1748 species belonging to 915 genera and 223 families are found in the IHR (**Table 1**). The families that signify the greatest number of medicinal plants in descending orders are, Asteraceae, Fabaceae, Lamiaceae, Rubiaceae, Euphorbiaceae, Ranunculaceae, Rosaceae, Poaceae, Orchidaceae, Polygonaceae, and Gentianaceae, respectively. The medicinal plant-rich genera are *Polygonum*, *Euphorbia*, *Piper*, *Ficus*, *Aconitum* and *Swertia*, *Artemisia*, *Solanum, Berberis, Desmodium,* and *Allium,* and *Saussurea*, respectively. A total of 675 wild edible plants representing 384 genera and 149 families are known in IHR. Of these, 285 species are herbs, 172 species of shrubs, 197 species of trees, 12 species of pteridophytes, 07 species of fungi, and 02 species of lichens (**Figure 2**).

5. Services of IHR biodiversity

Biodiversity provides several facilities and services such as food, fodder, fuel, medicine, timber, resins, oil, climate regulation, pollution control, soil and water

Taxonomic group	Families	Genera	Species	Herbs	Shrubs	Trees	Ferns
Angiosperms	191	878	1685	1020	335	330	—
Gymnosperms	4	6	12	—	3	9	—
Pteridophytes	28	31	51	—	—	—	51
Total	**223**	**915**	**1748**	**1020**	**338**	**339**	**51**
Threatened: 165, **Agro-techniques**: 30							

Source: Samant et al. [15].

Table 1.
Biodiversity of medicinal and aromatic plants in IHR.

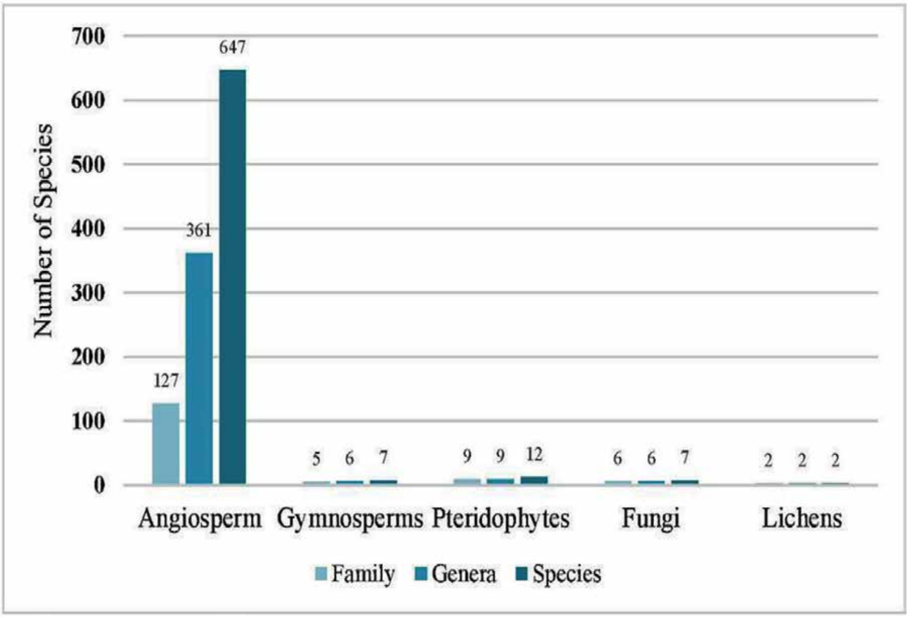

Figure 2.
Taxonomic groups, families, genera, and species representation of wild edible plants in the IHR.

conservation, nutrient cycling, pollination, and recreation [24]. Humans depend upon a variety of ecosystem services (ES) provided by forest ecosystems which are generated as a consequence of interaction and exchange between biotic and abiotic components of an ecosystem [24]. Brown et al. [25] described that "ecosystem services are derived from the functioning of an ecosystem and are of direct value to humans". Direct benefits obtained from the forests such as fuel, fodder, and food are known as ecosystem goods while indirect benefits such as detoxification and decomposition of waste, purification of air and water, etc. are known as ecosystem services. Costanza et al. [26] identified 14 types of services derived from forest ecosystems and estimated the economic value of the services provided by the Earth's ecosystems to be at least US$33 trillion/year. Classification of ecosystem services in the Western Himalayan region specified in the Millennium Ecosystem Assessment (MEA) (2003) has been categorized into the followings:

1. **Provisioning services**

    - Food
    - Fuel
    - Fodder and grazing land
    - Timber
    - Leaf litter
    - Ornamental resource

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- Non-timber forest products (NTFPs)

2. **Regulating services**
    - Climate regulation
    - Air quality
    - Water regulation
    - Water quality
    - Flood and erosion control
    - Pollination
    - Pest regulation
3. **Supporting services**
    - Soil formation
    - Nutrient cycling
    - Water cycling
    - Primary production
4. **Cultural services**
    - Cultural diversity
    - Knowledge systems
    - Recreation and ecotourism
    - Esthetics

6. Causes of biodiversity loss

The biodiversity losses in the IHR are due to several natural and anthropogenic (man-made) factors. Though natural factors have less effect on biodiversity loss, mitigation of these factors plays a major role since the increased human activities in mountain forests have caused a direct link between anthropogenic and natural factors. Periodic assessment and mitigation of various anthropogenic disturbances affecting Himalayan biodiversity are of crucial importance for the survival of mankind. Anthropogenic disturbances, however, play a major role in shaping the structure of forest stands and landscapes even in remote mountain areas of the world. In India, although the degree of anthropogenic pressure varies in different parts of the country, the anthropogenic disturbance has become a widespread feature in most of the forests throughout the Himalayas [27]. Humans have extensively altered the global environment by changing global biogeochemical cycles, transforming land, and enhancing the mobility of biota. Many species have been exterminated from the areas dominated by human activities. The causes of decline in the Himalayan ecospheres have been more radical because they are measured as ecologically delicate and the re-establishment of such ruined ecosystems is very complex due to the physical volatility and environmental uniqueness of the area. Any usual or artificial disturbance is a vital force adept of molding plant population structure and dynamics [28]. There are different causes of biodiversity losses in IHR including natural causes (wildfire, drought), Pollution (air, water, and soil), habitat destruction (deforestation, land fragmentation), wildlife trade and hunting, overexploitation of resources, climate change, and introduction of invasive species [29].

Due to the limited employment opportunities and dependence of local inhabitants and tribes, the forest ecosystem is an important source of income for them in the Western Himalayas [6]. Humans are dependent on the forest for their basic needs, such as fuel, food, fodder, cattle grazing, timber, and raw material for forest-based industries and other NTFPs. Rapid demographic changes and over-exploitation of valuable forest resources and plant products have led to the fast-track degradation and destruction of natural flora and fauna of this region. Since IHR consists of a number of religious places and snow-clad hilly stations, it is a major destination for pilgrimage, tourism, and adventure activities which are responsible for causing disturbances in the region. Several developmental projects such as the construction of roads, dams, tunnels, and hydroelectric projects also create excessive disturbances.

In mountainous regions, biodiversity is being vanished or endangered due to land deprivation and the over-exploitation of resources, e.g., IPCC [30] reported that in 1995, nearly 10 percent of the known species in the Himalayas were listed as *`threatened'*. The increasing scale of degradation of bio-resources in the Himalayas [31] has emerged as a conservation priority at the global level [20]. The importance of biodiversity conservation leading toward the sustenance of ecosystem services is a prevailing theme worldwide. The loss of biodiversity has been the part of international policy agenda for several decades [32] and this loss has not stopped yet, and still, we are facing many challenges regarding biodiversity conservation. The biodiversity conservation action and its success vary greatly, depending on the paradigms represented by various professionals in charge of conservation, as well as social-cultural and political context [32].

Beyond habitat degradation, fragmentation, and hunting, other threats to the conservation of biodiversity in protected areas include climate change, invasive species, and interactions between all threats. Mountains are early indicators of climate change [33]. Himalayan regions are one of the few regions where climate change might be rapid and where the penalty of climate change is likely to be as severe for biodiversity, ecosystem services and human well-being [34]. The increase in average temperature is expected to rise higher in the Himalayan region as compared to the global average temperature [35, 36]. A study indicates that the mean annual temperature in the Alaknanda valley (Western Himalaya) has increased by 0.15°C from 1960 to 2000 [37]. Further, climate change modeling studies for India exhibit that the Indian subcontinent is likely to experience an increase in temperature of 3–5°C. Also, anthropogenic pressures have emerged as a major contributing factor for increased vulnerability of the Himalayan forests [38]. Such changes in IHR ecosystems are bound to affect the livelihoods of millions of people living in the Himalayas and many more in the adjoining Indo-Gangetic plains those are directly depending on the goods and services of mountain ecosystems for their survival and development [33, 39]. Invasive plant species are likely competent to a particular climate change with assumed impacts on indigenous flora [40, 41]. Manish et al. [42] noticed that native plant species of higher altitudes were largely in danger due to global climate change. This might be attributed due to the reason that these are the elevations with the most confined area coverage [43].

7. Biodiversity conservation

Biodiversity conservation is important for maintaining ecological balance among different life forms of the planet and keeping natural ecosystems healthy and functional. Plant biodiversity is one the most crucial components which sustain humankind by meeting its demands for food, fodder, fiber, and fuel. Therefore, the need for the conservation of biodiversity should be mutually accepted. On the other hand, there lies a basic difference in views on what should be the major objectives focus on the conservation of biodiversity. Moral objectives oriented toward preserving all accessible biodiversity which stands in opponent to anthropocentric aims that believe plant diversity importantly maintaining only the coverage that it serves livelihood security in long run. This includes the preservation, maintenance, sustainable use (conservation), revival, and enrichment of the components of biological diversity. There are two approaches to achieving the objectives of conservation measures: (i) *ex-situ* conservation and (ii) *in-situ* conservation. The choice of the conservation measures depends on the nature of the material to be conserved i.e., the life cycle, mode of reproduction, size, and ecological strains.

- ***Ex-situ* conservation:** It means the conservation of biodiversity outside their natural habitats, for instance within museums, national and international gene banks, and botanical gardens/arboretums with the objective to protect the endangered species and stop their destruction. Various institutions, scientists, scientific societies, and NGOs are addressing the task of protecting biodiversity. The rare, endangered, threatened, and vulnerable medicinal plants such as Saussurea costus (Kut), and *Picrorhiza kurroa* (Kutki), have been brought under cultivation to the large extent. Seed banks, botanical gardens, and horticultural and recreational gardens are also important centers for *ex-situ* conservation of biodiversity.

- ***In-situ* conservation:** *In situ* **conservation refers** to protecting the biodiversity in their natural habitats. The highest priority has been given by the Convention on Biological Diversity to this approach of conservation, which includes the protection of species in the wild as well as landraces and other cultivated forms maintained by farmers. It involves the coordination of a broad range of economic and social activities within a country. In India, about 4.8% of the total geographical area has been earmarked for wide *in-situ* conservation of habitats and ecosystems. A protected area network of 96 national parks and 510 wildlife sanctuaries have been created for the purpose.

8. Biodiversity conservation: a pluralistic approach

Societies across the world have had long-standing traditions of using and caring for nature, but the recognized, conventional, and largely western ‘conservation movement’ is only about 120 years old. Discourses about why biodiversity matters and how it should be governed are dominated by ideas nurtured by this movement, in turn, aligned with—and legitimized by—normative positions in science, particularly by conservation biology. In reality, people have always related to the variety of living things in a range of different ways, determined by their own value systems, experiences, and ability to work with nature [44]. In view of its broad explanations, biodiversity must be developed as a thought in a multiculturalism way. It would be seen as prospect to accept people’s diverse ideas on what needs to be preserved and at what cost. If the belief of ecosystem is helpful as a means for preservation, it should be a part of a wider commitment with diverse informations and value systems about biodiversity. A pluralistic perspective on biodiversity could also facilitate communication across academic disciplines by applying a shared vocabulary, even though its precise interpretation may vary [45].

The pluralistic approach in biodiversity conservation should necessitate an unbiased commitment via two questions: (i) what the humankind desire from the rest of the living world? (ii) How we can mutually get from there? Subsequently, it should be recognized that the answers to these questions would essentially be multiple and consequently arrived to any answers through a process that is reasonable and communally acceptable. Additionally, the recognition of a pluralistic view of biodiversity protection should require the recent conservation advancement to give up its place of ethical authority and power to answer these above questions. Meanwhile, it demands the movement to put its thought on what needs and why to conserve, together with other understanding of the importance of nature and interactions between humans and nature to answer the first question, instead insisting that their concepts are scientifically derived and therefore, definitely better. Biodiversity science is, in fact, well positioned to promote such a pluralistic agenda given the multiple ways in which biodiversity is represented in academic disciplines, such as ecology and biology, economics, and social sciences and humanities. It may also be essential to recognize and include the layman’s views in the combination of conservation knowledge; mainly the sited, emotional and cherished trait of much of the rest of knowledge (local or indigenous) about nature [46] and its focus on how to live healthy with nature. It suggested that the manifold associations of human and non-human life must be recognized. One way to do this is by mesmerizing with intense interdisciplinary and extensive stakeholder involvement in knowledge sharing [47]. By mobilizing an appropriate mix of scientific and lay knowledge, conservation science, policy and practice would be better equipped to identify and facilitate more legitimate and effective goals and actions, for instance through different approaches to protected areas [48] or through payments for ecosystem services [49].

9. Plural drivers of biodiversity losses

To acquaint with what biodiversity is and why it should be important is the major step toward pluralism; however, it is not sufficient on its own. It is also important to recognize why bio-diversity in its diverse forms is being lost and what are different combinations of activities at various labels might reduce or repeal the damage to nature meticulously. Specifically, one has to take out what is generally called the causes of biodiversity loss and degradation of nature [50, 51] or—drawing on our plural characterization above—what kinds of human actions and social processes are leading to the undermining of facets of nature and what makes those actions and processes persist.

Firstly, there should be a strong tendency to cast explanation in universal or globalized terms. Even though it is useful to categorize the biggest drivers of biodiversity decline as a resource over and land-cover change for agriculture purposes at a large scale, these analyses have often been conducted in a collective way without distinguishing these processes in terms of localities or actors [52]. Thus, the driver-based studies should go further to find out what sectors are responsible for detrimental activities and who benefited from them.

Secondly, scientific analysis of drivers normally hazards reducing bio-diversity, to a set of the singular index, reflecting a desire to let science drive policy at the cost of opening space for other means to know the natural world and as a result for consideration. Adding to that, biodiversity cannot be just lessened to a singular index, but the issue itself is much more complex than, for instance, the conventional drivers—pressures—state—impacts—responses structure can be handled [53, 54]. There are manifold clarifications for several causes behind the continued reduction of biodiversity. Economists thought that mankind as mostly independent realistic drivers and thus, motivate the utilization of biodiversity to observe win-win solutions. Conversely, ecologists should give priority to dependent and post-colonial structures of authority that relieve local communities of land rights which leads to state community differences and as a result, may advocate restitution of these human rights, and chiefly respect to the world views of native local communities as the first step toward sustainable management of nature. Others may emphasize macro-level institutional failure based on ever-expanding capital accumulation as the overarching single cause of the ongoing ecological crisis [55].

Finally, communal analytic effect on biodiversity change has been assembled into 'a political' clarification that directly emphasizes population pressure-based descriptions for the loss of interpreted pristine environment and more political descriptions that unite concern for communal justice, and acceptance of racially co-established concept about the natural world, with other justifications like widespread property conjecture placed in the middle. This divergence allows conservation groups to accentuate what looks doable and gives the existence of leading economic-political structures rather than what desires to be done.

10. Role of science, policymakers, and practice

Visualization of a pluralistic approach to biodiversity conservation requires profound reflexivity by every social activist toward identifying the normative positions propagate their own justifications of the biodiversity concept, as well as the values of another player, leading to an perceptive of the various causes why humankind care it, and what is its importance. Many anthropologists, bureaucrats, and environmentalists need to recognize the reality of a kind of opinion, together with those of traditionally criticized people whose livelihood mostly depends on mother nature, to come up with equitable conservation intercessions. Such social approaches could be constructed, but the main root cause of the matter would still lie in the perceptive of what the community really wants to capture into decision making the diversity of interventions on what needs to be governed; what the objectives of conservation should be, and what alternate options present for perspectives to achieve such objectives. For conservationists and practitioners to take on these challenges, the first step is to come to up with the reality that present ways of working have created problems. Hence, it is imperative to reflect on not just due to the paucity of success of conservation perspectives in lessening biodiversity losses but also needs to reflect their harmful consequences for social justice.

Due attention should be disposed of by which ways the conception and information used in these approaches are adept in preserving, converting, and mitigating the pessimistic outcomes. Improvements in the current conventional conserving paradigm that overlook the wider picture are eventually bound to fail. It should be accepted that many communities, particularly those which are rightly reliant on bio-diversity may not value the ecosystem in the ways shown in the management movements, dominant discourses and approaches, and that the conservation of fascinating species is frequently an expansion of the destructive lifestyles of more wealthy societies. Many questions that must be addressed keeping in view the human and nature associations that accounts for peoples needs and desires includes: (1) what design of biodiversities are required in order to achieve set objectives viz., obtain esthetic satisfaction, maintain ecosystem processes, deliver good ecosystem benefits, and meeting an ethical imperative in respect to other species? (2) what may be the trade-offs among these nature-related goals, and among them and other interests like welfare and poverty improvement, social equality or democracy and are there any ways to ascribe expenses and powers fairly and curtail these trade-offs?, and (3) what micro- and macro-level drawbacks, such as a political one, would make it hard toward attaining specified outcomes with its socio-ecological associated trade-offs? These questions could be managed as pluralistic perceptions, keeping in mind the amount of

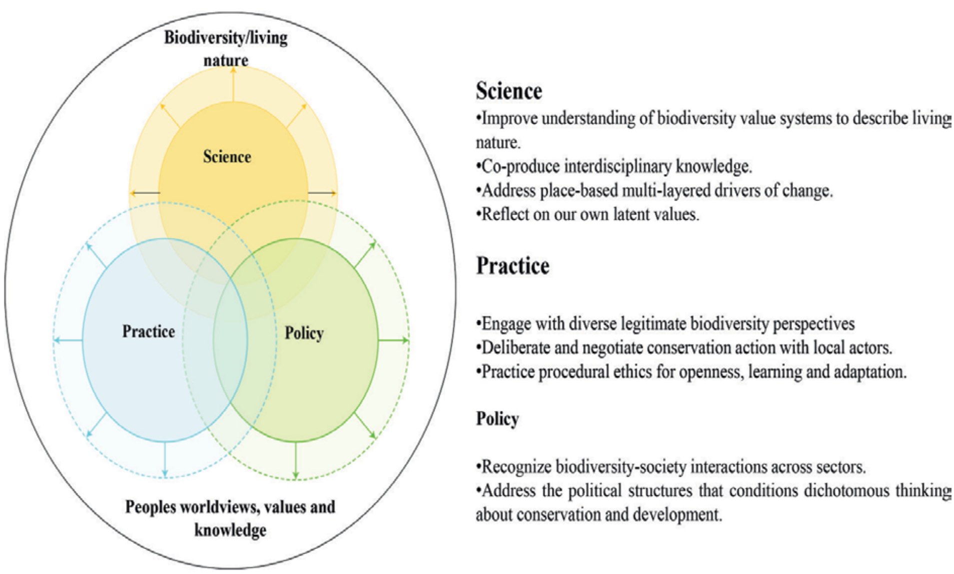

Figure 3.
An outline for a pluralistic view of biodiversity in science, policy and practice. Arrows show the desire for growing connections among science, policy, and practice to tackle the plurality of the living world, given people multiple world views, ethics, and information systems (source: [56]).

plurality and what views are officially measured is a complicated political issue. Based on all the above-mentioned arguments, we suggest different means to move conservation science, policy and practice forward, while fostering a pluralistic concept of biodiversity as a meeting point (**Figure 3**). First we emphasize conservation science. By precisely equating biodiversity with living nature, instead of treating biodiversity as one possible framing of living nature mostly conceived, conservancy skill risk omitted the spirit of a plural outlook on biodiversity as well as cut-off scientific values and layman applications. It indicates that the difficulty in the formulation should not start with the ecological level, and then addresses the social aspects or the other way around. Conservationist desires to adept a comparative lens [57] that is sensitive to how the ecological and the socio-cultural constantly conspire with each other and helps to develop a more affluent set of definitions, matrices and procedures to know human–nature relations and practices and formulate proper responses and policy interventions.

Secondly, conservationists understand the requirements to expand from a predominant focus on pristine ecospheres to incorporate what is habitually called distressed ecological community, it is important also to acknowledge that almost all ecospheres are adapted by humans to some extent [58]. Awareness in respect of ecosystems should itself appear through a process of co-production with particular liberty for traditionally marginalized groups, likewise, this will advance both the robustness and authenticity of the knowledge created. Thirdly, environmentalist needs to acquire a multiple causal approaches to perceptive biodiversity change, categorize who affects and benefited from the spoiling of nature and unpack how, when, and why assured values and people's interests may or may not take into conservation policy and practice. This requires not only collaboration among diverse disciplines but also some cohesion in their descriptive capacities. One approach to facilitate this may be, to support much more region-based research. Even though the diminishing trend of biodiversity is a worldwide challenge, the shape it takes, the welfare that defines it, and the mixture of processes that form it are environment-specific, and so are the solutions. Fourth, we as a scientific community, should be more irresponsible about our own concealed principles and normative positions about the environment [45, 59]. This will raise the question about how we define the research and what morals and presumptions are integrated or mistreated in attaining research goals, whose returns the resulting knowledge serves, whose voices might not be heard, and whose needs might not be met by the research process [60]. To support this indication, we must identify and find out the non-mainstream ways of understanding. However, what is essential is a dedication to diversity, directness to debate, and additional humility and answerability to all those who are directly or indirectly influenced by systematic research. As regards to conservation practices, it is suggested that the conservation groups should acknowledge that there is no fixed generic 'we' in conservation nor an exclusively obvious 'what'; its therefore necessary to differentiate that the conservation practices and envisage results have to be calculated upon and ultimately discussed, given wrong trade-offs stemming from conservation action. How to accomplish conservations should finally depend on what people need and consider authentic and satisfactory. This will need the conservation movement to reflect about socially procedures for making conservation decisions [47]. Despite technocratic projects, which are introduced in a top to the down manner, practices need to be guided by procedural ethics that is committed to openness, learning and adaptation [59]. Finally, what are the results of pluralistic thinking for biodiversity policy? As long as policymakers see only urban people as the voice of conservation and uncritically accept their particular understanding, and ethics about bio-diversity, as the only ones that are official, they will mainly depend on a narrower set of policy approaches, for example, those depend on conserving certain areas while turning a blind eye to the destruction of the rest of living surroundings in the name of economic growth. Although, if a new concept of conservation science captures the multiple objectives and values of biodiversity, brings together a broader set of nature-concerned societies, and questions the structure that forms the nature vs. human wellbeing disagreements, this would ultimately result in mainstreaming nature concern into policies across the sectors by legislative. In conclusion, what anthropologists, conservationists, and governmental organizations name biodiversity may be demonstrated and can be used in different manners, all of them should be significantly relevant and legitimate. It's the need of the hour that one should be more responsive toward this extent of values and their suggestions, such as analysis of the wide causes following the damage of the natural environment. This should be united with conservation policies and practices that encourage impartial decision-making, clearly considering the harmony of social justice when carrying out conservation actions.

11. Conclusion and future perspective

The plants play a significant role in food and nutritional security at the household level. The local people depend greatly on traditions and values that are rooted in nature. Farmers gave more importance to those species which provides them a multitude of benefits such as medicinal and harvested as edible food. Though, there is rising pressure on these species, which advocates that there is an urgent need for management and conservation, which requires proper research and policy support. It is essential to think about how such wild and non-cultivated edible plant species used for food, medicine, and other purposes can contribute to future food security. This requires a proper understanding of how to deal with the cultural changes affecting the use of species diversity and how to ensure sustainable availability. Integrated research and development approaches are immediately required to tackle the issue. To conclude, what scientists, conservationists, and policymakers describe biodiversity is interpreted and used in different ways all of which are potentially relevant and legitimate. Conservation of biodiversity will continue to fail to meet targets if scientists and practitioners are not efficiently able to partner with stakeholders and Indigenous landowners to form novel and dynamic institutions. Local peoples are the central point of any conservation program; attempts should be made to maintain balance among scientists, conservationists, policymakers, and people's livelihoods. Participations of local communities in the preparations and execution of conservation policies and management plans could facilitate to attain the biodiversity conservation objectives. Creation of understanding and educational programs on conservation and permissible utilization of plant genetic resources, and intensification coordination with the help of various governmental departments, NGOs, and local institutions is immediately required.

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Chapter 5

Traditional Ecological Customary Law for Conservation and Sustainability in Biodiversity

Lun Yin

Abstract

The Convention on Biological Diversity and the Nagoya Protocol have raised the issue of access and benefit sharing (ABS) and related traditional knowledge of genetic resources, particularly in the traditional knowledge conservation session. Additionally, the traditional customary law can play a significant impact. The author summarizes the concept, connotation, and nature of traditional ecological customary law, particularly that of genetic resources, and argues that it encompasses not only the common understanding of customary law for the conservation of plants and animals, but also the traditional knowledge necessary for effective classification, management, and promotion of genetic resources. Simultaneously, the author analyzes and discusses the rights recognized by traditional ecological customary law. Indigenous peoples and local communities should prioritize the establishment of their rights to genetic resources and related traditional knowledge, understand the fundamental principles of traditional ecological law and procedure, and enable them to be recognized and strengthened in international and national law, to ensure that common law and recognized rights are implemented in practice. Based on prospective progresses aforesaid, to boost the mainstreaming of traditional ecological customary law within the rule of law governing biodiversity conservation.

Keywords: traditional ecological customary law, biodiversity, genetic resources, traditional knowledge, access and benefit sharing

1. Introduction

The United Nations Biodiversity Conference (COP 15) took place in October 2021 and May 2022 in Kunming, Yunnan, China. As a signatory to both the Convention on Biological Diversity and the Nagoya Protocol, China has been compelled to create national law that meets the criteria of international conventions. China, on the other hand, continues to lack concrete legislative measures and implementation guidelines for the conservation of biological species resources and traditional knowledge, either at the national or local level [1]. The Convention on Biological Diversity provides a framework for the conservation of genetic resources and traditional knowledge. However, because China lacks a clear conservation policy, an effective legal and institutional system has not yet been established [2]. At the same time, due to the special property of traditional knowledge, it is difficult to protect it under the current intellectual property system [3]. Also, in the international arena, in regard to traditional national societies, there is an urgent need to establish special legal systems in the fields of genes, biological resources, and traditional knowledge to protect their rights, as well as the local traditional way of life and culture [4]. Therefore, all parties to the Convention on Biological Diversity, especially the resource-providing countries, have proposed that domestic laws and regulations should be formulated under the framework of the Convention on Biological Diversity, which is conducive to the conservation of biological diversity, biological genetic resources, and their traditional knowledge [5].

A common feature of current global biodiversity hotspots is that they are often rich in cultural diversity. As UNESCO states in the Convention on the Conservation and Promotion of the Diversity of Cultural Expressions, "Cultural diversity is a fundamental characteristic and a mutual heritage of all human beings, cultural diversity contributes to the creation of a colorful world" [6]. Clearly, biodiversity is the bedrock and critical component of this vibrant world, the conservation of biodiversity from cultural diversity is the guarantee for the continuous existence and development of this colorful world. Traditional laws and institutions can aid traditional ethnic societies in preserving the ecological environment, adapting to climate change, and utilizing natural resources, while also sustaining significant cultural values [7]. The value and function of traditional law and system on ecological resources should be recognized, cited, and utilized by modern national legal system; moreover, the mutual relationship between traditional legal culture and Western legal culture should be further discussed and finally brought into modern national legal system [8]. In China, traditional ecological culture, concepts, and local knowledge play an important role and significance in protecting the ecological environment and biodiversity in ethnic minority areas [9]. In particular, traditional knowledge associated with biodiversity is of great significance for the conservation and utilization of genetic resources and the realization of acquisition and the system for access and benefit sharing (ABS) [10]. In ethnic areas, a co-management mechanism of environmental governance can be formed based on ethnic customary laws such as township regulations and civil conventions on environmental conservation [11], maximize the positive impact of customary law on the ecological environment, and integrate it into the rule of law of ecological governance in ethnic minority areas and national laws [12]. Nowadays, China's environmental conservation laws are not perfect, especially with the imperfect of local environmental conservation laws and environmental conservation measures, the effective environmental conservation experience in the minority customary law can be used to make up and correct the loopholes and deficiencies of the current environmental conservation laws and environmental conservation measures [13]. Different ethnic groups living in biodiversity hot spots have produced traditional ecological customary laws associated with biodiversity in the process of long-term interaction with local ecosystems and the natural environment. It also promotes the conservation of biodiversity and can further play an essential role in the conservation of biological species' resources and their traditional knowledge [14].

Indigenous peoples and local communities possess rich biodiversity species resources, each ethnic minority has created a wealth of traditional knowledge for the conservation and utilization of biological species resources. Biological species resources and their associated traditional knowledge not only have great commercial and economic value, but also are of great significance to the sustainable life of indigenous peoples and local communities and of important cultural resources. Therefore, it is necessary to improve the rule of law for the conservation of biological species resources and improve the system of biosafety laws and regulations at the international and national levels. Involving the traditional ecological culture and customary law in the comprehensive management of biosafety risks. Ensure the biological species resources are legally protected, prevent the loss of biological species resources, promote the conservation and utilization of biological diversity, and safeguard the ecological rights of indigenous peoples and local communities.

2. Traditional ecological customary law: the concept, connotation, and property

Legal philosophers have identified three pillars of legal administration since the time of Aristotle in ancient Greece: natural law (universal moral principles), customary law (unwritten law that people bound by it believe binding), and positive law (written law, statutory law) [15]. A conventional social norm is customary law. To comprehend customary law, we must first comprehend the concept of a custom. According to the Osborne Concise Law Dictionary, a custom is a "norm of behavior, binding to those within its domain, established by repeated practice." To be valid, these conventions must be old, well-established, and reasonable. Although it may deviate from the common law, it is required and does not contradict written law. There are two types of customs: general and specific [16]. Customary law is based on custom, and the Oxford Law Dictionary defines it as follows: "When some custom, custom, and common practice has been established in a significant part of the country, it is recognized and regarded as legally binding. They can rightfully be called customary law because they are based on written legislative rules" [17]. "Customs considered as legal requirements or required standards of behaviour," according to Black's Law Dictionary. This type of behavior and beliefs are recognized as law since they are such an important and integral aspect of the social and economic structure [18]. Traditional ecological customary law is a type of customary law and the guidelines formed in traditional national society for dealing with the relationship with the natural environment. This customary law is particularly significant in resource management and environmental preservation [19]. Traditional societies are not born with the ability to live in harmony with nature. According to anthropology, it is shaped by man's close relationship with nature [20]. This relationship also involves sociocultural, religious, and belief aspects [21]. Customary law, which controls procedures for the interaction, conservation, conservation, and usage of natural resources, demonstrates these relationships [22]. Due to these qualities, traditional ecological customary law has increasingly attracted the attention of important international treaties, such as the United Nations Convention on Biological Diversity.

Currently, the international academic community does not seek a separate definition of traditional ecological customary law. Still, it conducts research on the concept of customary law or traditional knowledge as a whole. However, since such customary law has unique value and effect on protecting the ecological environment, it is necessary to define its concept clearly and clearly.

This article argues that traditional ecological customary laws governing biological diversity genetic resources encompass not only traditional beliefs and codes of conduct for the direct conservation of animals and plants, but also the classification, storage, efficient use, integrated management, promotion of genetic resources, and the development of traditional knowledge and technical techniques. In other words, traditional ecological customary law is not a single conservation norm for biodiversity genetic resources but a complex governance structure.

The connotation of traditional ecological customary law is twofold: one is the general level, that is, in the macro concept of ecological environmental conservation, traditional ecological customary law that can be valuable for ecosystem maintenance and natural resource conservation and sustainable use; the second is specific level, under the specific framework of the Convention on Biological Diversity, traditional ecological customary laws that play a role in the access and benefit sharing of genetic resources and their associated traditional knowledge.

When the broad scope of ecological conservation is combined with the specific context of the Convention on Biological Diversity, the nature of traditional ecological customary law takes on four dimensions. One is cultural characteristics. Traditional ecological customary law is a cultural phenomenon developed by traditional national societies according to their particular social history, beliefs, habits, and social norms, which is a dynamic cultural accumulation and development process. As a result, traditional ecological customary law will also adhere to traditional nationality. The cultural changes in society have evolved, and in response to the changes, new components have been updated and developed regularly. The second characteristic is ecological. Traditional ecological customary law is a collection of ecological knowledge systems developed through long-term interaction between traditional national societies and their natural environment and ecological system. It is a process of ecological knowledge accumulation. Similarly, traditional ecological customary law will alter in response to changes in the traditional ethnic society's ecological system, natural environment, and climatic circumstances. It will actively adapt to these changes in the ecological environment. The final category is national characteristics. Certain traditional national societies refuse to recognize the concept of "customary law" derived from Western jurisprudence and legal system, believing that the term "customary law" and its related definitions in English may imply a degree of denigration of their own legal system and a transformation into a common law vassal state. Because the majority of these traditional national societies are located in Western countries' former colonies, they believe that "customary law" is a legacy of Western countries' colony and postcolonial legal systems, and they regard traditional national social cultures and legal systems as "primitive" in comparison to Western legal principles and therefore as illogical and unjust as common law subordination. Indeed, not all traditional national social laws are based on customary law; they may also be based on written, positive, or natural laws. The phrase "customary law" does not encompass all legal systems prevalent in traditional national societies. National social law in its traditional form is a "law of life," including not only the exterior laws of life, but also the internal realities of existence. This legal system is based on the natural environment and ecosystem in which the traditional national society lives and develops into an integral part of its national culture and traditional knowledge, which in turn objectively protects the local natural environment and ecosystem, providing the traditional national society with the means to achieve sustainable life. The fourth is the right trait. Under the Convention on Biological Diversity's purpose of "conservation of biological diversity, sustainable use of its components, and equitable and equitable sharing of benefits resulting from genetic resource usage." In particular, under the Nagoya Protocol's special requirement that each party shall consider indigenous peoples' and local communities' customary laws when implementing the Protocol, traditional ecological customary laws acquire the status of rights and transform into the traditional national society's role in genetic resources and local communities. It is one of the critical mechanisms for safeguarding its own rights and interests in the process of access and benefit sharing (ABS) associated with traditional information, becoming an integral part of constructing a particular system for traditional knowledge.

3. Traditional ecological customary laws associated with biodiversity of ethnic groups in China

The diversity of ethnic groups in China enables the development of distinct economic and cultural types, cultural ecological zones, and livelihoods. Throughout history, whether it was a hunter-gatherer nation, an animal herder nation, or a farming nation, whether it is a nation engaged in slash-and-burn farming, a mountain-grazing nation, a mountain-hunting nation, or a hilly rice-cultivating nation, all played a role in preserving ecological balance, protecting traditional knowledge of the natural environment. Chinese ethnic groups have developed traditional ecological customary lanes in long-term production and life practice. This sort of ancient ecological customary rule maintains and enriches the genetic variety of the original varieties. Thus, the traditional ecological customary law of genetic diversity is mostly expressed in traditional subsistence techniques. In general, the traditional ecological customary law on crops and livestock in traditional livelihoods objectively protects the diversity of local biological genetic resources, making traditional livelihoods a "gene pool" for the conservation and utilization of biological diversity genetic resources, and this "gene pool" is evolving in a dynamic, constantly changing, and developing process.

3.1 Traditional ecological customary laws related to crop genetic diversity

The first is the traditional ecological customary law related to the genetic diversity of crops, which is of great value to the conservation, classification, management, and enrichment of the genetic diversity of crops. A more representative example is the rotation agriculture of the Jinuo people in Jinuo Mountain, Xishuangbanna Dai Autonomous Prefecture, Yunnan. These traditional ecological practices are valuable for conservation and sustainable utilization of crop genetic diversity. The customary law established through rotation farming encompasses selection, preservation, hybridization, and cultivation technology for indigenous upland rice varieties, which breed the abundant genetic variety of indigenous crops represented by upland rice germplasm resources. One may argue that the Jinuo people's resources for traditional upland rice varieties are the outcome of their cultivation and breeding utilizing appropriate customary procedures. These kinds exemplify the practice and invention of the Jinuo people's rotation agriculture's traditional ecological customary ways, which accurately depict the traditional highland rice varieties. Genetic diversity, these various resources are inextricably linked to and simultaneously complementary to crop rotation agriculture's traditional ecological customary rule.

On Jino Mountain, the laws governing the local Jino people's usage of varied cultivated crops, particularly the land classification and use system, can be considered an integral aspect of the Jino people's traditional ecological customary law. Jinuo People classify land into three distinct categories: Zhexiao, Zhejiao, and Dieta. In general, the first type of land, Zhexiao, is found at low elevations, the second type of land, Zhexiao, is found at moderate elevations, and the third type of land, Dieta, is found at high elevations. The Jinuo people cultivate food crops such as upland rice, corn, sorghum, millet; cash crops such as cotton, tea, tobacco leaves; oil crops such as peanut, suzi, sesame; there are cereals and vegetables such as sweet potatoes, potatoes, soybeans, taro, pumpkin, winter melon, cucumber, cantaloupe, eggplant, pepper, rice beans, green beans, green vegetables, cabbage, fennel, Chuanxiong, garlic, ginger, lemon grass, and a variety of grains and vegetables, including sweet potato, potato, soybean, taro, pumpkin, winter melon, cucumber, cantaloupe, eggplant, chili, rice beans, green beans, green vegetables, cabbage, fennel, Sichuan Qiong, garlic, ginger, and lemongrass, Soybeans, taro, pumpkin, winter melon, cucumber, cantaloupe, eggplant, chili, rice beans, green beans, green vegetables, cabbage, fennel, sichuan vault, garlic, ginger, vanilla. However, not all three types of land are conducive to cultivating all crops. Upland rice comes in a variety of cultivars that are ideal for growing on various types of land. Soybeans can be sown broadly; maize is grown exclusively on the first and second types of land, while cotton is cultivated only on the first type of land. Cotton fields are commonly referred to as "white treasure fields," and they are frequently interplanted with a range of crops. For instance, in a sloping field, cotton and glutinous rice can be planted in the lower section with a little warmer environment, while cold-resistant upland rice variety can be grown in the slightly cooler upper section, then plant sorghum, corn, coix, beans, melons, and vegetables into the cotton and upland rice in the low places or on the edge of the ground; taro, yam, and potato in areas with a heavy soil layer of fire ash; plant perilla, soybean, and sesame in areas with barren soil and thin soil; plant pepper, eggplant, sunflower, and other crops adjacent to ant mounds; ginger and pumpkin are frequently planted on the ground's edge. The photograph below shows many traditional upland rice varieties grown on diverse land types in Mount Jinuo (**Figure 1**).

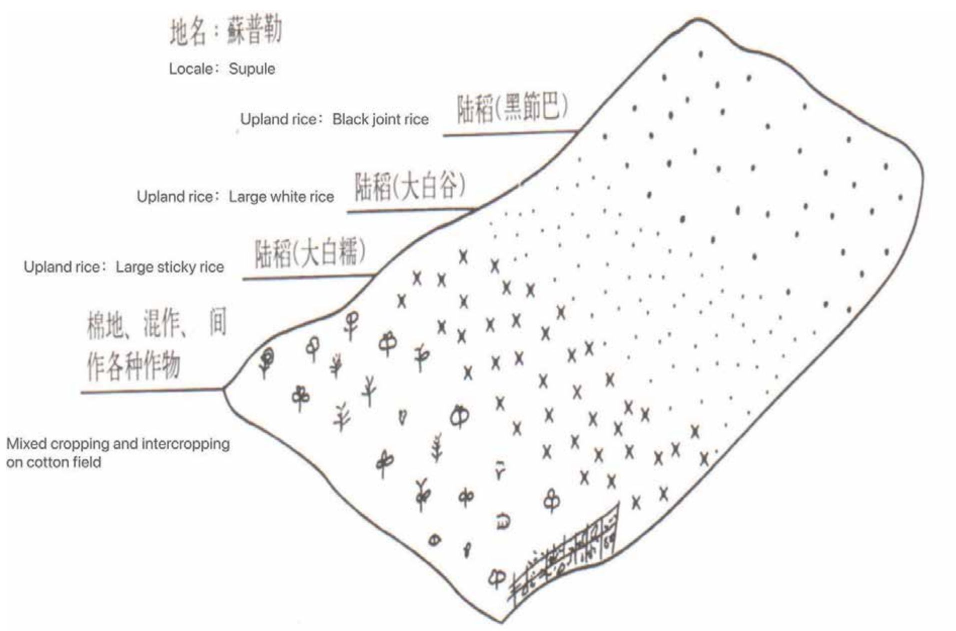

Figure 1.
Traditional upland rice varieties farmed by the Jinuo people in Jinuoshan on various types of land.

The Jino people are primarily upland rice planters who practice crop rotation agriculture on Jinuo Mountain. According to the survey, more than 100 upland rice varieties in Jinuo Mountain before the 1950s. Despite the loss of over 30 traditional upland rice types, there are still 71 varieties remaining, including 16 early-maturing varieties, 35 medium-maturing varieties, 20 late-maturing varieties, and 25 glutinous rice varieties. The Baya upland rice types are the most numerous in the region, totaling 38. Along with allocating different crop varieties according to altitude and climate, Jino people's traditional ecological customary law of crop and land allocation frequently set the cultivation ratio of early, middle, and late rice upon a piece of land, which can be avoided to a period of short supply and food scarcity occurs. And by utilizing a variety of varieties, different types of land, different years of planting with different varieties, according to local conditions, and crop rotation, the goal of making the best effort and ensuring the harvest may be accomplished. The following table summarizes the common regulations for upland rice varieties and land types used by Jino people, which reflect one component of their traditional ecological customary law for crop rotation agriculture (**Tables 1**–**3**) [23].

In the villages of Jinuo Mountain, the variety of upland rice varieties and land type distribution regulations are significantly more varied than those represented in the table above. Because the soil is deep and fertile, even a tiny plot of land may support a variety of crops or variants of the same crop. There are other comparable incidents of the Jino people in Yunnan's Xishuangbanna. For example, the traditional ecological customary law of the Honghe Hani people's terraced agriculture protects and promotes rice variety genetic diversity. In contrast, the old ecological customary law of Diqing's Tibetan plateau agriculture protects and develops the highland barley variety. Enhancement and enrichment of genetic variety, among other things.

3.2 Traditional ecological customary laws related to the genetic diversity of livestock

Traditional ecological customary rules also contribute to the conservation of animal husbandry by classifying, managing, and enriching livestock breed genetic variety. For instance, in Deqin County, in Diqing Tibetan Autonomous Prefecture in

Crop rotation	Land type	Rice variety
Annual	Fruitful soil	Sticky rice
	Barren soil	Mengwang rice
Biennial	Fruitful soil	/
	Barren soil	Rot land rice
Triennium	Fruitful soil	Mengwang rice
	Barren soil	/
Quadrennium	Fruitful soil	Black joint rice
	Barren soil	/
Quinquennium	Fruitful soil	Rot land rice
	Barren soil	/

Table 1.
Diversity of upland rice and configuration of planting environment – Land type 1 (Zhexiao).

Crop rotation	Land type	Rice variety	
		Fruitful soil	Barren soil
Annual	Sunny slope	Purple sticky rice; Yellow sticky rice	Rot land rice; Mengwang rice
	Shady slope	Purple sticky rice; Yellow sticky rice	Small red rice; Large red rice
Biennial	Sunny slope	Long grain rice	/
	Shady slope	Long grain rice; Long-haired rice	Small red rice; Thin white rice
Triennium	Sunny slope	Mengwang rice	Black hull rice
	Shady slope	Rot land rice	/
Quadrennium	Sunny slope	Rot land rice	/
	Shady slope	/	/
Quinquennium	Sunny slope	/	/
	Shady slope	/	/

Table 2.
Diversity of upland rice and configuration of planting environment – Land type 2 (Zhejiao).

Crop rotation	Land type	Rice variety	
		Fruitful soil	Barren soil
Annual	Sunny slope	Black joint rice; Thin white rice	Rot land rice; Thin red rice
	Shady slope	Black joint rice; Black hull rice	Rot land rice; Small red rice
Biennial	Sunny slope	Long grain rice; Long-haired rice	/
	Shady slope	/	/
Triennium	Sunny slope	Rot land rice	Rot land rice
	Shady slope	/	/
Quadrennium	Sunny slope	/	/
	Shady slope	/	/
Quinquennium	Sunny slope	/	/
	Shady slope	/	/

Table 3.
Diversity of upland rice and configuration of planting environment – Land type 2 (Dieta).

northeastern Yunnan, ancient ecological customary regulations governing Tibetan animal husbandry are incredibly beneficial for the conservation and sustainable use of cattle genetic variety. The customary laws governing animal husbandry contain measures governing the foundation for selection, methods of conservation, breeding hybrids, and feeding procedures for indigenous livestock breeds, thereby preserving the genetic variety of indigenous livestock represented by cattle. It can be said that the resources of traditional livestock breeds are the product of breeding and selection conducted by Tibetan herders under applicable customary laws. These breeds exemplify the practice and creativity associated with traditional Tibetan animal husbandry's traditional ecological customary regulations, accurately portraying the genetic diversity of traditional livestock breeds. Additionally, these breed resources are inextricably linked to and supplementary to animal husbandry's ancient ecological customary rule.

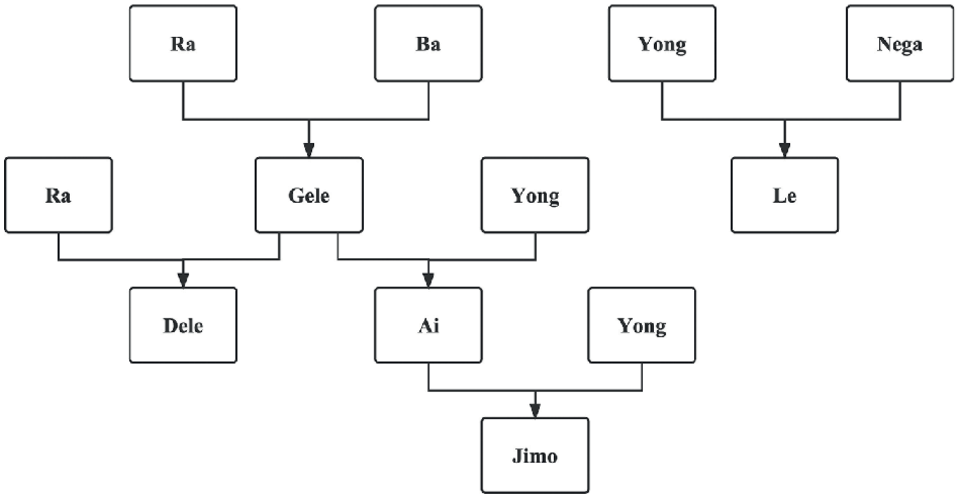

Figure 2.
Classification system of cattle breeds by Tibetan herdsmen in Deqin.

The large livestock raised by indigenous Tibetan animal husbandry in Deqin consists primarily of cattle, sheep, pigs, horses, and mules, with cattle being the most important. Thus, traditional animal husbandry has developed a customary rule governing cattle breeds, the center of which is a categorization system for cattle. According to the general categorization, local cattle breeds are classified as yak, dzo, and cattle; In the local indigenous language, this classification system is more complicated, and the breed of cattle is classified into seven distinct types, i.e., Ra, a male yak; Nega is the female yak, Yong is the male yak, Ba is the female yak, the hybrid dzo between a male yak and a female ox is called Zong; Gele is the female dzo; the male dzo is called Nezu, which is a cross between a male yak and a female yak; the female dzo is referred to as Le; Ai is a cross between female Gele and male cattle; a cross between female Gele and male yak is referred to as Dele, and Ai hybridizes male cattle to obtain the Jimo (**Figure 2**).

According to the traditional ecological customary law of animal husbandry, the local herdsmen herd the seven types of different breeds of cattle on pastures at different altitudes (**Table 4**).

Local herders will also select, protect, breed, and cross the seven breeds of cattle according to customary law to adapt to the local natural environment, ecosystem, and climatic conditions as Yak, Nezu, Le, Ai are cold-hardy that like cold climates breeds, grazing in high-altitude alpine pastures all year round; Cattle and Jimo are cold-hardy varieties that favor warm climates and graze in low-altitude valley pastures all year round; while Zong, Gele, and Ai belong to both cold and warm climates breed, they are rotated and transferred between the three types of pastures. These traditional ecological customary laws based on animal husbandry objectively protect and enrich the genetic diversity of livestock breeds represented by cattle [24]. Similarly, there are many similar cases in other ethnic groups and regions in Yunnan, such as the conservation and promotion of the genetic diversity of livestock breeds through the traditional ecological custom by Dulong people in Nujiang for Dulong cattle and Dulong chicken and improvement and enrichment of the genetic diversity of camellia chicken breeds by Dai people's traditional ecological habits in Xishuangbanna.

Cattle breeds			**Pasture grazing environment**		
No.	Tibetan	Chinese	Temperature preferences	Property	Altitude
1	Ra; Nega	Yak	Low temperature	Hardy	High altitude
2	Yong; Ba	Cattle	Warm	Drought enduring	Low altitude
3	Zong; Gele	Dzo	Low temperature; Warm	Hardy; Drought enduring	Highaltitu; Medium altitude
					Low altitude
4	Nezu; Le		Low temperature	Hardy	High altitude
5	Ai		Low temperature; Warm	Hardy; Drought enduring	Highaltitude; Medium altitude
					Low altitude
6	Dele		Low temperature	Hardy	High altitude
7	jimo		Warm	Drought enduring	Low altitude

Table 4.
Diversity of cattle breeds and configuration rules of pasture grazing environment.

4. Indigenous peoples and local communities biodiversity conservation and traditional ecological customary law

Indigenous peoples and local communities are frequently the world's most prosperous regions in terms of biodiversity and genetic resources. Each person has a close relationship with the genetic resources of biodiversity, having developed unique traditional knowledge, innovation, and customary law systems. Today, this knowledge is considered a critical resource for commercial and industrial research and development in various fields, including pharmaceuticals, agriculture, veterinary medicine, jewelry, fashion, and cosmetics, and is gradually demonstrating significant commercial value and non-monetary benefits. This has, however, resulted in the reckless use of genetic resources and related traditional knowledge. Numerous incidents demonstrate that industrialized countries rely on their superior biotechnology advantages without the authorization or consent of resource owners, disregarding the possession and conservation of natural resources.

Bio-piracy has led to the leakage of indigenous peoples' and local communities' genetic resources and the loss of traditional knowledge, jeopardizing indigenous peoples' and local communities' bio-security and sustainable development. The complexity of protecting genetic resources and related traditional knowledge under the rule of law requires not only statutory law but also the mutual support of statutory and customary law, particularly where bio-piracy occurs among indigenous peoples and local communities with abundant biodiversity. Therefore, traditional ecological customary law plays a significant role and has enormous potential value.

As a result of the previous, it is necessary to explore unique paths and specialized systems of the rule of law for the conservation of biodiversity genetic resources and related traditional knowledge based on indigenous peoples' and local communities' traditional ecological customary laws within the framework of the Convention on Biological Diversity. In the process of developing the rule of law and enacting legislation to protect biological diversity genetic resources and related traditional knowledge, indigenous peoples and local communities' traditional ecological customary laws should be respected, as these traditional ecological customary laws reflect the perspectives of various ethnic groups on genetic resources and related traditions. While the perspectives and stances of knowledge conservation are not legally binding, they frequently exert significant influence and act as a deterrent. As a result, the incorporation, reference, and recognition of traditional ecological customary law in the legislative process are critical for protecting and utilizing biological diversity genetic resources and associated traditional knowledge and serving as the primary manifestation of their value.

4.1 Customary law in the convention on biological diversity

Among the subjects on traditional knowledge in the Convention on Biological Diversity, customary rules relating to the conservation of biological species resources and their associated traditional knowledge have been mentioned numerous times. Particularly at the Conference of the Parties to the Convention on Biological Diversity's eighth, ninth, and tenth meetings, the distinctive systems, including traditional and customary laws, have become discussion issues and were highly regarded by the parties. Under relevant articles and issues of the Convention on Biological Diversity, traditional national societies have the right to own, utilize, and access genetic resources and associated traditional knowledge. Thus, parties may consider protecting genetic resources and associated traditional knowledge in accordance with traditional customary law. Conventional wisdom, relevant CBD rulings, interventions, and submissions to the Working Group's negotiations illustrate that customary law can contribute significantly to the effectiveness of access and benefit sharing measures. In this vein, the work program under Article 8(j) of the CBD, dealing with the safeguarding of traditional knowledge, calls for "a holistic approach that is consistent with the spiritual and cultural values and customs of indigenous peoples and local communities" [25]. The preamble to the Convention on Biological Diversity's terms VI/10 formally recognizes that indigenous peoples and local communities have their own mechanisms for protecting and disseminating traditional knowledge as part of their customary law. Notably, VI/10 asks Parties and governments to "create and execute policies for the conservation of traditional knowledge, innovations, and practices, using suitable techniques and adhering to customary law" [26]. Biological Diversity Convention Articles 8(j) and 10(c) call on Parties to "protect and promote traditional cultural uses of biological resources." When acquiring appropriate knowledge, it is necessary to adhere to the traditional and customary laws set by the local community.

In October 2002, the Ad Hoc Open-ended Working Group reached an agreement on Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of Their Utilization, the Bonn Guidelines. After that, COP 6 convened in The Hague, Netherlands in April 2002. The Bonn Guidelines state that prior informed consent shall in accordance with the traditional practices of indigenous and local communities," which includes customary law [27]. In October 2010, the Working Group on ABS drew The Protocol on access to genetic resources and benefit sharing, also known as the Nagoya Protocol, on the COP 10 held in Nagoya, Japan. Article 12 of the Nagoya Protocol formally recognizes traditional customary law directly in the text and clearly states that full recognition of customary law is critical issue that parties need to pay attention to [28].

The definition of customary law in the articles mentioned above, guidelines and protocols of the Convention on Biological Diversity provides a legislative basis for indigenous peoples and local communities to formulate regulations and systems for biodiversity conservation and utilization based on traditional ecological customary law in the future.

4.2 The rights of traditional ecological customary law

As mentioned previously, indigenous peoples and local communities have developed a comprehensive traditional ecological customary law governing the development, utilization, conservation, and development of biological diversity genetic resources and related traditional knowledge over time through long-term production and life practices. As a result, these traditional ecological customary regulations must be obeyed in the process of protecting and utilizing genetic resources and their associated traditional knowledge. Only in this manner can the interests of all ethnic groups as providers of genetic resources and associated traditional knowledge and their interests in appeals and expectations of applicable rights and interests be preserved to the fullest extent possible. Simultaneously, for external acquirers of genetic resources and associated traditional knowledge, understanding, respecting, and adhering to these traditional ecological customary laws will assist them in obtaining genetic resources and associated traditional knowledge from various peoples legally or ethically, establishing and enhancing long-term mutual trust between acquirers and providers, and laying the groundwork for future cooperation between the two parties. Out of this consideration, the core of the rule of law development and legislation for the conservation of biological diversity genetic resources and their associated traditional knowledge should be to respect and recognize the genetic resources and their associated traditional knowledge rights in traditional ecological customary laws. These rights include two parts: the customary right of biological genetic resources and the customary right of traditional knowledge.

4.2.1 Customary rights in biological genetic resources

For many indigenous peoples and local communities, customary rights are collectively owned, meaning that the associated rights and obligations are collectively shared and undertaken. The traditional faith of many ethnic minorities reckons gods exist in every part of the natural world and the ownership of species and ecosystems containing biological genetic resources belongs to these gods. Misappropriation and exploitation of biological genetic resources have a detrimental effect on minorities economically and culturally and spiritually. Thus, the process of accessing, using, and protecting biological genetic resources is determined by these peoples' distinctive cultures, traditional beliefs, and spiritual values, which are inextricably linked to customary rights regarding biological genetic resources and are defined in customary law. Customary rights relating to the use of biological genetic resources are frequently protected by customary laws such as specialized codes of ethics, ethical standards, and sanctions that help guarantee that persons adhere to the customary rights' rights and obligations. The customary rights of peoples with regard to biological genetic resources have strong spiritual characteristics and are closely linked to the belief systems related to natural resources and ecosystems—the basic values of nature safeguard social justice and the public interest. For example, in the sacred mountain belief of the Tibetan people in Yunnan, China. Human beings, plants and animals have become part of the world with the sacred mountain as the core, and they are jointly protected and punished by the sacred mountain. In the context of this symbiotic belief, Tibetan medicine has formed an understanding of the utilization of biological resources of Tibetan medicine, that is, the use of biological resources of Tibetan medicine and its benefits are premised on the permission of the sacred mountain. Therefore, the collection and utilization of Tibetan medicinal biological resources must be informed to the mountain in advance through religious beliefs such as live incense, chanting, Buddhist divination, etc., and pray for and obtain the consent of the mountain.

When Tibetan doctors ask the sacred mountain for permission to collect their medical biological resources, they must inform the sacred mountain through religious ceremonies and discuss the conditions for allowing the collection with the sacred mountain. Tibetan medicine believes that the mountain will accept their conditions in general, and all they have to do is fulfill their obligations.

4.2.2 Customary rights to traditional knowledge

As an important part of national culture, traditional knowledge is passed down from generation to generation among indigenous peoples and local communities and has formed corresponding rights and obligations. Since this traditional knowledge is also divided into different types, the rights and obligations under the corresponding customary rights are also different. According to the rights and obligations, the traditional knowledge of various ethnic groups can be roughly divided into three categories: (1) knowledge in the common or public domain that can be shared publicly; (2) expertise limited to families, clans, or relatives, such as traditional medical knowledge; (3) sacred knowledge that is kept secretly among the whole group, such as elders or priests. But in general, in many ethnic societies, traditional knowledge is seen as the collective heritage of a community or nation, even if the accumulation of knowledge is individual. As a result, individuals cannot assert ownership or property rights over traditional knowledge. Numerous ethnic groups collectively own their customary rights to traditional knowledge, these forms of jointly ownership and administration are critical for preserving and developing traditional knowledge. For example, traditional knowledge about the genetic diversity of crops grown by the Dai and other ethnic groups in Yunnan, China, must be transferred and disseminated within and between villages in order to meet the needs of seed exchange and crop variety renewal. To ensure that villages have access to diverse and higher-quality crop germplasm resources that will help them grow their livelihoods, their customary rights contain a collective solid component.

Similarly, traditional medicinal knowledge is openly shared and practiced within and between villages for the benefit of the community's health and well-being. Even classified information is fundamentally motivated by the goal of helping the ill, not profit. At the moment, in light of economic progress and modern intellectual property rights, some individual knowledge holders are beginning to regard their traditional knowledge as their own property rather than as part of the community. As a result, it is critical to reestablish and reinforce customary communal rights to indigenous knowledge.

4.3 Access and benefit-sharing system based on traditional ecological customary law

Based on system for access and benefit sharing (ABS), a critical component of recognizing and protecting indigenous peoples' and local communities' customary rights to their biological genetic resources and associated traditional knowledge is the construction of a just and equitable access and benefit-sharing mechanism, which customary law provides for. The three essential ideas and ideals embodied are instructive. The three guiding concepts are as follows: 1. Reciprocity: emphasizes that what is acquired must be returned with the same standard, contains the principle of fairness, and lays the foundation for communication and exchange between humans and between humans and the ecological environment. 2. Duality: emphasizes that everything has an antithesis and complements each other; no action can be individualistic in order to be accepted by others. 3. Balance: refers to the balance and harmony between nature and society, such as respecting nature and ecosystems; the principle of balance can resolve conflicts between man and nature and restore harmony between nature and society. The principle of balance needs to be observed in the application of customary law, as all customary law essentially derives from this principle [29]. The CBD, particularly the Nagoya Protocol, addresses access to genetic resources and their related traditional knowledge under the influence of three essential elements of customary law, namely the idea of prior informed consent, mutually agreed terms, and equitable benefit sharing. Numerous principles and parts of the benefit-sharing system emerge from customary law, particularly traditional ecological customary law governing access to and consent to the use of genetic resources and associated traditional knowledge. Thus, in the future, the fundamental content of the rule of law for the conservation of biological diversity's genetic resources and related traditional knowledge can also be based on traditional ecological customary law, in accordance with access and benefit-sharing procedures, to investigate the establishment of prior informed consent, access to genetic resources and related traditional knowledge, equitable benefit sharing, and other systems.

4.3.1 Traditional ecological customary law and informed prior permission

The Convention on Biological Diversity establishes the ethical basis for requiring prior informed consent from indigenous and local communities to access and use their traditional knowledge, innovations, and practices relating to biological resources, i.e., the obligation to seek prior informed consent from indigenous and local communities as a condition of using genetic resources and acquiring traditional knowledge on their territory. Traditional ecological customary law can be instrumental in establishing the principle of prior informed consent (PIC). The rule of law for protecting biological diversity's genetic resources and associated traditional knowledge should effectively recognize, respect, and enforce customary law. At the same time, it is necessary to clarify which issues require PIC and what PIC subjects, principles, and regimes are established under customary law.

To begin, indigenous peoples and local communities have historically had customary laws that recognize the authority of local regimes, and this customary law must be followed today when establishing the principle of prior informed consent and developing it as part of traditional ecological customary law, thus, prior informed consent should be sought from the local community. Second, because genetic resources and accompanying traditional knowledge are typically owned collectively, PIC choices must be made by representative local communities, not by individual knowledge holders. Third, because genetic resources and accompanying traditional knowledge are frequently recognized as the cultural heritage of one or more peoples, prior informed permission should not be sought from a single community or individual but from a group of peoples.

The PIC process may require consultation with local governments, communities, and individual owners in exceptional circumstances. For specialized knowledge such as traditional medical knowledge, local governments, communities, households, and individual owners all require PIC, thus requiring the establishment of multilevel PIC procedures and systems.

To sum up, the construction of the rule of law for the conservation of biological diversity genetic resources and related traditional knowledge should firstly establish a prior knowledge of the comprehensive participation and collective decision-making of various interest groups, including local governments, communities, and individuals, on the issue of access and benefit sharing.

4.3.2 Traditional ecological customary law and access to genetic resources

After establishing the prior informed consent system, under access and benefit sharing procedures, relevant regulations and special systems concerning access to genetic resources and their associated traditional knowledge should be further developed based on traditional ecological customary law, specifically including the following four parts.

The first step is to create and amend traditional ecological customary regulations that permit others to access genetic resources and indigenous knowledge. For some people, public knowledge and resources are accessible to everybody, and those with access to traditional knowledge connected with genetic resources are obligated to share it openly. In other words, customary law regulates access, requiring accessibility, which requires openness to access. Even for specialized traditional information, such as medicinal knowledge, is only accessible inside a single-family or clan, customary law imposes an obligation to ensure its transmission to future generations. However, open customary rules may jeopardize these peoples' rights when they conflict with external third parties who have access to traditional knowledge related to genetic resources. As a result, appropriate rules and special regimes should support indigenous peoples and communities in establishing and updating their customary laws to allow for free sharing in the presence of third parties.

The second is to permit and embrace traditional ecological customary rules that safeguard specific genetic resources and their associated traditional knowledge. Numerous peoples safeguard sacred biogenetic resources and traditional knowledge through beliefs, worship, and rituals, such as natural sacred locations, which confer religious importance on these biogenetic resources and information. These sacred genetic resources and their traditional knowledge are only accessible to individuals with special status in the community, such as monks, elders, or priests. They are obligated to maintain secrecy to preserve their sanctity if they are leaked or leaked in violation of customary law. They risk being punished by the gods for sharing, and other members of the community are likewise obligated to protect these genetic resources and traditional knowledge together. As a result, applicable policies and sui generis systems should permit communities to refuse access to other parties and respect traditional ecological customary laws prohibiting collecting, using, or transmitting secret genetic resources and traditional knowledge.

Thirdly, we must adhere to and maintain indigenous ecological customary laws which are governing reciprocal access and equitable exchanges. Indigenous peoples and communities have long-established ecological customary rules based on the ideas of reciprocal access and equal exchange. This customary law exists between man and nature. Tibetan medicine, for example, considers the acquisition of Tibetan medicinal biological resources to be a form of borrowing from sacred mountains; at a given time, Tibetan medicine's biological resources need to be "repaid" to the sacred mountain, payment is made in the form of semi-wild medicinal plants planted on the collection site or in a comparable setting. Tibetan physicians can preserve their careers and benefit from the sacred mountain's medical resources collection. As a result, they must share earnings with the sacred mountain through offering sacrifices, burning incense at the temple, reciting texts, and turning the mountain for benefit sharing.

Simultaneously, this customary law exists between individuals, as seen by the trade of seeds and other crop varieties between farmers or villages. To exchange seeds and various resources, villagers simultaneously give each other their own seeds, which is a responsibility to exchange and breed resources, and villagers who obtain seeds and breeding resources are likewise obligated to do so. Both sides will adhere to the idea of equal exchange in order to maximize reciprocity. Similarly, this customary law applies to access to genetic resources and associated traditional knowledge. When communities of people provide access to genetic resources and associated traditional knowledge with external third parties, they expect the same level of access to resources and knowledge. Thus, appropriate legislation and special regimes should respect and embrace traditional ecological customary norms requiring reciprocal access and equal exchange for community-provided access, rather than focusing exclusively on monetary advantages and financial compensation.

The fourth objective is to draw upon and embrace traditional ecological customary norms that assure the proper use of genetic resources and their associated traditional knowledge. This customary law creates rules and standards to ensure that genetic resources (GR) and traditional knowledge (TK) are distributed and shared exclusively to those with legitimate interests in ensuring their proper use following access. For example, the transmission of Dai medicine knowledge in Xishuangbanna and Tibetan medicine knowledge in Diqing is frequently governed by strong customary norms and ethics. Monks and masters who master traditional knowledge frequently need to analyze apprentices' personal characteristics and learning motivations to ensure that traditional medicinal knowledge is used for the greater good of the community and not for selfish gain. To ensure proper use in the future, relevant regulations and special systems should draw on and adopt traditional ecological customary law, establish a special rating process to assess the personal behavior and motivations of third-party applicants, and make it clear that third-party applicants are also responsible for the public interest and community welfare. The appropriate utilization of genetic resources and indigenous knowledge.

4.3.3 Benefit-sharing and traditional ecological customary law

After establishing appropriate regulations and unique systems for accessing and using genetic resources and their associated traditional knowledge, it is necessary to ensure that the benefits obtained are shared fairly and equitably with all peoples and their communities as providers of resources and traditional ecological knowledge. Customary law establishes the groundwork for forming a just benefit-sharing system, encompassing three pillars: justice and equity, suitability and moderation, and consensus decision.

The first is justice and equity. Justice and equity are the guiding principles and ideals of customary law, serving as the foundation for the notions of equality and reciprocity. According to customary law, biological genetic resources and traditional knowledge are frequently recognized as communal property of a particular nation or community, and the free and ongoing sharing of resources and knowledge is a critical component of the development of traditional livelihoods. Thus, customary law emphasizes shared benefits within communities or between neighboring groups and between specific individuals or families to manage resources and knowledge more equally and effectively. Due to the realities of indigenous peoples and local communities, genetic resources and traditional knowledge can be freely exchanged across nearby communities of various peoples, where they can be jointly maintained and exploited. Benefits must be shared across communities of different nationalities in this context to maintain fairness and justice and to promote the concept of local ownership. As a result, this necessitates the establishment of inter-ethnic processes and policies for the conservation of genetic resources and traditional knowledge in shared areas through suitable rules and sui generis systems.

The second principle is suitability and moderation. Suitability and moderation concepts and norms are also principles and values of customary law. As previously stated, prior informed consent enables the equitable distribution of benefits among ethnic groupings. Simultaneously, through prior informed agreement, local communities can exert control over external third parties' access to genetic resources and traditional knowledge, ensuring fair and equitable benefit sharing today and future generations, thereby achieving intergenerational equity and benefit-sharing equity. As a result, appropriate legislation and special systems should incorporate the concepts and values of moderation and moderation found in customary law and construct an intergenerational equitable and just system of benefit sharing.

The third is collective decision-making. The concepts and rules of collective decision-making are also principles and values of customary law, and collective decision-making contributes to the fair and equitable sharing of benefits. It is worth noting that fairness and justice do not imply equality, but rather that there should be fair and equitable benefit sharing within communities or between communities and communities according to the degree of ownership of genetic resources and traditional knowledge, which requires stakeholders make collective decisions. In the future, relevant regulations and special systems should be based on the concept and rules of collective decision-making in customary law. A collective decision-making mechanism involving the participation of local governments, communities, and villagers should be established to achieve fair and just sharing of benefits.

5. Mainstreaming of traditional ecological customary law in the rule of biodiversity conservation law

The role of traditional ecological customary law in the rule of law in biodiversity conservation, especially whether it is influential in protecting genetic resources and its associated traditional knowledge, depends to some extent on the degree of recognition of customary law in the formal legal system. Legal systems that recognize the legal status of customary law and develop specific implementing regulations are vital to protecting genetic resources and their associated traditional knowledge. As mentioned above, traditional ecological customary law is often regarded only as an informal custom because it has no record and no statute law. Even if it is regarded as a formal legal system source, it cannot change its weak status. Although, in practice, customary law is subordinate to statutory law, especially when there is a conflict between the two, customary law is often ignored.

Across the world, an increasing number of countries that are parties to the Convention on Biological Diversity have increasingly recognized the role of customary law in access to genetic resources and their associated traditional knowledge and benefit sharing and thus have recognized customary law. At present, relevant countries, including India, Brazil, South Africa, Malaysia, and the Andean Community, have formulated laws and systems for biological species resources and their related traditional knowledge, and have gradually begun to protect, manage, and control biological species resources and their related traditional knowledge. In addition, sustainable use and other aspects recognize and accept the traditional ecological customary laws and systems of traditional ethnic societies such as indigenous peoples, long-term inhabitants, indigenous peoples, and local communities and integrate them into the modern environmental legal system.

Based on the experience of the countries mentioned above, the international community and governments of various countries should explore the mainstreaming of traditional ecological customary law in the rule of law in biodiversity conservation and must carefully review the status of customary law in the construction of the rule of law in biodiversity conservation and discuss strengthening customary law, way, and method. To create traditional ecological customary law status, indigenous peoples and local communities must first establish their rights to genetic resources and associated traditional knowledge. Customary law can only be recognized if it respects the right of indigenous peoples and local communities to decide whether and how to use genetic resources and their associated traditional knowledge and under what conditions. Therefore, customary rights in traditional ecological law are at the core of protecting biodiversity genetic resources and their associated traditional knowledge. At the same time, recognizing the status of traditional ecological customary law requires understanding its basic principles and procedures. It needs to be recognized and strengthened in formal laws to ensure that customary laws and rights are recognized in practice by the formal legal system.

In conclusion, for the conservation and use of biodiversity, establishing a system of access and benefit sharing based on the recognition of customary law for genetic resources and their associated traditional knowledge is critical. It not only promotes biodiversity and ecosystem sustainability but also lays the groundwork for the conservation and use of biological diversity and its associated traditional knowledge. The endogeneity of conventional knowledge can shape the effective conservation and sustainable use of indigenous peoples and local communities' biodiversity in turn.

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Section 2

Aquatic Ecology

Chapter 6

Sustainable Development: The Case for Aquatic Biodiversity in Indonesia's Peatland Areas

Haryono Haryono, Rudhy Gustiano and Gema Wahyudewantoro

Abstract

Peatlands are inland water ecosystems that are very unique and vulnerable to environmental disturbances including forest fires. In fact, the peat ecosystem has a very diverse of fish species and has the potential for consumption and ornamental fish. One of the countries that has extensive peatlands is Indonesia. Various types of ornamental fish potentially found in peatlands, as well as various species of economic importance for food. Therefore, it is very necessary to conserve and utilize biodiversity of peatlands for the purpose of optimally utilizing sustainable development. The scope of this chapter is to provide a comprehensive view of fish diversity in Indonesian peatlands from the aspect of use, threats, and conservation strategies.

Keywords: peatland, biodiversity, utilization, conservation, Indonesia

1. Introduction

Indonesia is the largest archipelagic country in the world which has a high of fish diversity. Djajadiredja et al. [1] estimates the number of fish in Indonesia as many as 4000 species. According to Froese & Pauly [2], there are 4826 species. This number continues to grow along with the discovery of new species. Helfman et al. [3] reported that every year new types of fish are found ranging from 300 to 350 species. Haryono & Gustiano [4] reported that the addition of new types of fish in the world in the 2011–2020 decade was as many as 2904 species with an annual range of 104–448 species and an average of 290 species. The new species in Indonesia, especially for freshwater fish, was reported as many as 15 species in the period 2010–2014 [5].

The number of freshwater fish species in Indonesia is 1248 species [2, 6]. Dudgeon [7] estimated the number could reach 1700 species. The high richness of freshwater fish species in Indonesia is supported by thousands of islands with a diversity of inland aquatic ecosystems. Ambari [8] reported that the area of inland waters in Indonesia reaches 55 million ha which includes rivers, lakes, swamps, reservoirs, and other puddles. The distribution area of this fish is divided into three areas, namely 1) the Sunda Shelf which includes Sumatra, Java, and Kalimantan; 2) Wallacea area or transitional area covering Sulawesi and Nusa Tenggara; and 3) the presentation of Sahul covering the Maluku Islands and Papua. In the Sunda Shelf and Sulawesi, at least 900 species have been identified [9], while in Papua as many as 400 have been reported [10]. The Sunda Shelf is the center of fish species diversity in tropical Asia, which is rich in endemic fish species. Kottelat et al. [9] reported in detail the level of fish endemicity in Sumatra, namely 11% of 272 species, Kalimantan 38% of 394 species, and Java 9% of 132 species.

Among the freshwaters that are unique physically, chemically, and biologically are peatlands. Pages et al. [11] reported that some peatlands in the tropics are located in lowland areas where there are tropical rain forests with organic material deposits for thousands to tens of thousands of years with a thickness of more than 20 m. Simbolon [12] reported that the area of peatland in Indonesia is around 21 million hectares or about 57% of the total peatland in the world. Indonesia is a country with the largest tropical peat area in the world. The characteristics of waters in peatland areas are very acidic and have a high content of organic material and low levels of nutrients [13]. Peatlans is one of the natural resources that have important hydrological and ecological functions to support life in the ecosystem. On the island of Kalimantan, peatland occurs in coastal and inland areas. According to Soekardi & Hidayat [14], Central Kalimantan has 2,162,000 ha of peatland, ranking third in Indonesia after West Kalimantan and Irian Jaya. The potential of this large area of land is still not widely used, especially for the fishery sector. Blackfish mostly live in flooded lakes or peatlands, and they are resistant to low dissolved oxygen and high temperatures and tend to let the lake ecosystem inundate when the tide is too low. Crayfish migrate from adjacent rivers or permanent water bodies to flooded lakes when floods or monsoons [15, 16]. Some catfishes (pangas, redtail, and shape) are called crayfish, while walking catfish and snakehead are blackfish.

The existence of peatlands plays an important role in storing terrestrial carbon, the hydrological cycle, and maintaining biodiversity. Research on fish in peatland areas in Indonesia has been widely carried out in Tesso Nilo National Park [17], in Perawang, Riau Province [18] and peatlands in Central Kalimantan Province [19, 20]. Based on the research, in general, it shows that the waters in the peatlands area are important habitats for many unique and economically potential fish species. However, the threat to the existence of peatlands and the fish resources in them is getting more serious and has not been handled optimally. Thornton et al. [20] reported that the decline in peatlands in Indonesia is happening rapidly with the loss of peatlands swamp forest which has an impact on decreasing the fish population in the area. Conditions like this will indirectly interfere with the livelihoods of fishermen. Therefore, it is necessary to make conservation efforts for sustainable development. The purpose of the preparation of this manuscript is to reveal the diversity of fish species in peatland waters, their use and contribution nationally, as well as their conservation strategies.

2. Fish diversity of Indonesian peatlands

Peatlands are important habitats for aquatic biota including fish [19]. In general, the waters in peatland areas (blackwater) are poor in fauna but have unique characteristics, and many are endemic [21]. The percentage of fish fauna in peatlands areas is only 10% of the possibility that it is in non-peatlands waters. For example, Rachmatika et al. [17] reported that there are 50 species in the peatlands areas in Tesso Nilo National Park compared with non-peatlands areas in Way Kambas National Park,

Number	Areas	Number of species	Sources
1	Perawang Regency in Riau Province	17	Haryono & Tjakrawidjaja (2000)
2	The former million hectare Peatlands project in Central Kalimantan Province	75	Haryono, 2010
		39 (in rainy season)	
3	Tripa in Aceh Province	46	Muchlisin et al. (2015)
4	Sebangau in Central Kalimantan Province	55	Thornton et al. (2018)
5	Central Kalimantan Province	67	Haryono and Wahyudewantoro (2020)

Table 1.
Number of fish species of peatlands areas in Indonesia.

and the number of fish reaches 83 species [22]. The records of the species richness in some peatlands areas in Indonesia are listed in **Table 1**.

The specificity of fish communities on peatlands is very high. Anwar et al. [23] reported that the factors that cause the specificity of biota in peatland aquatic ecosystems are thought to be due to the low content of food ingredients, low pH, and low brightness, but the most influential is the very high humus acid (phenol) content. Many types of fish whose habitat is in the form of peatland waters have their own characteristics. Therefore, many have potential and have been traded as ornamental fish. Some of the fish species referred to and originating from peat waters in Indonesia include super red arowana (*Scleropages formosus*), gabus maru (*Channa marulioides*), betta (*Betta* spp.), botia (*Chromobotia macracantha*), seluang (*Rasbora* spp.), sepat pearl (*Trichopodus leerii*), *Luciocephalus pulcher, Sphaerichthys osphromenoides,* and *Chaca bankanensis*. In addition, peatland waters also store fish germplasm which is interesting for further study. The species in question is the world's smallest fish (*Paedocypris progenetica*) found in Jambi's peatlands. The adult size of this fish is only 7.9 mm in total length [24].

3. Utilization

The waters in peat areas are the habitat of various types of fish which are the main source of livelihood for many fishermen [25, 26]. Indonesia has significant potential and problems in utilizing biodiversity resources to meet human food demands by providing protein sources, enhancing well-being, and contributing to national development, due to its high number of genetic resources [27]. The Indonesian government has released a guidebook for the Strategic Plan for Indonesia's Biodiversity, which aims to increase the contribution of genetic resources as assets or natural capital in national development [28, 29], as well as a Blue Economic Development Framework for Indonesia's Economic Transformation [30].

Indonesia has regulated the sustainable exploitation of fish resources in inland waters and domesticated local freshwater fish species for aquaculture and conservation in terms of fish genetic resources [31]. The Asian red-tailed catfish, "bilih" (*Mystacoleucus padangensis*), snakehead, sheat catfish, tinfoil barb, pangas catfish, and dwarf gourami are among the 38 species that have been used, with a total production of 307,593 tons representing 7 dominant species (**Figure 1**). In comparison with overall freshwater fish output, total catches accounted for only 10% of total

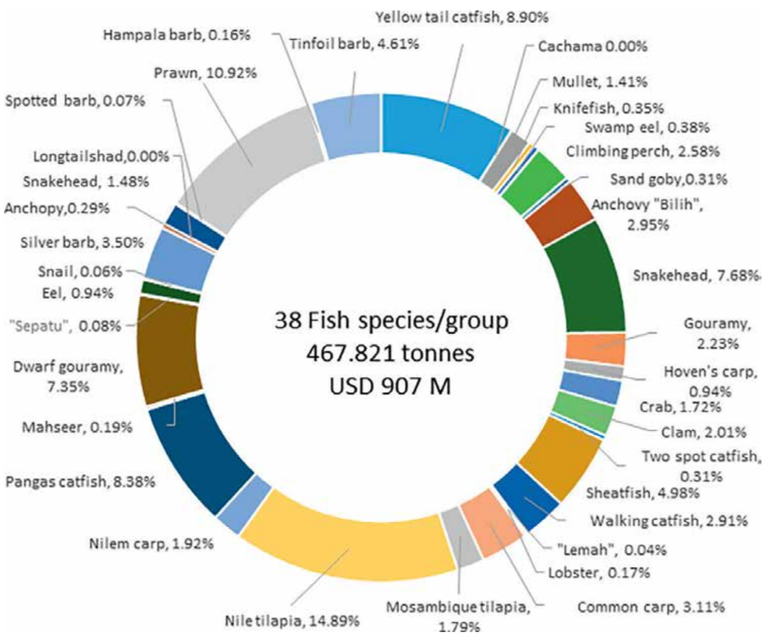

Figure 1.
Total capture production of Indonesian freshwater fish in 2017 [32].

freshwater fish production. Meanwhile, aquaculture produced 3.3 million tons, accounting for 90% of overall production. Nile tilapia, African catfish, pangas catfish, common carp, and giant gourami are five species that make significant contributions to aquaculture productivity. Despite the abundance of fish genetic resources, the low number of species and fish productivity imply that genetic resource exploitation is not yet ideal.

On the other hand, overexploitation of fish genetic resources and habitat as well as water pollution, land conversion, degradation, and climate change have harmed freshwater ecosystems [33, 34]. As a result, adequate strategic programming and planning are urgently needed to prevent fish biodiversity losses and improve the use of freshwater genetic resources.

The first strategy can be used to boost fisheries productivity in both the fisheries and aquaculture sectors by optimizing a variety of fish genetic environments. In general, the capture fisheries dominat the use of peatlands' fish resources. Meanwhile, pond culture using water from tidal rivers continues to dominate the growth of freshwater fish farming on peatlands. As a result, it is frequently hampered by the presence of acidic water with a pH of 3 or below, which causes complete fish mortality. The low pH factor, that it may be argued, is the most significant impediment to the growth of fish farming in Central Kalimantan Province.

A solution to solve the existing low pH problem is required to maximize the potential of peatlands through fisheries. The optimal use of indigenous fish that have adapted to the environment is a strategy that can be implemented using a biological approach. In general, fish that can take/breathe oxygen from the air (air breathing) dominate local fish in peat waters, such as betok/papuyu fish (*Anabas testudineus*), tambakan/biawan (*Helostoma temminckii*), siamese sepat (*Trichopodus pectoralis*), carp/kalui (*Osphronemus goramy*), cork/haruan (*Channa striata*), and to snakehead (*Channa micropeltes*). Another biological option is to introduce fish from outside the area, as well as designed fish that are resistant to peat waters with low pH. Siamese catfish (*Pangasianodon hypophthalmus*), African catfish (*Clarias gariepinus*), and BEST strain tilapia (*Oreochromis niloticus*) are among the fish that have been imported and developed in peat waters (Bogor Enhanced Strain Tilapia).

Local or native fish in peatland waterways, in general, have significant economic significance for the communities surrounding the peatlands. Due to extremely high price spikes that occur during specific seasons, peat fish can cause inflation, particularly in the Kalimantan region. It is thought that with a little aquaculture technology, it will be possible to maximize the potential of current local fish in order to increase the fishing community's welfare in a sustainable way. Local fish in peat waters with the ability to adapt directly in these waters can also be used in a sustainable biological development strategy, either through domestication or conservation programs based on local wisdom that will be able to develop local fisheries in the context of optimizing peatland waters.

Fisheries growth is inextricably linked to the development of fish commodities, which are the primary source of foreign cash for the country. Fish placed into peatland waters must have a monetary value for the individuals who raise them. Furthermore, these fish are capable of adapting to the harsh circumstances found in peat bogs. It is projected that peat waters' production and productivity will rise as a result of the farming technology that can be implemented in peat waters via introduced species of fish. The peat waters for fish culture with Siamese Catfish, Catfish, and Tilapia is for the utilization of peat waters.

To improve the peatland aquatic environment, an environmental management method can be applied, such as using materials that can be used to raise the pH content of the waters. This strategy is still in use today, since it is a practical way that can be used by all parties. Ponds must be prepared in numerous phases before they can be used for peatland fish farming. In the future, it is intended that fisheries development for community empowerment and welfare, such as catfish and snakehead fish farming in Indonesia, will be adopted [35, 36].

4. Threats

Waters in peat areas are unique ecosystems and are important habitats for various types of fish. However, this ecosystem is vulnerable to various disturbances, especially from human activities. Yesi and Tantoro [26] reported that more than 90% of the area of peat swamp forest in Southeast Asia has been degraded or converted. Many peatlands have been converted into oil palm plantations, acacia plantations to provide raw materials for the paper industry, and expansion for agricultural land. The clearing of peatlands into oil palm plantations is very intensive and continues to this day, especially in Sumatra and Kalimantan. However, this does not mean that in other areas there is no conversion of peatlands into oil palm plantations. Even the opening of oil palm plantations has also penetrated the easternmost region of Indonesia [37, 38]. Conversion of peatlands into plantation areas is a serious threat to the sustainability of the fish resources in it. Land clearing will change the ecological function of the surrounding waters, including increasing sediment and turbidity levels, increasing water temperature, reducing food sources for fish from outside the waters (allochthonous), decreasing shelter for fish, and changing river currents and flows. In addition, waste from the use of weed killers and fertilizers will enter the waters of rivers, lakes, and swamps, which are important habitats for fish and other aquatic biota.

Conversion of peatlands into agricultural areas is also easy to find in Indonesia. Yesi and Tantoro [26] reported that agricultural activities on peat areas in Riau are with crop commodities such as pineapple, chili, and tomatoes. Previously, Haryono [17] reported that Central Kalimantan is a province whose peat area was once used as a million-hectare peatland development project for agricultural activities, especially for rice fields. However, the success of these activities was not as expected, so many were stopped. The impact of these activities is the number of artificial canals that change the condition of the natural waters.

The threat to the sustainability of fish resources in the waters around peatlands is forest fires. Almost every year, especially in the dry season, forest fires occur in peatland areas [19, 39, 40]. The causes of forest fires in Indonesia include land clearing, and some are unintentional. The intensity of these forest fires is very high and a concern for human health. The forest fires will have a negative impact on the sustainability of fish communities in the surrounding waters. In fact, fish whose habitat is in peatland waters have a unique pattern and color intensity, and many are endemic species [19, 41]. In addition, there are peat mining activities which are used as fuel [18].

Waters in peatland areas are also a focus for inland fishermen [13, 26]. If there is a decrease in the diversity of fish species, it will have an impact on a decrease in their income. In general, fishermen in peatland areas still catch fish using environmentally friendly tools. However, some of them use fishing gear that is not environmentally friendly, including using electric shocks, poison/tuba, and nets placed at the mouths of creeks.

5. Conservation strategy

The preservation and utilization of biodiversity is referred to as conservation. The main factors affecting freshwater biodiversity loss include habitat degradation, overexploitation, water pollution, invasive species, and climate change [7]. The economic value of biodiversity loss is estimated to be 10 to 100 times larger than the cost of protection [42]. Indonesia has ratified the Convention on Biological Diversity (CBD), the Cartagena Protocol on Biosafety to the Convention on Biological Diversity, and the Nagoya Protocol on access and benefit-sharing of genetic resources to domestic regulations in order to participate in genetic resource conservation. These are crucial factors for a country participating in global frameworks for long-term development. When genetic resources are transferred to other countries through biopiracy and unsustainable uses, ensuring fair benefit-sharing is critical.

The government has released regulations for a material transfer agreement to preserve fish specimens analyzed and created overseas in the fisheries sector since 2010. It is critical to increase awareness, since technology advancements are likely to be used in biopiracy of material genetic information transmitted through digital sequence information. To conserve the diversity of genetic resources, it is necessary to anticipate this issue early. For example, in order to improve the identification of indigenous fish, DNA barcoding must be implemented [43]. This has been done in a number of economically important freshwater fish, including the snakehead *C. striata* [32, 35], Asian redtail catfish *Hemibagrus nemurus* [44], striped catfish *Pangasius hypophthalmus* [45], and African catfish *Clarias batrachus* [44].

Conservation-based fish genetics was carried out through the development of procedures based on quotas, licenses, distribution, monitoring, and assessment for the limited use of fish genetic resources. In the conservation of vulnerable endemic freshwater fish, the government also backed the International Union for Conservation of Nature (IUCN) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). To safeguard native species, a regulation was also created to limit the spread of invasive species. There are a total of 145 invasive species that have been prohibited from entering the country. Similarly, the government has regulated the introduction of new aquaculture species to Indonesia. The new species must be recorded, approved, monitored, and evaluated on a regular basis. A fish restocking scheme was also implemented.

Freshwater habitat is one of the most threatened ecosystems because it competes directly with human use [46]. Between 1970 and 2014, the global trend of freshwater biodiversity dropped by 83 percent (Reid et al., 2019). In most Indonesian freshwaters, there has been a growing tendency of fish biodiversity loss. Between 1890 and 2010, the diversity of native freshwater species of the Ciliwung and Cisadane rivers in West Java province decreased by 92.5%, from 187 to 20 species, and 75.6%, from 135 to 39 species, respectively [47]. The number of fish in the Djuanda reservoir declined from 31 to 18 species over a 40-year period from 1968 to 2007, and the ratio of native to alien fish decreased as well [48]. In addition, 14 native freshwater species on Sumatra Island were classified as threatened, with seven of them being endemic to the island [49]. Muchlisin [50] also discovered more than 19 foreign species that have been introduced to Indonesian freshwater. The majority of fish are invasive and have a negative influence on native species in natural ecosystems. In Indonesian mahseer *Tor soro* and *Tor tambroides*, indigenous fish populations are declining [51]. *T. tambroides, Notopterus* spp., striped catfish *Pangasius nasutus*, mad barb *Leptobarbus hoevenii*, marble goby *Oxyeleotris marmorata*, and Dinema catfish *Belodontichthys dinema* [52].

As a result, freshwater fish biodiversity management has become a critical issue in Indonesia, as most aquatic freshwater resources have been overexploited, as it is seen by a growing number of vulnerable species. Conservation initiatives based on three target conservations, including species, habitat, and ecoregion, can be implemented to address this issue [53]. Aquaculture is one of the most advanced species conservation approaches for increasing fish biodiversity. A genetic improvement was primarily implemented in expediting fish breeding and improving fish production for the aquaculture program's success [44]. In 2018, aquaculture contributed roughly 57.14 percent (5.4 million tons) to overall fisheries production in Indonesia, and it is expected to continue to rise significantly in the future [31]. Despite the fact that Indonesia is one of the world's fifth largest aquaculture producers, Nile tilapia *O. niloticus*, African catfish *C. batrachus*, Thai striped catfish *P. hypophthalmus*, carp *Cyprinus carpio*, and giant gourami *O. goramy* have dominated the primary aquaculture production. Only the giant gourami is a native species among the five most popular. According to Gustiano et al. [54], Indonesian farmers have cultivated 30 freshwater species, but only 15 of them use national best aquaculture methods. It has been brought to our attention, and we are aware of it.

One of the in situ conservation projects is aquatic habitat conservation, which entails a variety of measures to safeguard threatened animal populations in their natural habitat and ensure ecosystem viability [55]. There are 131 water conservation areas covering 15.76 million hectares in the country, which are allocated among different levels of government [56]. However, marine and coastal habitats account for the majority of conservation areas, with inland waters like lakes and rivers accounting for fewer than 10%. The way freshwater environment conservation efforts are implemented varies by location. Fisheries sanctuaries have existed on the island of Sumatra for a long time, regulating local traditions. The majority of areas have not been legally protected as a basic conservation need. However, in some locations, some local governments have begun to develop formal systems to identify conservation candidates [57]. The best conservation program for lake and reservoir ecosystems is habitat rehabilitation, whereas rivers, wetlands, and estuaries ecosystems are fisheries sanctuary, according to research in Sundaland seas comprising Sumatra, Borneo, Java, and Bali [58].

Adrianto [59] suggested that integrating fish resource management with community socioeconomic well-being is a critical strategy for the success of Indonesia's fisheries conservation programs. Riepe et al. [60] have reported that a successful freshwater conservation program is based on an economic strategy in four European countries: Norway, Sweden, Germany, and France. The work enhanced the native fish population, water quality for domestic use, river accessibility, and electrical supply, all of which help the community greatly.

Ex situ conservation refers to the care and breeding of living animals outside of their natural habitat [55]. Ex situ conservation comprises wild species domestication and cultivation efforts. Domestication is a set of acts taken by humans to gradually adapt wild animals to living and breeding outside of their natural habitat under controlled conditions [61]. This primarily entails acclimating fish to new environmental settings, providing artificial feed responses and ensuring that they are capable of developing and sexually mature enough to produce characteristics. Domesticated fish can also have extra characteristics that are desirable to fish farmers, such as fast growth [62]. As a result, breeders must comprehend the domesticated species' biological and genetic performance, illness, and socioeconomic features (Fabrice, 2018). Focus group discussions can be used to consider which fish species should be considered for domestication [63, 64]. This program is critical for the development of aquaculture-based native species that are combined with tradition and local wisdom to help rural communities achieve food security and poverty alleviation [65]. Fish farmers have domesticated a small number of native freshwater fish for human consumption, including the silver barb (*Barbonymus gonionotus*), bonylip (*Osteochilus vittatus*), giant gourami (*O. goramy*), and kissing gourami (*Helostoma temminckii*) [31], but productivity remains low. The government, on the other hand, has been successful in releasing and promoting domesticated animals.

6. Conclusions

Indonesia still has valuable fish genetic resources that must be preserved and exploited for economic well-being and national development, but it also faces enormous pressures on these resources and their habitat. As a result, conservation management and strategic planning must be adequately executed in order to improve its exploitation and avoid losses of fish biodiversity, which is one of the country's most valuable assets. Here are some suggestions for dealing with the problems: aquaculture species.

1. The execution of strategic strategies for the preservation of fish genetic resources through aquaculture development based on freshwater fish endemic is required. The government should boost legislation and policy development by releasing an international framework based on the Genetic Resources Act that has been publicly ratified as the primary regulation. Despite the fact that Indonesia has accepted international accords on genetic resource biodiversity conservation, the resulting legislations are sectoral entities with a variety of duties and objectives.

2. To maximize the efficiency of existing rules, synergic cooperation across institutions and stakeholders responsible for managing genetic resources and habitat preservation and usage needs to be strengthened from national policy, scientific approach, and execution.

3. The value of genetic resource preservation should also be emphasized to local communities so that they can participate and benefit from its use.

4. To strengthen the skill and competency of technical and management staff, advanced technological training and education for genetic preservation and biopiracy investigation should be done.

5. Ex situ conservation of endemic and threatened freshwater fish species must be supported by the preservation of endemic and threatened fish species in the inland water habitat (in situ conservation).

6. To ensure the species' long-term viability, the breeding process and restocking of endemic fish species in their natural habitat should be closely monitored.

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Chapter 7

A Case Study to Evaluate the Environmental Impact of Aquatic Lower Plants in Mesopotamia (Particularly the Kurdistan Region of Iraq)

Bahram K. Maulood, Abbas M. Ismail and Bushra A. Hamdi

Abstract

This study deals with the role of lower plants particularly (Ferns, Mosses & Algae) in the aquatic ecosystem within the fertile crescent in Mesopotamia. It focuses especially on the Kurdistan of Iraq, which might be one of the most productive and fertile areas in the whole Middle East. Furthermore, it is an endeavor to show the environmental impact and assess the effect of climatic and non-climatic parameters on non-flowering plants in the region. Knowledge about the presence and distribution of a such group of plants in this part of the world is so poor, particularly with respect to ferns, makes one to draw attention the necessity of such a study. This investigation is an attempt to reduce the existing gap of knowledge on lower plants in the region; furthermore, it will undoubtedly gravitate attention to the need for much more scientific information in this area, in years to come.

Keywords: Mesopotamia, Iraqi Kurdistan, lower plant, environmental impact, bryophytes

1. Introduction

It is a well-known fact that about 60% of the total global freshwater within our planet is confined to about 263 rivers within 145 countries, making up around 40% of the global population [1].

Unlike the Middle East, aquatic plants have gotten much more scientific attention, for planning and managing various water bodies in Europe and states. Lower plants (macrophytes and microphytes) have been widely used as ecological indicators in various parts of the world, also for the conservation and protection of natural resources as well as biodiversity [2–4].

The impacts of the continuous establishment of large dams on inland waters had become quite evident all over the world, as their total number approached 50,000 dams between 1950 and 2017 (a tenfold increase) when the number was only 5000 dams 60 years ago, whereas the total global irrigated area has only doubled, as it raised to around 280 million hectares only [5, 6].

Key climatic and non-climatic parameters affecting the distribution and abundance of aquatic lower plants, in both running and standing water bodies, have been thoroughly reviewed by [7]. They explained their potential role and application, to point out indicators for expected ecological changes in any natural ecosystem [8]. Aquatic plant studies with respect to concerning environmental impacts have been mainly confined to flowering plants [9, 10], whereas lower plants (ferns, mosses, and even algae) had obtained little attention and were poorly dealt with for environmental monitoring [11]. Higher plants rather than lower ones have been much more widely applied as criteria for any environmental changes or pollution [10].

The distribution and abundance of aquatic plants, in general, depend on three main factors, which are biogeography, climatic mainly (hydrology and temperature), and geomorphology [7]. Eutrophication, on the other hand, is known to cause an intense shading by phytoplankton and filamentous algae in inland water bodies that result in the decline of aquatic plants [12, 13].

Using aquatic lower plants as an environmental monitoring tool because of their sensitivity to any ecological changes has been the concern of many scientists all over the world [7, 11, 14, 15]. Lower plant species in general have been used as a reliable indicator of any environmental impact or changes. However, almost all studies ended up with around (50) criteria for ecological indicators that have been formulated throughout four sets of parameters. In 1998, Mc geoch had adapted all to only nine. This finally ends up with seven criteria for climatic and no climatic impact in any ecosystem. Almost all published articles books and websites up to 2018 were summarized and tabulated [14, 15]. However, out of the total published papers in this respect none were from Iraq or Kurdistan and only (17) were from Asia [14].

2. Aquatic ecosystem status in Mesopotamia

A part from general climatic and non-climatic impacts on the environment in the region, fertile crescent or even the whole of Mesopotamia had recently also faced serious water shortages and desertification [1, 18, 16–21]. **Figure 1**(**A-C**).

The establishment of hundreds of dams in Iran and Turkey also changed river flow direction in both countries, leading to the degradation of freshwater in the region and the desiccation of wetlands in Kurdistan or even the whole of Iraq [18, 20, 22–28]. Besides that deforestation is quite evident as the remaining forest area had fallen to only 10% in contrast to before 1961 in the Kurdistan region of Iraq [20, 29].

Much water in Iraq has been and still is wasted naturally through the direct flow to the gulf or evaporation. Such status is definitely because of a lack of a water harvesting system, almost absence of a good irrigation plan, and finally, imperfect water management and administration. The most obvious outcome of such environmental impact is the desiccation of southern Iraqi marshes by more than 65% over the last 50 years [3, 5–7, 12, 13, 15, 17–20, 24–26, 29–47].

The environment program of the United Nations in 2018 indicated that Iraq is losing every year around 25.000 hectares of arable land [47]. However, continuous degradation of the fertile crescent is expected in years to come if no consideration or precaution and action have been taken.

Lower plant studies [Pteridophytes (ferns), Bryophytes (mosses), or Green Thallophyte (algae)] and their role in environmental changes and impact are quite

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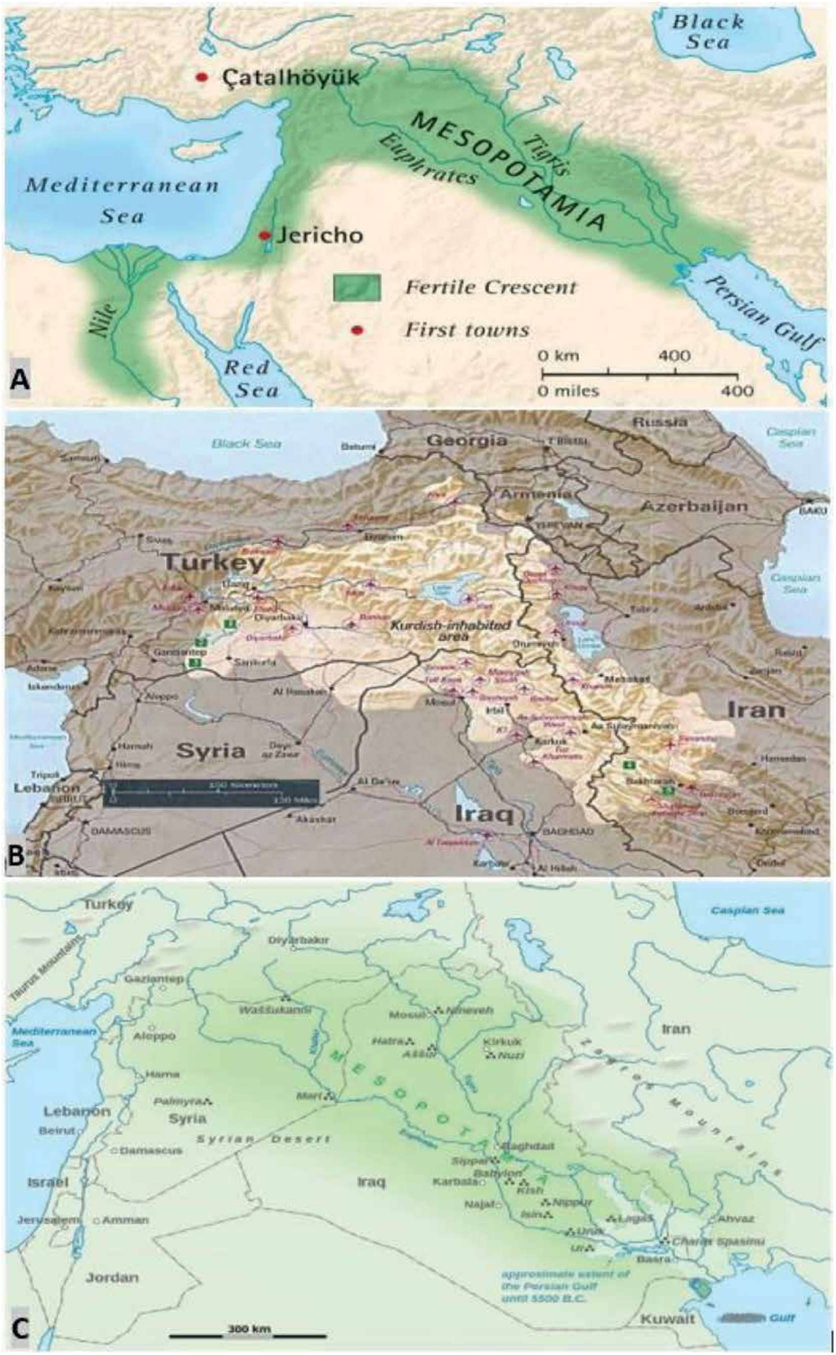

Figure 1.
Area under investigation: (A) showing ancient Mesopotamia, (B-C) recent political map all three above maps were taken from Google: Link: ***Mesopotamia fertile crescent map - Bing images.***

evident in a different part of the world as it was and still is the concern for many scientists [11, 14, 48]. However, such studies in Mesopotamia including Iraq, so far, seem to be confined to classification, habitat, and taxonomy, whereas their role in environmental integrity, climate change, environmental monitoring, and ecological indicators as well as biodiversity and their association with other vegetation remain vague and need much more investigation in this part of the world.

3. Status of lower plant studies in Mesopotamia

Non-flowering plant studies in Mesopotamia and Kurdistan go back to the end of the eighteen century [32, 37], whereas their role in the environment remains vague and needs much more investigation in this part of the world. However, more than 20 species of pteridophytes and around 180 Bryophyte species have been recorded so far from Iraq and Kurdistan, but almost all studies have been concerned with their distribution habitat, morphology, and taxonomy [34, 42, 49–53]. None of these studies dealt with monitoring or biodiversity and did not refer to any ferns in aquatic ecosystems apart from (Salvinia & Marsilia) in southern marshes of Iraq and only recently Azolla has been also recorded [54]. **Figure 1**(**A-C**).

Pteridophytes, which represent a great and huge number of plants, are least explored as an ecological indicator in most parts of the world. The majority of the papers showed potential use of Pteridophytes as ecological indicators and forwarded helpful criteria. It became evident that more investigation and research about such criteria particularly to use pteridophytes an ecological indicator are needed [7, 55].

Bryophytes on the other hand are commonly used as ecological indicator for the presence or absence of any pollutant since they are known to be among a stress tolerance group of organisms, within which two very widespread ones (Fontinalics & Playtypnidium) are the most common [11]. However, only the first one is common in Kurdistan. In fact, none of the published papers concerned with liverwort and mosses in the region had referred to their role in environment, although the total recorded number of the species so far exceeded 170 species [49, 51].

Almost about 3000 species of algae have been recorded in Iraq as whole and handers of scientific paper had appeared [41]. However, quite a few found to deal with biodiversity and ecological indicators, whereas most of it was concerned again with habitat taxonomy and morphological description. Such studies hopefully will extend to deal with algal role on climatic impact and environmental monitoring as well. That will undoubtedly contribute to fill up part of the existing gap of the knowledge about lower plants in this part of the world.

4. Pteridophytes studies in the region

Pteridophytes or fern studies in Iraq and Kurdistan in particular are scarce [53, 56]. However, still quite few papers on their distribution and medicinal role have been published recently [33–35, 43]. Fern role as a potential ecological indicator or on monitoring water ecosystem in Kurdistan or the whole of Iraq has not been taken enough attentions, in contrast to other parts of the world [34]. However, it is quite evident that scientific studies on pteridophytes in general, according to the published articles, have been and still are poorly explored all over the world [7, 14]. Still few species were found to be considered as ecological indicator and have shown to have impact on water quality in the ecosystem [55], but none of these species have been reported from Iraq or Kurdistan. Fern species in Mediterranean countries traditionally have

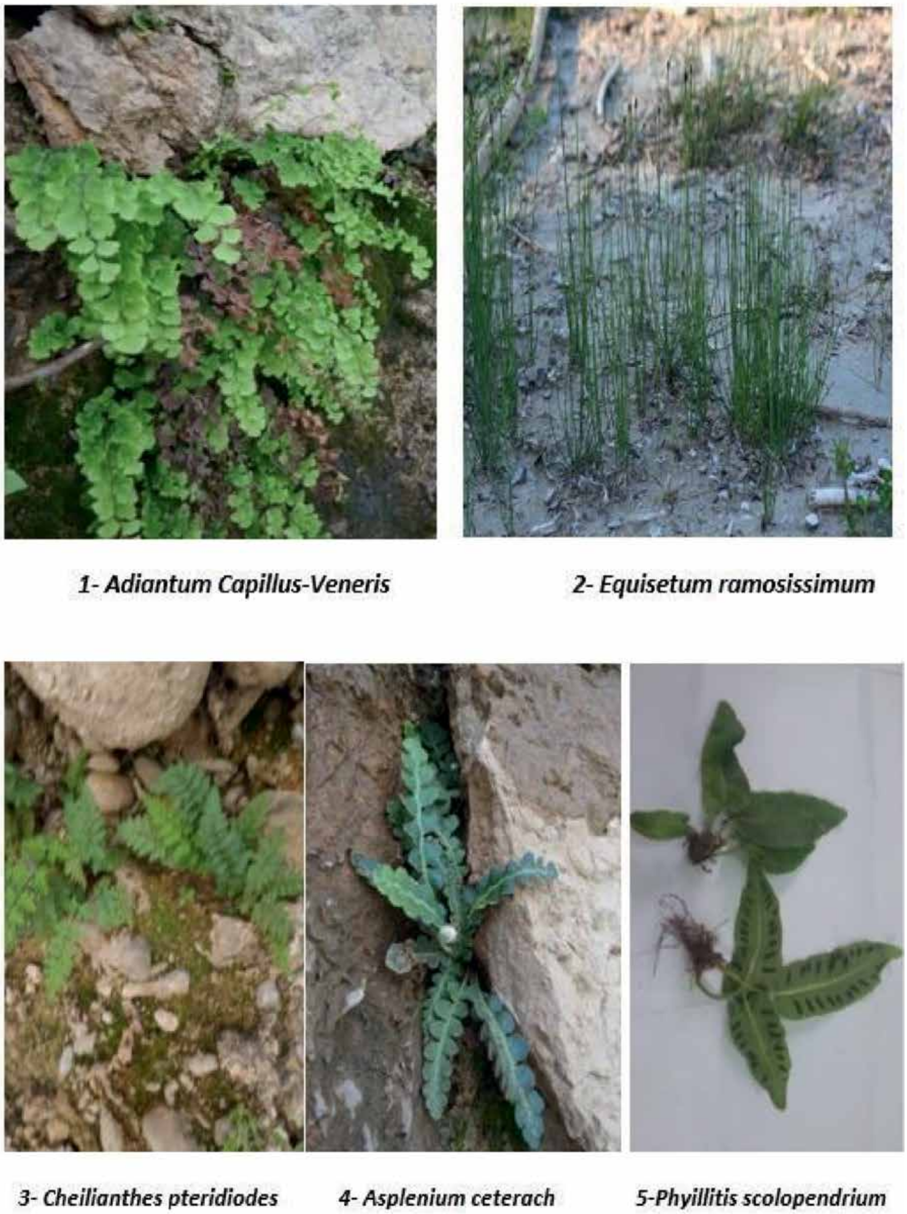

Figure 2.
Common ferns in Kurdistan of Iraq. All photos are taken personally by the author (B.K. Maulood).

been used and applied to remedy for quite a number of diseases such as kidney stone and spleen complains, but only recently few scientific investigations on this respect took place in the region **Figure 2** [35].

Systematically, only 8861 fern species have been identified and registered all over the world so far, they found to belong to 300 genera from 33 families and 7 orders only [46]. In contrast, only 18 genera belonging to 11 families and six orders of pteridophytes have been recorded in Iraq [34, 35, 43, 52–54].

Nu.	Taxa	Distribution
1	Adiantum capillus-veneris L.	Tweela, Biyarah, Jarmo near chamchemal, Aqra, Hauraman, Qaradagh, Gali Ali Beg, Beekhal, Sartaq, Ahmed Awa, Rawanduze, Khanaqin.
2	*Anograma leptophylla* (L.) Link	Gai Ali Beg, Zar gali, Meedan, Nawgali, Banibee.
3	Ceratopteris thalictroides (L.) Borgn.	Auzair, Qurna, Suthern marshes of Iraq.
4	*Cosentinia vellea* (Aiton) Tod.	Gali Ali Beg, Beekhal, Malakan, Meedan, Bawanoor, Sartaq.
5	*Oeosporangium persicum* (Bory.) Vis.	Bawanoor near Kalar city.
6	*O. pteridioides* (Richard) Fraser-Jenk. & Priyer	Sinjar, Haji Umran, Makhmor, Zar gali, Bawanoor, Banibee.
7	Asplenium ceterach L.	Malakan, Zargali, Beekhal, Sartaq, Biyarah, Meedan, Banibee, Taweela..
8	*Asplenium lepidum* C. Presl.	Sarsanq
9	Asplenium ruta-muraria L.	
10	*Asplenium sagitattum* (DC.) Bang	Malakan, Sulaimanyah
11	Asplenium scolopendrium L.	Malakan
12	Asplenium trichomanes L.	Beekhal, Taweela,
13	*Asplenium virid* Huds.	
14	Cystopteris fragilis (L.) Bernh.	Sarsanq, Qandeel,
15	*Cystopteris diaphana* (Bory) Litard.	Malakan
16	*Polystichum aculatam* (L.) Roth	Taweela (Sulaimaniyah)
17	Equisetum arvense L.	Khallana,Haji Umran, Rubari-Rusta, Chemi Rezan,(Sulaimaniyah) Halgurd mountain
18	Equisetum ramosissimum Desf.	Sarsanq, Deltawa, Tuz Khurmato, Qula Sotaw, Galizawita, Bakraju, Rawa.
19	*Marsilia capensis* A. Braun.	Chibaish marshes, Mediana near Qurna,
20	Salvinia natans (L.) ALL.	Shanaphia, Bani Said, Hammar marshes.
21	*Azolla filicoloides* Lam.	Kalar (Garmian), Basrah.
22	*E. ramosissimum* Desf. var. *flagelliferum*	Qula Sotaw (Garmian), Halgurd mountans (Choman province).

Table 1.
List of Pteridoflora and their geographical distribution in Iraq.

Out of the total (22) species of Iraqi Pteridophyte, only two were confined to the southern Iraqi marshes (Salvinia & Marsilia), whereas all others were reported from Iraqi Kurdistan. The four most common ferns in the region seem to be Adiantum capillus-veneris and Equisetum ramosissimum, *Cheilianthes pteridioides,* and Asplenium ceterach, whereas Phyllitis scolopendrium is found to be restricted only to high elevation that approached 1000 m.a.s.l or more in mountainous part. (**Table 1** and **Figure 2**).

In fact, none of these investigations had referred to fern's role on climatic and non-climatic impacts in the area, so it is quite evident that the role of fern species in the environment of Iraq or Kurdistan has not been thoroughly studied yet. This gap of knowledge in Mesopotamia remains to be filled in the future. However, such investigations and field studies are an open yard for scientific projects in years to come.

5. Bryophyte status

Mosses and liverwort as aquatic macrophytes (primary producers) are important components of some lentic and lotic freshwater ecosystems. The effect on the biodiversity and water chemistry, through changing the environmental condition and the availability of resources [3], in fact sometimes they even modify the water flow direction [36]. A review of monitoring heavy metal concentration through liverworts and mosses has been well revised by [57, 58]. However, bryophytes species (mosses and liverwort) as a monitor of environmental contamination have been also reviewed by [59, 60].

Recently, scientific studies indicate that bryophytes are going to become the target of investigation in Global Change Studies, particularly with respect to Climate Worming, as well as their effect on biodiversity. Their presence, distribution, and population density, as well as, their fertility are common parameters that are related to and applied for monitoring different ecosystems [36, 38, 60].

The effect of climatic and non-climatic factors on any ecosystem has to be considered well before an event takes place [44]. Aquatic bryophytes are found to be a quite fit example for such expectation. Quite many species of mosses and liverwort had shown to have a high tolerance for various sorts of pollution and contamination; therefore, using such species as biomonitoring the indicators of any impacts and bioavailability of any parameter have been widely proposed recently [44]. However, Bryophytes species have been already used for the last 30–40 years for monitoring water quality [11, 61].

Such a process of biomonitoring an aquatic ecosystem has been already applied in Europe by using bryophytes in order to monitor tens of heavy metals. The process involves field observation and analysis of native species of mosses or active monitoring depending on plant transplantation to the ecosystem for a limited period of time. In order to keep the biodiversity in the area, one should consider the impact of native and non-native macrophyte species on the ecosystem and the importance of system management [3].

Plant macrophytes are known to be sensitive to a particular threshold of climatic and non-climatic conditions. They potentially seem to be a good indicator of climatic impacts, changes, or hazards [7]. The use of Bryophyte species in monitoring programs is increasing because of the wide range of their anatomical, morphological, and physiological properties that have been extensively reviewed by (Zechmeister & Moser, 2003).

Bryophytes (mosses and liverwort) in fact are green Cryptogams comprising about (25,000) species, whereas mosses only make up around (15,000) species. Generally, this group of lower plants (Bryophytes) is known to be the major component of various different types of ecosystems from peat lands to the boreal forest floor [62]. Although sphagnum bags cover about 1–2% of the global land surface, many mosses are associated with the moist environment or freshwater, but no marine bryophytes so far have been recorded [48].

In Iraq, so far, only 209 species of Bryophytes have been recorded [51] from which only 16 species belong to liverworts, whereas the list includes 193 species of mosses. The most common ones in the area are illustrated in (**Figure 3**), one of the most

Figure 3.
Most common bryophytes (Mosses & Liverworts) in the Kurdistan part of Iraq. Photos are taken from reference no: 4 in the text with a written permission from the author B.A. Basheer Al-Ni'ma.

comprehensive investigations on Iraqi bryophytes is that of [49] as they described all identified mosses and liverwort species in Iraq up to 1960. They gave a good description of all taxa. Also, they forwarded the key of identification for all 54 genera and 145 species besides their habitat and environmental condition of the localities.

The detailed investigation of Bryophytes species and their influence on climatic or non-climatic impact, as well as their role in ecological monitoring for the best of our knowledge, have not been thoroughly dealt with in Mesopotamia (Iraq or Kurdistan) yet.

However, such a gap in knowledge on the role of bryophytes in the environment in this part of the world (Mesopotamia) needs to be fully filled in years to come by local or other scientists.

6. Status of algal studies

The use of algal species as environmental indicators goes back to the beginning of the eighteen century, whereas studies along this line are still proceeding. It is found that some algae in general have the ability to tolerate various levels of pollutants in nature. Undoubtedly, this property is behind using algal species to test for detecting eutrophication or any change in the aquatic ecosystem [45]. However, such phenomena nowadays are quite well developed and become evident from the appearance of an algal community in any ecosystem.

Collections and surveys of Handel-Mazzeti [32] from Mesopotamia and Kurdistan along the Tigris and Euphrates may be regarded as the first attempt at algal study in the area [37]. In fact, phycological studies in Iraq have got much more attention in comparison to other lower plants. However, investigations on algae as a whole and phytoplankton, in particular, have been the concern of many research and postgraduate projects for the last 50 years. In parallel with the establishment of various universities and institutes in other parts of Iraq apart from Baghdad as well as a scientific research center in Baghdad, also postgraduate (MSc. Ph.D.) projects were behind the development of algal studies in Iraq as a whole particularly in Kurdistan and Basrah in the south [41, 63]. All these investigations and projects had extended to cover various lotic and lentic water bodies including springs, impoundments, southern marshes Shatal-Arab beside the twin rivers (Tigris & Euphrates) and their tributaries [39, 40].

Round. [45] referred to the important role of aquatic plants and algae in particular in the community structure of any aquatic ecosystem. He showed that in general, algal species do influence habitat complexity and biodiversity and do affect other organisms.

Nowadays, studies on the potential impact of native and non-native plant species in any area have been well progressed, such studies on habitat complexity, particularly in an aquatic ecosystem in various parts of the world, have been well reviewed and demonstrated recently [3], whereas to the best of our knowledge, no such studies had been found yet in Iraq.

More than 2600 algal taxa [41] have been recorded so far from Iraq up to 2013. Hundreds of scientific papers have been published in various local and international journals concerning the lower plants particularly algae [39]. Diatoms are found to be the most dominant group.

Among all algal taxa making up about 44% of the total, whereas green algae contributed to about 30%, which makes it the second dominant group within algal flora in Iraqi inland waters. The most common taxa are illustrated in **Figure 4** and **Figure 5** and a number of master's degrees and tens of Ph.D. thesis have been performed [39, 40], on algae in general and phytoplankton in particular over the most aquatic ecosystem in Iraq since 1974 on the word. But, in fact, almost none of which had referred to their role on biodiversity or climatic impact on the ecosystem, the case, so far, remains vague and unclean in the region as a whole.

However, the existing gap of knowledge with respect to the lower plant role (fern, mosses, and algae) on environmental impact (climatic and non-climatic) is undoubtedly needed to be filled particularly when water policies and dams in Mesopotamia

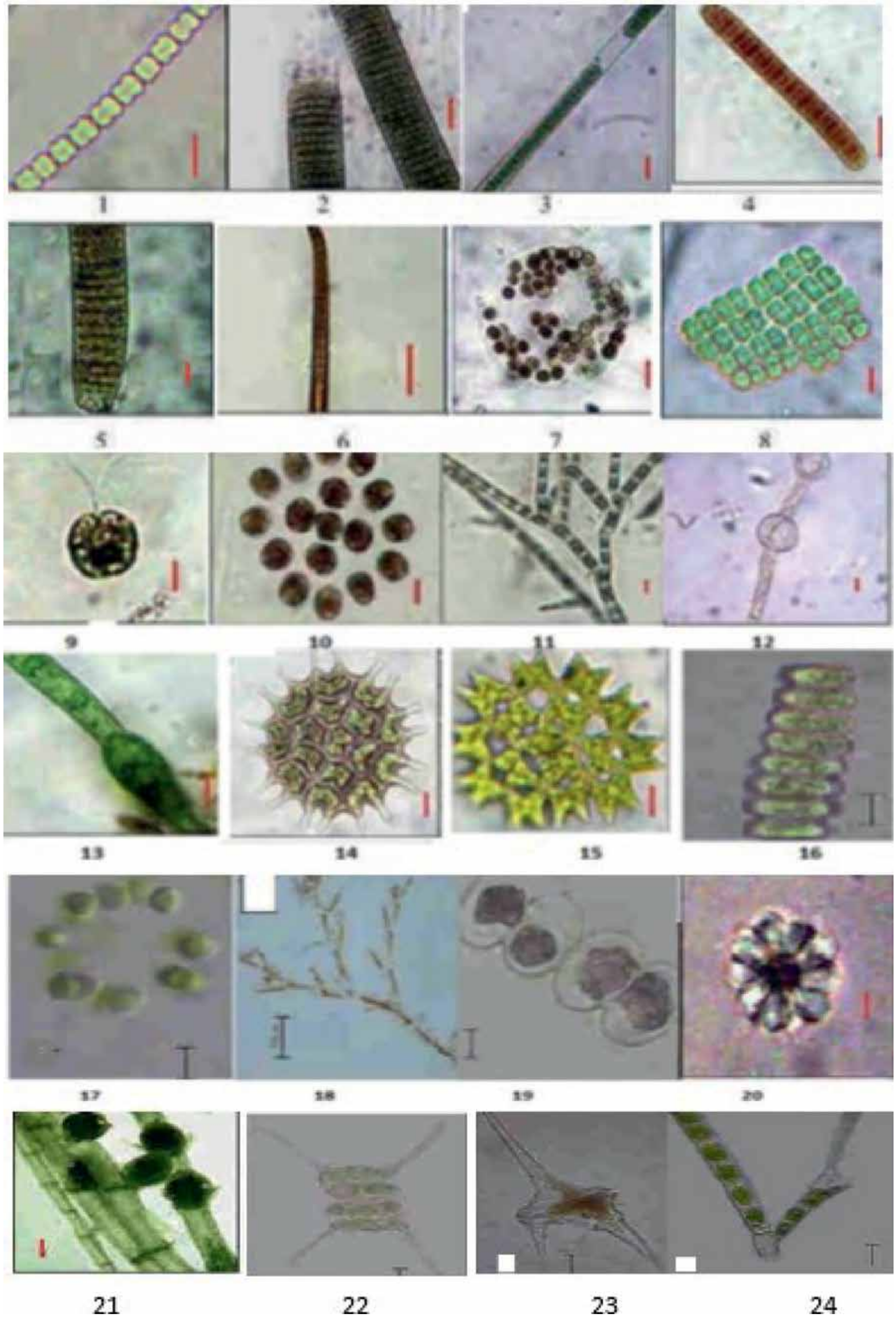

Figure 4.
Illustration of common non-diatom flora in Iraq. (1) Nostoc linckia. (2) Lyngbya aestuarii. (3) Lepidolaena taylorii. (4) Oscillatoria curviceps. (5) Oscillatoria limosa. (6) Oscillatoria tenius. (7) Aphanocapsa rivularis.. (8) Merismopedia glauca. (9) Chlamydomonas polypyreoideum. (10) Pandorina morum. (11) Stigeoclonium lubricum. (12) Oedogonium cardiacum (13) . Oedogonium plurisporum (14) Pedistrum boryanum. (15) P. duplex. (16) Sphaerozosma sp. (17) Dictyosphaerium ehrenbergia (18) Cladophora glomerata (19) Cosmarium (20) Synura uvella. (21) Scenedsmus opoliensis. Lla (22) Ceratium hirundine (23) Bulbochaete sp. (24) Chara sp. all photos are taken by the author (B.K. Maulood) personally.

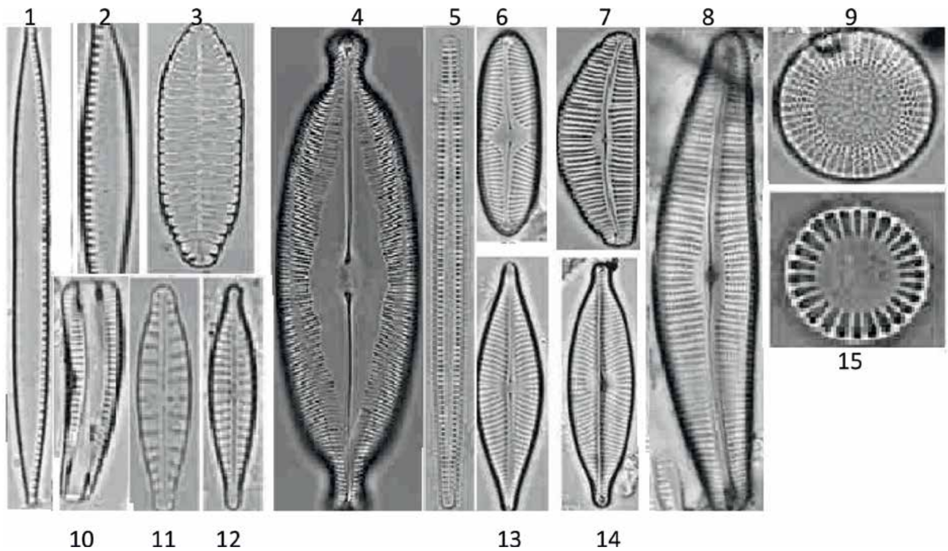

Figure 5.
Most common diatoms from Iraqi inland water (1–2) Nitzschia sp., (3–4) Caloneis sp, (5)- Tabularia sp. (6)- Diatoma sp, (7–8) Cymbella sp,(9) Stephanodiscus sp (10) Rhoicosphenia sp., (11–12) Gomphonema sp. (13–14) Navicula sp. (15) Cyclotella sp. All photos are taken by the author (B.K. Maulood).

Basin seem to be interacting. Various water projects in Turkey and Iran have been performed that will threaten the life in the area. Water shortage, dryness, and climate impacts are almost certainly expected in near future.

All these are behind the expected severe environmental degradation in the region. In fact, the country had faced and still is facing negative climatic and non-climatic impacts with respect to poor water quality, quantity, soil salinity, air, and pollution [20, 22, 26, 28]. Therefore, much more action and detailed studies are an urgent request in Mesopotamia in general and particularly in Iraq and Kurdistan.

7. Conclusion

A part of the recent global impact of climatic and non-climatic factors on the environment is the consequence of the lack of a good irrigation system, imperfect water management policy, as well as the absence of water harvesting techniques in the whole of Iraq and Kurdistan in particular. Still changing river flow direction and the establishment of hundreds of dams in Turkey and Iran remain the main reason for the degradation of the quality and quantity of freshwater bodies in the Kurdistan in the north, in fact, the effect of such impact is extended to far south part as the desiccation of southern Iraqi marshes is already a quite visible fact.

The knowledge on the status of lower plants in this part of the world still is vague, in spite of listing around 3000 taxa of algae in inland waters of Iraq with only around 190 identified species of Bryophytes in the whole country, in contrast to tens of thousands of known species belonging to this group of lower plants globally. However, unbelievably, only 22 fern species are recorded so far from Iraq, whereas Kurdistan is known to possess quite a fit and suitable habitat for such plants.

Biologically and even ecologically Kurdistan part of Iraq may be named a virgin area yet for exploration and tracing the environmental impact of climatic and non-climatic factors on such a group of lower plants. This gap of knowledge in this region needs to be filled in years to come by the local or international scientists.

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Chapter 8

Potential of Aquatic Plants for Pesticide Removal in Wastewater: A Case Study on Pentachlorophenol

Rim Werheni Ammeri, Faiza Souid, Feryell Hajjeji, Saifeddine Eturki and Mohamed Moussa

Abstract

Today, soil and water pollution by pesticides is a serious problem worldwide. Compared with conventionally expensive, invasive, and sometimes ineffective techniques for pentachlorophenol (PCP) dealing, such as excavation, dredging and some chemical methods, in situ treatment strategies are more effective at reducing risk and decreasing expenditures on management. Among the in situ treatments, bioremediation (microbial remediation and phytoremediation) is thought to be capable in permanent pollutants elimination at low cost. Therefore, phytoremediation has received more attention in the last decade. Phytoremediation is applicable owing to its esthetic value, environment friendly, manipulation in situ and economic benefit. However, the previous phytoremediation studies mostly focused on the use of terrestrial plants and remediation of heavy metals. Sediments in aquatic environment are regarded as ultimate sink of organic contaminants, but little information is available on the possibility of use of aquatic macrophytes for remediation of organic toxicants in aquatic environment. It is, therefore, necessary to develop phytoremediation method of PCP by using aquatic macrophytes.

Keywords: pentachlorophenol, soil, wastewater, plant, pesticide removal

1. Introduction

The pollution of water is one of the most important troubles of the whole globe, because of the unsuitable discharge of used water of the industries into the environment, excessive usage of chemical fertilizers in agricultural fields, production of roads, buildings, etc. [1, 2]. Further, the population growth is very expeditious, which harms the availability of drinking water to everyone [3]. Especially, industrialization and urbanization, pollution of water have accelerated on a large scale [4]. There are many chemical industries, which are dealing with the dyes and among them, the large quantity of dye utilization and wastewater discharge after the process is being done by the textile industries exclusively. The utilization of such dangerous substances has been ensuing in water pollution and environmental contamination. The water launched after the material guidance includes dissolved solids, color, harmful metals (chromium), production gums (pentachlorophenol, detergents), appropriating retailers (trisodium polyphosphate and sodium hexametaphosphate, chlorine, azo dyes), and stain removers (CCl4, residual chlorine, solving retailers similar; formaldehyde and benzidine). Maximum of the aforementioned chemical compounds are dangerous and a danger to the surroundings [5, 6]. From this time, the wastewater is wanted to be handled nicely earlier than it's far discharged into the environment or used for different purposes [7]. Thus, to minimize the toxicity, pollution, and to protect the environment, it is important to treat the dye wastewater before discharge [8]. Phytoremediation is a good and significantly hired environmental cleanup biotechnology primarily based totally on volatilization, stabilization, degradation, or extraction of pollution with the aid of using plants and their related microorganisms [9, 10]. Over the previous couple of decades, phytoremediation strategies had been elaborately studied and seemed as a effective tool for eliminating and degrading many unfavorable contaminants, which include antibiotics, HMs, landfill leachate, fabric dyes, pesticides, hormones, petroleum, explosives, or even poisonous gases [11, 12]. Phytoremediation is turning into an increasing number of famous in authorities corporations and industries because the cost-powerful and the restricted investment for environmental governance [13]. The phytoremediation procedure is pushed with the aid of using sun strength and might offer ecological landscapes for rehabilitated areas, which additionally has esthetic value at the same time as treating pollutants [11]. It provides a sustainable method for nutrients recovery and poisonous contaminants elimination. Numerous hydrophytes with distinct species had been applied for the control of LW, for example, Spirodela polyrhiza, Lemna minor, Polygonum hydropiper, Lemna gibba, Eichhornia crassipes, Pistia stratiotes, Scenedesmus quadricauda, Typha latifolia, Phragmites australis, Limnobium laevigatum, Chlamydomonas reinhardtii, Myriophyllum aquaticum, Coelastrella sp., Lemna aequinoctialis [14–23]. The main objective in this study to evaluate the Potential of aquatic plants for Pesticide removal in Wastewater: A case study on pentachlorophenol. Also, to discuss some example of phytoremediation process for pesticide removal.

2. Phytoremediation process

Biological methods using plants for treatment of polluted environment may also provide an alternative to traditional techniques [23, 24]. Phytoremediation (phyto = plant, remediation = correct evil) means re-vegetation of land which is spoiled by toxic substances and phytoremediation might be successful when plant using for phytoremediation material can accumulate high concentration of heavy metals in their shoots parts [23–28]. Phytoremediation as a brand new remedy approach for environmental pollutants communally anticipated to advantage all contemporary crises in better performance and decrease environmental effect in addition to economically feasible. This rising inexperienced technology, were won many severe anthropogenic pollutants. Fair evaluation required for risks, which associated with this approach. Even specifying it for a selected waste remedy inclusive of municipal wastewater [29] may also supply the reply key for consciousness on benefits and the accent risks. Aquatic macrophytes are vegetation that stay in water or moist soil and develop generously in lakes and waterways. This vegetation offer numerous ecological niches (meals, shelter), significantly contribute to biodiversity on the atmosphere level, and maintain meals chains. Besides their big position in nutrient cycle, oxygen balance, purification of water [30], and a source of some biologically

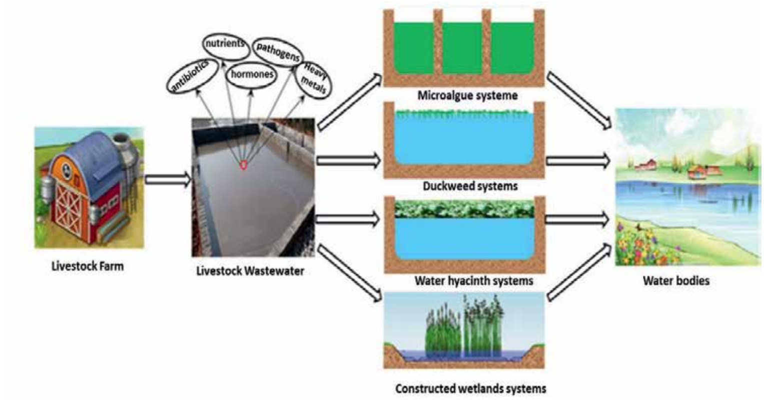

Figure 1.
Diagram of the different uses of phytoremediation techniques [37].

active substances like antibacterial and antifungal agents [31]. Emergent aquatic macrophytes constitute a numerous institution of flora with a giant cappotential for removal/degradation of a lot of toxic objects and pollutants [32]. Besides, aquatic macrophytes are greater appropriate for wastewater preparation than different terrestrial flora because of their quicker growth, manufacturing of greater biomass and a relative better cappotential of pollutant approval [33]. Phytoremediation is a rapidly developing method that uses plants to reduce, degrade, assimilate and metabolize environmental pollutants such as hydrocarbons, pesticides, etc. [34].

The main mechanisms of phytoremediation included phytoextraction, rhizofiltration, phytostabilization, phytodegradation, and phytovolatilization [13]. Generally, vegetation selected for phytoremediation had the possibility to concentrate on a wide range of or specific contaminants [35]. Phytoremediation is the direct use of living green plants and is an effective, cheap, non-invasive, and environmentally friendly technique used to transfer or stabilize all the toxic metals and environmental pollutants in polluted soil or ground [35, 36]. Furthermore, phytoremediation is concerned with the potential of a plant species to accumulate high concentrations of toxic pollutants in their tissues. A number of plant metabolic processes come into play to degrade various organic compounds. There are many types of phytoremediation for agricultural land and water Plants bodies, e.g., phytotransformation, rhizosphere bioremediation, phytostabilization, phytoextraction (phyto-accumulation), rhizofiltration, phytovolatization, phytodegradtion, and hydraulic control (**Figure 1**) [38–40]. After more than 20 years of development, phytoremediation has become mature and widely employed to refine contaminated soil, water, and atmosphere. Also, the achievement of phytoremediation relies upon upon a plant's potential to tolerate and to build up excessive portions of the contaminant, even as yielding a big plant biomass [25]. In herbal and man-made filtering systems, macrophytes play an crucial function withinside the biochemical approaches of water remedy in view that their presence should exert a few high quality outcomes on this environment [41].

3. Type of phytoremediation

Aquatic macrophytes are categorized into three principal classes, submerged, floating, and emergent macrophytes associated with vegetation' role concerning the

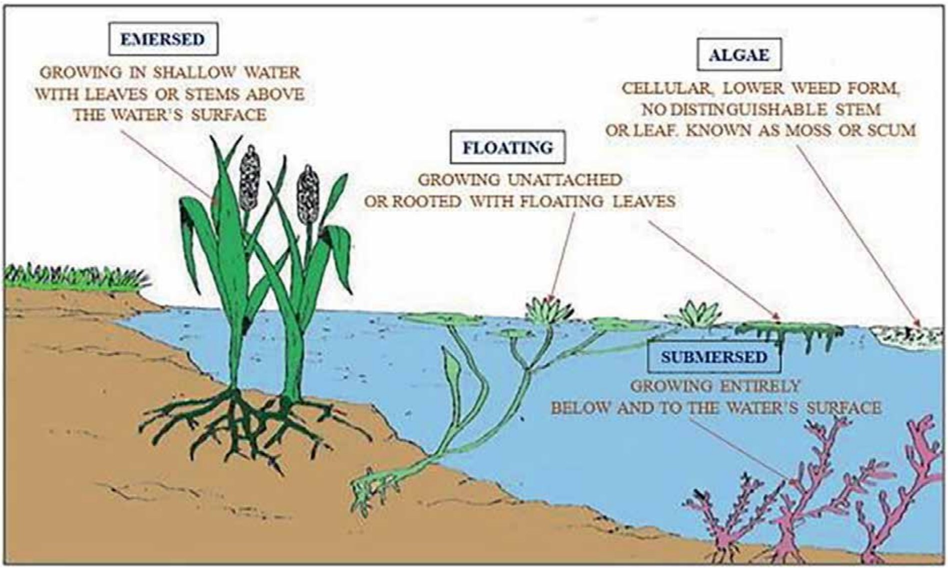

Figure 2.
Different types of the Phytoremediation process [45].

water floor (**Figure 2**). Submerged macrophytes: consist of vegetation completely submerged below the water surface without a vegetative components rising from the water floor (e.g., Myriophyllum spicatum and Najas marina). They are characterized through their particular morphological and anatomical constructions, which assist adapt to residing below the water floor. The increase and distribution of those vegetation are encouraged through numerous factors, which include water level, environmental condition, plant connections, and herbivory [42]. Floating macrophytes: consist of vegetation that develop at intermediate depths; a number of them (e.g., Eichhornia crassipes) are free-floating with roots that grasp unanchored with inside the water column, however others (which include Nymphaea lotus L.) are rooted withinside the soil with floating leaves. They are in large part unaffected through modifications in ranges and intensity of water and substratum characteristics [43]. Emergent macrophytes: consist of vegetation-rooted with inside the sediment with their essential vegetative components above the water floor (e.g., Typha sp.). They are impartial of water for aid and are characterized through their excessive increase price and biomass formation [44]. Lagoons cowl about 4% of the earth's continental ground.

4. Pesticide use in the world

The agrochemical enterprise has drastically improved over the last few years because of tremendous agricultural exercises [46]. Pesticides are the chemical materials that generally steady the rural commodities through controlling the extensive array of pests and insects [47]. Numerous styles of insecticides generate pollutants of air, soil, groundwater, and floor water, and unfavorable to human properly being as they are discharged into the ecosystem due to runoff from farming and civic areas [48, 49]. Among these pollutants, pesticides are of great concern because of

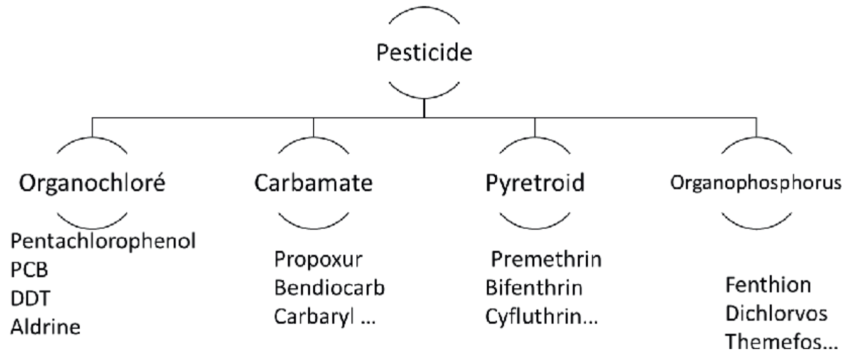

Figure 3.
Different types of pesticides based on chemical composition [60].

their broad use and persistence in the environment for up to decades [50], bringing negative impacts on ecosystems and human health [51, 52]. In the last century, organochlorine pesticides (OCPs), have been extensively used worldwide (**Figure 3**) [53], raising environmental concerns due to their toxicity, persistence, bioavailability, endocrine-disrupting properties and long-range transportation [54, 55]. Despite their worldwide ban between the 1970s et 1990s, concentrations of these pollutants remain in the environment, being a threat to the ecosystem and human health [56].

Pesticides are the second one largest potable water pollutant and posture the best danger [57]. A pesticide must be dangerous to the supposed pests however now no longer to non-supposed species like people and many different creatures. Nevertheless, because of the lack of precision, it's far toxic to each supposed and non-supposed species. The major reason for humans, fishes, birds, and bee's infection was the non - specific pesticide toxicity [58]. Phenol and chlorophenols (CPs) are representative examples of a wider group of phenolic pollutants. Their presence in the environment is due to intensive historical use, drinking water chlorination, biodegradation of organochlorinated chemicals, and their importance in the chemical industry [59].

5. Pentachlorophenol

Pentachlorophenol (PCP) is one of the World's worst chemical ever produced [61]. PCP was developed in the 1930s as one of the first synthetic organic wood preservatives [62]. PCP (C6Cl5OH) is well known as a highly chlorinated organic pollutant with stable aromatic ring structure and as highly persistent in the soil system [63]. The U.S. Environmental Protection Agency [64] regulates PCP as one of the priority pollutants. PCP pollutants has been released in large quantities into the environment as a wood preservative, pesticides, insecticides, fungicides and solvents [65]. PCP is also formed as a by-product during disinfection of water by chlorinated oxidants [66]. It is a synthetic organochlorine pesticide, a conjugate acid of pentachlorophenolate and a member of pentachlorobenzenes, which comprises aromatic fungicides and a chlorophenol (CPs) [67]. PCP is also a metabolite of lindane and other polychlorinated phenolic compounds [68]. Due to its stable aromatic ring structure and high chlorine content, PCP is chemically stable and not prone to degradation [69]. It is a significant environmental contaminant due to its widespread

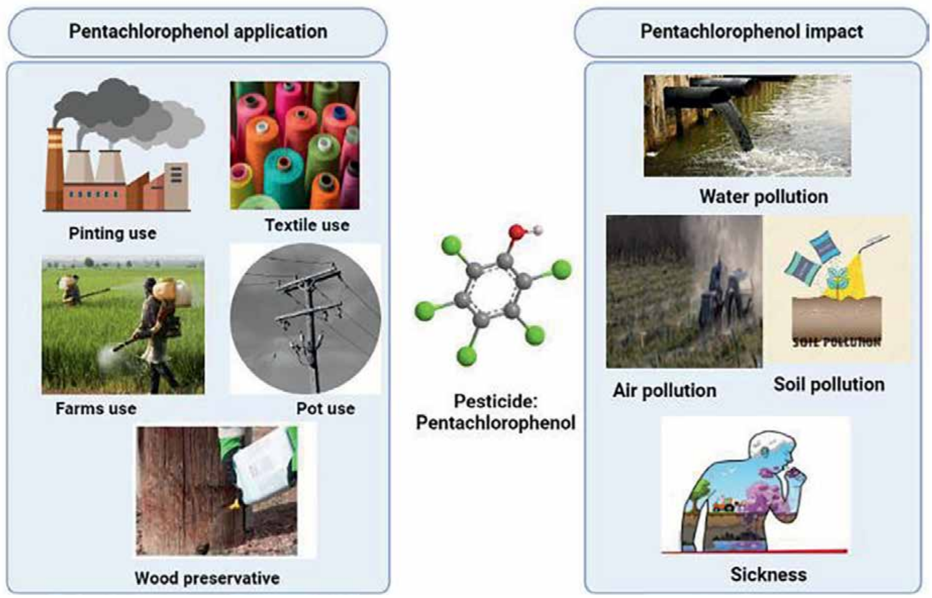

Figure 4.
Pentachlorophenol application and impact description.

use and chemical stability, persistency, and high toxicity. Human exposure to PCP occurs through inhalation, absorption through the skin, and consumption of contaminated water and food (**Figure 4**) [70]. It, therefore, has a very long half-life in the environment. PCP accumulates in the environment due to its lipophilicity and contaminates water and soil [71]. PCP used as a fungicide, insecticide, herbicide, and bactericide [72, 73]. that is widely employed as a wood preservative, especially for logs and wooden utility poles. There are many reports on the toxicity of PCP, including cases with fatal outcomes [70, 74]. The liver, thyroid, immune system, and reproductive system are the primary targets of PCP toxicity [70]. PCP inhibits spermatogenesis and has adverse effects on reproductive and inter-renal system at environmentally relevant concentrations [75].

In addition, PCP exposure is associated with renal, neurological, and carcinogenic effects. Several epidemiological studies suggest that PCP exposure is linked to human cancer [76]. PCP accelerates the incidence of hematopoietic cancer, multiple myeloma, lymphoma, soft tissue sarcoma, leukemia, and aplastic anemia [77]. This results in bioaccumulation of PCP in human testes, kidney, prostate gland, liver, and adipose tissue [78]. PCP is classified as possible human carcinogen (class 2B) by the International Agency for Research on Cancer [79]. PCP concentration at contaminated sites has been reported between 100 and 500 mg kg^{-1} in soil and 10–1000 mg L^{-1} in groundwater [80].

6. Pentachlorophenol wastewater treatment

For counteracting PCP pollution, wastewater-containing pesticides are commonly treated using biological and physico-chemical approaches [81]. The increasing of the accumulation of pollutants in the aquatic environment generated and activated many investigations concerning their removal and their biological treatment [82]. Unlike physical and chemical methods based techniques that are expensive and producing environmental side effects, biological methods could be useful for cost-effective and environmentally friendly approaches [83].

In addition, the bioremediation of PCP contaminated soil or water were widely examined in diferent research work, including phytoremediation [84] biostimulation [85] and bioaugmentation [64].

7. Example of pentachlorophenol phytoremediation

7.1 Typha genus

The Typha genus as a macrophyte always shows the advantage of development and growth under various climatic conditions, and function as bio-filters to protect lakes, estuaries and varied water bodies (**Table 1**) [86]. However, although it has been shown that Typha can tolerate and remove various xenobiotics: chlorinated benzenes, carbamazepine, diazinon, permethrin, chlorpyrifos and metformin (**Figure 5**) [87]. The two processes of phytoremediation and bioaugmentation are both biological methods used in PCP remediation process. Phytoremediation is a rapidly developing method that uses plants to reduce, degrade, assimilate and metabolize environmental pollutants such as hydrocarbons, pesticides, etc. [88].

Several studies have successfully evaluated phytoremediation of pollutants (i.e. nutrients, heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls) by mangroves [89].

7.2 Duckweed

This technology is suitable for sites with shallow contaminants [90]. They indicate that fullscale and pilot studies are going to demonstrate the promise and drawbacks of plant application for remediating hazardous waste in terrestrial and sediments. Aquatic media have been presented high quality and effective responses for phytoremediation especially for organic contamination.

Ant species	Polluants	Location	Reference
Lemna giba	PCP	Wastewater	[65]
Typha angustifolia	PCP	Wastewater	[64, 65]
Typha latifolia	Arsenic	Dringing water	[94]
Phragmites australis	Organic pollutants and pesticide	Constracted watland	[95]
Phragmites Australis	Organic pollutants	Contaminated aquifers	[96]
Phragmites Australis and *Typha latifolia*	Metalic elements	River water	[97]

Table 1.
Examples of plants use in phytoremediation process.

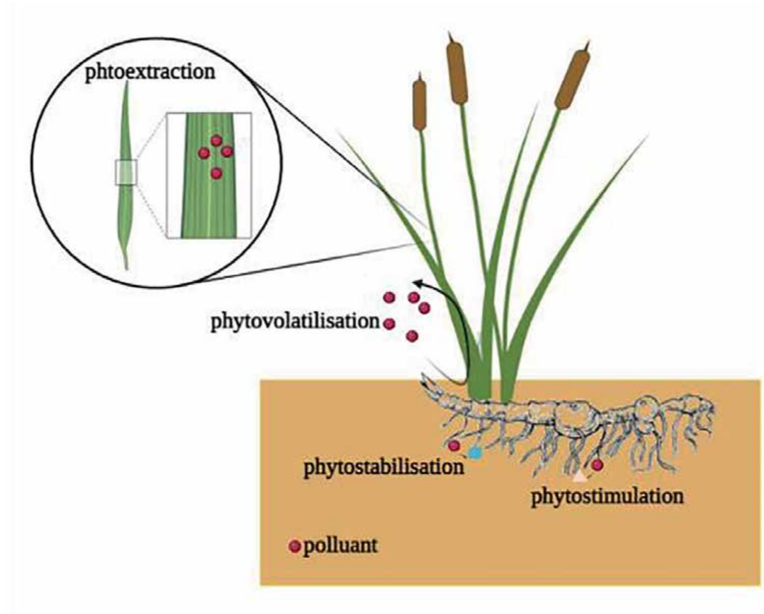

Figure 5.
Different phenomena of phytoremediation for Typha angustifolia plant.

Duckweed is composed of one or few leaves called fronds and a single root or rootlet with no stem, and the next generation generate through vegetative propagation [91]. Therefore, Lemnaceae is tremendously suitable for the phytoremediation of sewage. Duckweed is a highly efficient accumulator of various pollutants in surface water bodies and extensively used for xenobiotics, inorganic matters, HMs and pathogens removal from LW [10, 16, 23, 91]. Above all, duckweed needs plenty of nutrients to maintain its growth and development, which is beneficial for nitrogen and phosphorus recovery from LW. For example, Lemna sp. could remove 90% of PCP in constructed wetland with typha angustifolia [65].

7.3 Phytoremediation by microalgae

Microalgae could be adapted to a variety of water bodies and were extensively used to treat effluent [9]. Microalgae-based systems can absorb organic matter and nutrients from water bodies to meet their own growth needs [16]. Meanwhile, microalgae store various high value-added nutrients and chemical raw materials such as proteins, lipids, polysaccharides, vitamins, and beta-carrots, which could produce high-addition products such as biofuels and health products after purification [92]. Microalgae are also successfully employed to remove various antibiotics from LW. Initially, photobioreactors based on microalgae could remove 95% of doxycycline (DOX) and 93% of OTC from piggy wastewater [93]. In recent years, various studies have a smack at removing hormones and pathogens from LW via microalgae.

Phytoremediation by aquatic plants Aquatic plants have confirmed to be available materials for phytoremediation research, and dissimilar kinds of hydrophytes such as duckweed, water lettuce, water hyacinth, and watermilfoil were widely applied to phytoremediation of LW [10, 16].

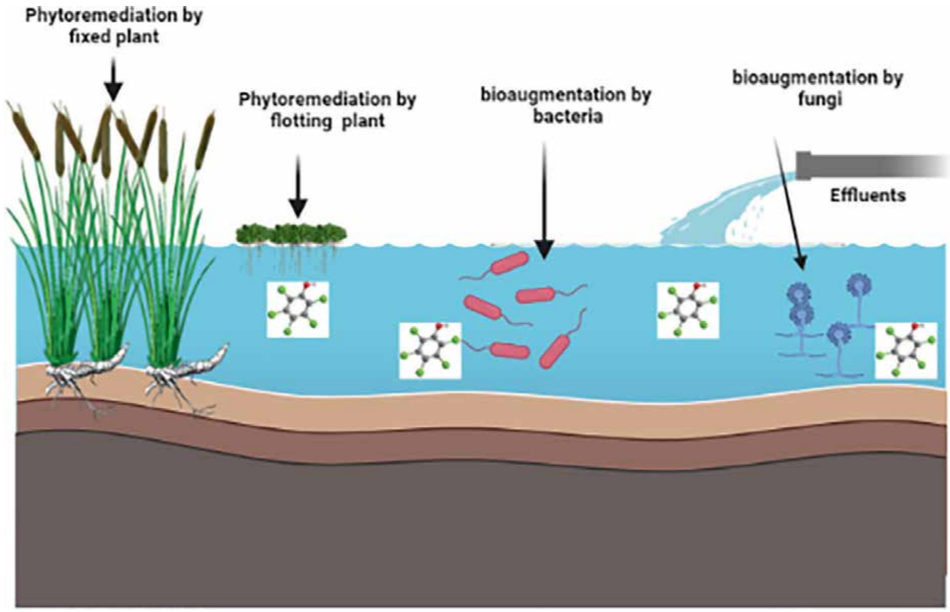

Figure 6.
The main mechanisms of phytoremediation- bioaugmentation process; case of constructed wetland.

7.4 Phytoremediation by constructed wetlands

Biological, physical, and chemical processes interactions between water and substrate, macrophytes, and associated microorganisms are the foundation of erasing pollutants from wastewater in constructed wetlands (CWs) (**Figure 6**) [98]. Eventually, although wetland plants could widely involve in removing organic matters from LW, research by [99] showed that the elimination performance of that did not alternate considerably in seasons while plants increase became reserved. It may be concluded that the elimination of natural topics from LW special from nutrients, which relies upon at the participation of microorganisms that distribute withinside the rhizosphere of vegetation and substrate of CWs. The organic technique is the important pathway to remove HMs from LW in CWs, and the performance of metals elimination via way of means of CWs varies extensively related to the neighborhood weather conditions, plant species, concentrations, and species of heavy metals [100].

In the end, the aerobic condition is more efficient than anaerobic on the biodegradation of antibiotics and hormones, and benefit from this, antibiotics and hormones in LW can be greatly reduced [101]. In order to hold the sustainable improvement of the ecological environment, the usage of aquatic plant life that applied to manipulate LW is rather important. Foremost, macrophytes including duckweed and water hyacinth had been used for farm animals feed because of better degrees of proteins, starches, and celluloses, and accomplished outstanding results.

8. Advantages of a Phytoremediation technology

The phytoremediation is an eco-friendly, maintainable, and hopeful method. Firstly, as compared with conventional organic and physical–chemical methods, phytoremediation is pushed through sun electricity and does now no longer require extra electricity matters, which leads to this manner is decrease cost, much less equipment, and clean to operate [102]. Secondly, the process of phytoremediation is multifaceted since aquatic plants can absorb substances from wastewater indiscriminately, which results in hydrophytes that can remove nutrients and hazardous chemicals such as heavy metals, antibiotics and hormones concurrently [16, 23].

Furthermore, aquatic plants applied for phytoremediation can use nutrients uptake from wastewater to synthesis a variety of high-value nutrients, so as to achieve the purpose of resource recovery [18, 19, 103].

Besides, aquatic macrophytes are more suitable for wastewater treatment than other terrestrial plants due to their faster growth, production of more biomass and a relative higher ability of pollutant [33]. Further, the success of phytoremediation depends upon a plant's capacity to tolerate and to accumulate high quantities of the pollutant, while yielding a large plant biomass [104, 105]. Due to their adaptive techniques to extraordinary environmental conditions, aquatic macrophytes can colonize numerous kinds of aquatic ecosystems. These plant life inhabit the littoral zone, wherein they turn out to be crucial additives affecting ecological methods in numerous ways, which includes 3 major categories (outcomes on network structure, the interplay among aquatic organisms, and limnological outcomes) [106].

In natural and man-made filtering systems, macrophytes play an important role in the biochemical processes of water treatment since their presence could exert some positive effects in this environment.

Overgrowth of aquatic macrophytes has a considerable impact on ecosystem processes [107], including constituting oxygen depletion, decreasing the phytoplankton production, interfering with navigation, increasing water pollution, and health hazards by providing an ideal breeding place for mosquitoes larvae and displace more desired species. The efficiency of full scale phytoremediation in natural condition significantly lower than lab-scale researches meanwhile, advantages of this treatment method cause concerning high attention and requests for future environmental cleaning strategies [108].

The cost of phytoremediation is highly variable and there a high correlation between cost of phyto-treatment and contaminant concentration, types, properties of soil and/water, site circumstances and importance of pollutant as a hazardous effect in the food chain. Anyway, phytoremediation is the most cost effective treatment methods with high social acceptance worldwide [109]. The value of decontamination could be growth approximately 7 times, whilst metal factors blended with natural pollutants [110]. Ligand software including glutamate affect reason growing phytoremediation (via the 30 days [111]. It shows that augmentation or modification system via the phytoremediation approach may also make contributions better efficiency, however it must be explored because the value of augmentation and associated environmental impacts [112]. The maximum appealing element of phytoremediation belongs to wastewater remedy and destiny of this software may also alternate the coverage of municipal wastewater remedy withinside the world [29].

In situ treatment method and easy large-scale applicability [113], generally applied in conjunction with other cleanup approaches [114], or augmentation such as adsorbents [115] nutrients, organic amendments [116] for effectively gaining with current environmental pollution. The plants applied to phytoremediation should possess a faster growth rate, high biomass, extensive fiber root system, easy to regulate, high tolerance to pollutants, and easy to cultivate and harvest [117]. On reason of their extraordinary metabolic and extraction capabilities, plants have been given an unparalleled decontamination capacity [12]. Meanwhile, the leaves, roots, and stems of plants provide residences for a variety of microbes, which can heighten the treatment process by synchronous decompose pollutants [12]. Over the past two decades, a fair amount of studies had been invested in the phytoremediation of LW [16].

9. Disadvantages of a Phytoremediation technology

Any disability, failure unknown reaction might also additionally divert as make a contribution a component to plant species and it additionally might also additionally motive growing dangers of phytoremediation. Literature suggests that infection concentration, toxicity and bioavailability and Plant preference and pressure tolerance are the primary dangers of phytoremediation, which include following tips:

- Accumulation of pollutant in fruit and different fit to be eaten elements of crop and vegetables.
- So a ways developing of phytoremediator plants (hyperaccumulators).
- Low biomass manufacturing in phytoremediators, so numerous planting and harvesting required for decontamination [118].
- Generally, precise selective specific accumulation of 1 metal detail in hyperaccumulator [119]
- Environmental pollution caused by chelate–enhanced phytoremediation [120]
- Very slow and seasonally effective treatment method [121]
- Handling and disposing contaminated plants through the phytoremediation is the major footprint of this green technology [122].
- Mobilization of radionuclides through the translocation in plants [123]
- Not applicable for all compounds [124]
- Dissolved contaminant in groundwater are not suitable case for aquatic phytoremediation [125].
- Originally, phytoremediation is a slow process that requires numerous hours, and extreme environmental weather conditions could also result in the death of hydrophytes and disturb management efficiency [126].

The plants cannot withstand higher contaminant levels [16]. Meanwhile, a few aquatic plant life with large quantity and quicker uptake price can gather the absorbed toxic and pernicious contaminants withinside the body. Although this will enhance the effluent best of wastewater, it'll additionally endanger the secondary usage of hydrophytes. Additionally, phytoremediation of wastewater requires a wide range of land, which is inexecutable in some regions, especially in areas with high population density and scarce land resources [127]. Ultimately, how to maintain the long-term effective and sustainable operation of the management systems still faces a variety of challenges.

10. Conclusion

Remedying technique for decontamination or pollutant elimination from the human surroundings. Advantages and downsides of this approach partially rely on challenge on vegetation as important main organisms via the remedy method, in the meantime maximum of hazards associated with right utility of this ecofriendly surroundings-cleansing technique. In different word, each performance advert blessings of phytoremediation noticeably associated with appropriate operation of remedy method. Combination with different remedy technique as sharpening or submit remedy method, crop plant utility for quicker pollution elimination, transgenic engineered plant species with expert cappotential in pollutant elimination in addition to appropriate utility of hyperaccumulator vegetation species will lead destiny researches to offering a clean image for blessings of this fee powerful technique. Furthermore, eligibility of phytoremediation for municipal wastewater were noticeably showed for destiny imaginative and prescient in wastewater remedy. Cost performance of phytoremediation, optimizing method of remedy and first-class mixture junction with different remedy strategies in phytoremediation has not been completely addressed and might keep in mind as destiny research objectives.

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Chapter 9

Invasive Water Hyacinth Challenges, Opportunities, Mitigation, and Policy Implications: The Case of the Nile Basin

Derese T. Nega, A. Venkata Ramayya, Million M. Afessa and Flavio Manenti

Abstract

Many lakes and rivers all over the globe are experiencing environmental, human health, and socio-economic development issues due to the spread of invasive water hyacinth (WH) weed. WH is regarded as one of the world's most destructive weeds and is nearly impossible to control and eliminate due to its rapid expansion and ability to double its coverage area in 13 days or fewer. However, most people in developing countries appear to be hoping for a miraculous cure; there are none and never will be. In this regard, this chapter aims to give an insight to raise awareness, research its biology and challenges, management options, and potential prospects on integrated control-valorization and its policy implications. WH biomass has demonstrated potential as a biorefinery feedstock for bioenergy and biofertilizer production, heavy metal phytoremediation, handicraft and furniture making, animal feed, and other applications. As a result, large-scale integrated control and valorization is an economically viable strategy for preventing further infestation through incentivizing WH control: providing a sustainable environment, increasing energy mix, increasing fertilizer mix, increasing food security, reducing GHG emissions, boosting socio-economic development, and creating new green jobs for local and riparian communities. Therefore, it is a leap forward in addressing global sustainable development goals (SDGs) through the water-energy-food-ecosystem (WEFE) nexus.

Keywords: water hyacinth, integrated control, valorization, economic feasibility, WEFE nexus, policy implications

1. Introduction

Invasive aquatic weeds such as water hyacinth (WH, Eichhornia crassipes, 'Emboch' in Ethiopia) pose a severe threat to the environment, human health, socio-economic development, and access to clean water around the world [1]. WH is found in the tropical and subtropical regions (see **Figure 1**). The first appearance of this

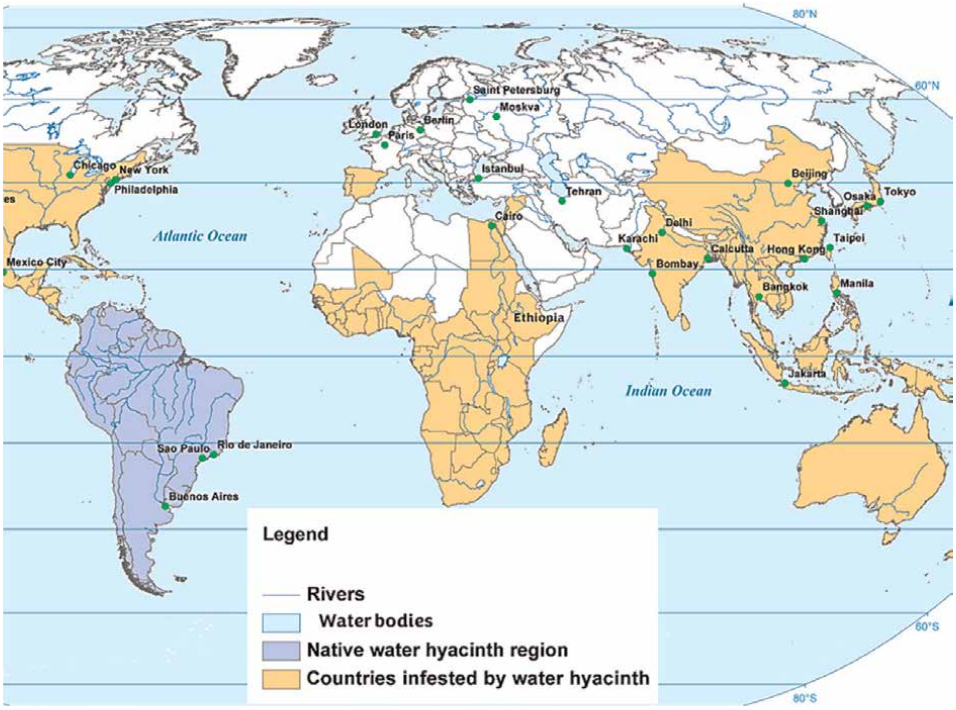

Figure 1.
Worldwide spread of WH; current and future potential spreads (adapted from [2]).

species comes from the Amazon basin in Brazil and dates back to 1816. Subsequently, it was introduced as an ornamental plant to North America at the end of the 1800s [3]. It first appeared in Africa in the early 1900s and in Europe in the 1930s [4]. Known for its rapid spreading rate and noxiousness, WH has been reported to be able to double its coverage in an average of 13 days, allowing plants to cover a wide range of water surfaces in a short period of time [5, 6]. The term "noxiousness" indicates that WH has severely damaged the water bodies due to its biology and function in aquatic ecosystems.

The magnitude of the invasive WH weed problem has increased exponentially nowadays over the different water bodies in East Africa [1, 7]. Most water bodies in Ethiopia such as the Abay River Basin (Lake Tana and the Blue Nile), the Awash River Basin (Koka Lake and Koka Dam), the Baro-Akobo River Basin (Sorbate, Baro, Gillo, and Pibor rivers), the Rift Valley Basin (Lake Ellen, Lake Elltoke, and Lake Abaya), and many other parts of East Africa have been attacked by this noxious weed [8]. These water bodies are located in the Nile Basin, and contribute 90% of the Nile's water [6, 9, 10]. However, WH is creating severe adverse impacts on these water bodies' ecosystems and causing problems in navigation, which strongly affects the daily life of the local population and riparian communities [7]; interrupts hydro-power generation systems, causes high water losses through evapotranspiration, and blocks turbines [11]. There are also other health issues, such as the incidence of breeding habitat for the malaria-causing Anopheles mosquito and other disease vectors [6, 12]. Fishermen, especially related to women fish sellers, have seen a considerable drop in their earnings [6, 13]. Another issue is irrigation system blockage, farmers that rely on irrigation water must spend a significant amount of time cleaning their water canals [11]. The previous attempts to biologically remove WHs or use chemicals to destroy them have been either economically infeasible or environmentally destructive [8, 13]. The alternative is to seek technology that encourages the valorization of this invasive plant, so its eradication will result in some cashback and, as a result, environmental benefits, incentivizing WH control by generating sustainable income [14–16].

Various studies have been conducted in this regard, and various scholars have evaluated the potential use and economic benefits of converting WH weed biomass into value-added materials via physical control (both manual and mechanical harvesting) mechanism and valorization. These include natural fertilizer substitutes [17], industrial raw materials for composite and biopolymer production [18], handicrafts and furniture production [19], non-conventional protein sources for animal feed [20], phytoremediation capacity to deal with toxins and heavy metals [21, 22], and biorefinery feedstock for bioenergy (fuel briquette, biogas, and bioethanol) production and others [6, 15, 16, 23–31]. Nonetheless, in the local context, there are some challenges confronting the control of WH weed infestation through valorization techniques such as lack of community awareness, lack of a constituted body to enforce control programs and integrated valorization projects, the absence of a comprehensive and suitable policy framework, and high amounts of effluents released in the water bodies leading to eutrophication [6, 9, 16].

This chapter intended to review and highlight the potential applications of the invasive WH plant to recover valuable resources and assist the aquatic ecosystem's sustainability by rewarding long-term WH control through the cash generated from its valorization. It also gives an overview of WH biology, its control measures, and associated risks, as well as its socio-economic and environmental risks, prospects on various valorization options, and techno-economic benefits, to raise awareness among local and riparian communities in the Nile Basin. It also recommends policy implications and research for future legal frameworks. Therefore, through integrated control-valorization within the Energy-Water-Food-Ecology (WEFE) nexus, this assessment will build resilience on more sustainable solutions to address the harmful ecological effects of WHs, clean water issues, increased energy mix, and long-term food security. It ultimately helps to achieve the universally initiated global sustainable development goals (SDGs). As a result, Ethiopia's policymakers, the water, agriculture, and energy sectors have the potential to be driven toward the valuable resource recovery technologies from integrated control-valorization prospects.

2. Biology of water hyacinth

The WH, a large, free-floating aquatic weed found either on the surface of fresh waters or anchored in mud, is a tropical aquatic plant with attractive purple flowers, 10–15 cm wide and bright, shiny green leaves on long petioles. The mature WH consists of roots, stolons, petiole, leaves, leaf isthmus, peduncle of the flower spike, inflorescence, adventitious roots, daughter plants, and fruit clusters (see **Figure 2**) [32, 33]. The root morphology is highly plastic and fibrous, having one single main root with many laterals, forming a huge root system. Because each lateral root has a root tip, WH may exploit nutrients in a low-nutrient water body, which makes the lateral roots longer and denser at low phosphorus concentrations [33]. It can replicate both sexually by seeds and asexually by vegetative implying budding and stolen

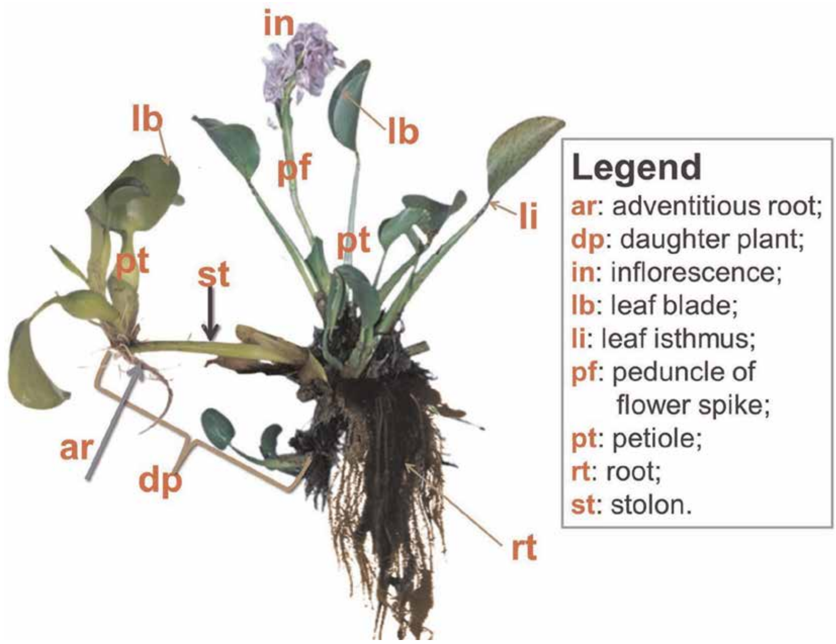

Figure 2.
Morphology of WH plants with stolons.

generation [32]. Both reproduction systems have a large production potential, within a very short period of time. The uniparental reproduction system happens through vegetative reproduction. In vegetative reproduction, 3.42 million plants can be produced in about 200 days and 43 daughter clusters of leaves in 50 days [32]. Three-parent plants can deliver up to 3000 new growing plants in 50 days, and two-parent plants can provide up to 30 offspring after 23 days. The sexual reproduction of the weed is through the production of seeds from its flowers by the agents of insects. Single WH plant can give flower in 26 days. The seed spread can be through a number of mechanisms including humans and the legs of birds [33]. Propagation by seeds may contribute to the spread of WH and can be a potent source of reinfestation [32].

Some authors report weight gains of 4.8% per day and the number of WH plants doubled on average every 13 days in a field observation [6]. It can grow most rapidly in water temperatures from 28 to 36°C [16] and at a pH from 4 to 8 [5]. They cease to grow when the water temperature is above 40°C or below 10°C, and the pH range for growth is between 4 and 10. The height of the plant can reach up to 1 m above the water surface, but its common height is 20–30 cm. The stalks are long, spongy, and bulbous. The roots are freely hanging on elongated treads with purple-black color and 2.54 cm underneath the water surface. The leaves of the weed have purple and yellow spots. Under favorable conditions, its biomass can reach up to 25 kg/m^2 or 300–442 tons/ha, 500,000 plants/ha, each flower can produce up to 400 seeds and a plant up to 5000 seeds [32]. In the tropics, it has been found a duplication of the population every 7 days and annual productivity of between 930 and 2900 tons/ha [34]. The seeds can live up to 15–20 years in water, silt, and mud [32, 35]. With these characteristics, the WH has become a major ecological and economic problem in this century in the tropics and subtropics [5, 16].

3. Chemistry of water hyacinth

Even though the chemical composition and characteristics of WH plants vary depending on the collecting locations and the environmental circumstances of growth sites, a WH plant can have a wide range of chemical compositions. Several studies confirmed that fresh WH plant has 95% moisture content, 0.04% nitrogen, 1.0% ash, 0.20% K_2O, 0.06% P_2O_5, and 3.5% organic matter. On a dry-weight basis, it has 75.8% organic matter, 1.5% nitrogen, and 24.2% ash. The ash also contains 28.7% K_2O, 1.8% Na_2O, 12.8% CaO, 21.0% Cl, and 7.0% P_2O_5. Through the analysis of the Kjeldahl technique, the WH plant yields: 0.72 g methionine, 4.72 g phenylalanine, 4.32 g threonine, 5.34 g lysine, 4.32 g isoleucine, 0.27 g valine, and 7.2 g leucine per 100 g crude protein (crude protein = quantity of nitrogen × 6.25) [36–39]. Furthermore, Lara et al. [40] presented the proximate analysis of the dried biomass of WH in **Table 1**.

Dry mass composition	**Plant parts**		
	Root	**Stems**	**Leaves**
Ash (wt %)	14.6–26.0	14.4–26.8	12.4–19.9
Alkali solubility (wt %)	54.4–55.9	48.9–52.4	51.2–51.8
Total extractives (wt %)	30.4–35.9	31.9–58.0	29.5–47.5
Runkel lignin (wt %)	8.8–13.4	5.9–4.5	11.5–14.3
Holocellulose (wt %)	23.7–43.4	11.4–40.0	17.1–36.8
Cellulose (wt %)	15.9–16.0	8.4–14.2	8.7–12.8
Hemicellulose* (wt %)	7.7–27.5	3.0–25.8	8.4–24.0
Elemental composition of WH from different plant parts (Atomic %)			
Sodium	0.67–5.80	2.01–4.43	0.68–1.51
Magnesium	0.46–16.37	5.33–6.00	3.76–7.39
Aluminum	0.25–8.84	0.27–0.82	0.03–0.21
Silicon	1.61–62.80	1.97–8.06	2.21–2.23
Phosphorus	1.81–5.99	4.64–5.12	5.87–8.61
Sulfur	1.07–5.91	0.37–2.44	0.44–2.76
Chlorine	0.71–12.20	19.43–21.47	15.93–17.44
Potassium	10.92–21.79	38.36–41.49	42.11–47.29
Calcium	5.30–28.92	15.05–20.27	16.11–23.98
Manganese	1.16–1.96	0.70–1.31	0.28–1.16
Iron	0.21–5.45	0.20–0.26	nd
Isolated primary metabolite (%) contents (mg/gdw) from different plant parts			
Carbohydrate	38.16 ± 0.102	56.33 ± 0.094	57.26 ± 0.065
Lipid/fat	2.79 ± 0.131	2.35 ± 0.187	5.22 ± 0.110
Protein	8.48 ± 0.200	5.53 ± 0.214	15.08 ± 0.084
Amino acid	1.14 ± 0.126	1.53 ± 0.082	1.67 ± 0.122

Table 1.
Analysis of dried WH biomass [39–41].

WH biomass also comprises chemical elements, such as Na, Mg, Al, Si, P, S, Cl, K, Ca, Mn, and Fe, with carbon and oxygen having the highest amounts see **Table 1** [39]. Ogamba et al. [41] also reported the composition of metabolites in WH biomass, shown in **Table 1**.

4. Environmental and socio-economic risks

Nowadays, WH weed causes major socio-economic and environmental concerns for millions of people in riparian communities and is, therefore, an added constraint on sustainable development [16, 42]. The common risks associated with WH weed are described under the following subsections and summarized in **Table 2**.

4.1 Environmental risks

WH weed distribution affects the ecological balance and changes natural diversity. These changes threaten the survival of many plants and sea-going creatures since weeds compete with the natives for food, sunlight, and space [6, 16]. This causes an imbalance in the aquatic micro-ecosystem and often means that a range of fauna that relies on a diversity of plant life for its existence will become extinct. Besides suppressing the growth of native plants and birds and negatively affecting microbes,

Problems posed by WH weed	Ent[a]	Eco[b] (%)	Soc[c]
Interference with irrigation and drainage system		x	x
Increase in disease outbreaks (malaria, cholera, etc.)			x
Less access to water points (domestic and livestock use)		x	x
Lack of clean water			x
Increase in incidence of snake and crocodile bite		x	x
Disappearance of the esthetic value of water bodies			x
Less access to harbors and docking	x	x	
Reduced fish catches	x	x	x
Difficulties in electricity generation	x	x	
Difficulties in water transportation		x	x
Difficulties in water extraction and purification	x	x	
Decline in diversity and abundance of aquatic life	x	x	
Effects on tourism	x	x	x
Decline in water quality	x	x	x
Increased water loss	x	x	
Increased siltation	x		
Increased potential for flooding	x		x

[a]*Environmental risks posed by spread of WH.*
[b]*Economic risks posed by spread of WH.*
[c]*Social risks posed by spread of WH.*

Table 2.
Summary of social, economical, and environmental risks of WH infestation.

WH prevents the growth and abundance of phytoplankton under large mats, ultimately affecting fisheries [16, 43]. For example, in Madagascar, many parts of the Alaotra Lake, a site of biological importance, have been reported as covered with carpets of WH that are detrimental to a number of animal species, such as the duck, Thalassornis leuconotus. A recent study in Lake Naivasha showed a massive reduction in the fish population due to reduced oxygen levels, which was attributed to the resurgence of WH [44]. The blockage of waterways by WH increases siltation and hinders activities like swimming, fishing, and sand extraction [1].

Large WH mats prevent the transfer of oxygen from the air to the water surface or decrease oxygen production by other plants and algae [16]. The oxygen dissolvability levels can reach harmfully minimum concentration for fish that are touchy to such changes. Besides, low dissolved oxygen situations initiate the release of phosphorus from the silt, which then quickens eutrophication and can prompt a resulting increment in algal or WH blooms [1]. Death and decay of WH vegetation in large masses deteriorate water quality and the quantity of potable water and increase treatment costs for drinking water [45]. People often complain of localized water quality deterioration [43]. This is of considerable concern when people come to collect water, swim, and wash.

In addition, Amare [46] pointed out that the rate of loss of water due to evapotranspiration can be 1.8 times the same rate of respiration from the water surface, but it is plant-free. This already has major impacts on the area where water is scarce. For instance, it is evaluated that the flow of water in the Nile could be decreased by up to one-tenth because of expanded misfortunes in Lake Victoria from the WH invasion [47]. Thick WH tangles also block canals, waterways, and rivers leading to hazardous flooding. This effect is more aggravated on riparian residents with little capacity to protect themselves from the flood as well as flood-associated risks [48].

4.2 Economic risks

WH infestation can exhibit numerous impacts on the fishing activities; access to destinations ends up troublesome when weed invasion is available, loss of fishing equipment frequently results when nets or lines become tangled in the root frameworks of the weed and the consequence of these issues is, as a rule, a decrease in catch and consequent loss of livelihood [44]. WH floating mats may also limit access to the breeding, nursery, and feeding grounds for some economically important fish species [16]. For instance, In lake Tana, Ethiopia, it is reported that fishermen have reduced their income, reduced fish catch, increased unemployment and reduced resource availability, increased poverty, and reduced efficiency of fishing activity [46]. It is additionally detailed, as in Lake Victoria, fish get rates to reach the Kenyan segment diminished by 45% in light of the fact that WH mats blocked access to fishing grounds, deferred access to business sectors, and increased costs of materials and effort [11]. Similarly, in Lake Naivasha, the WH infestation has been observed to have a negative impact on the economic status of the fishery community [44].

Many large hydropower schemes are also suffering the effects of WH weed infestation [49], WH causes high water losses through evapotranspiration and blocking turbines. For instance, it is estimated that the flow of water in the Nile could be reduced by up to one-tenth due to increased losses from evapotranspiration by WH in Lake Victoria [47]. Furthermore, the Tana Beles hydropower scheme on Lake Tana has suffered the impact of the weed, hence plenty of time and money has been invested to clear and prevent the weed from entering the turbines, which may cause damage and power interruptions [11]. On the Tana Beles hydropower scheme, the WH caused damage to water coolers and generators, prompting the power utility company to switch off generators for maintenance, and about 15 megawatts of electricity were lost causing a power cut in an urban area of Ethiopia [50].

4.3 Social risks

Water issues determine life and social sustainability. Both in Africa and worldwide, WH weed infestation is interfering with agriculture by closing irrigation and drainage systems and increasing water wastage [7, 11]. WH Floating mats have a significant impact on human life by supporting living creatures that are harmful to human health. For example, in Lake Victoria, the WH free-floating roots and semi-submerged leaves and stems reduce water currents and provide more breeding habitat for the malaria-causing Anopheles mosquito [6, 12]. The tangled weed mat is home to snails that serve as vectors for the Bilharzia parasite and Mansonioides mosquitoes, harmful to human health. WH has additionally been implicated in possession of an agent that causes the cholera virus [1, 6, 11]. For instance, from 1994 to 2008, the state of Nyanza in Kenya suffered from cholera on the border with Lake Victoria. The annual coverage of WH on Lake Kenya has also been directly linked to the number of cholera cases reported in the state [51].

At the local level increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed, which provides cover to the reptiles and poisonous snakes [45, 47]. These impacts pose, especially in the least developed countries, an additional burden on the limited health services and facilities available to the rural communities. In Ethiopia, Senayit et al. [52] reported an increase in malaria incidence and lack of drinking water, whereas during peak infestation periods, the floating weed serves as a host for snakes and crocodiles. Moreover, when the water level decreases, the unpleasant smell from decomposed WH residues disturbs the villagers. WH also impedes the recreational use of rivers and lakes. Decreased recreational and esthetic value are also among the major societal problems caused by invasive WH plants [7].

5. Existing control mechanisms and challenges

Biological, chemical, and physical (manual and mechanical removal) control, and/or an integrated approach (the use of two or three control mechanisms together) are used to eradicate WH. However, no single method seems ideal for all infested areas as suitable, and each method has its limitations and challenges [5, 53]. One of the significant components in deciding on a control approach is the uniqueness of the infested area (infestation chronology, water body uses, size, spatial arrangement, and weather) [16].

5.1 Biological control

Biological control is also one of the processes employed to remove or stop the growth of WH plants. In this mechanism, several insects, moths, fungi, pathogenic bacteria, and weevils among others have been distinguished as control agents for WH proliferation [53]. It should be noted that because of the fast proliferation rate, the major obstacle can be a long time to start such projects because it can take many years to reach a sufficiently large population to cope with pests [1].

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5.2 Chemical control

Chemical control is an immediate and short time solution to remove WH using chemical herbicides. However, it greatly affects the sustainability of the water systems since it utilizes herbicides and other poisonous synthetic compounds that impact and affect sea-going life [54]. Furthermore, chemical processes for WH control are wasteful when there is generous rain [55].

5.3 Physical control

Physical methods consist of two kinds of control(both manual and mechanical removal), the most widely utilized technique for WH management. Manual removal is done by human effort, to remove the WH plants from the water bodies [5], while the mechanical removal method is carried out by machines. Mechanical removal of WH consists of using weed cutters, harvesters, chaining, shredder boats, and a dredging process. Mowing, netting, and barriers are also used as ways of mechanical removal. Physical control remains the only method through which WH can be transformed into value-added products [16]. However, the significant disadvantage of this mechanism is that it expends a great deal of energy and needs a high investment cost [56].

6. Opportunities: valorization and value-added resource recovery

Although it has a significant negative impact on aquatic ecosystems, the valorization of WH offers a variety of potential economic benefits. The plant is known for many potential industrial applications reviewed in the following sections. The summary of the selected articles on valuable material recovery from WH is presented in **Tables 3** and **4**.

6.1 Animal fodder: nonconventional source of protein

The need for food security without exerting pressure on the global land use for agricultural purposes has necessitated the search for cost-effective, accessible, and healthy supplements. Studies have shown that WH is a decent source of creature feed because of its proven protein and mineral substance accessible to ruminants [63, 64]. WH leaf protein concentrate was shown to contain valuable amounts of nutrients including 56.38% crude protein, 33% carbohydrates, and 17 amino acids [63]. Researchers have promoted the use of WH as animal feed as it has high water and mineral content, which suggests that the nutritional value may be appropriate for certain animals, it can be used to supplement protein feed and roughage [65, 66]. Its utilization for creature feed is urged in developing countries to help tackle a portion of the dietary issues [67]. Fresh WH cooked with rice grain and fish feast and blended with vegetable waste, rice bran, copra cake, and salt and copra meal is utilized as feed for pigs, ducks, and lake fish in nations like Thailand, Malaysia, China, and the Philippines [57]. Other researchers also showed the utilization of WH as dairy cattle feed [56]. Akinwande et al. [68] also, with their study conducted on three water bodies in Nigeria, demonstrated that biomass yield, synthetic arrangement, and nutritive capability of WH to be used as feed for creatures, particularly ruminants.

Valorization	Aim	Investigations	Ref.
Animal feed	Analogizing the effects of replacing Tifton-85 silage with WH silage in sheep's diets.	The protein content of WH biomass silage was 159 g CP/kg DM, compared to 63.9 g CP/kg DM in Tifton-85. Tifton-85 silage can be substituted with WH and is not toxic to sheep.	[20]
	Tilapia fish in their early stages can be fed WH leaves as an alternative protein source.	In the diet of tilapia, WH leaves effectively replaced 20% of the high-cost protein source from fishmeal and soybean meals.	[57]
Phytoremediation	Citric acid cross-linked with WH root powder was used to bioremediate total inorganic arsenic and turbidity from polluted water.	Cross-linking improved stability while decreasing turbidity. The highest adsorption capacity was discovered to be 28 g arsenic/g.	[58]
	Treatment of zinc and chromium with WH biomass from electroplating wastewater. Powdered WH leaves, petioles, and roots hold a great deal of promise.	The dry roots removed the most zinc, with 98.9%, and the dry stem removed the most chromium, with 96.4%.	[22]
Insulation fiberboard	The possible application of WH petiole in the manufacture of thermal insulation particleboard.	Because of the low lignin content of WH weed and its internal porous structure, self-supporting binder-free WH panels can be manufactured.	[19]
Biopolymers	Use of WH biomass for producing Polyhydroxybutyrate (PHB)	WH is a cost-effective option for producing sustainable biopolymer as the PHB produced was of good standard	[18]
	A report on the phytochemistry and pharmacological purposes of WH	WH Extracts have pharmacological effects. The ethyl acetate and aqueous extracts have a suitable wound healing potential on an incision wound.	[59]
Biosorbent	Use of eï¬€ective microorganisms-based WH compost as biosorbent for removing basic dyes	The efficacy of effective microorganisms based WH compost to remove basic dyes were obtained as methylene blue (98.9%), malachite green (98.4%), and basic blue41 (89.1%).	[60]
	WH use as a biosorbent for removal of Cr (III)	WH removed 76.9 mg/g of Cr (III)	[21]

Table 3.
Summary of selected literature reviewed on animal feed, phytoremediation, biosorbent, insulation board, and biopolymers recovery technologies of WH.

Protein digestibility is a significant factor to evaluate the dietary quality of food; a high digestibility rate signifies high nutrients use. However, histology assessment revealed that the kidneys of the fish had degeneration of renal tubules, necrotic damage in tubular epithelial cells, and tubular lysis. There was no report of toxicity in the study of de Vasconcelos et al. [20], which was aimed at substituting Tifton-85 hay used in sheep diet with WH as the globulin concentrations were suitable. It is evident that WH is used as animal feed, however, it calls for suitable precautious procedures such as pretreatment before use to reduce its toxicity and seed viability.

Valorization	Aim	Investigations	Ref.
Briquette	Evaluating the fuel features of briquettes produced from the mixture of WH and empty fruit bunch (EFB)	The combination of WH and EFB showed a high perspective as the combustion properties: moisture content, ash content, fixed carbon content, and average calorific value is within a suitable range	[24]
	Development and characterization of charcoal briquettes from WH-molasses blend	The highest calorific value (16.6 MJ/kg) and compressive strength (19.1 kg/cm^2) with 30:70 charcoal/molasses ratio briquet was produced. Charcoal briquettes were tested for their flammable characteristics through their burning rates and ignition time	[23]
Bioethanol	Enhancing bioethanol yield from WH by integrated pretreatment method	1.40 g/L of bioethanol produced from the pretreatment of WH with microbial + dilute acid pretreatment. This was achieved without any additional cellulase.	[24]
	Evaluating the best method and the optimal conditions for fermentable sugar production from WH; these sugars were then fermented to bioethanol.	14 g/l bioethanol produced from C. tropical is Y-26 in the fermentation of fungal- and acid-treated hydrolysate was higher than the 6 g/l bioethanol produced from the fermentation of acid-only-treated hydrolysate.	[26]
Biogas	The potential bioenergy recovery from anaerobic digestion of WH and its co-digestion with fruit and vegetable waste (FVW)	The biogas potential of WH-FVW (0.141 m^3 /kg VS) co-digestion was 23% higher than that of WH alone (0.114 m^3/kg VS).	[29]
	Investigation of the effects of chemical pretreatment (H_2SO_4) on biogas production from WH	Cellulose was degraded during pretreatment. The optimum biogas yield of 424.30 mL resulted from the 5% v/v H_2SO_4 pretreatment at a residence time of 60 min	[30]
	Comparative investigation on biogas yield and quality from anaerobic digestion of WH and Salvinia	Biogas production from WH (552 L/kg VS) was considerably greater ($p < 0.05$) than Salvinia (221 L/kg VS). The biogas yield is estimated to generate 1.18 kWh and 0.47 kWh energy from WH and Salvinia (per kg VS), respectively.	[61]
Bio-fertilizer	Investigation of the viability of utilizing WH composted with pig manure and without pig manure as a peat substitute.	For tomato seedling germination, substrates 1–3 performed well (92.0–95.3%), while Figure substrate 4 was poor (76.0%). However, substrate1 (72.5%) performed better than others in cabbage growth, with substrate4 being the lowest.	[62]
	WH as green manure for organic farming.	WH can be used as a biofertilizer when incorporated into soil increasing the performance of the wheat plant. It is revealed that both physical and chemical parameters of the wheat plant treated with WH compost had higher values as compared to control.	[17]

Table 4.
Summary of selected literature review on renewable energy, biofuel, biogas, and agricultural fertilizer recovery technologies of WH.

6.2 Phytoremediation: scavenging toxic elements and heavy metals

Despite the negative impacts of the expansion of water bodies, WH can adsorb pollutants due to its polyfunctional meta-binding sites and chemical functional groups. In the use of WH for the adsorption of dye, most studies investigated the effects on cationic dyes [21, 60] with limited studies on anionic dyes [69]. In this respect, WH is an excellent choice for remediating contaminated sites because of its propensity to absorb heavy metals from wastewater [70]. WH was able to absorb and transport Ag, Cd, Cu, Pb, Sb, Sn, and Zn from an effluent waste recycling plant, demonstrating its ability to remove heavy metals from water. Nash et al. [71] tested the efficiency of WH in remediating sago mill effluent for a month at different concentrations of 20%, 15%, and 10%. Ammonia, phosphorus, and chemical oxygen demand (COD) concentrations were lowered approximately by 91–97%, 80–97%, and 86–97%, respectively. Other studies proved WH can be used to remediate heavy metals [22, 58, 71].

Because the interaction of numerous metals has yet to be defined, there have been significant differences in the degree of adsorption of heavy metals by WH; it is hypothesized that WH contains lignocellulose, which can result in the tethering of metal ions [21]. The use of WH as a biological agent for phytoremediation has been challenged because the plant has the potential to evade the chosen site and become a disturbance [69]. Along with phytoremediation, a sustainable mechanism to transform WH biomass into value-added products is required. For example, Sayago [72] designed a sustainability system in which WH is used to treat chromium-infested water, then its biomass was used to produce bioethanol. Therefore, when WH is used for phytoremediation, adequate precautions need to be accompanied as it has a terrible effect on the environment.

6.3 Handicraft materials: insulation boards, paper, rope, and furniture production

Nowadays, in the wake of global warming, bio-based building materials are becoming increasingly popular to reduce energy consumption in the construction industry. WH biomass can be professionally transformed into durable, esthetic furniture and handicrafts [67]. According to Salsa-Ruiz et al. [19] investigations, insulation boards made of WH have demonstrated their effectiveness in the construction sectors. Fiberboards (see **Figure 3**) made of WH fiber are also adequately useful for indoor partitions and low-cast roofing material due to their proven physical properties [47, 67, 73].

WH also provides a highly appealing mash that may be utilized to make a range of paper and sheets (see **Figure 3**) that are easy to produce [74]. Various studies have confirmed this; for instance, small-scale industry paper-making ventures have been fruitful in different countries, including the Philippines, Indonesia, and India [47, 67, 73, 74]. Paper made from WH stem is used for making envelopes and boxes. However, to increase the quality of WH paper, the fiber can be mixed with waste paper or jute [74].

The fiber from the WH plant's stems can also be used to produce rope; the rope-making process is like that of jute rope, used to make furniture (see **Figure 3**). However, because of the greater material quality interest and the difficulty of production procedures, using WH rope for furniture manufacturing is still challenging. In this case, the finished WH stem rope is treated with sodium metabisulfite $Na_2S_2O_5$ to prevent the product from rotting [67]. The rope, obviously, can be utilized

Figure 3.
Handcrafts: rope, furniture, fiberboard, paper, basket, and trash bin made from WH biomass.

accordingly, yet countless items, similar to those referenced above and bins/basket making (see **Figure 3**), can likewise be fabricated from it [53, 73].

6.4 Biopolymers

Several renewable resources are now being investigated for biopolymer synthesis; Because of its high cellulose content and rapid growth rate, WH has attracted interest as a potential source for cement composites and bioplastics. Salas-Ruiz et al. [19] discovered that WH root ash might be used to remediate pollutants in cement matrices as a substitute for pozzolans. These new biopolymers are highly compatible, readily available, cost-effective, and encourage waste and pollution recycling and eradication. They include polysaccharides, polypeptides, and polynucleotides [56]. WH could be used with other agricultural wastes to create bioplastic with a high biodegradability rate and replace synthetic plastics. Food packaging, hydrogels, medicine delivery, and pharmaceuticals are just a few of the applications for these biopolymers [18].

Thermochemical and alkaline-peroxide treatments were employed to obtain high-quality cellulose nanoparticles from WH stem cellulose [75]. The leaves of the WH plant are used to make silver nanoparticles. Also, environmentally friendly manufacture of platinum nanoparticles employing WH plant aqueous extracts as effective reducing and stabilizing agents has been suggested [76]. The synthesis of silver nanoparticles using cellulose extracted from WH was also achieved [77]. Nanomaterials produced from WH have been applied in wound dressings [59], biodegradable packaging films [18], and hydrogel [78]. However, more research on the WH plant's wound-healing abilities is required.

6.5 Biorefinery feedstock: bioenergy and biofertilizer production

Sustainable energy sources and organic fertilizers are essential to meet human energy consumption and agricultural needs, as hydrocarbon sources are depleting at an alarming rate [24]. WH can be explored for the production of bioenergy and bio-fertilizer due to its high hemicellulose and cellulose content, rapid growth on the water surface, accessibility to various tropical and sub-tropical areas, and quick proliferation after being gathered. WH offers many benefits as it can flourish on the water without competing for crops and vegetables [28]. Some techniques for valorizing WH biomass as bioenergy and organic fertilizer resource feedstock incorporate fuel briquette by biomass densification through mechanical conversion, biogas through anaerobic digestion; biohydrogen and bioethanol through hydrolysis and fermentation; syn-gas, biochar, and bio-oil through thermochemical conversion via pyrolysis, gasification, and hydrothermal liquefaction (HTL); and organic fertilizer creation by composting [14]. However, fresh WH biomass may contain up to 95% water, which may complicate harvesting and processing [6]. The biofuel yields from thermal processes such as combustion, gasification, and pyrolysis generally suffer from wet biomass resources, which necessitates pretreatment and dewatering [16]. As such, the scope of this chapter is limited to the biochemical and mechanical conversion of WH biomass via fuel briquette, bioethanol, and biogas production. This is based on the intention of this chapter to focus on economical benefits for rural communities, which require that approaches are less technologically complex yet economically feasible, as well as being based on local socio-economic capacity and the existing energy situation in Ethiopia.

6.5.1 Fuel briquette production

Briquetting is the densification of biomass to enhance the properties with more added values by increasing the energy density of different biomass residues [31]. The possibility of WH transformation to the briquettes has been evaluated for two decades, which was reviewed recently [73]. In terms of combustion characteristics, WH briquette showed a higher calorific value in comparison to the mangrove and firewood [79]. Carnaje [23] produced and tested the highest calorific value (16.6 MJ/kg) with 30:70 charcoal/molasses ratio WH briquette. Charcoal briquetting from WH weed is practiced by Kenyan researchers based on Lake Victoria WH biomass source and they proposed that development as a suitable technology for the briquetting of charcoal dust from the pyrolysis of WH [24]. It is suggested that a small-scale WH charcoal briquetting industry could have several beneficial aspects for the lakeside communities; for instance, providing an alternative income, source of biomass, improvement of the lake shore environment through the removal of WH, improved access to the lake and less risk to maritime transport, and reduced health risk associated with the presence of WH. It also serves as a potential alternative to firewood and charcoal, alleviation of pressure on other biomass fuel sources, such as wood, thereby reducing deforestation and associated soil erosion.

6.5.2 Ethanol production

Bioethanol is made from the fermentation of biomass and is a promising alcoholic biofuel existing in the market today because of its clean combustion. WH, because of its low lignin content is an alluring source of biomass, as cellulose and hemicellulose are all the more effectively changed over to fermentable sugar accordingly bringing about a lot of utilizable biomass for the biofuel business [28]. Production of bioethanol from WH demonstrates that in parallel with the physical control approach of gathering and landfill, it is financially viable to deliver bioethanol from the gathered biomass [28]. Nevertheless, some studies have reported high bioethanol yield in the absence of cellulase [24, 26]. The study conducted by Manivannan et al. [80] revealed that bioconversion of WH to bioethanol using two sequential steps of acid hydrolysis followed by fermentation with Candida intermedia NRRL Y-981 produced a maximum bioethanol yield of 0.21 g/g with a productivity of 0.01 g/l/h. The yield can be improved by integrating low-cost pretreatments followed by fermentation with improved bioethanol-producing microorganisms and will play a critical role in making the process economically viable [16, 24].

Several investigations proposed that pretreatment of WH biomass for ethanol generation is important and requires a moderately high temperature and strong acid/alkali pretreatments given that WH has low sugar and high lignocellulose substance; thus, energy cost is generally high, making it hard to accomplish a positive energy balance [6, 24, 26, 28]. Notwithstanding its commitment to energy enhancement, the creation of bioethanol utilizing WH as a feedstock can not just control the fast invasion of WH yet can likewise add to carbon discharge reduction and water quality improvement. While the production cost of bioethanol is high, ecological qualities assume a significant job in the financial support of the generation. The coupled utilization of WH as a phytoremediation plant and bioethanol feedstock is a potential reaction to green advancement techniques [28].

6.5.3 Biogas production

Many scientists have suggested that the valorization of invasive WH plants for biogas production plays a significant role in controlling weed infestation [24]. One of the options is anaerobic (AD) digestion, which takes place in a reactor or digester in the absence of oxygen, and the produced biogas can be used as a heat source for cooking, lighting, or heat energy to provide shaft power for generating electricity [6]. In addition to biogas, digestate from the AD process is utilized as a biofertilizer for soil conditioning and mushroom cultivation media [6, 81, 82]. WH biomass contains much water, rich in crude protein, and rich in nitrogen, cellulose, hemicellulose, and other natural substances with the C:N ratio (10-30:1) [4, 6]. Due to the reliance of the AD process on the activities of the microbial consortium, the maximum yield of biogas production depends on several parameters [30, 61]. Pretreatment [6], optimization of process parameters, suitable digester design, stimulation of microbial populations, and co-digestion with other organic wastes have all been used to increase the biogas generation yield of WH biomass [29, 83].

Furthermore, WH's energy potential is significant and encouraging. According to Castro and Agblevor, 2020 [84], one tonne of fresh biomass can produce 846.5 MJ of energy, with just 6.8 percent of the total energy required for mechanical harvesting. As a result, while power is necessary to collect the WH biomass from its infested water body, the total energy provided by the biomass is more than enough to keep operations running. Annually, 50 kg/m^2 ash-free WH biomass can be produced, with daily biomass productivity of 0.04–0.08 kg/m^2 [85]. The annual energy potential of one tonne of collected biomass is comparable to 13.3 m^3 biogas or 18.35–18.75 kWh electricity. Up to 75%, higher methane levels can be obtained, increasing electricity production by 25 MJ/kg [86]. That is an incredible opportunity for communities that have been severely affected by the WH invasion and are economically dependent on agriculture to manage weeds, generate income, and profit from self-sustaining energy resources.

6.5.4 Biofertilizer

The agricultural sector is in crisis because of the lack of cheap and accessible sources of organic nutrients to sustain the growing demand for food caused by overpopulation, especially in developing countries [6]. Biofertilizers are organic material of natural origin that provides one or more nutrients essential to plants for their growth. One of the most available strategies for soil fertility remediation is the valorization of WH weeds. The presence of phosphorus (P), potassium (K), and nitrogen in the WH biomass, and the C/N ratio make it a suitable substrate for composting as a biofertilizer [86, 87].

Composting is a high-temperature aerobic microbial disintegration process that is one of the most widely used ways of producing organic fertilizer from WH biomass [47]. WH Compost is an excellent natural supplement for sandy soils due to its hygroscopic nature and high moisture retention properties [64, 86]. A study by Vedya and Girish [17] shows that the WH plant can be used as a biofertilizer when mixed into the soil, boosting the performance of wheat plants. The study included control experiments that did not employ WH compost; physical and chemical properties were studied. Physical parameters such as root length, percentage germination, shoot length, and biomass content; shoot ratios were studied. The study also assessed chemical characteristics such as chlorophyll, reducing sugar, and protein content. According to the findings, both physical and chemical metrics exhibited greater values when compared to the control.

Therefore, composting WH biomass is a potentially feasible solution for WH biomass valorization on a large scale or in a commercial setting [88]. It is also a step toward overcoming the increasing food demand caused by overpopulation, particularly in developing countries, by utilizing the cost-free sustainable biofertilizer derived from WH biomass, increasing socio-economic benefits to rural communities while also assisting in the control of the WH invasion [86, 87].

7. Techno-economic analysis via valorization of WH

Ecological and economic assessments are influenced significantly by the feasibility analysis of environmental solutions for the valorization of WH at the industrial level. The objective of WH valorization into value-added products is to use an optimistic approach to addressing the threat of WH infestation while also meeting economic and environmental benefits. The techno-economic feasibility analysis of WH valorization for value-added material recovery practiced in different countries was appraised, as indicated in **Table 5**. The economic feasibility models used were more realistic and consistent with potential changes in future cash flow and discount rates because, unlike existing control approaches, costs and revenues of valorization technologies are intrinsic. In most cases, net present value (NPV) is used, which basically uses the current discount rate to identify the monetary value and support the sensitivity of future cash flow and exchange rate changes [27, 28, 90, 91]. Also, parameters that do not take into account the time value of money, such as life cycle analysis (LCA), return on assets (ROA), payback periods, profit margin, and internal rate of return

Valorization	Country	Model	Cost ($)	Benefit ($)	Lifetime (y)	Discount rate (%)	Investigations	Ref.
Bioethanol	USA	LCA	—	4×10^2	—	—	The cost of collecting WH as a biorefinery source does not exceed the cost of controlling the invader, making it a competitive biorefinery feedstock source.	[89]
	China	LCA	2.76×10^7	1.60×10^8	15	10	The study looked at the economic feasibility of producing bioethanol from WH and compared it to the ongoing status of landfill disposal. The results demonstrated that producing bioethanol from WH is cost-effective and that environmental advantages play an essential part in economic analysis.	[28]
Biogas	Mexico	LCA	6.4×10^7	—	15	5	The study looked at the viability of a constructed wetland and activated sludge plant as a wastewater treatment plant and anaerobic digestion of WH biomass for biogas generation. The results demonstrated that the biogas technology developed from WH biomass valorization is feasible since it reduces GHG emissions while addressing water pollution.	[25]
	Vietnam	NPV	4×10^2	1×10^3	15	3.5	The study looked at the cost–benefit analysis of co-digesting WH biomass and rice straw as feedstocks for biogas generation. It concluded that the technology is cost-effective considering the benefits to personnel and society.	[90]
	China	NPV	2×10^5	1.9×10^6	15	6	The study looked at an opportunity to generate biogas from WH biomass, and the results showed that biogas is a cost-effective option with a positive energy balance. WH valorization for biogas production increases water quality while lowering GHG emissions.	[91]

Table 5.
Techno-economic feasibility of WH valorization into bioenergy (bioethanol and biogas).

(IRR) are used [6, 25, 27, 92]. Various studies have used more than one feasibility model to compensate for the drawbacks of each model in quantifying and identifying costs and revenues from cost savings of valorization strategies [6, 25, 27, 28, 90–92].

The potential economic advantages of valorizing WH biomass are not intended to promote the spread of the invasive plant. Instead, they are meant to reduce the negative consequences and costs of controlling it. Bioenergy production such as bioethanol, biogas, and fuel briquettes has long been one of the most popular alternatives of WH valorization; experimentally justified and economically feasible options [6, 25]. In this regard, It is not the only sustainable solution for WH eradication; it also contributes to the energy mix, and fertilizer mix, increase food security, lowers greenhouse gas emissions, and improves water quality and livelihoods in riparian communities. Small and independent industries can utilize the new energy resources to cut their energy expenditure while utilizing the available waste streams means that no additional waste management costs are incurred. This allows communities to sustain their small industries, while local green jobs are created, eventually leading to wealth creation.

In addition, encouraging appropriate incentives for lowering feed costs, such as utilizing WH biomass, may benefit rural livelihoods that rely on livestock farming. Rural populations impacted by the WH invasion can be honored by using the plant for animal rearing, whether on a commercial or personal basis, because of the many options of employing the plant for animal feed. That could imply that controlling WH as feed could be done in a sustainable way to generate value, benefit society, and ensure long-term food security. [16, 65, 66].

Moreover, making handicrafts from WH biomass is becoming an appropriate technique to combine economic rewards and social empowerment while employing a plant that has traditionally been viewed simply as a problem [93]. The strategy can lower poverty levels associated with a lack of available jobs by creating new and green jobs for green development; to providing the community with the capacity to deal with environmental challenges. The opportunity to make biofertilizers from WH biomass should be appealing enough for affected riparian populations to use WH composting for soil amendment, which will help to ensure long-term food security [16]. As a result, WH waste can be adequately mitigated, and increased crop production will help improve the livelihoods of the local people.

8. Summary and policy implications

The rapid growth rate of WH weeds, the negative impact on the water ecosystem, and the high cost of eradication make the existing control mechanisms unattractive, so it calls for the adoption of alternative control strategies that exploit the unseen invasive WH potential valorization. WH weed could be considered a sustainable supply and biorefinery feedstock material for various value-added products rather than being perceived as an invasive noxious weed. WH weed biomass can be utilized for bioremediation and bioadsorption of different contaminants, animal feed, biopolymer, and composite material production, handicraft and furniture manufacturing, bioenergy generation, and organic fertilizer production, among other things. Techno-economic analyses have revealed that integrated valorization procedures with phytoremediation can be beneficial, particularly for more expensive valorization techniques such as bioethanol production. Therefore, the adoption of valorization techniques for widespread utilization of this noxious weed is an attractive and effective method of addressing energy shortages, long-term food security, and economic benefits in order to incentivize the control costs by integrating with the relatively unsuccessful traditional WH weed management mechanisms. It is also a step forward to contribute to achieving global sustainable development goals (SDG) by addressing the water, energy, food, and ecosystem nexus. As a result, for practicability, sustainability, and economic feasibility of WH mitigation, the combined control-valorization techniques are more viable to be adopted locally.

For policymakers to make enlightened decisions, much more techno-economic information is required on the costs and benefits of ecosystem management programs through valorization. For instance, it is often stated that there are not enough resources to control WH. However, when the costs of improved water ecosystems are weighed against the costs of increased water-borne diseases, reduced fish catches, reduced tourism income, and increased hydropower generation interruption, the resources required for WH control are likely tolerable compared to potential losses from its proliferation. There are untapped potential opportunities for WH biomass valorization, which can subsequently cover the control costs and boost the local economy.

In addition, widespread WH valorization requires the commitment of local communities, stakeholders, and decision-makers to raise awareness among local people and riparian communities for sustainable mitigation of the WH weed impacts. Nutrient runoff from industries, sewage, municipal waste, and agricultural lands should all be monitored to ensure that they do not leak into water bodies, as they are a significant contributor to the rapid growth of WH weeds. Industries that discharge effluents into bodies of water must be required to take corrective action and pay for the harm they have induced. There should be inspection mechanisms to ensure that all industries in the country have sewage treatment plants. Also, there is a need to encourage these industries to set up new business units or incorporate the harvested WH into their existing conversion process and motivate them through combined appropriate policy and institutional plans, insurance subsidies, and tax credits.

Furthermore, since most of the affected water basins in East Africa are cross-border resources, WH infestation can be seen as a symptom of broader watershed management and pollution-related problems. It calls for a concise national and cross-border resources legal framework for control through valorization. Also, the countries sharing it should come together to draft regional legislation pertaining to WH invasive species. This will ensure that the countries come up with a unified approach to controlling these species through interagency cooperation and coordination. These countries must collaborate to boost the Nile Basin's water resources, as well as pursue a variety of multifaceted projects in which they might share resources equitably. Countries, for example, may get involved in the biorefinery sector for mass usage and transformation of WH weed into valuable resources and also rescue the Nile Basin's source from further WH weed infestation apart from subsidizing control costs.

Finally, to stimulate the implementation of valorization measures, this chapter contributes to policy and research directions on the fiscal understanding of the material recovery from WH weed biomass. It also stimulates scholars to develop new techniques for valuing the weed and research into policy frameworks.

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

AD	anaerobic digestion
CBD	convention on biological diversity
COD	chemical oxygen demand
DM	dry matter
GHG	green house gas
EEB	empty fruit bunch
FVW	fruit and vegetable waste
HTL	hydrothermal liquefaction
IRR	internal rate of return
LCA	life cycle analysis
NPV	net present value
ROA	return on assets
SDGs	sustainable development goals
WEFE	water-energy-food-ecosystem nexus

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