Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study

THESIS

SUBMITTED TO

FOREST RESEARCH INSTITUTE DEEMED to be UNIVERSITY

DEHRADUN, UTTARAKHAND

FOR

THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY IN FORESTRY

(WILDLIFE SCIENCES)

By

Sameer Gautam

Under supervision of

Dr. B.S. Adhikari

Wildlife Institute of India, Dehradun, Uttarakhand

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

2025

Declaration

I hereby declare that the thesis "**Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study**" has conducted by me under the supervision of **Dr. B.S. Adhikari** faculty at the Wildlife Institute of India. The present thesis constitutes original research and has been submitted to the Forest Research Institute (Deemed to be) University, Dehradun for the award of the degree of doctor of philosophy in Forestry (Wildlife Sciences), and has not formed the basis for the award of any other degree. It embodies my own work and observations.

Place: Dehradun

Date: 4/7/2024

Sameer Gautam
Doctoral candidate

Dr. B.S. Adhikari

Supervisor
Scientist – G
Eco-development Planning &
Participatory Management
Wildlife Institute of India,
Dehradun, Uttarakhand

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Dr. B.S. Adhikari Ph.D.
Scientist G & Head
Ecodevelopment Planning & Participatory Management

4 July, 2024

CEERTIFICATE

This is to certify that the thesis entitled **"Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study"** submitted by **Mr. Sameer Gautam (Enrolment No. 18PHD515)** to the Forest Research Institute (Deemed to be) University, Dehradun, for the award of the degree of **Doctor of Philosophy in Forestry (Wildlife Science).** This is a record of original research work carried out by him, under my supervision. The thesis has been duly checked through 'DrillBit', a plagiarism detection tool approved by FRI (Deemed to be) University and the thesis has plagiarism to acceptable limits (5%). No part of this thesis has been submitted for any other Degree/Diploma of the same institution where the work is carried out or to any other Institution. It fulfils all requirements of the ordinance governing the award of a Ph.D. Degree of FRI (deemed to be) University, Dehradun. Mr. Sameer Gautam has adequate attendance during his thesis work and he was not engaged in any paid assignment.

Place: Dehradun

Date: 4/7/24

Dr. B.S. Adhikari
[Supervisor]

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248 001, भारत
Post Box No. 18, Chandrabani, Dehra Dun - 248001, INDIA
ई.पी.ए.बी.एक्स : + 91-135-2640111 से 2640115 फैक्स : 0135-2640117, तार : WILDLIFE
EPABX : + 91-135-2640111 to 2640115; Fax : 0135-2640117; GRAM : WILDLIFE
ई–मेल / E-mail : wii@wii.gov.in

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

FOREST RESEARCH INSTITUTE (DEEMED to be) UNIVERSITY DEHRADUN

This is to certify that **Mr. Sameer Gautam (enrolment no 18PHD515)** carried out research work under **Dr. B.S Adhikari**, Scientist G of Wildlife Institute of India, Dehradun. The topic of the research registered with FRI (Deemed to be) University is "**Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study**". The scholar presented his work in the pre-thesis submission seminar held on 04 August 2023 and the RAC found the work to be satisfactory and approves the work to be presented in the form of thesis for evaluation by examiners for "Award of Ph.D. Degree" by FRI (Deemed to be) University, Dehradun.

Dr. B.S. Adhikari
Scientist G & Supervisor
Wildlife Institute of India

Dr. Samrat Mondal
Scientist E & Nodal officer
Wildlife Institute of India

Dr. S.P. Goyal
Senior Scientist (Retired), WII &
Expert Member

Shri Qamar Qureshi
Scientist - G
Statistician/ Research
Methodology Expert &
Member

Dr. Salvador Lyngdoh
Scientist E & Expert Member
Wildlife Institute of India

INSTITUTE OF INDIA WILDLIFE CHANDRABANI DEHRADUN

Dr. Ruchi Badola
Scientist G & Dean, FWS
Chairman, RAC
Wildlife Institute of India
संकायाध्यक्ष / Dean
भारतीय वन्यजीव संस्थान
WILDLIFE INSTITUTE OF INDIA
देहरादून / Dehradun

पत्रपेटी सं0 18, चन्द्रबनी, देहरादून – 248 001, उत्तराखण्ड, भारत
Post Box No. 18, Chandrabani, Dehradun - 248 001, Uttarakhand, INDIA
ई.पी.ए.बी.एक्स. :+91–135–2640114, 2640115, 2646100 फैक्स : 0135–2640117
EPABX : +91-135-2640114, 2640115, 2646100 Fax: 0135-2640117
ई–मेल / E-mail : wii@wii.gov.in वेब / Website: www.wii.gov.in

Minutes of meeting of RAC for Pre-thesis submission seminar

- Name of scholar — Sameer Gautam
- Registration number — 18PHD515
- Name of Discipline & Topic of Research — Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study
- Name of Supervisor — Dr. B.S Adhikari
- Name of Co-Supervisor — N/A
- Name of Research Center/ Institute — Wildlife Institute of India, Dehradun.
- Date of meeting of R.A.C — 4 August 2023

Remarks if any of the supervisors: All the comments have been incorporated in the thesis by the candidates

Remarks of Chairman/Expert Members of R.A.C.:

Dr. B.S. Adhikari
Scientist G & Supervisor
Wildlife Institute of India

Dr. Samrat Mondal
Scientist E & Nodal officer
Wildlife Institute of India

Dr. S.P. Goyal
Senior Scientist (Retired), WII &
Expert Member

Shri Qamar Qureshi
Scientist – G
Statistician/ Research
Methodology Expert &
Member

Dr. Salvador Lyngdoh
Scientist E & Expert Member
Wildlife Institute of India

Dr. Ruchi Badola
Scientist G & Dean, FWS
Chairman, RAC
Wildlife Institute of India

संकायाध्यक्ष / Dean
भारतीय वन्यजीव संस्थान
WILDLIFE INSTITUTE OF INDIA
देहरादून / Dehradun

Minutes of the Pre-thesis seminar

The following comments were received in the pre-thesis seminar held on 04 August, 2023 at Wildlife Institute of India, Dehradun. All the given comments were incorporated in the thesis.

Comments	Responses
1. Use of statically analysis like Correlation, ANOVA, Cluster analysis and chi^2 test for plants and birds' data	a. Cluster analysis has done to find out the similarity of vegetation among habitat types of HWS. b. ANOVA has done to determine seasonal change in avian species richness across the habitat types of HWS.
2. Change in representation of seasonal variation of plants.	Graphs of seasonal change in the vegetation and different habit of plants have shown in each habitat type, as per suggestions.
3. Take mean flow of water in IGC for quantification and valuation of Provisioning of water.	Mean flow of water was taken for estimation of total water flow in IGC in a year and valuation was done.
4. Mention the threats to habitat	All the threats observed during field survey have been mentioned in the thesis.
5. Managerial aspect for improvement of ecosystem services in HWS.	Recommendations for improvement of ecosystem services such as ecosystem restoration, nature education for school and colleges have been mentioned in the thesis.
6. How did you estimate the flood area in downstream?	Flood data were collected through to the questionnaire survey. DEM map was prepared and area up to 207m elevation in the downstream has taken as active flood zone. Total area under 207m in the downstream and area of active River flow is subtracted to get area protected by Harike wetland.

वन अनुसंधान संस्थान सम विश्वविद्यालय, देहरादून
EST RESERCH INSTITUTE DEEMED TO BE UNIVERSITY, DEHRADUN

परीक्षक की रिपोर्ट

Report of the Examiner

शोध छात्र/छात्रा का नाम
Name of the Research Scholar: SAMEER GAUTAM

शोध प्रबंध का शीर्षक
Title of the Thesis: Valuation of ecosystem services at Harike wildlife Sanctuary, Punjab: A case study"

1. मैं संस्तुत करता हूँ/I recommend

Accepted of the thesis.

(a) शोध प्रबंध की स्वीकृति/Acceptance of the thesis

या/Or

(b) शोध प्रबंध की अस्वीकृति/ Rejection of the thesis

या/Or

(c) शोध प्रबंध का संशोधन/Revision of the thesis

2. विस्तृत टिप्पणियाँ (यदि आवश्यक हो तो कृपया पृष्ठ संलग्न करें)
Detailed comments (if required please attach sheet) Copy attached.

3. कृपया शोध प्रबंध की जांच करते समय आपके द्वारा प्रस्तुत सुझावों / टिप्पणियों को निर्देशित करने की कृपा करें जो कि मौखिक परीक्षा से पहले शोध छात्र को अपने शोध प्रबंध में सम्मिलित करने चाहिए:
Kindly indicate specifically that the suggestions/comments made by you while examining the thesis should incorporate in the thesis by the scholar before Viva: in thesis text.

4. मुझे यह भी व्यक्त करना है कि/I further state that

(a) यह तथ्यों की खोज या तथ्यों की व्याख्या के लिए एक नए दृष्टिकोण से विशेष अनुसंधान कार्य का एक अंश है। हाँ / नहीं Yes.
It is a piece of research work characterized either by discovery of facts or by a fresh approach towards interpretation of facts. Yes/No

(b) यह शोधप्रबंध शोध छात्र की आलोचनात्मक परख और उचित निर्णय लेने की क्षमता को दर्शाता है। हाँ / नहीं Yes.
The thesis evinces the Research Scholar's capacity for critical examination and sound judgment. Yes/No

(c) विषय की भाषा और प्रस्तुतीकरण के दृष्टि से यह संतोषजनक है। हाँ / नहीं Yes.
It is satisfactory in point of language and presentation of such matter. Yes/No

Name of scholar | Sameer Gautam
Name of Discipline & Topic of Research | Valuation of ecosystem services at Harike Wildlife Sanctuary, Punjab: A case study
Name of Supervisor | Dr. B.S Adhikari
Name of Research Center/ Institute | Wildlife institute of India, Dehradun.

Valuation of Ecosystem Services in Harike Wildlife Sanctuary, Punjab: A Case Study

A balanced relationship between humans and the environment is reflected in sustainable activities, which are accomplished by appropriately adhering to standards and conducting audits of human activities. In order to prevent additional harm and to enhance the interaction between the environment and humans, everything revolves around the assessment of environmental consequences. This has a significant impact on economic valuation. Different kinds of ecosystem services are discussed in detail in the thesis, including provisioning services (like raw materials, food, and water), regulating services (like flood control, water purification, and climate regulation), cultural services (like recreation and aesthetic value), and supporting services (like habitat formation and nutrient cycling). The importance of valuing bird species in ecosystem services is also discussed, highlighting the necessity of their sustainable management and protection since it is essential to comprehending the material and immaterial advantages that ecosystems offer.

Chapter 2: Review of literature

In order to help with conservation and sustainable management, this section of the thesis presents methods for valuing ecosystem services. Some of the strategies are non-market (e.g., contingent valuation for cultural assets), cost-based (e.g., avoided or replacement costs), and market-based (e.g., valuing things like lumber). The significance of biodiversity conservation is emphasized, policy decisions are supported, and environmental services are incorporated into economic planning.

Chapter 3: Study area and objectives

This section contains information about the Harike Wildlife Sanctuary (HWS), the research area, including the climate, soil type, flora, animals, and local community associations.

Chapter 4: Valuation of Ecosystem Services

This chapter provides a valuation of provisional, cultural, regulatory, and supporting services. Fuelwood, feed, medicinal plants, and raw materials are some of the various use categories for plant-based interim ecosystem services. Systematic quantification of each selected service has been done for valuation. While cultural ecosystem services are evaluated using the willingness to pay technique, provisional, regulatory, and sustaining ecosystem services are valued using the market price method. In addition to the distribution of medicinal plants in HWS habitats, ethnobotanical documentation of medicinal plants is also included in this section.

Comment: Some of the plant species scientific name spelling needs to be corrected before publication. The thesis is adequately backed by figures and graphs.

Chapter 5: Seasonal variation in vegetation across the habitats and mapping in HWS

The vegetation and its distribution across the several habitats of Harike Wildlife Sanctuary (HWS) were mapped in detail by research scholars, who also emphasized seasonal differences in the species makeup of each habitat. A map of each habitat provided, accompanied by information on the specific vegetation composition, offering a comprehensive view of how plant communities change throughout the year in response to environmental factors. This data contributes to a better understanding of the ecological dynamics within the sanctuary and the role of different habitats in supporting biodiversity. Cluster analysis used to determine the similarity of species composition among habitats of HWS.

Comment: figure 5.1 is it transit? or transect? Before publishing, the spelling needs to be checked again.

Chapter 6: Avian community and cultural ecosystem services across the habitat types

In the thesis, the services provided by the avian community and cultural ecosystems in various habitat types are thoroughly described. The information in figure 6.4 is good. In addition to observing seasonal variations in the bird's number and diversity, this section of the thesis examines the distribution of avian species in each HWS habitat. The Shannon diversity index and species richness change are computed monthly for a total of 18 months. This chapter includes information on the food guild, IUCN conservation status, and migration of avian species. ANOVA is used to estimate the seasonal shift in the species composition of avian species, and the Simpson similarity index is used to assess how similar the habitats are to the avian species. Additionally detailed in this chapter are the cultural ecosystem services linked to bird species. The avian population benefits from seasonal cropping, which may also have the potential to alter cropping crops because of bird oven feed, etc.

The chapters on discussion and conclusion are well-written. The findings of this study are contrasted with those of related studies carried out locally, nationally, and internationally. A wider context for comprehending the results of the current research is provided by carefully contrasting data and findings with pertinent studies on the same subjects. In order to place the study within the body of existing knowledge and provide a more thorough understanding of the current investigation, this comparison draws attention to the similarities or discrepancies in the findings. The findings of this study culminate in suggestions for improving ecosystem services by means of ecological restoration and encouraging frequent recreational and educational visits. Through the restoration of important habitats and the maintenance of ecosystem processes, the sanctuary can promote biodiversity and enhance the general well-being of its ecosystems.

The thesis is recommended overall, and Mr. Sameer Gautam may be awarded a Ph.D. for his outstanding effort.

Report

Incorporation of comments in the thesis received by reviewers

• Name of scholar	Sameer Gautam
• Registration number	18PHD515
• Name of Discipline & Topic of Research	Valuation of ecosystem services at Harike Wildlife Sanctuary, Punjab: A case study
• Name of Supervisor	Dr. B.S Adhikari
• Name of Research Center/ Institute	Wildlife institute of India, Dehradun.

Comment received by reviewers	Response by scholar
• For chapter 4: Some of the plant species scientific name spelling needs to be corrected before Publication, The thesis is adequately backed by figure and graphs.	I have updated all the plant species scientific name precisely in the thesis.
• For Chapter 5: Figure: 5.1 Is it line transit? Or Line transect? Before publishing spelling needs to be checked again.	I have updated the figure 5.1. Replaced "Line transit" by "Line transect".

I hereby declare that **Mr Sameer Gautam** has incorporated all the comments and suggestions provided by the reviewers in his thesis. The revised thesis has been thoroughly reviewed and meets the required academic and professional standards.

Date: 10/01/2025

Sam

Sameer Gautam
Doctoral candidate

Dr. B.S. Adhikari
(Supervisor)

Forest Research Institute, Dehradun

Certificate of Plagiarism Check for Thesis

Author Name	Sameer Gautam
Course of Study	PhD
Name of Guide	Dr. B.S Adhikari
Department	Ecodevelopment Planning & Participatory Management, Wildlife Institute of India, Dehradun,
Acceptable Maximum Limit	10%
Submitted By	bsadhikari75@gmail.com
Paper Title	Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study
Similarity	5%
Paper ID	2072991
Submission Date	2024-07-02 13:30:11

Signature of Student

Signature of Guide

The Report is Generated by DrillBit Plagiarism Detection Software

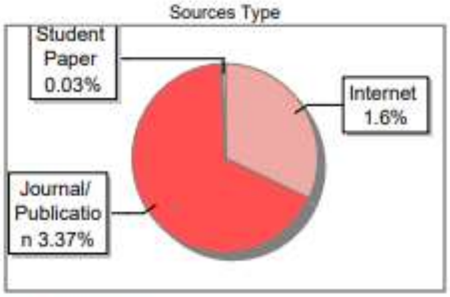
Submission Information

Author Name	Sameer Gautam
Title	Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study
Paper/Submission ID	2072991
Submitted by	bsadhikari75@gmail.com
Submission Date	2024-07-02 13:30:11
Total Pages, Total Words	193, 66190
Document type	Thesis

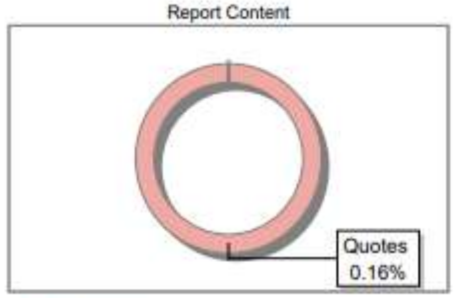
Result Information

Similarity **5 %**

Sources Type



Report Content



Exclude Information

Quotes	Excluded
References/Bibliography	Excluded
Source: Excluded < 1 Words	Excluded
Excluded Source	**0 %**
Excluded Phrases	Excluded

Database Selection

Language	English
Student Papers	Yes
Journals & publishers	Yes
Internet or Web	Yes
Institution Repository	Yes

A Unique QR Code use to View/Download/Share Pdf File

No. 1799 /18PHD515/2019/FRIDU
Forest Research Institute Deemed to be University
P.O.I.P.E., Kaulagarh Road,
Dehra Dun – 248 195

Dated 11/10/ 2019
☎: 0135 – 2751826
E-mail: registrarfriu@icfre.org

To,

Mr. Sameer Gautam
C/o Dr. B.S. Adhikari,
Scientist-F,
Dept of Habitat Ecology,
Wildlife Institute of India,
P.O. Box No. 18, Chandrabani, Dehra Dun -248 001

Sub: - Registration for Doctor of Philosophy Degree in Forestry.

Dear Sir/Madam,

I would like to inform you that the following decisions have been taken for your enrolment as Research Scholar for the Degree of Doctor of Philosophy in Forestry in this Institute:-

1. You have been registered for Doctor of Philosophy i.e **01.03.2019 to 31.08.2024** as PhD Research Scholar.

2. Your Enrolment number is: - **18PHD515**
(For all further correspondence please quote your enrolment number.)

3. Name of Research Centre: - **Wildlife Institute of India, Dehradun**

4. The Topic of research approved by the FRI University **"Valuation of ecosystem services in Harike Wildlife Sanctuary, Punjab: A case study."**

5. Name of Discipline: **- Wildlife Science**
(As per clause 3.3 of the Ph.D. Ordinance)

6. (i) Name of Supervisor : - **Dr. B.S. Adhikari**
(ii) Name of Co-Supervisor: - **Nil**

7. You are advised to deposit:-

(a) The next installment of Laboratory fee payable at FRIDU/Research Centre concerned through bank draft in the month of March, 2020

(b) Library fee payable at FRIU/Research Centre concerned in the month of March for each year of registration till submission of thesis.

(c) Annual fee payable every year in the month of March during the period of Registration at FRI Deemed to be University till the submission of thesis.

(d) The above mentioned fee should be deposited during the due month i.e. March every year failing which a late fee of Rs.1000/- (Bank Draft) will also have to be deposited in this office.

(e) You are also required to deposit the thesis fee and viva-voce exam fee to the University at the time of submitting the thesis and viva voce exam respectively.

P.T.O

8. **The research scholar is required to submit the six monthly progress report till the work is presented in the pre-thesis submission seminar and is approved by the Research Advisory Committee for submission of thesis.**

9. **The research scholar shall appear before the Research Advisory Committee to make a presentation of the progress of his/her work for evaluation and further guidance.**

10. Ph.D. Scholar shall be required to be present in the research center concerned for a minimum period of two years from the date of registration. Their presence shall be duly recorded and maintained in the research center concerned.

11. **Registration of a Ph.D. Scholar is liable to be cancelled by the Director at any time if:-**
   i. Two consecutive six monthly progress reports are not submitted at all or are not satisfactory as per recommendations/comments of RAC.
   However, the research scholar is required to submit the 1st six monthly progress report through his/her Supervisor & Chairman of RAC and 2nd and 3rd six monthly progress reports duly reviewed by RAC. The candidate will make six monthly presentation of 2nd & 3rd six monthly Progress report before RAC. After that all the 6 monthly Progress Reports shall be submitted through supervisor & Chairman, RAC while annual presentation would be held before RAC.
   The six monthly progress reports are to be submitted till pre-thesis submission seminar.
   ii. The attendance of Research Scholar is less than 75% in any term.
   iii. The scholar violates the clause 5.1.4 of the PhD ordinance regarding compulsion of 2 years Study leave for pursuing PhD in case of In-service candidates (except the employees of ICFRE and Research Centers of FRI Deemed to be University).

12. No Ph.D. Scholar (except in-service candidates availing study leave) shall accept during the period of research any paid assignment apart from Research Fellowships, Research Assistantship etc. (in the same institute) unless in the opinion of the RAC such an assignment will not interfere with his/her research work.

13. A Ph.D. Scholar shall not be permitted to take any other degree course, but may be permitted by the RAC to take part-time Diploma or Certificate course(s) not affecting the scholars research work adversely.

14. **A Research Scholar is required to pursue research in the Institute/Research Centre under the Supervisor on the approved subject for not less than twenty-four months commencing from the date of his/her registration.**

15. **The Research Scholar may not later than three months from the date of issue of registration letter, modify the scheme of the research work or nature or scope of the subject, on the recommendation of the Supervisor and RAC, with the approval of Director.**

16. In case a Research Scholar does not submit his/her thesis within a period of 6 years from the date of his/her admission unless the term is extended by the Research Degree Committee on the specific recommendation of the Research Advisory Committee for a period of upto1 calendar year, his/her registration shall lapse.

   The recommendations of the R.A.Cs for extension of term of registration must reach this office before expiry of the term of registration.

Contd....

The women candidates and Persons with Disability (more than 40% disability) may be allowed a relaxation of two years in the maximum duration of registration i.e. 5 years and six months. In addition, during the entire period of registration the women candidates may be provided Maternity Leave/Child Care Leave once in the entire duration of Ph.D. for up to 240 days with the approval of Vice Chancellor on the recommendation of Supervisor/Head of Division/Nodal Officer of the Research Centre concerned.

17. Prior to the submission of the thesis but at least 3 months before the expiry of term of registration, the scholar shall make a presentation in the Department before the Research Advisory Committee of the Institution concerned ' in Pre-thesis Submission Seminar. The minutes of RAC meeting for pre-thesis submission seminarts to be send to the Registrar, FRI Deemed University with full comments alongwith a panel of examiners duly signed by R.A.C.

18. Ph.D. scholars must publish at least one (1) research paper in refereed journal and make two paper presentations in conferences/seminars before the submission of the thesis for adjudication, and produce evidence for the same in the form of presentation certificates and/or reprints. While submitting for evaluation, the thesis shall have an undertaking from the research scholar and a certificate from the Research Supervisor attesting to the originality of the work, vouching that there is no plagiarism and that the work has not been submitted for the award of any other degree/diploma of the same Institution where the work was carried out, or to any other Institution..

19. **Please ensure that the clause 13 of the Ph.D. Ordinance is fully complied with before submission of the thesis to University.**

20. **Please note that your Registration as Research Scholar is to be governed as per rules, regulation, and ordinances of FRI Deemed to be University, with applicable amendments made by the University from time to time. For all further correspondence, please quote your enrolment number.**

(A.K. Tripathi)
Registrar
FRI Deemed to be University

Encl: 1. Fee receipt No. 795 dated 30.09.2019 for Rs. 36000/-
Format of progress repport

Copy to the following for information and necessary action:-

1. Dr. B.S. Adhikari, (Supervisor of the Scholar) Scientist-F, Dept of Habitat Ecology, Wildlife Institute of India, P.O. Box No. 18, Chandrabani, Dehradun-248001
2. Dr. V.P. Uniyal, (Nodal Officer FRIDU) Scientist-G, Wildlife Institute of India, P.O. Box No. 18, Chandrabani, Dehradun-248001

(A.K. Tripathi)
Registrar
FRI Deemed to be University

Acknowledgment

My deepest gratitude goes to Dr. B.S. Adhikari for his unwavering support throughout my doctoral journey. His clear vision, constant encouragement and insightful advice were instrumental in my progress. His patient guidance and regular feedback ensured the quality of my research and ultimately, the completion of my thesis. My sincere gratitude goes to the Wildlife Institute of India (WII), particularly the Director and Dean, for their helpful guidance and support throughout my doctoral research journey. I would like to thanks Director and Registrar FRI (deemed to be) University for providing this opportunity. I would also like to express my appreciation to the Principal Chief Conservator of Forests (PCCF) of Punjab and the Divisional Forest Officer (DFO) of Firozpur for their support. I am thankful to Dr. Salvador Lyngdoh and Dr. S.P Goyal for providing important inputs for data analysis. I want to extend my thanks to Prof. Qamar Qureshi for guidance. In the field, I am deeply grateful to Mr. Kamaljeet Singh, Ranger at HWS, for his exceptional assistance and cooperation during data collection. Their constant support was instrumental in allowing me to complete this PhD. I would like to express my sincere gratitude to Mr. Lakha Singh for his invaluable assistance and guidance in the field during sample collection. His expertise and support were instrumental to the success of this project. My deepest appreciation also goes to Mr. Jaspal Singh for his contributions to the boat survey and sample collection within the wetland. His adeptness in navigating the waterway and meticulous sample collection were crucial. I am particularly grateful to Mr. Raj for the insightful discussions on ethnobotany and the historical significance of the wetland. His knowledge enriched my understanding of the area and its cultural context. Last but not least, I extend my thanks to Mr. Gora for his assistance in the field and his keen eye for spotting rare avian species. His contributions enhanced the scope of the fieldwork and provided valuable data. Further I want thanks flood and irrigation department at Harike, managing flow of water in IGC for fruitful discussion. I am thankful to my parents for their unwavering support has been my pillar of strength. I want to thanks my brothers Sandeep Gautam and Mohinder Gautam and my sister Babita Gautam for their constant motivation and support, I am grateful to my friends, whose companionship and encouragement made this journey memorable. Special thanks to Rahul Kumar, Aditya Singh Chauhan, Rakesh Alhawat, Vishnu, Ritesh Gautam, Bablin and Kalzang for their support. Their collective support has been instrumental in shaping my research.

Table of Contents **Page No**

List of Table **Page No**

List of Fingers **Page No**

Chapter 1

Chapter 3

Chapter 4

Chapter 6

list of abbreviations

HWS	Harike Wildlife Sanctuary
ES	Ecosystem services
PES	Provisional ecosystem services
CES	Cultural ecosystem services
SES	Supporting ecosystem services
RES	Regulatory ecosystem services
PL	Plantation Habitat
AG	Agricultural Field Habitat
WL	Wetland Habitat
R	Ravine Habitat
SD	Sandy Habitat
SW	Swampy Habitat
IGC	Indra Gandhi Canal
HMP	Harike Management Plan
FL	Fidelity level
UV	Use value
SV	Summer visitor
WV	Winter visitor
FV	Floating vegetation
SV	Submersed vegetation

Chapter 1

Introduction

The notion of ecosystem services (ES) entered the global environmental discussion in the 1990s as a result of humankind's expanding demands on the planet's finite resources and mounting pressures on the natural order, which were also manifested in biodiversity loss and the energy and climate crisis (Groot 1992; Costanza et al. 1997; Daily 1997; Grunewald and Bastian, 2015). Significant landmarks included the Millennium Ecosystem Assessment (MEA 2005) and The Economics of Ecosystems and Biodiversity Studies (TEEB 2009). The three main sources are energy, food, and land. Nevertheless, the land is the most important resource because of its underappreciated rising scarcity. In the post-fossil and post-nuclear era, the land is required for the production of renewable energy, for maintaining other ecosystem services, for urban-industrial purposes, transportation, material extraction, refuse deposition, as well as for leisure, recreation, and environment preservation. All of these requirements fight for land, the production of food and non-food biomass, and suitable soils, which are becoming more and rarer (Graf 1984; Haber 2007). The importance of the notion of ecological services (ES) is to allow maximum consideration of ES—the services that nature offers us for free—in decision-making processes and to achieve sustainable land management, to prevent excessive usage and the destruction of essential habitats for life. The ES concept's appeal stems from its inclusive, multidisciplinary, and transdisciplinary nature as well as the way it links environmental and socioeconomic factors (Müller and Burkhard 2007; Keune et al. 2015). The business community is also becoming increasingly aware that the depletion of natural resources, the decline in biodiversity, and the degradation of ES not only pose an increasing risk to businesses, investors, banks, and insurance companies but that resolving these issues may also create opportunities with significant financial implications. Leading businesses are becoming more and more aware that maintaining and protecting nature is not just a minor concern or something that can be handled by the dedication of volunteers. To ensure sustainable growth and success, biodiversity and ES must be deeply ingrained in their business models and core strategies (BESWS 2010).

Even if an ecosystem or a part of it does not now provide any output value, it nevertheless has a potential value. Several different valuation methods may be used to determine the worth of the many services and benefits that ecosystems and biodiversity produce. Each of these has benefits as well as limitations (Tallis and Polasky 2009). Techniques that combine different valuation techniques may be capable of navigating their drawbacks. Volatility in valuation techniques generally and order to be properly methods particularly results from unanswered questions regarding ecosystem dynamics, consumer preferences, and technological valuation processing difficulties. In valuation research, uncertainty issues must be taken into account, and in cases of extreme uncertainty or lack of knowledge regarding regime shifts, valuation methodologies must be acknowledged as having limits (Pascual et al. 2010). Outcomes of valuation will be highly influenced by social, cultural, and economic circumstances, whose borders might not coincide with those of the pertinent ecological system. The identification and participation of pertinent stakeholders can lead to improved value. Benefits Transfer can be a practical, quick, and affordable way to get an estimate of the value of local ecosystems, especially when the goal is to assess a lot of different ecosystems. This is true even though it can be challenging to convey valuation approaches and results between world regions (Prager et al. 2015). Values will change depending on the features of the ecosystem and the people who benefit from the services it offers. When there are considerable discrepancies between the locations where the original values are collected from and the sites to which data are to be transferred, it is advisable to modify values accordingly. Transfer mistakes are inevitable, thus primary valuation assessments should be ordered if extremely accurate values are required. Although valuation methodologies have constraints that have not yet been resolved, monetary valuation can offer helpful information regarding changes to welfare that will be brought about by ecosystem management interventions. Lawmakers should analyze and use valuation data appropriately, and valuation practitioners should report their results in this manner. The constraints of monetary valuation are particularly crucial as ecosystems near critical points and changes to ecosystems become permanent or only possible at great expense (Patton, 2008).

Ecosystem services

Ecosystem services are the benefits derived from natural systems it could be direct and indirect contributions of ecosystems to human well-being, they support survival and quality of life (Haslett et al. 2010; Prusty et al. 2017) Ecosystem services can be categorized into four main types viz; Provisioning, cultural, supporting and regulating ecosystem services (Millennium Ecosystem Assessment 2005; Reid et al. 2005). The late 1970s are when the contemporary history of ecosystem services first began. To get people interested in biodiversity conservation, it begins by defining beneficial ecological functions as services from a utilitarian perspective (Westman 1977; Groot 1987).

Then it extends in the 1990s with a rise in interest in techniques for estimating the economic value of ecosystem services and their rising popularity in the literature (Perrings et al. 1992; Daily 1997; Costanza et al. 1997).

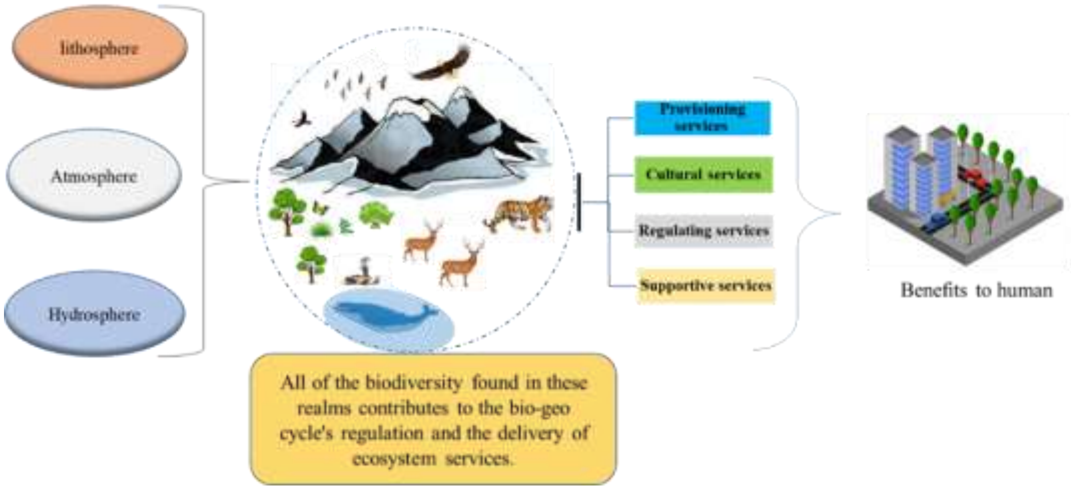


Fig 1.1: Genesis and flow ecosystem services on the Earth.

Ecosystem services are currently influencing financial decisions more and more due to the extensive advocacy of market-based mitigation measures (Bayon 2004; Wunder 2005) like markets for ecosystem services. A rapid expansion number of ecosystem functions have just recently been classified as services, given monetary values, and, to a lesser extent, included in markets and payment systems (Pagiola and Platais 2007; Engel et al. 2008). As a component of this procedure, the usage of the ecosystem services concept has surpassed the scientific domain to reach Governance as well as the non-profit, corporate, and commercial sectors (Bayon 2004).

Fig 1.2: Ecosystem services classification (Millennium Ecosystem Assessment 2005)

Provisional ecosystem services

The tangible advantages that people receive from ecosystems are referred to as "provisioning services," and include water, food, timber, and other items. Markets are used to trade a variety of provisioning services. Nonetheless, rural residents in many areas also rely directly on the provision of services for their means of subsistence. The value of the services in this situation can be significantly more significant than what is indicated by the amounts they command on local marketplaces. Many kinds of ecosystem services are affected by and are impacted by, farming, forest, and aquaculture. According to the framework of The Economics of Ecosystems and Biodiversity, we are examining the interactions between various production systems and various forms of ecosystem services (TEEB 2009).

Food: Currently, the world produces enough food to feed the 7 billion people who live there. With the rate of production increasing more quickly than the population over the last 20 years, there is 17% more food produced globally today than there was 30 years ago. Food production is one of the ecosystem services that has steadily increased over time. It is now understood, however, that the increases in agricultural productivity and production were frequently accompanied by detrimental consequences on agriculture's natural resource base, compromising its future productivity potential. Over the past two decades, ecosystem approaches to agriculture intensification have arisen as farmers adopted sustainable practices, which are essential to achieving the advantages of ecosystem services while minimizing the negative impact of agricultural operations. Almost one-third of the protein consumed by humans comes from livestock. When it comes to micronutrients, animal products are crucial to the human diet. The only way to create food on large tracts of grasslands that are not ideal for growing crops is through ruminant animals, which can digest the cellulose in grass and convert it to human-edible proteins. People all across the world get a considerable quantity of animal protein from the capture and culture of marine and freshwater fish. Between 15 and 20 percent of all animal proteins are thought to derive from aquatic creatures. Most of the fish consumed by humans is produced through aquaculture, one of the fastest-growing food-producing industries.

Raw material: A wide variety of materials are produced by ecosystems, such as wood, biofuels, and textiles from untamed or domesticated plant and animal species. Several forms of raw materials are generated by animals, including fiber (wool, mohair), leather, and other commodities utilized in the feed and food industries. Anything good or service generated in forests that aren't timber is known as a non-timber forest product (NTFP). Fruits, nuts, vegetables, fish, game, medicinal herbs, resins, essences, and a variety of barks and fibers, including bamboo, rattan, and a variety of different palm and grasses and palm fronds, are among them. Authorities, welfare, and conservation organizations, as well as non-governmental organizations, have promoted the marketing and sale of NTFPs during the past 20 years as a way to provide income for such poor in the tropics and promote forest preservation.

Fresh water: As hydro uses account for about 60% of all freshwater withdrawals worldwide, crops are strongly reliant on it. Cropping technologies that are improved can also help the soil retain more water and provide more water (Wu et al. 2022). A significant user of freshwater resources is livestock. The majority of this water usage is caused by the feed they eat. Approximately 15% of the water used in modern agriculture is used by livestock. Yet, in many of the major headwaters around the globe, grasslands are a critical habitat (FAO 2006). Woodlands are a stable source of pure freshwater and aid in maintaining healthy aquatic habitats. In addition to filtering and purifying water, forests also assist prevent soil erosion, lessen reservoir sedimentation, and lessen the likelihood of mudslides, floods, and other issues that could endanger downstream water supplies (Vieira 2020).

Medicinal plants: Herbal medicines or part of these, have indeed been gathered and utilized for ages by civilizations, for their medical powers. There is a growing interest in the use, development, cultivation, conservation, sustainable use, etc. of aromatic and medical plants all over the world, in both advanced and developing nations. In many nations today, medicines made from plants serve as the foundation for healthcare (Bhandari 2018).

Cultural ecosystem services

Cultural ecosystem services are "the non-material advantages humans gain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences (Sarukhán and Whyte 2005). According to the Millennium Ecosystem Assessment, 2005, Several different patterns of ecosystem services have included cultural ecosystem services, which are also known as socio-cultural fulfillment, life-fulfilling functions, informational features, conveniences and fulfillment, and cultural and amenity services (Constanza 1997; Daily 1999; Wallace 2007). The benefits that cultural ecosystem services offer on a physical, emotional, and mental level are frequently subtle, intuitive in character, and implicitly communicated through indirect expressions (Kenter et al. 2011; Anthony et al.

2009). So, the value given to cultural ecosystem services relies on how each person and culture evaluates how much they contribute to overall well-being (Eicken et al. 2009; Scullion et al, 2011). The vast bulk of cultural ecosystem services are excluded from neoclassical economics techniques (Chan et al. 2012) however given that they are expressed in human behavior, some scholars believe their significance to be quantifiable (Zhang et al. 2010). For instance, a subset of cultural ecosystem services that are susceptible to conventional valuation is precisely defined by the Economics of Ecosystems and Biodiversity program. These services include recreation, ecotourism, cultural heritage, and educational qualities, interestingly, the cultural ecosystem services that are most commonly investigated are also the ones that are easiest to measure (Chan and Ruckelshaus 2010). Increasing the discrepancy between measuring what is important to people and what is straightforward to measure (Groot et al. 2010). Even though ecotourism and recreation are sometimes regarded as cultural ecosystem services several authors contend they ought to be categorized as provisioning services instead (Abson and Termansen 2011) particularly for populations wholly reliant on these services (Daw et al. 2011). Even though it indicates a general inability to measure other cultural ecosystem services, an increased focus on recreation and ecotourism may mislead researchers and lawmakers into believing that these represent cultural ecosystem services as a whole, unwittingly marginalizing other significant cultural ecosystem services (Seppelt et al. 2011).

Regulatory ecosystem services

The various "regulatory services" that ecosystems give include maintaining the quality of the air and soil, preventing floods and diseases, and pollinating crops. As they are frequently undetectable, most people assume they exist. When they are harmed, the ensuing losses can be significant and challenging to repair. Many kinds of ecosystem services are influenced by and are influenced by forestry, fishery and agriculture (Fitter et al. 2010). Regional temperature and air quality are impacted by ecosystems. Trees, for instance, offer shade, and forests have an impact on local and regional rainfall and water supply. Eliminating pollutants from the air, trees, and other plants is also crucial for maintaining proper air quality (TEEB 2009).

Through sequestering greenhouse gases, ecosystems control the temperature on a global scale. For instance, as plants and trees mature, they absorb carbon dioxide from the air and essentially store it within their tissues. Living creatures and ecosystems act as barriers to natural calamities. They lessen the harm resulting from droughts, flooding, tornadoes, tsunamis, mudslides, and landslides. Water pollution is frequently caused by agricultural effluents. Using wetlands or buffer strips, agricultural systems can be created to support wastewater treatment. Trying to reduce these effluents can help relieve some of the ecosystem's stress. With their roots and their part in nitrogen cycling, trees play a significant role in waste-water treatment.

Plants as well as trees are pollinated by insects and the wind, which is crucial for the growth of fruit and vegetables. Animal pollination is primarily performed by insects, while some birds and bats also participate in this ecosystem service. In agroecosystems, pollinators are necessary for the growth of orchards, horticulture, forages, and the development of seeds for several root and fiber crops. 35 percent of the world's crop productivity is impacted by pollinators like bees, birds, and bats, which also increase the yields of the top 75 percent of food crops globally. The actions taken by predators and parasites in ecosystems keep populations of potential pests and disease vectors under control. When bio-control of pests is required in a forest, this strategy is frequently used since a forest's generally stable ecosystem ensures freedom from harmful effects like pesticide interference or disruptive agricultural practices. Forests that are left to their natural or sustainable state are a fantastic source of organic pest control agents. Forests have an impact on the availability of water and the time of water supply. The systems in the canopy of the forest are what allow forests to control streams.

Supporting Ecosystem services

The foundation of all ecosystems and their functions is the provision of habitat for plants and animals as well as the maintenance of a diversity of plants and animals. Many kinds of ecosystem services are influenced by agriculture, forestry, and fisheries. According to the typology of The Economics of Ecosystems and Biodiversity, Ecosystems offer habitats for plants and animals, as well as support a variety of intricate processes that support the other ecosystem services. 'Biodiversity hotspots' are ecosystems that have an unusually high number of species, making them biologically more varied than others.

Boreal, temperate, and tropical woods provide a variety of environments for microorganisms, plants, and animals many of the world's poorest nations derive more than 10% of their Economy from their forests. Despite playing such a significant part in the global economy, there has been little advancement in sustainable forest management, and forests are still being lost and degraded in many developing nations (Owens and Lund 2009). Different breeds or races are distinguished from one another by genetic diversity (the variability of genes between and within species populations), which serves as the foundation for locally well-adapted cultivars and a gene pool for creating commercially viable crops and livestock. Over 75% of plant genetic variety has been lost since the turn of the 20th century as farmers all over the world switched from their diverse local varieties and landraces to genetically uniform, high-yielding cultivars. Just 150 to 200 of the 250 000–300 000 identified edible plant species are consumed by humans, or 4%. Just three, including rice, maize, and wheat, account for over 60% of the calories and proteins that people get from plants (FAO 2006). Presently, it has been determined that more than 20% of the breeds are in danger of going extinct. 60 breeds have disappeared in the previous five years, or one each month on average. If livestock owners want to modify their animals' traits in response to shifting environmental factors, they require access to a large gene pool. Although the number of the 400,000 known terrestrial plant species that currently offer species-specific advantages to people is unknown, it is plausible to assume that the majority of them do not. Numerous more species are significant but potentially interchangeable sources of fodder, fuel, or timber. In addition, every species helps with primary production, nutrient cycling, and meeting the needs of animals, fungi, and other creatures such as those for food, shelter, and other necessities. Rare species make up a smaller fraction of these so-called "supporting services," but there is evidence that they have the most distinctive characteristics and can perform a greater variety of activities than other species (Mouillot et al. 2013, Leitão et al. 2016). These species may so serve as a hedge against potential environmental change, including climate change, thereby boosting ecosystem resilience over the long term. Biomass productivity as a stand-in for other supporting, total biomass, and service provision are significantly connected for certain services, like carbon storage or fodder production, while biomass and productivity are unreliable indicators for many other services. For instance, there is a negative correlation between plant biomass and several hydrological services, such as flood attenuation and stormwater retention (Dee et al. 2019).

Valuation of Ecosystem services

Economics, which focuses on how to distribute finite resources, uses the value to inform society about the relative degree of resource scarcity. The value of biodiversity and ecosystem services is a reflection of what our civilization is ready to give up to protect these natural treasures. Ecosystem services and biodiversity can be economically valued to make it clear to society at large and policymakers in particular that these resources are rare and that society bears costs when they are destroyed or degraded. If these costs are not taken into account, policy would be poor and society would suffer from poor resource allocation.

An asset is considered scarce economically if using it results in lost opportunities. That is, one must sacrifice a certain amount of something else to gain one more unit of the good. Quantifying and valuing ecological services is economically equivalent to doing so for human-produced products and services. Therefore, it is difficult to value ecosystem services in reality. In situations where well-developed markets exist, there are reasonable estimates of the value of many provisioning services, but there are few trustworthy estimates of the value of the majority of non-marketed cultural and regulating services (Carpenter et al. 2006; Barbier et al. 2009). The issue is that because biodiversity and the majority of ecosystem services are considered public goods, society tends to consume them excessively. Biodiversity (together with ecosystems) can be widely viewed from an economic perspective as a component of our natural capital, and the flow of ecosystem services is the 'interest' that society receives on that capital (Costanza and Daly 1992). To preserve long-lasting environmental quality and human well-being, including poverty alleviation, we must choose a level of biodiversity and natural capital that ensures future flows of ecosystem services, just as private investors choose a range of capital to manage uncertain returns (Perrings et al. 2006) therefore, ecological services and biodiversity may only be valued by society to the extent that they directly or indirectly satisfy human wants or provide satisfaction (Goulder and Kennedy 1997).

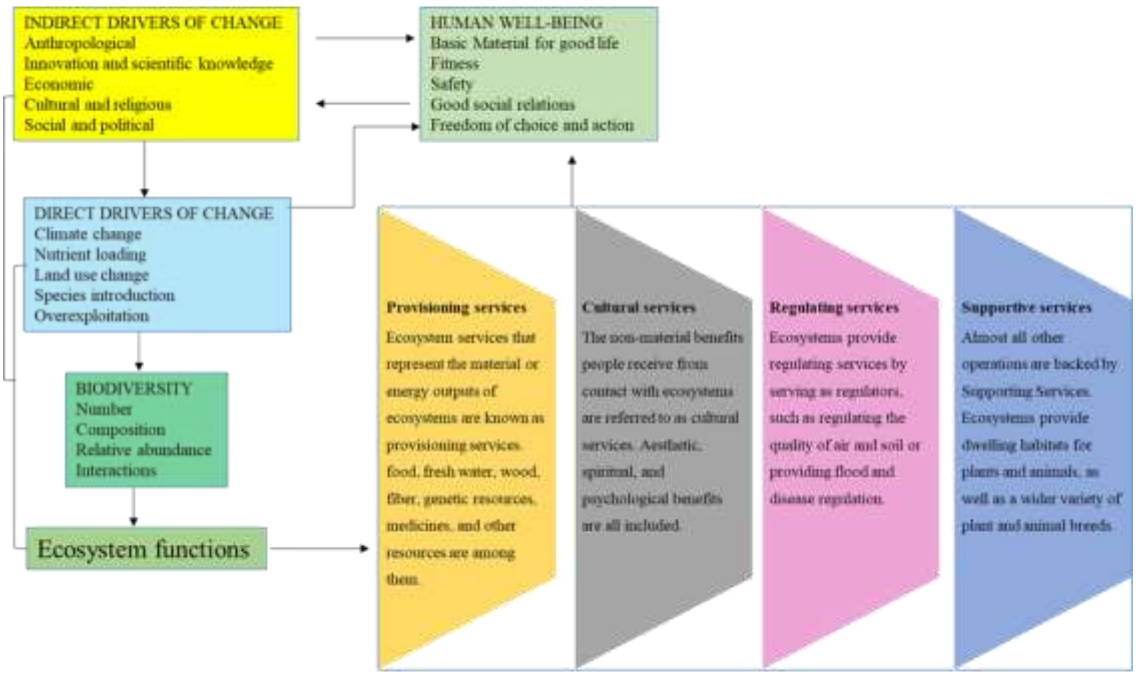


Fig 1.3: Different drivers of the ecosystem functions and services. (Source: Haines et al. 2010)

This method of valuing ecosystem services is based on how strongly preferences alter in response to slight variations in the amount or quality of products or services. As these values offer insights that can assist strategic decisions, the economic theory of value is therefore anthropocentric and, for the most part, instrumental. Such valuation technique should be used in conjunction with, but not in place of, other valid ethical or scientific justifications and arguments for conserving biodiversity (Turner and Daily 2008). Through initiatives like Payments for Ecosystem Services, valuation is crucial in developing markets for the survival of biodiversity and ecosystem services (Pascual et al. 2010). Three main steps are necessary for this market creation process: demonstrating values, appropriating values, and sharing the rewards of conservation (Kontoleon and Pascual 2007). Identification and evaluation of the flow of ecosystem services and their values are referred to as demonstration. Appropriation is the process of obtaining some or all of the ecosystem services' demonstrated and quantified values to provide incentives for their long-term provision. Through market systems, this stage essentially "internalizes" the proven values of ecosystem services such that they have an impact on decisions about how to use biodiversity resources. When markets are "incomplete," internalization is accomplished by making necessary corrections and/or by establishing new markets where none exist. Appropriation mechanisms must be created at the benefit-sharing phase so that the advantages of the captured ecosystem services are distributed to those who are responsible for the expenses of conservation. Throughout this study, the term total economic value (TEV) of ecosystems and biodiversity is utilized. It is described as the total, suitably discounted value of all service flows that natural capital produces now and in the future. These service flows are valued based on slight variations in how they are delivered. TEV includes all elements of utility derived from ecosystem services and uses money or any other market-based unit of measurement that enables comparisons of the advantages of diverse items as the common unit of account. Expressing relative preferences in terms of monetary values may provide useful information to policymakers because people are accustomed to using money as a unit of account in almost every region of the world.

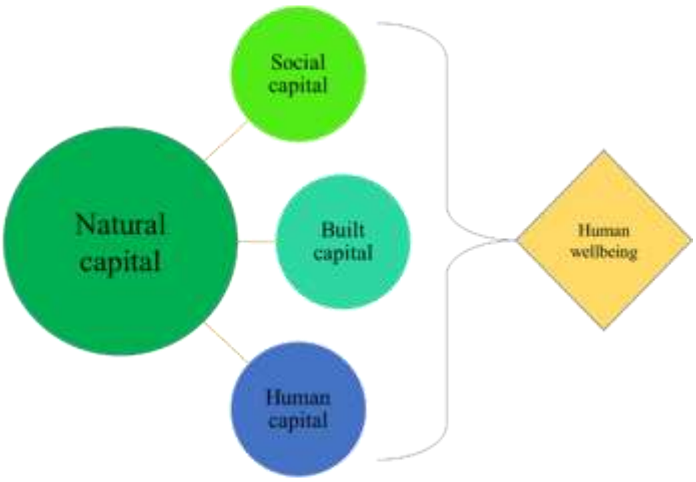


Fig 1.4: Benefits of natural capital, (source: Costanza et al. 2014).

Ecosystem services of Harike Ecosystem Services

One of the wealthiest states in India is Punjab, which is located in the northwest. The name Punjab, which means "region of five rivers," is made up of the two words Punj (Five) and Aab (Water). Sutlej, Beas, Ravi, Chenab, and Jhelum are the five rivers that makeup Punjab. Today's Punjab is only home to the Sutlej, Ravi, and Beas rivers. The other two rivers are currently found in Pakistan's Punjab state. Majha, Doaba, and Malwa are the 3 main areas that make up the Punjab State. Punjab's economy relies primarily on agriculture. Manufacturing of electrical products, financial services, machine tools, textiles, sewing machines, and scientific instruments are some other significant businesses. In Punjab, there are a total of 21 wetlands. 12 of them are natural wetlands, and the other 9 are artificial. The largest wetland in Northern India is the Harike Wetland, which is situated between the Punjabi districts of Tarn Taran Sahib and Ferozepur.

These multilateral wetland ecosystem services provide substantial benefits to society. However wetlands are important for the ecological and economic development of the concerned region despite this various wetlands in India are endangered due to inappropriate approaches (Verma et al. 2001). A few of the country's wetlands, which have a great deal of biological wealth are protected under the wildlife protection Act, whereas others that may not be as biologically rich do not share the same protection, and are easy targets of developers.

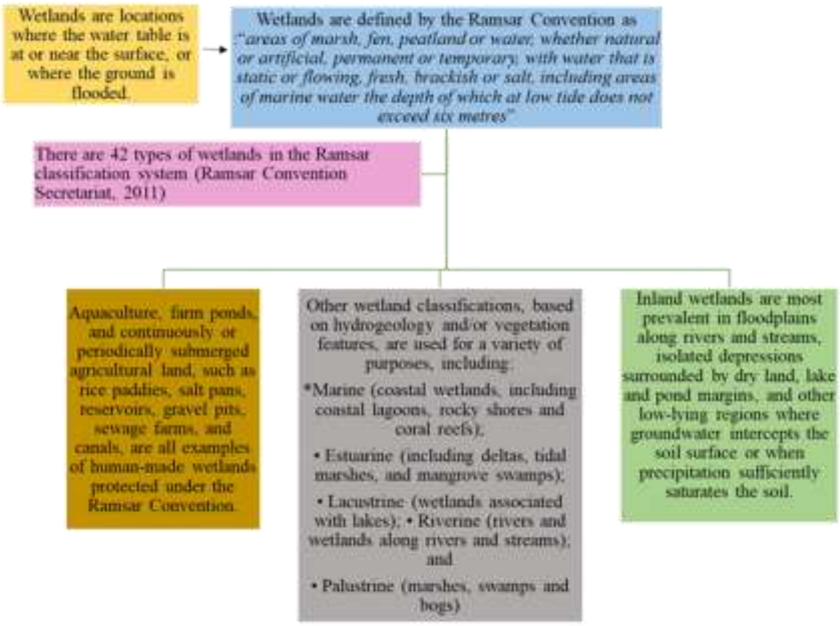


Fig 1.5: Wetland classification under Ramsar, Source: (Russi 2013)

Considered wastelands, wetlands are the obvious choice when land is needed for development. However more often than not these benefits are recognized and undervalued, as they fall outside the domain of the markets. People have well understood the uses of wetlands but not their use values. There have not been many efforts in the past to assign the use value or a price tag to various extractives and non-extractive uses of the wetland such that it can be sustainably managed. The marshy sites and seasonal pools may have small geographic areas but they are of critical importance in providing nurseries for the fish, nesting sites for residential birds, and habitat for migrating waterfowl (Weller 1999; Chatterjee et al. 2020). Wetland dynamics manifest different utilization pattern that leads to anthropogenic pressures. Wetlands are considered to be seriously threatened by climate change. A wetland's biogeochemistry and function might change as a result of altered hydrology and rising temperatures, and certain significant services may even become detrimental. As a result, they won't be able to purify the water as they once did, and they might even start to decay and discharge nutrients into the surface water (Salimi et al. 2021).

Wetlands are among the Earth's most productive ecosystems (Barbier et al. 1997). Wetlands have been described as the kidneys of the landscape (Mitsch et al. 2015), because of the functions they perform in the hydrological and chemical cycles, and as biological supermarkets, because of the extensive food webs and rich biodiversity, they support (Sarkar and Das 2016).

Ramsar Convention on wetlands defines wetlands as: "Areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters"("https://www.ramsar.org/wetland/India," 2019). The Ramsar Classified Wetland Types into 42 types which belong to one of the three broad categories Inland wetlands; Marine/coastal wetlands; Human-made wetlands (Russi et al. 2013)

The features of the wetland system may be grouped into components, functions, and attributes. The components of the system are the biotic and non-biotic features which include the soil, water, plants, and animals (Heimlich et al. 1998). The interactions between the components express themselves as functions, including nutrient cycling and the exchange of water between the surface and the groundwater and the surface and the atmosphere.

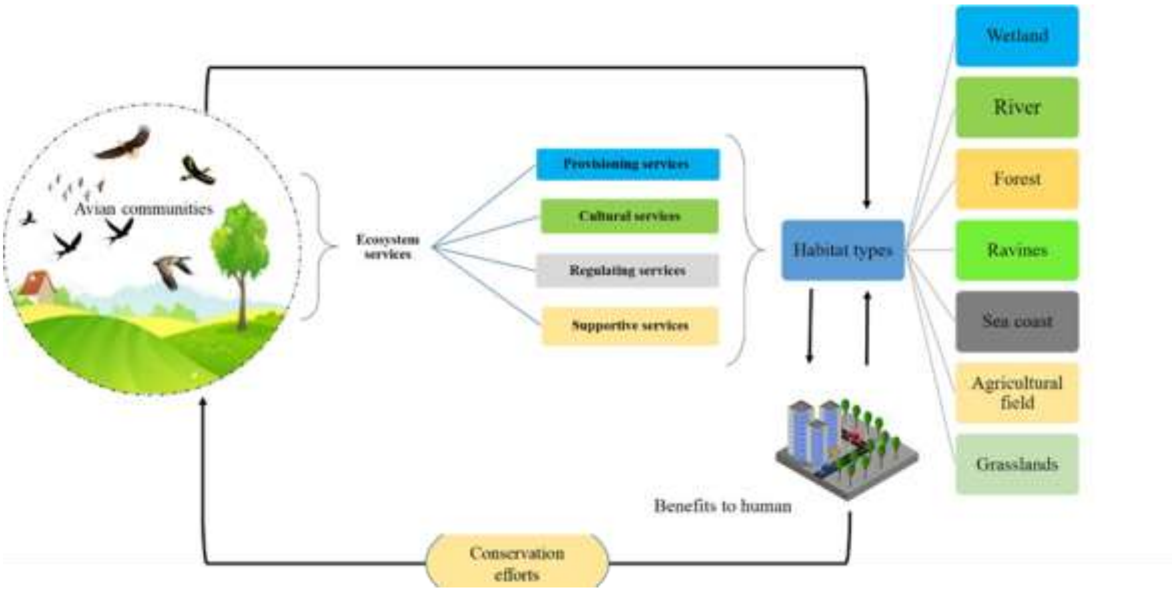


Fig 1.6: Impact of avian communities to regulate ecosystem services.

Wetlands are important in wild areas as well as in urban landscapes. Wetlands maintained a steady supply of water for the city, recharged the groundwater, cooled the city, and prevented flood as they were a natural drainage system (Beura 2017)

The world holds nearly 6% area of its geographical area under wetlands and supports extensive ecosystem services to humankind. Wetlands are transition zone between ecosystems therefore they provide habitats for flora and fauna. In India, nearly 4.7% of its total geographical area accounts for wetlands. India is associated with extensive river systems such as Ganga, Brahmaputra, Sutlej, Narmada and Godavari. These river systems have a plethora of wetlands in their catchment and command areas.

Wetlands provide various kinds of benefits to humans as well as other organisms. In the present scenario, the wetlands are vanishing day by day because of huge biotic pressures. The growing population required more land for different purposes such as settlements, agriculture, industries, roads, etc.

Mitsch et al. 2015 claimed that the 20th century saw most of the destruction of the world's wetlands, which totaled more than half. With data available between 1970 and 2015, the Ramsar Convention Secretariat reported a 35% decline in global wetlands. Around 60% of the world's population resides in coastal areas, where they rely on coastal wetlands for food and other necessities of life. The advantages that humans can enjoy are referred to as ecosystem services. The term "ecosystem service" describes the products and services that certain ecosystems produce for the benefit of people (Guerry 2015). In Punjab, there are three major wetlands namely Harike, Kanjli, and Ropar, which have been recognized as wetlands of International significance (Ramsar sites) (Tiwana et al. 2008). Harike wetland, covering a

4100ha area was included in the list of Ramsar sites in 1990. Subsequently, the Ropar wetland, covering 1365ha area and Kanjli wetland, situated at covering 183ha area was also added to the Ramsar list during 2002. Beas conservation reserve is a new addition to the Ramsar wetland network in the Punjab. These wetlands are important aquatic ecosystems in nature and are critical habitats for waterfowl, fish, and other flora and fauna. Harike wetland located at the confluence of two major rivers Sutlej and Beas is one of the largest wetlands in North India and also an important Bird Sanctuary. The total area of wetlands is 0.46% of the Punjab's geographical area. Where 414 are natural wetlands and 967 are man-made wetlands. The Harike wetland is witnessing high biotic pressure, as per (Hu et al. 2017) wetland's area has reduced by more than 30% over 13 years. Therefore, there is a need to study ecosystem services utilized by local communities. The baseline data and potential intervention for conservation and better utilization of ecosystem services.

The processes of production and consumption not only derive inputs from natural systems but also alter those systems through land-use change and the discharge of waste. Keeping track of how the transformation of ecosystems affects human welfare in both the short and long run is an important accounting activity. Norton (2005) also advocates economic valuation of ecosystem services (which otherwise remain outside the economic decision-making) can contribute positively to the formulation and evaluation of environmental policies in sustainable ways.

Chapter 2

Review of literature

The value of ecosystem services is a growingly significant area of research that aims to place a monetary value on the advantages that humans derive from ecosystems (Barbier et al. 2009). The term "ecosystem services" refers to the numerous ways that ecosystems benefit people, for as by supplying them with food, clean water, purified air, and climate control. The valuation of ecosystem services is crucial because it aids in highlighting their economic value and can influence public and private sector decision-making. Due to the growing awareness of the significance of protecting ecosystems and the benefits they offer to future generations, this field of study has attracted a lot of interest recently. In this situation, the valuation of ecosystem services can aid in ensuring both the sustainability of economic growth and the adequate consideration of environmental effects. The value of ecosystem services, including the approaches taken, the difficulties encountered, and the significance of this field in promoting sustainability, will be briefly discussed in this review.

A clear conceptual framework is necessary for the complicated process of valuing ecological services. The Economics of Ecosystems and Biodiversity (TEEB 2009), the Natural Capital Project (NCP) framework and the Millennium Ecosystem Assessment (MEA) are just a few of the frameworks that have been created to help with the valuing of ecosystem services.

Ecosystem services are the advantages that humans derive from ecosystems, including provisioning services (such as food and water), regulating services (such as climate regulation and water purification), supporting services (such as soil formation and nutrient cycling), and cultural services (such as recreation and aesthetic value). The MEA framework, developed by the United Nations, defines ecosystem services as the advantages that humans derive from ecosystems. The framework also includes factors that can affect ecosystem services and human well-being, such as climate change and changes in land use.

The MEA, 2005 framework is expanded upon in the European Union's TEEB, (2009) framework, which emphasizes the economic value of ecosystem services. The framework emphasizes the necessity of identifying the beneficiaries and those who bear financial responsibility for their preservation, as well as the importance of incorporating the value of ecosystem services into decision-making processes.

The Stanford University-developed NCP framework places a strong emphasis on the necessity of incorporating the valuation of ecosystem services into local planning and decision-making processes. Several tools and models are included in the framework to map and estimate the value of ecosystem services.

These frameworks all aim to promote the valuation and preservation of ecosystem services, notwithstanding their variances. The necessity to incorporate the pricing of ecosystem services into decision-making processes, as well as the difficulty of placing monetary values on non-market ecosystem services, are obstacles to the implementation of these frameworks, as are a lack of data and information about them.

The conceptual framework for the valuing of ecosystem services, in conclusion, is a crucial instrument for encouraging the preservation of ecosystems and the services they offer. To completely include the value of ecosystem services in decision-making processes, there are still issues that need to be resolved. The MEA, (2005) TEEB, (2009) and NCP frameworks offer helpful suggestions for valuing ecosystem services.

Ecosystem services are advantages that come to people from the environment. Clean air and water, a stable climate, the cycling of nutrients, and pollination are just a few of these advantages. Making informed decisions concerning the management and conservation of natural resources requires a thorough understanding of the value of ecosystem services. The many techniques and methodologies for valuing ecosystem services (Barbier et al., 2009; Pascual et al. 2012) are given below.

1. Market-based approaches

   Market-based strategies are predicated on the idea that market exchanges can be used to value ecosystem services. This strategy assumes that an item or service's market price accurately reflects its worth to society. For instance, timber's market price indicates how valuable it is as a resource for building and other purposes. Market-based strategies consist of:

a. Environmental markets: These are marketplaces for ecosystem services where buyers and sellers exchange licenses or credits that permit them to utilize or balance their utility of ecosystem services. For instance, a business might buy carbon offsets to reduce its greenhouse gas emissions.
b. Cost-benefit analysis: A technique for weighing the advantages and disadvantages of a project or policy that is being considered. It entails weighing the project's expenses

against the advantages it will bring about, including the importance of ecosystem services.

2. Non-market based approaches

   Non-market-based approaches are based on the principle that ecosystem services have value even if they are not bought or sold in a market transaction. These approaches include:

a) Stated preference methods: These are ways that elicit people's preferences for ecosystem services through surveys and other means. This data is used to calculate how much individuals think these services are worth.
b) Revealed preference methods: These techniques infer people's preferences for ecosystem services using market data or other sources of knowledge. For instance, the cost that individuals are willing to pay for residences close to the beach can be used to estimate the worth of a beach for recreational purposes.
c) Habitat equivalency analysis: This technique calculates the cost of preserving or establishing habitats that offer ecosystem services. The cost of the creation or restoration and the worth of the ecosystem services offered determine the value.

3. Integrated approaches

   To value ecosystem services, integrated techniques mix market- and non-market-based methodologies. These methods acknowledge that ecosystem services have both market and non-market values and that decision-making must take into account both categories of values. Integrated strategies consist of the following:

a) Ecological production function: Using the physical processes that provide ecosystem services as a basis, this method calculates the value of ecosystem services. For instance, the ability of wetlands to purify water can be used to determine the value of water purification services.
b) Multicriteria analysis: This approach assesses the advantages and disadvantages of a given project or program using a variety of factors. Market and non-market values of ecosystem services may be included in the criterion. Making educated judgments about the management and conservation of natural resources depends on the assessment of ecosystem services. A variety of instruments are available for valuing ecosystem services thanks to the methods and ideologies covered in this piece of writing. The strategy selected will rely on the particular context and the information at hand. The

most thorough and precise estimations of the value of ecosystem services are likely to come from integrated approaches that blend market- and non-market-based methods.

According to MA (2005) and TEEB (2009), provisioning services are the ecosystem's physical, transferable, and priced energy outputs. The Timber and Non-Timber Forest Products (NTFP) such as fruits, medicinal plants, fodder, and fuel wood, which are typically valued, are the provisional services. The fundamental reason is that their marketability and the ease with which use and non-use values may be determined. The NTFP's actual pricing has never been represented in the market because of informal marketing methods, but their tight ties to the neighborhood poor who live in the forest are what makes them noteworthy.

Although the importance of wetlands for fish and wildlife conservation has been recognized for over a century, some of the other benefits have only lately been discovered. Because they operate as downstream recipients of water and waste from both natural and human sources, wetlands are sometimes referred to as the landscape's kidneys. They prevent both floods and droughts by stabilizing the water supply. They have been discovered to purify polluted streams, defend shorelines, and replenish groundwater aquifers. Because of the extensive food chain and diverse biodiversity that they support, wetlands have been dubbed "nature's supermarkets." They are important in the landscape because they provide unique habitats for a diverse range of flora and fauna (Mitsch 2015).

Wetlands are still regarded as the most beneficial features of our landscape in ecosystem service assessments (Mitsch and Gosselink 2000; De Groot et al. 2012; McInnes 2013; Costanza et al. 2014). Costanza et al. (1997) used ecological unit estimators to demonstrate how much more valuable wetlands are than lakes, rivers, forests, and grasslands, especially inland wetlands, and mudflats. Only estuaries along the coast had unit values higher than freshwater and marine wetlands. Costanza et al. (2014) reassessed the 1997 paper's computations, using updated unit values from De Groot et al. (2012).

Provisional ecosystem services

Many intangible benefits of forests, such as controlling local and global temperatures, protecting watersheds, preventing soil erosion, and nutrient cycling, are overlooked by policymakers because these benefits are not recognized by traditional markets or are difficult to quantify. Historically, the utilization of biodiversity and ecosystems, as well as their intrinsic value, have been utilized to support conservation. The significance of ecosystem services for human well-being and sustainable development was a fresh perspective that the Millennium Ecosystem Assessment (2005) added. Ninan and Inoue (2014) had reviewed the valuation of ecosystem services. In a research Costanza et al. (1997) estimated the annual average value of all ecosystem services upto US $33 trillion and the value of all forests at US $969 per hectare. White et al. 2011 estimated the total economic value of Japan's forest ecosystem services around US $620 billion annually. Uddin et al. (2013) estimated the economic value of major provisioning services in the 6000 km^2 Sundarbans Reserve Forest in Bangladesh, home to the largest mangroves in the world, which offers a range of ecological services. In the economic valuation provisioning ecosystem services, they included timber, fuel wood, fish, thatching materials, honey, and waxes. The average estimated value of provisioning services in Sundarbans was US $ 744,000 and US $ 42,000 per year respectively during the financial year 2001–2002 to 2009–2010. Both directly and indirectly, the economy can gain from forest ecosystem services. To calculate the annual economic value of some ecosystem services provided by terrestrial ecosystems in the Qinba Mountains of China's Shaanxi Province, Li and Zhou (2006) used simulation models and a geographic information system. The total economic value of terrestrial ecosystem services in the Qinba mountains was estimated to be 968.33 billion renminbi per year, as well as a geographic information system to analyze the impact of ecological factors on ecosystem functions. Provisioning ecosystem services such as fuel wood is a very common good that is collected by local people. The effects of invasive species on ecosystem services have garnered attention on a global scale. The link between invasions and ecosystem services is rarely openly addressed by researchers and policymakers, despite the substantial evidence of these effects and a growing respect for ecosystem services. Numerous initiatives have been made to address how invasive species affect ecosystem processes (Levine et al. 2003; Dukes and Mooney 2004). Mensah et al. (2017) examined the significance and utilization of ecosystem services and questioned 86 householders in four villages in the South African province of Limpopo. The data also showed that employed households benefited from these services more than unemployed households. The use of providing Ecosystem services was not significantly impacted by wealth, indicating that the collection is likely intended for home consumption.

Cultural ecosystem services

Over the past ten years or more, there has been an increase in the number of research publications and studies devoted to the complicated and wide-ranging topic of ecosystem services research. The significance of cultural ecosystem services to landscapes has, however, received very little attention from researchers. The consequences for the development of rural landscape are examined in a study conducted by Csurgó and Smith (2021), they did in-depth interviews with a variety of local stakeholders to examine the importance of cultural ecosystem services in two rural landscapes in Hungary. The study examines the relative worth of various Cultural Ecosystem Services (CES) categories, concentrating primarily on social, symbolic, and economic qualities. The results highlight the crucial role that cultural heritage plays concerning other CES categories, particularly in terms of its social and symbolic significance. Additionally, it evaluates the CES categories' relative worth and how they relate to one another. Few studies have examined all CES categories and compared their relative values, even though Gould et al. (2014) research demonstrated that CES values are intricately linked. Previous research has tended to concentrate on particular CES categories as opposed to the entire spectrum (Tratalos et al. 2016). However, the majority of this research only looks at one or two CES categories and one type of landscape (e.g. Schirpke et al. 2016; Zoderer et al. 2016). The CES questionnaire created by Smith and Ram (2016), which was given out in six different types of landscapes and looked at all CES dimensions, is one exception. Using mapping and surveying methods, Zhou et al. (2020) measured all CES aspects in the setting of wetlands. The data presented in the current publication, however, is qualitative, which may better reflect the ephemeral character of CES values. After reviewing 130 articles on ecosystem services, Hlleland et al. (2017) found that just 2% of the articles were about cultural heritage and 75% were about the environment and ecology. The authors discovered that 70% of the articles used the phrase "various tangible and intangible benefits derived from the ecosystem, mostly defined as landscape" to describe cultural heritage. Additionally, they point out that the rare CES studies that address cultural heritage frequently concentrate on social and intangible aspects rather than architectural or material legacy.

A CES approach, according to Musacchio (2013) and Plieninger et al. (2015), identifies social values that stakeholders attach to landscapes that may not be represented in other ways. Numerous types of value (such as financial, environmental, social and cultural, sentimental, symbolic, and collective) could be identified or measured; however, it is obvious in a CES context that there is a need to go beyond 'use value' and to analyze social appraisal from various stakeholder perspectives. It's crucial to keep in mind that politics, resource governance, and potentially unequal power relations can all have an impact on how much CES is valued (Hirons et al. 2016).

There is a lot of discussion surrounding the concept of ES (Daily 1997; Fisher et al. 2009; Nahlik et al. 2012), which has brought attention to the semantic muddiness surrounding terminology like "services," "goods," and "benefits," which affects where CES sits inside ES. The Millennium Ecosystem Assessment (MA), which sought to create the scientific basis for the conservation and long-term utilization of ecosystems and identify their benefits to human well-being, provided a commonly used definition of ES (MEA, 2005).

Regulatory ecosystem services

The regulating services offered by the forest ecosystem are those that are difficult to assess since they are nonmarketable. There is frequently no accounting for these non-marketable services in the GDP contribution. Numerous valuation techniques are applied to get around these. The Damage Avoided Method, Replacement Cost Method, Contingent Valuation Method, and Choice Experiment Method are a few of them. The ecosystem's regulatory functions include controlling air quality, regulating climate change, preventing disturbances, storing carbon, preventing soil erosion, controlling water quality, pollinating plants, and treating waste. By reducing soil erosion, sedimentation, and pollution, forests can maintain soil fertility. Soil is connected to other ESs such as nutrient cycling, biomass production, water quality, climate regulation, and pollination because of its ability to buffer, filter, and convert. The cost of using an alternative way to replace this forest soil is high. When compared to ground soil, top soils are found to contain three times as many nutrients (Young 1989; Pimental 2006; Ninan 2014). As a consequence, maintaining forests is thought to be economical. Based on the amount of fertilizer that must be used to replace the nutrients that have been lost, the value of the soil erosion prevention function of pasture and agricultural land in Turkey was examined. Hacisalihoglu et al. (2010) reported that pastureland suffers a yearly economic loss of $59.54 and agricultural land suffers a yearly loss of $102.36 owing to soil erosion. A similar research was done in Gujarat's forest soil using the replacement cost method. Based on an analysis of market prices, the nutritional value was determined to be Rs. 13,233/ha. The revised universal soil loss equation is now frequently used to estimate the rate of soil erosion loss in watersheds, which is linked to anthropogenic activities and changes in land use (Kiran and Kaur 2011). Many studies have successfully combined the RUSLE model and GIS to produce more trustworthy results (Farhan et al. 2013; Gelagay and Minale 2016; Ganasri and Ramesh 2016). Wang et al. (2017) suggested that ecological restoration can aid in reducing environmental harm brought on by humans and re-establishing ecosystem services. The enhancement of ecosystem services examined using remote sensing and modeling approaches in the relevant study is crucial for the ecological viability of the Yangtze River basin. They found that switching non-irrigated agriculture to forest might result in a 24.89 percent boost in soil conservation.

Supporting ecosystem services

Ecosystems are complex networks of living organisms and their surrounding environments, providing a wide range of valuable services to support life on Earth. These services, often categorized as provisioning, regulating, cultural, and supporting services, are crucial for human well-being and the overall functioning of our planet. It is to highlight the importance of supporting services in ecosystems, referencing key studies and research that shed light on their significance and role in sustaining our environment.

1. Soil Formation and Nutrient Cycling:

   One of the fundamental supporting services provided by ecosystems is soil formation and nutrient cycling. Soil acts as a medium for plant growth and serves as a reservoir for water, nutrients, and organic matter. The research conducted by Lal (2020) emphasizes the importance of healthy soils in sustaining agricultural productivity and mitigating climate change through carbon sequestration.

2. Biodiversity Maintenance:

   Biodiversity, the variety of life forms within ecosystems, plays a crucial role in maintaining ecological balance and stability. Research by Cardinale et al. (2012) highlights the positive relationship between biodiversity and ecosystem functioning. The study emphasizes that diverse ecosystems tend to exhibit higher resilience to disturbances and are better able to provide supporting services such as pollination, pest control, and water purification.

3. Habitat Provision:

   Ecosystems provide habitats for a vast array of species, contributing to their survival and overall biodiversity. A study by Birgé (2016) reveals the critical role of natural habitats, such as forests and wetlands, in supporting migratory bird populations. Protecting and restoring these habitats is essential for ensuring the continuity of supporting services associated with wildlife conservation.

4. Water Filtration and Purification:

   The purification of water through natural processes is a vital supporting service provided by ecosystems. Wetlands, for instance, act as natural filters by trapping pollutants and removing excess nutrients from water. Mitsch and Gosselink (2015) underline the importance of wetland ecosystems in maintaining water quality and reducing the risk of harmful algal blooms. This research highlights the significance of preserving wetlands for water purification purposes.

5. Climate Regulation: Ecosystems play a crucial role in climate regulation through various processes such as carbon sequestration and temperature moderation. Forests, for example, act as carbon sinks, absorbing carbon dioxide from the atmosphere and mitigating climate change. The study by Pan et al. (2011) emphasizes the substantial carbon sequestration potential of intact forests and the importance of halting deforestation to maintain this supporting service.
6. Genetic Resources: Ecosystems harbor an immense diversity of genetic resources, which have significant implications for agriculture, medicine, and biotechnology. The research conducted by Rani et al. (2016) explores the medicinal potential of plants and highlights the importance of conserving biodiversity-rich ecosystems to ensure a continuous supply of genetic resources for drug discovery and development.

Supporting services provided by ecosystems are vital for maintaining the integrity and functionality of our planet. Supporting services such as soil formation, biodiversity maintenance, habitat provision, water filtration, climate regulation, and genetic resources. Recognizing the value of these services is essential for effective ecosystem management and the preservation of our natural environment for future generations.

Seasonal change in vegetation and ecosystem services

The interactions between an ecosystem's physical and biotic components, as well as their rates and variability through time and space, determine an ecosystem's capacity to deliver services (Kremen 2005). The advantages that humans derive from ecosystems also depend on the demographic, economic, political, cultural, scientific, and technical traits of the human groups that engage in ecosystem interactions (MA 2003; Castillo et al. 2005). Options regarding how to manage ecosystems are therefore driven by the services that human groups need, extract, or expect from them (MA 2003; Bennett and Balvanera 2007).

Given the close connection between the provision of ecosystem services and human well-being, it is crucial to maintain ecosystems' capacity to provide services over the long term to assure a bright future for humanity. To maintain the services necessary to promote human well-being, technological and social interventions must be planned (MA 2003).

Ecosystem services of avian species

When assessing the ecological health of a particular habitat, avian assemblage parameters like species richness, abundance, density, and diversity are frequently used as indicators. Over a wide geographic area, the species composition and population abundance of the avifauna vary from one landscape to another (Karr and Roth 1971; Nagarajan and Thiyagesan 1996; Richardson and Miller 1997; Hossain and Aditya 2016). The evenness of species has been reported to change with the complexity of habitats, species richness, and species diversity (Sogah 2012). When compared to less complex habitats, complex landscapes frequently offer more resources for birds, supporting a greater variety of species and feeding guilds (Luck and Daily 2003; Codesido et al. 2015). Heikkinen et al. (2004) studied the trends in bird population abundance concerning environmental elements in a mosaic of Finnish farmland and forest. The impacts of grazing intensity on bird abundance in Hungary's grasslands were investigated by Baldi et al. (2005). Florida's organic and conventional farms' avifaunal diversity and abundance were compared by Jones et al. (2005). Haslem and Bennett (2008) assessed how landscape form affected the variety of bird species in the agro-ecosystem in southeast Australia. At various stages of the paddy crop in Kendujhar District, Odisha, species richness and relative abundance of the avifauna were documented by Reddy et al. (2013). McKenzie and Whittingham (2009) evaluated the number and diversity of the avifauna on farms that were maintained organically and conventionally. According to Doxa et al. (2010), France's rich avifaunal abundances are favored by low-intensity agriculture. In a terrain where agriculture is the primary industry in north-eastern Austria, Lukasch et al. (2011) investigated the effects of land-use changes on farmland bird abundance. Due to the increase in migrating birds in Maharashtra's Osmanabad District throughout the winter, Narwade and Fartade (2011) found that the avifauna's species richness was highest. The relationship between bird diversity and varied landscape structures was evaluated by Bensizerara et al. (2013). Abdar (2014) noted the diversity and richness of species in the Maharashtra Western Ghats' agricultural settings. In agricultural landscapes of central Chile, Munoz-Saez et al. (2017) found that the winter period had a comparatively higher species richness. Wilson et al. (2017) investigated the relationship between avifaunal diversity and geographical variability in North American agricultural settings. In agricultural fields in Central Gujarat, Borad and Parasharya (2018) assessed numerous diversity indicators at various phonological stages of the wheat crop. In contrast to crop diversity, Redlich et al. (2018) found that mosaic landscape patterns encourage increased avifauna variety in agro-ecosystems. The year-round availability of avifauna's essential needs—food, water, and shelter—varies depending on the season (Mukhopadhyay and Mazumdar 2017; Sohil and Sharma 2020). To shape the community structure, diversity, and population abundance of birds in a given location, seasonality is therefore important (Kumar et al. 2016; Li et al. 2019) According to Sinha and Chatterjee (1998), the abiotic and biotic components of the wetland ecosystem influence the annual changes in waterfowl populations that live in different wetland habitats. The spatiotemporal distribution and relative abundance of the avifauna in a given environment are largely dependent on the quality and amount of food available (Mukhopadhyay and Mazumdar 2017). A foraging guild is a collection of organisms that utilizes comparable food sources in an area. The relevance of food abundance too, and use of it by, avifauna in structuring the feeding guilds of bird assemblages was documented by Sohil and Sharma 2020.

Governments worldwide are considering using ecosystem services in public policy to advance sustainability goals. As of 2013, 68 countries worked on ecosystem services with activities ranging from convening task forces to implementing new policies (Waage and Kester 2014). Mexico and the United Kingdom (UK) conducted national assessments (Sarukh et al. 2010; United Kingdom National Ecosystem Assessment (UK NEA) 2011), and the European Union (EU) asked Member States to map and assess ecosystem services for accounting systems (European Commission (EC) 2011). China is implementing national policies on ecosystem services, and the United States (US) formally incorporated ecosystem services in a new national forest planning rule (United States Department of Agriculture Forest Service (USDA FS) 2012). Vietnam, Brazil, Costa Rica, Columbia, and Peru are creating payment for ecosystem services (PES) programs at municipal and state levels (Waage and Kester 2014). Recent government activities have created a demand for standardized practices to measure, value and map ecosystem services (Haines-Young and Potschin 2009; Maes et al. 2012; Landers and Nahlik 2013; Leu et al. 2013; Waage and Kester 2014).

Chapter 3

Study area and objectives

Harike Wildlife Sanctuary, in Punjab, is a man-made reservoir at the confluence of the rivers Beas and Sutlej, covering an area of around 86 square kilometers. When a barrage was built over the Beas and Sutlej rivers in 1952, Harike Reservoir was created. It is a man-made wetland that was built to provide water security to the inhabitants of Punjab and neighboring regions. The area lies between 31º05’15” N and 31º14’15” North latitudes and 74º-55’30’’and 75º-07’30’’ East longitudes and falls in three districts of Punjab namely Ferozepur, Tarn Taran, and Kapurthala. The sanctuary is governed by the Punjab Department of Forests and Wildlife Preservation and is protected under the Wildlife (Protection) Act, 1972, as amended by the Wildlife (Protection) Amendment Act, 2002. Harike Wildlife Sanctuary was classified as a Ramsar Site (Wetland of International Importance) in 1990, greatly enhancing its importance. Despite the fact that Harike is primarily a bird sanctuary with a population dominated by aquatic birds, the presence of trees, woods, and woodland is critical to the wetland ecology. The current crop is primarily restricted to the outskirts of the bundhs. Except for a few isolated and scattered trees, there are some trees on the many islands. Agriculture has encroached over most flat areas in Ferozepur and Kapurthala districts on the eastern side. The encroached land must be regained by tree planting; tree species that grow quickly should be chosen for planting.

Even though Harike is a marsh area with a total area of 86 square kilometers, about 45 square kilometers are dry land. The majority of this dry land is found on the outskirts, in the form of rich floodplains, flood protection embankments, and numerous marshy islands of all forms and sizes (HMP 2020-30). The flood plains in the peripheral areas, particularly in the eastern half of Ferozepur and Kapurthala districts, are extremely fertile and heavily encroached and cultivated. The soil is extensively eroded and in the form of ravines on the western side of the Sanctuary, which falls in the Taran Taran district, particularly in the villages of Kirian, Marar, Chamba and Kambo. Check dams and other mechanical structures have been built as part of the Department of Soil Conservation's coordinated efforts to control erosion. These initiatives, however, must be continued and given more impetus.

On the western and southern limits, there are large trees, however, the northern and northeast boundaries are devoid of trees. To maintain boundaries and biodiversity, a biological fence with native vegetation is required, and this method will be effective in preventing unlawful expansion in the sanctuary. The flood protection embankments are frequently found along the boundary and serve a variety of purposes, including serving as physical barriers, approach roads, and perfect habitats for animals such as partridges, pheasants, and lapwings. On the Left are an inspection/approach road, a trekking path, and a bird-watching location.

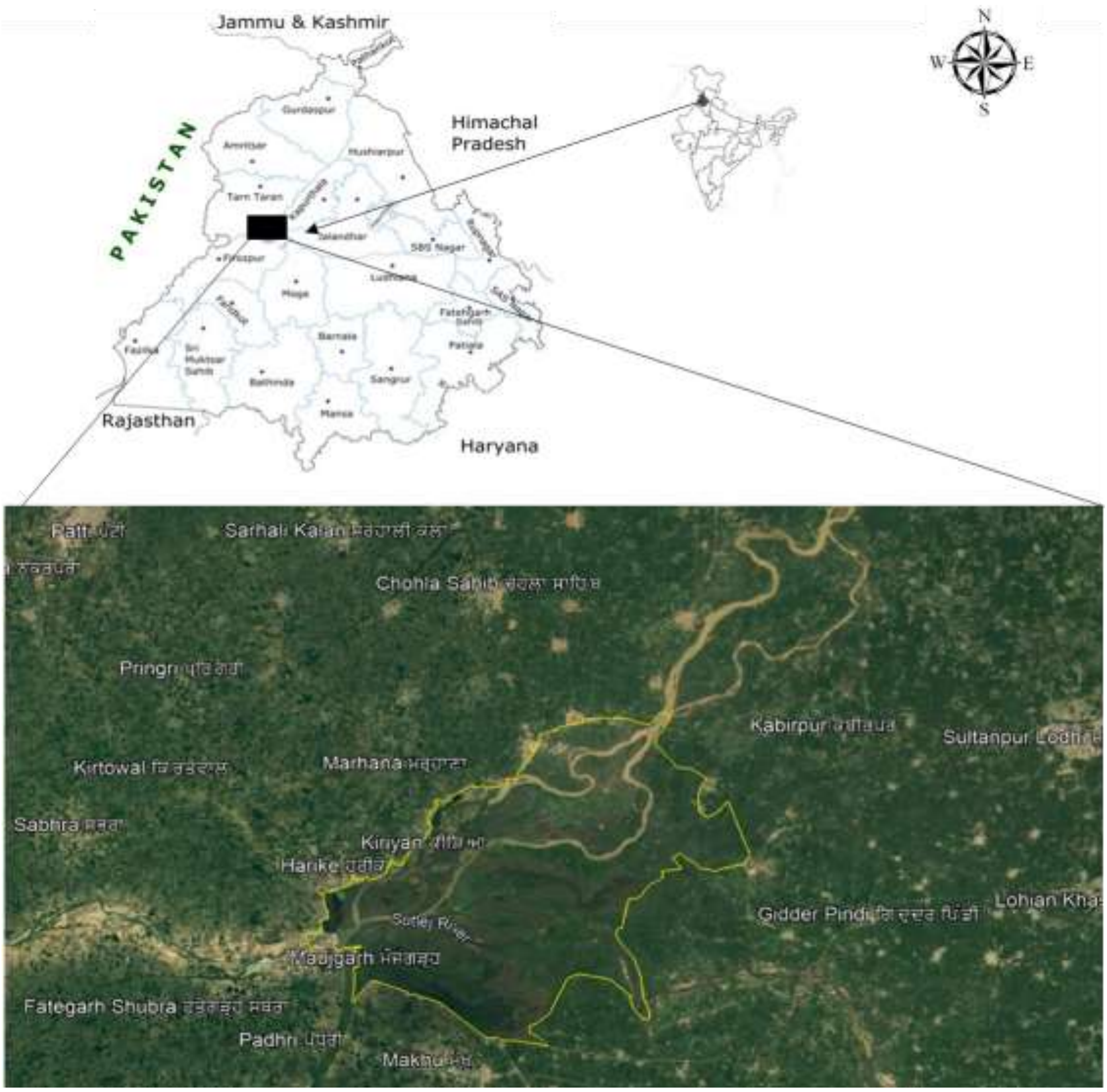


Fig 3.1: Satellite image of the study area.

The LMB (left marginal bund) in particular is thickly wooded with the presence of old trees of Indian rosewood (*Dalbergia sissoo*), Babool (*Vachellia nilotica*), Jamun (*Syzygium cumini*), Horse tamarind (*Leucaena leucocephala*), Algaroba (*Prosopis juliflora*), Peepal (*Ficus religiosa*), Indian Elm (*Holoptelea integrifolia*), Pongame Oil Tree (*Pongamia pinnata*), and Jerusalem thorn (*Parkinsonia aculeata*) etc. There are also 4-5 year old plantations of Arjun (*Terminalia arjuna*), Willow tree (*Salix alba*), Siris (*Albizia lebbeck*) and Subabul (*Leucaena leucocephala*). However, most of the other embankments are not enough populated with trees.

These embankments are under plantation of suitable species to not only augment the habitat, but also to conserve the soil and water regime and to deter encroachments and cultivation by encroachers.The islands are a perfect place for birds, with almost no trees and an abundance of tall grasses and reeds. Wild boars (*Sus scrofa*) can be spotted sunbathing in the winter season, while jackals can be observed in the early mornings or late evenings on these islands.

The area was first declared a Sanctuary by the Government of Punjab in 1976 via gazette notification No. 4223- Ft-III-76/35745 dated 19th October 1976. which declared an area of approximately 148 Km Sq. as a Wildlife Sanctuary for ten years under section 18 (I) of the Wildlife (Protection) Act, 1972, prohibiting the killing, capturing, shooting, and hunting of all kinds of wild birds and wild animals. The sanctuary was further notified in 1978 vide gazette notification of Punjab Government No. 4716-FT- III 78/ 4324 dated 15th March 1978. In 1982, the sanctuary was again notified for 10 years under section 18 (I) of the Wildlife (Protection) Act, 1972 vide Gazette notification of Punjab Government No. 34 (4) FT –III- 82/11677 dated 26th August 1982, However, this time the "notified" area of the sanctuary has been reduced to 41. Sq Km. approximately. By gazette notification No 34 (81) 92-1-T-IV/10818 Chandigarh, the notification under section 18 (I) of the Wildlife (Protection) Act, 1972 was extended for another ten years in 1992. However, because the area downstream from the barrage is the sole place where turtles spawn and waders use the area near the Left Marginal Bund and Rajasthan Canal, it was determined to include this valuable habitat in the revised notification. As a result, the "notified" area was enlarged from 41 to 86 square kilometers.

In 1999, the land was officially designated as a Sanctuary under section 26-A of the Wildlife (Protection) Act, 1972, with notice No. 34/7/99-F.t-IV/16393 dated November 18, 1999. The sanctuary covers an area of 86 square kilometers. It should also be noted that, in recognition of the area's value as a wetland of international significance, the United Nations Wetlands International designated the area as a Ramsar site in 1990, which is a rare and unique status.

In many regions, the sanctuary's perimeter is not clearly defined. This is primarily due to the unfriendly and inaccessible nature of the marshy and waterlogged environment. Furthermore, the presence of encroachments and squatters has made demarcating and delineating the boundary problematic. The Sanctuary is surrounded by the natural limits listed below.

NORTH: River Beas Bundh area terminated Village Kirian, Kambo Dhaiwala, Chamba Kalan, Marar and Harike (district Amritsar), Marsh and River area (Government land) of Village Kirian, Kambo Dhaiwala, Chamba Kalan, Marar, and Harike.

SOUTH: Left Bundh of Rajasthan canal (excluding Gurdwara Nanaksar, Harike Ishar Dham having an area of 104 Kanal 16 Marla) terminating at Bengaliwala Bridge and left bank of drain touching Village Mauzgarh (Ferozepur), Government land of Village Rasulpur and Bhottiwala in the north of bund (district Ferozepur).

EAST: Government land of Village Jagjitpur, Khara, Mand Fatehpur, Nikki, Mand Kambo, Mand Kirian, Pipal, Singh-Ke-Kalan (district Kapurthala), and Kot Khaim Khan (district Ferozepur).

WEST: Harike-Makhu Road (Government land) of downstream Harike (district Amritsar), Government land of Village Talwandi Nepalan (district Ferozepur), Harike Head Works, River Sutlej downstream running water up to boundary touching Village Talwandi Nepalan.

Fig 3.2: Regular supply of water in the Indira Gandhi Canal from Harike wetland.

Geology

The geological formation of Harike Wetland mainly consists of alluvial deposits. The Beas and Sutlej rivers bring sediment from the Himalayas and deposit it in the wetland, leading to the formation of fertile soils. Three chronostratigraphic units make up the state's Quaternary alluvium: (i) Older alluvium, (ii) Newer alluvium, and (iii) Aeolian deposit. The depositional processes of the pre-existing palaeo-drainage from the Middle to Late Pleistocene period resulted in the formation of the older alluvium, which is composed of an admixture of subrounded to subangular unsorted pebble, gravel, and cobble beds as well as reddish clay, silt, and sand with gravels. The Holocene/Recent period's modern streams, which make up the newer alluvium, are what formed it. With an alluvium interband of purple and red clay, it is primarily made up of blue to white-grey micaceous sand. Except for the places where the siwalik supergroup's hard rocks are present, the aeolian deposits are dispersed throughout Punjab.

Temperature

During April, may, and June, the wetland experiences high heat. In June, the average daily maximum temperature reaches 43°c, while the average daily minimum temperature drops to 0.60°c in January. The winter season lasts from mid-november until mid-march. The coldest month is January, with average daily minimum temperatures as low as 0.60°c and temperatures occasionally plunging below the freezing point of water.

Particular	Winter	Summer	Monsoon	Post-monsoon
	Mean	Mean	Mean	Mean
Temperature (°c)	15.37±4.27	30.4±3.25	28.9±1.1	19±5.55
Min. Temperature (°c)	9.13±3.56	22.8±4	24.94±1.45	12.73±5.3
Max Temperature (°c)	21.83±4.64	37.37±2.59	33.1±0.78	25.87±5.45

Table 3.1: Seasonal variation in the temperature in the study area.

Rainfall

The region has a dry climate throughout the year, with monsoon showers accounting for roughly 70% of the yearly rainfall. The months of July, August, and September are typically wet, while the remaining months of the year are more or less dry. During the winter months of December to February, just a small amount of rain falls. During the summer months of April, May, and June, there are a few showers. The first week of July marks the start of the southwestern monsoon, which lasts until mid-September.

Particular	Summer	Monsoon	Post-monsoon	Winter
	Mean	Mean	Mean	Mean
Rainfall (mm)	54.67±14.74	46± 30.81	146.33±70.32	15±3.61
Humidity (%)	67.67±7.77	37.33±6.51	0.76±0.04	0.61±0.05
Rainy days (d)	4±1	5.67±2.08	12.33±4.62	1.67±0.58
avg. Sun hours	8.87±1.5	11.93±0.40	10.07±0.21	9.17±0.95

Table 3.2: Rainfall pattern across the seasons in the study area.

During May and June hot and dry westerly winds locally called “LOO” are quite common. Dust storms also occur during these months. These are responsible for creating dry conditions.

The strong winds followed by the rain during summer are responsible for the uprooting of trees and the breaking of big branches of large size old trees. During winter the cold spell carried by northerly winds is responsible for the retarded growth of plants. Frost is extremely common in the winter. The frost is intense wherever there is a protracted dry spell. It does a lot of damage to early seedlings. Every year, from November through February, frost can be seen. In late December and early January, visibility drops by ten meters.

Water Quality

One of the most important variables that directly affect the health of humans and aquatic organisms is the quality of surface water. The hazardous components contained in the water may be linked to the state's greater incidence of cancer and other health consequences (Mathur et al. 2005). Pollution of aquatic systems can come from a variety of places.

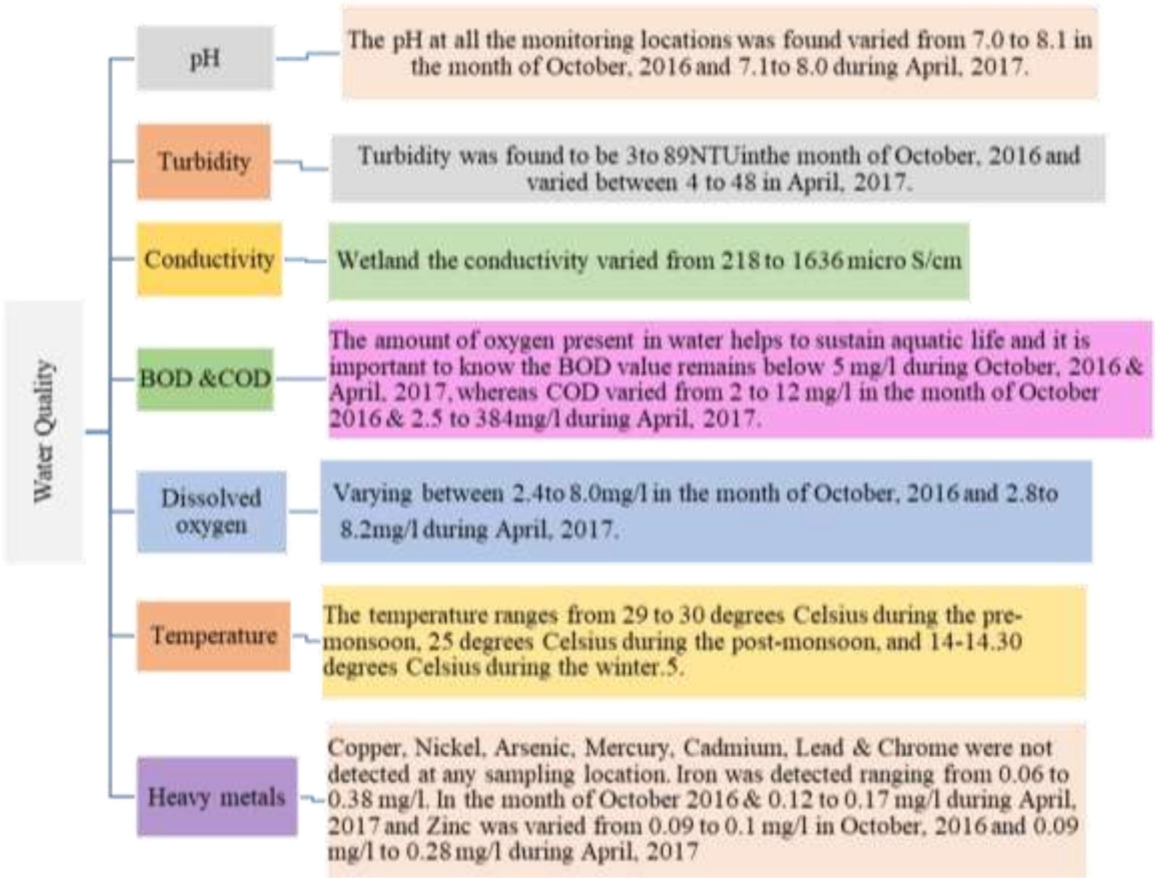


Fig3.3: Water parameters recorded at HWS (HMP, 2022)

Wetlands are one of the world's most endangered ecosystems. Even low-level pollution of these ecosystems can have negative consequences for the environment (Hildebrandt et al. 2008). Kaur et al. (2015) suggest that Harike wetlands are flanked by agricultural fields where wheat, rice, and other seasonal crops are grown. The wetland has long been threatened by a developing economy that places increasing demands on its resources (Chopra et al. 2001; Jain et al. 2008). As a result, health issues have arisen in several districts of southern Punjab and Rajasthan. Pollution has a significant impact on the plants and animals that live in the wetland

The excessive growth of water hyacinth is caused by high levels of organic pollutants (BOD and COD) and nutrients (NO3, SO4, and P). The river Satluj also brought in the most harmful components into the wetland, according to heavy metal studies. According to Kaur et al. (2015), higher levels of pollution, as well as the highest number and concentrations of heavy metals, cause considerable mutagenicity and genotoxicity. Mutagenicity, genotoxicity, physicochemical, and heavy metal analytical results indicate that the water in the Harike wetland is contaminated with many types of organic pollutants and toxic chemicals that may be causing the mutations and DNA damage.

Fauna

Harike Wildlife Sanctuary is also known as a bird sanctuary since it draws thousands of migratory birds in addition to many resident species. Many resident bird species, including some endangered species like the Oriental darter, are nesting in the sanctuary (*Anhinga melanogaster*). The varied ecosystem supports a rich range of fauna, including highly endangered species like the Indus River dolphin (*Platanista gangetica minor*) and Gharial (*Gavialis gangeticus*). Mammals including the Sambar deer (*Rusa unicolor*), Golden jackal (*Canis aureus*), Indian porcupine (*Hystrix indica*), and wild boar use the woods for hiding, foraging, and reproduction all year (*Sus scrofa*). The current state of knowledge on the occurrence and status of animals, particularly fish, is significant from a management standpoint.

Fig 3.4: Fauna of Harike wildlife sanctuary (1: Golden jackal, 2: Smooth-coated otter, 3: Sambar, 4: Monitor lizards, 5: Checkered keelback)

Avian Species

Harike Wetland is a birdwatcher's and bird lover's dream come true. This is due to the wetland's ability to provide a range of habitats for various bird species throughout the year. During the monsoon season, the islands within the wetlands are prone to flooding and then drying out. As a result, they become thick and sparsely vegetated, providing great habitat for a variety of bird species. They also provide a haven for nest building and breeding.

Every year, the Department Of Forest And Wildlife Preservation conducts a bird census in Harike Wildlife Sanctuary with the assistance of field staff, technical experts from WWF, and expert members from various organizations such as BNHS, Chandigarh Bird Club, Amritsar Bird Club, Avian Habitat and Wetland Conservation Society, Chandigarh, Ludhiana Bird Club, Faridkot Bird Club, Jagriti Samiti, Nangal, and independent birders/naturalists from all over the country. In partnership with wildlife professionals, the WWF team conducts reconnaissance surveys, member orientation, data gathering, compilation, and technical reporting. The census is carried out with the help of WWF workers and with the permission of the Punjab Chief Wildlife Warden's office. Harike wildlife sanctuary also provides habitat to near-threatened species of birds like the Oriental darter (*Anhinga melanogaster*), Painted stork *(Mycteria leucocephala),* Asian Openbill *(Anastomus oscitans),* White-backed vulture *(Gyps bengalensis),* and Longbilled vulture *(Gyps indicus)* besides some Vulnerable species like Pallas's fish eagle (*Haliaeetus leucoryphus),* Greater spotted eagle *(Clanga clanga*, and Indian skimmer *(Rynchops albicollis),* in addition to this Near Threatened species such as Ferruginous pochard (*Aythya nyroca*) can be seen in the wetland during winter. Black-bellied tern (*Sterna acuticauda*) which is a winter migrant and an endangered species is also found alone in shallow wetlands **(**HMP, 2021).

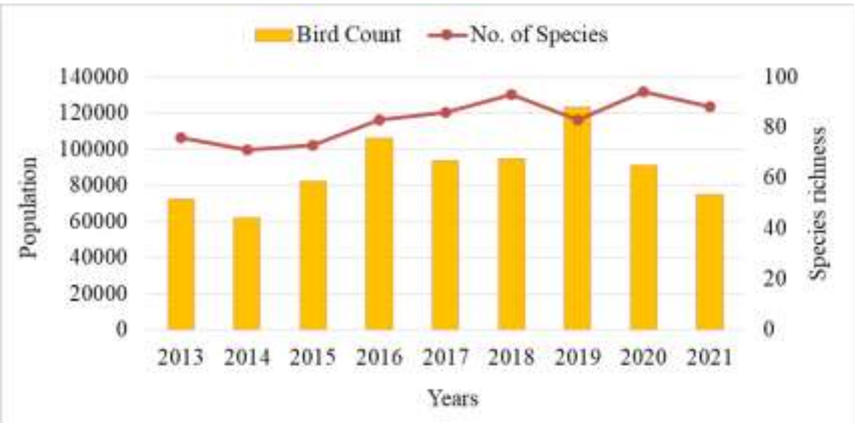


Fig 3.5: A trend of species richness and population of water birds at HWS (HMP, 2021).

Floral diversity

The Swampy environment dominates the sanctuary's flora. But both aquatic and terrestrial plants, including plankton, are vital to the ecosystem and have crucial roles to play. Since maintaining biodiversity depends on the species makeup of the vegetation, constant vegetation monitoring is required. The unique habitats of terrestrial animals and birds help to maintain a healthy environment. For habitats to be viable, floral diversity must be available.

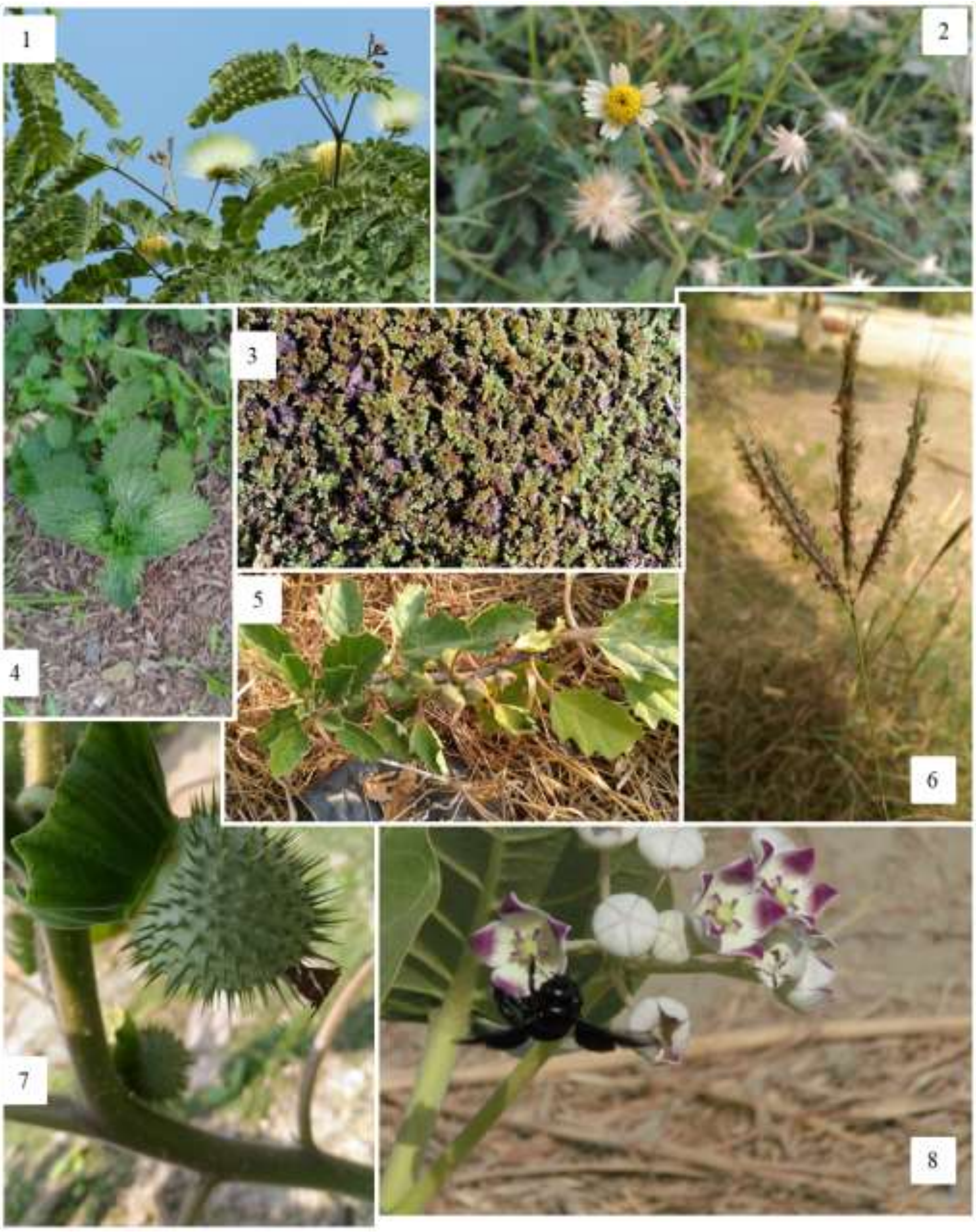


Fig 3.6: Floral diversity of HWS (1: *Albizia lebbeck* 2: *Tridax procumbens*, 3*: Azolla pinnata*, 4: *Urtica urens*, 5: *Pedalium murex*, 6: *Dichanthium annulatum*, 7: *Datura stramonium*, 8: *Calotropis procera).*

The upland area which is also a non-flooded zone in the sanctuary supports a population of *Dalbergia sissoo*, *Vachellia nilotica*, *Mangifera indica*, *Morus alba, Syzygium cumini, Albizzia lebbeck, Acacia leucophloea, Azadirachta indica, Melia azadirachta* and *Prosopis cineraria* However, there is also scattered existence of other species like *Ficus benghalensis, Ficus religiosa, Butea monosperma, Pheonix sylvestris, Populus deltoids, Ziziphus mauritiana, Bombax ceiba* and *Cassia fistula.*

The plant species found in the wetland area were *Anagallis arvensis, Azolla pinnata, Bacopa monnieri, Centella asiatica, Ceratophyllum demersum, Convolvulus arvensis, Cyperus michelianus, Cyperus rotundus, Diplazium esculentum, Eclipta prostrate, Hydrilla verticillata, Ipomoea aquatic, Lemna minor, Ludwigia adscendens, Ludwigia perennis* and *Marsilea quadrifolia*. The ground vegetation is dominated by herbs like *Cannabis sativa,* and *Chenopodium album,* in addition to this, many grasses like *Chrysopogon zizanioides, Cynodon dactylon, Dactyloctenium aegyptium, Desmostachya bipinnata* and *Digitaria ciliaris.* Invasive species like *Eichhornia crassipes*, and *Pistia stratiotes* distributed in the wetland area.

Harike wildlife sanctuary also supports a population of medicinal plants, which are also used by local people. These species were *Centella asiatica, Cleome viscosa, Boerhaavia diffusa* and *Barleria prionitis.* An ecosystem's overall biodiversity is influenced by its wild flora. Numerous other species of life, including insects, birds, mammals, and microbes, are supported by a wide array of plant species. The ecosystem is better able to endure environmental changes and disturbances due to its diversity, which also ensures ecological balance and resilience. Numerous creatures can find shelter and protection in wild flora. Various animals can find food, shelter, and nesting locations in plants. Additionally, they produce microhabitats including tree canopies, understory vegetation, and ground covers that serve as niches for a variety of species.

Village around Harike Wildlife Sanctuary

Fig 3.7 : Livstock grazzing on boundary of HWS.

Fig 3.8 :Local people using boat to reach agricultural field

The villages were located adjacent right bank of the Beas River, which makes the northern boundary of the HWS. The largest village was Harike in terms of area as well as population. Three districts—Kapurthala, Taran Taran, and Ferozepur—have communities surrounding the wetland that are predominantly agricultural and that either directly or indirectly depend on the wetland for their water needs. A small number of the neighboring villagers have been employed as watch and wards who maintain the sanctuary on a daily wage basis. The wetland provides groundwater recharge and supplies water to the areas surrounding the sanctuary. Village located along Beas River is Harike, Kirian, Marrar, Kambo and Chamba kalan, Harike village has a population of 9798 with livestock of 3250, followed by village Kirian with a 1676 population with 310 livestock. In Kambo village, 810 people live with 495 livestock, village Chamba Kalan has 3371 people with 800 livestock, and in the village, Marrar only 204 people settled with 95 livestock as per the census of 2011. People are engaged in agricultural activity and many people use boats to cross the Beas River for taking care of their crops. The local population also collects fuel wood, fodder, medicinal plants, and useful plants from HWS. The valuation of ecosystem services is a tool to advocate the importance of the ecosystem in terms of economic value besides the present study is also significant to document ecosystem services availed by local people. This study has also incorporated the seasonal change in flora and avian species and its impact on ecosystem services delivery. To conduct the study following objectives were framed.

Objectives

1. To assess ecosystem services* provided by Harike Wildlife Sanctuary for economic valuation.

   *Ecosystem services

   I. Provisioning ecosystem services: Fuel, fodder, food, Raw material and water utilization.

   II. Cultural ecosystem services: Educational, religious and recreational value.

   III. Regulatory ecosystem services: flood impact on local people.

   IV. Supporting ecosystem services: Economic valuation of different habitat types.

   Research Questions

   a) What are the ecosystem services utilized by local people at and around Harike WS?

2. Habitat characterization of Harike Wildlife Sanctuary with special reference to habitat mapping.

   Research Questions

   a) What is the present distribution of different habitats in HWS?
   b) How different habitats are providing considered ecosystem services?
   c) How the vegetation composition is changing in different seasons in particular habitat?

3. To assess the bird diversity in relation to various habitat types in Harike Wildlife Sanctuary.

   Research Questions

   a) Is there any association between avian species and micro-habitats?
   b) How does avifaunal diversity support cultural ecosystem services at HWS?

These objectives have been achieved through fieldwork and standard methods explained in the next chapters.

Chapter 4

Valuation of Ecosystem services

The valuation of provisioning ecosystem services is an important area of research that aims to quantify the economic value of the benefits humans derive from natural ecosystems (Davidson 2013). Provisioning services refer to the tangible goods that ecosystems provide, such as food, water, timber, and fuel. These services are essential for human well-being, and their value can be significant, both in monetary and non-monetary terms. However, the valuation of provisioning ecosystem services is a complex task that involves accounting for ecological, social, and economic factors, as well as the cultural and ethical dimensions of natural resource use. Several methods have been developed to assess the value of provisioning ecosystem services, including market-based approaches, non-market valuation techniques and ecosystem services modeling. These methods have been applied in various contexts, ranging from small-scale local assessments to global-scale analyses. The results of these studies can inform policy and decision-making processes, providing insights into the trade-offs and synergies between different ecosystem services and their impacts on human well-being (Cord et al. 2017). Using the prices of commodities and services that are traded in marketplaces, the market value method is a simple way to value ecosystem services that are provided temporarily (Barbier et al. 2009). The foundation of this approach is the idea that market prices accurately represent the economic worth of the ecosystem services required to generate these items.This topic has received growing attention in recent years, reflecting the increasing recognition of the importance of natural capital and the need to incorporate ecosystem services into economic and development planning. The present study has followed by maket cost value for valuation of provisional ecosystem services. The valation of ecosystem services can be used to develop strategies for conservation of ecosystem services and suitable marke instuments can be used to manage the balance between human needs and ecosystems.

Seccombe-Hett (2000) and Badola et al. (2014) advocated that market-based instruments (MBIs), which define the updated rights and obligations and modify pricing in the current markets rather than using explicit directives, are intended to bring about behavioral change. MBIs include payment for ecosystem services, incentives for conservation-friendly behavior and price- or quantity-based measures (such as fees, and penalties that would internalize negative externalities). Economists have long advocated for MBIs such as taxes, subsidies, tradable licenses, and property rights auctions to facilitate effective environmental policy-making.

Wetlands are complex and diverse ecosystems that provide a variety of important benefits to both people and wildlife. One of the key benefits that wetlands offer is the provisioning of goods, such as food, fiber, and fuel, that are essential for human well-being (Vymazal 2011). In this research we have explored the different ways in which wetlands provide essential goods and the importance of conserving these valuable ecosystems. Wetlands are home to a wide range of plant and animal species that are important sources of food for humans. Wetland plants such as rice, lotus, and water chestnuts are cultivated in many parts of the world and are important staples in local diets. Additionally, wetlands support a diverse range of fish species, including catfish, tilapia, and carp, which are important sources of protein for millions of people worldwide (Mitsch 2015). Wetlands also provide habitat for many other aquatic species such as shrimp, crabs, and clams, which are also valuable sources of food. Wetland plants such as cattails, sedges, and rushes are important sources of fiber, which can be used for a variety of purposes, including basket weaving, mat-making, and thatching. In many parts of the world, wetland plants are also used to make paper, clothing and other textiles (Chakma 2019). Wetlands are important sources of fuel, particularly in rural areas where access to other sources of energy is limited. Wetland plants such as reeds and grasses can be harvested and dried to create biomass fuel, which can be burned for heat or used for multiple purposes. Wetlands are essential ecosystems that provide a wide range of important goods, including food, fiber, and fuel. These ecosystems are under threat from human activities, making their conservation and sustainable use critical for the well-being of both people and the environment. by protecting, restoring, and sustainably using wetlands, we can ensure that these valuable ecosystems continue to provide essential goods and services for generations to come. Economic valuation of selected ecosystem services has been done for HWS.

Methods

Provisional ecosystem services of biotic goods at HWS were estimated through market value method by following Badola et al. (2010). Questionnaire survey and line transect survey were conducted for socio-economic data and field survey respectively to collect primary data for selected ecosystem services (Plumptre 2000; Joshi and Negi 2011). Monthly field surveys were conducted between September 2019 and September 2021. Data regarding the consumption of fuel wood, fodder, raw materials and agricultural output were collected using formally structured questions (fig 4.1). Annual estimates of harvested or consumed volume are used to determine economic value, which is then determined using the market value approach.

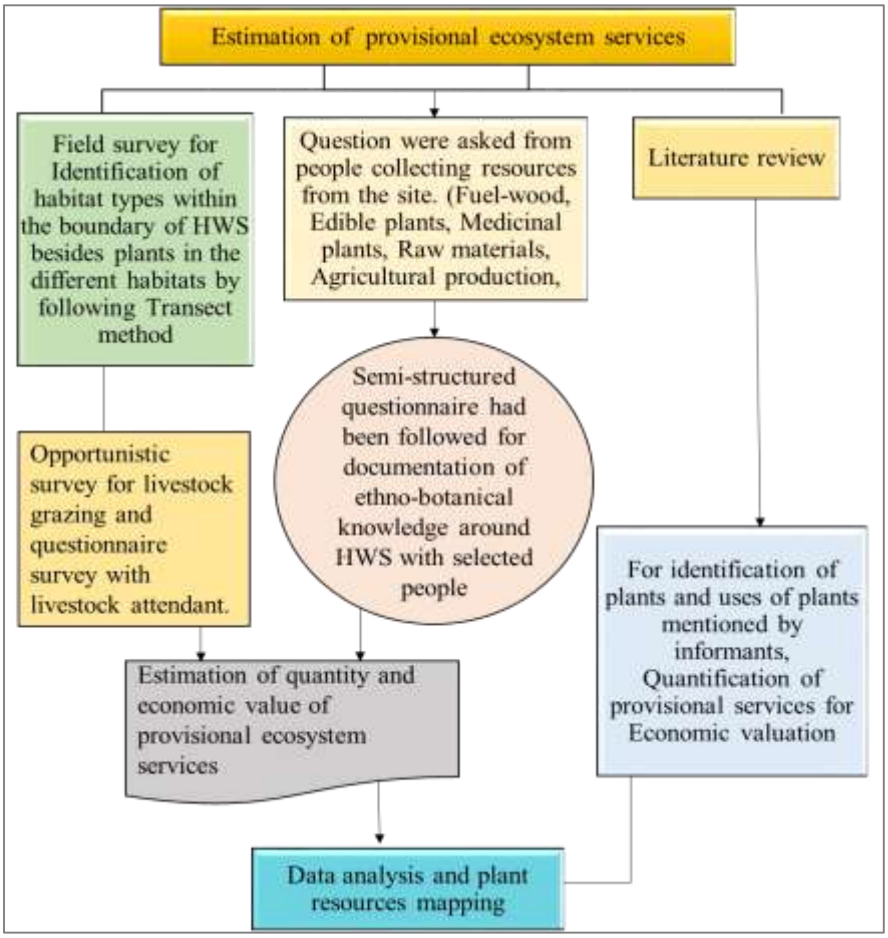


Fig 4.1: Schematic diagram of process for estimation of Provisional ecosystem services.

To estimate the fodder consumption quantity and its economic value (fig 4.2). A rapid survey has been carried out by following Zeleke (2011) to determine active grazing areas in the HWS, as an outcome of the survey three habitats were identified as active for grazing. Counting grazing livestock populations in each habitat in the morning and evening by line transect method in each month (Eberhardt 1978) and opportunistic sighting are also included after getting the average population of each type of livestock per day. The questions were asked from livestock attendees and farmers for different livestock such as " Capacity of fodder consumption by an individual livestock in a day". then by using the market value of fodder Kg^{-1} in the local market (fig 4.2), the total economic value is estimated for each type of livestock in a year by following Croitoru (2007).

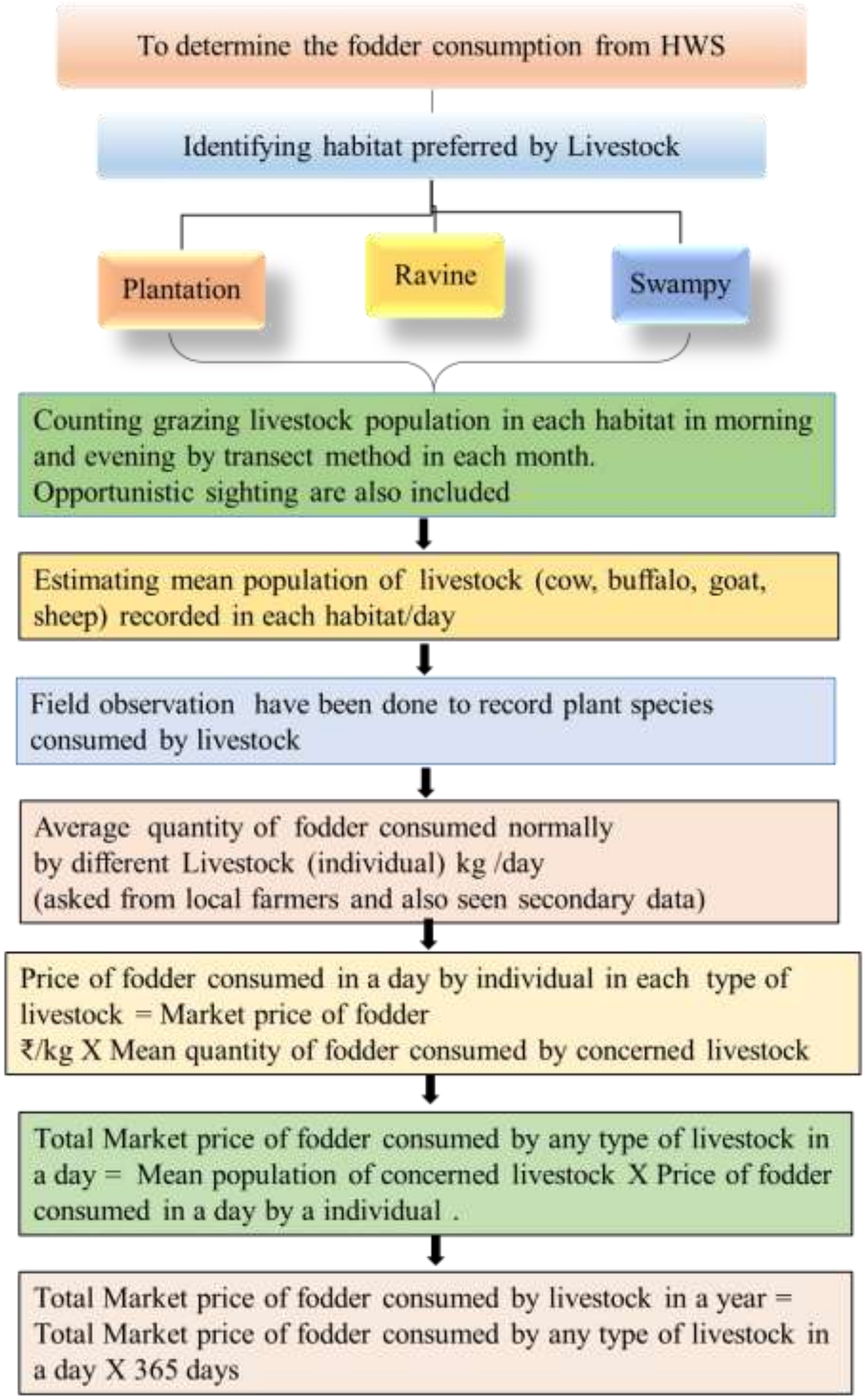


Fig 4.2: Estimation of fodder consumption by livestock HWS.

Since the locals' efforts to collect fuelwood were being observed, a survey was carried out at various locations within the HWS. Seasonal data was gathered in order to quantify and value the fuelwood that was obtained from HWS (fig. 4.3).

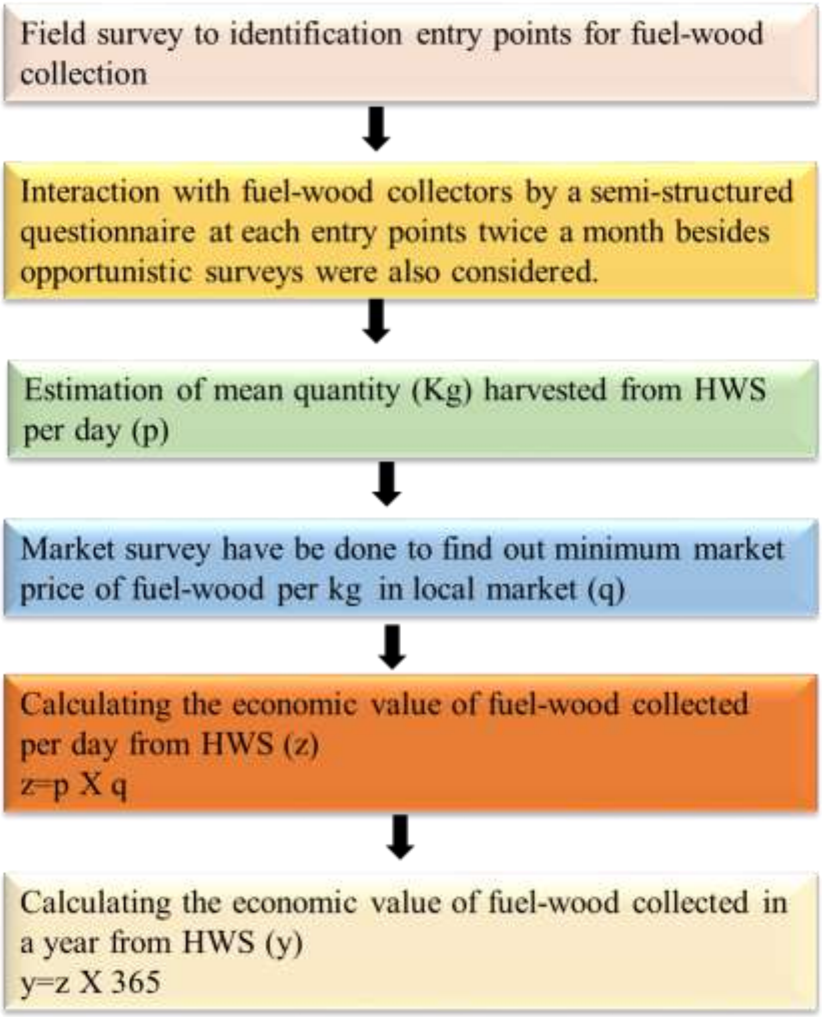


Fig 4.3: Process of valuation for fuel-wood in HWS.

Plants are important contributors to our food security and plant-based food material harvesting for ecosystems is important provisional ecosystem services.Wetland ecosystems are also known as the cultivation of crops like *Trapa natans* and *Nelumbo nucifera* beside in HWS a large area is under cultivation therefore crop production (wheat and rice) is also considered a provisional ecosystem service (fig 4.4). Some wild edible plants were also identified in the study area. The market value method is used to estimate the economic value of the above-mentioned crops. To estimate the total benefits of crop production especially for wheat and rice, www.farmer.gov.in is followed.

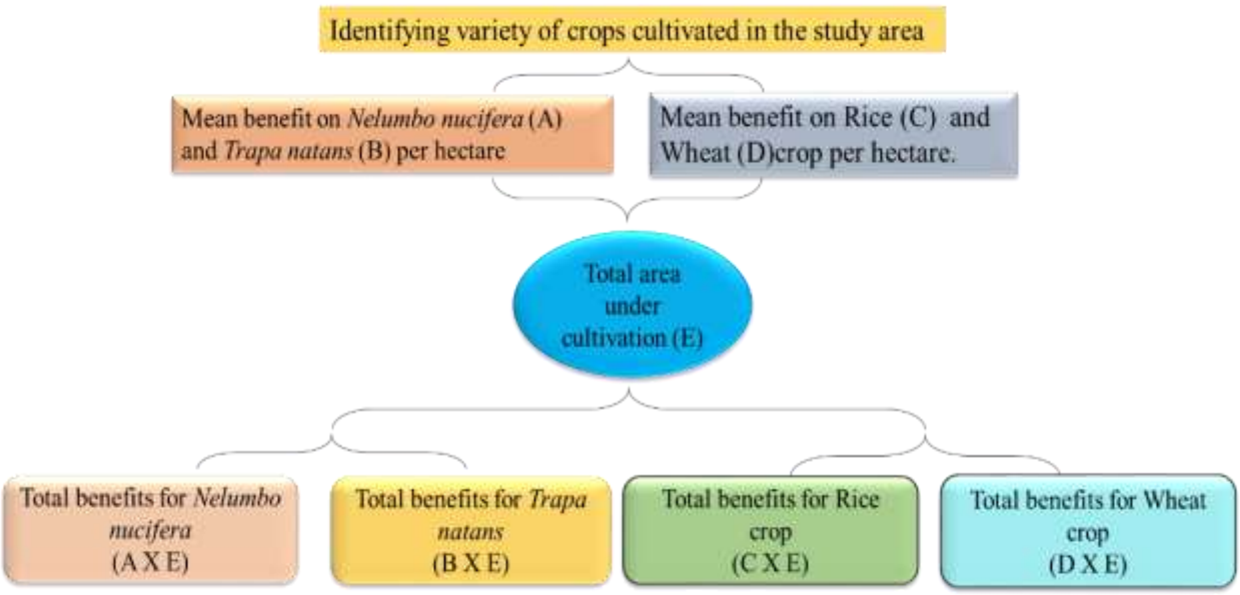


Fig 4.4: Estimation of the quantity of Produce for Different crops

In the field investigation, a total of four species were identified as crops used by local people. Three species are hydrophytes and mesophytes like *Oryza sativa*, *Trapa natans*, *Nelumbo nucifera* and *Triticum* respectively. The crop cultivation is considered a provisional ecosystem service from the different habitats of HWS and the crop's economic value is estimated based on its spatial expansion in the sanctuary as well as a net economic benefit on a particular crop per hectare in a year. Investigation revealed edible plants, which were taken into account for valuing as providing ecosystem services (fig 4.5).

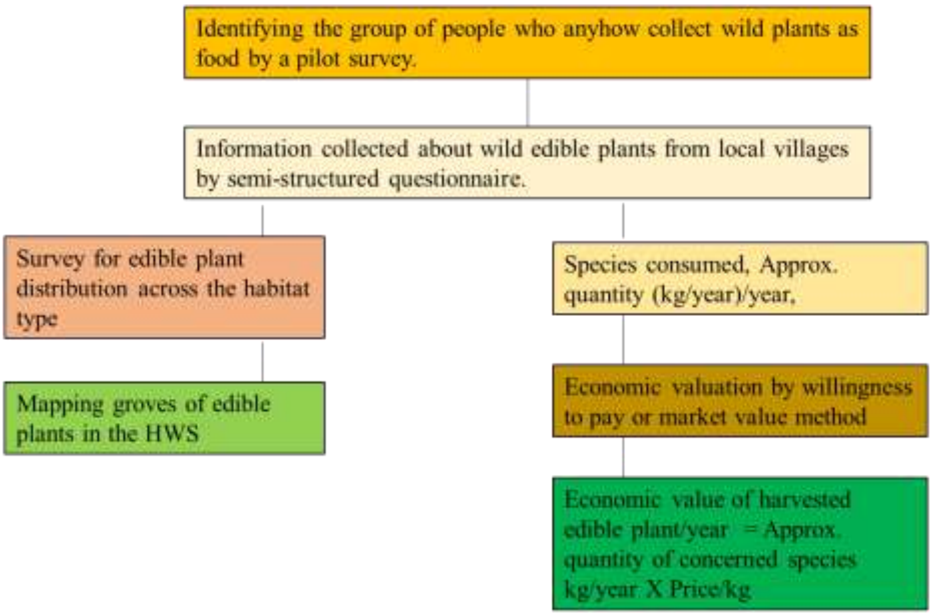


Fig 4.5: Consumption of edible plants.

A preliminary field survey and semi-structured questionnaire have been used to find out the plant species used as raw material. Direct (seen direct collection from the field) and Indirect (chopped grass clumps) evidences were recorded for precise quantity estimation of plants used as raw material (fig 4.6).

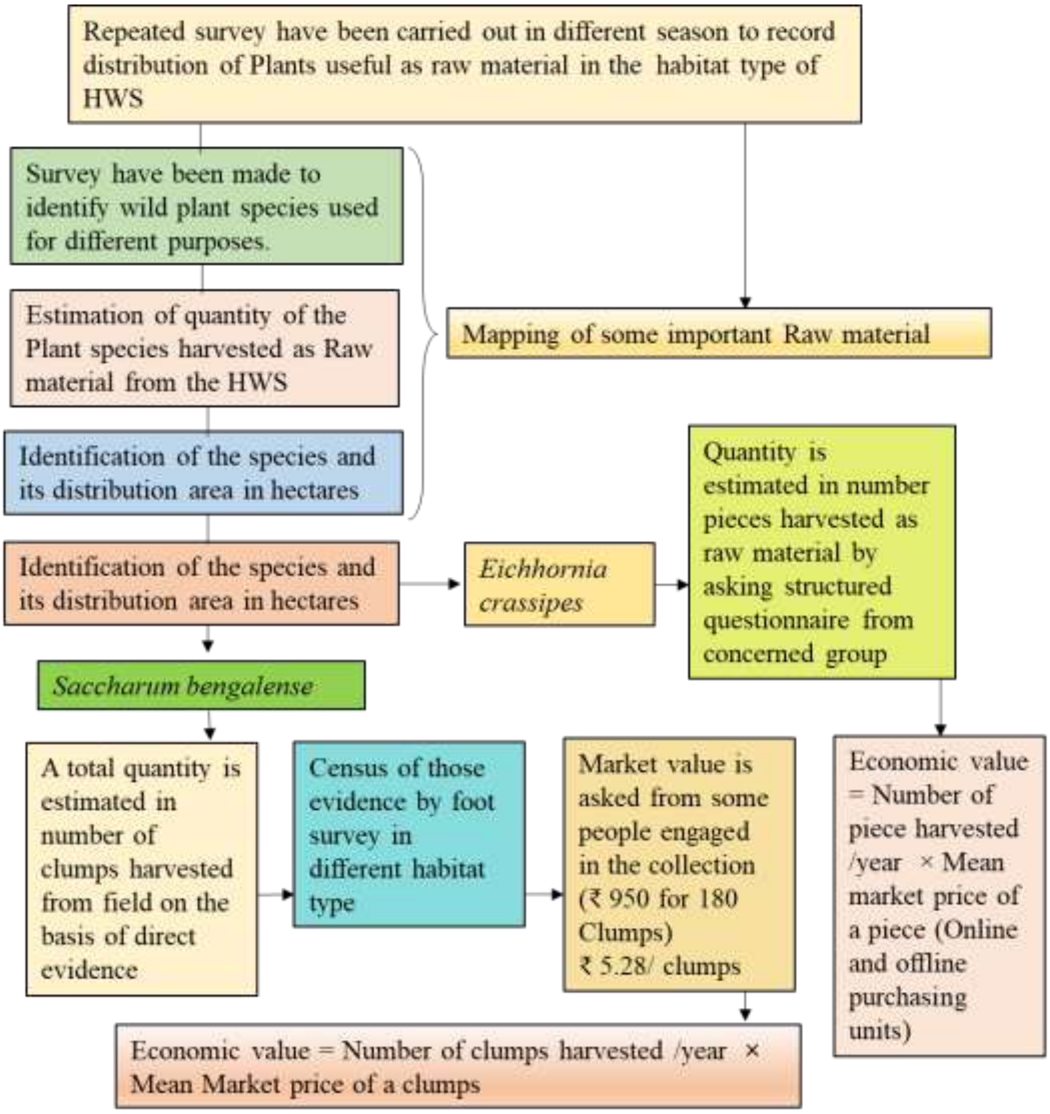


Fig 4.6: Process of estimating the value of plant-based raw material harvested from HWS.

Ethnobotanical documentation for medicinal plants

Ethno-botanical data was collected through semi-structured interviews and observations were recorded during the field surveys held between September 2019 and March 2021. A total of 110 informants were interviewed and the composition of informants include medicinal plant collectors, traditional drug makers, farmers, daily wage laborers, and government servants. A semi-structured questionnaire (Annexure I) was used for data collection following snowball sampling (Goodman 1961). The field observations with some informants have been made for the confirmation of plant species mentioned for the treatment of ailments. A total of 72 field surveys have been carried out following the line transit method (Buckland et al. 2007) across the habitat types in HWS to record the status and distribution of medicinal plants mentioned by informants. In each habitat type, a one-kilometer line transect was laid and transects were repeated in each season (summer, monsoon, post-monsoon and winter). In order to look for both direct and indirect signs of medicinal plants throughout the Sanctuary, each line transect was prepared three times per season. The wild plants mentioned by the informant have been identified by following Nair (1978) and Sharma (1990) with some online resources like www.theplantlist.org, http://www.flowersofindia.net, and www.efloras.org were used. Plants species were photographed from the field and a voucher specimen of pictures has been submitted to the herbarium of the Wildlife Institute of India, Dehradun.

Data analysis

Data analysis were done for use value, relative importance index and fidelity level which is as follows:

Use value

To find out the significant plant species used by people, the Use Value (UV) index is calculated by following Rossato et al. (1999) and Silva and Albuquerque (2004).

UV: $\Sigma U_i/N_i$

U_i = Number of uses mentioned by all informants.

N_i = Number of the informant.

For example: if informant A has mentioned 2 uses and informant B has mentioned 6 uses, therefore, the Use Value will be (2+6)/2 = 4.

Relative Importance Index

The Relative Importance Index is calculated by following Bennett and Prance (2000).

RI = NUC + NT

NUC = number of use categories of a given species divided by the total number of most versatile species in use categories.

NT = is given by the number of kinds of uses attributed to a given species divided by the total number of types of uses attributed to the most important taxon.

Fidelity level

This is adapted from Friedman et al. (1986) to determine the particular medicinal plant used for certain ailments. A high percentage shows that the given species is used by people for the treatment of a particular ailment.

Fidelity level (FL) = $I_p / I_u \times 100$

I_p = number of informants that cited the principal use of the species.

I_u = the total number of informants that cited the species for any purpose.

The distribution of medicinal plants has been recorded from wild sources after direct field visits conducted every month from September 2019 to March 2021. A timeline chart for the availability of medicinal plants in the HWS is also been mentioned in the study.

Provisional ecosystem services of abiotic goods at HWS

Sand Excavation

The tangible benefit from the natural ecosystem is considered as Provisional ecosystem services. The major area of the Harike wildlife Sanctuary is covered by vegetation and water in a small area on the western boundary. During the monsoon season, the Beas and Sutlej rivers flood with water rising above their banks and flowing out onto the surrounding land. Floodwater filled with sediment (clay, sand and silt) is deposited on land next to the River. An over-bank deposit is sand that has been left behind. Sand excavation is estimated (fig 4.7) for economic valuation by following Sayami and Tamrakar (2007) and Madyise (2013).

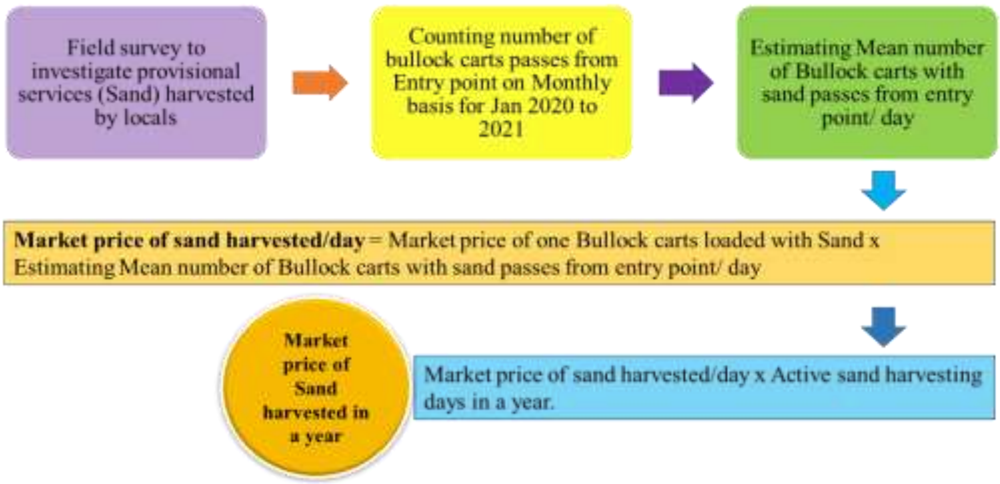


Fig 4.7: Method for estimating the market price of sand excavation from HWS in a year.

Water utilization

Water is an essential requirement for the survival of all life forms on the planet. It is acceptable to claim that water is the reason for Earth's status as the only planet capable of supporting life. One of the most important resources we have on this planet is this universal solvent. Without water, life would be hard to sustain. After all, it accounts for over 70% of the planet's surface area. The HWS is a very significant water reservoir as India's longest irrigation canal, which covers a total area of 12.58 lakh hectares, and provides water for irrigation in Sriganganagar, Bikaner and Jaisalmer. Water discharge from a Harike wetland to Indira Gandhi Canal accounts for 18500 cubic foot water per second. The market value of tank water is referred to determine the market price of water discharged into the Indira Gandhi Canal. Hence the irrigation department of Punjab and Rajasthan keep recording the water discharge from the Harike wetland to Indira Gandhi Canal. The quantity of water is estimated by conversion method from cubic foot/sec to litters/ sec (fig 4.8). Then the value of water released is extrapolated to minutes, hours, and for a day. After getting the value for the quantity of water released from Harike wetland to Indira Gandhi Canal for a day then the market price of water is estimated for a day by following the market cost method (Ramachandra et al. 2005), In this case, the market price of a litter of water is referred from a water tanker available at the local market.

Water discharge in Indira Gandhi Canal

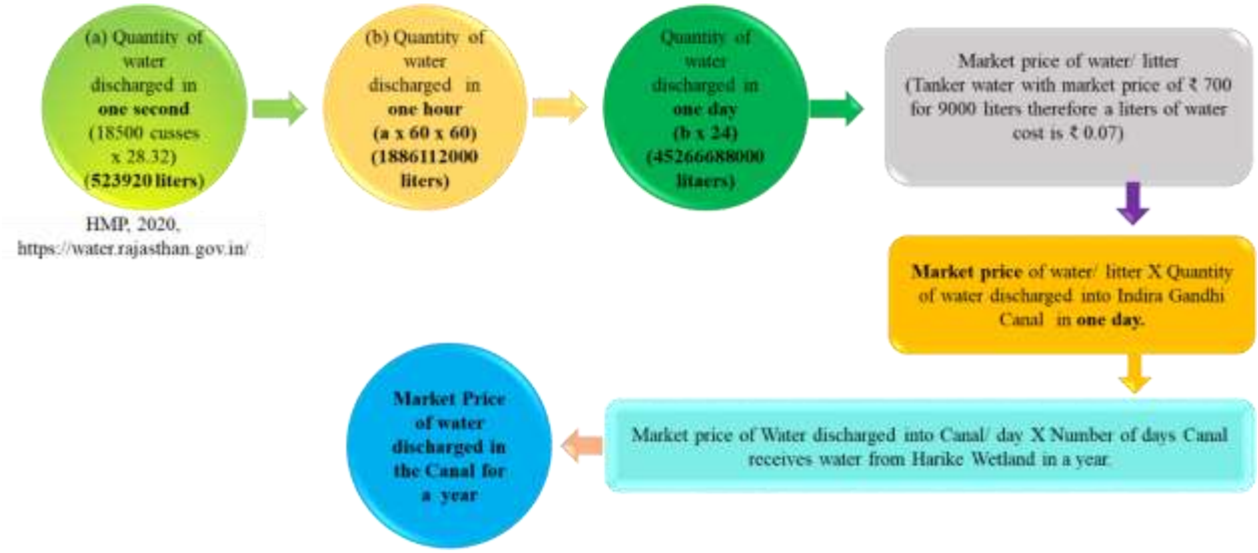
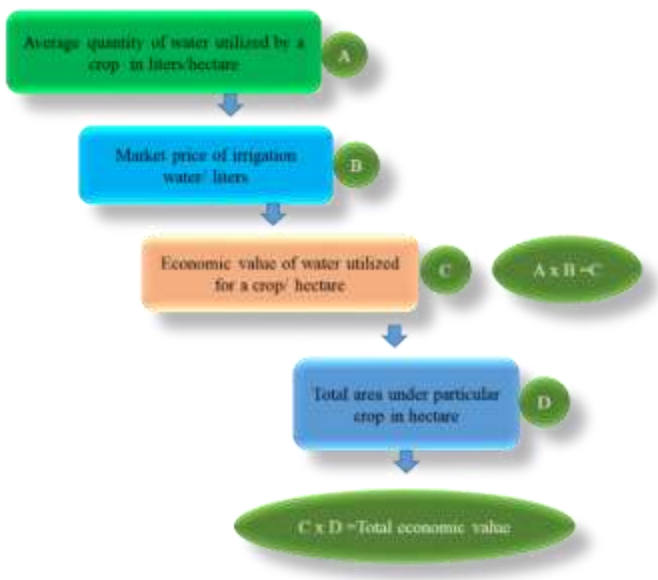
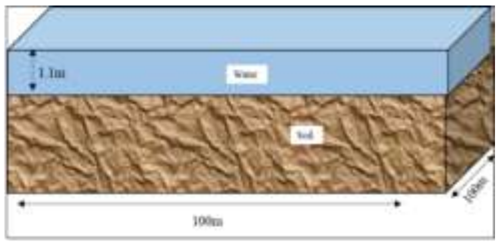


Fig 4.8: Estimation of water discharge from Indira Gandhi Canal for economic valuation.

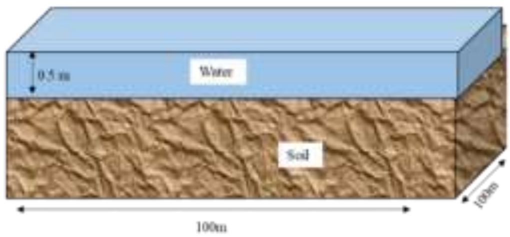
Irrigation water

Irrigation water is an important ecosystem service provided by rivers and wetlands. The Harike wildlife Sanctuary provides irrigation water to local people. In the present study, primary and secondary data are used for the estimation of the quantity of water utilized for rice and wheat cultivation with its market price.





Ground water utilisation in rice cultivation per hectare. *Source*: Tiwana *et al*., 2005; Kaur *et al*., 2015.



Ground water utilisation in wheat cultivation per hectare, *Source*: Tiwana *et al*., 2005; Kaur *et al*., 2015)

Fig 4.9: Economic value of water utilized for irrigation of rice and wheat crops.

The total water requirement for the rice and wheat crop is adopted from Tiwana et al. (2005); Kaur et al. (2015). The total area under cultivation is estimated with the help of google earth pro with ground truthing besides market value method is used for the estimation of the price of water therefore we took the market price of tank water (₹700/9000liters = ₹ 0.07/liter) available at local market (fig 4.9).

To calculate the volume of water in one hectare for rice cultivation (1100mm ha^{-1}), There is a need to know the area of one hectare and the conversion factor for millimeters to cubic meters.

One hectare is equal to 10,000 square meters. To convert the water from millimeters to meters, we need to divide it by 1000.

So, the calculation can be done as follows:

Area of one hectare = 10,000 square meters, Water in meters = 1100mm / 1000 = 1.1 meters

Now, to calculate the volume of water, multiply the area by the water:

Volume of water = Area x water = 10,000 square meters x 1.1 meters = 11,000 cubic meters

Therefore, the volume of water in one hectare with a rainfall of 1100mm is 11,000 cubic meters.

To convert cubic meters to liters, there is a need to multiply the volume in cubic meters by 1000, as there are 1000 liters in one cubic meter.

So, to convert 11,000 cubic meters to liters: Volume in liters = 11,000 cubic meters x 1000 = 11,000,000 liters, Therefore, 11,000 cubic meters is equal to 11,000,000 liters ha^{-1}.

Similarly, water is used for the wheat cultivation to calculate the volume of water in one hectare with a depth of 500 mm, need to convert the measurements into a consistent unit.

1 hectare is equal to 10,000 square meters.

To calculate the volume, we can use the formula: Volume = Area x Depth

First, let's convert 500 mm to meters: 500 mm = 500/1000 = 0.5 meters

Now, we can calculate the area of one hectare: Area = 10,000 square meters

Finally, we can calculate the volume:

Volume = Area x Depth (Volume = 10,000 m^2 x 0.5 m)

Volume = 5,000 cubic meters

Therefore, the volume of water in one hectare with a depth of 500 mm is 5,000 cubic meters.

Conversion to liters: 1 cubic meter is equal to 1000 liters. Therefore, 5000 cubic meters of water is equal to 5000 x 1000 = 5,000,000 liters of water ha^{-1}.

Domestic use of water

In the selected village near the Harike wetland, a total of 40 households were sampled for the extraction of ground water for domestic consumption. The primary data was gathered for various groundwater extraction and storage sources, water tank size, water tank refill frequency, family size and livestock strength. To estimate the value of ground water usage (fig 4.10), a market price of bottled water is being considered. In a market survey, a 20 litter water bottle ranging from ₹20 to ₹80 was available in the local market, this study has adopted a minimum price that is ₹20, for the estimation of the economic value of the domestic water consumption and therefore cost of one litter water was considered ₹1 for estimation of economic value in the current study.

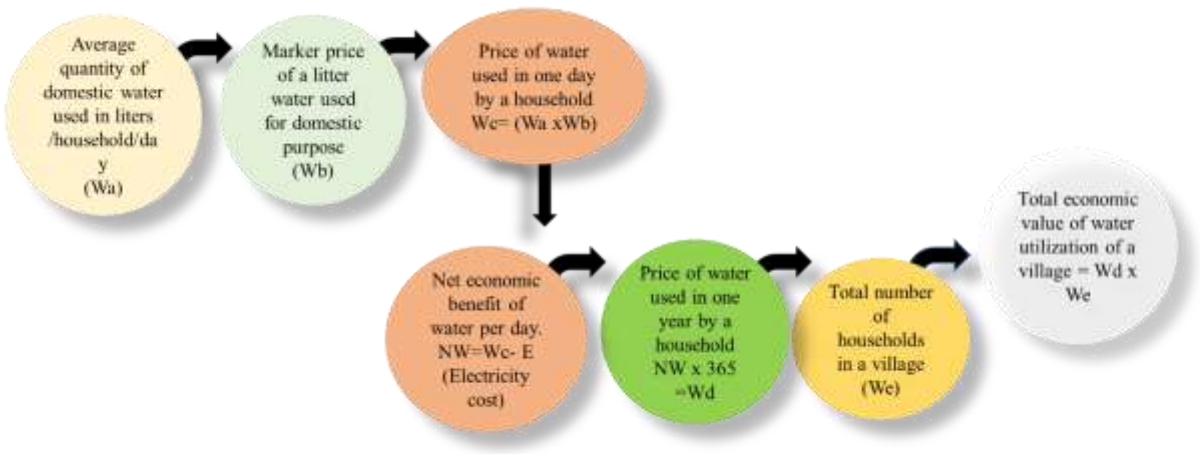


Fig 4.10: Process of Estimating the economic value of water used for domestic purposes.

The cost of electricity used is subtracted from the total value estimated. Electricity consumption is calculated based on the power of the Pump in Watts and the average duration of running a pump in a day. Mostly people have used a 1hp (735 watts) submersible pump for household purposes. The cost of electricity incurred for running a pump in a day is ₹3.86 and for a year it accounts for ₹1408.9 per household.

Customized equations for quantification and valuation of ecosystem services

<table>
<tr><td>Fuel wood collection
EvF= ($\bar{x}$ × a) e
EvF= Economic value of fuelwood
$\bar{x}$ = mean quantity (kg) of fuel wood harvested in a day from HWS
a = Market cost of fuel wood/kg
e = number of collection days</td><td>Fodder (grazing)
Evf = {($\bar{x}$ × L) a } d
Evf = Economic value of fodder
$\bar{x}$ = mean quantity (kg) of fodder consumed by adult livestock /day
L = Mean number of particular adult livestock in a day
a= Market cost of fodder/kg
d = number of grazing days</td></tr>
<tr><td>Raw-material
EvR = t × a
EvR = Economic value of rawmaterial
t = total number of clumps or pieces harvested in a year
a= Market cost of the concerned species</td><td>Crop harvesting
Evc = C × A
C = Economic benefit per hectare on crop
A = Area cover (in hectare) by each crop</td></tr>
</table>

<table>
<tr><td>Sand excavation
EVF= ($\bar{x}$ × p) e
$\bar{x}$ = mean number of Bullock Cart collecting sand /day
p = Market cost of a sand cart
e = number of extraction days</td><td>Water discharge in IGC
EvW = {(L × 60 × 60 × 24) × a } × D
L = Quantity (Liter) of water discharged in one second.
a = Market cost of construction water
D = number of functional days</td></tr>
<tr><td>Water used in irrigation
EvIr = (w × a) A
w = Quantity (Liter) of water essential for any crop in one hectare
a = Market cost of irrigation water
A = area under cultivation in hectare</td><td>Domestic use of water
EvDu = {($\bar{x}$ × a) - Eb } N
$\bar{x}$ = mean quantity (Liter) of water used per household
a = Market cost of drinking water
Eb= Cost of running pumps
N = Number of households</td></tr>
</table>

Method for Cultural Ecosystem Services

Data collection

Primary data has been collected to investigate the present status of Cultural Ecosystem Services (CES) across the habitat types of Harike Wildlife Sanctuary, Field observation as well as Questionnaire survey were conducted. Before designing a questionnaire for data collation pilot survey has been made to identify the type of CES perused by visitors. Different habitat types have been classified at Harike wildlife sanctuary for observation and recording utility of each habitat for different ECS. A total of 15 questionnaires were used to test, whether the collected data is enough for addressing objectives. Some questions were added to the questionnaire as the utility level of CES for each group varies. A total of 104 groups (689 individuals) with random sampling, were asked for willingness to pay (Fig 4.11) for certain CES such as guided tours, wildlife photography, boating, content creation for social media, aesthetics and cycling, besides other information like occupation, Annual income, the objective of visit, the vehicle used for arriving at sanctuary, distance covered, expected cost incurred to complete visit, problems faced in the sanctuary, and suggestion for improvement. Volunteering has been done as guided tours and bird watching to build familiarity with visitors' therefore precise and accurate data can be collected (Nichols 1991). Secondary data like total visitors arrived at HWS for the year 2019-2020 is acquired from Range Office HWS under the department of Forests & Wildlife Preservation, Punjab, India.

Willingness to pay

In theory, any use value, direct or indirect, can be evaluated based on direct interviews utilizing contingency valuation or choice analysis. These methods of valuation are applied to determine both use and nonuse values. Willingness to pay is a contingency valuation used for the valuation for ecosystem services, in the present study valuation has been done following Bann (1999), Yacob et al. (2009), Sathya and Sekar (2012) and Grunewald and Bastian (2015) for the identified cultural ecosystem in HWS. Willingness to pay depends upon the gender, social status, and economic advancement of a particular region therefore mean value is calculated for each CES then it is considered as a final amount that can be paid by any person to avail particular CES in the HWS.

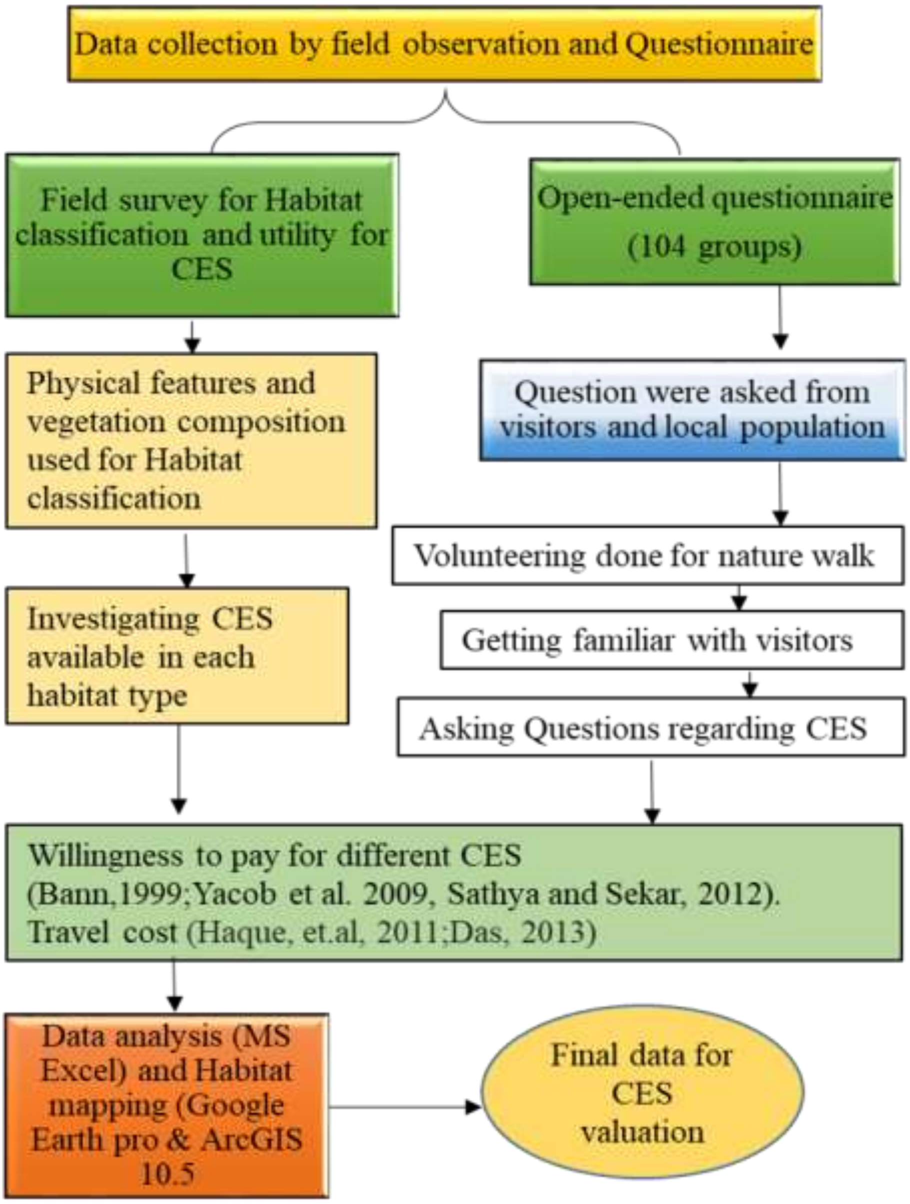


Fig 4.11: Data collection and valuation process for CES.

Travel cost method

The travel cost method is a recognized method that uses the expenses that visitors pay in traveling to a recreational site (Haque et.al. 2011) and the questionnaire survey method is effective for the collection of such data direct from visitors (Das 2013). In this study Total travel cost has been estimated

(Total Travel cost) TTC= (T+E) ×V

(where T= Cost of travel, E= cost of food, drinks, and other and V= total number of visitors)

Method for Supporting Ecosystem Services

In the field survey plantation and ravine, habitat is identified as tree dominant area whereas other habitats like Wetland, Sandy, Swampy, and Agricultural field have devoid of trees therefore Plantation and Ravine habitats are selected for estimation of Biomass. A total of 36 quadrats with size 10 x 10 m quadrat (fig 4.13) has been laid for tree sampling besides Girth at Breast height (1.37 m) and the height of each tree is recorded. Every tree inside the plot that is greater than 5 cm was measured to estimate above-ground biomass (AGB) and root biomass (RB) by following Chave's et al. (2015) allometric equation:

$$\text{AGB (kg)} = 0.0673 \text{ X } (\rho D^2 H)^{0.976} \qquad \ldots(1)$$

Where:

D (cm) = Diameter at breast height (Girth at Breast height / 3.14)

ρ (g/cm3) = Wood specific density

H (m) = height of the tree

The Food and Agriculture Organization (FAO) website is used to acquire the measurement for wood-specific density.

While RB and Tree biomass (TB) was estimated using the following equations:

$$\text{RB (kg)} = \text{AGB (kg) X } 0.26 \qquad \ldots (2)$$

$$\text{TB (kg)} = (\text{AGB} + \text{RB}) \text{ X } 0.80 \qquad \ldots (3)$$

Further, mean TB is estimated in 100 m^2 and then extrapolated to project TB per Hectare in selected habitat types.

The economic value of biomass is estimated based on market value which is ₹1.2/kg in the local market.

Aboveground biomass (AGB) and root biomass (RB) were combined to calculate tree biomass. While RB was determined using the root-to-shoot ratio estimate of 0.26 by Cairns et al. (1997), AGB was computed using the improved allometric model for tropical trees of Chave et al. (2015). According to Nowak (1994), the calculated tree biomass result was modified by a factor of 0.8 to take into consideration the documented differences between forest and urban trees.

Random quadrat 25 samples (1m x 1m) were taken to estimate the biomass of grasses and herbs by followings Akwee et al. (2010). A pilot survey was conducted to determine the areas that have good availability of submerged and floating vegetation, selected area has shown high evenness in the plant community. Through a pilot survey, a total of 1157 hectares were identified as significant for sampling due to high homogeneity. Process of biomass estimation is given in Fig 4.12.

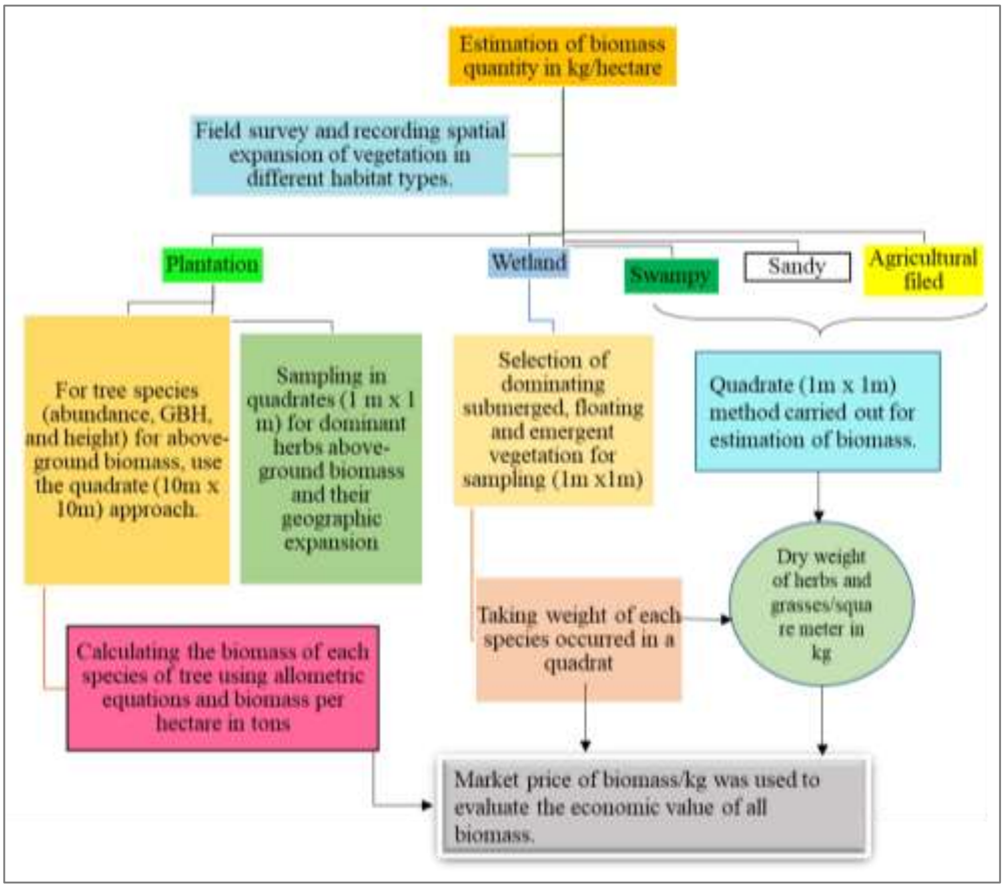


Fig 4.12: Method used for above-ground biomass estimation.

- Shannon diversity index was calculated by the following (Shannon and Wiener, 1949)

$$H' = -\sum_{i=1}^{S}\{(\mathrm{Pi}) * (InPi)\}$$

Where

H'=Shannon diversity Index.

Pi= Proportion of the individual in the sample belonging to ith species.

S= Number of species found.

$\sum$= Sum of species from 1 to S.

In = natural logarithm.

- Species richness (s) in each habitat was calculated by

s= $\sum$n

n= number of species

- Species evenness expresses the distribution of species among habitat types, Shannon–Wiener evenness index (E) as Nolan and Callahan, (2006).

E= H'/H_{max}

H'= Shannon diversity Index

H_{max}= Total of the natural logarithm of all the species (S).

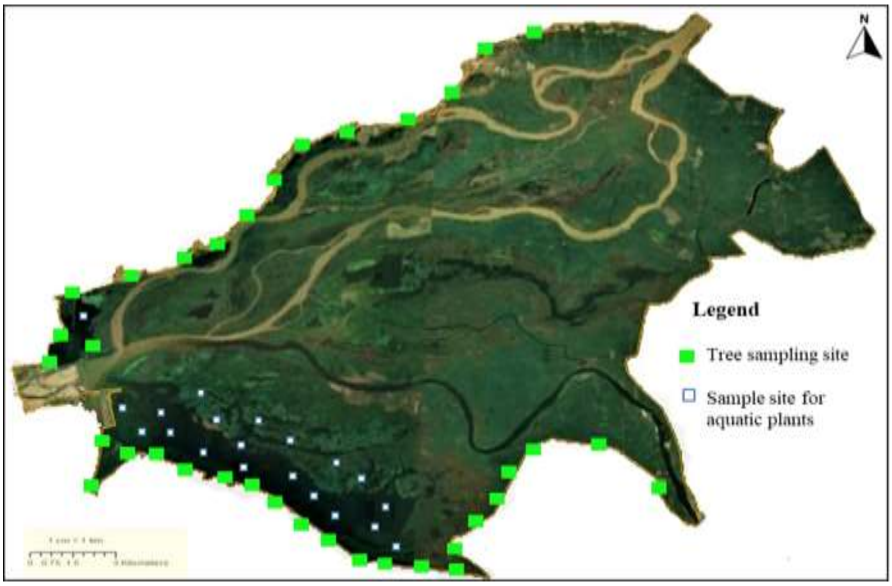


Fig 4.13: Sampling sites for biomass estimation.

Method for Regulatory Ecosystem Services

A structured questionnaire was used to identify the past flood information and potential loss by the flood (Fig 4.14). Down-steam flooding, potential has been estimated by field surveys in the monsoon and post-monsoon season seasons. A total of 20 informants shared information regarding flood, target groups such as employees of the Flood and Irrigation Department, the Forest Department, and farmers having land downstream of the Sutlej River. Questions like "When did you see the last flood", "Have you lost your crop due to flood", what was the last flood elevation" and "When did you see an overflow of Sutlej River" were asked. A digital elevation model (DEM) is used to identify potential flood areas in the downstream. A DEM is a representation of the topography of an area in a digital format, typically in the form of a raster grid, where each cell or pixel contains elevation data (Manfreda and Samela, 2019). DEM is created by 5185 sample points taken in 257 km^2 including the study area by using Google earth pro and ArcGIS 10.5. Downstream width is also calculated with Google earth pro. Field surveys were carried out to record the habitat type and dominating plants in the river channel therefore runoff coefficient can be determined according to Subramanya, (2017).

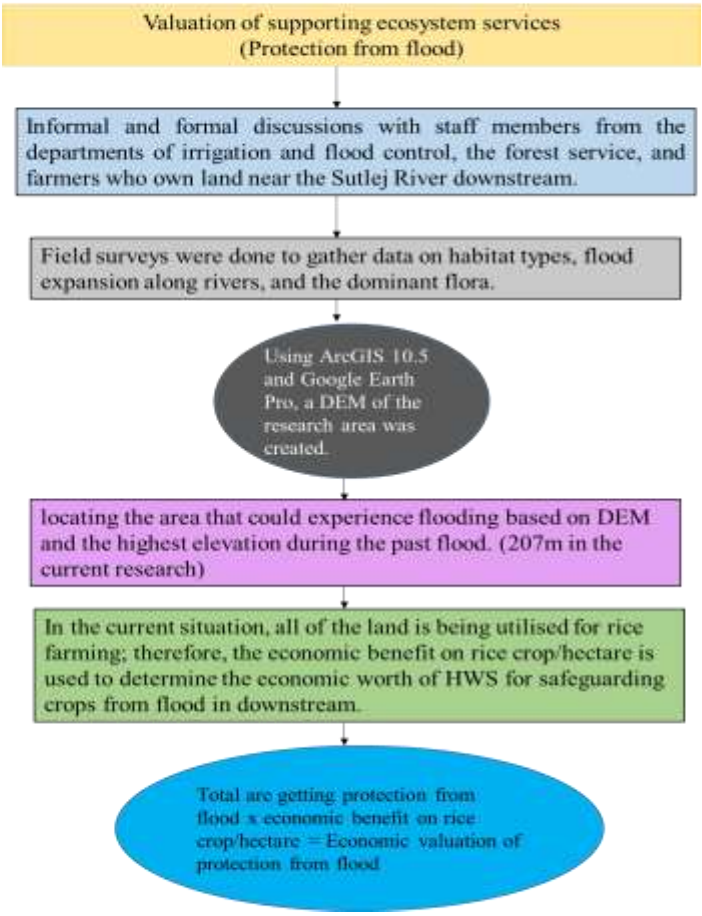


Fig 4.14: Estimating economic value of protection from flood.

Results

The direct goods that plants offer that are necessary for both economic activity and human well-being are included in the category of plant-based ecosystem services. Food production is one of these services; vegetables, grains and cereals are essential for human nourishment. Additionally, plants provide ingredients for the manufacture of paper and fibers for textiles like flax and cotton. Because they provide resources like firewood and biofuels made from different vegetation, they are essential for fuel. Medicinal plants improve health by serving as sources of ingredients for both conventional and contemporary medications. Furthermore, plants provide resources for building such as bamboo and timber, decorative materials for artistic and cultural uses and genetic resources essential for crop improvement and biodiversity preservation. In the present study, plants important for provisional ecosystem services were recorded from HWS. A total of 115 species were recorded from 101 Genera belonging to 48 families (fig 4.15). Dominating families were Poaceae (17 species) followed by Leguminosae (15 species), Solanaceae (7 species), Moraceae (5 Species) Amaranthaceae (4 species), Convolvulaceae (4 species), Euphorbiaceae (4 species), Malvaceae (4 species), Myrtaceae (3 species), Boraginaceae, Chenopodiaceae, Combretaceae, and Compositae contributes 2 species from each family. Detail of each family recorded is given under the Table 4.1.

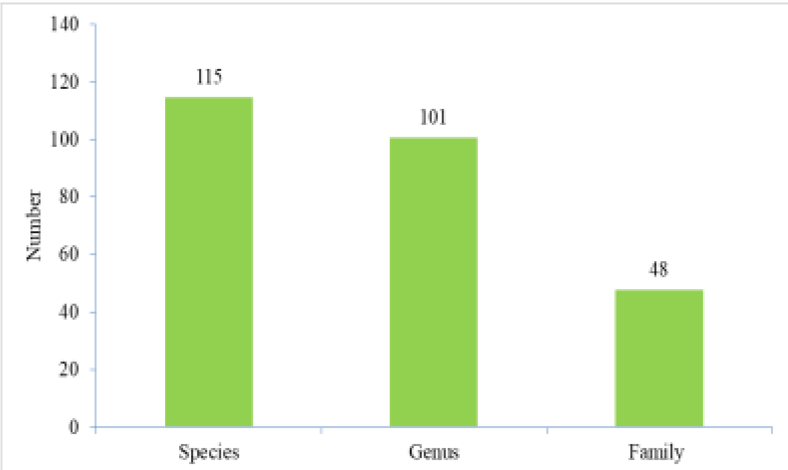


Fig 4.15: Taxonomical detail of plants identified for Provisional ecosystem services.

The habit (fig 4.16) of Bio-resources used by local communities includes Herbs (39 species) like *Withania somnifera*, *Bacopa monnieri*, *Boerhavia diffusa*, *Boerhavia erecta*, *Aerva javanica*, *Chenopodium album*, *Amaranthus viridis Argemone ochroleuca*, *Artemisia scoparia Cleome viscosa*, *Cyperus rotundus Cannabis sativa*, *Centella asiatica*, *Chenopodium murale*, *Datura metel*, *Datura stramonium*, *Digera muricata* and *Eclipta prostrata*.

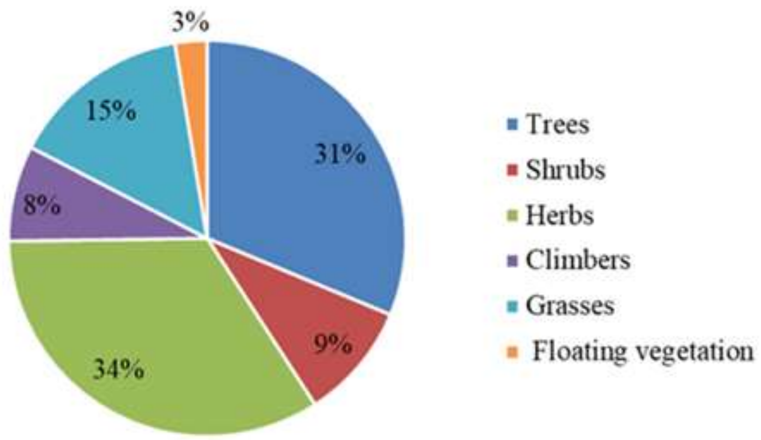


Fig 4.16: Habit contribution of vegetation

followed by Trees (36 species) such as *Acacia tortilis, Aegle marmelos, Ailanthus excels, Albizia lebbeck, Azadirachta indica, Cordia myxa, Bombax ceiba, Callistemon viminalis, Cassia fistula, Dalbergia sissoo, Ficus racemosa, Ficus religiosa, Kigelia Africana, Ehretia laevis, Eucalyptus camaldulensis, Ficus benghalensis, Ficus palmata* and *Leucaena leucocephala*. Shrubs (11 species) including *Ziziphus nummularia, Calotropis procera, Capparis decidua, Lantana camara, Lycium edgeworthii, Murraya koenigii, Clerodendrum phlomidis, Grewia tenax, Ipomoea carnea, Jatropha gossypiifolia* and *Ricinus communis.* Climbers (9 species) like *Abrus precatorius, Asparagus officinalis, Basella alba, Citrullus colocynthis, Clitoria ternatea, Coccinia grandis, Convolvulus arvensis, Convolvulus prostrates* and *Cuscuta reflexa.* Grasses (17 species) *Arundo donax, Avena sativa, Brachiaria ramose, Cenchrus ciliaris, Chloris barbata, Chrysopogon zizanioides, Digitaria ciliaris, Eragrostis minor, Panicum virgatum Cynodon dactylon, Dichanthium annulatum Dactyloctenium aegyptium, Eleusine indica, , , Phragmites karka, Saccharum bengalense, Saccharum spontaneum* and *Polypogon monspeliensis.* Floating vegetation (3 species) used as provisioning ecosystem services are *Nelumbo nucifera, Eichhornia crassipes* and *Trapa natans.* Details of each species is given in table 4.4.

Plants under different use-category

A total of 115 species were recorded under five use-categories viz. edible plants, fodder, fuel-wood, medicinal plants, raw- material (fig 4.17). maximum number of species used under medicinal plants (62 species) *Terminalia bellirica, Terminalia arjuna, Withania somnifera, Ziziphus nummularia, Amaranthus viridis, Argemone ochroleuca, Bacopa monnieri, Boerhavia diffusa, Boerhavia erecta, Cannabis sativa, Centella asiatica, Oxalis corniculata,* *Pedalium murex, Sida cordifolia, Phyllanthus niruri, Physalis minima, Senna occidentalis Plumbago zeylanica* and *Sisymbrium irio*. Species like *Oxalis corniculata, Physalis minima, Portulaca oleracea, Senna occidentalis, Syzygium cumini, Vachellia nilotica, Ziziphus mauritiana, Basella alba, Coccinia grandis, Chloris barbata, Cynodon dactylon, Dactyloctenium aegyptium, Dichanthium annulatum, Digitaria ciliaris, Arundo donax, Avena sativa, Brachiaria ramosa* and *Cenchrus ciliaris* were used as fodder (42 species). During the field survey, people were seen collecting fuel-wood (38 Species) from different habitat types. People were observed collecting dry leaves, broken twigs, fallen trees, dry grasses and dry herbs.

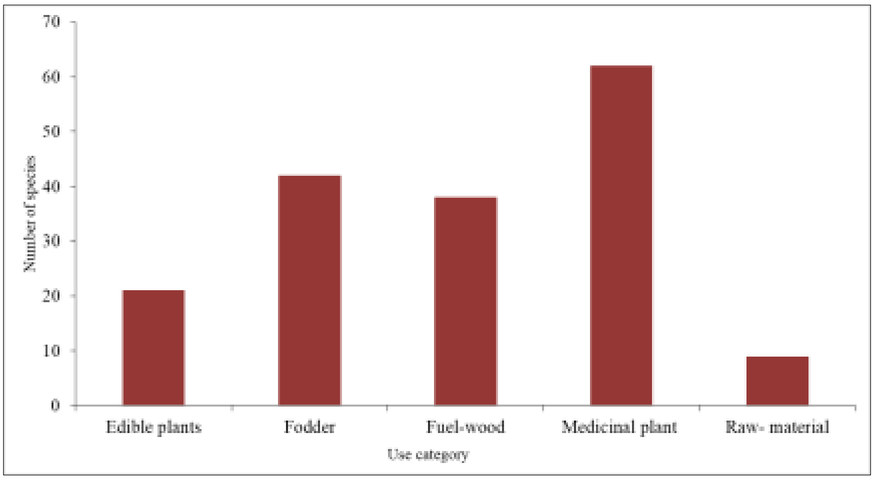


Fig 4.17: Number of species recorded under various use-categories.

Fuel-wood species includes *Acacia tortilis, Ailanthus excelsa, Albizia lebbeck, Bombax ceiba, Callistemon viminalis, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Parkinsonia aculeata, Pithecellobium dulce, Pongamia pinnata, Prosopis juliflora, Salix alba, Senna siamea, Lycium edgeworthii, Ricinus communis, Arundo donax, Phragmites karka, Saccharum bengalense* and *Saccharum spontaneum.* The Sanctuary also supports the population of Edible plants (21 species) like *Cordia myxa, Ficus racemosa, Mangifera indica, Moringa oleifera, Morus alba, Phoenix sylvestris, Phyllanthus emblica, Pithecellobium dulce, Schleichera oleosa, Trapa natans, Ziziphus nummularia, Amaranthus viridis, Chenopodium album*. *Syzygium cumini, Ziziphus mauritiana, Capparis decidua, Murraya koenigii, Basella alba* and *Nelumbo nucifera.* The local people also follow the traditional method of utilizing bio-resources for different purposes. Species such as *Dalbergia sissoo, Eucalyptus camaldulensis, Typha angustifolia, Arundo donax,* *Chrysopogon zizanioides, Phragmites karka, Saccharum bengalense, Saccharum spontaneum* and *Eichhornia crassipes* contributes to rawmaterial (9 species).

Distribution of useful plants across the habitat types

The diversity of habitat supports a wide range of vegetation that is used by the local inhabitants in the village on the Harike Wildlife Sanctuary's outskirts. A total of 115 species were observed in the field under various use categories across the habitat types (fig 4.18).

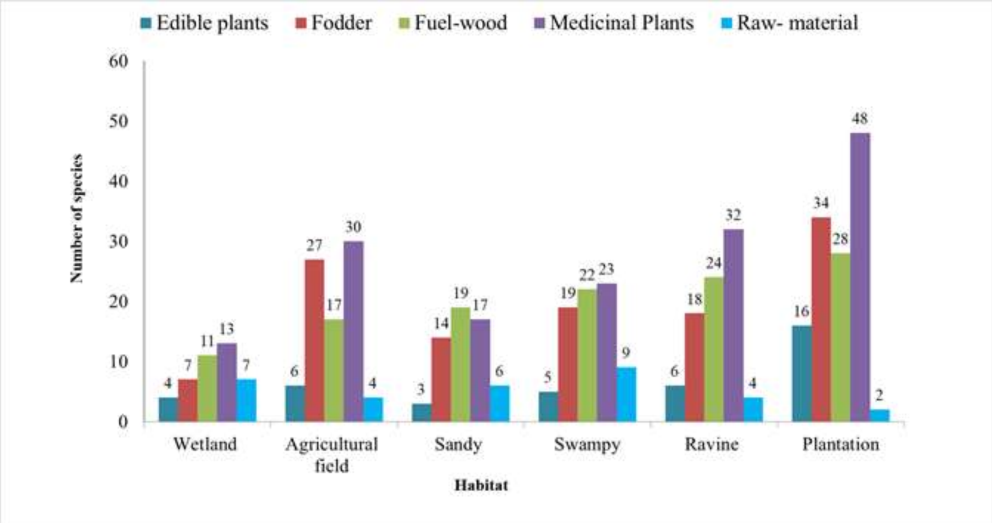


Fig 4.18: Number of species contributing provisional ecosystem services in each habitat.

The sanctuary's habitat types support populations of 48.5±20.95 species across all use categories. There are 85 species of useful plants in the Plantation habitat, with a mean of 25.6±17.52 for each use category. Medicinal plants have the most species (48 species), followed by fuel wood (28 species), fodder (34 species), edible plants (16 species), and raw materials (2 species). In the case of agricultural field habitat, a total of 54 kinds of beneficial plants were recognized. Agricultural filed habitat supports the population of 30 species of medicinal plants followed by 27 species of fodder, 17 species of fuel-wood and 6 species of edible plants.

A total of 50 species of valuable plants are found in the Ravine habitat along the River Beas in the north of the sanctuary, including 32 species of medicinal plants, 24 species of fuel wood, 18 species of fodder, 6 species of edible plants and 4 species of raw material. A total of 44 species were found in the swampy habitat, divided into five usage categories. There are 23 medicinal plant species in the swampy habitat, as well as 22 species of fuel wood, 19 species of fodder, 9 species of raw material and 5 species of edible plants. Sandy terrain along the Sutlej River, on the western edge of the Harike Wildlife Sanctuary, is home to a community of

34 species good for a variety of purposes. There were 19 species of medicinal plants documented in the Sandy habitat, followed by 17 species of medicinal plants, 14 species of fodder, 6 species of raw-material and 3 species of edible plants. The Sutlej, Beas and Kali-bein rivers all flow into this wetland ecosystem. Which supports a community of 24 valuable plant species, including 13 medicinal plants, 11 fuel-wood species, 7 rawmaterial and fodder species and 4 edible plant species.

Table 4.1: Species number and percentage under each family.

Family	Species (%)	Family	Species (%)
Acanthaceae	1 (0.87)	Malvaceae	4 (3.48)
Aizoaceae	1 (0.87)	Meliaceae	2 (1.74)
Amaranthaceae	4 (3.48)	Moraceae	5 (4.35)
Anacardiaceae	1 (0.87)	Moringaceae	1 (0.87)
Apiaceae	1 (0.87)	Myrtaceae	3 (2.61)
Apocynaceae	1 (0.87)	Nyctaginaceae	2 (1.74)
Arecaceae	1 (0.87)	Nymphaeaceae	1 (0.87)
Asparagaceae	1 (0.87)	Oxalidaceae	1 (0.87)
Basellaceae	1 (0.87)	Papaveraceae	2 (1.74)
Bignoniaceae	1 (0.87)	Pedaliaceae	1(0.87)
Boraginaceae	2 (1.74)	Phyllanthaceae	2 (1.74)
Brassicaceae	1 (0.87)	Plantaginaceae	1 (0.87)
Cannabaceae	1 (0.87)	Plumbaginaceae	1 (0.87)
Capparaceae	1 (0.87)	Poaceae	17 (14.78)
Chenopodiaceae	2 (1.74)	Pontederiaceae	1 (0.87)
Cleomaceae	1 (0.87)	Portulacaceae	1 (0.87)
Combretaceae	2 (1.74)	Rhamnaceae	2 (1.74)
Compositae	2 (1.74)	Rutaceae	2 (1.74)
Convolvulaceae	4 (3.48)	Salicaceae	1 (0.87)
Cucurbitaceae	2 (1.74)	Sapindaceae	1 (0.87)
Cyperaceae	1 (0.87)	Simaroubaceae	1 (0.87)
Euphorbiaceae	4 (3.48)	Solanaceae	7 (6.09)
Lamiaceae	1 (0.87)	Typhaceae	1 (0.87)
Leguminosae	15 (13.04)	Verbenaceae	1 (0.87)
Lythraceae	1 (0.87)	Zygophyllaceae	1 (0.87)

The economic value of ecosystem services

Economic valuation of Fuel wood

The economic valuation of fuelwood collection from a wildlife sanctuary involves assessing the monetary value associated with the collection and use of fuelwood resources from the Sanctuary. To estimate the quantity of fuelwood is being collected from the Sanctuary and to estimate the economic value of the fuelwood (fig 4.19).

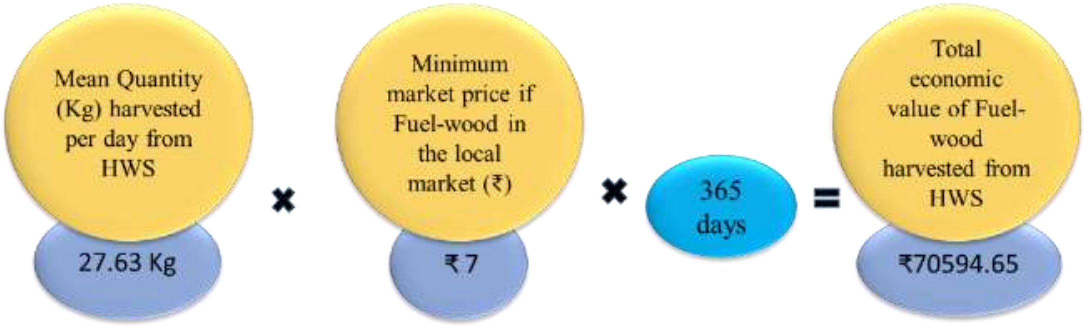


Fig 4.19: Process of economic valuation of fuel-wood.

A total of 37 species were identified which are contributing to the composition of fuel-wood for local people. Habitats like Swampy, Ravines and Plantation were used by local people for harvesting fuelwood (fig 4.21).

Fig 4.20: Fuelwood collection by locals at the fringe area of HWS.

Women were seen more frequent than men for fuelwood collection. In the Swampy habitat men (73.68%) and women (26.32%) were engaged in the collection of fuel wood, whereas in the Ravine habitat men (15.15%) and women (84.85%) were recorded and in the plantation habitat men (28.26%) and women (71.74%) visits for fuel-wood collection (Fig 4.20). To estimate the economic value of provisioning ecosystem services from fuelwood, the mean quantity of fuel-wood (27.63 kg) harvested per day is estimated then the lowest market price (₹7) fuelwood is recorded from the local market. A total of ₹70594.65 of provisioning ecosystem services for fuel-wood is provided by HWS in a year.

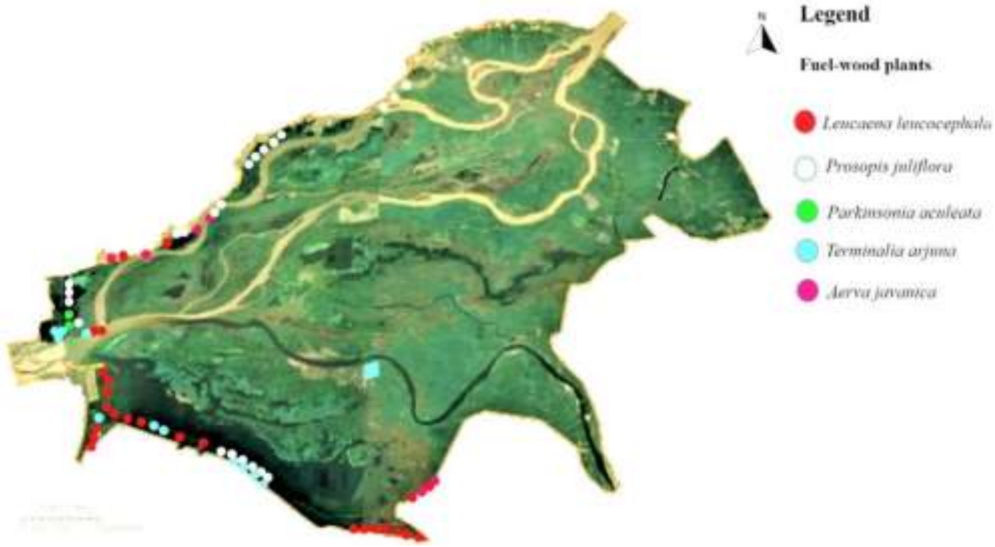


Fig 4.21: Distribution map of plants recorded as fuelwood.

Fodder (Grazing) consumption by livestock from the HWS

The plant species were identified which are consumed by different livestock across the habitat types of HWS. The mean population of livestock for a day is counted by line transect method and opportunistic survey. Pandey (2011) estimated the value of fodder consumed by different livestock based on a particular type of livestock fodder consumption in kg/ per day

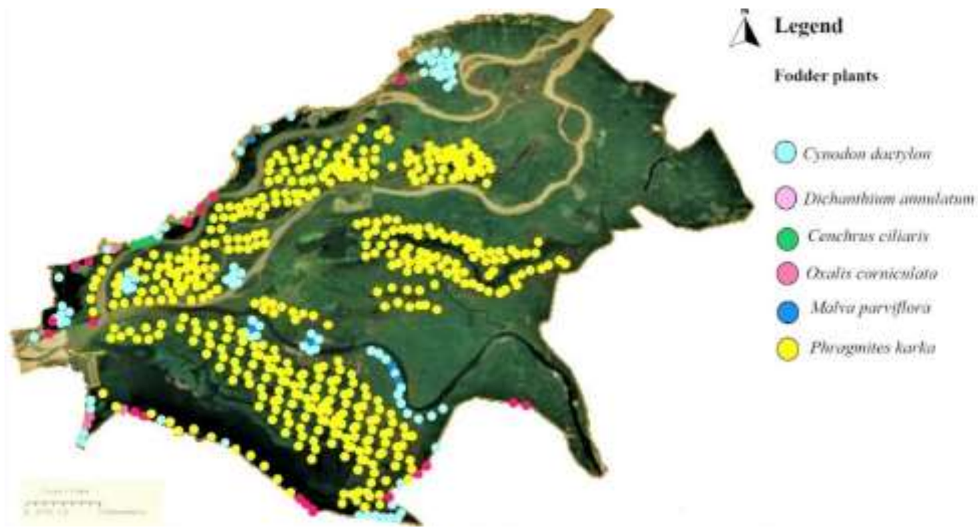


Fig 4.22: Distribution map of plants used by livestock as fodder.

Which is used in this study. The consumption of fodder is estimated according to a questionnaire with livestock attendants and farmers having livestock from nearby villages, secondary data is referred to as drive mean quantity of fodder consumption (kg/per day) by particular type of livestock. The economic value of fodder consumption by livestock was estimated by following Pandey (2011). Distribution of plants used as fodder is shown in the fig 4.22.

During the field survey, four types of livestock were recorded (Fig 4.25) viz. Buffalo (*Bubalus bubalis)* (55%), Cow (*Bos Taurus*) (30%), Goat (*Capra hircus*) (6%) and Sheep (*Ovis aries*) (9%). These livestock were recorded during grazing (Fig 4.23) mean population is recorded for Buffalo (96.67) followed by Cow (52), Sheep (16.33) and Goat (11) grazing per day in different habitat types (fig 4.21) of HWS. The questionnaire is used to infer the mean quantity of fodder in kg per day consumed by a particular type of livestock by local people. The individuals who feed their livestock at home or dairy were the ones who posed the questions.

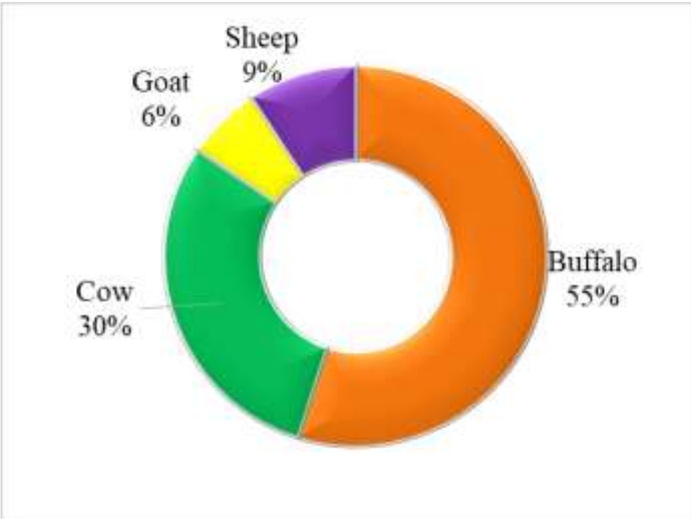


Fig 4.23: % of Livestock recorded in the HWS

The mean quantity of fodder consumption is recorded for Buffalo (20.7 kg) followed by Cow (18.5 kg), Goat (5 kg) and Sheep (5 kg). The provisional ecosystem service of fodder in the economic terms is calculated with the help of the market price of fodder in the local market (₹ 5kg^{-1}).

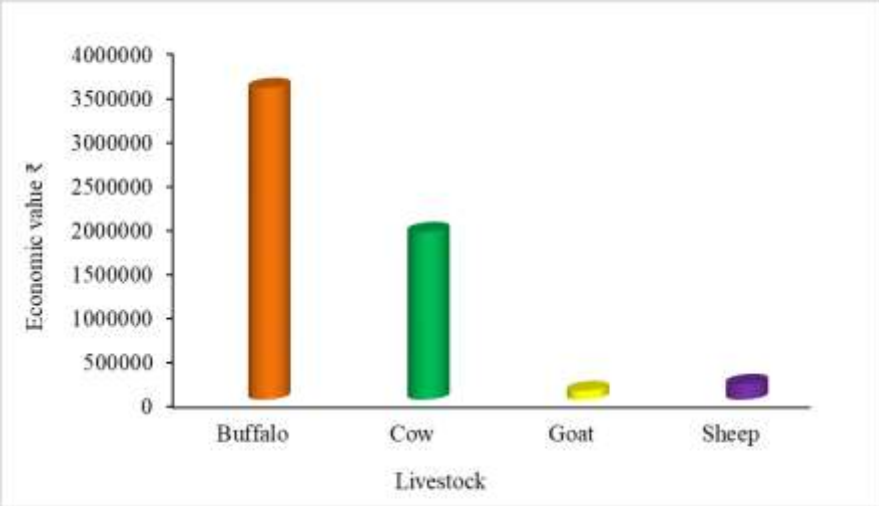


Fig 4.24: Economic value of the fodder consumed by livestock from HWS

Fig 4.25: Livestock grazing in the HWS

The total quantity of fodder consumed in a day is estimated by the mean population of the particular type of livestock multiplied by the mean quantity of fodder consumed by concerned livestock, therefore the maximum fodder consumed per day by buffalo (2001 kg for ₹10005) followed by cow (962 kg for ₹962), sheep (81.67 kg for ₹408.33), and goat (55 kg for ₹275). The economic value of fodder per day is estimated by multiplying the quantity of fodder (kg) per day with the minimum market price of fodder per kg. Maxium economic value of fodder consumed (Fig 4.24) by buffalo (₹3528333.33) followed by cow (₹1898000), goat (₹100375) and sheep (₹178850) (fig 4.20), therefore provisional ecosystem services for fodder worth ₹5656891.67 is estimated for the year.

Medicinal plants

During the field investigation, it is found that the people acknowledge many medicinal plants and people have been using those medicinal plants for various ailments. The species like *Centella asiatica* and *Bacopa monnieri* (Fig 4.27) are hydrophytes, whereas species such as *Withania somnifera, Withania coagulans* and *Datura metel* are mesophytes, these specie are shown in the map (Fig 4.26). The ethno-botanical study has been made concerning medicinal plants in HWS.

Fig 4.26: Distribution map of some medicinal plants in HWS.

During the investigation, only two people were found engaged in the collection and selling of medicinal plants in the market. Both plant collectors are agricultural labor as their main occupation but they can identify medicinal plants and have traditional knowledge of different medicinal plants. Some evidence has also been found during field investigation.

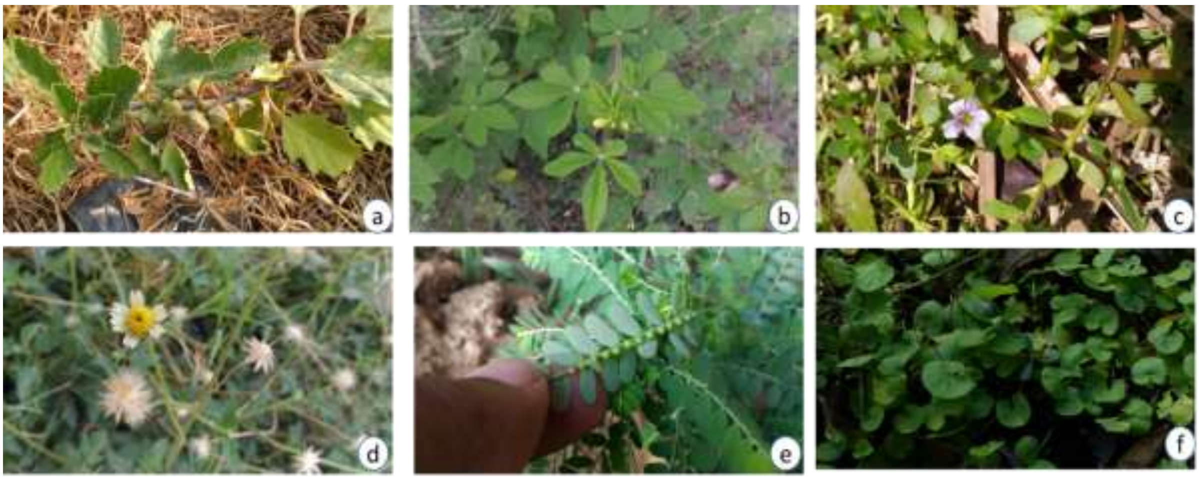


Fig 4.27: Some important medicinal plants found in the HWS (a-*Pedalium murex*, b-*Cleome viscosa*, c-*Bacopa monnieri*, d-*Tridax procumbens*, e- *Phyllanthus niruri*, f-*Centella asiatica*)

To estimate the economic value of medicinal plants collected from HWS is calculated based on market price. In the direct interview, informants accepted that they harvest medicinal plants like *Tribulus terrestris, Achyranthes aspera, Terminalia arjuna, Withania somnifera, Sisymbrium irio, Justicia adhatoda*, *Pedalium murex, Centella asiatica* and *Bacopa monnieri.* They get an economic benefit of ₹6000 to 10000 per year after selling different medicinal plants. Though, the local population uses different medicinal plants in the treatment of various ailments while the frequency of collection is very less, therefore, quantification of the total amount of medicinal plants harvested is a constraint.

Economic value of edible plants

The mosaic of habitat supports various plant species which yield edible fruits (fig 4.28). A total of 21 species were recorded that can be used as food, some species like *Phoenix sylvestris, Phyllanthus emblica, Pithecellobium dulce, Schleichera oleosa, Trapa natans, Ziziphus nummularia, Amaranthus viridis, Chenopodium album, Chenopodium murale, Syzygium cumini* and *Ziziphus mauritiana* were found important for consumption as food.

Fig 4.28: Distribution map of some edible plants.

It was not possible to estimate the quantity of each species that is consumed as food because of lack in systematic collection. Direct evidence was found for some species (Fig 4.30) like *Syzygium cumini*, *Capparis decidua, Mangifera indica*, *Ziziphus nummularia* and *Ziziphus mauritiana*, used by local people therefore it could be quantified for economic valuation with minimum market price.

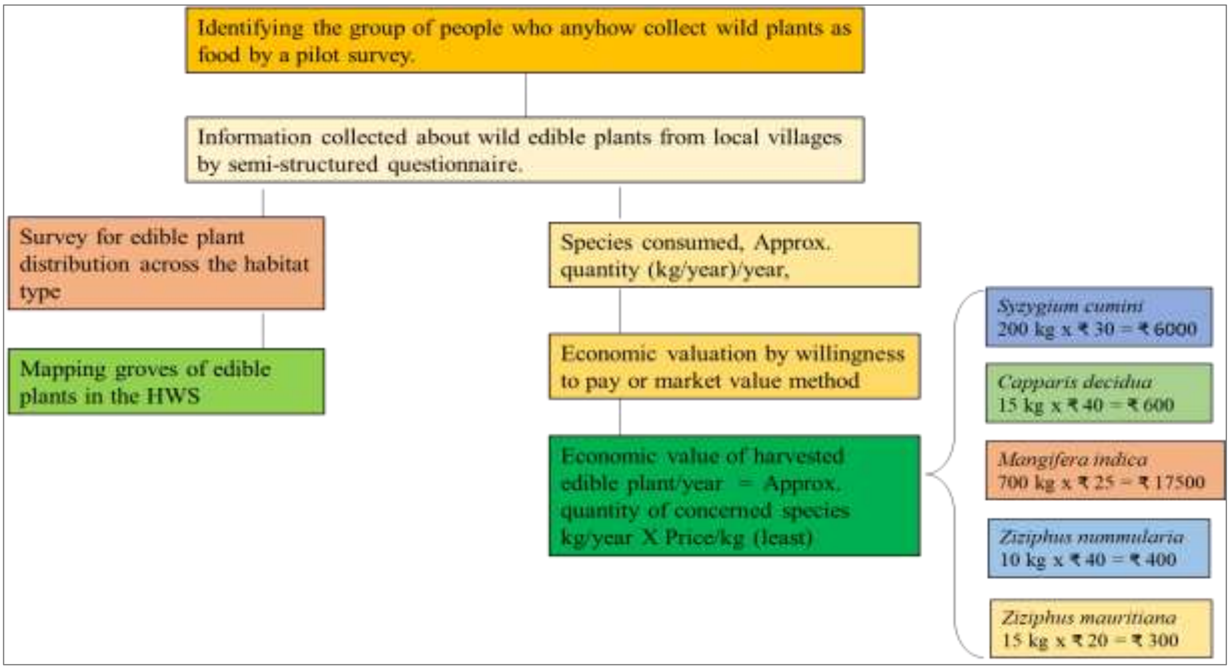


Fig 4.29: Economic value of selected plant used as food.

A total economic value estimated for considered species is ₹19,400 per year (Fig 4.29). Maximum economic value is estimated for *Mangifera indica* (₹17,500), followed by *Syzygium cumini* (₹6000), *Capparis decidua* (₹600), *Ziziphus nummularia* (₹400) and *Ziziphus mauritiana* (₹300).

Fig 4.30: Plant's support as food to the local community. a- *Ziziphus nummularia*, b- *Mangifera indica*, c- *Capparis decidua*, d- *Nelumbo nucifera* and e-*Cordia myxa*

Crops cultivated in HWS

In the summer and winter, respectively, rice and wheat are the main crops grown in the sanctuary's eastern region. These lands have traditionally provided for the needs of the local population. When the barrage was built across the river in 1952, the current agricultural was flooded, and the owners of those lands were compensated by lands at other locations with equal size. However, as the flooded wetland got sediments from the Beas and Sutlej rivers slowly over time, parts of the wetland started coming out of the water and people reclaimed their land then began cultivating crops. The wetland's north-eastern edge saw significant changes, which were accompanied by an expansion of agricultural land (Mabwoga and Thukral 2014).

The average economic benefit on crops has been asked from farmers and also been referred from secondary sources to validate the primary data therefore precise valuation could be possible. The crops like *Oryza sativa* and *Triticum* is cultivated on 3022.6 hectares in a different season where *Trapa natans* and *Nelumbo nucifera* were recorded in the area of 3.2 and 6.61 hectare respectively. The total economic value is estimated for each crop by multiplying the mean economic benefit per hectare on a particular crop with the total area under the concerned crop. The total economic value of crops as provisioning ecosystem services is estimated ₹30,27,93,834.03 per year. Maximum economic value is estimated for crop *Triticum* (₹190,357,302.8) followed by *Oryza sativa* (₹111,617,061.5), *Nelumbo nucifera* (₹587331.55) and *Trapa natans* (₹232,138.17).

Valuation of rawmaterial

During the field survey, two species such as *Eichhornia crassipes* and *Saccharum bengalense* were identified as raw materials for different purposes. These two species were distributed in various habitats (fig 4.30). The Water hyacinth (*Eichhornia crassipes*) is used for preparing stuff like bags, table covers and file covers. The fibers are extracted from water hyacinth to make useful products. *Saccharum bengalense* is used for various purposes like the construction of temporary huts in the agricultural field in the winter season. *Saccharum bengalense* is collected by local people in the winter season (fig 4.31) only where *Eichhornia crassipes* is available across the year.

Fig 4.31: Collection and utilization of *Saccharum bengalense* in and around HWS.

The data analysis revealed thst a total of 12600 clumps of *Saccharum bengalense* were calculated from different habitat types. In the field survey locations were collected for plants used as raw-material and mapped in fig 4.33. Maximum harvested clumps were recorded from Swampy (7087 clumps) followed by Sandy (3140 clumps) and Ravine (2373 clumps) habitat types (fig 4.32). The market price of one clump of *Saccharum bengalense* is up to ₹5.28 in local market. The local people engaged in the collection of *Saccharum bengalense* for sale for some purposes.

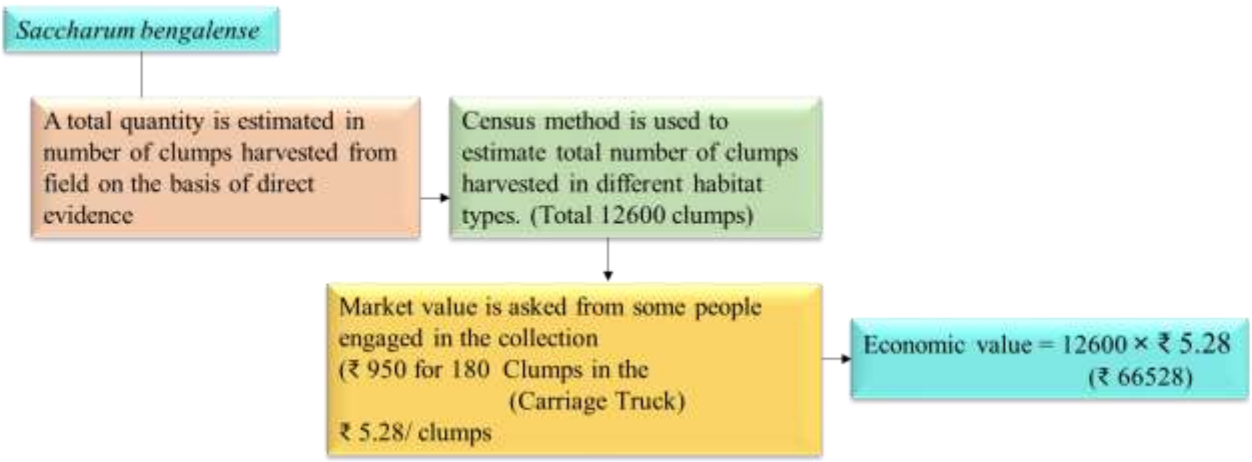


Fig 4.32: Economic value of *Saccharum bengalesnse* harvested from HWS.

To calculate the total economic value of harvested clumps of *Saccharum bengalense,* total number of clumps harvested is multiplied by the market price of a single clump therefore

Saccharum bengalense provides provisioning ecosystem services to local people with a worth of ₹ 66528 in a year.

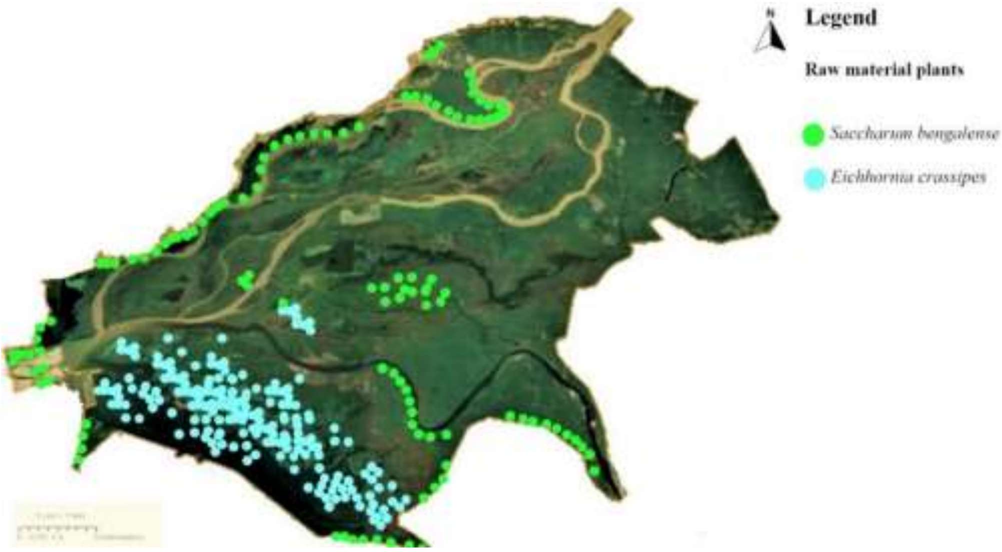


Fig 4.33: Distribution map of some plants used as Raw material.

Utility of *Eichhornia crassipes*

Eichhornia crassipes is a dominating floating vegetation in the wetland of HWS (fig 4.34). This species keep growing round the year but in monsoon season river Sutlej carries plenty of *Eichhornia crassipes* from the upper catchment area, while the same time some load of *Eichhornia crassipes* comes through River Beas. Local people use *Eichhornia crassipes* for manufacturing handmade bags, file-cover, bows, sleepers, pen pots, and handbags. The economic valuation of *Eichhornia crassipes* used as Raw-material is estimated based on market price. The total number of pieces (6000) of *Eichhornia crassipes* harvested in a year for manufacturing of different products is estimated by direct conversation with the people engaged in the process of collecting *Eichhornia crassipes* from the wetland, while the mean market price (₹20) of a piece is estimated from the online and offline selling sources. Total economic value is estimated by multiplying the total number of pieces used per year and the market price per piece, therefore provisional ecosystem services of *Eichhornia crassipes* as raw-material is estimated up to ₹120000/- in a year.

Fig 4. 34: Different products manufactured by using *Eichhornia crassipes.*

Seasonal variation in the availability of useful plants

Seasonal variations in the availability of useful plants have been registered from the sanctuary. In summer season, on an average 28.4±7.93 species can be found across all habitat types in HWS (fig 4.35). In summer season, HWS harbours 51 species of medicinal plants like *Terminalia bellirica, Ziziphus nummularia, Withania somnifera, Terminalia arjuna, Argemone ochroleuca, Datura metel, Cannabis sativa, Boerhavia diffusa, Bacopa monnieri, Cleome viscosa, Euphorbia thymifolia, Datura stramonium, Physalis minima, Euphorbia hirta,* *, Justicia adhatoda, Oxalis corniculata* and *Plumbago zeylanica* where as 37 species are used for Fuel-wood including *Parkinsonia aculeate, Pithecellobium dulce, Pongamia pinnata, Prosopis juliflora, Salix alba, Senna siamea, Terminalia arjuna, Aerva javanica, Artemisia scoparia, Cannabis sativa, Syzygium cumini, Typha angustifolia, Vachellia nilotica, Calotropis procera* and *Capparis decidua* and 27 species as fodder like, *Cynodon dactylon, Ziziphus mauritiana, Syzygium cumini, Cenchrus ciliaris, Dactyloctenium aegyptium, Phragmites karka, Saccharum spontaneum, Polypogon monspeliensis, Vachellia nilotica, Saccharum bengalense, Trianthema portulacastrum* and *Achyranthes aspera* used by local people.

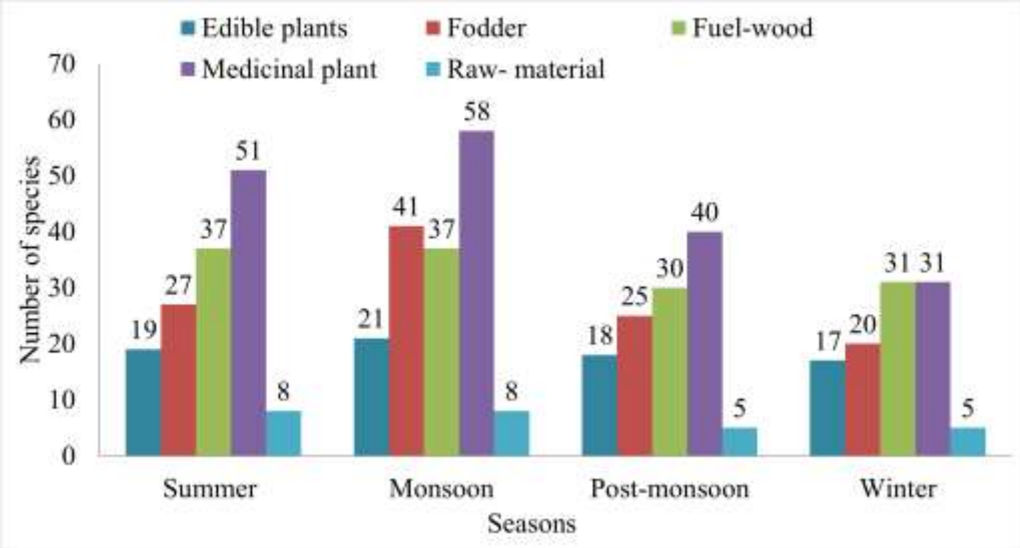


Fig 4.35: Seasonal variation in the plants' availability for provisional ecosystem services.

In summer season, 19 species are recorded as edible plants including *Cordia myxa, Ficus racemosa, Mangifera indica, Moringa oleifera, Morus alba, Chenopodium album*, and *Chenopodium murale.* During the filed survey people were seen collecting *Eucalyptus camaldulensis, Typha angustifolia, Chrysopogon zizanioides, Saccharum spontaneum, Phragmites karka, Saccharum bengalense* and *Eichhornia crassipes* are useful as rawmaterial. In the monsoon season, 33±8.58 species are available under different use-category. Important medicinal plants can be found across the habitat types of HWS. A total of 58 species were recorded during monsoon season, species include *Bacopa monnieri, Boerhavia diffusa, Withania somnifera, Boerhavia erecta, Eclipta prostrata, Euphorbia hirta, Phyllanthus niruri*, and *Physalis minima.* Fuel-wood is an important resource for certain people around the sanctuary.

A total of 37 species such as *Acacia tortilis, Ehretia laevis, Eucalyptus camaldulensis, Leucaena leucocephala, Parkinsonia aculeata, Pithecellobium dulce, Pongamia pinnata, Prosopis juliflora, Salix alba, Senna siamea, Terminalia arjuna, Aerva javanica, Artemisia scoparia, Cannabis sativa* and *Syzygium cumini* were recorded useful for Fuel-wood. The monsoon rain helps in the propagation and germination of various herbs and grasses that are also helpful for fodder for livestock, Total of 41 species were recorded as fodder and these species includes *Syzygium cumini, Vachellia nilotica, Ziziphus mauritiana, Basella alba, Coccinia grandis, Brachiaria ramose, Cenchrus ciliaris, Chloris barbata, Cynodon dactylon, Dactyloctenium aegyptium, Dichanthium annulatum, Digitaria ciliaris, Eleusine indica, Eragrostis minor, Panicum virgatum* and *Phragmites karka.* In monsoon season, a total of 21 species of edible plants have been recorded such as *Ficus racemosa, Mangifera indica, Morus alba* and *Syzygium cumini* get ripe besides some plants like *Amaranthus viridis* and *Basella alba* are used as edible plants and can be found in various habitat types. In monsoon season, species like *Typha angustifolia, Chrysopogon zizanioide, Phragmites karka, Saccharum bengalense, Saccharum spontaneum* and *Eichhornia crassipes* were recorded as useful for rawmaterial. Habitat types of Harike Wildlife Sanctuary support a community of plants providing provisional ecosystem services in post-monsoon for local people. A total of 23.6±5.87 species can be found in each use-category. Medicinal plants (40 species) like *Calotropis procera, Capparis decidua, Clerodendrum phlomidis, Murraya koenigii, Ricinus communis, Convolvulus arvensis, Cuscuta reflexa, Achyranthes aspera, Euphorbia hirta, Fumaria indica,* and *Justicia adhatoda* can be witnessed. A total of 30 species were registered for fuel-wood including *Callistemon viminalis*, *Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Leucaena leucocephala, Mangifera indica, Melia azedarach, Morus alba, Parkinsonia aculeata, Pithecellobium dulce, Pongamia pinnata, Prosopis juliflora, Salix alba*, and *Senna siamea*.

Several species which are used as fodder were recorded in the sanctuary during post-monsoon *Terminalia arjuna, Amaranthus viridis, Malva parviflora, Melilotus indicus, Syzygium cumini, Vachellia nilotica, Ziziphus mauritiana, Basella alba, Arundo donax, Cynodon dactylon, Dichanthium annulatum, Phragmites karka, Trianthema portulacastrum,* and *Achyranthes aspera*. Edible plants (18 species) used as food are *Cordia myxa, Ficus racemosa, Mangifera indica, Moringa oleifera, Morus alba, Phoenix sylvestris, Phyllanthus emblica, Pithecellobium dulce, Schleichera oleosa, Trapa natans, Ziziphus nummularia, Amaranthus viridis* and *Syzygium cumini.* The species available in a post-monsoon season used as raw-material (5 species) for various purposes include *Dalbergia sissoo, Eucalyptus camaldulensis, Arundo donax, Phragmites karka,* and *Eichhornia crassipes.* In winter season a total of 57 species were recorded in all use-category besides in each category 20.8±4.86 species can be collected from the different habitat types of the Sanctuary. In medicinal plant (31 species) category species like *Aegle marmelos, Azadirachta indica, Cassia fistula, Cordia myxa, Dalbergia sissoo, Ficus benghalensis, Ficus palmata, Ficus religiosa, Kigelia africana, Mangifera indica, Melia azedarach, Moringa oleifera, Phyllanthus emblica, Pongamia pinnata, Terminalia bellirica, Terminalia arjuna, Withania somnifera* and *Ziziphus nummularia.* As per field survey author recorded 31 species (table 4.2). In the winters season Fuel-wood harvesting increases for cooking and other domestic tasks, as the species include *Acacia tortilis, Ailanthus excela*, *Albizia lebbeck, Bombax ceiba, Callistemon viminalis, Dalbergia sissoo, Eucalyptus camaldulensis, Melia azedarach, Mangifera indica, Leucaena leucocephala Ehretia laevis, Pongamia pinnata, Pithecellobium dulce, Prosopis juliflora, Parkinsonia aculeate, Morus alba, Salix alba, Senna siamea, Terminalia arjuna, Cannabis sativa* and *Syzygium cumini.* A total of 20 species were recorded under the fodder use-category, some common species are *Mangifera indica*, *Morus alba*, *Parkinsonia aculeate*, *Pongamia pinnata, Terminalia arjuna*, *Amaranthus viridis*, *Syzygium cumini*, *Vachellia nilotica*, *Ziziphus mauritiana, Arundo donax*, *Avena sativa*, *Cynodon dactylon* and *Phragmites karka.*

Seventeen species that produce fruits and other edible parts for local people in different seasons were recorded during the investigation, includes *Aegle marmelos, Cordia myxa, Ficus racemosa, Mangifera indica, Moringa oleifera, Morus alba, Phoenix sylvestris, Ziziphus nummularia, Amaranthus viridis, Chenopodium murale, Syzygium cumini, Ziziphus mauritiana, Capparis decidua, Phyllanthus emblica, Pithecellobium dulce, Schleichera oleosa* and *Murraya koenigii.* In raw-material use-category a total of 5 species were recorded, including *Dalbergia sissoo, Eucalyptus camaldulensis, Arundo donax, Phragmites karka* and *Eichhornia crassipes*. Details of recorded species is given in table 4.3.

Table 4.2: Species richness of plants for provisional ecosystem services in different seasons.

Season	Edible plants	Fodder	Fuel-wood	Medicinal Plants	Raw-material	Mean
Summer	19	27	37	51	8	28.4±7.93
Monsoon	21	41	37	58	8	33±8.58
Post-monsoon	18	25	30	40	5	23.6±5.87
Winter	17	20	31	31	5	20.8±4.86
Mean	18.75±1.71	28.25±9	33.75±3.77	45±11.92	6.5±1.73	

Table 4.3: Plants used for provisional ecosystem services across use-categories, season and habitat type.

Plant species used for provisional ecosystem services (1-Present, 0-Absent)																		
		Seasons				Habitat types						Use-categories						
Species	Family	Summer	Monsoon	Post monsoon	Winter	Wetland	Sandy area	Plantation	Agriculture field	Ravine	Swampy	Edible Plants	Fodder	Fuel-wood	Medicinal Plants	Raw- material	Number of uses	Number of habitat types
Acacia tortilis (Forsk.) Hayne	Leguminosae	1	1	1	1	0	0	1	1	1	0	0	0	1	0	0	1	3
Achyranthes aspera L.	Amaranthaceae	1	1	1	0	0	0	0	1	1	1	0	1	0	1	0	3	3
Aegle marmelos (L.) Correa	Rutaceae	1	1	1	1	0	0	1	0	0	0	1	1	0	1	0	3	1
Aerva javanica (Burm.f.) Juss. ex Schult	Amaranthaceae	1	1	0	0	0	0	0	1	1	0	0	0	1	0	0	1	2
Ailanthus excelsa Roxb.	Simaroubaceae	1	1	1	1	0	0	1	0	1	1	0	1	1	0	0	3	3
Albizia lebbeck (L.) Benth.	Leguminosae	1	1	1	1	0	1	1	1	1	1	0	0	1	0	0	2	5
Amaranthus viridis L.	Amaranthaceae	0	1	1	1	0	0	1	0	0	0	1	1	0	1	0	3	1
Argemone ochroleuca Sweet	Papaveraceae	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1
Artemisia scoparia Waldst. & Kitam.	Compositae	1	1	0	0	0	1	1	1	1	1	0	0	1	0	0	2	5
Arundo donax L.	Poaceae	0	0	1	1	1	0	0	0	0	1	0	1	1	0	1	4	2
Asparagus officinalis L.	Asparagaceae	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Avena sativa L.	Poaceae	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	1
Azadirachta indica A. Juss.	Meliaceae	1	1	1	1	0	1	1	1	1	1	0	0	0	1	0	2	5
Bacopa monnieri (L.) Wettst.	Plantaginaceae	1	1	0	0	1	0	0	0	0	1	0	0	0	1	0	2	2
Basella alba L	Basellaceae	0	1	1	0	0	0	1	0	0	0	1	1	0	0	0	2	1
Boerhavia diffusa L.	Nyctaginaceae	1	1	0	0	0	0	1	1	1	1	0	0	0	1	0	2	4
Boerhavia erecta L.	Nyctaginaceae	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1
Bombax ceiba L.	Malvaceae	1	1	1	1	1	1	1	0	0	1	0	1	1	0	0	3	4
Brachiaria ramosa (L.) Stapf	Poaceae	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1
Callistemon viminalis (Sol. ex Gaertn.) G.Don	Myrtaceae	1	1	1	1	0	0	1	0	0	0	0	0	1	0	0	1	1
Calotropis procera (Aiton) Dryand	Apocynaceae	1	1	1	1	0	0	1	1	1	0	0	0	1	1	0	2	3
Cannabis sativa L.	Cannabaceae	1	1	0	1	0	1	1	1	1	1	0	0	1	1	0	3	5

Capparis decidua (Forssk.) Edgew	Capparaceae	1	1	1	1	0	0	0	0	1	0	1	0	1	1	0	3	1
Cassia fistula L.	Leguminosae	1	1	1	1	0	0	1	0	1	1	0	0	0	1	0	2	3
Cenchrus ciliaris L.	Poaceae	1	1	0	0	0	0	1	1	1	0	0	1	0	0	0	1	3
Centella asiatica (L.) Urb.	Apiaceae	0	1	1	0	1	0	0	0	0	1	0	0	0	1	0	2	2
Chenopodium album L.	Chenopodiaceae	1	1	0	0	0	0	1	1	0	0	1	0	0	0	0	1	2
Chenopodium murale L.	Chenopodiaceae	1	1	0	1	0	0	1	0	0	0	1	0	0	0	0	1	1
Chloris barbata Sw.	Poaceae	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1
Chrysopogon zizanioides (L.) Roberty	Poaceae	1	1	0	0	1	1	0	0	0	1	0	0	0	1	1	3	3
Citrullus colocynthis (L.) Schrad.	Cucurbitaceae	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1
Cleome viscosa L.	Cleomaceae	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Clerodendrum phlomidis L.f.	Lamiaceae	1	1	1	1	0	0	0	0	1	0	0	0	1	1	0	2	1
Clitoria ternatea L.	Leguminosae	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Coccinia grandis (L.) Voigt	Cucurbitaceae	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	2	2
Convolvulus arvensis L.	Convolvulaceae	0	1	1	0	1	1	1	1	1	1	0	0	0	1	0	2	6
Convolvulus prostratus Forssk	Convolvulaceae	1	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1
Cordia myxa L.	Boraginaceae	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	3	4
Cuscuta reflexa Roxb	Convolvulaceae	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1
Cynodon dactylon (L.) Pers.	Poaceae	1	1	1	1	0	1	1	1	1	1	0	1	0	0	0	2	5
Cyperus rotundus L.	Cyperaceae	0	1	0	0	1	1	0	1	0	1	0	0	0	1	0	2	4
Dactyloctenium aegyptium (L.) Willd.	Poaceae	1	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	2
Dalbergia sissoo DC.	Leguminosae	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	4	6
Datura metel L.	Solanaceae	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Datura stramonium L.	Solanaceae	1	1	1	0	0	0	1	1	1	0	0	0	0	1	0	1	3
Dichanthium annulatum (Forssk.) Stapf	Poaceae	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	1	1
Digera muricata (L.) Mart.	Amaranthaceae	1	1	0	0	0	1	1	1	0	0	0	1	0	0	0	1	3
Digitaria ciliaris (Retz.) Koeler	Poaceae	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1
Eclipta prostrata (L.) L	Compositae	0	1	1	0	1	1	0	0	0	1	0	0	0	1	0	2	3
Ehretia laevis (Rottler ex G. Don) Roxb.	Boraginaceae	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	3	5
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	1	1	1	1	1	0	0	0	0	1	0	0	0	0	1	2	2
Eleusine indica (L.) Gaertn	Poaceae	0	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	2
Eragrostis minor Host	Poaceae	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1

Eucalyptus camaldulensis Dehnh.	Myrtaceae	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	3	6
Euphorbia hirta L.	Euphorbiaceae	1	1	1	0	0	1	1	1	1	0	0	0	0	1	0	1	4
Euphorbia thymifolia L.	Euphorbiaceae	1	1	0	0	0	0	1	1	0	0	0	0	0	1	0	1	2
Ficus benghalensis L.	Moraceae	1	1	1	1	1	1	1	0	0	1	0	0	0	1	0	2	4
Ficus palmata	Moraceae	1	1	1	1	0	0	1	1	1	1	0	1	0	1	0	3	4
Ficus racemosa L.	Moraceae	1	1	1	1	0	0	1	0	0	0	1	1	0	0	0	2	1
Ficus religiosa L.	Moraceae	1	1	1	1	1	1	1	1	1	1	0	0	0	1	0	2	6
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	0	1	1	1	0	1	1	1	0	0	0	0	0	1	0	1	3
Grewia tenax (Forssk.) Fiori	Malvaceae	1	1	1	1	0	0	1	0	1	0	0	0	1	0	0	1	2
Ipomoea carnea Jacq.	Convolvulaceae	1	1	0	0	1	1	0	0	0	1	0	0	1	0	0	2	3
Jatropha gossypiifolia L.	Euphorbiaceae	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1
Justicia adhatoda L.	Acanthaceae	1	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Kigelia africana	Bignoniaceae	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1
Lantana camara L.	Verbenaceae	1	1	1	1	0	0	1	0	1	0	0	0	1	0	0	1	2
Leucaena leucocephala (Lam.) de Wit	Leguminosae	1	1	1	1	0	1	1	1	1	1	0	1	1	0	0	3	5
Lycium edgeworthii Miers	Solanaceae	1	1	1	1	0	0	0	0	1	0	0	0	1	0	0	1	1
Malva parviflora L.	Malvaceae	0	1	1	0	0	0	1	1	1	1	0	1	0	0	0	2	4
Mangifera indica L.	Anacardiaceae	1	1	1	1	0	0	1	0	0	0	1	1	1	1	0	4	1
Melia azedarach L.	Meliaceae	1	1	1	1	0	1	1	1	1	1	0	0	1	1	0	3	5
Melilotus indicus (L.) All.	Leguminosae	0	1	1	0	0	0	1	1	0	0	0	1	0	0	0	1	2
Moringa oleifera Lam	Moringaceae	1	1	1	1	0	0	1	1	0	0	1	0	0	1	0	2	2
Morus alba L.	Moraceae	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0	4	5
Murraya koenigii (L.) Spreng	Rutaceae	1	1	1	1	0	0	1	0	0	0	1	0	0	1	0	2	1
Nelumbo nucifera Gaertn.	Nymphaeaceae	1	1	0	0	1	0	0	0	0	1	1	0	0	0	0	2	2
Oxalis corniculata L.	Oxalidaceae	1	1	0	0	1	1	1	1	1	1	0	1	0	1	0	3	6
Panicum virgatum L.	Poaceae	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1
Parkinsonia aculeata L.	Leguminosae	1	1	1	1	0	0	1	0	1	0	0	1	1	0	0	2	2
Pedalium murex L.	Pedaliaceae	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1
Phoenix sylvestris (L.) Roxb.	Arecaceae	1	1	1	1	1	1	0	0	0	1	1	0	0	0	0	2	3
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	1	1	1	1	1	1	0	0	0	1	0	1	1	0	1	4	3
Phyllanthus emblica L.	Phyllanthaceae	1	1	1	1	0	0	1	0	0	0	1	0	0	1	0	2	1
Phyllanthus niruri L.	Phyllanthaceae	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	1	1
Physalis minima L.	Solanaceae	1	1	0	0	0	0	1	1	0	0	0	1	0	1	0	2	2

Pithecellobium dulce (Roxb.) Benth.	Leguminosae	1	1	1	1	0	0	1	0	0	0	1	0	1	0	0	2	1
Plumbago zeylanica L.	Plumbaginaceae	1	1	1	0	0	0	1	0	1	0	0	0	0	1	0	1	2
Polypogon monspeliensis (L.) Desf.	Poaceae	1	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	2
Pongamia pinnata (L.) Pierre	Leguminosae	1	1	1	1	0	0	1	1	1	1	0	1	1	1	0	4	4
Portulaca oleracea L.	Portulacaceae	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	1
Prosopis juliflora (Sw.)DC.	Leguminosae	1	1	1	1	0	1	1	1	0	1	0	0	1	0	0	2	4
Ricinus communis L.	Euphorbiaceae	1	1	1	1	0	0	1	0	0	0	0	0	1	1	0	2	1
Saccharum bengalense Retz	Poaceae	1	1	0	0	0	1	0	1	1	1	0	1	1	0	1	4	4
Saccharum spontaneum L.	Poaceae	1	1	0	0	0	1	0	1	1	1	0	1	1	0	1	4	4
Salix alba L.	Salicaceae	1	1	1	1	1	1	1	0	0	0	0	0	1	0	0	1	3
Schleichera oleosa (Lour.) Oken.	Sapindaceae	1	1	1	1	0	0	1	0	0	0	1	0	0	0	0	1	1
Senna occidentalis (L.) Link	Leguminosae	1	1	0	0	0	0	1	1	1	0	0	1	0	1	0	2	3
Senna siamea (Lam.) H.S.Irwin & Barneby	Leguminosae	1	1	1	1	0	0	1	0	0	0	0	0	1	0	0	1	1
Sida cordifolia	Malvaceae	1	1	0	0	0	0	1	1	0	0	0	0	0	1	0	1	2
Sisymbrium irio L.	Brassicaceae	0	0	1	1	0	1	1	1	1	0	0	0	0	1	0	1	4
Solanum nigrum L.	Solanaceae	1	1	0	0	0	0	1	1	1	0	0	0	0	1	0	1	3
Solanum virginianum L.	Solanaceae	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0	1	2
Syzygium cumini var. cumini	Myrtaceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	5	6
Terminalia bellirica	Combretaceae	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	1	1	1	1	1	1	1	1	0	1	0	1	1	1	0	4	5
Trapa natans L.	Lythraceae	1	1	1	0	1	0	0	0	0	0	1	0	0	0	0	1	1
Trianthema portulacastrum L.	Aizoaceae	1	1	1	0	0	0	1	1	0	0	0	1	0	0	0	1	2
Tribulus terrestris L.	Zygophyllaceae	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	2
Typha angustifolia L	Typhaceae	1	1	0	0	1	0	0	0	0	1	0	0	1	0	1	3	2
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	4	6
Withania somnifera (L.) Dunal	Solanaceae	1	1	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1
Ziziphus mauritiana Lam	Rhamnaceae	1	1	1	1	0	0	1	1	1	0	1	1	0	1	0	3	3
Ziziphus nummularia (Burm.f.) Wight & Arn.	Rhamnaceae	1	1	1	1	0	0	0	0	1	0	1	0	0	1	0	2	1

Present status of Ethnobotanical knowledge around HWS

Traditional health practices with medicinal plants have been supporting human civilizations globally and are being used to extract useful phytochemicals to produce modern medicine (Schippmann et al. 2002). Medicinal plants are usually accessible in plenty, particularly in the tropics. The effectiveness of any healthcare system endures due to suitable medicines. The marginal communities of society are unable to afford the cost of modern medicines hence medicinal plants are essential for healthcare (Rao 1991). Around 80% of people in Asia and Africa use traditional medicine (Oyebode et al. 2016). The Ayurveda, Unani, and Siddha healthcare systems evolved with medicinal plants in the course of a sequence of several centuries. Seventy-five percent of the needs of the third world are met by an estimated 6,000 species utilized in traditional and herbal medicine, while 3,000 plants have been formally recognized for their therapeutic benefits (Laldingliani et al. 2022). About 80% of the population of developing counties is actively engaged in using medicinal plants to treat health ailments (Hamilton 2004). The continuous rapid destruction of natural habitats is leading to the shrinking of the sources leading to the loss of biodiversity as well as the population of medicinal plants. Therefore, the studies of ethnobotany is important for developing conservation strategies (Panigrahi et al. 2021). The use of traditional knowledge of plant materials for disease treatment and prevention has got a lot of attention from the plant-based research community, which has led to an increase in drug discovery based on phytochemicals (Newman and Crag 2007; Anupama et al. 2014). There are many bioactive compounds usually acquired from plants. Few medicinal plants like *Tribulus terrestris* and *Urena lobata* have been identified as a repository of diosgenin and quercetin, respectively, *Acacia catechu* contains catechin and a climber *Basella alba* produces carotenoids (Khare 2008). Harike Wildlife Sanctuary (HWS) is a natural bank of medicinal plants and native flora, therefore regular monitoring is required to maintain such diversity as there are many natural and anthropogenic pressures like an invasion of alien species and encroachment. The objective of the present study is to document the medicinal plants used by local people settled around HWS besides developing a systematic record of traditionally used medicinal plants. This study also examines the variety of medicinal plant species found in various habitat types of HWS.

Demographical details

The Sanctuary is surrounded by agricultural fields and villages; the major population is engaged in mixed farming. Harike and Marrar village is the largest and smallest village around the Sanctuary, respectively. Developing fine communication between informants is necessary therefore, gathering information always starts with informal talks. After developing a familiarity with the informants, numerous questions had been asked. A total of 110 informants from six villages (22 from Makhu, 28 from Harike, 8 from Marrar, 15 from Kiriyan, 10 from Kambo-Dhaiwala, and 27 from Chamba Kalan) belong to different age groups and gender (87 men and 23 women) were interviewed for ethnobotanical use of plants, including literacy level and occupation (Table 4.4). The literacy level of informants was in the order: Illiterate (42.7%) > below matric (40.9%) > above matric (16.4%). The informants from the age group above 50 years were found to be more aware of the use and identification of medicinal plants. During the investigation, 3 individuals were found engaged in practicing drug preparation and sale, while 5 individuals were involved in the collection of medicinal plants. The knowledge of medicinal plants has been observed at a young age (< 40 years), but they were unable to identify the wild medicinal plants, besides many elder informants also accepted that there is a depletion in the population of medicinal plants and a loss of biodiversity due to habitat destruction and conversion of habitats into agricultural fields.

Table 4.4: Demographical information of adjacent village of HWS.

Variable	Category	Number of individuals
Gender	Male	87
	Female	23
Age	<30 years	6
	30-40 years	20
	40-50 years	22
	>50 years	62
Educational level	Illiterate	47
	< matriculation	45
	>matriculation	18

Taxonomic details

A total of 85 species belonging to 79 genera and 51 families have been mentioned by the informants to treat 40 different ailments (table 4.4). The maximum number of species were recorded from Leguminosae family (4 species), followed by Apiaceae, Apocynaceae, Brassicaceae, Euphorbiaceae, Lamiaceae, Myrtaceae, Papaveraceae, Rutaceae, Solanaceae, Zingiberaceae (3 species each) and Amaranthaceae, Amaryllidaceae, Combretaceae, Cucurbitaceae, Lythraceae, Malvaceae, Meliaceae, Moraceae, Phyllanthaceae, Poaceae (2 species each), while 30 families were represented by single species. Herbs (51.8%) were recorded as the higest used medicinal plants mentioned by informants followed by trees (27.1%), shrubs (11.8%), climbers (7.1%), and grasses (2.4%). There are 49 species common to the study conducted by Sidhu et al. (2011) with major species like *Allium cepa, Acacia nilotica, Allium sativum, Aegle marmelos, Aegle marmelos, Brassica campestris, Bryophyllum pinnatum, Argemone mexicana, Azadirachta indica, Citrus reticulata* and *Euphorbia hirta.* The study conducted in the Kapurthala district of Punjab by Kaur et al. (2017) shows that 29 species are common with major species like *Abutilon indicum, Achyranthes aspera, Aegle marmelos, Asparagus racemosus, Cinnamomum zeylanicum, Cassia fistula*, and *Ficus benghalensis*. However, Sidhu et al. (2012) reported 50 species common in the Jalandhar district of Punjab including *Achyranthes aspera, Argemone mexicana, Bacopa monnieri, Bryophyllum pinnatum, Calotropis procera, Brassica campestris, Camellia sinensis, Carica papaya, Cannabis sativa, Cassia fistula, Curcuma longa, Emblica officinalis, Ficus palmata, Fumaria indica* and *Piper nigrum.*

Table 4.5: Number of species, genera and families of ethnobotanical used plants.

Habit	Species	Genus	Family
Climber	6	5	4
Grasses	2	2	1
Herbs	44	41	26
Shrubs	10	10	3
Trees	23	21	17

Ethnobotanical use of species for various ailments

The ailments mentioned by the informants have been classified under 15 major ailments' categories along with the medicinal plant species (fig 4.36) used are in following order: Gastrointestinal with 48 species [ailments: constipation (15 species), diarrhea (12 species), indigestion (7 species), piles and stomachache (5 species each), gastritis (3 species), ulcer (1 species)] > Circulatory with 19 species [ailments: diabetes (13 species), anaemia (3 species), blood pressure (2 species), blood infection (1 species)] and General with 17 species [ailments: fever (8 species), cough & cold (5 species), headache (3 species), bee sting (1 species)] > Dental with 11 species [ailments: bad breath (1 species), periodontitis (5 species) and toothache (5 species)], Skeleton and Muscle with 10 species [ailments: arthritis (2 species), body pain (5 species), weakness (3 species)], Respiratory with 9 species [ailments: asthma (5 species), lung infection (4 species)] and Dermatological with 9 species [ailments: skin disease (5 species), cut and wound (4 species)] > Vital organs with 7 species [ailments: cardiovascular disease (1 species), kidney stone (2 species), liver disorder (4 species)] and Vector-Borne with 7 species [ailments: malaria (3 species), dengue (4 species)] and Body heat [ailment: Heatstroke] with 7 species > Mental with 6 species [ailments: memory loss (1 species), mental disorder (3 species), insomnia (2 species)], Genital with 6 species [ailments: sexual disorder (4 species), urinary tract infections (1 species), azoospermia (1 species)] and Hair with 6 species [ailment: hair loss] > Hepatic with 2 species [ailment: jaundice] > Ophthalmic with 1 species [ailment: eye irritation]. A detailed description of each medicinal plant is mentioned in Annexure II.

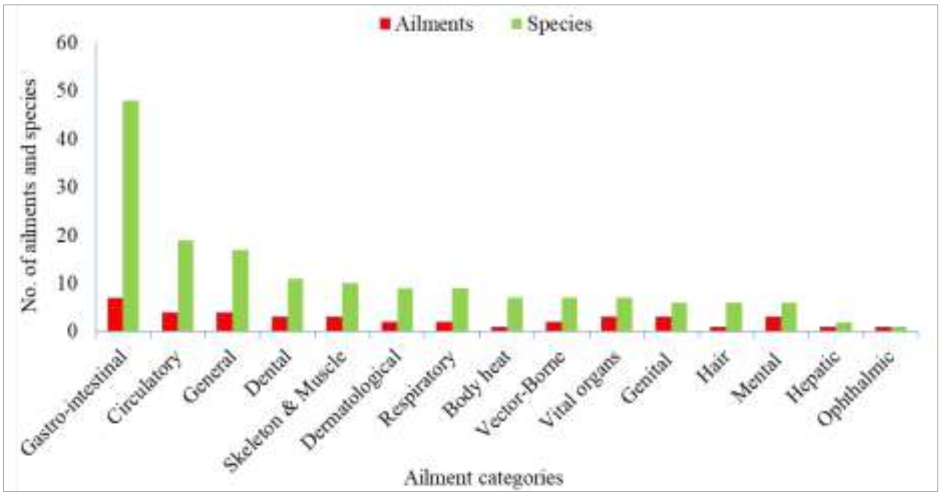


Fig 4.36: Number of species recorded under various ailment categories.

Plant parts used

The plant parts used (Fig 4.37) for medicinal purposes to treat various ailments is in the following order: Leaves (26 species) > Fruits (22 species) > Whole plant (14 species) > Seeds (11 species) > Roots (9 species) > Stem ≈ Rhizome (5 species each) > Latex (4 species) > Flower ≈ Bark (3 species) > Oil (2 species)

The species like *Achyranthes aspera, Azadirachta indica, Withania somnifera, Moringa oleifera* and *Carica papaya* contribute for leaves; *Aegle marmelos, Cordia myxa, Kigelia africana, Mangifera indica, Moringa oleifera, Musa paradisiaca, Phyllanthus emblica, Terminalia bellirica, Ziziphus nummularia,* and *Vachellia nilotica* for fruits; *Bacopa monnieri, Centella asiatica, Coriandrum sativum, Sisymbrium irio, Phyllanthus niruri, Euphorbia hirta, Cuscuta reflexa,* and *Fumaria indica* as whole plant; *Abrus precatorius, Achyranthes aspera, Asparagus officinalis, Azadirachta indica, Boerhavia diffusa, Beta vulgaris, Ficus palmata,* and *Solanum virginianum* for roots; *Brassica campestris, Cleome viscosa. Piper nigrum, Sisymbrium irio. Trachyspermum ammi, Vachellia nilotica* and *Trigonella foenum-graecum* for seeds; *Curcuma longa, Zingiber officinale, Allium sativum,* and *Allium cepa* for rhizome; *Azadirachta indica, Mimusops elengi, Achyranthes aspera, Nerium oleander* and *Pongamia pinnata* for stems; *Ficus palmata, Ficus benghalensis, Calotropis procera,* and *Argemone mexicana* for latex; *Azadirachta indica, Cinnamomum verum,* and *Terminalia arjuna* for bark; *Catharanthus roseus, Hibiscus rosa-sinensis,* and *Syzygium aromaticum* for flowers and *Brassica campestris* and *Ricinus communis* for oil.

Source for collection of medicinal plants

The medicinal plants were collected by the local inhabitants from various sources, such as wilderness areas, agricultural lands, wilderness areas/agricultural lands and market (Fig 4.38) The study area is primarily dominated by agricultural fields, which supports many cultivated species, among them 23 species used for medicinal purposes as cited by the informants, *Curcuma longa, Allium sativum, Zingiber officinale, Bryophyllum pinnatum, Ocimum tenuiflorum, Brassica campestris, Ocimum basilicum, Raphanus sativus, Trigonella foenum-graecum, Beta vulgaris, Murraya koenigii* and *Allium cepa* were the common species. However, species like *Asparagus officinalis, Mangifera indica, Phyllanthus emblica, Syzygium cumini, Psidium guajava, Moringa oleifera, Melia azedarach, Papaver rhoeas, Mangifera indica* and *Nerium oleander* were collected from the wilderness areas. The maximum species (45 species) were collected from the wilderness areas according to informants and the prominent species were *Tinospora cordifolia, Datura metel, Cannabis sativa, Tribulus terrestris, Phyla nodiflora, Pedalium murex, Cordia myxa, Withania somnifera, Achyranthes aspera, Ricinus communis, Bacopa monnieri, Calotropis procera* and *Lawsonia inermis*. The species like *Piper longum, Piper nigrum, Trachyspermum ammi, Syzygium aromaticum, Camellia sinensis, Amomum subulatum* and *Cinnamomum verum* were procured from the market only.

Preparation of drug

Various modes of consumption of medicinal plants for the treatment of different ailments mentioned by informants are in Fig 4.39. The treatment of different ailments with the change in combination is in the following order: Decoction (19 species) > Raw form (18 species) > Fresh juice (17 species) > Powder (10 species) > Blend (9 species) > Fresh fruits (6 species) > Paste (6 species) > Smoke ≈ Fry (1 species each)

The important species used for decoction were: *Tinospora cordifolia, Justicia adhatoda, Fumaria indica, Cleome viscosa, Cinnamomum verum, Chenopodium ambrosioides, Amomum subulatum, Piper nigrum, Curcuma longa* and *Zingiber officinale;* as raw forms: *Abutilon indicum, Allium sativum, Azadirachta indica, Euphorbia hirta, Euphorbia prostrate, Withania somnifera* and *Zingiber officinale*.

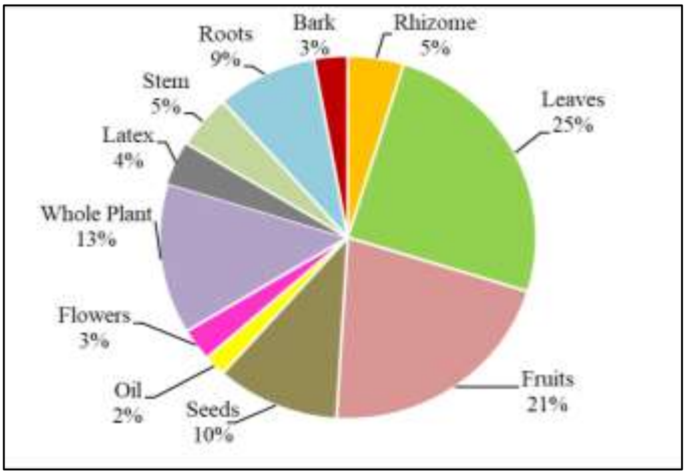


Fig 4.37: Plant parts used as a drug

As fresh juice: *Aegle marmelos, Punica granatum, Phyllanthus niruri, Citrus aurantium, Lagenaria siceraria, Raphanus sativus, Allium cepa* and *Carica papaya*; as powder: *Abrus precatorius*, *Curcuma longa, Terminalia bellirica, Tribulus terrestris, Vachellia nilotica, Withania somnifera* and *Tribulus terrestris*; as blend or juice: *Aegle marmelos, Carica papaya*, *Brassica campestris, Beta vulgaris, Zingiber officinale, Ricinus communis, Hibiscus rosa-sinensis, Mangifera indica* and *Ficus palmata*.

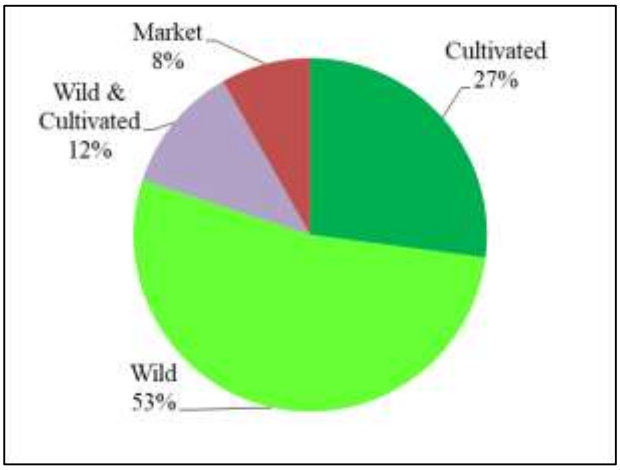


Fig 4.38: Sources of medicinal plants

As fresh fruits: *Cordia myxa, Phyllanthus emblica, Ziziphus nummularia* and *Syzygium cumini*; as paste: *Lawsonia inermis, Mimusops elengi, Oxalis corniculata, Papaver rhoeas* and *Phyla nodiflora*, while *Cannabis sativa* as smoke and *Sisymbrium irio* as fry administered to cure various ailments.

Administration of drug

The drugs administered orally were 84.7% and the major species were *Withania somnifera, Phyllanthus emblica, Piper longum, Terminalia arjuna, Tinospora cordifolia, Vachellia nilotica, Phyllanthus emblica, Raphanus sativus* and *Justicia adhatoda.*

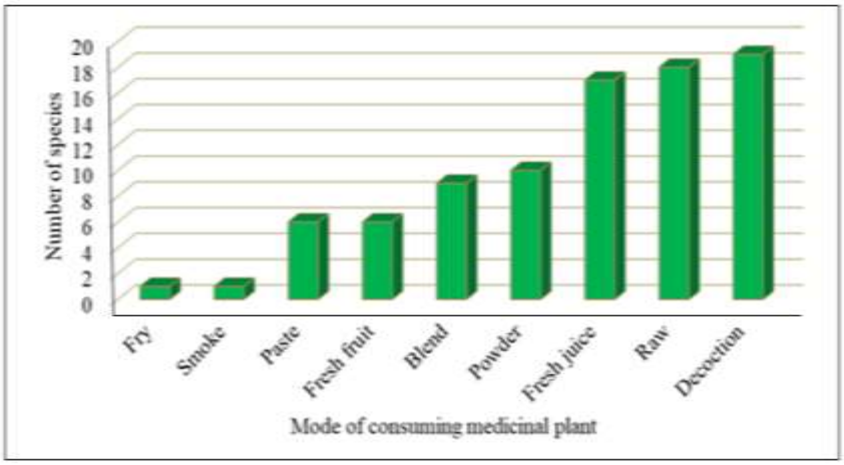


Fig 4.39: Mode of consuming medicinal plants.

The drugs administered topically were 11.8% and the major species were *Ageratum conyzoides, Argemone mexicana, Calotropis procera, Cuscuta reflexa, Eclipta prostrata, Ficus palmata, Hibiscus rosa-sinensis, Lawsonia inermis, Mimusops elengi* and

Nerium oleander. However, the drugs administered orally/topical were 3.5% and the species were *Allium cepa, Azadirachta indica,* and *Mangifera indica.*

Use Value

The UV of medicinal plants ranged from 1.8 to 0.3 in the study area and are given in Annexure II. The higher UV indicates more utilization of a species. Species with high UV are *Tinospora cordifolia* and *Curcuma longa* (1.8 each), *Piper longum* and *Allium sativum* (1.2 each), *Zingiber officinale* (1.0), *Euphorbia hirta*, *Azadirachta indica* and *Justicia adhatoda* (0.9 each) and *Withania somnifera* (0.8). However, species with low UV are *Fumaria indica* (0.09), *Pedalium murex* (0.09), *Tribulus terrestris* (0.08), *Cannabis sativa* (0.06), *Phyllanthus niruri* (0.06) and *Datura metel* (0.03).

Relative Importance (RI)

The RI (Table 4.7) has been driven by the number of ailment categories for a particular species and the number of uses for concerned species, therefore the species which were recorded under various uses with multiple ailment categories exhibit higher value. The higher RI of medicinal plants suggests the level of awareness and use for the treatment of various ailments. In the present study, the higher RI were recorded for *Allium sativum* with RI value 2 (7 uses under 5 ailment categories) followed by *Azadirachta indica* with RI value 1.86 (6 uses under 5 ailment categories), *Curcuma longa* with RI value 1.51 (5 uses under 4 ailment categories) and *Withania somnifera, Punica granatum, Oxalis corniculata* and *Cleome viscosa* with RI value 1.37 (each with 4 uses under 4 ailment categories). The least RI value (0.34) was recorded for *Ricinus communis, Ficus benghalensis, Amomum subulatum, Hibiscus rosa-sinensis, Lawsonia inermis, Argemone mexicana, Catharanthus roseus, Ficus palmata* and *Sisymbrium irio*.

Fidelity Level (FL)

FL is useful to know the most preferred species used by the informants for treating certain ailments and is given in Table 4.7. The FL specifies that certain species are used for the treatment of a particular ailment and is expressed in the percentage, given in Table 3. The FL values for different ailments like fever, blood infection, and constipation were 70%, 80%, and 40%, respectively shown by *Fumaria indica*. Similarly, FL values of *Withania somnifera* were 91.8% for malaria, 94.1% for the sexual disorder, and 65.9% for Stomachache. The species with 100% FL values for the treatment of certain ailments include *Catharanthus roseus*

(Diabetes), *Camellia sinensis* (Diarrhoea) *Cleome viscosa* (Fever), *Mimusops elengi* (Periodontitis), *Argemone mexicana* (Skin disease), *Amomum subulatum* (Indigestion), *Datura metel* (Insomnia) and *Phyllanthus niruri* (Jaundice).

Collection of medicinal plants

There are 6 major habitat types in the HWS and each habitat type supports a population of wild medicinal plants viz. Plantation (16 species of trees, 2 species of shrubs,18 species of herbs, 1 species of grass, and 4 species of climbers), Agricultural fields (7 species of trees, 1 species of shrub, 12 species of herbs, 1 species of grass, and 1 species climber), Swampy (9 species of trees, 9 species of herbs, 2 species of grass, and 2 species climbers), Wetland (5 species of trees, 6 species of herbs, and 1 species of grass), Sandy (6 species of trees, 10 species of herbs, and 2 species of grass), and Ravine (5 species of trees, 2 species of shrubs, 13 species of herbs,1 species of grass, and 1 species of climber) and are shown in Fig 4.40. The harvesting time of different medicinal plants has been recorded to estimate the annual availability of wild medicinal plants for locals. A total of 45 medicinal plant species are collected from the wild and the mean number of species available for harvesting is 25.4±8.4 species in a year at any point in time.

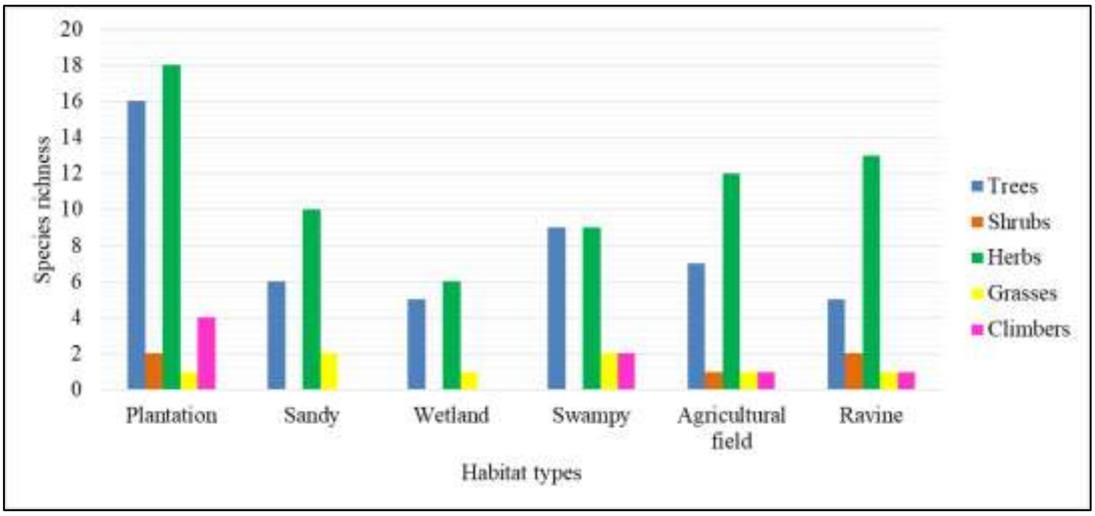


Fig 4.40: Species richness of wild medicinal plants across the habitat types.

Nine species found throughout the year for medicinal use are (tree: *Azadirachta indica, Ficus benghalensis, Ficus palmata, Mimusops elengi, Pongamia pinnata, Terminalia arjuna, Vachellia nilotica*; shrub: *Calotropis procera* and herb: *Withania somnifera*). It has been observed that there is a seasonal variability in the availability of medicinal plants for collection as shown in (Fig 4.41). There are 13 medicinal plant species available for harvest in the winter season (January-February) including species like *Abrus precatorius, Ageratum conyzoides, Sisymbrium irio* and *Ziziphus nummularia*.

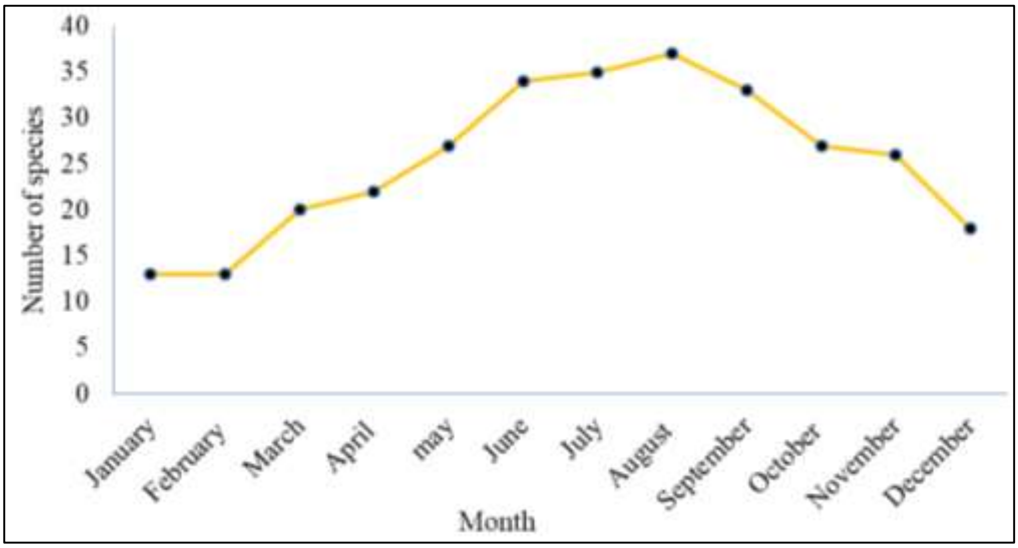


Fig 4.41: Availability of wild medicinal plant species across months.

A total of 27 species including *Tribulus terrestris, Cleome viscosa, Argemone mexicana, Justicia adhatoda,* and *Boerhavia diffusa* are available for harvest in the summer season (March-June), wherein 37 species comprising *Euphorbia hirta, Bacopa monnieri, Centella asiatica, Cordia myxa, Datura metel, Nyctanthes arbor-tristis,* and *Tinospora cordifolia* can be found in monsoon season (July-September). However, 27 species including *Chrysopogon zizanioides, Kigelia africana, Pedalium murex, Terminalia bellirica,* and *Ricinus communis* are available for harvest in the post-monsoon season (October-December) (Table 4.7). Some medicinal plants are seasonal and hence not available throughout the year for use. The timeline chart of medicinal plants available in the field is given in Table 4.6.

The availability of wild medicinal plants in the study area is depicted in grey color (a timeline chart) (Table 4.6). The month of collection for medicinal plants from the field is mentioned according to informants.

Table 4.6: Availability of wild medicinal plants in the study area across the year.

Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Abrus precatorius L.	■	■	■									
Abutilon indicum (L.) Sweet					■	■	■	■				
Achyranthes aspera L			■	■	■	■	■	■				
Aegle marmelos (L.) Correa						■	■	■	■			
Ageratum conyzoides L	■	■	■								■	■
Argemone mexicana L.					■	■	■	■	■			
Azadirachta indica A. Juss.	■	■	■	■	■	■	■	■	■	■	■	■
Bacopa monnieri (L.) Wettst.					■	■	■	■	■			
Boerhavia diffusa L.			■	■	■	■	■	■	■			
Calotropis procera (Aiton) Dryand	■	■	■	■	■	■	■	■	■	■	■	■
Cannabis sativa L.			■	■	■	■	■	■				
Centella asiatica (L.) Urb.					■	■	■	■	■			
Chenopodium ambrosioides L.			■	■	■	■	■	■	■	■		
Chrysopogon zizanioides (L.) Roberty										■	■	■
Cleome viscosa L				■	■	■	■					
Cordia myxa L.								■	■			
Cuscuta reflexa Roxb				■	■	■	■	■	■	■	■	■
Cynodon dactylon (L.) Pers.			■	■	■	■	■	■	■	■	■	
Datura metel L.								■	■	■	■	
*Eclipta prostrata (*L.) L			■	■	■	■	■	■	■			
Euphorbia hirta L.			■	■	■	■	■	■	■	■	■	
Euphorbia prostrata Aiton				■	■	■	■	■	■			
Ficus benghalensis L.	■	■	■	■	■	■	■	■	■	■	■	■
Ficus palmata Forssk.	■	■	■	■	■	■	■	■	■	■	■	■
Fumaria indica (Hausskn.) Pugsley					■	■	■	■	■	■	■	■
Justicia adhatoda L.				■	■	■	■	■	■	■		
Kigelia Africana L										■	■	■
Lawsonia inermis L.				■	■	■	■	■	■			
Melia azedarach L.				■	■	■	■	■	■			
Mimusops elengi L.	■	■	■	■	■	■	■	■	■	■	■	■
Nyctanthes arbor-tristis L				■	■	■	■	■	■			
Oxalis corniculata L		■	■	■	■	■	■	■	■	■	■	
Papaver rhoeas L									■	■	■	
Pedalium murex L.										■	■	
Phoenix sylvestris (L.) Roxb								■	■			
*Phyla nodiflora (*L.) Greene						■	■	■	■			
Phyllanthus emblica L.										■	■	■
Phyllanthus niruri L						■	■	■	■			
Pongamia pinnata (L.) Pierre	■	■	■	■	■	■	■	■	■	■	■	■

Ricinus communis L.									■	■	■	
Solanum virginianum L.										■	■	■
Sisymbrium irio L	■	■	■									
Syzygium cumini var. cumini						■	■	■				
Terminalia arjuna (Roxb. ex DC.) Wight & Arn	■	■	■	■	■	■	■	■	■	■	■	■
Terminalia bellirica (Gaertn.) Roxb									■	■	■	
Tinospora cordifolia (Willd.) Miers						■	■	■	■	■	■	■
Tribulus terrestris L.						■	■	■	■			
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	■	■	■	■	■	■	■	■	■	■	■	■
Withania somnifera (L.) Dunal	■	■	■	■	■	■	■	■	■	■	■	■
Ziziphus nummularia (Burm.f.) Wight & Arn.	■	■	■									

Economic value of sand

The Sandy habitat is dominated by *Saccharum bengalense*, and *Saccharum spontaneum* which provides a platform to sand particles to get deposited with in the standing crop of tall grasses. A significant amount of sand on the banks of Sutlej Rivers provides fertile ground for new recruitment of Saccharum *bengalense,* and *Saccharum spontaneum* with other associated herbs like *Cannabis sativa*, *Eclipta prostrata*, *Cyperus rotundus*, and *Verbesina encelioides*. The sandy habitat is found useful for some local people. A point count has been made followed by a personal interview along with seasonal changes happing in the sandy habitat. In the field intervention, people were seen collecting sand without using any kind of modern tools or vehicles. The sand extraction was seen in all seasons except Monsoon. The local people use Bullock carts to carry sand. On average 14.09±3.24 Bullock carts were recorded per day and a single Bullock cart can be sold for ₹400 in the market, therefore Sandy habitat provides provisioning ecosystem services in the form of sand worth ₹5636 per day. The sand worth ₹1600800 is being extracted in a year.

Value of water supply to Indira Gandhi canal

The catchment draining into the wetland increases during the monsoon season. The Harike wetland provides water to Rajasthan's magnificent Indira Gandhi Canal. The wetland is said to be rich in subsurface water resources, and the lake's perimeter is surrounded by agricultural land. The Secondary data suggested that the mean amount of water discharge accounts for 18500 cubic feet per second (www.rajras.in/indira-gandhi-canal). The head-works constructed on the Sutlej River downstream of its confluence with the Beas River, which forms the Harike wetland and the expanded wetland, are a deliberate project that serves for irrigation and drinking water supplies through Firozpur, and Rajasthan, feeder canals (Fig 4.42) to supply to the command areas situated in the states of Punjab and Rajasthan.

Fig 4.42: Indira Gandhi canal beginning from Harike wetland.

To determine the market price of water discharged from Harike wetland into the Indira Gandhi Canal. Secondary data was collected through informal conversations with the on-ground staff of irrigation departments of Punjab and Rajasthan. In the conversation official admitted that there is fluctuation in the water supply in different months besides the irrigation department spending several days for maintenance work in a year, therefore, the value is estimated at 300 days.

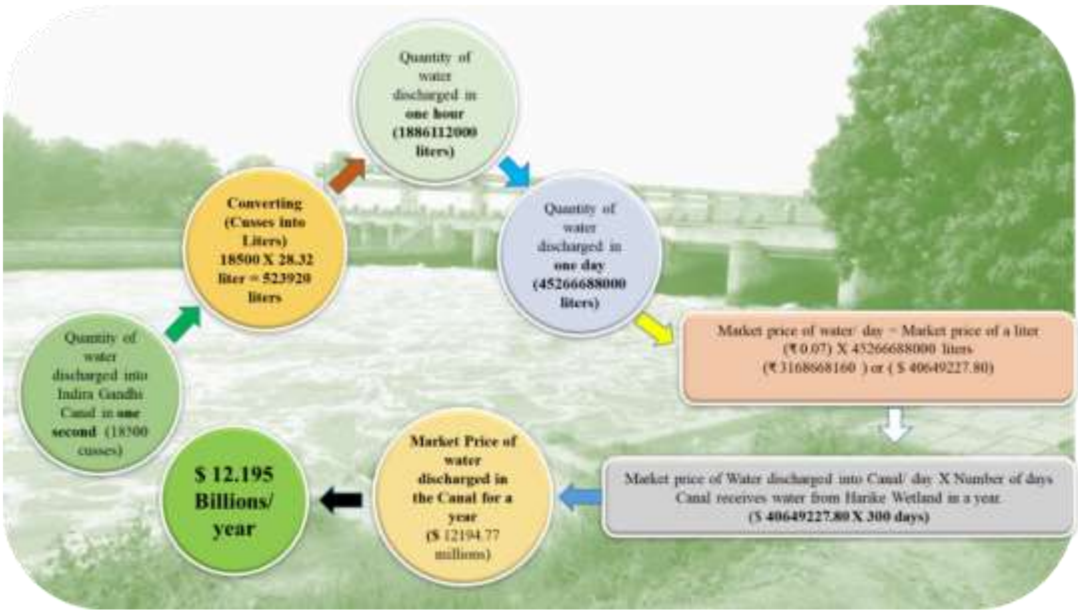


Fig 4.43: Market Price of Water Discharged in Indira Gandhi Canal from HWS.

Natural areas among the settled regions of Beas and Sutlej River offer various goods and services that have economic values, not just for the individuals within or adjacent to those natural areas but additionally for the communities remoter away.

Serving as sources of natural capital, these areas provide such goods and services as clean water supply, water flow stabilization, Greenhouse gas mitigation, erosion control, nutrient cycling, genetic resources, biodiversity, tormenter management, habitat, recreation, and cultural pursuits. Nonetheless, these natural areas are facing degradation and encroachment undoubtedly, the quantity of those natural areas to society way outweighs any gains from changing them for human uses admire urban development or intensive agriculture.

The estimated daily flow of water into the Indra Gandhi Canal is 4.527 billion liters, and the market price of a litter of water is calculated at ₹ 0.7 per litter. This means that over 300 days, the total economic value of the water discharged into the Indra Gandhi Canal from the Harike Wetland is estimated (Fig 4.43) to be ($12.195 billion) per year.

Economic value of water utilized for rice and wheat cultivation

The primary goal of water irrigation is to provide crops with an adequate amount of water to support their growth, development, and yield. Irrigation helps compensate for water deficits caused by natural rainfall patterns, seasonal variations, or specific crop water requirements.

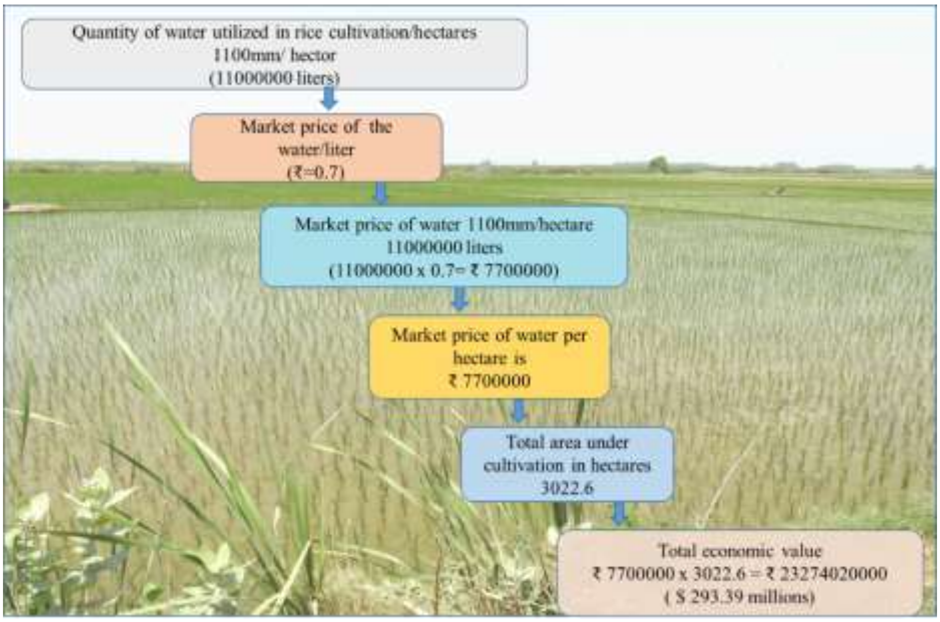


Fig 4.44: Estimation of the market price of water required for rice cultivation.

The water extraction by Pumps for irrigation of agricultural filed. Wheat and Rice are the major crops cultivated within and outside the study area. A total of 3022.6 hectares are under farming by local people. Rice requires irrigation water up to 1100mm ha^{-1} where Wheat requires around 500mm ha^{-1} of water from sowing to harvesting.

To estimate the quantity of water used for the cultivation of particular crops within the sanctuary, secondary information is used from Tiwana et al. (2005) and Kaur et al. (2015). According to the local market price of water, rice (Fig 4.44) consumes water worth ($293.39 million), and water used for growing wheat in an area of 3022.6 ha, consumes water worth ($133.36 million). A total value of $ 426.75 million of ecosystem services for irrigation (Fig 4.45) is provided by Harike wetland for the cultivation of wheat and rice in 3022.6 ha.

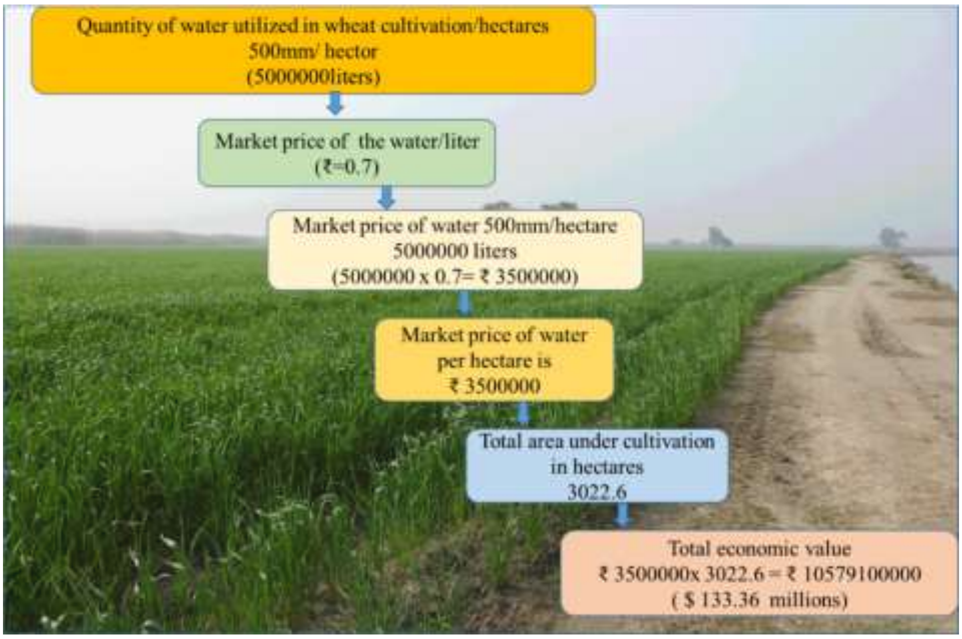


Fig 4.45: Estimation of the economic value of water utilized for cultivation of the wheat crop.

Economic value of water used for domestic purposes.

The mean quantity of water used for domestic purposes is estimated up to 840±215.79 liters per day by a household, which accounts for ₹836.14 in terms of economic benefit to each household after deducting electricity cost (₹3.86) used for running the pump.

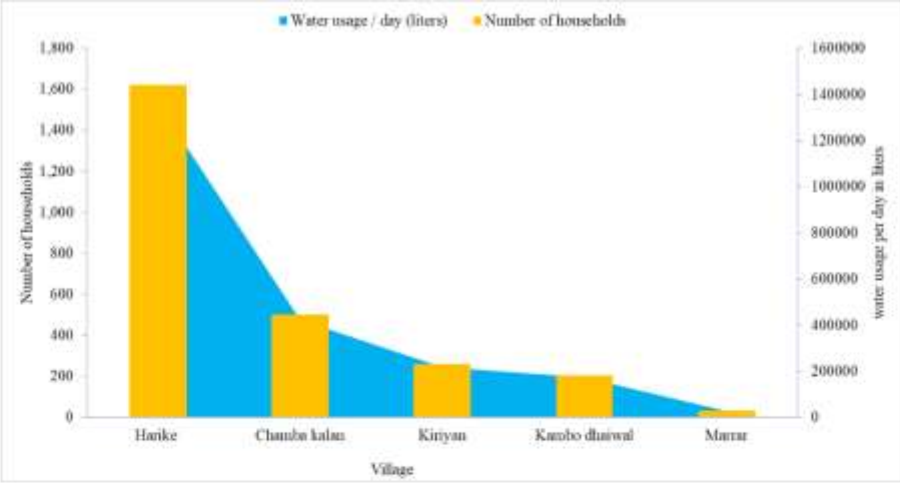


Fig 4.46: Strength of households and quantity of water usage.

The total number of households in Harike village near about 1,620, followed by Chamba kalan (503 households), Kiriyan (259 households), Kambo dhaiwal (206 households), and Marrar village recorded with the lowest number of households (32) (Fig 4.46). The people use hand pumps and submersible pumps for the extraction of groundwater. The total economic value for domestic water usage is estimated at around ₹799600682 for five villages. The highest benefit of water usage per year is estimated for village Harike (₹494409582 for 496692000 liters) followed by Chamba kalan (₹153511123.3 for 154219800 liters), Kiriyan (₹79044494.9 for 79409400 liters), Kambo dhaiwal (₹62869366.6 for 63159600 liters), and Marrar (₹9766115.2 for 9811200) (Fig 4.46).

The total economic value of provisional ecosystem services accounts for ₹985.57 billion per year, of which 96.45 % is contributed by water discharge into IGC, followed by water used in irrigation and domestic purposes (3.52 %), and only 0.03 % is contributed by plant-based provisional ecosystem services with the addition of sand extraction.

Economic Valuation of Cultural Ecosystem Services

Ecosystem services are essential for the sustainable development of humans and the survival of other organisms on the planet. Human civilizations evolved across the globe according to approachable natural ecosystems. The diversity of food, clothing, and social rituals are the manifestation of ecosystem services besides food gathering and processing methods also influenced by the ecosystem such as fishing will be preferred by people around the wetland ecosystem. Fishing is the process of collecting fish a “provisional ecosystem service” same time it is a cultural ecosystem service as “enjoyment”. The non-material benefits that people receive from nature, such as spiritual, artistic, educational, and recreational values, are referred to as cultural ecosystem services. These services are an essential component of the total advantages that nature offers human societies, and they have a significant positive impact on people's quality of life and well-being. As they give a sense of place and a link to nature and tradition, cultural ecosystem services are crucial for preserving and enhancing cultural identity and social cohesion.

Outdoor recreation activities like hiking, camping, fishing, and hunting, as well as cultural and spiritual practices like traditional medicine, worship, and artistic expression, are just a few examples of the diverse ways that cultural ecosystem services can be provided. They also encompass the aesthetic value of natural landscapes, which can be appreciated through artistic techniques like painting and photography. Additionally, educational opportunities like environmental education programs and scientific research that can result in new technologies and discoveries can be provided by cultural ecosystem services. However, because they are not always immediately measurable or monetizable, cultural ecosystem services are sometimes disregarded in conservation and resource management choices. This could lead to a lack of awareness of and respect for their significance, as well as the destruction of the natural world and a decline in cultural values.

One example of the importance of cultural ecosystem services is the traditional knowledge and practices of Indigenous people around the world. These communities have lived in close relationship with nature for thousands of years, and have developed rich cultural traditions and practices that are intimately tied to the natural environment. These practices often involve sustainable resource use and management and can provide valuable insights and solutions for modern conservation and resource management challenges. Another example is the potential economic importance of cultural ecosystem services. For instance, ecotourism, a sector that is expanding quickly, depends on the cultural and ecological aspects of ecosystems to draw tourists and make money. Natural landscapes' aesthetic value can also raise property values and draw in business to a region.

Cultural ecosystem services are an important part of the overall benefits that nature provides to human societies. They play a crucial role in enhancing human well-being and quality of life and are important for maintaining and strengthening cultural identity and social cohesion. It is important to recognize and incorporate cultural ecosystem services into conservation and resource management decisions to ensure their continued provision for future generations. This present study is conducted to record different types of cultural ecosystem services available at various habitat types of Harike Wildlife Sanctuary besides economic valuation has been estimated for identified Cultural ecosystem services.

Demographical details of visitors

The visitors are comprised of 65.11% male and 34.8% female. The average number of members in each group is 6.62 where the ratio of males and females in a group is 4:3. The group size between 2 to 5 members accounts for 71.15% followed by group strength of 6 to 10 accounts for 18.27%, group strength between 11 to15 members recorded up to 4.81% and the group size 16 to 20 and more than 20 observed 1.92% and 3.85% respectively. The sanctuary receives visitors of different age groups mostly the young generation between 15 to 45 years (46.38%) and ages less than 15 years account for 42.70%. Around 10% of visitors were found more than 45 years. The sanctuary provides a platform for educational tours for schools and colleges. The majority of visitors were recorded under high school and high school, around 28.7% of visitors with graduate and master level of education. The composition of visitors at the level of the profession includes Students, Teachers, Doctors, Photographers, Journalists, Bureaucrats, Entrepreneurs, and people serving under the state government. Willingness to pay for any kind of service depends on purchasing power of a particular person, among the visitors nearly 46% belong to the annual income group between ₹250000 to ₹500000 followed by ₹500000 to ₹1000000 (39%) and 10% visitors have been recorded in the income group of above than ₹1000000 per annum.

Distribution of Cultural ecosystem services

In the field observation, a total of 18 types of CES have been recorded from six types of habitat viz. Plantation, Wetland, Swamp, Sandy area, Ravine and Agricultural field (Fig 4.48). The maximum utility for cultural ecosystem services are observed (Fig 4.47) for Wetlands (18 types) like Aesthetics, Bird watching, Birthday celebrations, Boating, Celebrating important days for the environment, Content creation for social media, Cycling, Educational tour, Employment, Immersion of ashes, Notion of natural capital, Painting, Peace, Pre-wedding shoot, Research, Singing practice, Wildlife Photography, and Writing poetry followed by Plantation (12 types) habitat, these services are comprised of Aesthetic, Bird watching, Celebrating important days for the environment, Content creation for social media, Cycling, Educational tour, Employment, Notion of natural capital, Peace, Research, Wildlife Photography, and Writing poetry.

Fig 4.47: Number of CES observed in each habitat

Swamp habitat provides 7 types of cultural ecosystem services including Aesthetics, Bird watching, Educational tours, Employment, Notion of natural capital, Research, and Wildlife Photography, where as in the Agricultural field habitat also provides cultural ecosystem services like Aesthetics, Bird watching, Employment, the Notion of natural capital, Research, and Wildlife Photography. Sandy (5 types) Aesthetic, Bird watching, Notion of natural capital, Research, Wildlife Photography, and ravine habitat supports 4 types of cultural ecosystem services including Bird watching, Notion of natural capital, Research and Wildlife Photography (Fig 4.49). There are 4 types of CES including Bird watching, Notion of natural capital, Research and Wildlife Photography are pursued by visitors in all mentioned habitats. Wetlands are more beautiful because they draw a lot of birds and they also have large bodies of water that make boating possible.

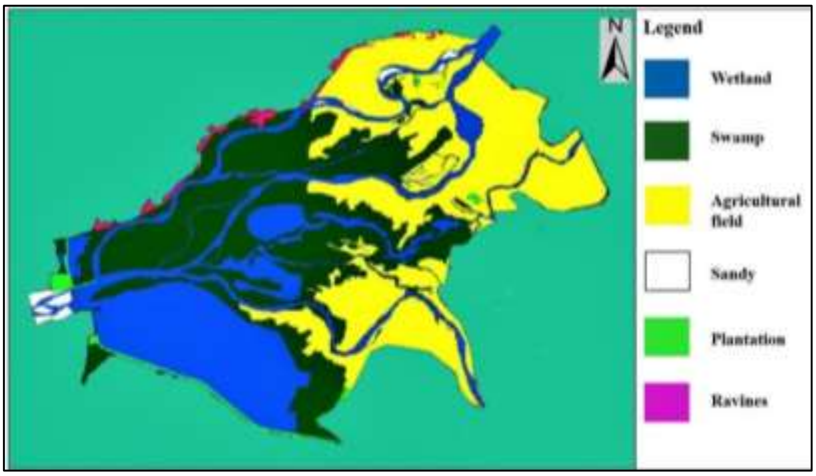


Fig 4.48: Habitat types at Harike Wildlife Sanctuary

In the present study Wetland habitat provides six types of CES that were recorded along Wetland of HWS. These CES are boating, birthday celebrations, ashes immersion, singing practice, painting and pre-wedding photography.

Fig 4.49: Cultural ecosystem services at HWS

Distance traveled by visitors

The visitors prefer to travel by road through Light Motor vehicles (93.27%) and Heavy Motor Vehicles (6.73%). The average distance covered by visitors is 73.64km±46.44km, while around 38.46% of visitors cover the distance between 50km to 75 km to avail of certain CES and 16.35% of visitors travel between 75km to 100km to reach the sanctuary.

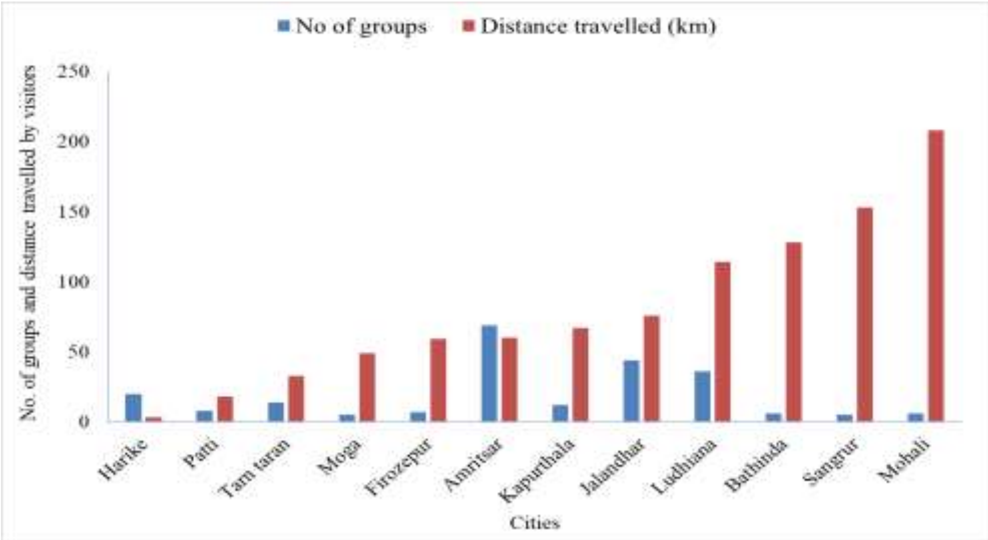


Fig 4.50: Proportion of visitors and distance travelled.

There are only 12.5% of visitors come to the sanctuary from less than 25km. The sanctuary receives a maximum number of visitors from 50 to 75km from the Majha, Doaba, and Malwa regions of the Punjab state (Fig 4.50). Distance is a very important factor in the major utility of certain goods and services, the sanctuary is well known among the population because of "Gurudwara Nanaksar" besides people also come for the Immersion of ashes at Harike Wetland, popularly known as "Hari-ke-Pattan". Harike Wildlife Sanctuary received around 300 groups in the year 2019-2020. Visitor mobilization is observed from 38 cities in the Punjab state only. Maximum number of visitors received from Amritsar (69 groups) followed by Jalandhar (44 groups). Ludhiana (35 groups), Harike (20 groups), Tarn Taran (4 groups), Kapurthala (11 groups), and 32 cities were identified with group sizes of less than 10 from each city. A total of 104 groups belonging to 21 different cities and 5 states, were considered for inquiry for willingness to pay for various cultural ecosystem services.

Travel cost for CES

In this study, travel cost has been calculated for the visitors coming to the sanctuary for CES. The average distance covered by visitors is 74.64km±46.44km multiplied by the average travel cost per km at market cost (₹10) then the addition of the average cost of extra expenses on food and refreshments ₹740±464. The final average cost bear by visitors is calculated ₹1477.31, then this amount is multiplied by the total number of groups visited in the year 2019-2020. The total economic value of CES is estimated ₹443193 for 300 groups in the year. The Sanctuary did not get enough visitors because of a pandemic in the year of 2020.

Willingness to pay

A total of 18 types of CES have been witnessed in the various habitat types of the sanctuary. The large water body and the confluence of rivers provide water security for the state as well as support biodiversity, the aesthetic, and migratory birds which attracts many visitors. CES can be a tool for the propagation of public awareness and sensitization with respect to the conservation of natural capital therefore it is required to investigate the present status of CES at the sanctuary besides the potential of visitors to contribute to improving the utility of the sanctuary and their expectation from management. The initial pilot survey for CES at the sanctuary helped in the identification of CES, which can get an economic value as per visitors' average willingness to pay for certain CES (Fig 4.51). A total of 14 types of CES have been considered to ask for willingness to pay (table 4.8).

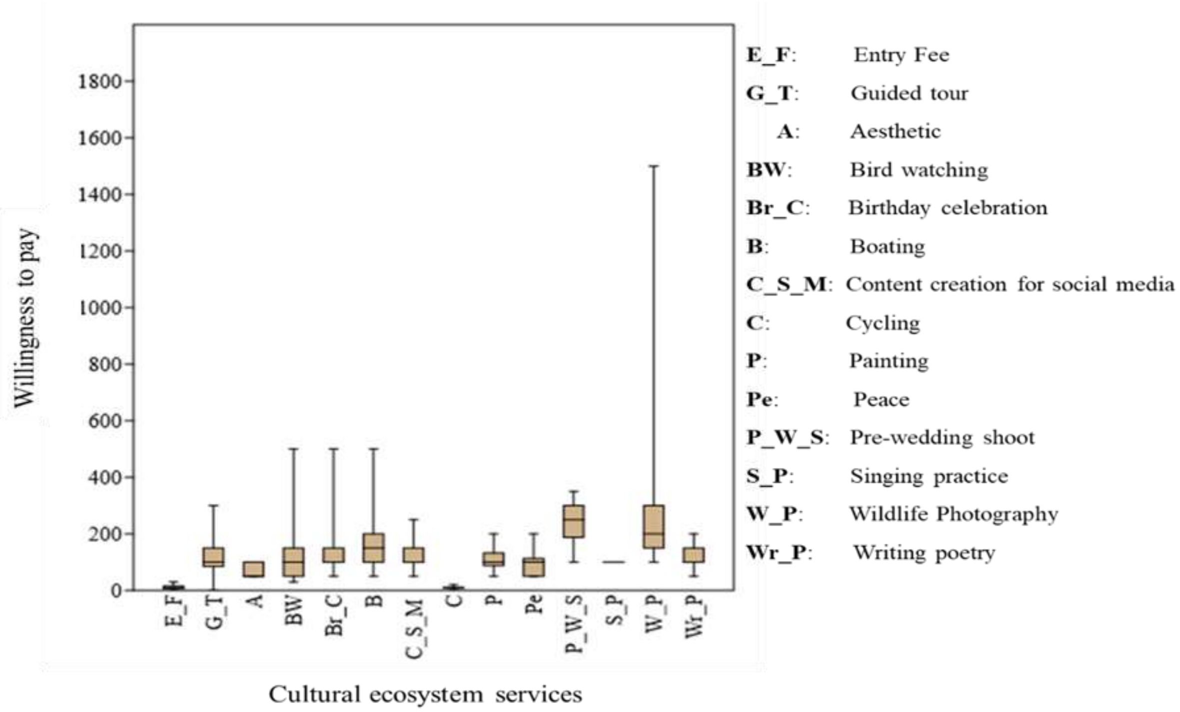


Fig 4.51: Willingness to pay (₹) for various CES.

The willingness to pay for CES have been asked from individual or group after a small session on the importance of wetland and biodiversity and volunteer facilitation for bird observation with their consent. The difference amount for willingness to pay for a particular CES depends on personal interest and the objective of the visit for each individual. The people were willing to pay for entry fees, Guided tours, Bird watching, Aesthetics, Bird watching Birthday celebrations, Boating, Content creation for social media, Cycling, Painting, Peace, Pre-wedding shoot, Singing practice, Wildlife Photography, and Writing poetry. The response for each CES was different for the Guided tour and entry fee 94.05% of visitors responded to pay whereas response for other CES such as Boating and Bird Watching is recorded around 79.54% and 46.88 %, respectively. The people came for enjoying many CES but most of them visit the Sanctuary for Recreational and Educational Services. The students from different schools and colleges accepted the fact there is a need for a facilitator for nature education. The willingness to pay for each CES was found different, where maximum and minimum mean willingness to pay for CES is calculated for Wildlife photography (₹289) and cycling (₹11.62).

The economic value is calculated according to an average willingness to pay for different CES. The valuation of natural ecosystems is a tool for addressing the importance or utility of natural ecosystems for humans because money applies to humans only. The sample mean amount of willingness to pay for each CES is used to infer the mean amount of willingness to pay for the total population visited in the year 2019-2020. A total of 7500 individuals have visited in the considered time, therefore the proportion of responses (Table 4.8) has been estimated before estimating the final economic value of the considered CES. Maximum CES is estimated for Boating (₹9,55,918) followed by Guided tour (₹8,50,535.27), Wildlife Photography (₹6,66,923.08), Bird watching (₹4,23,111.25), Content creation for social media (₹2,52,804.64), Birthday celebration (₹2,18,664.73), Pre-wedding shoot (₹1,77,039.08), Aesthetic (₹1,09,560.85), Entry Fee (₹84,150.65), Writing poetry (₹48,982.08), Peace (₹46,223.19), Cycling (₹36,554.93), Painting (₹16,763.43) and Singing practice (₹7,619.74). The sample mean amount of CES according to willingness to pay is calculated (table 4.8) for estimation of total economic value. Total economic value accounts for ₹3894850.91 ($52083.74) for the concerned CES.

Table 4.7: Estimated value of identified Cultural ecosystem services in ₹.

CES	**Number of group responded for particular CES**	**Number of individuals in total group**	**% of Informants responded**	**Total number of visitors in the year 2019-2020 (7500 visitors)**	**Sample mean of Willingness to pay for different CES**	**Economic value for the year 2019-2020**
Aesthetic	29	139	20.17	1513.06	₹ 72.41	₹ 109560.85
Bird watching	58	323	46.88	3515.97	₹ 120.34	₹ 423111.25
Birthday celebration	28	150	21.77	1632.80	₹ 133.92	₹ 218664.73
Boating	78	548	79.54	5965.17	₹ 160.25	₹ 955918.00
Content creation for social media	31	192	27.87	2089.99	₹ 120.96	₹ 252804.64
Cycling	43	289	41.94	3145.86	₹ 11.62	₹ 36554.93
Entry Fee	100	648	94.05	7053.70	₹ 11.93	₹ 84150.65
Guided tour	100	648	94.05	7053.70	₹ 120.58	₹ 850535.27
Painting	5	14	2.03	152.39	₹ 110	₹ 16763.43
Peace	14	41	5.95	446.30	₹ 103.57	₹ 46223.19
Pre-wedding shoot	14	69	10.01	751.09	₹ 235.71	₹ 177039.08
Singing practice	2	7	1.02	76.20	₹ 100	₹ 7619.74
Wildlife Photography	40	212	30.77	2307.69	₹ 289	₹ 666923.08
Writing poetry	10	27	3.92	293.90	₹ 166.66	₹ 48982.08

Inconvenience in pursuing CES

A guide is necessary, according to 51 out of the respondents. This implies that there might be some kind of activity or place where having a guide present is necessary for safety, knowledge, or other reasons. In another situation, 50 percent stated that restrooms are necessary (Fig 4.52). This suggests that the activity or site might last for a longer time and necessitate facilities for necessities like basic hygiene. Further, the activity or location may involve wildlife observation, bird watching, or other comparable activities that call for a closer view of distant objects, as indicated by the 47 respondents who indicated that binoculars are necessary.

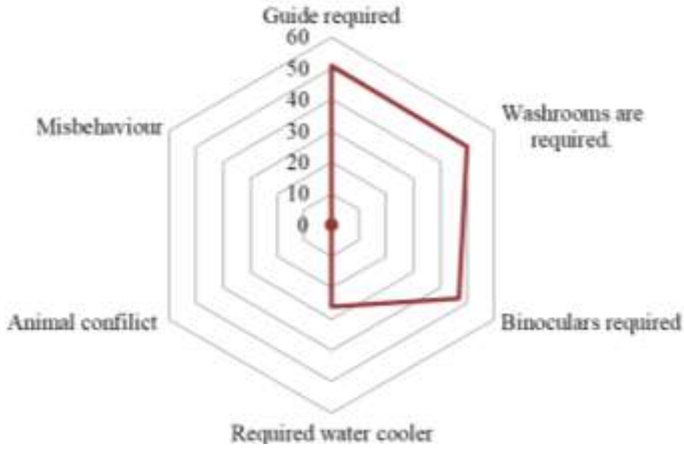


Fig 4.52: Response of visitors for the inconvenience encountered.

A water cooler is essential, according to 26 survey respondents. This suggests that the activity or location may be physically demanding or involve a high level of exertion, which necessitates the availability of clean drinking water. Nobody reported animal conflict among the visitors. This suggests that the activity or location may not be located in a region where there is a high likelihood of encountering wildlife or animal-related conflicts.

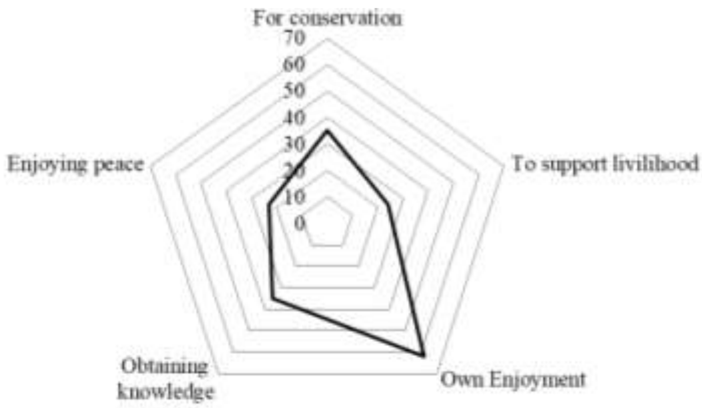


Fig 4.53: Support of willingness to pay

Nobody reported misbehaviour by any person during visit. This suggests that the activity or location may be well-regulated, and the visitors or participants may be following the rules and regulations set by the authorities or organizers. No animal conflict is witnessed by visitors while pursuing CES.

Purpose for paying

The highest reason cited for willingness to pay is for "Own Enjoyment" at 62, which suggests that people are willing to spend money on experiences that they enjoy. "Obtaining knowledge" and "Conservation" are tied for the second-highest reason at 35, indicating that individuals are willing to pay to learn something new or to support environmental causes (Fig 4.53). Another reason cited for willingness to pay is "To support livelihood" at 24, suggesting that people are willing to spend money to support local businesses or communities. Lastly, "Enjoying peace" was cited at 23, which implies that individuals are willing to pay for experiences that offer tranquility or calmness. Overall, the data suggests that people are willing to spend money for a variety of reasons, ranging from personal enjoyment to environmental conservation and supporting livelihoods.

Impact of pandemic

The COVID-19 pandemic has had a significant impact on the global tourism industry, including ecotourism and wildlife sanctuaries. The closure of borders, restrictions on travel, and fear of contracting the virus have led to a decrease in tourism, resulting in a decline in revenue and employment opportunities for many tourism-dependent communities. In the case of ecotourism and wildlife sanctuaries, the pandemic has both positive and negative impacts. On the one hand, the temporary closure of these protected areas has allowed ecosystems and wildlife to recover and thrive without human disturbance. The absence of tourists has also reduced pollution and minimized human-wildlife conflicts, which can be detrimental to conservation efforts. In summary, the impact of the COVID-19 pandemic on ecotourism and wildlife sanctuaries is complex, with both positive and negative effects. While the temporary closure of these protected areas has allowed for ecological recovery, the loss of revenue has placed a strain on conservation efforts and resulted in increased pressure on wildlife populations. It is essential to find a balance between conservation and economic development to ensure the long-term sustainability of ecotourism in wildlife sanctuaries. There is the decline of visitors has been recorded in the lockdown situation due to the pandemic. The sanctuary receives most visitors in the winter season when migratory birds arrive in the wetlands. In the summer season, people visit the sanctuary for recreational activities like boating.

Economic Valuation of Supporting Ecosystem Services

Biomass estimation

Biomass is described as biological residue produced by water-based vegetation, woodland or organic material, agricultural production by-products, or trash from the agro or food sectors. Various biomass resources are available in India in different forms (Fig 4.54). They can be categorized simply according to what is found in nature, which includes grasses, woody plants, fruits, vegetables, organic manure, and aquatic plants. Algae and *Jatropha* are used for manufacturing bio-diesel. The three main categories of biomass energy are municipal and industrial waste, energy plant residue, and residue of agricultural and horticultural crops (Williams et al. 1997).

Biomass and carbon sequestration are two critical components of our planet's ecosystem. Biomass refers to living and recently dead plant material, such as trees, crops, and grasses. Carbon sequestration, on the other hand, refers to the process by which carbon dioxide (CO_2) is removed from the atmosphere and stored in long-term sinks, such as forests and oceans. Biomass is a source of renewable energy that can be used to generate electricity, heat homes, and power vehicles. It is considered a carbon-neutral energy source because the carbon dioxide emitted during combustion is offset by the carbon dioxide absorbed during plant growth. Using biomass as an energy source can help reduce our dependence on fossil fuels, which are a significant contributor to greenhouse gas emissions and climate change.

Carbon sequestration reduces atmospheric carbon dioxide: Carbon sequestration helps to remove carbon dioxide from the atmosphere, which it contributes to global warming. Trees and other plants absorb carbon dioxide during photosynthesis, and this carbon is stored in the plant's biomass. Forests are particularly effective at carbon sequestration, as they can store carbon for decades or even centuries. Forests, grasslands, and other ecosystems that contain high levels of biomass are often home to a wide variety of plant and animal species. By preserving these ecosystems and promoting the growth of biomass, we can help protect biodiversity and ensure that our planet remains habitable for all species. Sustainable forestry and agriculture practices that promote biomass growth and carbon sequestration can provide economic benefits to local communities. For example, sustainable logging practices can provide jobs and income while preserving forest ecosystems, and sustainable agriculture practices can increase crop yields while reducing carbon emissions.

In conclusion, biomass and carbon sequestration are essential components of our planet's ecosystem, with significant environmental, social, and economic benefits. By promoting sustainable forestry and agriculture practices and investing in renewable energy sources, we can help mitigate climate change and ensure a livable planet for future generations.

Fig 4.54: Classification of available biomass resources in India (*Source*: Kumar et al. 2015)

Indians have used biomass energy since prehistoric times. It is used as cow dung cake, fuel, husk, and a variety of other naturally occurring feedstocks. Direct usage of biomass in solid form, however, was not painless or safe because it produces a lot of smoke. The Indian government is so encouraging biogas plants because they provide pollution-free, smoke-free gas. For the building of the biogas plant, numerous subsidies are offered. Additionally, new biomass gasification technology has developed, converting biomass into syngas that is more effective. Power generation using biomass is currently steadily increasing. It is primarily due to rising electricity demand overall and fewer alternative fuel options in rural areas (Bhattacharyya 2006).

According to Kumar et al. (2015), there is enormous potential for exploring biomass that is already present in India and turning it into electricity. In India, a vast range of resources in various forms of biomass are available. There are many sources available to obtain waste biomass, such as agricultural waste, food waste, and industrial wastewater, which suggests a propensity to move to unconventional energy sources. In India, organizations and businesses are putting this into practice and reporting benefits from turning various types of waste biomass into electricity.

Plant-based biomass is used for various purposes and biomass could be seen as supporting ecosystem services for an ecosystem according to (Assessment M. E. 2005). In the present study dominating plant species across the habitat types of HWS were considered for biomass estimation with its economic value according to market prices in the local market.

Biomass quantification and economic value for aquatic plants

Quantification of submerged plants

Excellent natural filters include floating plants like water lilies and duckweed as well as submerged plants, commonly referred to as aquatic or underwater plants. Removing extra nutrients, like nitrogen and phosphorus, from the water, aid in enhancing the quality of the water. Nutrient uptake, also known as assimilation, is a process that aids in preventing eutrophication, which is the excessive development of algae and other aquatic plants (Fig 4.55) that can harm aquatic life and deplete oxygen levels. Wetlands are the most productive ecosystem on the planet and store carbon from the atmosphere.

Fig 4.55: Growth of Aquatic plants in Harike wetland.

In the sampled quadrat for aquatic plants, the maximum proportion (Fig 4.56) of submersed plants in wetlands recorded for *Hydrilla verticillata* (65%) spread over 752.64 hectares followed by *Vallisneria natans* with 31% occupy 358.94 hectares, *Ceratophyllum demersum* with 3% spread over in 34.74 hectares, and *Najas minor* with 1% spread over in 13.57 hectare. A total of 4980.94 tons of biomass is estimated for 4 species, maximum biomass is calculated for *Hydrilla verticillata* (2634.2 tons), followed by *Vallisneria natans* (2297.27 tons), *Ceratophyllum demersum* (36.82 tons) and *Najas minor* (12.62 tons). The total economic value is estimated based on the market price of biomass in the local market (1.2 kg^{-1}), therefore total amount in economic terms is estimated at around ₹5977126.12.

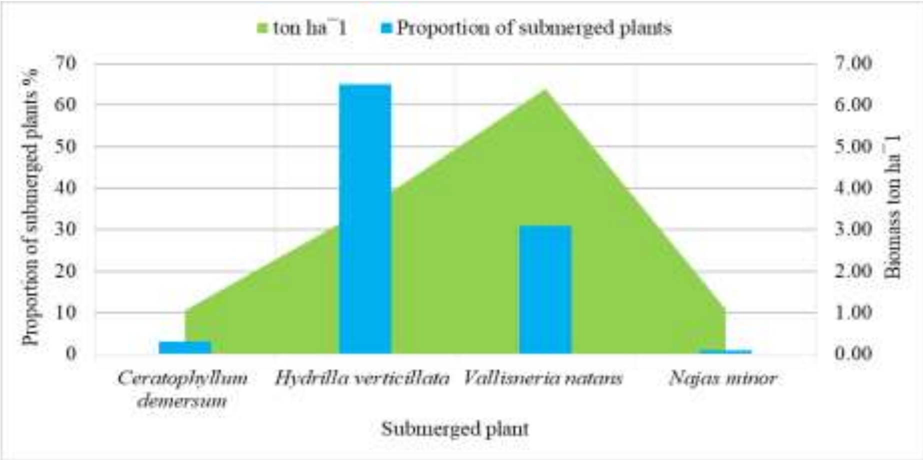


Fig 4.56: Area percentage of submersed plants in the wetland.

Submersed and floating plants provide essential habitats for many organisms. They offer shelter, nesting sites, and food sources for a wide range of aquatic organisms, including fish, invertebrates, amphibians, and waterfowl. These plants provide hiding places for small organisms, support the growth of biofilms and periphyton (microbial communities), and act as nurseries for fish and other aquatic species.

Quantification of floating vegetation

Prominent free floating pant such as *Eichhornia crassipes* and *Pistia stratiotes* cover most of the wetland besides *Nelumbo nucifera* can be seen as a rooted floating plants in the summer season (Fig 4.57). The biomass of floating plants was estimated with the help of a quadrat sampling (1m x 1m) and plants were collected and dried to estimate biomass.

Fig 4.57: Wetland dominated by *Eichhornia crassipes.*

Mean biomass in kg/m^2 is estimated for each species and then multiplied by the area occupied by particular species. Maximum biomass per ha^{-1} is estimated for *Nelumbo nucifera* (4 t ha^{-1}), covering an area of 6.61 hectares, followed by *Eichhornia crassipes* (1.9 t ha^{-1}), spread over 642.59 hectares and *Pistia stratiotes* (0.6 t ha^{-1}), grows over an area of 316 hectares of wetland. A total of 1258.94 tons of biomass is estimated for the above-mentioned species per year which is worth of ₹1503572.46/year.

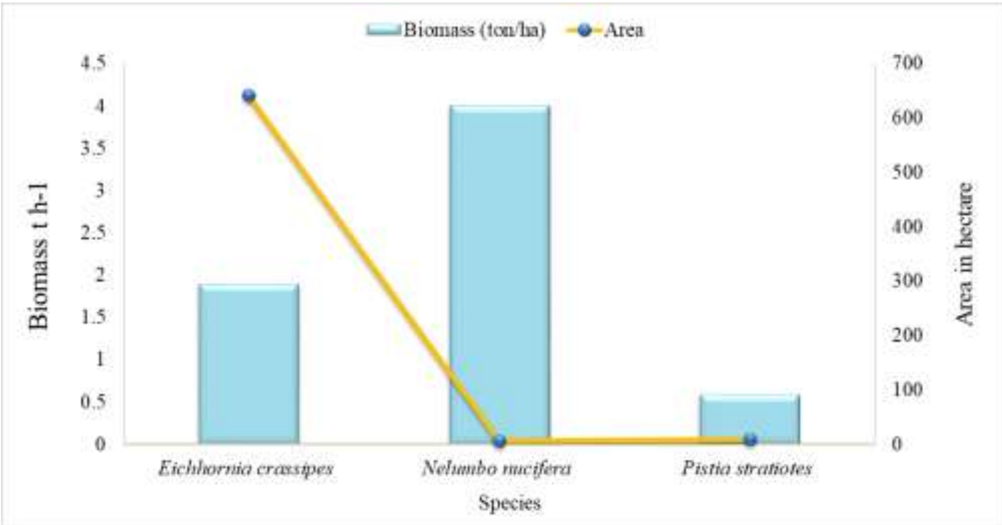


Fig 4.58: Biomass of floating vegetation in ton ha^{-1}

The market value of selected floating vegetation is estimated according to the market value of Biomass (₹1.20 kg^{-1}) according to a systemic calculation for biomass maximum biomass is estimated for *Eichhornia crassipes* (₹1465126.86), *Nelumbo nucifera* (₹31738.08), and *Pistia stratiotes* (₹6707.52). This estimated value in total ₹7480698.58 is the value of wetland habitat for supporting services (Biomass) in a year.

Dominated herbs

Cannabis sativa was found most dominating and frequent in the plantation habitat in the field survey therefore biomass of *Cannabis sativa* (Fig 4.59) is measured as supporting services. The mean biomass of *Cannabis sativa* is estimated up to 1.48 kg m^{-2}, it covers a total area of around 17.11 hectares, therefore 14800 kg ha^{-1} or 1.48 t ha^{-1} of biomass is supported by *Cannabis sativa* in the plantation habitat. A total of 25.32 tons of biomass a worth of economic value of (25320 x ₹1.2 kg^{-1}) ₹ 30,384/year is provided in the HWS.

Fig 4.59: Plantation habitat dominated by *Cannabis sativa.*

Dominated grass species

Phragmites karka

The Swampy habitat is dominated by *Phragmites karka* hence this species is considered for estimation of biomass to address the carbon stock in the swampy habitat type. Mean biomass per 1 square meter is recorded up to 5.4±0.77 kg.

Fig 4.60: Swampy habitat dominated by *Phragmites karka.*

This value is used to estimate the total biomass spread over per hectare area and then further used for calculation for Swampy habitat. Swampy habitat supports 54 t ha^{-1} of biomass through *Phragmites karka* only and the total area (2776.2 hectare) under Swampy habitat produces

149914.8 tons of biomass per year through *Phragmites karka* with a total economic value of ₹179897760 $year^{-1}$.

Biomass of *Saccharum bengalense*

The expansion of *Saccharum bengalense* across the habitat types is calculated on the basis field survey followed by Google earth pro. The mean Biomass of *Saccharum bengalense* is estimated at up to 9 kg in 1 square meter and 90 tons per hectare, *Saccharin bengalense* covers 43.4 hectares across the HWS therefore total biomass is estimated at up to 3906 tons/year with the total economic value of ₹4687200 $year^{-1}$.

Agricultural crop biomass and its economic value

A significant area is under cultivation of Wheat and Rice therefore biomass of crops is estimated by secondary data (biomass per hectare for each crop). The Area under cultivation is identified as the Agricultural field habitat type. According to Chahal and Chhabra, (2014) Wheat and paddy crop produces biomass of 2.51 and 6.78 tons per hectare respectively. A total of 3022.6 hectares were recognized for the cultivation of crop wheat and paddy. The total biomass produced by Wheat is 75867.6 tons whereas paddy produces biomass of around 204932.28 t $year^{-1}$. The mean market price of biomass is ₹1.2 kg^{-1} therefore the total economic value of biomass produced by wheat and paddy within the boundaries of HWS is ₹ 91040712 and ₹245918736 for a year respectively.

Biomass of tree species across the HWS

It is well known that trees can remove carbon dioxide from the atmosphere by photosynthesis. The trunks, branches, and leaves of trees store carbon as they develop and build more biomass. By lowering the amount of greenhouse gases in the atmosphere, especially carbon dioxide, which is a key contributor to global warming, this technique helps to ameliorate climate change. High biomass accumulation forests frequently sustain diverse wildlife. Trees generate niches for a variety of plant and animal species as they develop and provide habitat. The complex biological interactions made possible by forests' varied tree species, sizes, and layerings help many different organisms survive. The buildup of biomass in forests improves the overall resilience and health of ecosystems.

Plantation habitat

In the quadrat sampling total of 112 individuals were recorded under 22 species of trees belonging to 11 families. Some dominating tree species with population are *Dalbergia sissoo*

(16), followed by *Syzygium cumini* (14), *Leucaena leucocephala* (12), *Eucalyptus camaldulensis* (10), *Prosopis juliflora* (10), *Terminalia arjuna* (9) and *Parkinsonia aculeata* (8). The Diversity indices for tree species show Simpson_1-D 0.91 and Shannon_H 2.71 with Evenness 0.68. Frequency and density per 100m^2 of each species were estimated and given in Table 4.9.

Table 4.8: Frequency and density of tree species in the plantation habitat.

Species	Abundance	Frequency	Density	Species	Abundance	Frequency	Density
Dalbergia sissoo	19.00	0.39	0.74	*Ficus religiosa*	3	0.08	0.12
Syzygium cumini	14.00	0.38	0.54	*Kigelia africana*	3	0.04	0.12
Leucaena leucocephala	12.00	0.23	0.46	*Azadirachta indica*	2	0.08	0.08
Eucalyptus camaldulensis	10.00	0.27	0.38	*Melia azedarach*	2	0.08	0.08
Prosopis juliflora	10.00	0.23	0.38	*Senegalia catechu*	2	0.08	0.08
Terminalia arjuna	9.00	0.19	0.35	*Vachellia nilotica*	2	0.04	0.08
Parkinsonia aculeata	8.00	0.08	0.31	*Albizia lebbeck*	1	0.04	0.04
Ficus palmata	5.00	0.12	0.19	*Cassia fistula*	1	0.04	0.04
Cordia myxa	4.00	0.15	0.15	*Mangifera indica*	1	0.04	0.04
Ziziphus mauritiana	4.00	0.15	0.15	*Phyllanthus emblica*	1	0.04	0.04
Tectona grandis	1.00	0.04	0.04	*Pongamia pinnata*	1	0.04	0.04

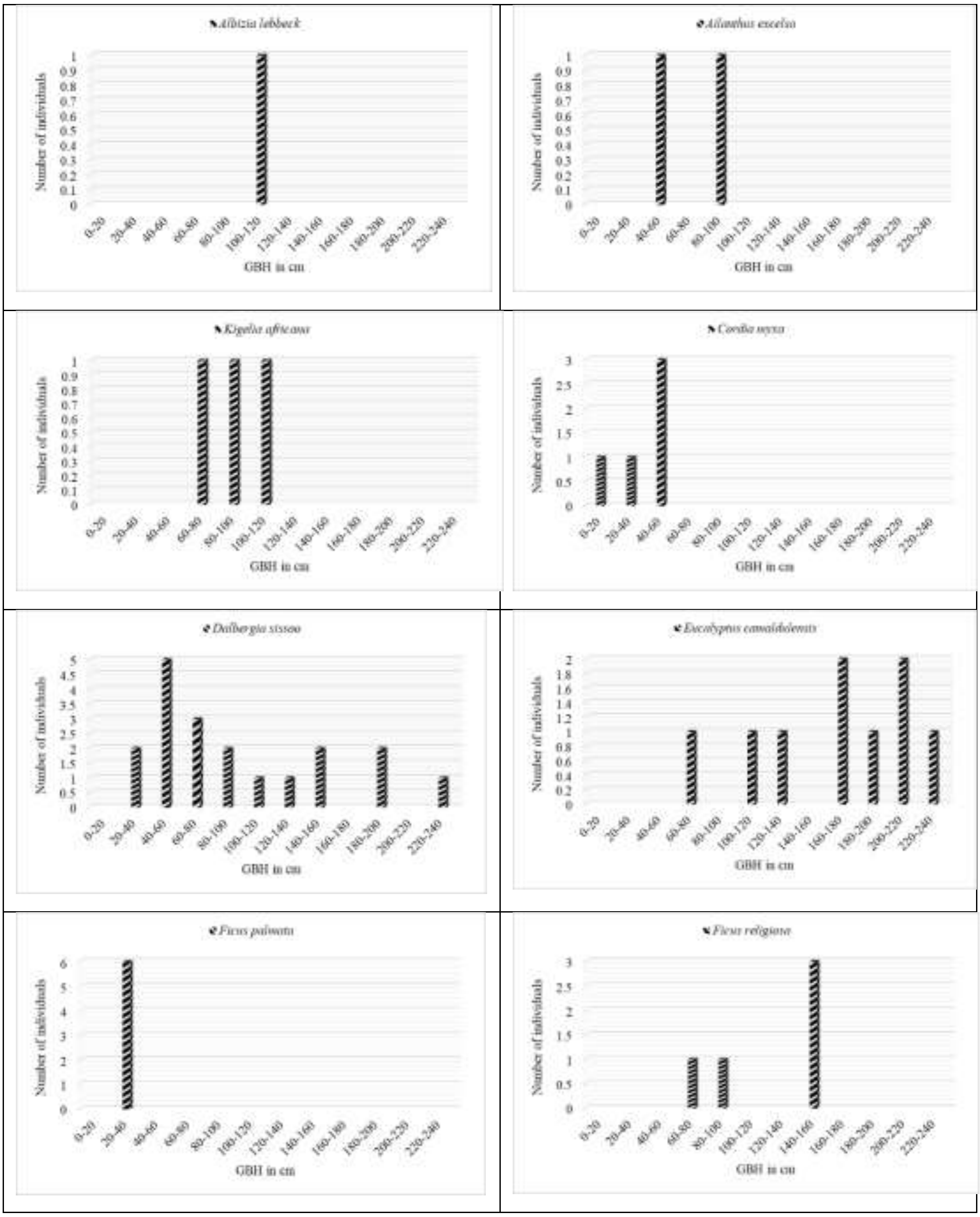
The mean Population of trees and total Tree Biomass per 100 m^2 is found 4.30±1.51 and 1.84±1.80 (tons) respectively. In the Plantation habitat total tree biomass has estimated at up to 184.06 ton ha^{-1} and the total area under the plantation habitat is 99.68 hectares, therefore, Plantation habitat is a repository of 18347.1008 tons (18347100.8 kg) of Tree biomass including above-ground biomass and Root Biomass. Uppermost mean biomass (Table 4.10) is realized for *Eucalyptus camaldulensis* 1.59 ton followed by *Mangifera indica* (1.27 ton), *Dalbergia sissoo* (0.84 ton), *Ficus religiosa* (0.8 ton), *Albizia lebbeck* (0.73 ton), *Terminalia arjuna* (0.45 ton), *Kigelia Africana* (0.41 ton), *Syzygium cumini* (0.36 ton), *Vachellia nilotica* (0.34 ton), *Ziziphus mauritiana* (0.32 ton), *Cassia fistula* (0.14 ton), *Leucaena leucocephala* (0.11 ton), *Prosopis juliflora* (0.09 ton), *Parkinsonia aculeata* (0.08 ton), *Melia azedarach* (0.06 ton), *Pongamia pinnata* (0.04 ton), *Tectona grandis* (0.04 ton), *Azadirachta indica* (0.03 ton), *Cordia myxa* (0.02 ton) and *Ficus palmata* (0.02 ton).

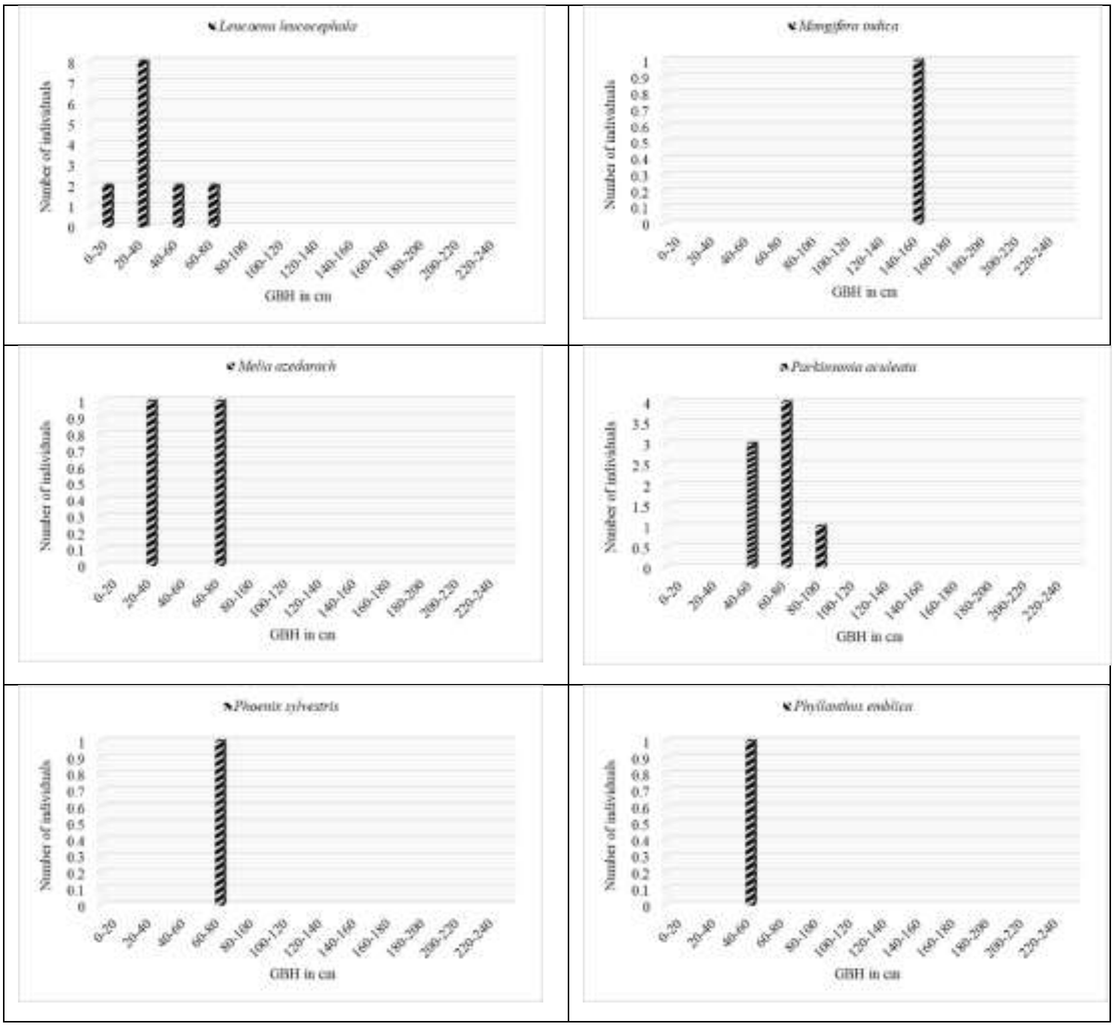
Table 4.9: Mean of different tree parameters and total tree biomass.

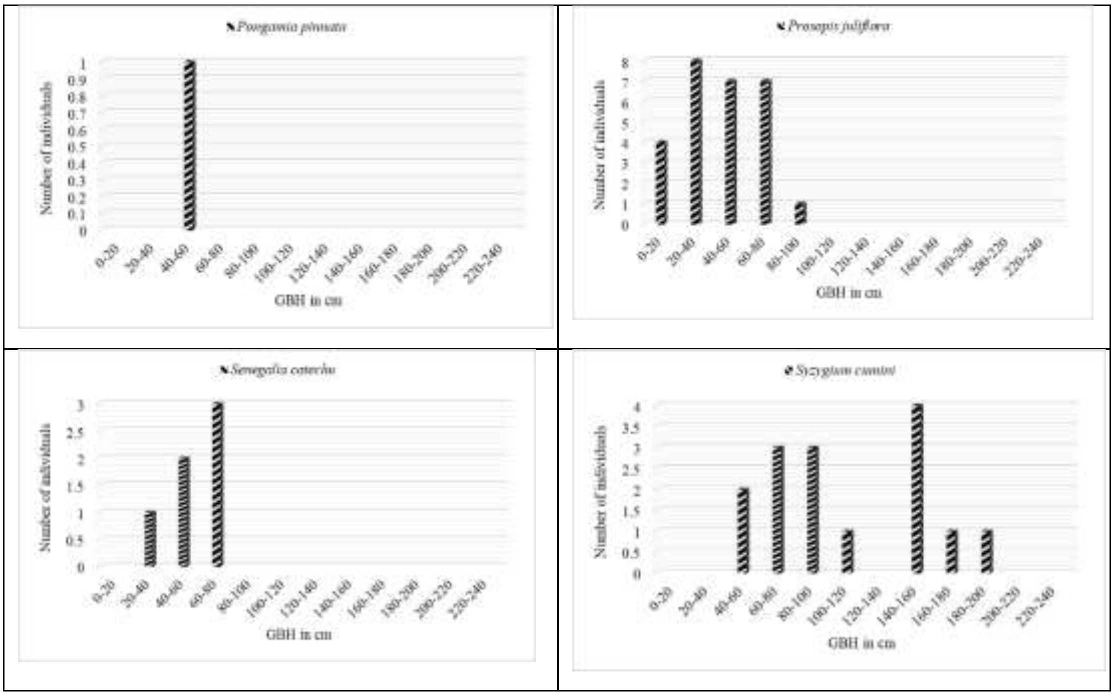
Species	Mean GBH (cm)	Mean Height (m)	Specific Wood density (g cm^{-3})	Mean Tree biomass (t)
Albizia lebbeck	109.00	17.00	0.55	0.73
Azadirachta indica	31.00	5.00	0.73	0.03
Cassia fistula	61.00	7.00	0.79	0.14
Cordia myxa	39.33	4.50	0.38	0.02
Dalbergia sissoo	104.68	10.06	0.63	0.84
Eucalyptus camaldulensis	106.66	17.88	0.41	1.59
Ficus palmata	28.80	5.30	0.56	0.02
Ficus religiosa	159.33	9.33	0.51	0.80
Kigelia africana	84.66	11.26	0.72	0.41
Leucaena leucocephala	39.66	8.87	0.74	0.11
Mangifera indica	150.00	14.50	0.60	1.27
Melia azedarach	50.00	7.00	0.52	0.06
Parkinsonia aculeata	62.87	5.16	0.50	0.08
Pongamia pinnata	40.00	6.00	0.60	0.04
Prosopis juliflora	43.45	5.00	0.80	0.09
Syzygium cumini	110.21	11.71	0.30	0.36
Tectona grandis	38.00	6.00	0.70	0.04
Terminalia arjuna	80.62	10.94	0.74	0.45
Vachellia nilotica	89.50	9.50	0.67	0.34
Ziziphus mauritiana	76.75	9.10	0.55	0.32

Tree species under various girth categories in HWS.

In the sampled quadrat for tree species, maximum individuals (Fig 4.61) were found in between 60-80 cm girth category (14 individuals) with species like *Prosopis juliflora, Parkinsonia aculeate, Dalbergia sissoo, Senegalia catechu, Syzygium cumini, Leucaena leucocephala* and *Vachellia nilotica* followed by 40-60 cm girth category with 13 individuals including species like *Syzygium cumini, Leucaena leucocephala, Terminalia arjuna* and *Vachellia nilotica*, 11 individuals were recorded between 20-40 cm girth category for species like *Prosopis juliflora, Dalbergia sissoo, Senegalia catechu, Leucaena leucocephala, Terminalia arjuna, Azadirachta indica* and *Melia azedarach*. In the girth category 80-100 cm, 8 individuals were recorded for tree species like *Syzygium cumini*, *Terminalia arjuna*, *Dalbergia sissoo*, *Prosopis juliflora* and *Parkinsonia aculeate*. In the girth category 100-120 cm, 7 individuals of *Syzygium cumini, Terminalia arjuna, Dalbergia sissoo, Ziziphus mauritiana, Albizia lebbeck, Vachellia nilotica* and *Eucalyptus camaldulensis* were recorded.




Leucaena leucocephala
Mangifera indica
Melia azedarach
Parkinsonia aculeata
Phoenix sylvestris
Phyllanthus emblica
Number of individuals
GBH in cm
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
200-220
220-240


Pongamia pinnata
Prosopis juliflora
Senegalia catechu
Syzygium cumini
Number of individuals
GBH in cm
0-20
20-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
200-220
220-240

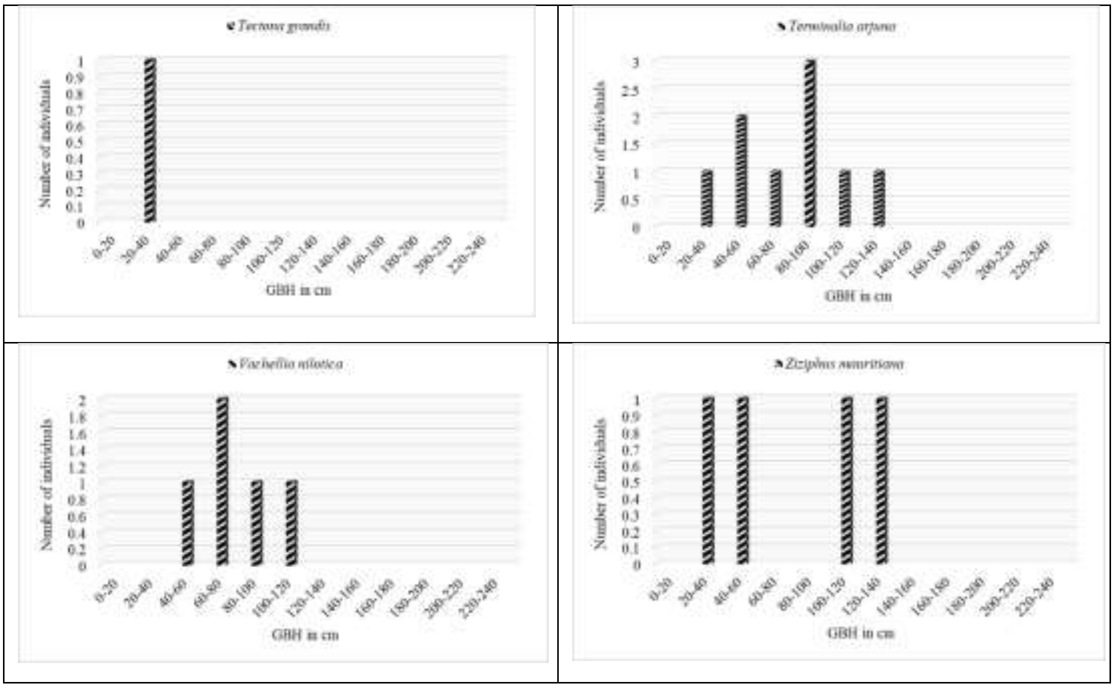


Fig 4.61: Community of tree species in different girth categories in HWS.

4 individuals were recorded in the girth category of 120-140 cm for species like *Terminalia arjuna, Dalbergia sissoo, Ziziphus mauritiana*, and *Eucalyptus camaldulensis.* Tree species such as *Syzygium cumini, Dalbergia sissoo, Mangifera indica* and *Ficus religiosa* were recorded under the girth category of 140-160 cm (4 individuals). 0-20 cm (3 individuals), 180-200 (3 individuals) 160-180 cm (2 individuals), 220-240 cm (2 individuals), and 200-220 cm (1 individual). The girth of trees suggests there are more mature trees in the HWS besides species like *Prosopis juliflora* and *Leucaena leucocephala* have shown more new recruitment in the habitat. Tree girth of species like *Syzygium cumini, Terminalia arjuna, Dalbergia sissoo, Vachellia nilotica* and *Kigelia africana* Suggest these species have more mature populations, therefore, these species are supporting the ecosystem by producing seeds, habitat, soil quality, and biomass accumulation. The mean biomass of tree species is shown in table 4.10.

Economic value of biomass

To address the valuation of tree biomass is estimated concerning market price in the local area. The market value of per Kg biomass is ₹1.2, hence the total economic value of tree biomass of plantation habitat is calculated around (18347100.8 x 1.2 = ₹22016520.96) ($275603.41). Biomass accumulation helps in the reduction of CO_2 from the atmosphere, therefore significant for combating climate change.

Ravine habitat tree biomass: economic worth

The Ravine habitat possess tree community with species like *Ailanthus excelsa*, *Azadirachta indica, Cordia myxa, Dalbergia sissoo, Ficus religiosa, Ficus palmata, Leucaena leucocephala*, *Prosopis juliflora, Senegalia catechu*, *Syzygium cumini* and *Vachellia nilotica* with Simpson 0.741, Shannon_H 1.89 and Evenness 0.606. The mean biomass per 100 m^2 is estimated at 0.36 ± 0.27 tons and 35.94 t ha^{-1}. The Ravine habitat is spread over 106.12 hectares hence total biomass present is 3814.69 tons. The economic value is estimated with reference to market prices of biomass in the local market. i.e. ₹ 1.2 kg^{-1}, therefore, the total economic value of the supporting service of tree biomass in the Ravine habitat is ₹ 4577629.169. In ecosystems, trees are essential for the cycling of nutrients. Trees absorb nutrients from the soil including nitrogen, phosphorus, and potassium as they build more biomass. These nutrients are kept in their tissues and released into the environment via processes like the breakdown of leaf litter or during the decay of dead trees. This nutrient cycle keeps ecosystems fertile and productive by ensuring that vital nutrients are available for other living things. Additionally, the accumulation of tree biomass helps stop soil erosion. Because trees have deep roots, there is less chance of soil erosion brought on by wind or water. Rainfall is deflected away from the soil surface by tree canopies, avoiding erosion and nutrient loss. Additionally, organic matter derived from tree biomass and leaf litter improves soil fertility and structure, which in turn increases soil's ability to hold onto moisture and support plant growth. The increase in tree biomass is also important economically. Timber, wood products, and non-timber forest products are all valuable commodities that can be found in forests with significant biomass. These resources support livelihoods, and the economy, and supply the necessary raw materials for numerous industries. Biomass production is important in supporting ecosystem services, therefore the estimation of economic value to address sustainable management techniques that take biomass buildup into account can guarantee the long-term availability of these resources.

Economic Valuation of Regulatory Ecosystem Services

Protection from flood

Wetlands are critical ecosystems that provide a host of environmental benefits. One of the most important functions of wetlands is their ability to protect against floods. Wetlands are often described as nature's sponges because they can absorb and store large amounts of water. This feature makes them essential in protecting against flooding, especially in areas that are prone to frequent flooding. In the present study, we will explore the role of wetlands in protecting against floods.

Firstly, wetlands act as natural buffers. They are often located in areas that are prone to flooding, such as riverbanks, coastal zones, and low-lying areas. As water levels rise, wetlands act as a buffer by absorbing excess water and slowing down the rate of water flow. This means that water flows more slowly through wetlands, reducing the impact of floods downstream. Secondly, wetlands act as natural water storage areas. They can absorb and store large amounts of water, which is slowly released over time. This helps to regulate water levels and reduce the impact of floods downstream. In addition, wetlands help to recharge groundwater, which helps to maintain water levels in rivers during dry periods.Thirdly, wetlands provide habitat for a range of wildlife, including birds, fish, and other aquatic animals. This biodiversity helps to maintain the health of wetland ecosystems, which in turn helps to protect against floods. For example, the roots of wetland plants help to stabilize soil, preventing erosion and reducing the risk of floods. Fourthly, wetlands act as filters. As water flows through wetlands, it is filtered by the plants and soils. This helps to remove pollutants and contaminants from the water, improving water quality downstream. This is particularly important in areas that are heavily polluted, as wetlands can help to reduce the risk of contamination during floods. Finally, wetlands provide recreational opportunities and are important cultural and historical sites. They are often valued by local communities and provide important economic benefits through tourism and recreation. By protecting wetlands, we are also protecting these cultural and economic benefits.

Wetland provides important Regulatory ecosystem services, and one of the major services is flood control. Harike Wetland impounds a substantial amount of flood water that keeps a sustainable supply of water in the Indra Gandhi Canal as well as downstream of the Sutlej River. In the present study downstream of the Sutlej River within the boundary of Indian territory from Harike onwards is considered as a potential flood zone area at both banks. After flowing 30.3 kilometers to the west from the Harike Wetland, the Sutjel River approaches Parkisan and crosses the India Territorial Border. The information gathered from the flood and irrigation department revealed that high flood is not a regular phenomena in the downstream of Harike wetland. The last flood came in 1986 which touched the elevation up to 207m, which is a low point as compared to the adjacent area in the down-stream. The farmers along the downstream said they have not experienced a flood that could damage their rice crop. By setting a flooded threshold of 207 meters, a digital elevation model (DEM) is utilized to determine the possible flood zone (Fig 4.62), marked as the maximum flood level in Fig 4.63. To obtain precise information for the estimation of flood expansion in the scenario that the flood level reaches up to 207 meters, a DEM is created by selecting 5185 points from Google Earth Pro and classifying the selected area under 15 classes of elevation. The downstream river has sandy habitat with tall grasses with a mean width of 1.31± 0.37 km and a meandering path. According to DEM the mean elevation downstream and adjacent to the study area is 210.53±10.67m with 191m and 233m as the lowest and highest elevations, respectively.

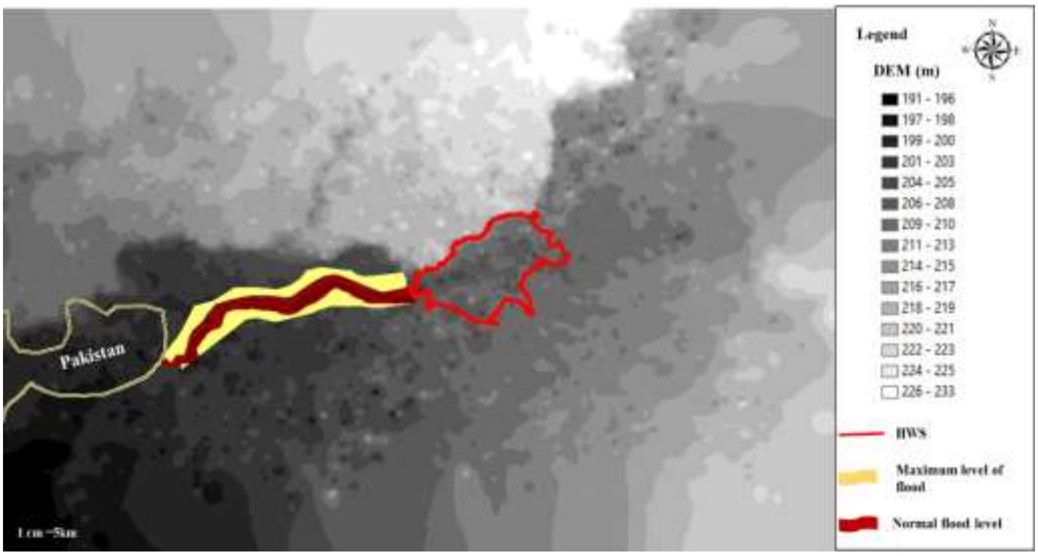


Fig 4.62: Flood zone marked with the help of DEM (191m to 207m) along downstream.

On both sides of the river around 4962 hectares of land can receive a flood in monsoon season only if the flood rises to 207m. Harike wetland protects downstream by flooding, in support much of the water is diverted in IGC besides Sandy habitat with tall grasses like *Saccharum spontaneum* and *Saccharum bengalense* have fibrous root system which allows water to percolate fast and that helps in protecting crop by limiting the flood conditions. Tsutsumi et al, (2004) and Subramanya (2017) also advocate that Sandy habitat can significantly helps in controlling flood because of the low run-off coefficient (0.05-0.10), in other words, 95% to

90% of water can be percolated in the sandy habitat with grasses. The mean production of rice is around 6.472 t h^{-1} in the region. The area which is protected by flood through HWS produced (4962 x 6.472) 32114.064 tons of rice crop, worth ₹623012841.6 $year^{-1}$. Valuation of regulatory ecosystem services of wetlands and sandy habitat of HWS is estimated at around ₹623012841.6 per $year^{-1}$.

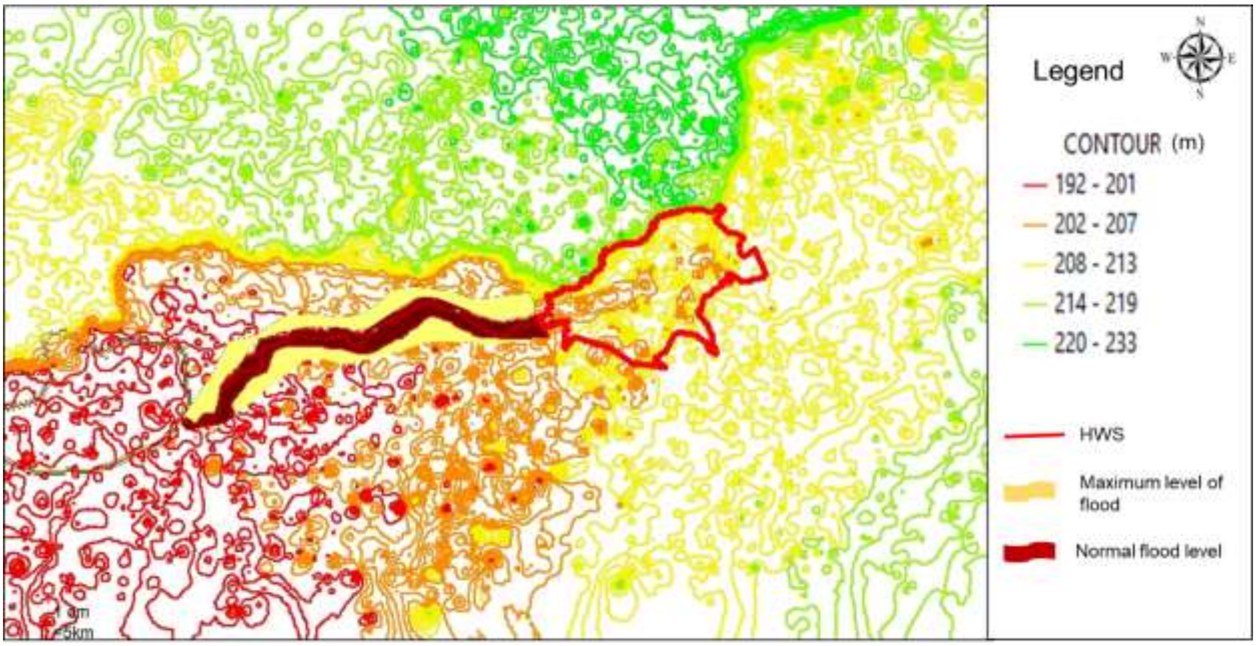


Fig 4.63: Contour arrangement and flood limits (207m) around HWS.

Wetlands play a critical role in protecting against floods. They act as natural buffers, water storage areas, filters, and habitats for a range of wildlife. By protecting wetlands, we can reduce the impact of floods, improve water quality, and provide important cultural and economic benefits. We must recognize the value of wetlands and take steps to protect them for future generations. Wetlands are well known to affect groundwater recharge, low flows, evaporation, and floods as part of the hydrological cycle. This has prompted the development of policies on a global scale to manage and maintain wetlands to provide these essential functions, particularly the decrease of flood risk. It can be challenging to generalize the flood mitigation benefits of wetlands because each of these wetland forms can have hydrological functions that are slightly different (Adams 1993; Carter 1996; Erwin 2009; Acreman 2013).

Discussion

In the present study ecosystem services were identified and considered for economic valuation through natural ecosystems are national capital hence available for every citizen of the nation as per current laws and policies. Economic valuation is a tool to address the value or importance of particular commodities. The conditions and procedures by which natural ecosystems and the species that make them up support and fulfill human life are referred to as ecosystem services. To address the historical undervaluation of ecosystem services in policy decisions, ecosystem service value is being developed as a vehicle to connect ecological knowledge with economic considerations (Chee 2004; Acharya et al. 2019; Su et al. 2020). In the present study provisional ecosystem services are studied under biotic and abiotic goods. All the plant-based provisional ecosystem services have been recorded under biotic on the other hand resources like sand and water is studied under abiotic goods. Systematic quantification per unit is calculated based on direct observation in the field and questionnaires. A total of 115 species of plants are contributing to provisional ecosystem services, Habitats such as Swampy, Ravines, and Plantations are used by locals for fuel-wood collection, and 37 species that contribute to the composition of this fuel-wood were identified and the quantity of fuel-wood collection is estimated and considered for economic valuation by market cost method. The worth of ₹70594.65 of provisioning ecosystem services for Fuel-wood is provided by HWS in a year. The value ₹ 5656891.67 of fodder is grazed by livestock in a year from the HWS where a benefit of ₹6000 to 10000 per year is obtained on medicinal plants by locals. The economic value of edible plants (₹19,400 per year) such as *Mangifera indica* (₹17,500), followed by *Syzygium cumini* (₹6000), *Capparis decidua* (₹600), *Ziziphus nummularia* (₹400), and *Ziziphus mauritiana* (₹300) were estimated. Two species such as *Eichhornia crassipes* and *Saccharum bengalense* were identified as raw materials for different purposes, the collection worth ₹120000 and ₹66528 estimated for a year respectively. The major part of HWS is under agricultural habitat, local people cultivate rice (*Oryza sativa*) and wheat (*Triticum*) crops in that area wetlands also support the natural population *Nelumbo nucifera* and *Trapa natans* which are harvested by locals. Maximum economic value is estimated for crop *Triticum* (₹190,357,302.8) followed by *Oryza sativa* (₹111,617,061.5), *Nelumbo nucifera* (₹472, 442, 0.35) and *Trapa natans* (₹232,138.17). Sharma et al. (2015) found 135 plant species important for collection from the forest of Arunachal Pradesh, India, and economic valuation had been done for collections. Schaafsma et al. (2014) have an estimated value of USD 42 million per year for the benefits flow of charcoal, firewood, poles, and thatch from the Eastern Arc

Mountains (EAM) in Tanzania. Behera and Nath (2012) also recorded 85 plant species from dry deciduous forests in the Boudh district, Orissa important for different uses for local people.

In the case of abiotic goods such as sand and water, utilization is studied for the valuation of provisioning ecosystem services. The Eastern part of study area or downstream of Sutlej River from HWS is sandy habitat due to the accumulation of sand carried through the river during flooding. The local people harvest sand from the edges of HWS. On an average 14.09±3.24 Bullock carts were recorded per day and a single Bullock cart can be sold for ₹400 in the market therefore Sandy Habitat provides provisioning ecosystem services in the form of sand worth ₹5636 per day. The sand worth ₹1600800 is being extracted in a year.

Provision of water from Harike wetland into IGC is estimated worth ₹962,826,108,768 ($12.195 billion) per year. The water utilized in the production of crops wheat and rice is also estimated, Rice requires irrigation water upto 1100mm ha^{-1}, where wheat requires around 500mm ha^{-1} of water from sowing to harvesting therefore using the market cost method value of water for irrigation is calculated for respective crops. As per the local market price of water, rice consumes water worth ₹23274020000 ($293.39 million), and water used for growing wheat in an area of 3022.6 ha, consumes water worth ₹10579100000 ($133.36 million). A total value of $426.75 million of ecosystem services for irrigation is provided by Harike wetland for the cultivation of wheat and rice in 3022.6 ha. Harike wetland recharges the groundwater which is any indirect provisional ecosystem services provided to locals, therefore, the economic worth of water used for domestic use is estimated for selected villages. The total economic value for domestic water usage is estimated at around ₹ 799600682 for five villages. The highest benefit of water usage per year is estimated for village Harike (₹494409582 for 496692000 liters) followed by Chamba kalan (₹153511123.3 for 154219800 liters), Kiriyan (₹79044494.9 for 79409400 liters), Kambo dhaiwal (₹62869366.6 for 63159600 liters), and Marrar (₹9766115.2 for 9811200).

The habitat diversity of HWS supports several cultural ecosystem services, in the field observation a total of 18 types of CES have been recorded from six types of habitat viz. Plantation, Wetland, Swampy, Sandy area, Ravine, and Agricultural. The visitors prefer to travel by road through Light Motor Vehicles (93.27%) and Heavy Motor Vehicles (6.73%). The average distance covered by visitors is 73.64±46.44km, while around 38.46% of visitors cover the distance between 50 to 75 km to avail of certain CES and 16.35% of visitors travel between 75 to 100 km to reach the sanctuary. The total economic value of CES is estimated ₹

443193 for 300 groups by travel cost method for the year 2019-2020. Different ecosystem services are also estimated by a willingness to pay method. The sample mean amount of willingness to pay for each CES is used to infer the mean amount of willingness to pay for the total population visited in the year 2019-2020. A total of 7500 individuals visited in the considered time, therefore the proportion of responses has been estimated before estimating the final economic value of the considered CES. The sample mean amount of CES according to Willingness to pay is calculated for the estimation of total economic value. Total economic value accounts for ₹3894850.91 ($52083.74) for the concerned CES for a year.

In the case of supporting services, biomass of different plants was estimated for economic valuation. A total of 4980.94 tons of biomass is estimated for 4 species of submersed plants, maximum biomass is calculated for *Hydrilla verticillata* (2634.2 tons), followed by *Vallisneria natans* (2297.27 tons), *Ceratophyllum demersum* (36.82 tons), *Najas minor* (12.62 tons). The total economic value was estimated based on the market price of biomass in the local market (1.2 kg^{-1}) therefore total amount in economic terms is estimated at around ₹5977126.12 per year. In floating vegetation, maximum biomass ha^{-1} is estimated for *Nelumbo nucifera* (4 ton ha^{-1}), covering an area of 6.61 hectares, followed by *Eichhornia crassipes* (1.9 t ha^{-1}), spread over 642.59 hectares, and *Pistia stratiotes* (0.6 t ha^{-1}), grows over an area of 316 hectares of wetland. A total of 1258.94 tons of biomass is estimated for the above-mentioned species per year which is worth ₹1503572.46/year according to the market cost method. The supporting services of *Cannabis sativa* for biomass are calculated at about 25.32 tons, which is worth of economic value of (25320 x ₹1.2 kg-1) ₹30,384 $year^{-1}$. Two species of dominating grasses in the HWS, such as *Phragmites karka and Saccharin bengalense*. Swampy habitat supports 54 tons per hectare of biomass through *Phragmites karka* only and the total area covered by *Phragmites karka* under Swampy habitat produces 149914.8 tons of biomass per year through *Phragmites karka* with a total economic value of ₹179897760 $year^{-1}$. *Saccharin bengalense* covers 43.4 hectares across the HWS and total biomass is estimated at up to 3906 tons/year with a total economic value of ₹4687200 $year^{-1}$. Biomass of crops which are produced in the HWS is considered as supporting services therefore biomass of wheat and rice is estimated and incorporated for valuation. The total biomass produced by Wheat is 7586.73 tons whereas paddy produces biomass of around 20493.22 t $year^{-1}$. The mean market price of biomass is ₹1.2/kg therefore the total economic value of biomass produced by wheat and paddy within the boundaries of HWS is ₹9104076 and ₹24591864 for a year, respectively. Tree biomass was estimated and incorporated for the valuation of supporting ecosystem services. In the Plantation habitat total tree Biomass is estimated at up to 184.06 t ha^{-1} and the total area under the plantation habitat is 99.68 hectares therefore Plantation habitat is a repository of 18347.1008 tons (18347100.8 kg) of Tree biomass including above-ground biomass and Root Biomass. The total economic value of tree biomass of plantation habitat is calculated around (18347100.8 x 1.2 = ₹22016520.96) ($275603.41). The Ravine habitat also supports the tree population hence biomass of trees in the Ravine habitat is calculated for valuing supporting ecosystem service. The ravine habitat is spread over 106.12 hectares hence total biomass present is 3814.69 tons. The economic value is estimated by market prices of biomass in the local market. i.e. ₹1.2 kg^{-1} therefore the total economic value of the tree biomass present in the Ravine habitat is ₹4577629.169.

The economic value of regulatory ecosystem service was estimated through the flood control capacity of HWS downstream. DEM is used to mark the maximum flood zone by following flood history in the region. HWS holds the flow of water and protects against flooding downstream and also protect rice crop worth ₹623012841.6 protected by the wetlands and sandy habitat of HWS from flooding in the region of India.

Rosadi and Patria (2018) found direct economic value was obtained by the local community through direct exploitation. They recorded the benefits of Mangrove forests worth Rp. 227.040.000 $year^{-1}$. Indirect value gain from the mangrove forest's ecosystem service, valued at Rp. 1,455,041,200 per year. Utilizing the CVM (Contingent Valuation technique) technique, an existence value advantage of Rp. 1.520.000 $year^{-1}$ was derived. Biodiversity value provided an option value benefit with an annual value of Rp. 1.200.000. The mangrove's total economic value (TEV) was Rp. 1.634.801.200 each year. Başkent (2021) estimated the Total economic value of the key ecosystem services was estimated $438,128,571 besides composition and conFiguration of ecosystems determine the sustainable provision of ecosystem services. The services and benefits that the nearby wetlands gave to the residents had a yearly value of USD 1 billion estimated by Camacho-Valdez (2013) for the coastal wetlands in northwest Mexico. Ecosystem services, or the advantages that humans derive from ecosystems, are a useful lens for examining how people relate to the environment and for developing environmental policy (Brauman 2007).

According to Atkinson et al. (2012) focus on economic value has provided an empirical voice to interest in the economics of biodiversity and wider ecological services. This emphasis has been brought about by a rising realization that the advantages and opportunity costs related to such services are frequently either superficially or even totally taken into account in policy studies. As a result, a growing corpus of relevant research has shown that the valuing of biodiversity and ecosystem services is increasingly recognized as an essential component of sound decision-making.

Chapter 5

Seasonal variation in vegetation across the habitats and mapping in HWS

The Punjab Plain is situated in India's semi-arid and sub-tropical zones, with extensive river systems. The exogenic forces of river systems have manifested variation in the physical aspects of Punjab's landscapes (Naruse 1976) and these different topographical features provide a variety of habitats, including highlands, dry ravines, wetlands, marsh and swamps. Because terrain influences water flow and moisture gradient, habitat diversity is also important for floral variation. Bamber (1916), Nair (1978), Meenakshi and Sharma (1985), Sharma and Khosla (1989), Sharma (1990), Sharma and Rajpal (1995), Tiwana et al. (2005), Jeratth et al. (2006), Santapau (1958) and Kaur et al. (2017) were among the first to document Punjab flora. An essential characteristic of terrestrial ecosystems is seasonal fluctuation in the vegetation (de Lampe et al. 1992; Suepa et al. 2016). Throughout the year, plants experience various changes in their growth, flowering and fruiting patterns as a result of the environment and the availability of resources (Reynolds 1999). For effective habitat management and conservation measures, understanding these variations is crucial (Zacharias et al. 2007). On the other hand, habitat mapping enables scientists to measure and depict the distribution and patterns of vegetation throughout distinct habitats (Küchler and Zonneveld 2012). Seasonal variations in vegetation are significantly influenced by climate (Huang 2016). Plant growth, dormancy and reproductive activities are directly influenced by temperature, precipitation and photoperiod (Gray and Brady 2016). Deciduous trees lose their leaves in the winter and grow new ones in the spring because temperate regions have distinct seasons (Lechowicz 1984). Plant nutrient availability, water retention and drainage are all significantly influenced by soil composition (Lal 2020). Different soil types have different mineral contents and capacities for storing water, which causes variances in plant communities (Sardans and Penuelas 2013). Vegetation patterns are also influenced by interactions between creatures, such as competition, predation and mutualism (Clarke 1995). For instance, pollinators help plants reproduce successfully (Thomann 2013) whereas herbivores' grazing might affect the makeup of plant species (Clarke 1995). Seasonal variations in these ecological interactions may influence the dynamics of plant communities. Data on vegetation composition, quantity and variety are directly gathered from the study site during field surveys. Field investigations offer in-depth data on particular areas, enabling the ground truthing and validation of remote sensing and GIS data. Effective habitat conservation depends on an understanding of seasonal fluctuation in vegetation. Species interactions, migratory patterns and the health of an ecosystem as a whole can all be impacted by changes in vegetation composition and phenology. Habitat mapping according to the present status can be useful for better mamangement of peticular area besides it is important for guiding land-use planning, identifying priority conservation sites and reducing the effects of habitat fragmentation. To monitor and protect the flora of HWS, present study has created a detailed record for each habitat with reference to seasonal fluctuation in vegetation. Understanding seasonal variation in vegetation is essential for efficient habitat management and conservation because vegetation plays a significant role in ecosystem dynamics. In the present study, seasonal variation in vegetation across the habitats has examined, along with the habitat mapping for the conservation and monitoring of biodiversity (Lang 2015). This study has also included focused habitat mapping to evaluate the distribution and patterns of vegetation.

The present study has included plant based provisional ecosystem services in chapter 4 besides the seasonal variation in the plants have significant impact on migratory birds that has been concluded in the chapter 6. This chapter is devoted to second objective of the present study "Habitat characterization of Harike Wildlife Sanctuary with special reference to habitat mapping". The Harike Wildlife Sanctuary (HWS) is a potential place for high floral diversity, located at the confluence of the Beas and Sutlej rivers. The recording of plant composition is necessary for developing conservation management strategies to sustain ecological functions, hence the current study is an attempt to investigate floral variety in distinct HWS habitats.

Methods

The intensive field surveys on foot were carried out by following line transect in the different seasons across habitats of HWS. A total of sixty-five field surveys had been conducted since September 2019 to March 2021 for primary data collection process has shown in fig 5.1.

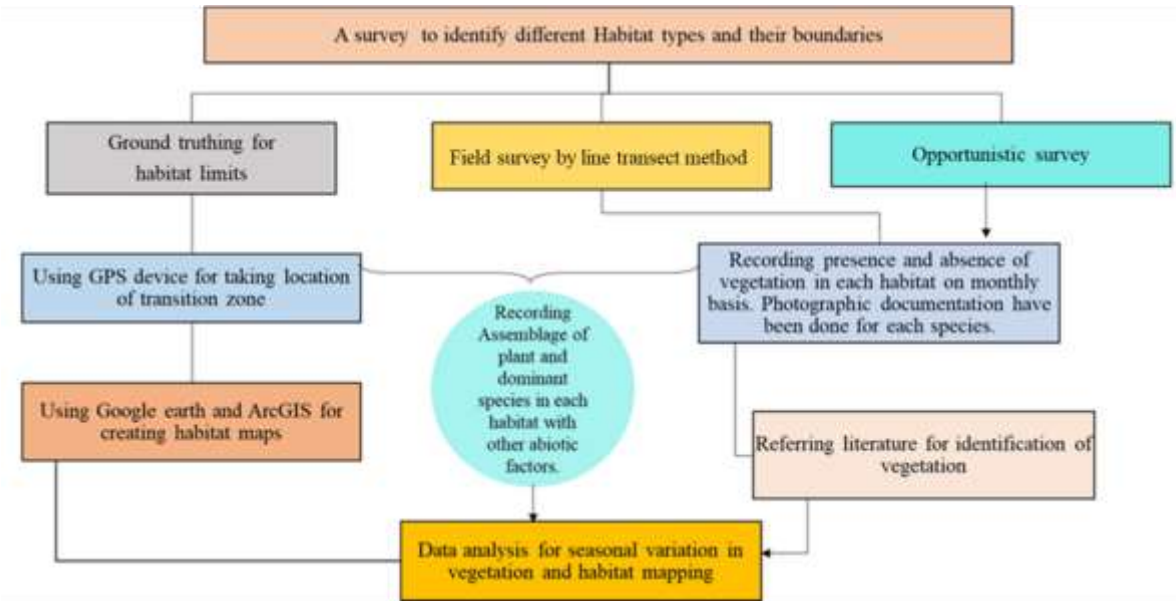


Fig 5.1: Schematic representation of investigation and systematic record of vegetation.

There are six habitats identified in the HWS viz., Wetland, Sandy, Plantation, Agricultural field, Ravine and Swamps based on physical characteristics and vegetation. In each habitat type, vegetation data were collected through line transect method (Buckland et al. 2007). Source of plants were also recorded (wild, cultivated and ornamental) as well as intensive photography (picture of flowers, leaves, fruits and bark) was done through mobile and digital cameras for documentation and evidence of plants. Seasonal data for plants were collected, Summer (April, May and June), Monsoon (July, August and September), Post-monsoon (October, November and December), Winter (January, February and March). The distribution of plants were registered through ocular estimation viz., Occasional (species recorded in more than three habitats with a regular interval during surveys), Frequent (the species present in more than three habitats), Rare (the species restricted to a single habitat) and Very Rare (less than five individuals found during the survey). To determine the spatial expansion of a particular habitat field survey were carried out and habitat maps were prepared (Anchang 2020) with the help of Google Earth Pro and Arc GIS10.5 after precise ground-truthing. The plant species were identified following Nair (1978), Sharma and Khosla (1989), Sharma (1990). Sharma and Rajpal (1995) and Kumar (2001). The checklist of plants was prepared according to the currently accepted name given at www.theplantlist.com and www.flowersofindia.net. The voucher specimens of all the recorded plants as photographic records had submitted to the WII herbarium (Wildlife Institute of India, Dehradun).

Data analysis

All the collected data of plants were used for calculating species richness across the habitats. Seasonal change in the habitat had been addressed by the seasonal change in species richness of plants in a perticular habitat (Ricklefs and Renner 1994; Pausas and Austin 2001).

- Species richness (s) in each habitat was calculated by

$s = \sum n$

n= number of species

Cluster analysis

Cluster analysis was done by following Reid et al. (2002) for different habitat types based on plant species composition (presence /absence), through Past 4.03 software.

Jaccard similarity Index of plant communities between habitats

To evaluate the similarity of plant communities between habitats, Jaccard similarity coefficient was applied by following He et al. (2017) and Mao et al. (2023), Jaccard similarity coefficient is used to measure association similarity (C_J) and it was calculated as $C_J = \frac{c}{A+B-c}$ where c denotes the number of species shared by the two communities and a and b denote the total number of species in communities A and B, respectively. For C_j % = $\{\frac{c}{A+B-c}\}$ x100. To comprehend how the HWS plant association is related to other plant communities, 15 habitat groups were put together.

Results

Wildlife sanctuaries are places that have been set aside to preserve biodiversity and offer suitable habitat for various species. For the upkeep and care of these habitats, determining the type of land use and land cover within a sanctuary is essential. It entails safeguarding natural ecosystems, including forests, marshes, grasslands and rivers and lakes, which are vital habitats for a wide variety of plant, bird and animal species.

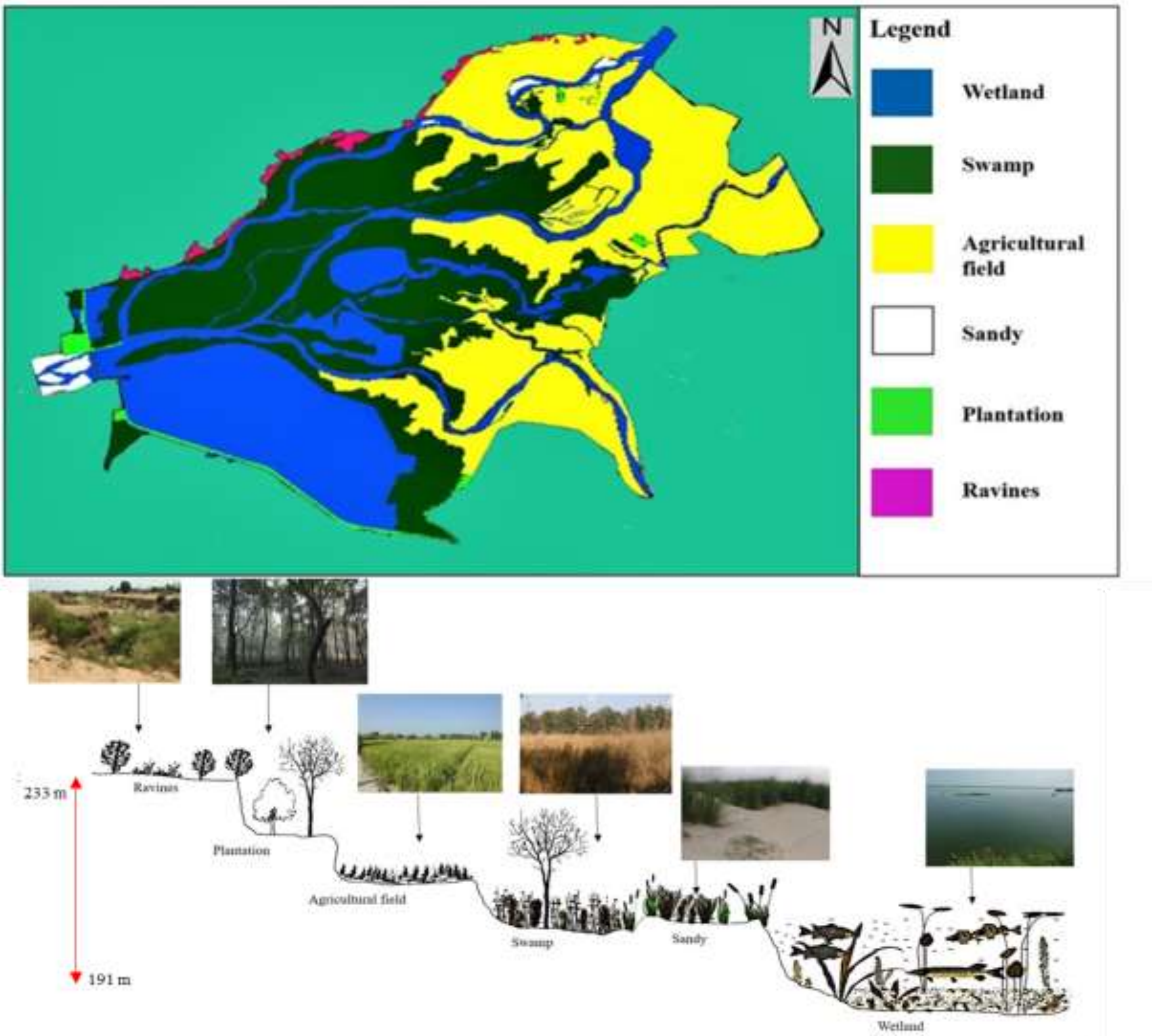


Fig 5.2: Type of habitats recorded from Harike Wildlife Sanctuary.

Habitat	Characteristics
	**Sandy area** This area located at western part of the sanctuary and receive sand from the Beas and Satlej rivers. The dominated vegetation were *Saccharum bengalense* and *Saccharum spontaneum* with herbs such as *verbesina encelioides*, *Cannabis sativa* and sedge *Cyperus rotundus*.Medicinal plants like *Eclipta prostrata*, *Ipomoea aquatic* and *Phyla nodiflora* were recorded form this habitat.
	**Wetland** The major part of the sanctuary was covered by the wetland. Dominated submersed vegetation were *Hydrilla verticillata* and *Vallisneria natans* where *Eichhornia crassipes*, *Pistia stratiotes* and *Nelumbo nucifera* were found as floating vegetation. The wetland supports a variety of essential medicinal plants like *Bacopa monnieri*, *Centella asiatica* and *Ranunculus sceleratus*.
	**Plantation** The tree cover was seen on all boundaries except the northeastern side. Dominated vegetation were *Terminalia arjuna, Syzygium cumini, Leucaena leucocephala, Prosopis juliflora, Dalbergia sissoo* and *Kigelia Africana*. The ground vegetation covered with medicinal plant such as *Cannabis sativa, Sida acuta, Senna occidentalis, Achyranthes aspera* and *Chenopodium album*.
	**Ravine** The ravines area was located beside the right bank of the Beas River. Soil was comparatively hard and dry among all habitats in HWS. Vegetation composition was comprised of shrubs such as *Calotropis procera*, *Capparis decidua*, *Lycium edgeworthii* and *Ziziphus nummularia*. Some medicinal plants such as *Boerhavia erecta, Peganum harmala* and *Aerva javanica* were recorded from this site.

Swampy

The Swamp area with tree species along wetland habitat exposed to seasonal flooding in the HWS. A major area is dominated by *phragmites karka* and *Typha angustifolia.* Tree species like *Terminalia arjuna*, *Syzygium cumini* and *Leucaena leucocephala*. The outer boundary of the Swamp area is associated with tall grasses like *Chrysopogon zizanioides*, *Saccharum bengalense* and *Saccharum spontaneum.* Medicinal Plants such as *Bacopa monnieri, centella asiatica* and *Convolvulus arvensis* were recorded.

Agricultural Field

The eastern part of the sanctuary was dominated by agricultural field habitat, along Beas and Sutlej River. *Triticum aestivum* and *Oryza sativa* are the main crops harvested in a year. The intact agricultural bunds were found important concerning holding a population of medicinal plants like *Withania coagulans*, *Solanum nigrum*, *Tribulus terrestris* and *Sida acuta* can be found on agricultural bunds.

Fig 5.3: Habitat and its characteristics

Land use pattern

The Sanctuary is a mosaic of habitats with an area of 8600 hectares, the association of lotic and lentic wetlands supports flora and fauna of HWS. Fig 5.2 is showing distribution of habitats across the HWS. A diverse flora is supported by dynamic moisture levels and geographical factors. Agricultural field habitat had the most area with 35.15 percent (3022.6 hectares), followed by Swampy habitat with 32.28 percent (2776.2 hectares), Wetland with 29.15 percent (2507.2 hectares), Ravines with 1.23 percent (106.12 hectares), Plantation with 1.16 percent (99.68 hectares) and Sandy habitat with 1.03 percent (88.2 hectares). The present active flood zone can extend upto Wetland, Swampy and Sandy habitats, collectively these habitats covered 62.46% (5371.56 hectares) of the total area of HWS.

Classification and distribution of species

The present study has recorded a total of 386 species, belonging to 320 genera and 103 families. There were 84 trees, 40 shrubs, 173 herbs, 33 climbers, 33 grasses, 6 submerged vegetation, 10 floating vegetation, 3 ferns and 4 succulents identified (Table 5.1). Leguminosae, Poaceae, Compositae, Malvaceae, Solanaceae and Euphorbiaceae are the most dominant families. There are around 1843 species have been reported by Sharma (1990) therefore in the present investigation, about 20.94% of plants from the flora of Punjab state have been documented.

Table 5.1: Number of species, genera and family according to habit.

Habit	Species	Genus	Family
Trees	84	70	34
Shrubs	40	34	20
Herbs	173	136	51
Climbers	33	27	12
Grasses	33	30	1
Submerged vegetation	6	6	4
Floating vegetation	10	10	7
Ferns	3	3	3
Succulent	4	4	2

The dominating families were Leguminosae with 13.21% (51 species) followed by Poaceae 8.55% (33 species), Compositae 5.18% (20 species), Malvaceae 4.92% (19 species), Solanaceae 3.63% (14 species) and Euphorbiaceae 3.63% (14 species), Number of species and its percentage under concerned family according to Habit shown in Table 5.2.

The herbs account for 44.82% with dominating families like Leguminosae (21 species) followed by Compositae (19 species), Malvaceae (12 species) and Solanaceae (11 species). Common herb species distributed among habitats are *Cannabis sativa, Chenopodium album, Oxalis corniculata, Parthenium hysterophorus, Aerva javanica, Ageratum conyzoides, Artemisia scoparia and Senna occidentalis*. All the species of herbs were recorded from 51 families. Tree species contributed 21.76% from 34 families and species distributed among habitats were *Dalbergia sissoo, Syzygium cumini, Terminalia arjuna, Leucaena leucocephala, Ficus religiosa, Prosopis juliflora, Parkinsonia aculeata, Eucalyptus camaldulensis* and *Kigelia africana.* A maximum number of tree species were listed under the family

Leguminosae (24 species) followed by Moraceae (9 species), Bignoniaceae (5 species) and Meliaceae (4 species). The shrubs accounted for 10.36% of 20 families, comprised of species like *Lantana camara, Ricinus communis, Ziziphus nummularia and Grewia tenax.* Six shrub species were documented from each family (Apocynaceae & Euphorbiaceae).

Climbers accounted for 8.2% belonging to 12 families, species such as *Abrus precatorius, Mukia maderaspatana, Convolvulus arvensis* and *Oxystelma esculentum* were common among some habitats. Grasses such as *Saccharum spontaneum, Cynodon dactylon, Dactyloctenium aegyptium, Phragmites karka* and *Setaria viridis* contributed 8.6%. The common floating vegetation was dominated by *Eichhornia crassipes, Pistia stratiotes* and *Nelumbo nucifera* accounted for 2.6% belonging to 7 families. The submerged vegetation like *Hydrilla verticillata, Vallisneria natans* and *Najas minor* were recorded from 4 families which were spreadout across wetland and contributed 1.6% to the plants in HWS.

Table 5.2: Number of species mentioned under particular family according to habits.

(T: Trees, S: Shrubs, H: Herbs, Cl: Climbers, G: Grasses, Sv: Submerged vegetation, Fv: Floating vegetation, Fr: Ferns Su: Succulent)

Family	T	S	H	Cl	G	Sv	Fv	Fr	Su	Total species	Species %
Leguminosae	24	3	21	3	-	-	-	-	-	51	13.2
Poaceae	-	-	-	-	33	-	-	-	-	33	8.6
Compositae	-	1	19	-	-	-	-	-	-	20	5.2
Malvaceae	3	4	12							19	4.9
Euphorbiaceae	1	6	7							14	3.6
Solanaceae		3	11							14	3.6
Apocynaceae	1	6	1	3						11	2.9
Convolvulaceae		1	1	8						10	2.6
Lamiaceae	2	2	6							10	2.6
Amaranthaceae			9							9	2.3
Cucurbitaceae				9						9	2.3
Moraceae	9									9	2.3
Brassicaceae			7							7	1.8
Plantaginaceae			7							7	1.8
Polygonaceae			6	1						7	1.8
Apiaceae			5							5	1.3
Bignoniaceae	5									5	1.3
Lythraceae	3		1				1			5	1.3
Asparagaceae				1					3	4	1.0
Meliaceae	4									4	1.0
Myrtaceae	4									4	1.0
Nyctaginaceae		1	3							4	1.0
Rutaceae	1	3								4	1.0

Acanthaceae		1	2						3	0.8
Amaryllidaceae			3						3	0.8
Araceae			1			2			3	0.8
Caryophyllaceae			3						3	0.8
Chenopodiaceae			3						3	0.8
Hydrocharitaceae					3				3	0.8
Menispermaceae				3					3	0.8
Onagraceae			3						3	0.8
Papaveraceae			3						3	0.8
Portulacaceae			3						3	0.8
Verbenaceae		1	2						3	0.8
Aizoaceae			2						2	0.5
Arecaceae	2								2	0.5
Asteraceae			1	1					2	0.5
Boraginaceae			2						2	0.5
Cannabaceae			1	1					2	0.5
Combretaceae	2								2	0.5
Commelinaceae			2						2	0.5
Crassulaceae			2						2	0.5
Cyperaceae			2						2	0.5
Nymphaeaceae						2			2	0.5
Oleaceae	1	1							2	0.5
Pedaliaceae			2						2	0.5
Phyllanthaceae	1		1						2	0.5
Rhamnaceae	1	1							2	0.5
Rubiaceae		1	1						2	0.5
Salicaceae	2								2	0.5
Salviniaceae						2			2	0.5
Sapotaceae	2								2	0.5
Zygophyllaceae			2						2	0.5
Alismataceae			1						1	0.3
Anacardiaceae	1								1	0.3
Annonaceae	1								1	0.3
Aspleniaceae							1		1	0.3
Athyriaceae							1		1	0.3
Basellaceae				1					1	0.3
Cactaceae								1	1	0.3
Capparaceae		1							1	0.3
Capparaceae	1								1	0.3
Caricaceae	1								1	0.3
Casuarinaceae	1								1	0.3
Ceratophyllaceae					1				1	0.3
Cleomaceae			1						1	0.3
Cupressaceae		1							1	0.3

Cycadaceae	1									1	0.3
Ebenaceae	1									1	0.3
Equisetaceae								1		1	0.3
Geraniaceae			1							1	0.3
Haloragaceae						1				1	0.3
Juncaceae			1							1	0.3
Lemnaceae							1			1	0.3
Marsileaceae			1							1	0.3
Menyanthaceae							1			1	0.3
Molluginaceae			1							1	0.3
Moringaceae	1									1	0.3
Musaceae	1									1	0.3
Nitrariaceae			1							1	0.3
Oxalidaceae			1							1	0.3
Phrymaceae			1							1	0.3
Pontederiaceae							1			1	0.3
Potamogetonaceae						1				1	0.3
Primulaceae			1							1	0.3
Proteaceae	1									1	0.3
Punicaceae		1								1	0.3
Putranjivaceae	1									1	0.3
Ranunculaceae			1							1	0.3
Rosaceae		1								1	0.3
Rubiaceae	1									1	0.3
Sapindaceae				1						1	0.3
Sapindaceae	1									1	0.3
Scrophulariaceae			1							1	0.3
Simaroubaceae	1									1	0.3
Sphenocleaceae			1							1	0.3
Tamaricaceae	1									1	0.3
Typhaceae			1							1	0.3
Ulmaceae	1									1	0.3
Urticaceae			1							1	0.3
Vitaceae				1						1	0.3
Zamiaceae		1								1	0.3
Zingiberaceae			1							1	0.3
Total	84	40	173	33	33	6	10	3	4	386	100.00

The contribution of succulents was 1.0% while *Sansevieria aethiopica* and *Opuntia dillenii* were present in some habitats. Ferns accounted for 0.8% belonging to 3 families and the most common species was *Diplazium esculentum.* During the survey, various habits were registered in each habitat according to field observation carried out in 18 months in HWS.

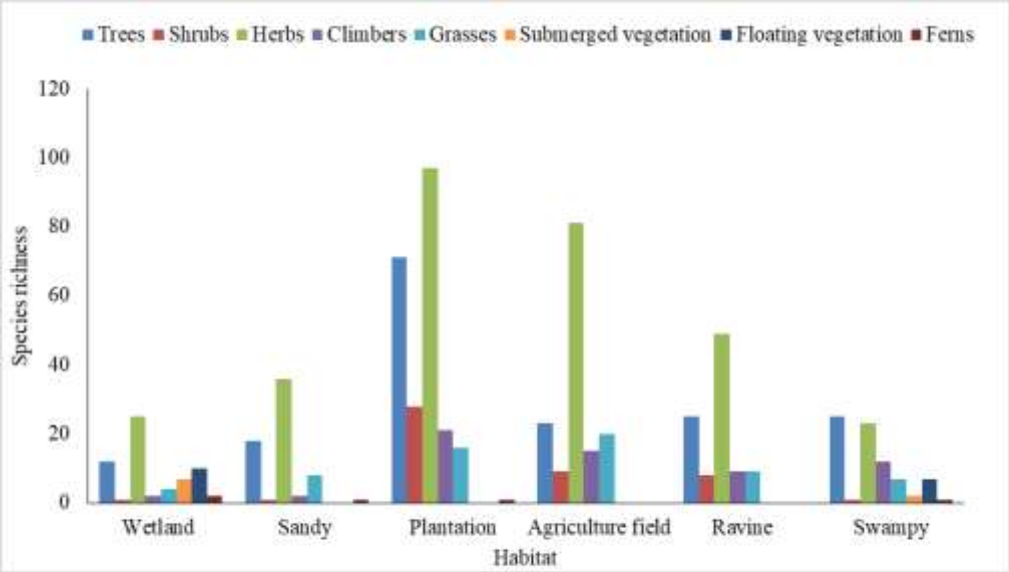


Fig 5.4: Species distribution across habitats as per their habit.

Among habitats, the maximum number of species were recorded from Plantation habitat (233 species), with most common species such as *Terminalia arjuna, Syzygium cumini, Leucaena leucocephala, Prosopis juliflora, Dalbergia sissoo, Ficus benghalensis, Ficus palmata, Kigelia Africana, Cannabis sativa, Sida acuta, Senna occidentalis, Achyranthes aspera* and *Chenopodium album*, followed by Agricultural field habitat (146 species) with common species such as *Melia azedarach, Cordia myxa, Malva parviflora, Ziziphus mauritiana, Calotropis procera, Ageratum conyzoides, Artemisia scoparia, Erigeron canadensis* and *Rumex dentatus*. Ravin habitat accommodated 100 species, like *Cocculus pendulus, Commelina benghalensis, Commelina erecta, Convolvulus arvensis, Convolvulus prostratus, Cordia myxa, Crotalaria burhia, Crotalaria medicaginea, Croton bonplandianus, Cyathula prostrata, Cymbopogon martini* and *Cynodon dactylon.* In the Swampy habitat a total of 80 species were recorded, species of plant were *Anagallis arvensis, Tamarix dioica, Anisomeles indica, Prosopis juliflora, Artemisia scoparia, Blumea axillaris, Syzygium cumini, Blumea lacera, Pongamia pinnata, Morus alba* and *Terminalia arjuna.* Sandy habitat was dominated by *Saccharum spontaneum* and supported a plant association of 67 species, like *Convolvulus arvensis, Ipomoea aquatica, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus benghalensis, Cardamine hirsuta, Digera muricata, Fumaria indica, Juncus bufonius, Ludwigia adscendens* and *Mecardonia procumbens.* The minimum number of species were recorded from wetland habitats (63 species) comprised of submerged vegetation (*Hydrilla verticillata*, *Vallisneria natans*) and floating vegetation (*Eichhornia crassipes*, *Pistia stratiotes* and *Nelumbo nucifera*). Wetland habitat (moist shore) was dominated by tree species like *Bombax ceiba*, *Eucalyptus camaldulensis, Salix alba, Phoenix* *sylvestris*, *Terminalia arjuna* and *Syzygium cumini* and herbs such as *Bacopa monnieri*, *Centella asiatica* and *Ranunculus sceleratus* and *Phragmites karka* and *Paspalum distichum* as common grass species.

Source and occurrence of plant species

A total of 289 species was identified as wild (58 trees, 13 shrubs, 143 herbs, 26 climbers, 29 species of grasses. Six species of submerged plants and ten species of floating plants, three species of ferns and a species Succulent) followed by ornamental plants with 56 species (19 trees, 21 shrubs, 11 herbs, 2 climbers and 3 succulent) and cultivated plants with 41 species (7 trees, 6 shrubs, 19 herbs, 5 climbers and 4 species of grass). Occurrences of plants were documented for different habits (fig 5.5). Frequency of floating vegetation accounts for 3.62% of frequent, 1.18% of occasional and 0.85% of rare. Submerged vegetation comprises 4.35% of frequent, 2.54% of rare and 1.82% of very rare. Grasses represented 17.39% of frequent, 5.88% of occasional, 2.54% of rare and 3.64% of very rare. Climber species had shown 7.97% of frequent, 9.41% of occasional, 9.32% of rare and 12.73% of very rare. Shrubs accounted for 3.62% of frequent, 9.41% of occasional, 16.95% of rare and 16.36% of very rare. Trees represented 15.22% of frequent, 25.88% of occasional, 20.34% of rare and 27.27% of very rare. Herbs were recorded the most, constituting 47.10% of frequent, 48.24% of occasional, 46.61% of rare and 38.18% of very rare. Ferns accounted for 0.72% of frequent and 0.85% of rare.

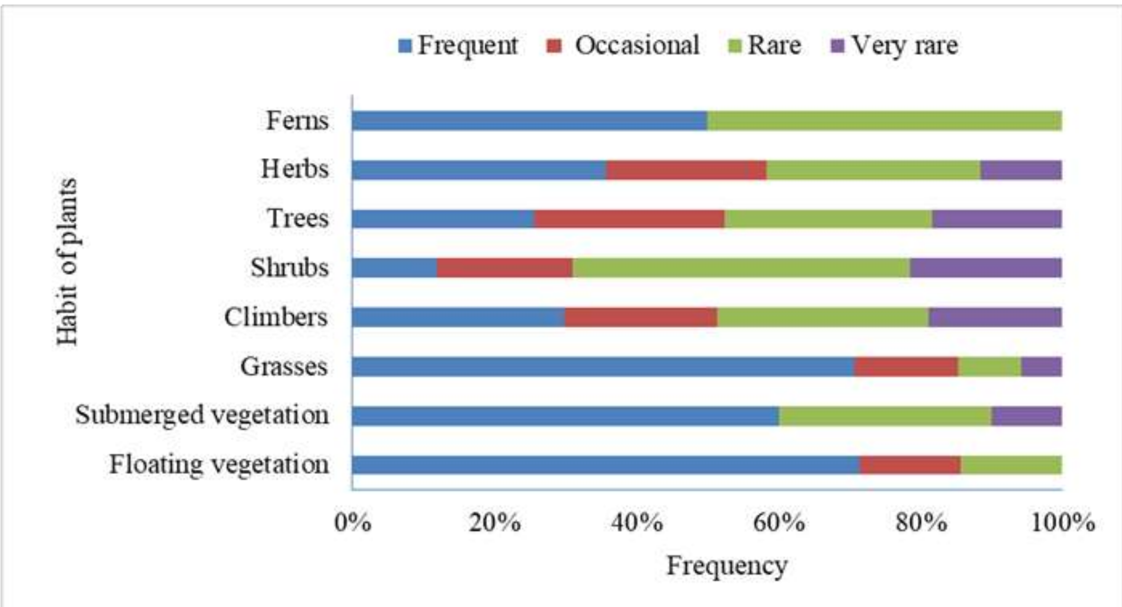


Fig 5.5: Frequency of plant species under each habit.

Dynamics of vegetation across habitat types in Harike WS

The diverse habitat type of Harike Wildlife Sanctuary supports various plant communities. The Sanctuary harbors 386 species of plants under various habit categories. On average, a standing crop of 247.5±70.29 species of plants can be found at any point in time. A significant change in the species composition had been recorded in different seasons at wetland habitats, this supported the population of *Ageratum conyzoides, Anagallis arvensis, Bacopa monnieri, Centella asiatica, Chrysopogon zizanioides, Cyperus rotundus, Dalbergia sissoo, Eichhornia crassipes, Eucalyptus camaldulensis, Hydrilla verticillata, Ipomoea carnea, Ludwigia perennis, Marsilea quadrifolia, Najas minor, Nelumbo nucifera, Oxalis corniculata, Persicaria glabra, Phoenix sylvestris, Phyla nodiflora, Pistia stratiotes, Ranunculus sceleratus, Salvinia natans, Syzygium cumini, Vallisneria natans* and *Veronica anagallis-aquatica*. The mean species richness in wetland habitat remains to 40.27±12.07 in each season.

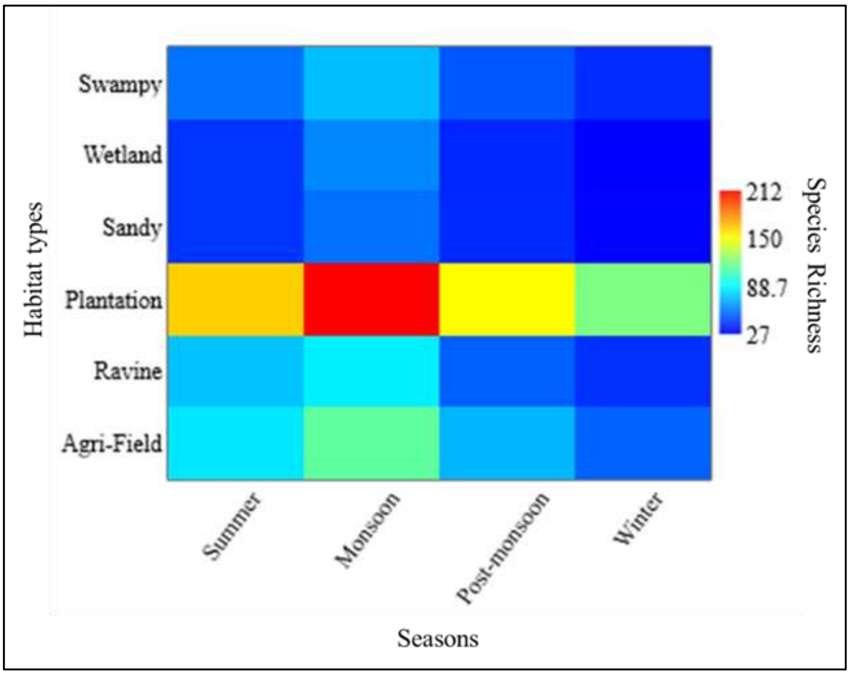


Fig 5.6: Seasonal variation in species richness across the habitat types.

In the case of Swampy habitat dominated by *Phragmites karka* grass with associate species like *Cannabis sativa, Dalbergia sissoo, Eichhornia crassipes, Eucalyptus camaldulensis, Hydrilla verticillata, Ipomoea carnea, Ipomoea pes-tigridis, Leucaena leucocephala, Malva parviflora, Pergularia daemia, Saccharum bengalense, Syzygium cumini, Terminalia arjuna, Typha angustifolia* and *Xanthium strumarium*. The mean species richness upto 53.5±12.78 throughout all seasons. A plant association dominated by tree species like *Ailanthus excelsa, Albizia lebbeck, Dalbergia sissoo, Delonix regia, Ficus racemosa, Leucaena leucocephala, Parkinsonia aculeata, Pithecellobium dulce, Prosopis juliflora, Salix alba, Syzygium cumini and Terminalia arjuna* in the Plantation habitat shown the mean species richness by 162.7±39.47 across the seasons.

Sandy habitat had shown domination of *Saccharum bengalense* and *Saccharum spontaneum* with other species like *Bolboschoenus maritimus, Cannabis sativa, Chrysopogon zizanioides, Cynodon dactylon, Desmostachya bipinnata, Eclipta prostrata, Euphorbia hirta, Fumaria indica, Leucaena leucocephala, Oxalis corniculata, Phragmites karka, Sisymbrium irio, Sphenoclea zeylanica, Verbascum thapsus* and *Polygonum plebeium* with mean species richness 39.75±9.34 in any season.

The Ravine habitat supports a plant association dominated by *Calotropis procera* and *Capparis decidua* with other associate species like *Aerva javanica, Croton bonplandianus, Heliotropium strigosum, Peganum harmala, Pluchea lanceolata, Saccharum bengalense, Saccharum spontaneum, Sisymbrium irio, Tribulus terrestris, Tridax procumbens, Verbesina encelioides, Ziziphus nummularia* and *Pulicaria undulata* with the mean species richness 62±18.34 throughout the year. The Agricultural field supported the mean species richness of plants 79.25±22.09 in all seasons.

The population of species that can be seen in the Agricultural field habitat are *Achyranthes aspera, Ammannia baccifera, Alhagi maurorum, Alternanthera pungens Aerva javanica, Launaea procumbens, Commelina benghalensis, Alysicarpus ovalifolius, Artemisia scoparia, Dalbergia sissoo, Blumea lacera, Cannabis sativa, Chenopodium album, Medicago sativa, Solanum nigrum, Erigeron canadensis, Fumaria indica, Oxalis corniculata, Saccharum bengalense, Sida acuta,* and *Withania coagulans* in different season.

Seasonal variation in plant association of Wetland habitat

The wetland habitat is distributed across the sanctuary (Fig 5.9). The wetland receives water from the Beas, Sutlej and Kali Bean Rivers. The water flow remains moderate in the Beas River besides more depth can be seen in the Beas River the submersed vegetation is only visible in the seasonal wetland along the Beas River, however, submersed vegetation is not visible in the main channels of Beas River.

The seasonal variation in the wetland habitat has been observed. Variations in the Species richness have been for each habit witnessed during field investigation except the Trees (Fig 5.7). In the summer season around 40 species including all habits. In the summer season around 12 species of herbs were recorded including *Alternanthera paronychioides, Anagallis arvensis, Bacopa monnieri, Euphorbia helioscopia, Ludwigia adscendens, Oxalis corniculata, Persicaria barbata, Persicaria glabra, Persicaria lanigera, Phyla nodiflora, Sagittaria sagittifolia* and *Typha angustifolia.* There is an increase in herbs richness from 12 to 21 species has been recorded, composition of herbs species includes *Adenostemma platyphyllum, Alternanthera paronychioides Colocasia esculenta, Anagallis arvensis, Bcopa monnieri, Centella asiatica, Oxalis corniculata, Ludwigia adscendens Cyperus michelianus, Cyperus rotundus, Eclipta prostrata, Euphorbia helioscopia,, Ludwigia perennis, Marsilea quadrifolia, Persicaria barbata, Persicaria glabra, Persicaria lanigera, Phyla nodiflora, Sagittaria sagittifolia, Typha angustifolia* and *Verbascum thapsus.* In the post-monsoon season herbs richness decreases from 21 to 8 species as compared to the monsoon season, the association of herb species in the post-monsoon season includes *Ageratum conyzoides*, *Alternanthera paronychioides*, *Centella asiatica*, *Colocasia esculenta*, *Eclipta prostrata*, *Ludwigia perennis*, *Ranunculus sceleratus* and *Stellaria media*. In the winter season, most of the herbs survived as compared to post-monsoon season and the species richness of herbs decreases from 8 to 6 species, which included species like *Ageratum conyzoides*, *Alternanthera paronychioides*, *Colocasia esculenta*, *Ranunculus sceleratus*, *Stellaria media* and *Veronica anagallis-aquatica.*

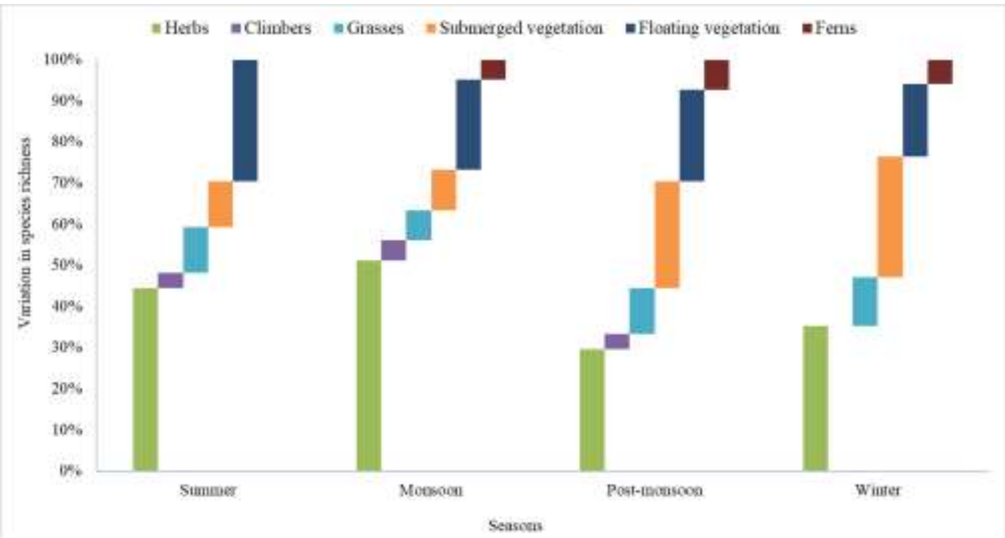


Fig 5.7: Seasonal variations in plant species richness within each habit in wetland.

In case of grass species, wetland supports a population of *Chrysopogon zizanioides, Paspalum distichum* and *Phragmites karka* in summer and monsoon seasons where *Arundo donax* can be seen in post-monsoon and winter seasons along with other 3 species. During field survey in wetland habitat floating vegetation (8 species) like *Eichhornia crassipes, Lemna minor, Nelumbo nucifera, Nymphaea nouchali, Nymphoides cristata, Salvinia natans, Spirodela polyrrhiza* and *Trapa natans* is recorded (Fig 5,8). Species such as *Pistia stratiotes* and *Azolla pinnata* can be seen in the monsoon and post-monsoon seasons respectively. The species richness of floating vegetation decreased from 8 to 3 species. Species composition comprised of *Azolla pinnata, Eichhornia crassipes* and *Pistia stratiotes* were observed in the winter season.

Fig 5.8: Plant composition of wetland habitat (1: *Centella asiatica*, 2: *Nymphoides cristata*, 3: *Vallisneria natans*, 4: *Azolla pinnata*, 5: *Nelimbo nucifera*, 6: *Persicaria lanigera*, 7: *Pistia stratiotes*, 8: *Marsilea quadrifolia*)

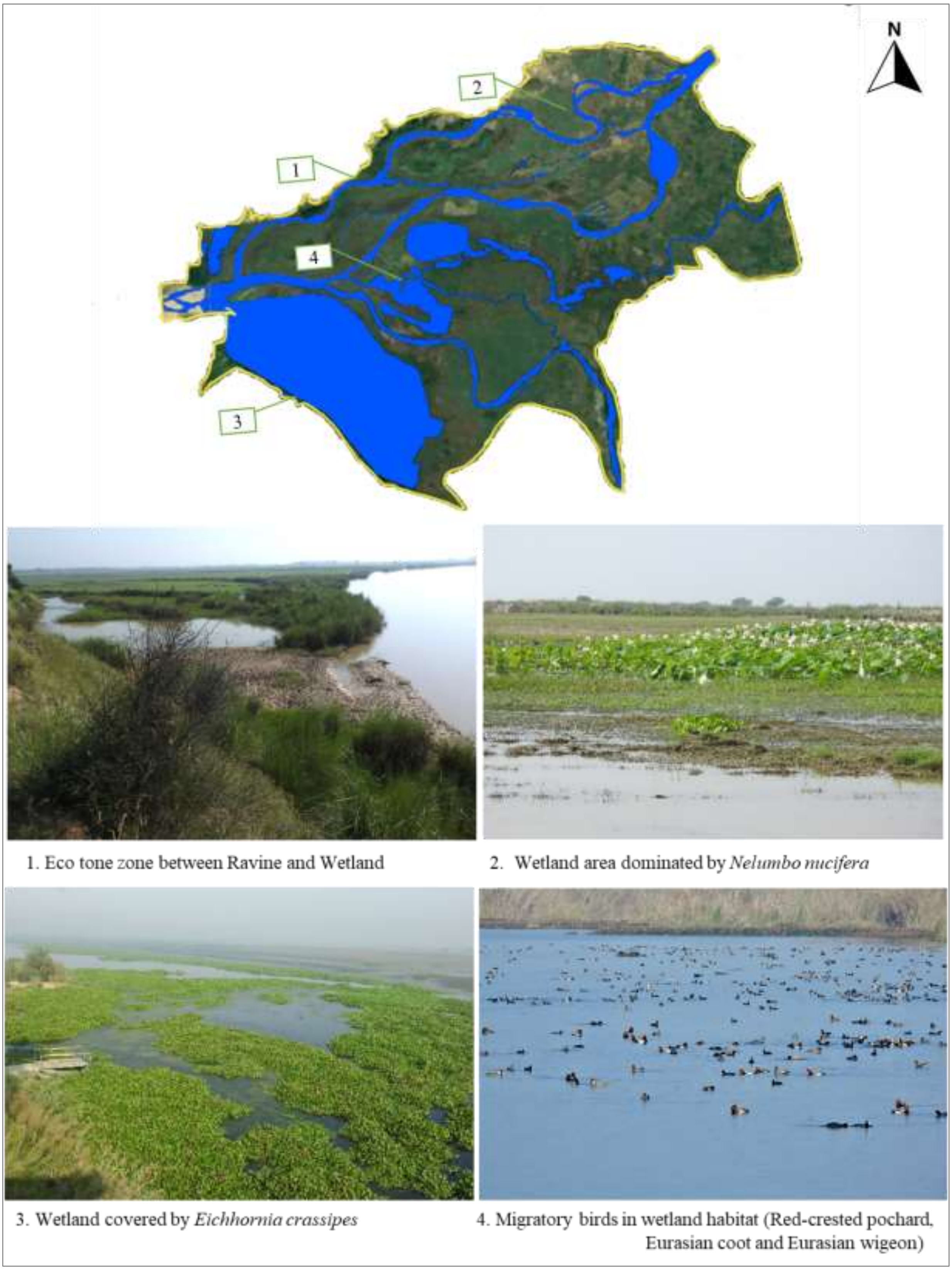
Species like *Hydrilla verticillata*, *Myriophyllum spicatum* and *Vallisneria natans* formulated an association of submersed vegetation in the summer season where *Hydrilla verticillata, Myriophyllum spicatum, Najas minor* and *Vallisneria natans* took over the wetland in monsoon season. In the post-monsoon season, species richness of submersed vegetation soared from 3 to 6 species (Fig 5.7), the association of species like *Ceratophyllum demersum, Hydrilla verticillata*, *Myriophyllum spicatum*, *Najas minor*, *Potamogeton natans* and *Vallisneria natans* were recorded. In the winter season association strength of submersed vegetation decreases from 6 to 4 species like *Ceratophyllum demersum, Hydrilla verticillata, Potamogeton natans* and *Vallisneria natans.* Some species of plant communities of wetland habitats are shown in Fig 5.8. Two species of ferns *Diplazium esculentum* and *Equisetum ramosissimum* were recorded in the monsoon and post-monsoon season around the wetland habitat. Climber species such as *Ipomoea aquatica* was found in the wetland habitat along floral edges of other aquatic vegetation where it was witnessed as a protective natural rope that limits the lateral expansion of *Eichhornia crassipes* and *Pistia stratiote*s. *Ipomoea aquatica* remains in the wetland in summer, monsoon and post-monsoon seasons. Another species *Convolvulus arvensis* grew in the post-monsoon season along wetland habitat. Dominanted tree species like *Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis, Salix alba, Syzygium cumini* and *Terminalia arjuna* besides a shrub species *Ipomoea carnea* were present throughout the year with different phenophases. The seasonal change of plant communities with different habits is given in Table 5.3.

Table 5.3: List of plants recorded from the wetland habitat in different seasons.

Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr) {■= Present and healthy condition of plants, ☐ = absent or about to dry}

Species	Family	Habit	Summer			Monsoon			Post monsoon			Winter		
			April	May	June	July	August	September	October	November	December	January	February	March
Adenostemma platyphyllum Cass	Compositae	H				■	■	■	■					
Ageratum conyzoides (L.) L	Compositae	H	■						■	■	■	■	■	■
Alternanthera paronychioides A.St.-Hil.	Amaranthaceae	H	■	■	■	■	■	■	■	■	■	■	■	■
Anagallis arvensis L.	Primulaceae	H	■	■	■	■	■	■						■
Arundo donax L.	Poaceae	G	■						■	■	■	■	■	■
Azolla pinnata R. Br.	Salviniaceae	Fv	■						■	■	■	■	■	■
Bacopa monnieri (L.) Wettst.	Plantaginaceae	H	■	■	■	■	■	■	■					■
Bombax ceiba L.	Malvaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Centella asiatica (L.) Urb.	Apiaceae	H				■	■	■	■	■	■			
Ceratophyllum demersum L	Ceratophyllaceae	Sv						■	■	■	■	■	■	■
Chrysopogon zizanioides (L.) Roberty	Poaceae	G	■	■	■	■	■	■						■
Colocasia esculenta (L.) Schott.	Araceae	H				■	■	■	■	■	■	■	■	■
Convolvulus arvensis L.	Convolvulaceae	C		■	■	■	■	■	■	■	■			
Cyperus michelianus (L.) Delile	Cyperaceae	H				■	■	■	■					
Cyperus rotundus L.	Cyperaceae	H			■	■	■	■	■	■				
Dalbergia sissoo DC.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■

Diplazium esculentum (Retz.) Sw.	Athyriaceae	Fr
Eclipta prostrata (L.) L	Compositae	H
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Fv
Equisetum ramosissimum Desf	Equisetaceae	Fr
Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Euphorbia helioscopia L.	Euphorbiaceae	H
Ficus benghalensis L.	Moraceae	T
Ficus religiosa L.	Moraceae	T
Hydrilla verticillata (L.f.) Royle	Hydrocharitaceae	Sv
Ipomoea aquatica Forssk	Convolvulaceae	C
Ipomoea carnea Jacq.	Convolvulaceae	S
Lemna minor L	Lemnaceae	Fv
Ludwigia adscendens (L.) H.Hara	Onagraceae	H
Ludwigia perennis L.	Onagraceae	H
Marsilea quadrifolia L.	Marsileaceae	H
Musa × paradisiaca L	Musaceae	T
Myriophyllum spicatum L	Haloragaceae	Sv
Najas minor All.	Hydrocharitaceae	Sv
Nelumbo nucifera Gaertn.	Nymphaeaceae	Fv
Nymphaea nouchali Burm.f	Nymphaeaceae	Fv
Nymphoides cristata (Roxb.) Kuntze	Menyanthaceae	Fv
Oxalis corniculata L.	Oxalidaceae	H
Paspalum distichum L.	Poaceae	G
Persicaria barbata (L.) H.Hara	Polygonaceae	H
Persicaria glabra (Willd.) M.Gómez	Polygonaceae	H
Persicaria lanigera (R.Br.) Soják	Polygonaceae	H
Phoenix sylvestris (L.) Roxb.	Arecaceae	T
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G
Phyla nodiflora (L.) Greene	Verbenaceae	H
Pistia stratiotes L	Araceae	Fv
Populus deltoides Marshall	Salicaceae	T
Potamogeton natans L	Potamogetonaceae	Sv
Ranunculus sceleratus L.	Ranunculaceae	H
Sagittaria sagittifolia L	Alismataceae	H
Salix alba L.	Salicaceae	T
Salvinia natans (L.) All.	Salviniaceae	Fv
Spirodela polyrrhiza (L.) Schleid	Araceae	Fv
Stellaria media (L.) Vill.	Caryophyllaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T
Trapa natans L	Lythraceae	Fv
Typha angustifolia L	Typhaceae	H
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Vallisneria natans (Lour.) H.Hara	Hydrocharitaceae	Sv
Verbascum thapsus L.	Scrophulariaceae	H
Veronica anagallis-aquatica L	Plantaginaceae	H



1. Eco tone zone between Ravine and Wetland

2. Wetland area dominated by *Nelumbo nucifera*

3. Wetland covered by *Eichhornia crassipes*

4. Migratory birds in wetland habitat (Red-crested pochard, Eurasian coot and Eurasian wigeon)

Fig 5.9: Map of wetland habitat with different locations

Seasonal variation of plants in Sandy habitat

This habitat was found as accumulating ground of sand collected by the Beas and Sutlej Rivers in the western part of the sanctuary (fig 5.12). The sandy area is dominated by vegetation like *Saccharum bengalense* and *Saccharum spontaneum* associated with herbs such as *verbesina encelioides, Cannabis sativa* and *Cyperus rotundus*. In this study, a total of 65 species of plants have been recorded, in which This habitat supports medicinal plants like *Eclipta prostrata, Ipomoea aquatic*, *Phyla nodiflora* and *Oxystelma esculentum*. In summer season 14 species of herbs were recorded, including *Abutilon indicum, Artemisia scoparia, Cannabis sativa, Portulaca grandiflora, Oxalis corniculata, Dysphania ambrosioides, Digera muricata, Anagallis arvensis, Ludwigia adscendens, Euphorbia hirta, Phyla nodiflora, Portulaca oleracea, Scoparia dulcis* and *Verbesina encelioides*. In monsoon season species richness of herbs increased in the Sandy habitat from 14 to 30, this association was formed by species like *Fumaria indica, Ludwigia adscendens, Mecardonia procumbens, Mollugo nudicaulis, Nicotiana plumbaginifolia, Oxalis corniculata, Phyla nodiflora, Portulaca grandiflora, Portulaca oleracea, Portulaca pilosa, Rumex dentatus, Salvia plebeian, Scoparia dulcis, Spergula arvensis* and *Sphenoclea zeylanica.* Flood is a regular phenomenon in the Sandy habitat and the flood took huge sand load during monsoon season.

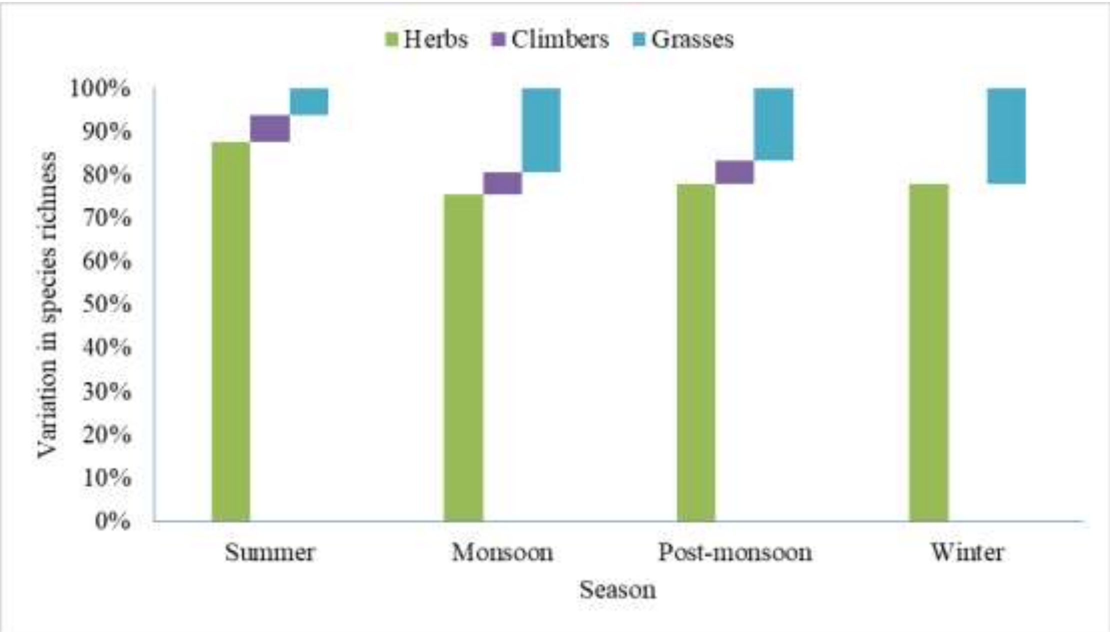


Fig 5.10: Seasonal variations in plant species richness within each habitat in Sandy habitat.

This sand load buried the herbaceous flora which led to a decrease in the species richness of herbs from 30 to 14 in the Post-monsoon season, but with different species composition, this included species like *Ageratum conyzoides, Cardamine hirsute, Eclipta prostrata, Euphorbia hirta, Fumaria indica, Gnaphalium pensylvanicum, Juncus bufonius, Mollugo nudicaulis, Nicotiana plumbaginifolia, Ranunculus sceleratus, Salvia plebeian, Sisymbrium irio, Sphenoclea zeylanica* and *Stellaria media*. When winter comes the herbs of Sandy habitat started drying and further reduced the species richness of herbs from 14 to 7, then the species composition included *Ageratum conyzoides, Cannabis sativa, Fumaria indica, Gnaphalium pensylvanicum, Ranunculus sceleratus, Sisymbrium irio* and *Stellaria media.* In case of grass species, a total of 6 species were recorded such as *Chrysopogon zizanioides, Cynodon dactylon, Paspalum distichum, Phragmites karka, Saccharum bengalense* and *Saccharum spontaneum.* Some of them are also supported provisioning ecosystem service. In monsoon season species richness of grass grew from 6 to 8, due to the addition of two more species in the grass association of summer season, these species were *Desmostachya bipinnata* and *Eragrostis amabilis.*

Fig 5.11: Plant association of Sandy habitat (1: *Scoparia dulcis*, 2: *Saccharum bengalense*, 3: *Salix alba*, 4: *Mecardonia procumbens*, 5: *Cyperus rotundus*, 6: *Saccharum spontaneum*)

As the post-monsoon hits the region, some species of grasses start drying due to flood in the area resulting in a decrease in the species richness from 8 to 3, The association holds a population of *Cynodon dactylon, Paspalum distichum* and *Phragmites karka.* In the winter season, grass species richness further decreased from 3 to 2 and the population of two species such as *Cynodon dactylon* and *Phragmites karka* were seen in the wither season. There was slight change in the climber's species richness in different seasons. The population of *Ipomoea aquatic* was found in summer and monsoon seasons where a population of

Convolvulus arvensis propagated in monsoon season and persisted up to the winter season. *Equisetum ramosissimum* a fern species can be seen in the monsoon season. A association of Tree species including *Albizia lebbeck, Azadirachta indica, Bombax ceiba, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Phoenix sylvestris, Populus deltoids, Prosopis juliflora, Salix alba, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica* found as standing crop throughout the year, details of plant association is given in Table 5.4

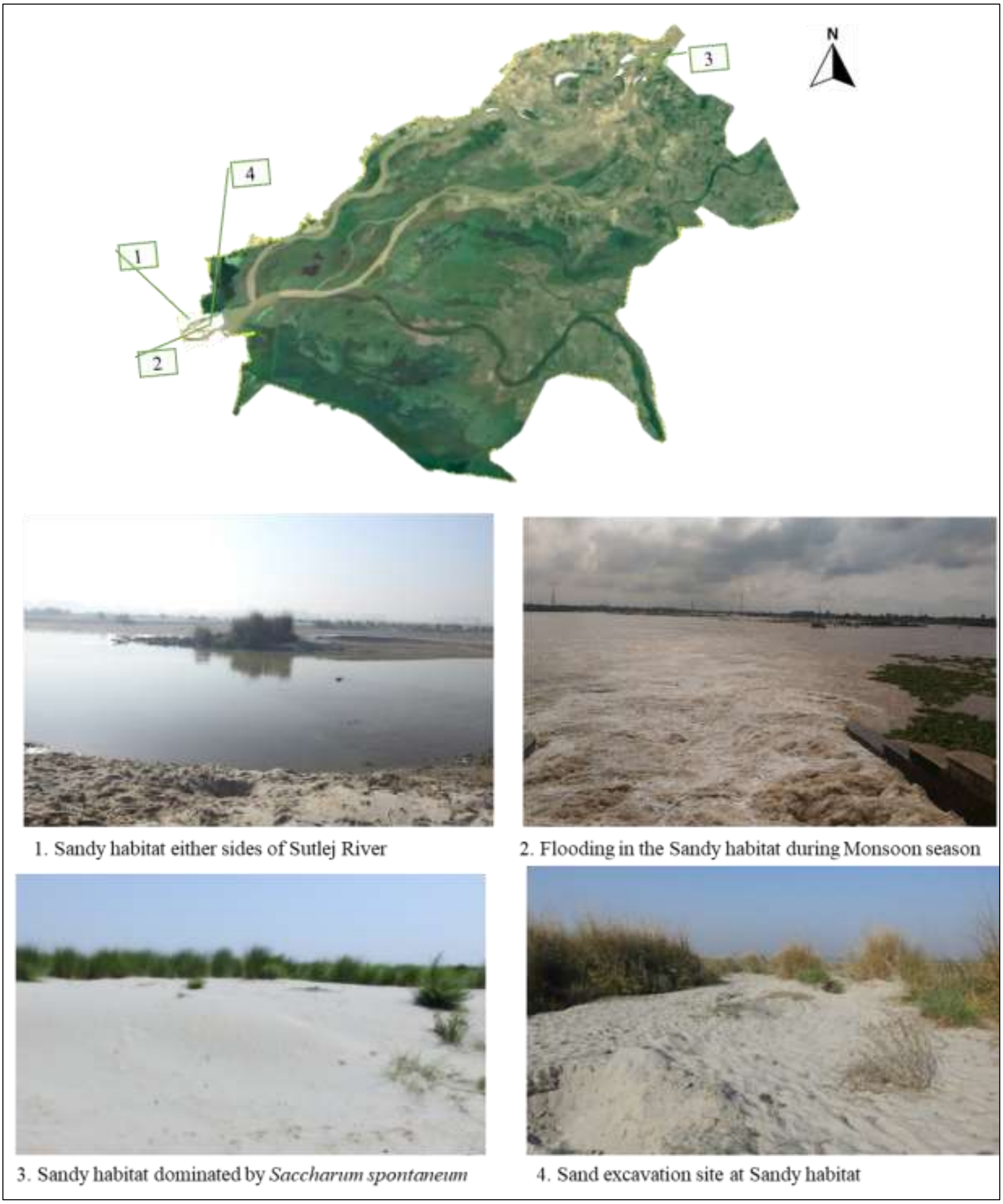
Table 5.4: List of plants recorded in the Sandy habitat in different seasons

Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr)

{■ = Present and healthy condition of plants, ☐ = absent or about to dry}

Species	family	Habit	Summer			Monsoon			Post monsoon			Winter		
			April	May	June	July	August	September	October	November	December	January	February	March
Abutilon indicum (L.) Sweet	Malvaceae	H	■	■	■	■	■	■	■					
Ageratum conyzoides (L.) L	Compositae	H						■	■	■	■	■	■	■
Albizia lebbeck (L.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Anagallis arvensis L.	Primulaceae	H	■	■	■	■	■	■	■					■
Artemisia scoparia Waldst. & Kitam.	Compositae	H	■	■	■	■	■	■						■
Azadirachta indica A. Juss.	Meliaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Bolboschoenus maritimus subsp. maritimus	Cyperaceae	H				■	■	■	■					
Bombax ceiba L.	Malvaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Cannabis sativa L.	Cannabaceae	H	■	■	■	■	■					■	■	■
Cardamine hirsuta L.	Brassicaceae	H				■	■	■	■	■	■			
Chrysopogon zizanioides (L.) Roberty	Poaceae	G	■	■	■	■	■	■						
Convolvulus arvensis L.	Convolvulaceae	C				■	■	■	■	■	■			
Cynodon dactylon (L.) Pers.	Poaceae	G	■	■	■	■	■	■	■	■	■	■	■	■
Cyperus michelianus (L.) Delile	Cyperaceae	H				■	■	■						
Cyperus rotundus L.	Cyperaceae	H				■	■	■	■					
Dalbergia sissoo DC.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Desmostachya bipinnata (L.) Stapf	Poaceae	G				■	■	■	■					
Digera muricata (L.) Mart.	Amaranthaceae	H	■	■	■	■	■	■						
Dysphania ambrosioides (L.) Mosyakin & Clemants	Chenopodiaceae	H	■	■	■	■	■	■						
Eclipta prostrata (L.) L	Compositae	H				■	■	■	■	■	■			
Ehretia laevis (Rottler ex G. Don) Roxb).	Boraginaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Equisetum ramosissimum Desf	Equisetaceae	Fr				■	■	■						
Eragrostis amabilis (L.) Wight & Arn.	Poaceae	G				■	■	■	■					

Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Euphorbia hirta L.	Euphorbiaceae	H
Ficus benghalensis L.	Moraceae	T
Ficus religiosa L.	Moraceae	T
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	H
Gnaphalium pensylvanicum Willd.	Compositae	H
Ipomoea aquatica Forssk	Convolvulaceae	C
Ipomoea carnea Jacq.	Convolvulaceae	S
Juncus bufonius L.	Juncaceae	H
Leucaena leucocephala (Lam.) de Wit	Leguminosae	T
Ludwigia adscendens (L.) H.Hara	Onagraceae	H
Mecardonia procumbens (Mill.) Small	Plantaginaceae	H
Melia azedarach L.	Meliaceae	T
Mollugo nudicaulis Lam.	Molluginaceae	H
Morus alba L.	Moraceae	T
Nicotiana plumbaginifolia Viv.	Solanaceae	H
Oxalis corniculata L.	Oxalidaceae	H
Paspalum distichum L.	Poaceae	G
Phoenix sylvestris (L.) Roxb.	Arecaceae	T
Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G
Phyla nodiflora (L.) Greene	Verbenaceae	H
Populus deltoides Marshall	Salicaceae	T
Portulaca grandiflora Hook.	Portulacaceae	H
Portulaca oleracea L	Portulacaceae	H
Portulaca pilosa L.	Portulacaceae	H
Prosopis juliflora (Sw.)DC.	Leguminosae	T
Ranunculus sceleratus L.	Ranunculaceae	H
Rumex dentatus L.	Polygonaceae	H
Saccharum bengalense Retz	Poaceae	G
Saccharum spontaneum L	Poaceae	G
Salix alba L.	Salicaceae	T
Salvia plebeia R.Br.	Lamiaceae	H
Scoparia dulcis L.	Plantaginaceae	H
Sisymbrium irio L.	Brassicaceae	H
Spergula arvensis L	Caryophyllaceae	H
Sphenoclea zeylanica Gaertn	Sphenocleaceae	H
Stellaria media (L.) Vill.	Caryophyllaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Verbascum thapsus L.	Scrophulariaceae	H
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray	Compositae	H
Polygonum plebeium R.Br.	Polygonaceae	H



1. Sandy habitat either sides of Sutlej River

2. Flooding in the Sandy habitat during Monsoon season

3. Sandy habitat dominated by *Saccharum spontaneum*

4. Sand excavation site at Sandy habitat

Fig 5.12: Map of sandy habitat with different locations.

Seasonal change of vegetation in Swampy habitat

The Swampy habitat covered 2776 hectare in the HWS. The Swampy habitat is located along the wetland dominated by *Phragmites karka* with tall grasses like *Saccharum bengalense* in less moist areas. In the field investigation 80 species of plants under various habits were recorded in a year. There was significant seasonal change recorded in the species richness of plants under different habits. In summer season a total of 11 species of herbs were recorded, association with *Abutilon indicum*, *Anagallis arvensis*, *Artemisia scoparia*, *Bacopa monnieri, Boerhavia diffusa*, *Cannabis sativa, Oxalis corniculata*, *Phyla nodiflora, Typha angustifolia, Urena lobata* and *Xanthium strumarium* were present. When monsoon arrived in the area, regular rainfall supported the propagation of seasonal herbs, therefore, a steep increase in the species richness of herbs from 11 to 20 was recorded (Fig 5.13), then association with species like *Abutilon indicum, Adenostemma platyphyllum, Anagallis arvensis, Artemisia scoparia, Bacopa monnieri, Boerhavia diffusa, Cannabis sativa, Centella asiatica, Cyperus rotundus, Eclipta prostrata, Lepidium didymum , Malva parviflora, Marsilea quadrifolia, Oxalis corniculata, Phyla nodiflora, Salvia plebeian, Typha angustifolia, Urena lobata, Xanthium strumarium* and *Berula erecta* were present.

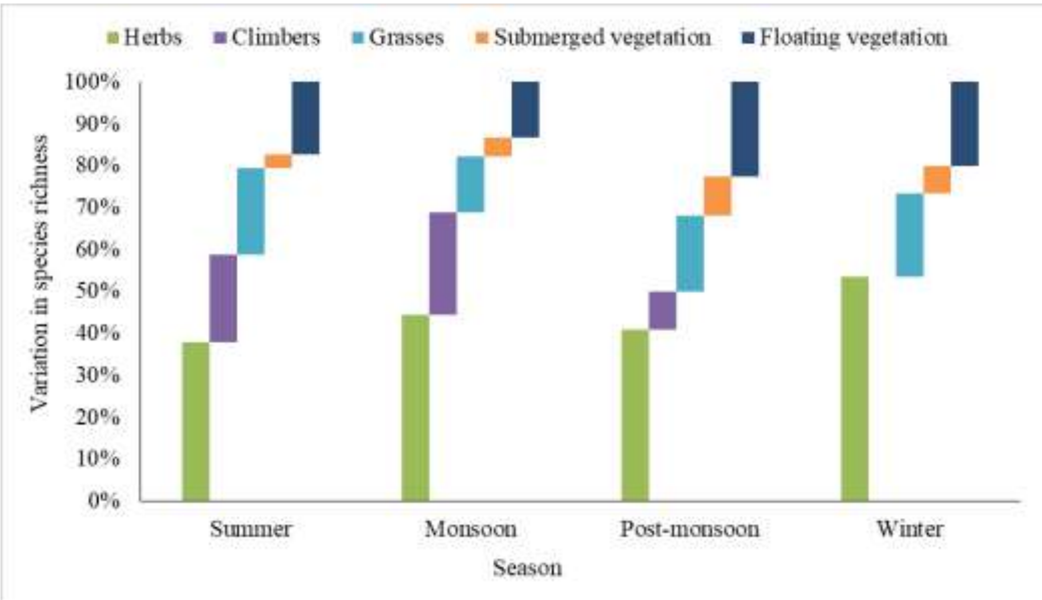


Fig 5.13: Seasonal variations in plant species richness within each habit in Swampy habitat.

As post-monsoon season approached there was a drop in the species richness of herbs from 20 to 9, which changed the association significantly, this association included species like *Ageratum conyzoides, Centella asiatica, Eclipta prostrata, Gnaphalium pensylvanicum, Lepidium didymum, Malva parviflora, Ranunculus sceleratus, Salvia plebeian* and

Stellaria media. Further, in the winter season, there was a change in the association of herbs species richness from 9 to 5, in winter season Swampy habitat supported population of *Ageratum conyzoides, Cannabis sativa, Gnaphalium pensylvanicum, Ranunculus sceleratus* and *Stellaria media*. In the case of grass species, a total of 7 species were recorded. In the summer season, a association of grasses with 6 species prevailed. This association included species *Chrysopogon zizanioides, Cynodon dactylon, Paspalum distichum, Phragmites karka, Saccharum bengalense* and *Saccharum spontaneum.* Species like *Chrysopogon zizanioides* became dry in the post-monsoon whereas *Arundo donax* propagated in winter season.

Fig 5.14: Plant composition of Swampy habitat (1: *Mukia maderaspatana*, 2: *Ipomoea aquatic*, 3: *Phragmites karka*, 4: *Syzygium cumini*, 5: *Oxystelma esculentum*, 6: *Vachellia farnesiana*, 7: *Dichrostachys cinerea*, 8: *Morus alba*, 9: *Typha angustifolia*)

A total of 12 species of climbers were recorded from swampy habitats. In the summer season, a association of *Abrus precatorius, Ipomoea aquatic, Ipomoea cairica, Merremia hederacea, Mukia maderaspatana* and *Oxystelma esculentum* were recorded. In monsoon season species richness of climber species increased from 6 to 11 with the addition of species like *Coccinia grandis, Convolvulus arvensis, Ipomoea nil, Ipomoea pes-tigridis, Pergularia daemia* and *Tinospora cordifolia.* Among these climbers, many species were useful for human consumption for different purposes which is mentioned in the present study under documentation of ethnobotany part in chapter 4. As post-monsoon season approached the sanctuary a change in the species richness of climbers was witnessed in the form of drying and new germination of some climbers. In post-monsoon and winter season species richness of climbers decreased from 11 to 2. A significant population of floting vegetation was observed in the Swampy habitat. A total of seven species of floating vegetation were documented including *Azolla pinnata, Eichhornia crassipes, Lemna minor, Nelumbo nucifera, Pistia stratiotes, Salvinia natans* and *Spirodela polyrrhiza*. The species richness of floating vegetation were found lowest in winter season with species like *Azolla pinnata, Eichhornia crassipes* and *Pistia stratiotes*. *Eichhornia crassipes* was found predominant throughout the year in the Swampy habitat. *Diplazium esculentum* and *Equisetum ramosissimum* are two fern species that were found in all seasons except summer. Around 25 species of trees including *Albizia lebbeck, Albizia procera, Bombax ceiba, Dalbergia sissoo, Dichrostachys cinerea, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Leucaena leucocephala, Phoenix sylvestris, Syzygium cumini, Terminalia arjuna, Vachellia farnesiana* and *Vachellia nilotica* were recorded throughout the year. The association of vegetation belonging to the Swampy habitat is mentioned in Table 5.5.

Table 5.5: List of plants recorded from the Swampy habitat in different seasons.

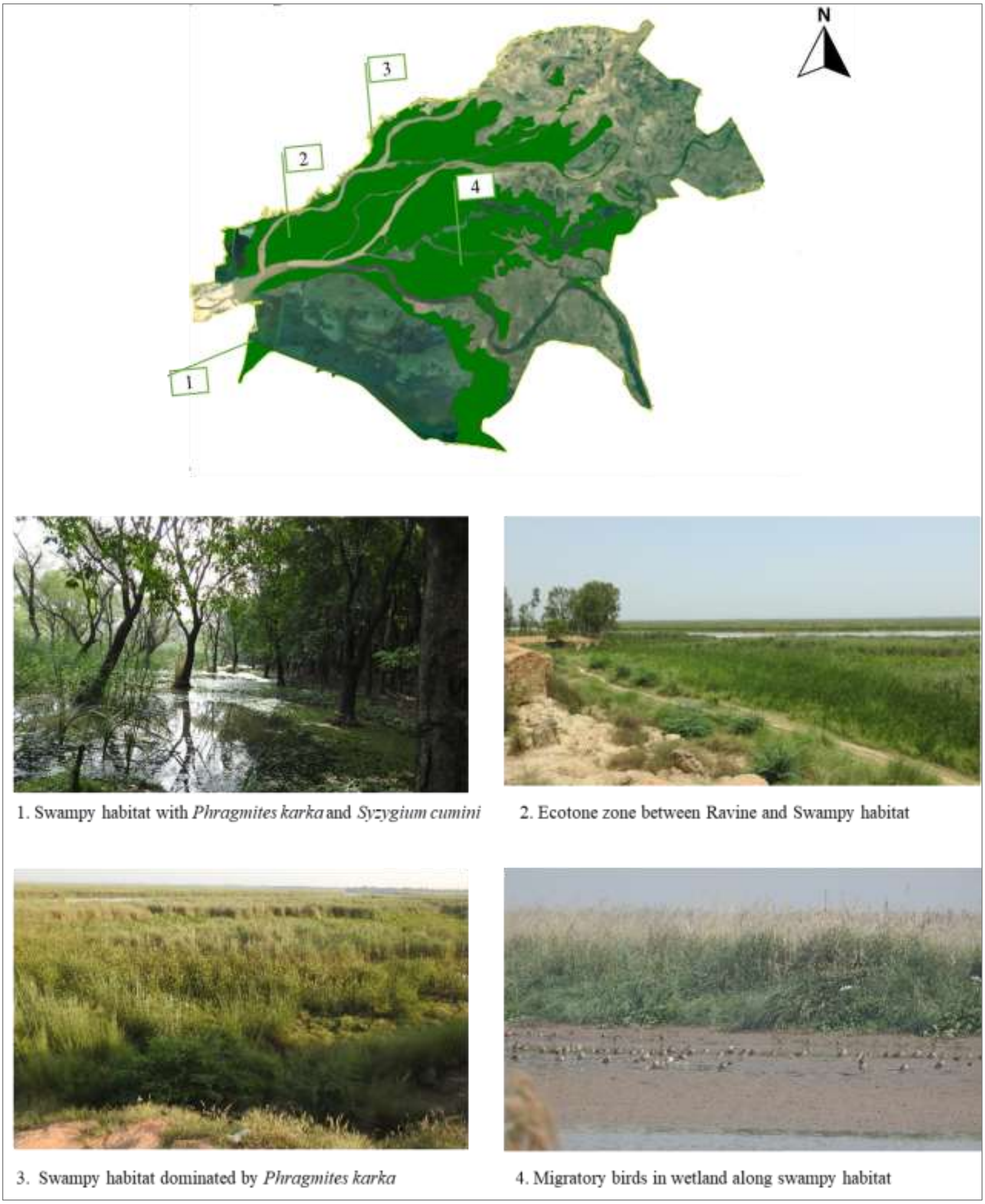
Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr)

{■= Present and healthy condition of plants, □ = absent or about to dry}

Species	Family	Habit	Summer			Monsoon			Post-monsoon			Winter		
			April	May	June	July	August	September	October	November	December	January	February	March
Abrus precatorius L.	Leguminosae	C	■	■	■	■	■	■	■	□	□	□	□	□
Abutilon indicum (L.) Sweet	Malvaceae	H	■	■	■	■	■	■	□	□	□	□	□	■
Acacia auriculiformis Benth	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Adenostemma platyphyllum Cass	Compositae	H	□	□	□	■	■	■	■	□	□	□	□	□
Ageratum conyzoides (L.) L	Compositae	H	■	□	□	□	□	□	■	■	■	■	■	■
Ailanthus excelsa Roxb.	Simaroubaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Albizia lebbeck (L.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Albizia procera (Roxb.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Anagallis arvensis L.	Primulaceae	H	■	■	■	■	■	■	□	□	□	□	□	■
Artemisia scoparia Waldst. & Kitam.	Compositae	H	■	■	■	■	■	■	■	□	□	□	□	□
Arundo donax L.	Poaceae	G	□	□	□	□	□	□	■	■	■	■	■	■
Azadirachta indica A. Juss.	Meliaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Azolla pinnata R. Br.	Salviniaceae	Fv	□	□	□	□	□	□	■	■	■	■	■	■

Bacopa monnieri (L.) Wettst.	Plantaginaceae	H
Boerhavia diffusa L.	Nyctaginaceae	H
Bombax ceiba L.	Malvaceae	T
Cannabis sativa L.	Cannabaceae	H
Cassia fistula L.	Leguminosae	T
Centella asiatica (L.) Urb.	Apiaceae	H
Chrysopogon zizanioides (L.) Roberty	Poaceae	G
Coccinia grandis (L.) Voigt	Cucurbitaceae	C
Convolvulus arvensis L.	Convolvulaceae	C
Cordia myxa L.	Boraginaceae	T
Cynodon dactylon (L.) Pers.	Poaceae	G
Cyperus rotundus L.	Cyperaceae	H
Dalbergia sissoo DC.	Leguminosae	T
Dichrostachys cinerea (L.) Wight & Arn.	Leguminosae	T
Diplazium esculentum (Retz.) Sw.	Athyriaceae	Fr
Eclipta prostrata (L.) L	Compositae	H
Ehretia laevis (Rottler ex G. Don) Roxb.	Boraginaceae	T
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	Fv
Equisetum ramosissimum Desf	Equisetaceae	Fr
Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Ficus benghalensis L.	Moraceae	T
Ficus palmata	Moraceae	T
Ficus religiosa L.	Moraceae	T
Gnaphalium pensylvanicum Willd.	Compositae	H
Hydrilla verticillata (L.f.) Royle	Hydrocharitaceae	Sv
Ipomoea aquatica Forssk	Convolvulaceae	C
Ipomoea cairica (L.) Sweet	Convolvulaceae	C
Ipomoea carnea Jacq.	Convolvulaceae	S
Ipomoea nil (L.) Roth	Convolvulaceae	C
Ipomoea pes-tigridis L.	Convolvulaceae	C
Lemna minor L	Lemnaceae	Fv
Lepidium didymum L.	Brassicaceae	H
Leucaena leucocephala (Lam.) de Wit	Leguminosae	T
Malva parviflora L.	Malvaceae	H
Marsilea quadrifolia L.	Marsileaceae	H
Melia azedarach L.	Meliaceae	T
Merremia hederacea (Burm. f.) Hallier f	Convolvulaceae	C
Morus alba L.	Moraceae	T
Mukia maderaspatana (L.) M.Roem	Cucurbitaceae	C
Najas minor All.	Hydrocharitaceae	Sv
Nelumbo nucifera Gaertn.	Nymphaeaceae	Fv
Oxalis corniculata L.	Oxalidaceae	H
Oxystelma esculentum (L. f.) Sm	Apocynaceae	C
Paspalum distichum L.	Poaceae	G
Pergularia daemia (Forssk.) Chiov.	Apocynaceae	C
Phoenix sylvestris (L.) Roxb.	Arecaceae	T

Phragmites karka (Retz.) Trin. ex Steud.	Poaceae	G
Phyla nodiflora (L.) Greene	Verbenaceae	H
Pistia stratiotes L	Araceae	Fv
Pongamia pinnata (L.) Pierre	Leguminosae	T
Prosopis juliflora (Sw.) DC.	Leguminosae	T
Ranunculus sceleratus L.	Ranunculaceae	H
Saccharum bengalense Retz	Poaceae	G
Saccharum spontaneum L	Poaceae	G
Salvia plebeia R.Br.	Lamiaceae	H
Salvinia natans (L.) All.	Salviniaceae	Fv
Spirodela polyrrhiza (L.) Schleid	Araceae	Fv
Stellaria media (L.) Vill.	Caryophyllaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T
Tinospora cordifolia (Willd.) Miers	Menispermaceae	C
Typha angustifolia L	Typhaceae	H
Urena lobata L.	Malvaceae	H
Vachellia farnesiana (L.) Wight & Arn	Leguminosae	T
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Xanthium strumarium L.	Compositae	H
Berula erecta (Huds.) Coville	Apiaceae	H



1. Swampy habitat with *Phragmites karka* and *Syzygium cumini*

2. Ecotone zone between Ravine and Swampy habitat

3. Swampy habitat dominated by *Phragmites karka*

4. Migratory birds in wetland along swampy habitat

Fig 5.15: Map of Swampy habitat with different locations.

Seasonal variation in plantation habitat

The Plantation habitat was located along the western boundary of the wetland. There were many old trees of *Albizia lebbeck, Azadirachta indica, Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa, Kigelia Africana, Leucaena leucocephala, Mangifera indica, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica* which were planted at the time of landscape management of wetland. There was continuous seasonal change had been witnessed during field investigation with reference to the species composition belonging to various habits in the Plantation habitat. In summer season, a total of 51 species of herbs were recorded. The herbs association included species like *Anagallis arvensis, Artemisia scoparia, Boerhavia diffusa, Bryophyllum pinnatum, Cannabis sativa, Capsicum annuum, Catharanthus roseus, Chenopodium album, Chenopodium murale, Cleome viscosa, Croton bonplandianus, Datura metel, Datura stramonium, Digera muricata, Euphorbia cyathophora, Euphorbia hirta, Euphorbia prostrata, Euphorbia thymifolia, Justicia adhatoda, Leucas cephalotes, Malvastrum coromandelianum, Melochia corchorifolia* and *Ocimum tenuiflorum.*

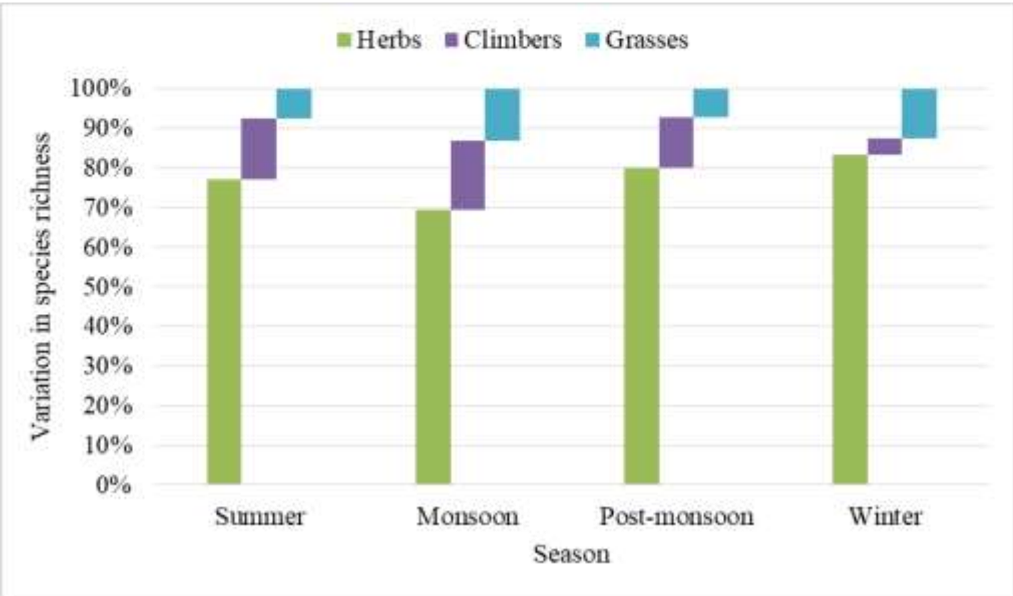


Fig 5.16: Seasonal variations in plant species richness under different habits in the Plantation habitat.

In monsoon season, continuous rainfall made suitable conditions for the germination of the natural seed bank from the soil. The herbs species like *Alysicarpus vaginalis, Amaranthus spinosus, Amaranthus viridis, Anisomeles indica, Cirsium arvense, Commelina benghalensis, Desmodium triflorum, Erigeron Canadensis, Euphorbia tithymaloides, Foeniculum vulgare, Fumaria indica, Glandularia pulchella,* *Gomphrena celosioides, Kalanchoe daigremontiana, Launaea nudicaulis, Launaea procumbens, Lepidium didymum , Ludwigia hyssopifolia, Malva parviflora, Mazus pumilus, Medicago polymorpha* and *Melilotus indicus* formed an association of herbs and led to increase in the species richness of herbs from 51 to 80. *Cannabis sativa* was found as the dominant herb in the Plantation habitat besides after a few monsoon rains *Cannabis sativa* started drying therefore local people were seen using dry *Cannabis sativa* as fuel for household purpose. A change in the herbs composition was witnessed in post-monsoon season with a steep decline in the species richness from 80 to 44 (fig 5.16), which included species like *Ageratum conyzoides, Capsella bursa-pastoris, Emex spinosa, Galium aparine, Geranium lucidum, Gnaphalium pensylvanicum, Sisymbrium irio, Sonchus oleraceus, Stellaria media, Urtica urens* and *Zaleya pentandra*. A total of 20 species of herbs were recorded from the plantation habitat which shows a further decrease in the species richness in the herbs species from 44 to 20. The dominant herb species like *Ageratum conyzoides, Amaranthus spinosus, Amaranthus viridis, Emex spinosa, Fumaria indica, Gnaphalium pensylvanicum, Sisymbrium irio, Sonchus oleraceus* and *Stellaria media* were recorded. New recruitment of *Cannabis sativa* and *Chenopodium album* had been witnessed during winter rains with mass germination of *Galium aparine*, it was resembling like a green carpet in some patches.

Fig 5.17: Plant composition of Plantation habitat (1: *Ehretia laevis*, 2: *Aegle marmelos*, 3: *Dalbergia sissoo*, 4: *Kigelia Africana*, 5: *Leucaena leucocephala*, 6: *Cassia fistula*, 7: *Senegalia catechu*, 8: *Syzygium cumini*)

In case of grass species, summer season supported an association of grasses that included *Cenchrus ciliaris, Cynodon dactylon, Dactyloctenium aegyptium, Dendrocalamus strictus* and *Polypogon monspeliensis* whereas, in monsoon season, rainfall supported the rapid growth of grass species, therefore, a sharp rise was detected in the species richness of grasses from 5 to 15. An association of grasses was comprised of species like *Brachiaria ramose, Chloris barbata, Desmostachya bipinnata, Digitaria ciliaris, Eleusine indica, Eragrostis amabilis, Oplismenus burmannii, Panicum maximum, Panicum virgatum* and *Setaria viridis* in monsoon season. The grass species has shown rapid growth in monsoon season but as post-monsoon approached the grasses started drying which led to a decline in the species richness of grass species, the population of *Cynodon dactylon, Dendrocalamus strictus, Oplismenus burmannii, Panicum maximum* were seen in the post-monsoon season. In winter season *Cynodon dactylon, Dendrocalamus strictus* and *Poa annua* constituted the grass community.

A total of 20 species of climbers were recorded from Plantation habitat. In summer season, an association of *Abrus precatorius, Antigonon leptopus, Asparagus officinalis, Cayratia trifolia, Cocculus pendulus, Cuscuta reflexa, Mukia maderaspatana, Oxystelma esculentum* and *Rhynchosia minima* were recorded. In monsoon season, there was a surge witnessed in the species richness of climbers from 9 to 19. The association of climbers in monsoon season included *Abrus precatorius, Antigonon leptopus, Asparagus officinalis, Basella alba, Cardiospermum halicacabum, Cayratia trifolia, Clitoria ternatea, Coccinia grandis, Cocculus pendulus, Convolvulus arvensis, Cuscuta reflexa, Humulus scandens, Ipomoea nil, Ipomoea pes-tigridis, Mukia maderaspatana, Oxystelma esculentum, Pergularia daemia, Tinospora cordifolia* and *Vernonia elaeagnifolia.* The post-monsoon season allowed the growth of climbers like *Antigonon leptopus, Basella alba, Cardiospermum halicacabum, Convolvulus arvensis, Cuscuta reflexa, Tinospora cordifolia,* and *Vernonia elaeagnifolia.* In the winter season *Cuscuta reflexa* was observed on the trees like *Holoptelea integrifolia, Morus alba, Parkinsonia aculeate, Pongamia pinnata, Salix alba* and *Ziziphus mauritiana.* The shrub’s association consisting of *Calotropis procera, Clerodendrum inerme, Grewia tenax, Hamelia patens, Hibiscus rosa-sinensis, Jatropha gossypiifolia, Lantana camara, Murraya koenigii, Nerium oleander, Ricinus communis* and *Vernonia amygdalina* were found in the Plantation habitat. Dominated tree species such as *Albizia lebbeck, Bombax ceiba, Butea monosperma, Cassia fistula, Dalbergia sissoo, Erythrina variegate, Ficus benghalensis, Ficus palmata, Gmelina arborea, Holoptelea integrifolia, Kigelia africana,* *Leucaena leucocephala*, *Mangifera indica*, *Moringa oleifera*, *Neolamarckia cadamba*, *Parkinsonia aculeate*, *Pongamia pinnata*, *Prosopis cineraria*, *Prosopis juliflora*, *Salix alba*, *Senegalia catechu*, *Syzygium cumini*, *Tectona grandis*, *Terminalia arjuna*, *Vachellia nilotica* and *Ziziphus mauritiana* were distributed in the Plantation habitat. Seasonal change in the association of Plantation habitat is shown in Table 5.6.

Table 5.6: List of plants recorded from the Plantation habitat in different seasons.

Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr){■ = Present and healthy condition of plants, □ = absent or about to dry}

Species	Family	Habit	Summer			Monsoon			Post monsoon			Winter		
			April	May	June	July	August	September	October	November	December	January	February	March
Abrus precatorius L.	Leguminosae	C	■	■	■	■	■	■						■
Abutilon indicum (L.) Sweet	Malvaceae	H	■	■	■	■	■	■	■					■
Acacia tortilis (Forsk.) Hayne	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Acacia auriculiformis Benth	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Achyranthes aspera L.	Amaranthaceae	H	■	■	■	■	■	■						
Aegle marmelos (L.) Correa	Rutaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Agave sisalana Perrine	Asparagaceae	S	■	■	■	■	■	■	■	■	■			
Ageratum conyzoides (L.) L	Compositae	H							■	■	■	■	■	■
Ailanthus excelsa Roxb.	Simaroubaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Albizia lebbeck (L.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Albizia procera (Roxb.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Alstonia scholaris (L.) R. Br.	Apocynaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Alysicarpus vaginalis (L.) DC	Leguminosae	H			■	■	■	■	■					
Amaranthus spinosus L.	Amaranthaceae	H				■	■	■	■	■				
Amaranthus viridis L.	Amaranthaceae	H				■	■	■	■	■	■	■	■	■
Anagallis arvensis L.	Primulaceae	H	■	■	■	■	■	■						■
Anisomeles indica (L.) Kuntze	Lamiaceae	H				■	■	■	■	■	■			
Antigonon leptopus Hook. & Arn	Polygonaceae	C	■	■	■	■	■	■	■	■	■			
Artemisia scoparia Waldst. & Kitam.	Compositae	H	■	■	■	■	■	■						
Artocarpus heterophyllus Lam.	Moraceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Asparagus officinalis L.	Asparagaceae	C	■	■	■	■	■	■						
Azadirachta indica A. Juss.	Meliaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Basella alba L	Basellaceae	C				■	■	■	■	■	■			
Boerhavia diffusa L.	Nyctaginaceae	H	■	■	■	■	■	■						
Bombax ceiba L.	Malvaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Bougainvillea spectabilis Willd.	Nyctaginaceae	S				■	■	■						
Brachiaria ramosa (L.) Stapf	Poaceae	G				■	■	■	■					

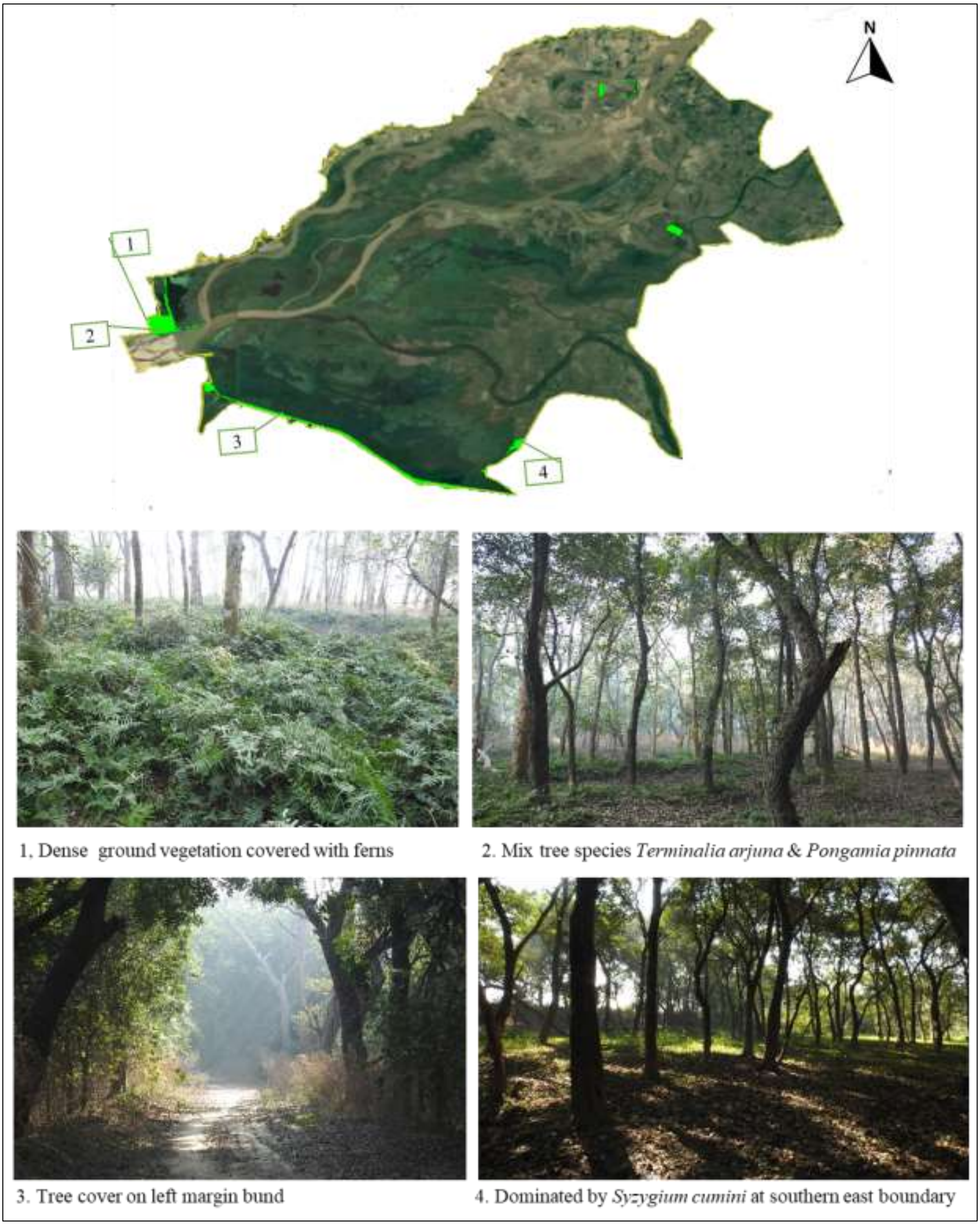
Bryophyllum pinnatum (Lam.) Oken	Crassulaceae	H
Butea monosperma (Lam.) Taub.	Leguminosae	T
Callistemon viminalis (Sol. ex Gaertn.) G.Don	Myrtaceae	T
Calotropis procera (Aiton) Dryand	Apocynaceae	S
Cannabis sativa L.	Cannabaceae	H
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	H
Capsicum annuum L.	Solanaceae	H
Cardiospermum halicacabum L.	Sapindaceae	C
Carica papaya L	Caricaceae	T
Carissa spinarum L	Apocynaceae	S
Caryota urens L.	Arecaceae	T
Cascabela thevetia (L.) Lippold	Apocynaceae	S
Cassia fistula L.	Leguminosae	T
Casuarina equisetifolia L	Casuarinaceae	T
Catharanthus roseus (L.) G.Don	Apocynaceae	H
Cayratia trifolia (L.) Domin	Vitaceae	C
Ceiba pentandra	Malvaceae	T
Cenchrus ciliaris L.	Poaceae	G
Cestrum nocturnum L	Solanaceae	S
Chenopodium album L.	Chenopodiaceae	H
Chenopodium murale L.	Chenopodiaceae	H
Chloris barbata Sw.	Poaceae	G
Chukrasia tabularis A. Juss.	Meliaceae	T
Cirsium arvense (L.) Scop.	Asteraceae	H
Cleome viscosa L	Cleomaceae	H
Clerodendrum inerme (L.) Gaertn	Lamiaceae	S
Clitoria ternatea L.	Leguminosae	C
Coccinia grandis (L.) Voigt	Cucurbitaceae	C
Cocculus pendulus (J.R.Forst. & G.Forst.) Diels	Menispermaceae	C
Commelina benghalensis L.	Commelinaceae	H
Convolvulus arvensis L.	Convolvulaceae	C
Cordia myxa L.	Boraginaceae	T
Crateva religiosa G.Forst.	Capparaceae	T
Croton bonplandianus Baill.	Euphorbiaceae	H
Cuscuta reflexa Roxb	Convolvulaceae	C
Cycas revoluta Thunb	Cycadaceae	T
Cynodon dactylon (L.) Pers.	Poaceae	G
Dactyloctenium aegyptium (L.) Willd.	Poaceae	G
Dalbergia sissoo DC.	Leguminosae	T
Datura metel L.	Solanaceae	H
Datura stramonium L.	Solanaceae	H
Delonix regia (Hook.) Raf.	Leguminosae	T
Dendrocalamus strictus (Roxb.) Nees	Poaceae	G
Desmodium triflorum (L.) DC.	Leguminosae	H
*Desmostachya bipinnata (*L.) Stapf	Poaceae	G
Dichrostachys cinerea (L.) Wight & Arn.	Leguminosae	T

Digera muricata (L.) Mart.	Amaranthaceae	H
Digitaria ciliaris (Retz.) Koeler	Poaceae	G
Diospyros montana Roxb	Ebenaceae	T
Ehretia laevis (Rottler ex G. Don) Roxb.	Boraginaceae	T
Eleusine indica (L.) Gaertn	Poaceae	G
Emex spinosa (L.) Campd.	Polygonaceae	H
Equisetum ramosissimum Desf	Equisetaceae	Fr
Eragrostis amabilis (L.) Wight & Arn.	Poaceae	G
Erigeron canadensis L.	Compositae	H
Erythrina variegata L.	Leguminosae	T
Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Euphorbia cotinifolia L	Euphorbiaceae	S
Euphorbia cyathophora Murray	Euphorbiaceae	H
Euphorbia hirta L.	Euphorbiaceae	H
Euphorbia milii Des Moul	Euphorbiaceae	S
Euphorbia prostrata Aiton	Euphorbiaceae	H
Euphorbia thymifolia L.	Euphorbiaceae	H
Euphorbia tithymaloides L	Euphorbiaceae	H
Ficus benghalensis L.	Moraceae	T
Ficus benjamina L	Moraceae	T
Ficus carica L.	Moraceae	T
Ficus palmata	Moraceae	T
Ficus racemosa L.	Moraceae	T
Ficus religiosa L.	Moraceae	T
Foeniculum vulgare Mill.	Apiaceae	H
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	H
Galium aparine L.	Rubiaceae	H
Geranium lucidum L	Geraniaceae	H
Glandularia pulchella (Sweet) Tronc	Verbenaceae	H
Gmelina arborea Roxb	Lamiaceae	T
Gnaphalium pensylvanicum Willd.	Compositae	H
Gomphrena celosioides Mart	Amaranthaceae	H
Grevillea robusta	Proteaceae	T
*Grewia tenax (*Forssk.) Fiori	Malvaceae	S
Hamelia patens Jacq	Rubiaceae	S
Hibiscus mutabilis L	Malvaceae	S
Hibiscus rosa-sinensis L.	Malvaceae	S
Holoptelea integrifolia Planch	Ulmaceae	T
Humulus scandens (Lour.) Merr.	Cannabaceae	C
Ipomoea nil (L.) Roth	Convolvulaceae	C
Ipomoea pes-tigridis L.	Convolvulaceae	C
Jacaranda mimosifolia D.Don	Bignoniaceae	T
Jasminum sambac (L.) Sol	Oleaceae	S
Jatropha gossypiifolia L	Euphorbiaceae	S
Jatropha integerrima Jacq	Euphorbiaceae	S
Justicia adhatoda L.	Acanthaceae	H

Kalanchoe daigremontiana Raym.-Hamet & H. Perrier	Crassulaceae	H
Kigelia africana	Bignoniaceae	T
Lantana camara L.	Verbenaceae	S
Launaea nudicaulis (L.) Hook. f.	Asteraceae	H
Launaea procumbens (Roxb.) Ramayya & Rajagopal	Compositae	H
Lawsonia inermis L.	Lythraceae	S
Lepidium didymum L.	Brassicaceae	H
*Leucaena leucocephala (*Lam.) de Wit	Leguminosae	T
Leucas cephalotes (Roth) Spreng.	Lamiaceae	H
Ludwigia hyssopifolia (G.Don) Exell	Onagraceae	H
Malva parviflora L.	Malvaceae	H
Malvastrum coromandelianum (L.) Garcke	Malvaceae	H
Mangifera indica L	Anacardiaceae	T
*Mazus pumilus (*Burm.f.) Steenis	Phrymaceae	H
Medicago polymorpha L.	Leguminosae	H
Melia azedarach L.	Meliaceae	T
Melilotus indicus (L.) All.	Leguminosae	H
Melochia corchorifolia L.	Malvaceae	H
Millettia peguensis Ali	Leguminosae	T
Mirabilis jalapa L	Nyctaginaceae	H
Moringa oleifera Lam	Moringaceae	T
Morus alba L.	Moraceae	T
Mukia maderaspatana (L.) M.Roem	Cucurbitaceae	C
*Murraya koenigii (*L.) Spreng	Rutaceae	S
Murraya paniculata (L.) Jack	Rutaceae	S
Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae	T
Nerium oleander L.	Apocynaceae	S
Nicotiana plumbaginifolia Viv.	Solanaceae	H
Nyctanthes arbor-tristis L	Oleaceae	T
Ocimum basilicum L	Lamiaceae	H
Ocimum tenuiflorum L.	Lamiaceae	H
Oplismenus burmannii (Retz.) P.Beauv.	Poaceae	G
Osteospermum fruticosum (L.) Norl	Compositae	H
Oxalis corniculata L.	Oxalidaceae	H
Oxystelma esculentum (L. f.) Sm	Apocynaceae	C
Panicum maximum Jacq.	Poaceae	G
Panicum virgatum L.	Poaceae	G
Papaver rhoeas L	Papaveraceae	H
Parkinsonia aculeata L.	Leguminosae	T
Parthenium hysterophorus L.	Compositae	H
Pedalium murex L.	Pedaliaceae	H
Pergularia daemia (Forssk.) Chiov.	Apocynaceae	C
Peristrophe bicalyculata (Retz.)	Acanthaceae	H
Phyllanthus emblica L.	Phyllanthaceae	T
Physalis minima L.	Solanaceae	H
Pithecellobium dulce (Roxb.) Benth.	Leguminosae	T

Platycladus orientalis (L.) Franco	Cupressaceae	S
Plumbago zeylanica L.	Plumbaginaceae	H
Plumeria obtusa L	Apocynaceae	S
Poa annua L	Poaceae	G
Polyalthia longifolia (Sonn.) Thwaites	Annonaceae	T
Polypogon monspeliensis (L.) Desf.	Poaceae	G
*Pongamia pinnata (*L.) Pierre	Leguminosae	T
Portulaca grandiflora Hook.	Portulacaceae	H
*Prosopis cineraria (*L.)Druce	Leguminosae	T
Prosopis juliflora (Sw.)DC.	Leguminosae	T
Psidium guajava L.	Myrtaceae	T
Pterospermum acerifolium Willd.	Malvaceae	T
Putranjiva roxburghii Wall	Putranjivaceae	T
Rhynchosia minima (L.) DC	Leguminosae	C
Ricinus communis L.	Euphorbiaceae	S
Rumex dentatus L.	Polygonaceae	H
Salix alba L.	Salicaceae	T
Sansevieria aethiopica Thunb	Asparagaceae	H
Schleichera oleosa (Lour.) Oken.	Sapindaceae	T
Senegalia catechu (L. f.) P.J.H. Hurter & Mabb.	Leguminosae	T
Senna occidentalis (L.) Link	Leguminosae	H
Senna siamea (Lam.) H.S.Irwin & Barneby	Leguminosae	T
Senna tora (L.) Roxb.	Leguminosae	H
Setaria viridis (L.) P.Beauv	Poaceae	G
Sida cordifolia	Malvaceae	H
Sida acuta Burm.f.	Malvaceae	H
Sida cordata (Burm.f.) Borss.Waalk.	Malvaceae	H
Sida rhombifolia L	Malvaceae	H
Sisymbrium irio L.	Brassicaceae	H
Solanum nigrum L	Solanaceae	H
Solanum villosum Mill.	Solanaceae	H
Solanum virginianum L.	Solanaceae	H
Sonchus oleraceus (L.) L.	Compositae	H
*Stellaria media (*L.) Vill.	Caryophyllaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Tabernaemontana divaricata (L.) R.Br. ex Roem. & Schult.	Apocynaceae	S
Tagetes erecta L	Compositae	H
Tecoma stans var. stans	Bignoniaceae	T
Tectona grandis L.f.	Lamiaceae	T
Tephrosia purpurea (L.) Pers.	Leguminosae	H
Terminalia bellirica	Combretaceae	T
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T
Tinospora cordifolia (Willd.) Miers	Menispermaceae	C
Toona ciliata M.Roem	Meliaceae	T
Trianthema portulacastrum L.	Aizoaceae	H
Tribulus terrestris L.	Zygophyllaceae	H

Tridax procumbens (L.) L.	Compositae	H
Trifolium dubium Sibth	Leguminosae	H
Trifolium repens L.	Leguminosae	H
Triumfetta rhomboidea Jacq.	Malvaceae	H
Urena lobata L.	Malvaceae	H
Urtica urens L.	Urticaceae	H
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray	Compositae	H
Vernonia elaeagnifolia	Asteraceae	C
Vernonia amygdalina Delile	Compositae	S
Vernonia cinerea (L.) Less.	Compositae	H
Veronica agrestis L.	Plantaginaceae	H
Vicia sativa L	Leguminosae	H
Withania somnifera (L.) Dunal	Solanaceae	H
Xanthium strumarium L.	Compositae	H
Yucca filamentosa L	Asparagaceae	S
Zaleya pentandra (L.) C.Jeffrey	Aizoaceae	H
Zamia furfuracea L.f. ex Aiton	Zamiaceae	S
Ziziphus mauritiana Lam	Rhamnaceae	T
Bauhinia variegata L.	Leguminosae	T



1. Dense ground vegetation covered with ferns

2. Mix tree species *Terminalia arjuna* & *Pongamia pinnata*

3. Tree cover on left margin bund

4. Dominated by *Syzygium cumini* at southern east boundary

Fig 5.18: Map of Plantation habitat with different locations

Seasonal variation of vegetation in Agricultural-field habitat

The Agricultural field habitat located in the eastern part of the sanctuary was associated with Rivers and wetlands. Wheat and Rice were predominantly grown by local people with modern tools. Other crops such as *Allium cepa, Allium sativum, Brassica oleracea, Brassica rapa, Solanum melongena* and *Trigonella foenum-graecum* were also grown seasonally. The Agricultural field had old embankments that were untouched or faced litter interventions by people therefore those embankments supported the population of wild plant species. In this study, precise seasonal observations had been recorded to unfold the dynamics of vegetation in different seasons (fig 5.19). In summer season, population of herb species was documented from embankments of Agricultural field habitat. During the summer season, an association of herbs with total of 35 species were observed on embankments of agricultural field including species like *Achyranthes aspera, Aerva javanica, Alhagi maurorum, Anagallis arvensis, Blumea lacera, Boerhavia diffusa, Cannabis sativa, Croton bonplandianus, Datura stramonium, Euphorbia thymifolia, Leucas cephalotes, Oxalis corniculata, Physalis minima, Senna tora, Sida acuta, Solanum nigrum, Tridax procumbens* and *Verbesina encelioides* were recorded (Fig 5.20).

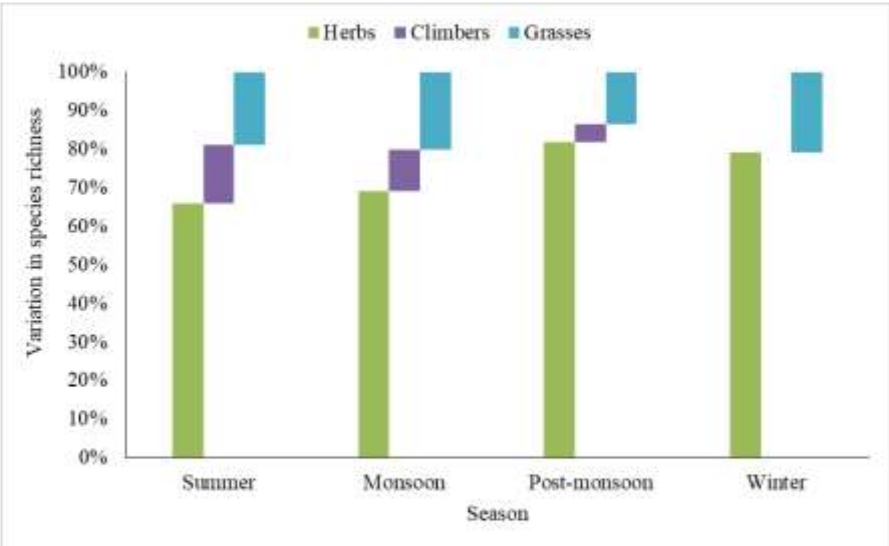


Fig 5.19: Seasonal variations in plant species richness within each habit in Agricultural habitat.

In monsoon season, this area also experienced floods sometimes overflow of water in monsoon season caused the loss of rice crops but there is an increase in species richness of wild herbs from 35 to 55, which were recorded from embankments of agricultural field. The association of herbs consists of *Alysicarpus ovalifolius, Alysicarpus vaginalis, Commelina benghalensis, Cyperus rotundus, Desmodium triflorum, Mazus pumilus, Phyllanthus niruri, Pisum sativum,* *Rumex dentatus, Sesamum indicum, Trifolium resupinatum, Verbascum Thapsus* and *Veronica persica* were found in the Agricultural field habitat.

The post-monsoon season supported the population of 32 species hence there was decline in the species richness of herbs from 55 to 32 was noticed. The common species like *Ageratum conyzoides, Allium cepa, Allium sativum, Brassica oleracea, Brassica rapa, Daucus carota, Gnaphalium pensylvanicum, Raphanus sativus, Sisymbrium irio, Sonchus oleraceus* and *Stellaria media* were found on the embankment of Agricultural field.

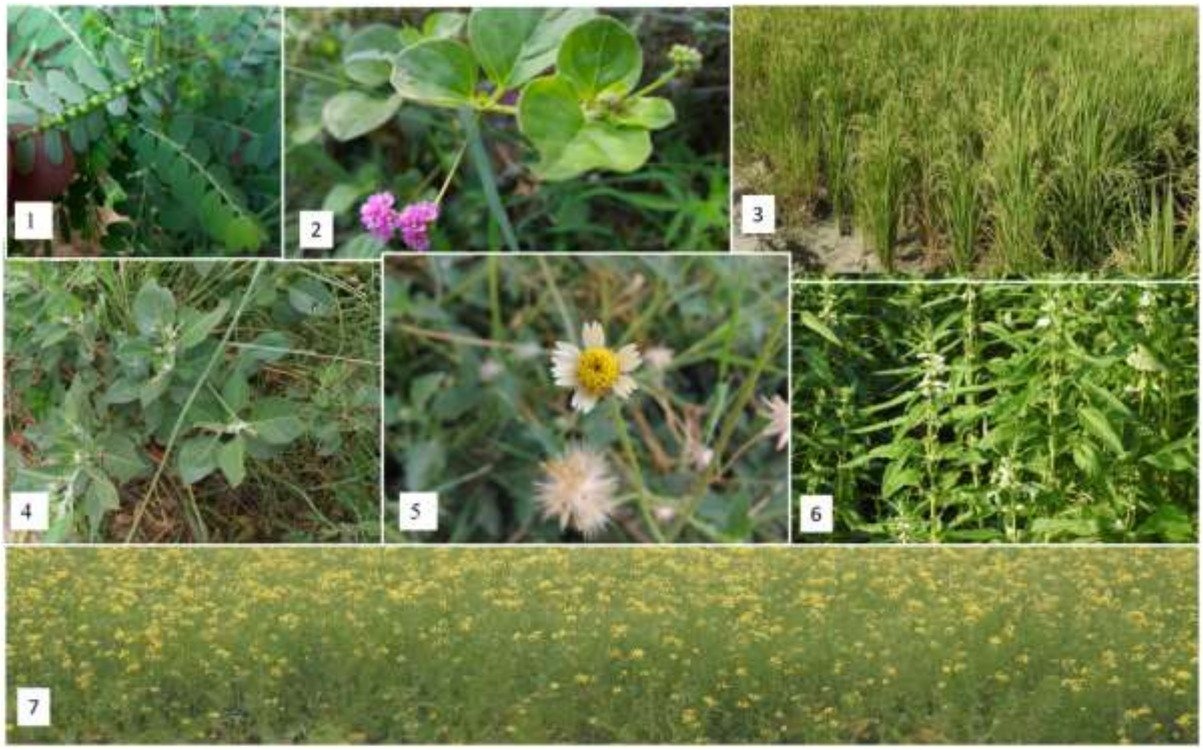


Fig 5.20: Plant association of Agricultural habitat (1: *Phyllanthus niruri*, 2: *Boerhavia diffusa*, 3: *Oryza sativa*, 4: *Withania coagulans*, 5: *Tridax procumbens*, 6: *Sesamum indicum*, 7: *Brassica rapa*)

In winter season herbs species like *Ageratum conyzoides, Allium cepa, Allium sativum, Brassica oleracea, Brassica rapa, Daucus carota, Gnaphalium pensylvanicum, Raphanus sativus, Sisymbrium irio, Sonchus oleraceus* and *Stellaria media*. Grass species such *Cenchrus ciliaris, Cynodon dactylon, Dactyloctenium aegyptium, Oryza sativa, Pennisetum typhoides, Polypogon monspeliensis, Saccharum officinarum, Saccharum bengalense, Saccharum spontaneum* and *Triticum aestivum* were recorded in the summer season along Agricultural field habitat. In monsoon species richness of grasses increases from 10 to 17 species which included species like *Desmostachya bipinnata*, *Dichanthium annulatum,* *Echinochloa colona, Eleusine indica, Eragrostis minor, Panicum maximum, Setaria viridis* and *Sorghum halepense*. Post-monsoon season supported the population of *Cynodon dactylon, Dichanthium annulatu, Oryza sativa, Panicum maximum, Saccharum officinarum* and *Triticum aestivum* where in winter season species richness of grasses decreased up to 3 including species like *Cynodon dactylon, Saccharum officinarum* and *Triticum aestivum.*

The association of climber species such as *Cayratia trifolia, Cucumis melo, Cucumis sativus, Cucurbita maxima, Luffa cylindrical, Momordica charantia* and *Oxystelma esculentum* were recorded in the summer season where in monsoon season species richness of climbers increased from 7 to 8 with the population of *Cayratia trifolia, Convolvulus arvensis, Cucumis melo, Humulus scandens, Oxystelma esculentum, Pergularia daemia, Tinospora cordifolia* and *Trichosanthes dioica.* In post-monsoon season, there was a steep decline in the species richness of climber species from 8 to 2 with *Convolvulus arvensis* and *Tinospora cordifolia.* Agricultural habitat was found devoid of climber species in winter season. The untouched embankments of the Agricultural field habitat was found very significant in supporting a population of threatened shrub species like *Withania coagulan* other shrub species such as *Cajanus cajan, Calotropis procera, Citrus aurantifolia, Citrus reticulate, Gossypium arboretum, Jatropha curcas* and *Punica granatum* were recorded throughout the year along with tree species like *Acacia tortilis, Albizia lebbeck, Azadirachta indica, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus virens, Leucaena leucocephala, Madhuca longifolia, Moringa oleifera, Tamarix dioica, Terminalia arjuna* and *Ziziphus mauritiana*. The seasonal change of plant communities in Agricultural habitats is shown in Table 5.7.

Table 5.7: List of plants recorded from the Agricultural habitat in different seasons.

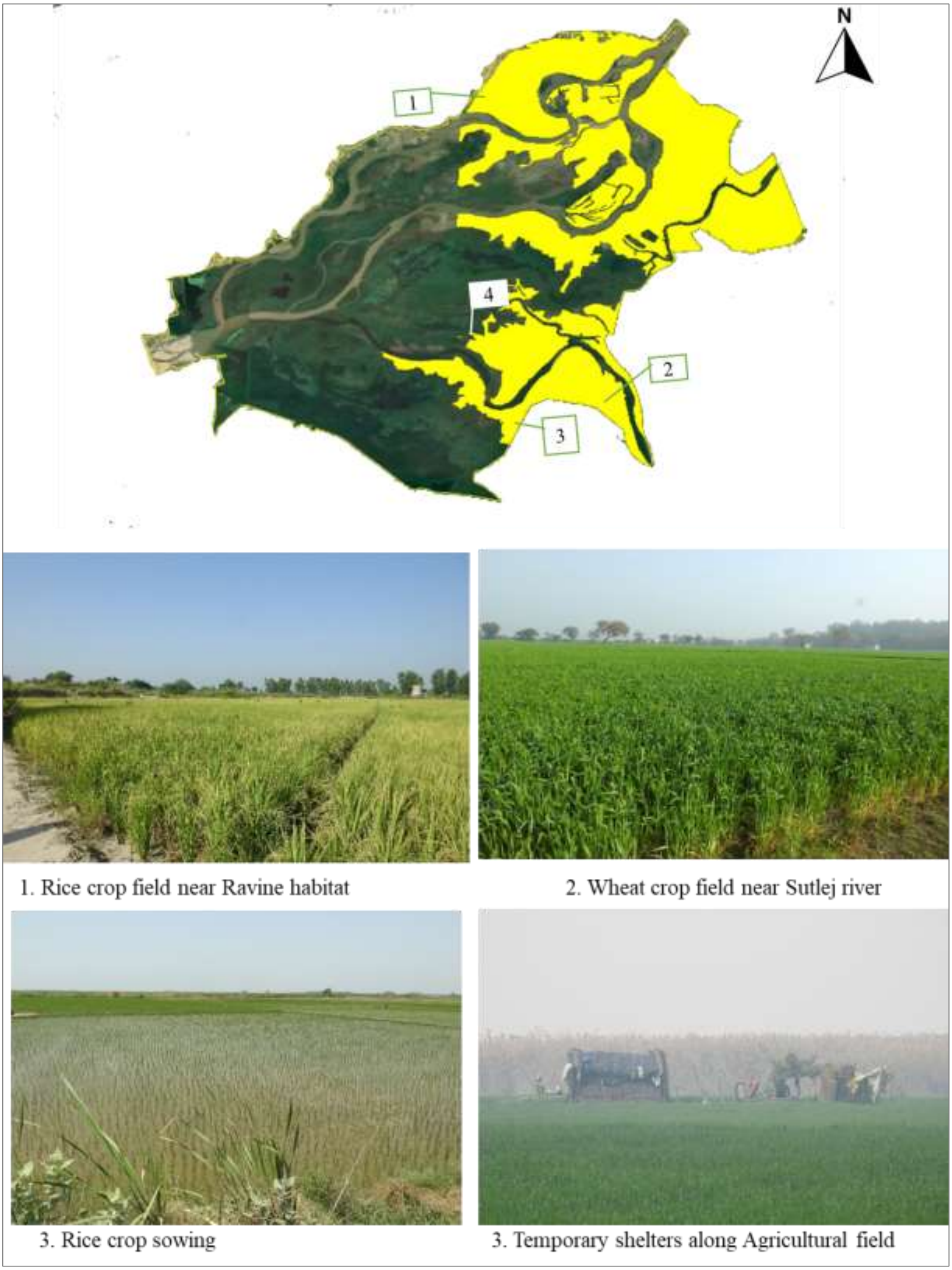
Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr)
{■= Present and healthy condition of plants, □ = absent or about to dry}

Species	**family**	**Habit**	**Summer**			**Monsoon**			**Post monsoon**			**Winter**		
			April	May	June	July	August	Septembe	October	November	December	January	February	March
Abelmoschus esculentus (L.) Moench.	Malvaceae	H	■	■	■	■	■							
Acacia tortilis (Forsk.) Hayne	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Acacia auriculiformis Benth	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Achyranthes aspera L.	Amaranthaceae	H	■	■	■	■	■	■						

Aerva javanica (Burm.f.) Juss. ex Schult	Amaranthaceae	H
Ageratum conyzoides (L.) L	Compositae	H
*Albizia lebbeck (*L.) Benth.	Leguminosae	T
Alhagi maurorum Medik	Leguminosae	H
Allium cepa L.	Amaryllidaceae	H
Allium sativum L	Amaryllidaceae	H
Alternanthera pungens Kunth	Amaranthaceae	H
Alysicarpus ovalifolius (Schum.) Leonard	Leguminosae	H
Alysicarpus vaginalis (L.) DC	Leguminosae	H
Ammannia baccifera L.	Lythraceae.	H
Anagallis arvensis L.	Primulaceae	H
Anisomeles indica (L.) Kuntze	Lamiaceae	H
Artemisia scoparia Waldst. & Kitam.	Compositae	H
Avena sativa L.	Poaceae	G
Azadirachta indica A. Juss.	Meliaceae	T
Blumea lacera (Burm.f.) DC	Compositae	H
Boerhavia diffusa L.	Nyctaginaceae	H
Brassica oleracea var. botrytis (L.) Alef.	Brassicaceae	H
Brassica rapa var. rapa L.	Brassicaceae	H
Cajanus cajan (Linn.) Millsp.	Leguminosae	S
*Calotropis procera (*Aiton) Dryand	Apocynaceae	S
Cannabis sativa L.	Cannabaceae	H
Cayratia trifolia (L.) Domin	Vitaceae	C
Cenchrus ciliaris L.	Poaceae	G
Chenopodium album L.	Chenopodiaceae	H
Cirsium arvense (L.) Scop.	Asteraceae	H
*Citrus aurantifolia (*Christm) Sw.	Rutaceae	S
Citrus reticulata Blanco	Rutaceae	S
Commelina benghalensis L.	Commelinaceae	H
Convolvulus arvensis L.	Convolvulaceae	C
Cordia myxa L.	Boraginaceae	T
Coriandrum sativum L.	Apiaceae	H
Croton bonplandianus Baill.	Euphorbiaceae	H
Cucumis melo var. callosus Rot	Cucurbitaceae	C
Cucumis sativus L.	Cucurbitaceae	C
Cucurbita maxima Duchesne.	Cucurbitaceae	C
Curcuma longa L.	Zingiberaceae	H
Cynodon dactylon (L.) Pers.	Poaceae	G
Cyperus rotundus L.	Cyperaceae	H
Dactyloctenium aegyptium (L.) Willd.	Poaceae	G
Dalbergia sissoo DC.	Leguminosae	T
Datura stramonium L.	Solanaceae	H
Daucus carota L.	Apiaceae	H
Desmodium triflorum (L.) DC.	Leguminosae	H
Desmostachya bipinnata (L.) Stapf	Poaceae	G
Dichanthium annulatum (Forssk.) Stapf	Poaceae	G

Digera muricata (L.) Mart.	Amaranthaceae	H
Echinochloa colona (L.) Link	Poaceae	G
Ehretia laevis (Rottler ex G. Don) Roxb.	Boraginaceae	T
Eleusine indica (L.) Gaertn	Poaceae	G
Eragrostis minor Host	Poaceae	G
Erigeron canadensis L.	Compositae	H
Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Euphorbia hirta L.	Euphorbiaceae	H
Euphorbia thymifolia L.	Euphorbiaceae	H
Ficus palmata	Moraceae	T
Ficus religiosa L.	Moraceae	T
Ficus virens Aiton	Moraceae	T
Fumaria indica (Hausskn.) Pugsley	Papaveraceae	H
Gnaphalium pensylvanicum Willd.	Compositae	H
Gossypium arboreum L	Malvaceae	S
*Humulus scandens (*Lour.) Merr.	Cannabaceae	C
Jatropha curcas L.	Euphorbiaceae	S
Launaea procumbens (Roxb.) Ramayya & Rajagopal	Compositae	H
Lepidium didymum L.	Brassicaceae	H
Leucaena leucocephala (Lam.) de Wit	Leguminosae	T
Leucas cephalotes (Roth) Spreng.	Lamiaceae	H
Luffa cylindrica (L.) M. J. Roem.	Cucurbitaceae	C
Lycopersicon esculentum Mill.	Solanaceae	H
Madhuca longifolia var. latifolia (Roxb.) A.Chev.	Sapotaceae	T
Malva parviflora L.	Malvaceae	H
Mazus pumilus (Burm.f.) Steenis	Phrymaceae	H
Medicago sativa L	Leguminosae	H
Melia azedarach L.	Meliaceae	T
Melilotus indicus (L.) All.	Leguminosae	H
Mentha × piperita L	Lamiaceae	H
Momordica charantia L.	Cucurbitaceae	C
Moringa oleifera Lam	Moringaceae	T
Morus alba L.	Moraceae	T
Nicotiana plumbaginifolia Viv.	Solanaceae	H
Oryza sativa L.	Poaceae	G
Oxalis corniculata L.	Oxalidaceae	H
Oxystelma esculentum (L. f.) Sm	Apocynaceae	C
Panicum maximum Jacq.	Poaceae	G
Pennisetum typhoides Rich.	Poaceae	G
Pergularia daemia (Forssk.) Chiov.	Apocynaceae	C
Peristrophe bicalyculata (Retz.)	Acanthaceae	H
Phalaris minor Retz.	Poaceae	G
Phyllanthus niruri L	Phyllanthaceae	H
Physalis minima L.	Solanaceae	H
Pisum sativum L.	Leguminosae	H
*Polypogon monspeliensis (*L.) Desf.	Poaceae	G

Pongamia pinnata (L.) Pierre	Leguminosae	T
Prosopis juliflora (Sw.) DC.	Leguminosae	T
Punica granatum L.	Punicaceae	S
Raphanus sativus L.	Brassicaceae	H
Rumex dentatus L.	Polygonaceae	H
Saccharum officinarum L.	Poaceae	G
Saccharum bengalense Retz	Poaceae	G
Saccharum spontaneum L	Poaceae	G
Senna occidentalis (L.) Link	Leguminosae	H
Senna tora (L.) Roxb.	Leguminosae	H
Sesamum indicum L.	Pedaliaceae	H
Setaria viridis (L.) P.Beauv	Poaceae	G
Sida cordifolia	Malvaceae	H
Sida acuta Burm.f.	Malvaceae	H
Sisymbrium irio L.	Brassicaceae	H
Solanum melongena L.	Solanaceae	H
Solanum nigrum L	Solanaceae	H
Solanum virginianum L.	Solanaceae	H
Sonchus oleraceus (L.) L.	Compositae	H
Sorghum halepense (L.) Pers.	Poaceae	G
Spinacia oleracea L.	Amaranthaceae	H
Stellaria media (L.) Vill.	Caryophyllaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Tamarix dioica Roxb. ex Roth	Tamaricaceae	T
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	T
Tinospora cordifolia (Willd.) Miers	Menispermaceae	C
Trianthema portulacastrum L.	Aizoaceae	H
Trichosanthes dioica Roxb	Cucurbitaceae	C
Tridax procumbens (L.) L.	Compositae	H
Trifolium alexandrinum L.	Leguminosae	H
Trifolium resupinatum L.	Leguminosae	H
Trigonella foenum-graecum L.	Leguminosae	H
Triticum aestivum L.	Poaceae	G
Triumfetta rhomboidea Jacq.	Malvaceae	H
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Verbascum thapsus L.	Scrophulariaceae	H
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray	Compositae	H
Veronica persica Poir.	Plantaginaceae	H
Vigna mungo (L.) Hepper	Leguminosae	S
Withania coagulans (Stocks) Dunal	Solanaceae	S
Ziziphus mauritiana Lam	Rhamnaceae	T



1. Rice crop field near Ravine habitat

2. Wheat crop field near Sutlej river

3. Rice crop sowing

3. Temporary shelters along Agricultural field

Fig 5.21: Map of Agricultural field habitat with different locations.

Seasonal variation of vegetation in Ravine habitat

The Ravine habitat was located along the Beas River in the northern part of the Sanctuary. This Ravine habitat possessed hard and dry soil as compared to other habitats and associated with small gallies besides it was like a small cliff from the Beas river. The Ravine habitat was also positioned at the highest elevation of the Sanctuary. This area possessed a plant association dominated by shrubs like *Capparis decidua* with associated species such as *Aerva javanica, Alhagi maurorum, Argemone ochroleuca, Artemisia scoparia, Blumea lacera, Boerhavia erecta, Grewia tenax, Lantana camara, Leucaena leucocephala, Lycium edgeworthii, Plumbago zeylanica* and *Pulicaria undulata* with variety of other plants, on an average 62±18.35 species can be found in each season. The summer season supported the population of herbs like *Achyranthes aspera, Aerva javanica, Alhagi maurorum, Argemone ochroleuca, Blumea lacera, Boerhavia diffusa, Cannabis sativa, Croton bonplandianus, Datura stramonium, Echinops echinatus, Euphorbia hirta, Fagonia indica, Heliotropium bacciferum, Herniaria hirsuta, Oxalis corniculata, Plumbago zeylanica, Senna occidentalis, Solanum nigrum, Tribulus terrestris* and *Tridax procumbens* with species richness of 30. In monsoon season species richness increases from 30 to 35.

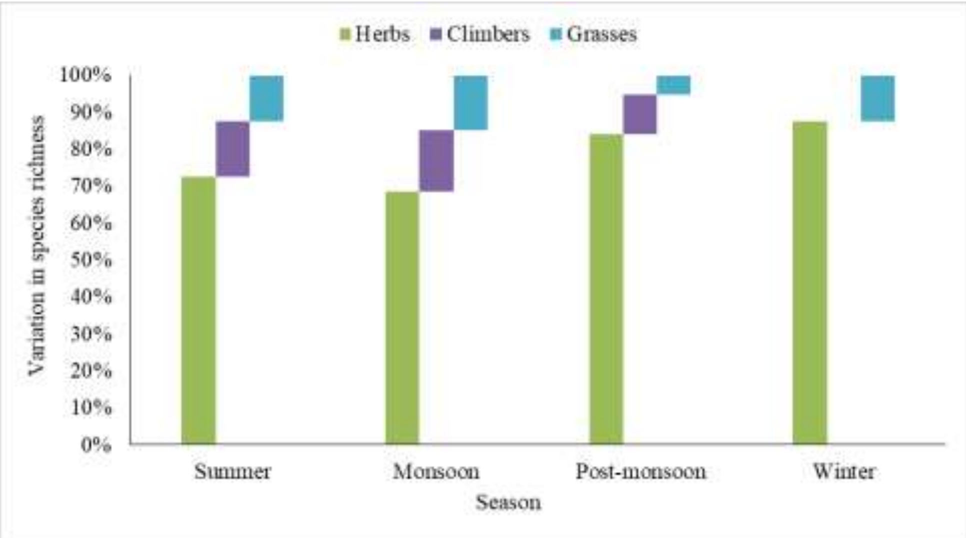


Fig 5.22: Seasonal variations in plant species richness within each habit in Ravine habitat.

The herbs association with species like *Alternanthera pungens, Astragalus sinaicus, Boerhavia erecta, Cirsium arvense, Commelina benghalensis, Commelina erecta, Crotalaria burhia, Cyathula prostrata, Heliotropium strigosum, Indigofera spicata, Malva parviflora, Pluchea lanceolata* and *Pupalia lappacea* was found in monsoon season at

Ravin habitat. In post-monsoon season, there was a decline in the species richness of herbs species from 35 to 14. The post-monsoon season supported the population of herbaceous flora like *Ageratum conyzoides, Alternanthera pungens, Cirsium arvense, Crotalaria burhia, Croton bonplandianus, Datura stramonium, Euphorbia hirta, Heliotropium bacciferum, Heliotropium strigosum, Malva parviflora, Pluchea lanceolata, Plumbago zeylanica, Sisymbrium irio* and *Zaleya pentandra*.

Fig 5.23: Plant association of Ravine habitat (1: *Tribulus Terrestris*, 2: *Citrullus colocynthis*, 3: *Capparis decidua*, 4: *Echinops echinatus* 5: *Aerva javanica*, 6: *Pluchea lanceolata,* 7: *Alhagi maurorum*, 8: *Ziziphus nummularia,* 9: *Cenchrus ciliaris,* 10: *Peganum harmala*)

As the winter approached the Sanctuary then herbs started drying, resulted a rapid decline in the species richness of herbs from 14 to 5 (Fig 20.22). The population of *Ageratum conyzoides, Alternanthera pungens, Cannabis sativa, Sisymbrium irio* and *Zaleya pentandra* were seen very frequently in the Ravine habitat during the winter season. The species of grasses had shown variation according to the season change. In summer season grass species like *Aristida adscensionis, Cenchrus ciliaris, Cynodon dactylon, Saccharum bengalense* and *Saccharum spontaneum* dominated the Ravine habitat and supported various ecosystem services. In monsoon season species richness of grass increased from 5 to 8. Species like *Cenchrus ciliaris, Cymbopogon martini, Cynodon dactylon, Desmostachya bipinnata, Eragrostis amabilis, Saccharum bengalense, Saccharum spontaneum* and *Setaria viridis* constituted the grass association for monsoon season in the Ravine habitat at the

Sanctuary. A steep decline was recorded in the species richness of grasses from 8 to 1. Only the population of *Cynodon dactylon* was found in the Ravine habitat during the post-monsoon and winter seasons. Climber species like *Abrus precatorius*, *Citrullus colocynthis* (fig 20.23), *Cocculus pendulus*, *Convolvulus* , *Mukia maderaspatana*, *Oxystelma esculentum* were recorded in summer season wherein monsoon season species richness of climbers increased from 6 to 9. The species like *Abrus precatorius*, *Citrullus colocynthis*, *Cocculus hirsutus*, *Cocculus pendulus*, *Convolvulus arvensis*, *Convolvulus prostratus*, *Mukia maderaspatana*, *Oxystelma esculentum*, *Pentatropis nivalis* constitutes were contributed to species composition of climbers in monsoon season in the Ravine habitat. In post-monsoon season species richness of climbers decreases from 9 to 2 with species like *Convolvulus arvensis* and *Pentatropis nivalis*. The Ravine habitat was found devoid of climber species in the winter season. The seasonal dynamics of the plant association is shown in Table 5.8.

Table 5.8: List of plants recorded from the Ravine habitat in different seasons.

Habit: Herbs (H), Trees (T), Grasses (G), Climber (C), Summered vegetation (Sv), Floating vegetation (Fv), Ferns (Fr)

{ ■ = Present and healthy condition of plants, □ = absent or about to dry}

Species	**Family**	**Habit**	**Summer**			**Monsoon**			**Post monsoon**			**Winter**		
			April	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**January**	**February**	**March**
Abrus precatorius L.	Leguminosae	C	■	■	■	■	■	■	■					
Abutilon indicum (L.) Sweet	Malvaceae	H	■	■	■	■	■	■	■	■				
Acacia tortilis (Forsk.) Hayne	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Acacia auriculiformis Benth	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Achyranthes aspera L.	Amaranthaceae	H	■	■	■	■	■	■	■	■				■
Aerva javanica (Burm.f.) Juss. ex Schult	Amaranthaceae	H	■	■	■	■	■	■						■
Ageratum conyzoides (L.) L	Compositae	H	■						■	■	■	■	■	■
Ailanthus excelsa Roxb.	Simaroubaceae	T	■	■	■	■	■	■	■	■	■	■	■	■
Albizia lebbeck (L.) Benth.	Leguminosae	T	■	■	■	■	■	■	■	■	■	■	■	■
Alhagi maurorum Medik	Leguminosae	H	■	■	■	■								■
Alternanthera pungens Kunth	Amaranthaceae	H				■	■	■	■	■	■	■	■	■
Anagallis arvensis L.	Primulaceae	H	■	■	■	■	■	■						
Argemone ochroleuca Sweet	Papaveraceae	H	■	■	■	■								■
Aristida adscensionis L.	Poaceae	G				■	■	■	■	■	■	■		
Artemisia scoparia Waldst. & Kitam.	Compositae	H	■	■	■	■	■	■						

Astragalus sinaicus Boiss.	Leguminosae	H
Azadirachta indica A. Juss.	Meliaceae	T
Blumea lacera (Burm.f.) DC	Compositae	H
Boerhavia diffusa L.	Nyctaginaceae	H
Boerhavia erecta L.	Nyctaginaceae	H
Calotropis procera (Aiton) Dryand	Apocynaceae	S
Cannabis sativa L.	Cannabaceae	H
Capparis decidua (Forssk.) Edgew	Capparaceae	S
Cassia fistula L.	Leguminosae	T
Cenchrus ciliaris L.	Poaceae	G
Cirsium arvense (L.) Scop.	Asteraceae	H
Citrullus colocynthis (L.) Schrad.	Cucurbitaceae	C
Clerodendrum phlomidis L.f.	Lamiaceae	S
Cocculus hirsutus (L.) W.Theob	Menispermaceae	C
Cocculus pendulus (J.R.Forst. & G.Forst.) Diels	Menispermaceae	C
Commelina benghalensis L.	Commelinaceae	H
Commelina erecta L.	Commelinaceae	H
Convolvulus arvensis L.	Convolvulaceae	C
Convolvulus prostratus Forssk	Convolvulaceae	C
Cordia myxa L.	Boraginaceae	T
Crotalaria burhia Benth.	Leguminosae	H
Crotalaria medicaginea Lam	Leguminosae	H
Croton bonplandianus Baill.	Euphorbiaceae	H
Cyathula prostrata (L.) Blume	Amaranthaceae	H
Cymbopogon martini (Roxb.) W.Watson	Poaceae	G
Cynodon dactylon (L.) Pers.	Poaceae	G
Dalbergia sissoo DC.	Leguminosae	T
Datura stramonium L.	Solanaceae	H
Desmostachya bipinnata (L.) Stapf	Poaceae	G
Echinops echinatus Roxb	Compositae	H
Ehretia laevis (Rottler ex G. Don) Roxb.	Boraginaceae	T
Eragrostis amabilis (L.) Wight & Arn.	Poaceae	G
Eucalyptus camaldulensis Dehnh.	Myrtaceae	T
Euphorbia hirta L.	Euphorbiaceae	H
Euphorbia prostrata Aiton	Euphorbiaceae	H
Fagonia indica Burm.f.	Zygophyllaceae	H
Ficus palmata	Moraceae	T
Ficus religiosa L.	Moraceae	T
Flacourtia indica	Salicaceae	T
Grewia tenax (Forssk.) Fiori	Malvaceae	S
Heliotropium bacciferum Forssk.	Boraginaceae	H
Heliotropium strigosum Willd	Boraginaceae	H
Herniaria hirsuta L	Caryophyllaceae	H
Indigofera spicata Forssk.	Leguminosae	H
Lantana camara L.	Verbenaceae	S

Leucaena leucocephala (Lam.) de Wit	Leguminosae	T
Lycium edgeworthii Miers	Solanaceae	S
Malva parviflora L.	Malvaceae	H
Malvastrum coromandelianum (L.) Garcke	Malvaceae	H
Melia azedarach L.	Meliaceae	T
Morus alba L.	Moraceae	T
Mukia maderaspatana (L.) M.Roem	Cucurbitaceae	C
Opuntia dillenii (Ker Gawl.) Haw.	Cactaceae	S
Oxalis corniculata L.	Oxalidaceae	H
Oxystelma esculentum (L. f.) Sm	Apocynaceae	C
Parkinsonia aculeata L.	Leguminosae	T
Parthenium hysterophorus L.	Compositae	H
*Peganum harmala (*Maxim.) Bobrov	Zygophyllaceae	H
Pentatropis nivalis (J.F.Gmel.) D.V.Field & J.R.I.Wood	Apocynaceae	C
Pluchea lanceolata (DC.) C.B.Clarke	Compositae	H
Plumbago zeylanica L.	Plumbaginaceae	H
Pongamia pinnata (L.) Pierre	Leguminosae	T
Prosopis cineraria (L.)Druce	Leguminosae	T
Pupalia lappacea (L.) Juss	Amaranthaceae	H
Pulicaria undulata (L.) C.A.Mey.	Compositae	H
Saccharum bengalense Retz	Poaceae	G
Saccharum spontaneum L	Poaceae	G
*Senegalia catechu (*L. f.) P.J.H. Hurter & Mabb.	Leguminosae	T
Senegalia modesta (Wall.) P.J.H. Hurter	Leguminosae	T
Senna occidentalis (L.) Link	Leguminosae	H
Setaria viridis (L.) P.Beauv	Poaceae	G
Sisymbrium irio L.	Brassicaceae	H
Solanum nigrum L	Solanaceae	H
Syzygium cumini var. cumini	Myrtaceae	T
Tribulus terrestris L.	Zygophyllaceae	H
Tridax procumbens (L.) L.	Compositae	H
Vachellia leucophloea (Roxb.) Maslin, Seigler & Ebinger	Leguminosae	T
Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Leguminosae	T
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray	Compositae	H
Zaleya pentandra (L.) C.Jeffrey	Aizoaceae	H
Ziziphus mauritiana Lam	Rhamnaceae	T
Ziziphus nummularia (Burm.f.) Wight & Arn.	Rhamnaceae	S

1. Lowland area in Ravine habitat

2. Dominated by *Dalbergia sissoo* and *Aerva javanica*

3. Cattle grazing in Ravine habitat

4. Dominated by *Capparis decidua* and *Lycium edgeworthii*

Fig 5.24: Map of Ravine habitat with different locations.

Cluster analysis of different habitats for vegetation

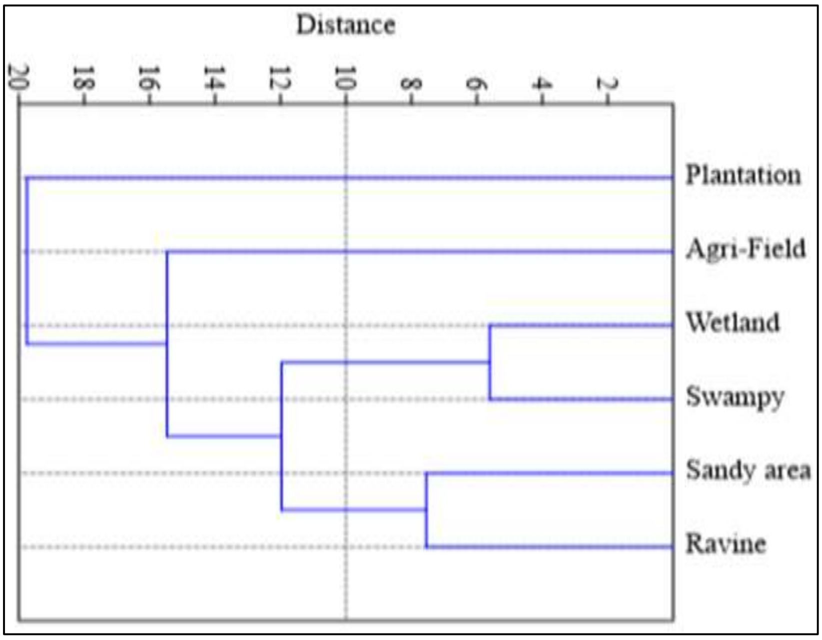


Fig 5.25: Cluster analysis of different habitat types based on plant species distribution.

The cluster analysis (Jaccad similarity index) suggested that vegetation association of Wetland and Swampy habitats was similar among all habitats (Fig 5.25) followed by Sandy habitat and Ravine habitat. Indicators of similar ecological conditions, such as soil type, moisture content and climate, embrace similar plant communities in various settings. This resemblance suggests that the habitats might host related animal species and provide interaction among various natural areas. The cluster analysis shows the 4 vegetarian groups viz. Wetland and Swampy group, Sandy and Ravine group, Agi-field and Plantation. The vegetation of the Wetland habitat was found most similar to the Swampy habitat. Additionally the plant composition of the Sandy habitat was mostly similar to the Ravine habitat, moreover plant composition of the Agri-field and Plantation habitat was different from other recorded habitats of HWS. To be more precise presentation of plant composition had been shown by common species between habitats and Jaccad similarity index (Cj) in the 15 groups of habitats (Fig 5.26). For many plant and animal species to travel and survive among habitats. Among the habitats of HWS, Each habitat of the sanctuary shares 35.13±18.86 species of plants with plant association similarity with Cj= 20.37%±10.68%. Plantation and agricultural fields have 80 species common species with Cj=26.75%, followed by Plantation and Ravines habitats with 60 common species and Cj=32.25%, Agricultural field and Ravines with 51 common species and Cj=26.15% Plantation and Swampy habitats share 46 common species resulting Cj=17.35%, Wetland and Swampy habitat have 38 common species with 37.62%, Sandy and Swampy have also 38 common species with Cj=35.84%, Sandy and Plantation have 36 common species with Cj=13.68%. Agricultural fields and Swampy with 35 common species with Cj=18.51%, Ravines and Swampy share 32 common species and result in Cj=21.91%, Wetland and Sandy have 28 common species and Cj=28.28%, Sandy and Ravines have 26 common species with Cj=18.57%, Sandy and Agricultural field have 21 common species and Cj=10.99%, Wetland and Plantation share 14 common species with Cj=5%, Wetland and Agricultural field supports 13 common species resulting Cj=6.70% and Wetland and Ravines habitat have 9 common species with Cj=5.92%.

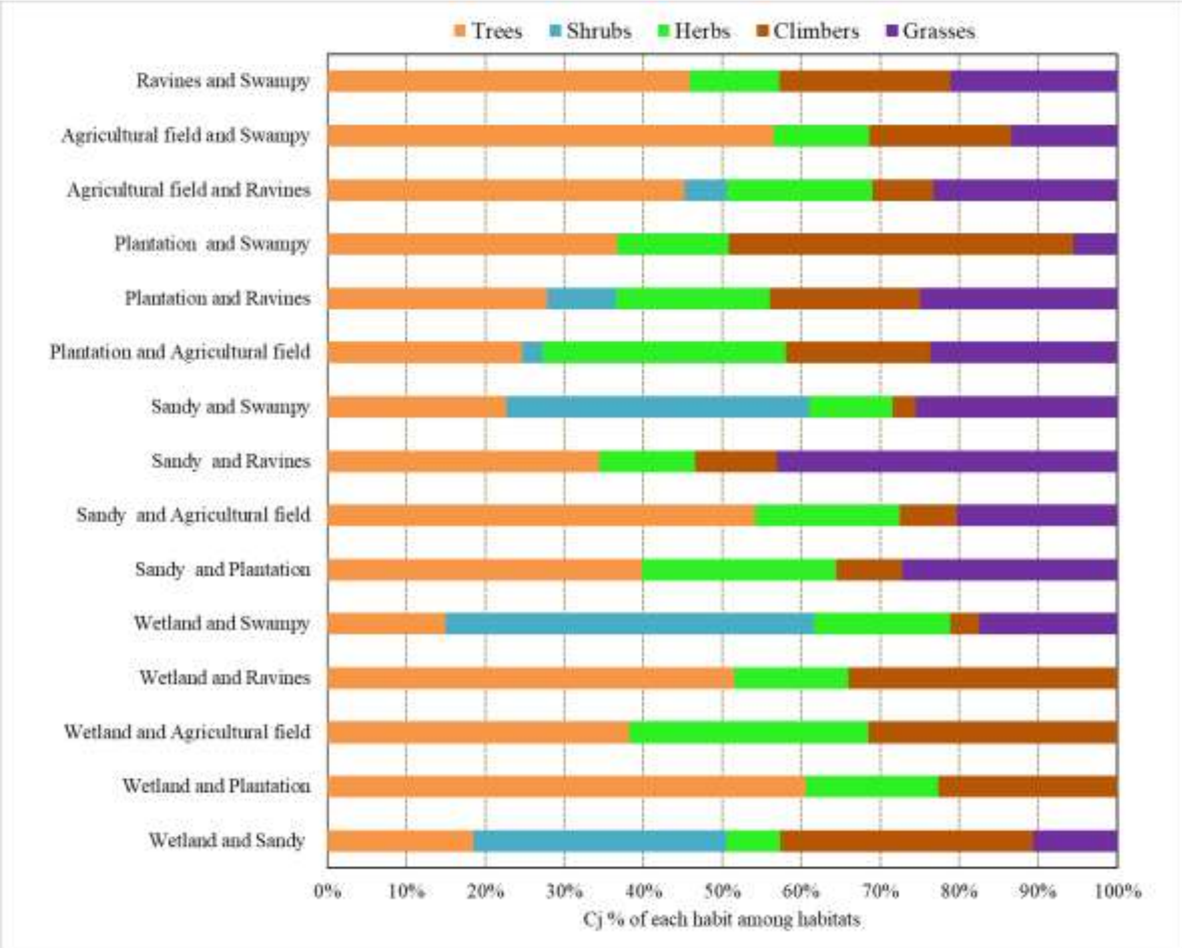


Fig 5.26: Similarity (Cj %) of plant association among habitats of HWS.

In the HWS all the six habitats shared 14±5.54 tree species with Cj=35.45%±17.02%. In tree species maximum similarity (Cj%) was recorded between Sandy habitat and swampy habitat (Fig 5.65) with common 16 species (Cj=59.26%) like *Albizia lebbeck*, *Azadirachta indica*, *Bombax ceiba*, *Dalbergia sissoo*, *Ehretia laevis*, *Eucalyptus camaldulensis*, *Ficus benghalensis*, *Ficus religiosa*, *Leucaena leucocephala*, *Melia azedarach*, *Morus alba*, *Phoenix sylvestris*, *Prosopis juliflora*, *Syzygium cumini* *Terminalia arjuna* and *Vachellia* *nilotica***,** followed by Wetland habitat and Sandy habitat with 11 species in common (Cj=57.89%) such as *Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa, Phoenix sylvestris, Populus deltoids, Salix alba, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica.*

In the Agricultural field habitat and Swampy habitat 17 species (Cj=54.84%) are common, it included *Acacia auriculiformis, Albizia lebbeck, Azadirachta indica, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Pongamia pinnata, Prosopis juliflora, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica.* Agricultural field habitat and Ravines habitat also have 17 species (Cj=53.13%) were common including *Acacia tortilis, Acacia auriculiformis, Albizia lebbeck, Azadirachta indica, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Pongamia pinnata, Syzygium cumini, Vachellia nilotica* and *Ziziphus mauritiana*. Common tree species between Ravine habitat and Swampy habitat are 17 species (Cj=50%) such as *Acacia auriculiformis, Ailanthus excels, Albizia lebbeck, Azadirachta indica, Cassia fistula, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Pongamia pinnata, Syzygium cumini* and *Vachellia nilotica*. The similarity of plant association between Sandy and Agricultural field habitat is Cj=46.43% with 13 species in common, these species are *Albizia lebbeck, Azadirachta indica, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Prosopis juliflora, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica.* The common species between Sandy and Ravines habitat are 11 species (Cj=33.33%) like *Albizia lebbeck, Azadirachta indica, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Morus alba, Syzygium cumini* and *Vachellia nilotica.* Wetland habitat and Swampy habitat had 9 species (Cj=32.14%) in-common these species were *Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa, Phoenix sylvestris, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica*. A total of 23 species of trees share the Plantation habitat and Swampy habitat with Cj=31.51%, common tree species are *Acacia auriculiformis, Ailanthus excels, Albizia lebbeck, Albizia procera, Azadirachta indica, Bombax ceiba, Cassia fistula, Cordia myxa, Dalbergia sissoo, Dichrostachys cinerea, Ehretia laevis, Eucalyptus camaldulensis, Ficus benghalensis, Ficus palmata, Ficus religiosa,* *Leucaena leucocephala*, *Melia azedarach, Morus alba*, *Pongamia pinnata, Prosopis juliflora, Syzygium cumini*, *Terminalia arjuna* and *Vachellia nilotica.* Tree association share Plantation habitat and Ravine habitat with 22 common species (Cj=29.33%) encompasses *Acacia tortilis, Acacia auriculiformis, Ailanthus excels, Albizia lebbeck, Azadirachta indica*, *Cassia fistula, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis*, *Ficus palmata, Ficus religiosa*, *Leucaena leucocephala, Melia azedarach, Morus alba, Parkinsonia aculeate, Pongamia pinnata, Prosopis cineraria, Senegalia catechu, Syzygium cumini, Vachellia nilotica* and *Ziziphus mauritiana.* In case of Plantation habitat and Agricultural field habitat have 20 common tree species (Cj=27.03%), these included *Acacia tortilis*, *Acacia auriculiformis, Albizia lebbeck, Azadirachta indica, Cordia myxa, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus palmata, Ficus religiosa, Leucaena leucocephala, Melia azedarach, Moringa oleifera, Morus alba, Pongamia pinnata, Prosopis juliflora, Syzygium cumini, Terminalia arjuna, Vachellia nilotica* and *Ziziphus mauritiana.* Between Sandy habitat and Plantation habitat, a total of 16 species of trees were common (Cj=21.92%) including *Albizia lebbeck, Azadirachta indica, Bombax ceiba, Dalbergia sissoo, Ehretia laevis, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa*, *Leucaena leucocephala, Melia azedarach, Morus alba, Prosopis juliflora, Salix alba, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica*. The habitat with very different abiotic structures such as wetlands and ravines share 5 common species of trees (Cj=15.15%) like *Dalbergia sissoo, Eucalyptus camaldulensis, Ficus religiosa, Syzygium cumini* and *Vachellia nilotica.* Species such as *Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis, Ficus religiosa, Salix alba, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica* were found common (9 species) between Wetland habitat and Plantation habitat (Cj=12.16%) and in the Wetland and Agricultural field habitat, a total of 6 tree species were found common with Cj=7.59%, these species are *Dalbergia sissoo, Eucalyptus camaldulensis, Ficus religiosa, Syzygium cumini, Terminalia arjuna* and *Vachellia nilotica.*

These common species among habitats can be used for restoration of particular habitats in the HWS to improve and sustain ecosystem services. In the association of shrubs maximum similarity is recorded between Wetland habitat and Sandy habitat have *Ipomoea carnea* as common species with Cj=100% followed by Wetland habitat and Swampy habitat followed by Sandy habitat and Swampy habitat with *Ipomoea carnea* as common species with Cj=100%. In Plantation habitat and Ravine habitat a total of 3 species were found common with

Cj=9.09%, these species are *Calotropis procera*, *Grewia tenaxand* and *Lantana camara*. A shrub species *Calotropis procera* found common between Agricultural fields and Ravines habitat, these habitats have a association similarity of Cj=6.25%. In Plantation habitat and Agricultural field habitat, *Calotropis procera* is a common species with Cj=2.78%.

In the herb community, around 14.53±10.60 species were found common with association similarity of Cj=16.91%±10.15% among habitats. Maximum common species were recorded between Plantation habitat and Agricultural field habitat, an association of 45 herb species shared both habitat with association similarty of Cj=33.83%, these species were *Achyranthes aspera, Ageratum conyzoides, Alysicarpus vaginalis, Anagallis arvensis, Anisomeles indica, Artemisia scoparia, Boerhavia diffusa, Cannabis sativa, Chenopodium album, Cirsium arvense, Commelina benghalensis, Croton bonplandianus, Datura stramonium, Desmodium triflorum, Digera muricata, Erigeron Canadensis, Euphorbia hirta, Euphorbia thymifolia, Fumaria indica, Gnaphalium pensylvanicum, Launaea procumbens, Lepidium didymum, Leucas cephalotes, Malva parviflora, Mazus pumilus, Melilotus indicus, Nicotiana plumbaginifolia, Oxalis corniculata, Peristrophe bicalyculata, Physalis minima, Rumex dentatus, Senna occidentalis, Senna tora, Sida cordifolia, Sida acuta, Sisymbrium irio, Solanum incanum, Solanum nigrum, Solanum virginianum, Sonchus oleraceus, Stellaria media, Trianthema portulacastrum, Tridax procumbens, Triumfetta rhomboidea* and *Verbesina encelioides* followed by Agricultural field and Ravine habitat with common 25 herb species (Cj=21.74%) like *Achyranthes aspera, Aerva javanica, Aerva lanata, Ageratum conyzoides, Alhagi maurorum, Alternanthera pungens,Anagallis arvensis, Artemisia scoparia, Blumea axillaris, Blumea lacera, Blumea membranacea, Boerhavia diffusa, Cannabis sativa, Cirsium arvense, Commelina benghalensis, Croton bonplandianus, Datura stramonium, Euphorbia hirta, Malva parvifloram, Oxalis corniculata, Senna occidentalis, Sisymbrium irio, Solanum nigrum, Tridax procumbens* and *Verbesina encelioides*. The herb species in the plantation habitat and Ravine habitat have 25 species common (Cj=20.66%) such as *Abutilon indicum, Achyranthes aspera, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Boerhavia diffusa, Cannabis sativa, Cirsium arvense, Commelina benghalensis, Croton bonplandianus, Datura stramonium, Euphorbia hirta, Euphorbia prostrata, Malva parviflora, Malvastrum coromandelianum, Oxalis corniculata, Parthenium hysterophorus, Plumbago zeylanica, Senna occidentalis, Sisymbrium irio, Solanum nigrum, Tribulus terrestris, Tridax procumbens, Verbesina encelioides* and *Zaleya pentandra.*

A association of 16 herb species was found in Sandy habitat and Agricultural field habitat with Cj=15.69%, these species were *Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia , Cannabis sativa, Cyperus rotundus, Digera muricata, Euphorbia hirta, Fumaria indica, Gnaphalium pensylvanicum, Nicotiana plumbaginifolia, Oxalis corniculata, Rumex dentatus, Sisymbrium irio, Stellaria media Verbascum Thapsus* and *Verbesina encelioides*. In Sandy habitat and Plantation habitat, there were 16 species common in both habitats (Cj=13.56%) like *Abutilon indicum, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Cannabis sativa, Digera muricata, Euphorbia hirta, Fumaria indica, Gnaphalium pensylvanicum, Nicotiana plumbaginifolia, Oxalis corniculata, Portulaca grandiflora, Rumex dentatus, Sisymbrium irio, Stellaria media* and *Verbesina encelioides.* There were 13 species of herbs prevailing in Swampy habitat and Wetland habitat (Cj=37.14%), like *Adenostemma platyphyllum, Ageratum conyzoides, Anagallis arvensis, Bacopa monnieri, Centella asiatica, Cyperus rotundus, Eclipta prostrata, Marsilea quadrifolia, Oxalis corniculata, Phyla nodiflora, Ranunculus sceleratus, Stellaria media* and *Typha angustifolia*. Sandy habitat and Swampy habitat had 13 common species (Cj=27.66%) such as *Abutilon indicum, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Cannabis sativa, Cyperus rotundus, Eclipta prostrata, Gnaphalium pensylvanicum, Oxalis corniculata, Phyla nodiflora, Ranunculus sceleratus, Salvia plebeia*and *Stellaria media*. Between Plantation habitat and Swampy habitat, 13 species were found common (Cj=12.15%) like *Abutilon indicum, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Boerhavia diffusa, Cannabis sativa, Gnaphalium pensylvanicum, Lepidium didymum, Malva parviflora, Oxalis corniculata, Stellaria media, Urena lobata* and *Xanthium strumarium,* There are 11 species common between Wetland habitat and Sandy habitat (C=21.57%), such as *Ageratum conyzoides, Anagallis arvensis, Cyperus michelianus, Cyperus rotundus, Eclipta prostrata, Ludwigia adscendens, Oxalis corniculata, Phyla nodiflora, Ranunculus sceleratus, Stellaria media* and *Verbascum Thapsus.* In Agricultural field and Swampy habitat 11 species are common (Cj=11.83%), like *Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Boerhavia diffusa, Cannabis sativa, Cyperus rotundus, Gnaphalium pensylvanicum, Lepidium didymum , Malva parviflora, Oxalis corniculata* and *Stellaria media*. The Sandy habitat and Ravine habitat had common 9 species of herbs (Cj=11.69%) like *Abutilon indicum, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Cannabis sativa, Euphorbia hirta, Oxalis corniculata, Sisymbrium irio and Verbesina encelioides.* In Ravine habitat and Swampy habitat, there are 8 common speices

(Cj=12.50%) such as *Abutilon indicum, Ageratum conyzoides, Anagallis arvensis, Artemisia scoparia, Boerhavia diffusa, Cannabis sativa, Malva parviflora* and *Oxalis corniculata*. The herb communities of Wetland habitat and Agricultural field habitat have 6 species common (Cj=6%) *Ageratum conyzoides, Anagallis arvensis, Cyperus rotundus, Oxalis corniculata*, *Stellaria media* and *Verbascum thapsus*. The Wetland habitat and Plantation habitat have 4 species common with Cj=3.36%, these species included *Ageratum conyzoides, Anagallis arvensis*, *Oxalis corniculata* and *Stellaria media.* Between Wetland habitat and Ravine habitat, 3 species of herbs were found common (Cj=4.23%) such as *Ageratum conyzoides, Anagallis arvensis* and *Oxalis corniculata.*

The association of climbers was also recorded across the habitat of HWS, There are 2.20 ±1.70 species of climber found in each habitat with a association similarity Cj=16.76%±23.78% among habitats. The maximum association similarity (Cj=100%) was found between wetland and Sandy habitats with two species common including *Convolvulus arvensis* and *Ipomoea aquatic*. Common species between Plantation and Swampy habitat were *Abrus precatorius, Coccinia grandis, Convolvulus arvensis, Ipomoea nil, Ipomoea pes-tigridis, Mukia maderaspatana, Oxystelma esculentum, Pergularia daemia and Tinospora cordifolia* with Cj=37.50%. In the Ravines and Swampy habitat 4 species of climber were found common (Cj=23.53%), such as *Abrus precatorius, Convolvulus arvensis, Mukia maderaspatana and Oxystelma esculentum*. The similarity of climber association between Plantation and Agricultural field habitats is Cj=20% with six species in common *Cayratia trifolia, Convolvulus arvensis, Humulus scandens, Oxystelma esculentum, Pergularia daemia and Tinospora cordifolia*. There are 5 species found common in the habitats of Plantation and Ravines with Cj=20%, common species are *Abrus precatorius, Cocculus pendulus, Convolvulus arvensis, Mukia maderaspatana and Oxystelma esculentum*. In the Wetland and Ravines habitat, only *Convolvulus arvensis* was found common between habitat Cj=10%. In the Sandy and Ravines habitat, *Convolvulus arvensis* was found common with Cj=10%, Species like Convolvulus *arvensis* and *Oxystelma esculentum*, are common in the Agricultural field and Ravines habitat with Cj=9.09%.

Agricultural fields and Swampy habitats have 2 species common Convolvulus *arvensis, Oxystelma esculentum, Pergularia daemia and Tinospora cordifolia* with Cj=17.93%. In the Wetland and Swampy habitat, *Ipomoea aquatica* was found common with Cj=7.69%. In the Sandy and Swampy habitat *Convolvulus arvensis* and *Ipomoea aquatica* with Cj=7.69%. Convolvulus arvensis was found common between Sandy habitat and Agricultural field with

Cj=6.25%. Convolvulus arvensis was found common among Wetland, Plantation and Sandy habitats with Cj=4.55%.

The grass association among the habitats of HWS supports food security for herbivores besides providing different ecosystem services. There are 3.25±1.86 species of common grasses in the habitat of HWS with Cj= 19.56%±10.78%.

In the Sandy and Swampy *Chrysopogon zizanioides*, *Cynodon dactylon*, *Paspalum distichum, Phragmites karka*, *Saccharum bengalense and Saccharum spontaneum* with Cj=66.67%. Species like *Cynodon dactylon, Desmostachya bipinnata, Eragrostis amabilis, Saccharum bengalense, Saccharum spontaneum* are common in Sandy and Ravines habitat with association similarity Cj=41.67%. Species like *Chrysopogon zizanioides, Paspalum distichum, Phragmites karka* were found common between Wetland and Swampy (Cj=37.50%), these 3 species were also found common between Wetland and Sandy habitats with association similarity of Cj=33.33%. In the Agricultural field and Ravines habitat 6 species were common *Cenchrus ciliaris, Cynodon dactylon, Desmostachya bipinnata, Saccharum bengalense, Saccharum spontaneum and Setaria viridis* with Cj=27.27%. Plantation and Ravines habitat have common species like *Cenchrus ciliaris, Cynodon dactylon, Desmostachya bipinnata, Eragrostis amabilis and Setaria viridis* with Cj= 26.32%. In the grass community, 7 species including *Cenchrus ciliaris, Cynodon dactylon, Dactyloctenium aegyptium, Desmostachya bipinnata, Eleusine indica, Panicum maximum, Setaria viridis, Polypogon monspeliensis* were found common in the Plantation and Agricultural field with Cj=25.93%. Ravines and Swampy habitats have common species like *Cynodon dactylon, Saccharum bengalense* and *Saccharum spontaneum* with Cj=23.08%. The association of grass shares Sandy and Plantation, these species are *Cynodon dactylon, Desmostachya bipinnata and Eragrostis amabilis* with Cj=15%. In the habitats of the Agricultural field and Swampy have common species like *Cynodon dactylon, Saccharum bengalense, Saccharum spontaneum* with Cj=13.04% whereas in Sandy and Agricultural field *Cynodon dactylon, Desmostachya bipinnata, Saccharum bengalense and Saccharum spontaneum* were common between habitats with Cj=17.39%. Species like *Cynodon dactylon* were found common between Plantation and Swampy habitats with Cj=4.76%.

A region's biodiversity and ecological health can be inferred from the similarities of its plant communities. A lack of different habitats and a decline in overall biodiversity may be indicated by habitats with a high degree of homogeneity in their plant composition. On the other hand, ecosystems with distinct plant communities imply a range of niches and a larger potential for biodiversity. Insights into the stage of ecological succession within a habitat can also be gained by comparing or contrasting the plant groups. While mature or climax habitats may show increased similarity due to stable environmental conditions and competition for resources, early successional habitats, such as freshly disturbed areas, may have unique plant communities dominated by pioneer species.

Discussion

To keep ecosystems functioning properly and maintaining ecological balance, plants are essential. They go through different seasonal variations that have a big impact on ecological activities and processes. This study examines seasonal changes in the vegetation composition in each habitat. Seasonal change in the plant association is the effect of multiple factors such as temperature, moisture and sunlight availability, the habitat with high moisture provides a habitat for hydrophytes, in the present study, an area with 191m elevation to 200m most of the hydrophytes were recorded from HWS these species includes *Hydrilla verticillata, Nelumbo nucifera, Vallisneria natans, Centella asiatica, Bacopa monnieri, Typha latifolia, Pistia stratiotes* and *Marsilea quadrifolia.* Pagag and Borthakur (2012) recorded *Eclipta prostrata, Ipomoea aquatica, Euphorbia hirta* as wild edible wetland plants. The mesophytes were recorded from 200m to 233m elevation which includes habitats like Plantation, Sandy, Swampy, Agricultural and Ravine, these habitat support mesophytes comprising species like *Abrus precatorius, Abutilon indicum, Acacia tortilis, Achyranthes aspera, Aegle marmelos, Aerva javanica, Amaranthus viridis, Anagallis arvensis, Azadirachta indica, Basella alba, Boerhavia diffusa, Boerhavia erecta, Calotropis procera, Cannabis sativa, Cassia fistula, Cenchrus ciliaris, Chenopodium album, Citrullus colocynthis, Cleome viscosa, Digera muricata, Euphorbia tithymaloides, Fumaria indica, Hamelia patens, Justicia adhatoda, Leucaena leucocephala, Parkinsonia aculeate, Pedalium murex, Pennisetum typhoides, Phoenix sylvestris* and *Prosopis juliflora.* Plants begin to emerge from the seed bank of soil and experience tremendous development in the summer season because of their robust seed production in the summer, species like *Cannabis sativa, Chenopodium album, Parkinsonia aculeate, Leucaena leucocephala* and *Prosopis juliflora* were been found in a variety of habitats in HWS. Warming temperatures and more sunlight encourage photosynthesis, which results in the creation of carbohydrates and oxygen. The main production by this increase in photosynthetic activity, which leads to the development of new leaves, flowers and fruits which further enhances the ecosystem functions and services, the growth of new plants supports a variety of ecosystem services for human populations including numerous interactions between plants, herbivores, carnivores and soil biota are necessary for the preservation of a range of soil activities, including the cycling of carbon and nitrogen (Bardgett and Wardle 2003) in different ecosystems. Plant and other trophic-level interactions are crucial for many ecological services (De Bello et al. 2010; Cardinale et al. 2012) such as the interaction of insects for example a variety of plants, pollinators and the species with which they interact are all necessary for pollination (Kremen et al. 2007). HWS is also a habitat for Pollinators like bees and butterflies are drawn to summer blossoming plants, which helps with pollination and promotes the reproduction of both wild plants as well as crops cultivated in and around This season's increase in plant biomass gives herbivores food and habitat, which in turn sustains the entire food chain. Summer is characterized by high temperatures, extended daylight hours and limited rainfall in HWS. Plants have adapted to cope with these conditions through various strategies. Transpiration rates increase due to the heat, leading to higher water loss. This process contributes to the cooling of the surrounding environment through evapotranspiration. Additionally, the dense vegetation cover during summer helps regulate soil temperature, preventing excessive heat buildup and reducing the risk of soil erosion.

The monsoon season, which is characterized by intense rain and high humidity, has a significant effect on ecosystem services and vegetation. Semi-arid areas of HWS receive rainfall during the monsoon season, allowing plants to flourish. The increasing rainfall supplies the moisture that plants need to thrive and for seeds to germinate in Ravine habitats such as *Anagallis arvensis, Peganum harmala, Aerva javanica* and *Cynodon dactylon*. As a result, during the monsoon season, vegetation grows more quickly and is more productive which further supports provisional ecosystem services such as fodder, edible plants, raw materials and medicinal plants. The overall biodiversity and ecosystem stability are aided by the lush vegetation and thick cover of leaves. The rainfall adds a significant level of micro-nutrients in the soil which are essential for the growth of vegetation (Allen et al. 1968). Habitats of hydrophytes such as sandy, swampy and wetland have shown comparatively low seasonal variation though the habitats of mesophytes such as Plantation, Ravine and Agricultural habitats have shown more variation. Hydrophytes species like *Eclipta prostrata*, *Azolla pinnata, Ipomoea carnea, Ipomoea equatica, Cyperus rotundus, Arundo donax, Persicaria glabra, Ranunculus sceleratus* and *Phyla nodiflora* were recorded from different habitats of HWS and Ali et al. (2020) also recorded these plants from tehsil Shakargarh, Punjab, Pakistan which is 208 km from the study area. Ahmad et al. (2008) also recorded *Acacia modesta,* *Vachellia nilotica*, *Dalbergia sissoo*, *Propsopis juliflora*, *Justicia adhatoda*, *Ziziphus mauritiana, Ziziphus nummularia, Cynodon dactylon, Saccharum spontaneum and Cyperus rotundus* from Punjab, region of Pakistan. Johansson et al. (2013) argued that in a typical global warming scenario, seasonal increases in temperature can have an impact on plant growth at various phenophases as a result, recording seasonal changes in plant communities in the current study can aid in predicting the effects of climate change for a specific region. Climate change can impact the function of ecosystems (Bhardwaj 2016) which will impact the ecosystem services. Due to similar environmental factors, such as climate, soil type and topography, plant communities within a certain habitat type, such as Forests, Grasslands, Wetlands and Ravines, frequently have similar traits. In the present study similarity among plant communities has been documented. Each habitat of the sanctuary shares 35.13±18.86 species of plants with plant association similarity with Cj= 20.37%±10.68%. Specific common factors may encourage the occurrence of related plant species or functional groupings in specific settings. Paudel and Vetaas (2014) documented the effects of topography and land use on woody plant species composition in an arid Trans-Himalayan landscape of Nepal. Kassas and Girgis (1970) recorded Habitat and plant communities in the Egyptian Desert and Jordan et al. (1997) mentioned Habitat structure and plant association composition in wetland landscapes. Despite some similarities, plant communities can also vary significantly among habitats. Factors such as geographical location, local disturbances and historical influences can result in differences in plant species composition, diversity and structure among different habitats.

Chapter 6

Avian community and cultural ecosystem services across the habitat types

Birds are amazing creatures that adorn our skies, woods, wetlands, and a variety of other environments all around the globe. The avian community is essential to the health and balance of the ecosystem (Emlen, 1974; Rapport, 1989; O'Connell et al. 2000; Wheeler et al. 2015; ROSLI, 2023). Effective conservation and ecological management depend on knowing the dynamics of bird populations and how they react to various environments and seasonal changes. The aggregate array of bird species found in a certain habitat or geographic region is referred to as the "avian community" (Willson, 1974). Each type of bird contributes differently to ecosystem functions like pollination, seed dissemination, pest management, and nutrient cycling (Whelan, 2008). The bird population is made up of migratory species that fly great distances to breed or spend the winter in various locations and resident species that live in one area all year. Different habitats provide unique resources and environmental circumstances, which cause variances in the makeup of bird communities. Coastal areas, wetlands, grasslands, and forests all offer particular niches that draw particular bird species. For instance, in forests, a wide range of species, including those that live in the canopy, specialize in the understory, and feed on the forest floor, are supported. While wetlands offer vital nesting habitats for waterfowl and waders (O'Neal et al. 2008), grasslands draw open-country species like larks and pipits. Seasonal migration is one of the most amazing events in the avian world. To take advantage of seasonal variations in resource availability, birds travel great distances and frequently face danger. Factors including photoperiod, food availability, and breeding requirements have an impact on migration patterns (Trierweiler et al. 2014). The dynamics and composition of bird populations in particular environments can be considerably changed by the presence and departure of migratory species. Because many species nest during the spring and summer, these seasons are crucial for bird groups (Perrins, 1970). Numerous species move in search of suitable habitats as a result of changes in food supply and environmental conditions that occur in the autumn and winter (Faaborg et al. 2010). Waterfowl, such as ducks and geese, find refuge in wetlands, while raptors like hawks and eagles pursue their prey. During migration seasons, a variety of migratory species inhabit various habitats, enhancing the richness and ecological complexity of bird groups. Conservation efforts must take into account the bird community and how it responds to habitat and seasonal changes. Bird populations are seriously threatened by human activities such as habitat degradation, pollution, and climate change. Conservationists can establish focused plans to maintain and restore habitats (Marzluff and Ewing, 2008; Wilcove, 2010; Allison, 2012). Conserve nesting sites, and construct corridors for migratory species by identifying crucial habitats for various bird species and understanding the critical seasons for breeding and migration.

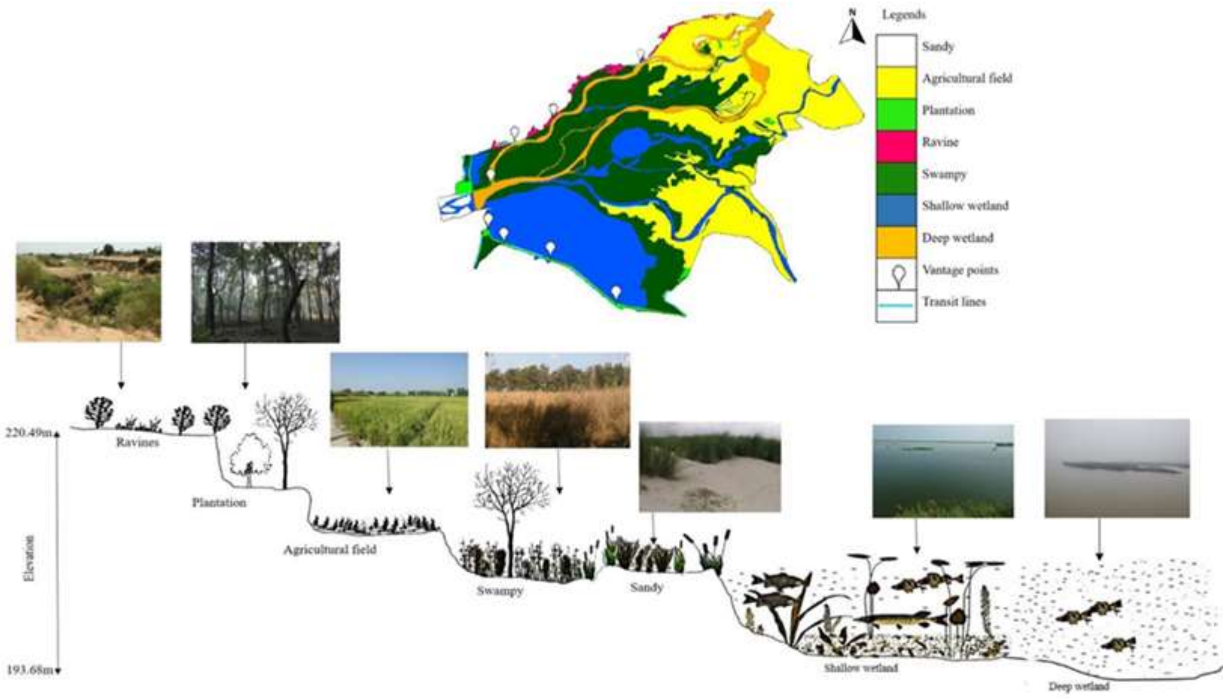


Fig 6.1: Habitat diversity across the HWS shared by avian community.

To find out the avian community structure and diversity among habitat types, and to estimate the avian community present in particular habitat total 7 habitat types (Fig 6.1) has been identified. The bird's population and diversity have been calculated to understand the composition of bird species in different habitats. The bird species have different feeding behavior, nesting sites, hiding places, roosting sites, and hunting grounds hence birds community share habitats. This study is carried out to estimate the bird's community in each habitat and its potential for cultural ecosystem services. The habitats are provided different ecosystem services under various categories such as provisional ecosystem services like Fuel-wood, fodder, water, raw material, and medicinal plants, whereas in cultural ecosystem services, habitats provide recreational and educational benefits. Habitat diversity provides regulatory services such as water filtration, flood regulator, carbon-storing and temperature regulation, and supporting services like habitat for flora and fauna, production of biomass, oxygen production, and formation of soil, nutrient and water cycling.

Methods

A precise study of a satellite image on google earth pro had been done followed by a pilot survey on the field to set boundaries for bird surveys for each habitat for systematic sampling (Gregory et al, 2004). To set habitat boundaries vegetation types and abiotic components like the extent of water and soil types have been considered, thereafter HWS is classified into 7 types of habitat (Plantation, Sandy, Ravine, and Agricultural filed, Swampy, Deep and Shallow wetland) estimate the structure of the avian community. The point count method has been carried out along wetlands (Bibby et al. 2000; Nadeau et al. 2008) and line transects (Anderson et al. 1979) are adopted for Plantation, Sandy, Ravine, and Agricultural field habitats. Paired data for avian species include data from September 2019 to August 2021. Field data collection is recorded seasonally like winter (January to March), summer (April to June), monsoon (July to September), and post-monsoon (October to December). Bird's surveys were conducted for 10 minutes at each point count from 6:00 am to 10:00 am and 5:30 pm to 7:30 pm for summer and monsoon season. In the post-monsoon and winter season, the survey timing was 7:00 am to 11:00 am and 4:00 pm to 6:00 pm for morning and evening, respectively. A total of 46 points were plotted for Swampy (12 points), Deep wetland (9 points), and Shallow wetland (24 points), with a fixed radius of 100 meters (Morissette et al. 2013). Point count has been plotted by covering wetland habitat with the interval of 500 Meters distance gap between any two points to cover the maximum area and avoid double counting (Gregory et al. 2004). Total 6 belt transects of 1km strip (1000 m x 50 m) for Sandy (1 line transect), Planation (2 line transects), Ravine (2 Line transects), and Agricultural filed (1 line transect). Birds were identified with the help of Grimmett et al. (2012) and the ebird database (http://www.ebird.org) Praveen et al. (2016) are followed for nomenclature and classification of birds. Avian species were recorded under various feeding categories besides migratory status (Grimmett et al. 2012; Rai and Vanita, 2021) and conservation status is confirmed by IUCN red list version 2021,(https://www.iucnredlist.org). Opportunistically encountered species have been recorded. Boat surveys have been made in the Deep and Shallow wetlands in each season. Bird monitoring has been carried out with the help of binoculars (Nikon 8245 ACULON A211 8x42) and a Nikon P900 camera.

Data analysis

- Shannon diversity index was calculated by the following (Shannon and Wiener, 1949)

$$\mathrm{H}' = -\sum_{i=1}^{S}\{(\mathrm{Pi}) * (InPi)\}$$

Where

H'=Shannon diversity Index.

Pi= Proportion of the individual in the sample belonging to ith species.

S= Number of species found.

∑= Sum of species from 1 to S.

In = natural logarithm.

- Species richness (s) in each habitat was calculated by

s= ∑n

n= number of species

- Species evenness expresses the distribution of species among habitat types, Shannon–Wiener evenness index (E) as Nolan and Callahan (2006).

E= H'/H_{max}

H'= Shannon diversity Index

H_{max}= Total of the natural logarithm of all the species (S).

Survey for Cultural Ecosystem Serevcies (CES) of avian species

The significance of avian species in the cultural environment was documented using a field survey and a standardised questionnaire. Seasonal change in the utility of cultural ecosystem supported by avian species. Hypothesis testing has been done through ANOVA by following Myers et al. (2013).Following hypothesis were considered for ANOVA.

$H_{0=}$ There is a seasonal change in the cultural ecosystem services provided by avian species.

$H_{1=}$ There is no seasonal change in the cultural ecosystem services provided by avian species.

Results

Status of avian Species

A total of 205 species of avian species belonging to 140 genera, 59 families, and 16 orders were recorded in the different habitat types of HWS. The highest number of bird species are recorded from the order (Fig 6.2) Passeriformes with 80 species under Acrocephalidae, Alaudidae, Campephagidae, Cisticolidae, Corvidae, Dicruridae, Estrildidae, Hirundinidae, Laniidae, Leiothrichidae, Monarchidae, Muscicapidae, Nectariniidae, Oriolidae, Paridae, Passeridae, Pellorneidae, Phylloscopidae, Ploceidae, Pycnonotidae, Rhipiduridae, Stenostiridae, Sturnidae, Sylviidae, Turdidae, and Zosteropidae families followed by order Charadriiformes with 27 species from Charadriidae, Glareolidae, Laridae, Recurvirostridae, Jacanidae, and Scolopacidae families and Pelecaniformes order with 20 species under Anhingidae, Ardeidae, Ciconiidae, Phalacrocoracidae, and Threskiornithidae families while Anseriformes order with 19 species under single family (Anatidae).

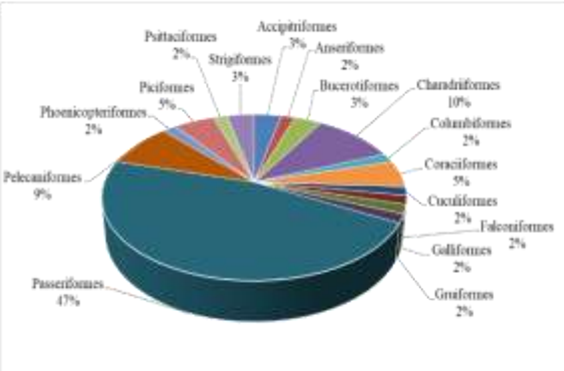


Fig 6.2: Family % of avian species under various orders.

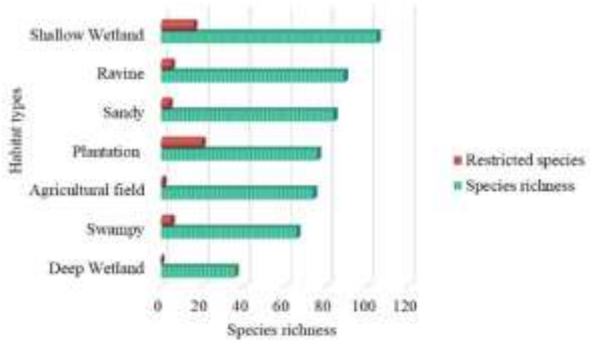


Fig 6.3: Species distribution across the habitats

Order Accipitriformes is comprised of 16 species under Accipitridae and Pandionidae families, under order Columbiformes 7 species are recorded from the Columbidae family, Coraciiformes with 7 species under Alcedinidae, Coraciidae, and Meropidae families followed by Gruiformes order with 5 species under single family (Rallidae), Piciformes with 4 species from 3 species, Galliformes with 4 species from single family (Phasianidae) and Cuculiformes with 4 species under single family (Cuculidae). There are 3 species from Strigidae and Tytonidae families under order Strigiformes. Phoenicopteriformes with 3 species from a single family (Podicipedidae), Psittaciformes order with 2 species from the Psittaculidae family, Falconiformes with 2 species from Falconidae family, while Bucerotiformes order is comprised of one species from Bucerotidae and Upupidae families each.

The dominating family is Anatidae with a total of 19 Species, this accounts for 9.3 % of bird species recorded from HWS in the present study, followed by the family Accipitridae with 15 species contributing to 7.3% of the community composition of the birds. There is a total of 11 species have been recorded from the family Scolopacidae, which contributes to 5.4 % of the community. Twenty species have been recorded from Ardeidae and Muscicapidae families, ten species from each that collectively contribute up to 7.7% in the avian community of HWS. Families like Cisticolidae and Motacillidae have 8 species under each, whereas in the Columbidae and Laridae families seven species have been recorded in each, these four families have contributed to 14.6% of bird community across the habitats of HWS. Three species of birds were recorded from each family, theses families are Acrocephalidae, Alcedinidae, Corvidae, Estrildidae, Hirundinidae, Phalacrocoracidae, Phylloscopidae, Ploceidae, Podicipedidae, Sylviidae and Turdidae. These 11 families' accounts for 16.1% of the total bird's species recorded from HWS. Two species under each family have been recorded, these families are Ciconiidae, Coraciidae, Falconidae, Laniidae, Meropidae, Passeridae, Psittaculidae, Pycnonotidae, Ramphastidae, Recurvirostridae and Strigidae and these 11 families contributed to 10.7 % into the community of birds recorded in the HWS. Single species are recorded in families like Anhingidae, Bucerotidae, Campephagidae, Dicruridae, Glareolidae, Indicatoridae, Jacanidae, Monarchidae, Nectariniidae, Oriolidae, Pandionidae, Paridae, Pellorneidae, Picidae, Rhipiduridae, Stenostiridae, Tytonidae, Upupidae, and Zosteropidae and these 19 families hold 9.3% share in the bird community of HWS. Details of the number of species and genus under each family are shown in Table 6.1.

Table 6.1: Taxonomic details (Family, genus, species, and species %)

Family	Genus	Species	Species %
Accipitridae	13	15	7.32
Acrocephalidae	2	3	1.46
Alaudidae	4	4	1.95
Alcedinidae	3	3	1.46
Anatidae	10	19	9.27
Anhingidae	1	1	0.49
Ardeidae	6	10	4.88
Bucerotidae	1	1	0.49
Campephagidae	1	1	0.49

Charadriidae	2	5	2.44
Ciconiidae	2	2	0.98
Cisticolidae	3	8	3.90
Columbidae	3	7	3.41
Coraciidae	1	2	0.98
Corvidae	2	3	1.46
Cuculidae	4	4	1.95
Dicruridae	1	1	0.49
Estrildidae	3	3	1.46
Falconidae	1	2	0.98
Glareolidae	1	1	0.49
Hirundinidae	2	3	1.46
Indicatoridae	1	1	0.49
Jacanidae	1	1	0.49
Laniidae	1	2	0.98
Laridae	5	7	3.41
Leiothrichidae	2	4	1.95
Meropidae	1	2	0.98
Monarchidae	1	1	0.49
Motacillidae	2	8	3.90
Muscicapidae	5	10	4.88
Nectariniidae	1	1	0.49
Oriolidae	1	1	0.49
Pandionidae	1	1	0.49
Paridae	1	1	0.49
Passeridae	1	2	0.98
Pellorneidae	1	1	0.49
Phalacrocoracidae	2	3	1.46
Phasianidae	3	4	1.95
Phylloscopidae	2	3	1.46
Picidae	1	1	0.49
Ploceidae	1	3	1.46
Podicipedidae	2	3	1.46
Psittaculidae	1	2	0.98
Pycnonotidae	1	2	0.98

Rallidae	5	5	2.44
Ramphastidae	3	2	0.98
Recurvirostridae	2	2	0.98
Rhipiduridae	1	1	0.49
Scolopacidae	6	11	5.37
Stenostiridae	1	1	0.49
Strigidae	2	2	0.98
Sturnidae	5	6	2.93
Sylviidae	2	3	1.46
Threskiornithidae	4	4	1.95
Turdidae	2	3	1.46
Tytonidae	1	1	0.49
Upupidae	1	1	0.49
Zosteropidae	1	1	0.49
Total	**140**	**205**	**100.00**

Avian Community composition across the habitats of HWS

In the HWS, a total of 205 species were recorded from 7 different habitat types. Each habitat of HWS supports a community with mean species strength of 74.9±21, which accounts for 36.5%±10.3% of the community of avian species present throughout the year in the HWS. A maximum number of species can be seen (Fig 6.3) in the Shallow Wetland habitat with 105 species (51.2%) in a year. Among 105 species of Shallow Wetland habitat 16 species were found restricted to Shallow Wetland only, these species are Kentish Plover (*Charadrius alexandrines*), River Lapwing (*Vanellus duvaucelii*), White-tailed Lapwing (*Vanellus leucurus*), Small Pratincole (*Glareola lacteal*), Black-winged Stilt (*Himantopus himantopus*), Common Greenshank (*Tringa nebularia*), Common Redshank (*Tringa tetanus*), Common Sandpiper (*Actitis hypoleucos*), Ruff (*Calidris pugnax*), Spotted Redshank (*Tringa erythropus*), Wood Sandpiper (*Tringa glareola*), Green Sandpiper (*Tringa ochropus*), Marsh Sandpiper (*Tringa stagnatilis*), Common Kingfisher (*Alcedo atthis*), Plumbeous water Redstart (*Rhyacornis fuliginosa*) and Great Egret (*Ardea alba*). Similarly, in Ravine habitat total of 89 species (43.4%) were recorded of which 5 species were found in Ravine habitat only including species like Short-toed Snake Eagle (*Circaetus gallicus*), Peregrine Falcon (*Falco peregrinus*), Rain Quail (*Coturnix coromandelica*), Long-billed (*Pipit Anthus*), and Himalayan Bulbul (*Pycnonotus leucogenis*).

In Sandy habitat a total of 84 species (41%) were sighted, of which 4 species are Indian Bushlark (*Mirafra erythroptera*), Sand Lark (*Alaudala raytal*), Crested Lark (*Galerida cristata*) and Eurasian Wryneck (*Jynx torquilla*) were only recorded from Sandy habitat. In Plantation habitat a total of 76 species (37.1%) were found, of which 20 species are restricted to the plantation habitat, these species are Booted Eagle (*Hieraaetus pennatus*), Oriental Honey-buzzard (*Pernis ptilorhynchus*), Northern Goshawk (*Accipiter gentilis*), Indian Grey Hornbill (*Ocyceros birostris*), Yellow-footed Green-Pigeon (*Treron phoenicopterus*), Common Hawk-Cuckoo (*Hierococcyx varius*), Long-tailed Minivet (*Pericrocotus ethologus*), Large-billed Crow (*Corvus macrorhynchos*), Indian Paradise-Flycatche (*Terpsiphone paradise*), Cinereous Tit (*Parus cinereus*), White-browed Fantail (*Rhipidura aureola*), Grey-headed Canary-Flycatcher (*Culicicapa ceylonensis*), Orange-headed Thrush (*Geokichla citrine*), Oriental White-eye (*Zosterops palpebrosus*), Lesser Golden-backed Woodpecker (*Dinopium benghalense*), Brown-headed Barbet (*Psilopogon zeylanicus*), Coppersmith Barbet (*Psilopogon haemacephalus*), Indian Scops-Owl (*Otus bakkamoena*), Spotted Owlet (*Athene brama*) and Barn Owl (*Tyto alba*). The Swampy habitat supports a community of 66 species (32.20%) including species like Common Snipe (*Gallinago gallinago*), Clamorous Reed Warbler (*Acrocephalus stentoreus*), Yellow-eyed Babbler (*Chrysomma sinense*), Jerdon's Babbler (*Chrysomma altirostre*), and Black Bittern (*Ixobrychus flavicollis*). The Agricultural field habitat supports a community of 73 species (36.1%) where European Roller (*Coracias garrulus*) was found in the Agricultural field habitat only. Though the Deep Wetland provides habitat for 36 species (17.5%) however bird species of Deep Wetland habitat can be found in the other habitats. Details of community composition in various habitat types are shown in Annexure I.

Foraging behavior of birds across habitat types in HWS

Habitat diversity may include elements like nesting locations, food sources, water sources, and vegetation structure. Birds have evolved to efficiently utilize these resources because habitats and the resources they deal differ. The accessibility of food sources has a significant impact on how birds forage. Some species may adopt a sit-and-wait approach in settings with plenty of food, including dense forests, while perched attentively and surveying their surroundings for potential prey. In present study, birds are recorded under different food guilds such as

Insectivorous (87 species) followed by Carnivorous (54 species including Piscivoure and meat-eater), Herbivorous (31 species), Granivorous (16 species), Omnivores (12 species) and Frugivorous (5 species). The mean number of species under each category: Insectivore 30.1±13.2, followed by Carnivore 20.4 ±7.4, Piscivore 12.3±9.4, Herbivores 12.1±7.36, Meat-eater 10.8±6.5, Granivorous 7.4±3.9, Omnivore 4.4±3, Frugivore 1.3±2.2 were recorded from each habitat of HWS. Food is necessary for the survival of various creatures in different forms. The productive habitats of HWS provide a wide food guild for avian communities across the habitat types.

Plantation habitat

In Planataion habitat variety of flora provides a niche for reptiles (Lizards and snakes), and mammal species like palm squirrels (*Funambulus palmarum*) are part of the food guild of avian species. A total of 76 species have been recorded from the plantation including Carnivore birds with 24 species, of which 4 species are Piscivor species (Osprey *Pandion haliaetus*, White-throated Kingfisher *Halcyon smyrnensis*, Cattle Egret *Bubulcus ibis*, Little Egret *Egretta garzetta* and 20 species of meat-eating birds, Booted Eagle *Hieraaetus pennatus*, Indian Spotted Eagle *Clanga hastata*, Oriental Honey-buzzard *Pernis ptilorhynchus*, Shikra *Accipiter badius*, Common Kestrel *Falco tinnunculus*, Spotted Owlet *Athene brama*, and Barn Owl *Tyto alba*, details are given in the table 6.2. Plantation habitat support the population of tree species like *Syzygium cumini*, *Ficus religiosa*, *Ficus benghalensis*, *Morus alba* and *Cordia myxa* which provides food support to 6 species of Frugivore birds (Indian Grey Hornbill *Ocyceros birostris*, Yellow-footed Green-Pigeon *Treron phoenicopterus*, Asian Koel *Eudynamys scolopaceus*, Jacobin Cuckoo *Clamator jacobinus*, Brown-headed Barbet *Psilopogon zeylanicus*, and Coppersmith Barbet *Psilopogon haemacephalus*.

The grass species like *Desmostachya bipinnata*, *Panicum maximum*, *Cenchrus ciliaris* and herbs species such as *Cleome viscosa*, *Amaranthus viridis*, *Chenopodium album* and *Chenopodium murale* produces edible seeds for granivorous birds, total 6 species including (Oriental Turtle-Dove *Streptopelia orientalis*, Red Collared-Dove *Streptopelia tranquebarica*, Rock Pigeon *Columba livia*, Spotted Dove *Streptopelia chinensis*, Indian Silverbill *Euodice malabarica*, and House Sparrow *Passer domesticus*) were observed in the plantation habitat. In the case of Herbivores, birds total 6 species (Eurasian Collared-Dove *Streptopelia decaocto*,

Fig 6.4: Foraging behavior of avian species in different habitats

Laughing Dove *Streptopelia senegalensis*, Grey Francolin *Francolinus pondicerianus*, Purple Sunbird *Cinnyris asiaticus*, Alexandrine Parakeet *Psittacula eupatria* and Rose-ringed Parakeet *Psittacula krameri*) were observed feeding on seeds as well as other plant parts. Insectivore birds were observed feeding on Hymenoptera (Bees and Wasps), Lepidoptera (Butterflies), Hemiptera (Bugs) and Coleoptera (Beetles), A community of insectivore birds with total of 31 species were recorded (Eurasian Hoopoe *Upupa epops*, Indian Roller *Coracias benghalensis*, Green Bee-eater *Merops orientalis*, Common Hawk-Cuckoo *Hierococcyx varius* Booted Warbler *Iduna caligata*, Common Tailorbird *Orthotomus sutorius*, Rufous Treepie *Dendrocitta vagabunda*, Black Drongo *Dicrurus macrocercus* and Indian Paradise-Flycatcher *Terpsiphone paradisi*) in table 6.2. The community of Omnivore birds (House Crow Corvus splenden, Large-billed Crow *Corvus macrorhynchos*, Jungle Babbler *Turdoides striata*, Indian Golden Oriole *Oriolus kundoo*, Red-vented Bulbul *Pycnonotus cafer* and Common Myna *Acridotheres tristi*).

Deep Wetland habitat

The Deep Wetland area is part of the Beas River running across the sanctuary from North-east direction to the west boundary of HWS. The deep wetland supports a community of avian species dominated by Carnivore birds with 14 species, of which 13 species are Piscivores (Osprey (*Pandion haliaetus*, Black-headed Gull *Chroicocephalus ridibundus*, Common Tern *Sterna hirundo*, Horned Grebe *Podiceps auritus*, Pallas's Gull *Ichthyaetus ichthyaetus*, Brown-headed Gull *Chroicocephalus brunnicephalus*, Oriental Darter *Anhinga melanogaster* and Great Cormorant *Phalacrocorax carbo*) where Eurasian Marsh-Harrier is recorded as meat-eater. A community of Herbivores avian species was observed feeding on aquatic vegetation like *Eichhornia crassipes*, *Azolla pinnata* and *Lemna minor*.

A total of 21 species were identified as Herbivores consist of species like Bar-headed Goose (*Anser indicus*), Common Pochard (*Aythya ferina*), Eurasian Wigeon (*Mareca penelope*), Ferruginous Duck (*Aythya nyroca*), Gadwall (*Mareca strepera*), Garganey (*Spatula querquedula*), and Greylag Goose (*Anser anser*) and other species are given in the Annexure I. The population of River Tern (*Sterna aurantia*) was seen feeding on aquatic insects like water hyacinth weevil (*Neochetina* sp).

Shallow wetland habitat

Shallow wetlands contribute to a significant area of HWS, a major part of Shallow wetland located along the left bank of the Sutlej River. The shallow wetland with well-developed trophic levels provides a dynamic avian community in different seasons. The shallow wetland provides a foraging ground for 103 species throughout the year. A total of 39 species of Carnivore birds were recorded, which includes a population of 29 species of Piscivore birds and 10 species of Meat-eater birds. Species like Common Kingfisher (*Alcedo atthis*), White-throated Kingfisher (*Halcyon smyrnensis*), Pied Kingfisher (*Ceryle rudis*), Oriental Darter (*Anhinga melanogaster*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Cattle Egret (*Bubulcus ibis*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Great Egret (*Ardea alba*), Grey Heron (*Ardea cinerea*), Indian Pond-Heron (*Ardeola grayii*), Little Egret (*Egretta garzetta*), Purple Heron (*Ardea purpurea*), Intermediate Egret (*Ardea intermedia*), Painted Stork (*Mycteria leucocephala*), Woolly-necked Stork (*Ciconia episcopus*), Great Cormorant (*Phalacrocorax carbo*), Indian Cormorant (*Phalacrocorax fuscicollis*), and Little Cormorant (*Microcarbo niger*) where as a community of avian species including top predator such as Eurasian Marsh-Harrier (*Circus aeruginosus*), and Shikra (*Accipiter badius*) were observed as meat-eater with other species like Greater Coucal (*Centropus sinensis*), Cattle Egret (*Bubulcus ibis*), Indian Pond-Heron (*Ardeola grayii*), and Little Egret (*Egretta garzetta*). The small islands and edges of shallow wetland have a community of grasses particularly dominated by population of *Phragmites karka* and *Arundo donax*, which provides habitat for Granivorous (6 species) birds like Spotted Dove (*Streptopelia chinensis*), Scaly-breasted Munia (*Lonchura punctulata*), Sind Sparrow (*Passer pyrrhonotus*), Baya Weaver (*Ploceus philippinus*), Streaked Weaver (*Ploceus manyar*) and Black-breasted Weaver (*Ploceus benghalensis*). A total of 36 species of insectivore birds were identified including Kentish Plover (Charadrius alexandrines), Red-wattled Lapwing (*Vanellus indicus*), River Lapwing (*Vanellus duvaucelii*), White-tailed Lapwing (*Vanellus leucurus*), Small Pratincole (Glareola lacteal), River Tern (*Sterna aurantia*), Black-winged Stilt (*Himantopus himantopus*), Pied Avocet (*Recurvirostra avosetta*), Common Greenshank (*Tringa nebularia*), Common Redshank (*Tringa tetanus*), Common Sandpiper (*Actitis hypoleucos*), Ruff (*Calidris pugnax*), Siberian Stonechat (*Saxicola maurus*), Taiga Flycatcher (*Ficedula albicilla*), Plumbeous Water Redstart (*Rhyacornis fuliginosa*), Black-headed Ibis (*Threskiornis melanocephalus*), Glossy Ibis (*Plegadis falcinellus*), and Red-naped Ibis (*Pseudibis papillosa*). Twenty three species were recorded as Herbivores such as Greylag Goose (*Anser anser*), Indian Spot-billed Duck (*Anas* *poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*), Mallard (*Anas platyrhynchos*), Northern Pintail (*Anas acuta*), Northern Shoveler (*Spatula clypeata*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*), Common Shelduck (*Tadorna tadorna*) and Eurasian Coot (*Fulica atra*) were observed feeding on aquatic vegetation. Species like Jacobin Cuckoo (*Clamator jacobinus*), Pheasant-tailed jacana (*Hydrophasianus chirurgus*), House Crow (*Corvus splendens*) and Striated Babbler (*Argya earlei)* were recorded as Omnivore birds.

Ravine habitat

The Ravine habitat is located between the Agricultural field and Beas River along the north boundary in HWS. This habitat supports a community of 89 species throughout the year, of which 21 species were seen as carnivores among them all are meat-eater, and some species were seen feeding on Fish, including White-throated Kingfisher (*Halcyon smyrnensis*), Cattle Egret (*Bubulcus ibis*), and Little Egret (*Egretta garzetta*). The Insectivore community of birds consists of 41 species, such as Indian Roller (*Coracias benghalensis*), Rufous-fronted Prinia (*Prinia buchanani*), Jungle Prinia (*Prinia sylvatica*), Ashy Prinia (*Prinia socialis*), Graceful Prinia (*Prinia gracilis*), Wire-tailed Swallow (*Hirundo smithii*), Large Gray Babbler (*Argya malcolmi*), Tree Pipit (*Anthus trivialis*), Long-billed Pipit (*Anthus similis*), Black Redstart (*Phoenicurus ochruros*), Indian Robin (*Saxicoloides fulicatus*), Pied Bushchat (*Saxicola caprata*), Red-breasted Flycatcher (*Ficedula parva*), Bluethroat (*Luscinia svecica*), Common Starling (*Sturnus vulgaris*), Tickell's Thrush (*Turdus unicolor*), Black-throated Thrush (*Turdus atrogularis*) and Black-headed Ibis (*Threskiornis melanocephalus*). These species were observed feeding on Araneae (spiders), Odonata (Dragonflies), Opisthopora (earthworms), Diptera (Crane fly), Orthoptera (Grasshoppers & locusts), Lepidoptera (Butterflies & moths), and Hymenoptera (Bees, bumblebees, wasps and ants). Ravine habitat also possesses the patches of grasses like *Cenchrus ciliaris, Cymbopogon martini, Panicum maximum, Saccharum officinarum* and *Saccharum bengalense* besides cropland are the source of food for the population of granivore birds (12 species) including Red Collared-Dove (*Streptopelia tranquebarica*), Rock Pigeon (*Columba livia*), Spotted Dove (*Streptopelia chinensis*), Oriental Skylark (*Alauda gulgula*), Scaly-breasted Munia (*Lonchura punctulata*), Indian Silverbill (*Euodice malabarica*), Red Munia (*Amandava amandava*), House Sparrow (*Passer domesticus*), Sind Sparrow (*Passer pyrrhonotus*), Baya Weaver (*Ploceus philippinus*), Streaked Weaver (*Ploceus manyar*) and Black-breasted Weaver (*Ploceus benghalensis*).

Community of omnivore birds like House Crow (*Corvus splendens),* Common Babbler (*Argya caudate*), Jungle Babbler (*Turdoides striata*), Striated Babbler (*Argya earlei*), Red-vented Bulbul (*Pycnonotus cafer*), Himalayan Bulbul (*Pycnonotus leucogenis*) and Common Myna (*Acridotheres tristis*) were recorded. Asian Koel (*Eudynamys scolopaceus*) was recorded as Frugivore birds.

Sandy habitat

Sandy habitat is located in the western part of the Sanctuary along the Sutlej River, the Sandy habitat is associated with tall grasses besides patches of wet and dry sand deposited by the River. The species observed feeding on fish or meat (carnivore birds) are Eurasian Marsh-Harrier (*Circus aeruginosus*), Steppe Eagle (*Aquila nipalensis*), Black-headed Gull (*Chroicocephalus ridibundus*), Common Tern (*Sterna hirundo*), Gull-billed Tern (*Gelochelidon nilotica*), Long-tailed Shrike (*Lanius schach*), Oriental Darter (*Anhinga melanogaster*), Indian Pond-Heron (*Ardeola grayii*), Purple Heron (*Ardea purpurea*), Intermediate Egret (*Ardea intermedia*), Painted Stork (*Mycteria leucocephala*), Woolly-necked Stork (*Ciconia episcopus*), Great Cormorant (*Phalacrocorax carbo*), Indian Cormorant (*Phalacrocorax fuscicollis*) and Little Cormorant (*Microcarbo niger*). The Plant species like *Saccharum officinarum*, *Saccharum bengalense* besides crops like *Triticum*, *Pennisetum glaucum* and *Oryza sativa* provide food stock for Grainivore birds like Indian Bushlark (*Mirafra erythroptera*), Sand Lark (*Alaudala raytal*), Oriental Skylark (*Alauda gulgula*), Scaly-breasted Munia (*Lonchura punctulata*), Indian Silverbill (*Euodice malabarica*), House Sparrow (*Passer domesticus*), Sind Sparrow (*Passer pyrrhonotus*), Baya Weaver (*Ploceus philippinus*) and Streaked Weaver (*Ploceus manyar*). Herbivore bird species such as Common Pochard (*Aythya ferina*), Common Teal (*Anas crecca*), Eurasian Wigeon (*Mareca penelope*), Gadwall (*Mareca strepera*), Greylag Goose (*Anser anser*), Indian Spot-billed Duck (*Anas poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*) and Northern Pintail (*Anas acuta*) were recorded from Sandy habitat. Insectivore bird's community in the sandy habitat includes species like Green Bee-eater (*Merops orientalis*), Blyth's Reed Warbler (*Acrocephalus dumetorum*), Plain Prinia (*Prinia inornata*), Rufous-fronted Prinia (*Prinia buchanani*), Graceful Prinia (*Prinia gracilis*), Black Drongo (*Dicrurus macrocercus*), Grey-throated Martin (*Riparia paludicola*), Isabelline Shrike (*Lanius isabellinus*), Citrine Wagtail (*Motacilla citreola*), White Wagtail (*Motacilla alba*), White-browed Wagtail (*Motacilla maderaspatensis*), Black Redstart (*Phoenicurus ochruros*), Brown Rock Chat (*Oenanthe *fusca*), Pied Bushchat (*Saxicola caprata*), Siberian Stonechat (*Saxicola maurus*), Bluethroat (*Luscinia svecica*), Black-headed Ibis (*Threskiornis melanocephalus*). Omnivore birds species includes Jacobin Cuckoo (*Clamator jacobinus*), Indian Peafowl (*Pavo cristatus*), House Crow (*Corvus splendens*), Large-billed Crow (*Corvus macrorhynchos*), Common Babbler (*Argya caudate*), Jungle Babbler (*Turdoides striata*) and Striated Babbler (*Argya earlei*) were recorded from Sandy habitat.

Swampy Habitat

The Swampy habitat is distributed across the Sanctuary along Beas and Sutjel Rivers. This habitat supports a community of Carnivore birds that feed on fish as well as Small birds, Reptiles, and Amphibians. These species including species like Eurasian Marsh-Harrier (*Circus aeruginosus*), Osprey (*Pandion haliaetus*), Greater Coucal (*Centropus sinensis*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Indian Pond-Heron (*Ardeola grayii*), Purple Heron (*Ardea purpurea*) and Black Bittern (*Ixobrychus flavicollis*). A community of Insectivore birds (32 species) like Common Snipe (*Gallinago gallinago*), Green Bee-eater (*Merops orientalis*), Clamorous Reed Warbler (*Acrocephalus stentoreus*), Plain Prinia (*Prinia inornata*), Yellow-bellied Prinia (*Prinia flaviventris*), Graceful Prinia (*Prinia gracilis*), Large Gray Babbler (*Argya malcolmi*), Rufous-vented Grass Babbler (*Laticilla burnesii*), Hume’s Leaf Warbler (*Abrornis humei*), Common Chiffchaff (*Phylloscopus collybita*), Yellow-eyed Babbler (*Chrysomma sinense*), Jerdon's Babbler (*Chrysomma altirostre*) and Glossy Ibis (*Plegadis falcinellus*) were recorded feeding on Araneae (spiders), Odonata (Dragonflies), Opisthopora (earthworms), Diptera (Crane fly) and Orthoptera (Grasshoppers & locusts).

Agricultural field habitat

This habitat is situated in eastern and north eastern part of the Sanctuary. Agricultural habitat supports community of Insectivore (34 species) birds like Eurasian Hoopoe (*Upupa epops*), Indian Roller (*Coracias benghalensis*), European Roller (*Coracias garrulous*), Blue-tailed Bee-eater (*Merops philippinus*), Green Bee-eater (*Merops orientalis*), Common Tailorbird (*Orthotomus sutorius*), Ashy Prinia (*Prinia socialis*), Graceful Prinia (*Prinia gracilis*), Rufous Treepie (*Dendrocitta vagabunda*), Black Drongo (*Dicrurus macrocercus*), Tree Pipit (*Anthus trivialis*), Red-breasted Flycatcher (*Ficedula parva*) and Glossy Ibis (*Plegadis falcinellus*). Some bird species of heigher trophic level like Black-winged Kite (*Elanus caeruleus*), Eurasian

Marsh-Harrier (*Circus aeruginosus*), Long-legged Buzzard (*Buteo rufinus*), Shikra (*Accipiter badius*), White-eyed Buzzard (*Butastur teesa*), Common Kestrel (*Falco tinnunculus*) and Greater Spotted Eagle (*Clanga clanga*) were recorded as Carnivore birds. The community of Granivore birds includes species like Spotted Dove (*Streptopelia chinensis*) Scaly-breasted Munia (*Lonchura punctulata*), Indian Silverbill (*Euodice malabarica*), House Sparrow (*Passer domesticus*), Sind Sparrow (*Passer pyrrhonotus*), Baya Weaver (*Ploceus philippinus*), Streaked Weaver (*Ploceus manyar*) and Black-breasted Weaver (*Ploceus benghalensis*) in the Agricultural field habitat. Bird's community observed feeding on plants are Bar-headed Goose (*Anser indicus*), Eurasian Collared-Dove (*Streptopelia decaocto*), Laughing Dove (*Streptopelia senegalensis*), Black Francolin (*Francolinus francolinus*), Grey Francolin (*Francolinus pondicerianus*), Alexandrine Parakeet (*Psittacula eupatria*) and Rose-ringed Parakeet (*Psittacula krameri*).

Table 6.2: Number of species recorded in different habitats under various food guilds.

Habitats / Food guilds	Plantation	Deep wetland	Sandy	Ravine	Shallow wetland	Swampy	Agricultural
Carnivore*	**24**	**14**	**28**	**21**	**39**	**17**	**19**
Frugivore	**6**	**0**	**0**	**2**	**0**	**0**	**1**
Granivorous	**6**	**0**	**10**	**12**	**6**	**9**	**9**
Herbivores	**6**	**21**	**14**	**9**	**23**	**5**	**7**
Insectivore	**31**	**1**	**35**	**40**	**38**	**32**	**34**
Omnivore	**6**	**0**	**1**	**8**	**4**	**5**	**7**
***Piscivore**	**4**	**13**	**20**	**3**	**29**	**10**	**7**
***Meat-eater**	**20**	**1**	**8**	**18**	**10**	**7**	**12**

Migration status of birds in various habitats of HWS

Bird migration refers to the seasonal movement of birds between their breeding grounds and their wintering grounds. This remarkable phenomenon is observed in various bird species across the globe and plays a crucial role in their survival and reproductive success. Migration is often triggered by changes in weather conditions, availability of food, and the need to find suitable breeding sites. One of the key factors influencing bird migration is habitat diversity. Birds rely on a variety of habitats throughout their annual cycle, including breeding, wintering, and stopover sites during migration. Habitat diversity is essential as it provides birds with the necessary resources such as food, shelter, and nesting sites, which are crucial for their survival and successful reproduction. During migration, birds encounter diverse habitats along their journey, including forests, wetlands, grasslands, Rivers and even urban environments. These habitats offer different food sources and shelter options, allowing birds to replenish their energy reserves, rest, and find suitable conditions for nesting and breeding. The availability and quality of these habitats greatly influence the success of migration. Loss or degradation of habitats poses a significant threat to migratory birds. Human activities such as deforestation, urbanization, pollution, and climate change have resulted in the destruction and fragmentation of habitats, making it challenging for birds to find suitable areas to rest and refuel during migration. This can lead to increased mortality rates, reduced breeding success, and overall population declines. HWS is a mosaic of habitats and each habitat goes through seasonal change with respect to plants and birds. In addition to identifying several habitats that support the population of migratory birds, the current study has also elaborated on the migration status of many bird species.

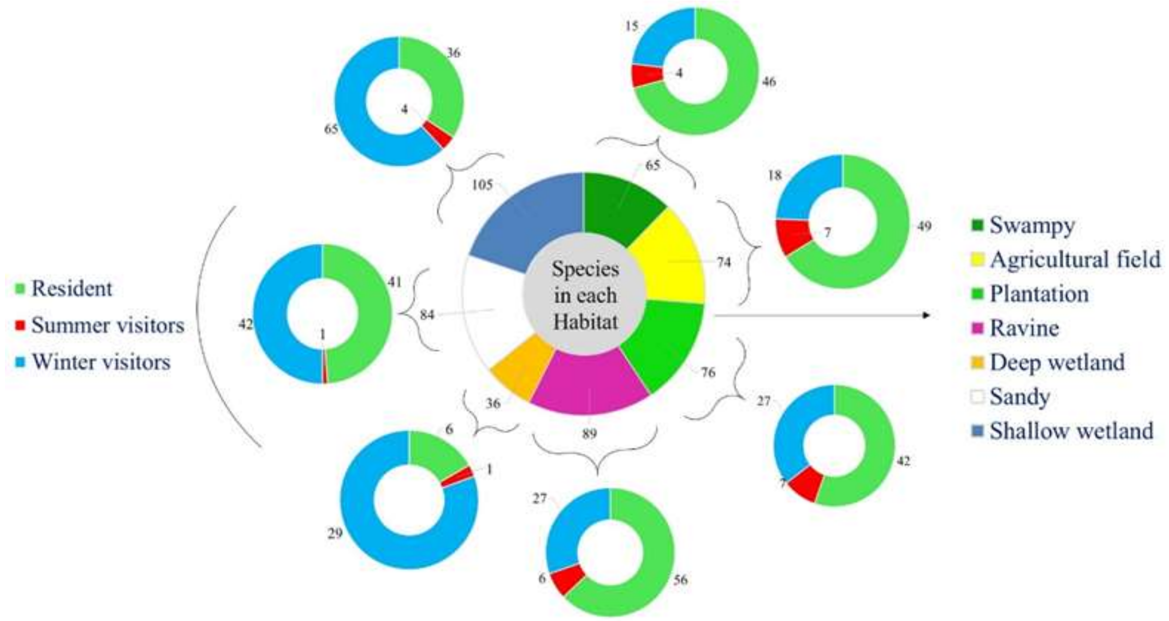


Fig 6.5: Migratory status of avian species across the habitat types of HWS.

Shallow wetland habitat supports a community of 105 species (Fig 6.5) in which resident birds (36 species) like Red-wattled Lapwing (*Vanellus indicus*), Pied Kingfisher (*Ceryle rudis*), Greater Coucal (*Centropus sinensis*), Grey-headed Swamphen (*Porphyrio porphyria*), Common Moorhen (*Gallinula chloropus*), Streaked Weaver (*Ploceus manyar*), Oriental Darter (*Anhinga melanogaster*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Cattle Egret (*Bubulcus ibis*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Indian Pond-Heron (*Ardeola grayii*), Little Egret (*Egretta garzetta*), Purple Heron (*Ardea purpurea*), Painted Stork (*Mycteria leucocephala*) and Indian Cormorant (*Phalacrocorax fuscicollis*) were recorded. Summer visitors (4 species) are Lesser Whistling-Duck (*Dendrocygna javanica*), Pheasant-tailed jacana (*Hydrophasianus chirurgus*), Jacobin Cuckoo (*Clamator jacobinus*) and Rosy Starling (*Pastor roseus*). Shallow wetland habitat receives many winter visitors (65 species) including species like Eurasian Marsh-Harrier (*Circus aeruginosus*), Osprey (*Pandion haliaetus*), Bar-headed Goose (*Anser indicus*), Common Teal (*Anas crecca*), Ferruginous Duck (*Aythya nyroca*), Gadwall (*Mareca strepera*), Garganey (*Spatula querquedula*), Mallard (*Anas platyrhynchos*), Northern Pintail (*Anas acuta*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*), Common Shelduck (*Tadorna tadorna*), Black-headed Gull (*Chroicocephalus ridibundus*), Brown-headed Gull (*Chroicocephalus brunnicephalus*), Gull-billed Tern (*Gelochelidon nilotica*), Common Redshank (*Tringa tetanus*), Spotted Redshank (*Tringa erythropus*), Black-tailed Godwit (*Limosa limosa*), Marsh Sandpiper (*Tringa stagnatilis*), Plumbeous water Redstart (*Rhyacornis fuliginosa*), Woolly-necked Stork (*Ciconia episcopus*), Great Cormorant (*Phalacrocorax carbo*) and Eurasian Spoonbill (*Platalea leucorodia).* Ravine habitat dominated by shrubs like *Capparis decidua*, *Lycium edgeworthii* and *Ziziphus nummularia* supports 89 species of which 56 species are identified as resident species like Eurasian Hoopoe (*Upupa epops*), Eurasian Collared-Dove (*Streptopelia decaocto*), Laughing Dove (*Streptopelia senegalensis*), Green Bee-eater (*Merops orientalis*), Greater Coucal (*Centropus sinensis*), Black Francolin (*Francolinus francolinus*), Indian Peafowl (*Pavo cristatus*), Common Tailorbird (*Orthotomus sutorius*), Jungle Prinia (*Prinia sylvatica*), Graceful Prinia (*Prinia gracilis*), House Crow (*Corvus splendens*), Indian Silverbill (*Euodice malabarica*), Long-tailed Shrike (*Lanius schach*), Jungle Babbler (*Turdoides striata*), Paddyfield Pipit (*Anthus rufulus*), Indian Robin (*Saxicoloides fulicatus*), Pied Bushchat (*Saxicola caprata*), Oriental Magpie-Robin (*Copsychus saularis*), Common Myna (*Acridotheres tristis*) and Cattle Egret (*Bubulcus ibis*) where 6 species are summer visitors including species like Short-toed Snake Eagle (*Circaetus gallicus*), Red Collared-Dove (*Streptopelia tranquebarica*), Indian Roller (*Coracias benghalensis*), Jacobin Cuckoo (*Clamator jacobinus*), Purple Sunbird (*Cinnyris asiaticus*) and

Rosy Starling (*Pastor roseus*), In winter, 27 species prefer to use Ravine, including Crested Serpent-Eagle (*Spilornis cheela*), Indian Spotted Eagle (*Clanga hastate*), Long-legged Buzzard (*Buteo rufinus*), Steppe Eagle (*Aquila nipalensis*), Black Kite (*Milvus migrans*) Greater Spotted Eagle (*Clanga clanga*), Common Kestrel (*Falco tinnunculus*), Citrine Wagtail (*Motacilla citreola*), Tree Pipit (*Anthus trivialis*), Black Redstart (*Phoenicurus ochruros*), Red-breasted Flycatcher (*Ficedula parva*), Siberian Stonechat (*Saxicola maurus*), Taiga Flycatcher (*Ficedula albicilla*), Himalayan Bulbul (*Pycnonotus leucogenis*) and Black-throated Thrush (*Turdus atrogularis*). Sandy habitat holds a community strength with 83 species of which 41 species are resident species like Eurasian Hoopoe (*Upupa epops*), Red-wattled Lapwing (*Vanellus indicus*), White-throated Kingfisher (*Halcyon smyrnensis*), Blyth's Reed Warbler (*Acrocephalus dumetorum*), Indian Bushlark (*Mirafra erythroptera*), Oriental Skylark (*Alauda gulgula*), Rufous-fronted Prinia (*Prinia buchanani*), Ashy Prinia (*Prinia socialis*), Black Drongo (*Dicrurus macrocercus*), Indian Robin (*Saxicoloides fulicatus),* Pied Bushchat (*Saxicola caprata*), Oriental Magpie-Robin (*Copsychus saularis*), Sind Sparrow (*Passer pyrrhonotus*), Indian Pond-Heron (*Ardeola grayii*), Purple Heron (*Ardea purpurea*), Painted Stork (*Mycteria leucocephala*) and Little Grebe (*Tachybaptus ruficollis*). Lesser Whistling-Duck (*Dendrocygna javanica*) was recorded as summer visitors and 42 species were recorded as winter visitors including Eurasian Sparrowhawk (*Accipiter nisus*), Common Pochard (*Aythya ferina*), Common Teal (*Anas crecca*), Northern Pintail (*Anas acuta*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Common Tern (*Sterna hirundo*), Brown-headed Gull, (*Chroicocephalus brunnicephalus*), Black-tailed Godwit (*Limosa limosa*), Western Yellow Wagtail (*Motacilla flava*), White-browed Wagtail (*Motacilla maderaspatensis*), Intermediate Egret (*Ardea intermedia*), Great Cormorant (*Phalacrocorax carbo*) and Eurasian Wryneck (*Jynx torquilla*). Plantation habitat prefered as habitat of 76 species in which resident birds accounts for 42 species including Black-winged Kite (*Elanus caeruleus*), Eurasian Collared-Dove (*Streptopelia decaocto*), Laughing Dove (*Streptopelia senegalensis*), White-throated Kingfisher (*Halcyon smyrnensis*), Asian Koel (*Eudynamys scolopaceus*), Grey Francolin (*Francolinus pondicerianus*), Large Gray Babbler (*Argya malcolmi*), Oriental Magpie-Robin (*Copsychus saularis*), House Sparrow (Passer domesticus), Red-vented Bulbul (*Pycnonotus cafer*) and Lesser Golden-backed Woodpecker (*Dinopium benghalense*), Brown-headed Barbet (*Psilopogon zeylanicus*), Coppersmith Barbet (*Psilopogon haemacephalus*), Rose-ringed Parakeet (*Psittacula krameri*), Indian Scops-Owl (*Otus bakkamoena*), Spotted Owlet (*Athene brama*) and Barn Owl (*Tyto alba*) where 7 species like Red Collared-Dove (*Streptopelia tranquebarica*), Indian Roller (*Coracias benghalensis*), Jacobin Cuckoo (*Clamator jacobinus*), Indian Paradise-Flycatcher (*Terpsiphone paradise*), Purple Sunbird (*Cinnyris asiaticus*), Indian Golden Oriole (*Oriolus kundoo*), and Rosy Starling (*Pastor roseus*) were recorded as summer visitors similarly 27 species including Booted Eagle (*Hieraaetus pennatus*), Crested Serpent-Eagle (*Spilornis cheela*), Indian Spotted Eagle (*Clanga hastate*), Black Kite (*Milvus migrans*), Greater Spotted Eagle (*Clanga clanga*), Northern Goshawk (*Accipiter gentilis*) and Oriental Turtle-Dove (*Streptopelia orientalis*), Spotted Dove (*Streptopelia chinensis*), Common Hawk-Cuckoo (*Hierococcyx varius*), Common Kestrel (*Falco tinnunculus*), Taiga Flycatcher (*Ficedula albicilla*), Cinereous Tit (*Parus cinereus*), Common Chiffchaff (*Phylloscopus collybita*) and Tickell's Thrush (*Turdus unicolor*) were recorded as winter visitors. Agricultural field in the easter part of the Sanctuary supports 74 species, in which 49 species are resident birds including Black-winged Kite (*Elanus caeruleus*), Shikra (*Accipiter badius*), Eurasian Hoopoe (*Upupa epops*), Red-wattled Lapwing (*Vanellus indicus*), Pied Kingfisher (*Ceryle rudis*), Black Francolin (*Francolinus francolinus*), Grey Francolin (*Francolinus pondicerianus*), Scaly-breasted Munia (*Lonchura punctulata*), Grey-throated Martin (*Riparia paludicola*), Oriental Magpie-Robin (*Copsychus saularis*), Streaked Weaver (*Ploceus manyar*), Indian Pond-Heron (*Ardeola grayii*), Red-naped Ibis (*Pseudibis papillosa*), Alexandrine Parakeet (*Psittacula eupatria*) and Rose-ringed Parakeet (*Psittacula krameri*). Seven bird species like Pheasant-tailed jacana (*Hydrophasianus chirurgus*), Indian Roller (*Coracias benghalensis*), European Roller (*Coracias garrulous*), Blue-tailed Bee-eater (*Merops philippinus*), Jacobin Cuckoo (*Clamator jacobinus*), Indian Golden Oriole (*Oriolus kundoo*), Rosy Starling (*Pastor roseus*) were recorded as summer visitos where18 species were recorded as winter visitors including Eurasian Marsh-Harrier (*Circus aeruginosus*), Long-legged Buzzard (*Buteo rufinus*), Greater Spotted Eagle (*Clanga clanga*), Spotted Dove (*Streptopelia chinensis*), Common Kestrel (*Falco tinnunculus*), Barn Swallow (*Hirundo rustica*), Citrine Wagtail (*Motacilla citreola*), White-browed Wagtail (*Motacilla maderaspatensis*), Tree Pipit (*Anthus trivialis*), Red-breasted Flycatcher (*Ficedula parva*), Taiga Flycatcher (*Ficedula albicilla*), Common Starling (*Sturnus vulgaris*) and Eurasian Spoonbill (*Platalea leucorodia*). Swampy habitat supports 65 species in which resident birds (46 species) like Black-winged Kite (*Elanus caeruleus*), Eurasian Hoopoe (*Upupa epops*), Green Bee-eater (*Merops orientalis*), Greater Coucal (*Centropus sinensis*), Black Francolin (*Francolinus francolinus*), Grey Francolin (*Francolinus pondicerianus*), Common Tailorbird (*Orthotomus sutorius*), Black Drongo (*Dicrurus macrocercus*), Jungle

Babbler (*Turdoides striata*), Baya Weaver (*Ploceus philippinus*), Brahminy Starling (*Sturnia pagodarum*) and Cattle Egret (*Bubulcus ibis*). Some species like Pheasant-tailed jacana (*Hydrophasianus chirurgus*), Indian Roller (*Coracias benghalensis*), European Roller (*Coracias garrulous*), Blue-tailed Bee-eater (*Merops philippinus*), Jacobin Cuckoo (*Clamator jacobinus*), Indian Golden Oriole (*Oriolus kundoo*) and Rosy Starling (*Pastor roseus*) are recoreded as summer visitots. Fifteen species, including Eurasian Marsh-Harrier (*Circus aeruginosus*), Greater Spotted Eagle (*Clanga clanga*), Bar-headed Goose (*Anser indicus*), Black-tailed Godwit (*Limosa limosa*), White-browed Wagtail (*Motacilla maderaspatensis*), Red-breasted Flycatcher (*Ficedula parva*), Common Starling (*Sturnus vulgaris*), Black-headed Ibis (*Threskiornis melanocephalus*), Eurasian Spoonbill (*Platalea leucorodia*) and Glossy Ibis (*Plegadis falcinellus*) were recorded as winter visitors. The lowest community strength was recorded from Deep wetland habitats with 36 species of which 6 species are resident species like the Indian Spot-billed Duck (*Anas poecilorhyncha*), Common Moorhen (*Gallinula chloropus*), Oriental Darter (*Anhinga melanogaster*), Indian Cormorant (*Phalacrocorax fuscicollis*), Little Cormorant (*Microcarbo niger*) and Little Grebe (*Tachybaptus ruficollis*) where Lesser Whistling-Duck (*Dendrocygna javanica*) was recorded as summer visitors. Some species like Bar-headed Goose (*Anser indicus*), Common Pochard (*Aythya ferina*), Eurasian Wigeon (*Mareca Penelope*), Ferruginous Duck (*Aythya nyroca*), Northern Pintail (*Anas acuta*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*), Black-headed Gull (*Chroicocephalus ridibundus*), Caspian Gull (*Larus cachinnans*) and Horned Grebe (*Podiceps auritus*) were recorded as winter visitors.

Conservation status of birds of HWS

The Harike wildlife Sanctuary supports a population of threatened avian species across the habitat types. Each habitat holds a community of least-concerned species with a mean species number of 70.±21 followed by Near-threatened with a mean specie number of 3.7±2.4, Species under the Vulnerable category with a mean of 1.6±0.5, and species in Endangered category with mean 0.4±0.5. The conservation status of each species has been confirmed by the IUCN red list of threatened species (2020).

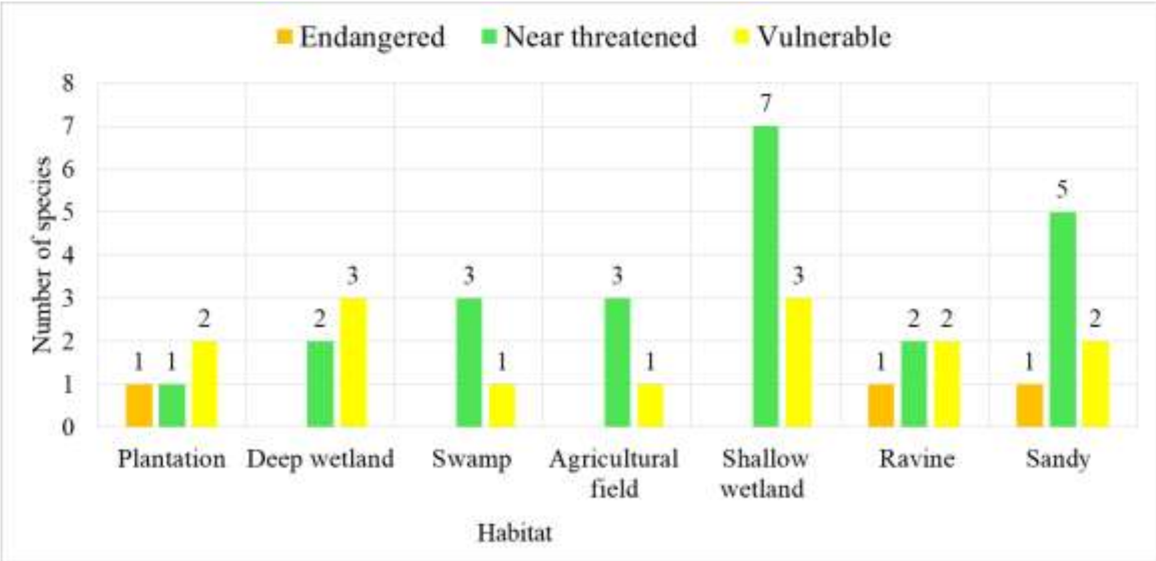


Fig 6.6: Number of Threatened bird species in particular habitat of HWS.

Under the least concern category maximum species has been reported from Shallow wetland habitat (95 species) including species like Bar-headed Goose (*Anser indicus*), Comb Duck (*Sarkidiornis melanotos*), Common Teal (*Anas crecca*), Black-headed Gull (*Chroicocephalus ridibundus*), Brown-headed Gull (*Chroicocephalus brunnicephalus*), Black-winged Stilt (*Himantopus himantopus*), Common Greenshank (*Tringa nebulari*), Common Redshank (*Tringa tetanus*), Common Sandpiper (*Actitis hypoleucos*), Common Kingfisher (*Alcedo atthis*), Common Moorhen (*Gallinula chloropus*), Baya Weaver (*Ploceus philippinus*), Bank Myna (*Acridotheres ginginianus*), Black-crowned Night-Heron (*Nycticorax nycticorax*), and Cinnamon Bittern (*Ixobrychus cinnamomeus*) followed by Ravine habitat (86 species) species composition is consist of Eurasian Hoopoe (*Upupa epops*), Eurasian Collared-Dove (*Streptopelia decaocto*), Greater Coucal (*Centropus sinensis*), Common Kestrel (*Falco tinnunculus*), Common Tailorbird (*Orthotomus sutorius*), Graceful Prinia (*Prinia gracilis*), Black Drongo (*Dicrurus macrocercus*), Common Babbler (*Argya caudate*), Black Redstart (*Phoenicurus ochruros*), Bluethroat (*Luscinia svecica*), Black-breasted Weaver (*Ploceus benghalensis*), Common Myna (*Acridotheres tristis*), Common Starling (*Sturnus vulgaris*) and Cattle Egret (*Bubulcus ibis*). Details of each species are given in the Annexure I.

In Sandy habitat a total of 76 species were recorded under Least-concerned category, species composition includes Eurasian Marsh-Harrier (*Circus aeruginosus*), Bar-headed Goose (*Anser indicus*), Common Teal (*Anas crecca*), Eurasian Wigeon (*Mareca Penelope*), Gadwall (*Mareca strepera*), Eurasian Hoopoe (*Upupa epops*), Black-headed Gull (*Chroicocephalus *ridibundus*), Common Tern (*Sterna hirundo*), Brown-headed Gull (*Chroicocephalus brunnicephalus*), Green Bee-eater (*Merops orientalis*), Crested Lark (*Galerida cristata*), Grey Wagtail (*Motacilla cinerea*), Great Cormorant (*Phalacrocorax carbo*), Glossy Ibis (*Plegadis falcinellus*) and Eurasian Wryneck (*Jynx torquilla*).

Similarly, in Plantation habitat a total of 72 species were recorded under the Least-concerned category, these speciIndian Grey Hornbill (*Ocyceros birostris*), Eurasian Hoopoe (*Upupa epops*), Eurasian Collared-Dove (*Streptopelia decaocto*), Laughing Dove (*Streptopelia senegalensis*), Indian Roller (*Coracias benghalensis*) Common Hawk-Cuckoo (*Hierococcyx varius*), Jacobin Cuckoo (*Clamator jacobinus*), Booted Warbler (*Iduna caligata*), Common Tailorbird (*Orthotomus sutorius*), Black Redstart (*Phoenicurus ochruros*), Indian Golden Oriole (*Oriolus kundoo*), Cinereous Tit (*Parus cinereus*), Grey-headed Canary-Flycatcher (*Culicicapa ceylonensis*), Lesser Whitethroat (*Curruca curruca*), Black-throated Thrush (*Turdus atrogularis*), Brown-headed Barbet (*Psilopogon zeylanicus*), Indian Scops-Owl (*Otus bakkamoena*) and Barn Owl (*Tyto alba*).

Agricultural field habitat supports 70 species of birds under least-concerned category. This community includes species like Black-winged Kite (*Elanus caeruleus*), Eurasian Marsh-Harrier (*Circus aeruginosus*), Long-legged Buzzard (*Buteo rufinus*), White-eyed Buzzard (*Butastur teesa*), Pheasant-tailed jacana (*Hydrophasianus chirurgus*), Pied Kingfisher (*Ceryle rudis*), Indian Roller (*Coracias benghalensis*), Common Kestrel (*Falco tinnunculus*), Scaly-breasted Munia (*Lonchura punctulata*), Indian Silverbill (*Euodice malabarica*), Tree Pipit (*Anthus trivialis*), Indian Robin (*Saxicoloides fulicatus*), Oriental Magpie-Robin (*Copsychus saularis*), Streaked Weaver (*Ploceus manyar*), Red-vented Bulbul (*Pycnonotus cafer*), Brahminy Starling (*Sturnia pagodarum*), Common Starling (*Sturnus vulgaris*) and Rose-ringed Parakeet (*Psittacula krameri*).

Swampy habitat supports 62 species of birds under the Least-concerned category , these species are Eurasian Marsh-Harrier (*Circus aeruginosus*), Lesser Whistling-Duck (*Dendrocygna javanica*), Little Ringed Plover (*Charadrius dubius*), Pheasant-tailed jacana (*Hydrophasianus chirurgus*), Blue-tailed Bee-eater (*Merops philippinus*), Grey-headed Swamphen (*Porphyrio porphyria*), Common Moorhen (*Gallinula chloropus*), Clamorous Reed Warbler (*Acrocephalus stentoreus*), Rufous-fronted Prinia (*Prinia buchanani*), Jungle Babbler (*Turdoides striata*), Bluethroat (*Luscinia svecica*), Black-breasted Weaver (*Ploceus benghalensis*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Grey Heron (*Ardea cinerea*)

Indian Pond-Heron (*Ardeola grayii*), Black Bittern (*Ixobrychus flavicollis*), and Intermediate Egret (*Ardea intermedia*).

A community with 36 avain species under least-concerned category has been recorded from Deep wetland habitat, including Eurasian Marsh-Harrier (*Circus aeruginosus*), Bar-headed Goose (*Anser indicus*), Cotton Pygmy-Goose (*Nettapus coromandelianus*), Eurasian Wigeon (*Mareca Penelope*), Greylag Goose (*Anser anser*), Northern Pintail (*Anas acuta*), Northern Shoveler (*Spatula clypeata*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*), Common Shelduck (*Tadorna tadorna*), Black-headed Gull (*Chroicocephalus ridibundus*), Pallas's Gull (*Ichthyaetus ichthyaetus*), Eurasian Coot (*Fulica atra*), Common Moorhen (*Gallinula chloropus*), Great Cormorant (*Phalacrocorax carbo*), Indian Cormorant (*Phalacrocorax fuscicollis*), Little Cormorant (*Microcarbo niger*) and Great Crested Grebe (*Podiceps cristatus*).

Under the Near-threatened category, the maximum number of species is recorded from Shallow wetlands (8 species) including Ferruginous Duck (*Aythya nyroca*), River Tern (*Sterna aurantia*), Black-tailed Godwit (*Limosa limosa*), Rufous-vented Grass Babbler (*Laticilla burnesii*), Oriental Darter (*Anhinga melanogaster*), Woolly-necked Stork (*Ciconia episcopus*) Painted Stork (*Mycteria leucocephala*) and Black-headed Ibis (*Threskiornis melanocephalus*), where in the Sandy habitat has 6 species of birds, recorded under Near-threatened category, these species are Black-tailed Godwit (*Limosa limosa*), Oriental Darter (*Anhinga melanogaster*), Painted Stork (*Mycteria leucocephala*), Woolly-necked Stork (*Ciconia episcopus*) and Black-headed Ibis (*Threskiornis melanocephalus*). In the Swampy habitat species such as Black-tailed Godwit (*Limosa limosa*), Black-headed Ibis (*Threskiornis melanocephalus*) and Rufous-vented Grass Babbler (*Laticilla burnesii*) were recorded under the Near-threatened category. In Shallow wetland habitat 7 species were recorded as Near-threatened species including Ferruginous Duck, Black-tailed Godwit, Rufous-vented Grass Babbler, Oriental Darter, Painted Stork, Woolly-necked Stork and Black-headed Ibis. Deep wetland habitats was used by Ferruginous Duck (*Aythya nyroca*) and Oriental Darter (*Anhinga melanogaster*) which were recorded under the Near-threatened category. Ravine habitat provides habitat to Near-threatened species including Black-headed Ibis (*Threskiornis melanocephalus*) and Alexandrine Parakeet (*Psittacula eupatria*).

The species recorded under the vulnerable category are Indian Spotted Eagle (*Clanga hastate*) which can be seen in the Plantation and Ravine habitat, Greater Spotted Eagle (*Clanga clanga*) used habitats like Plantation, Agricultural fields and Ravine.Water bird such as Common Pochard (*Aythya ferina*) and River Tern (*Sterna aurantia*), has been recorded from Sandy, Shallow and Deep wetland habitats where Horned Grebe (*Podiceps auritus*) was recorded from Shallow and Deep wetland only. Jerdon's Babbler (*Chrysomma altirostre*) was recorded from Swampy habitats only. One Endangered species Steppe Eagle (*Aquila nipalensis*) was recorded from Plantation, Sandy and Ravine habitats.

Species richness and Shannon diversity index monthly in each habitat

In 19 months bird species richness (Fig, 6.7) and diversity (Fig, 6.8) have been determined for each habitat. Deep wetlands manifest a comparatively diminished mean species richness of avifauna. The average avian richness within deep wetlands is approximately 10, accompanied by a noteworthy variability (±1), signifying potential fluctuations in bird populations. Shallow wetlands, in contrast, reveals a significant heightened mean species richness of birds relative to Deep wetlands. The average species richness of avifauna in Shallow wetlands is 46.2, with considerable variability (±3.7), indicating potential variations in bird diversity and population sizes. Sandy habitats present a substantial mean species richness of birds, with an average species richness of 39.5 and a moderate level of variability (±2.4).

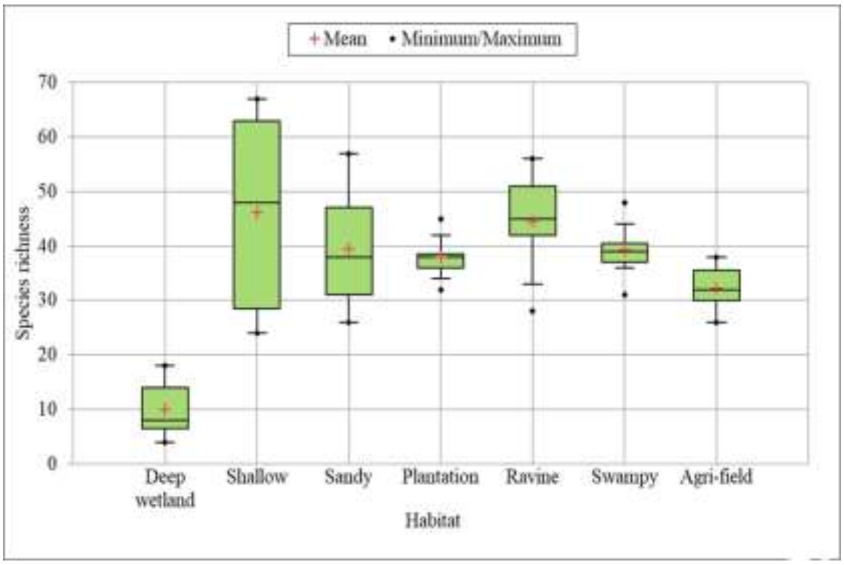


Fig 6.7: Variation in bird species richness in each habitat types in HWS.

Plantation habitat has shown a robust mean species richness of birds akin to sandy habitats, with an average species richness of 38 and relatively low variability (±0.7). Ravine habitats exhibit a markedly elevated mean species richness of birds, suggestive of a diverse bird population. The average species richness of birds in ravines is 44.5, with a moderate level of variability (± 1.8). Swampy areas display a heightened mean species richness of birds akin to Sandy and plantation habitats. The average species richness of birds in Swampy areas is 39.3, with relatively low variability (±0.9). Agricultural fields demonstrate a moderate mean species richness of birds, with an average of 32.3 and relatively low variability (±0.8).

Similarly, Shannon-Weiner index (H) (Fig 6.8), the diversity of birds in each habitat has been assessed on a monthly basis, Deep wetlands display the lowest avian diversity among the enumerated habitats, with an average bird species diversity of (H'=1.57±0.09) and a notable degree of variability. Shallow wetlands manifest a moderate level of bird diversity, indicated by an average diversity of (H'=2.60), accompanied by comparatively lower variability (±0.06). Sandy areas present a slightly elevated bird diversity when compared to shallow wetlands, with an average species diversity of (H'=2.71) and similar variability (±0.06).

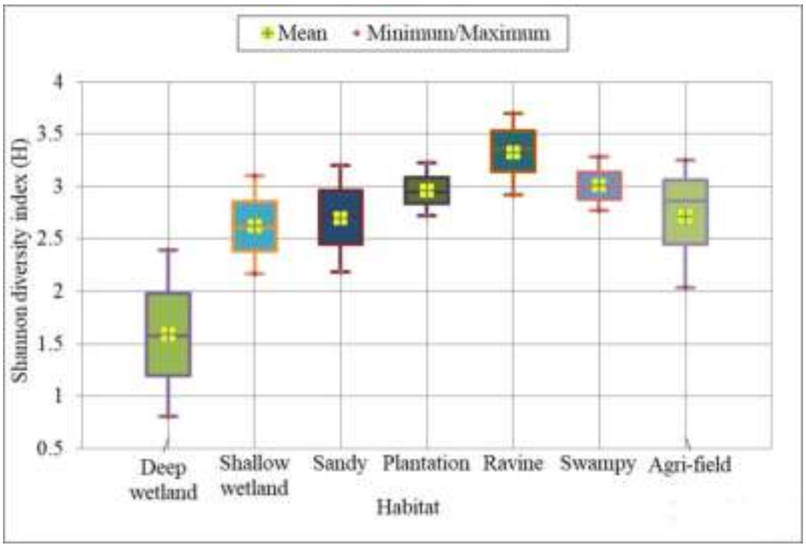


Fig 6.8: Variation in bird diversity in each habitat types in HWS.

Plantation areas displayed a higher bird diversity than Sandy habitat, with an average species diversity of (H'=2.95) and relatively low variability (±0.03). Ravine habitat demonstrated significantly high bird diversity in comparison to the aforementioned habitats, as evidenced by an average diversity of (H'=3.36) and a moderate level of variability (±0.06). Swampy areas exhibit a relatively high bird diversity akin to Ravine habitat, with an average species diversity of (H'=2.99) and low variability (±0.03). Agricultural fields displayed a moderate level of bird diversity, comparable to Sandy habitat, with an average species diversity of (H'=2.86) and relatively high variability (±0.07). The mean seasonal Shannon-Weiner index (H) of birds in each habitat is shown, the summer season (H'=2.57±0.55) has witnessed a lower Shannon-

Weiner index (H) as compared to Post-monsoon (H'=2.78±0.58) and winter season (H'=2.77±0.60).

The bird's evenness (Fig 6.9) data of different habitats indicates the relative uniformity or balance in species abundance within each habitat. Evenness values range from 0 to 1, with higher values indicating a more even distribution of species, while lower values suggest that a few species dominate the habitat.

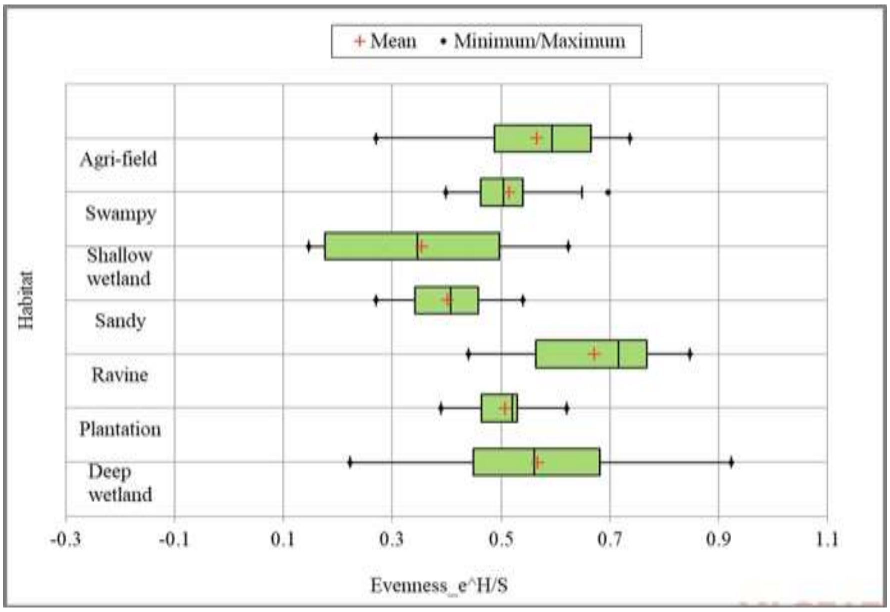


Fig 6.9: Evenness in the bird population across the habitat types in HWS.

In the present study Ravine habitat (0.67±0.20) exhibits relatively high evenness, suggesting a balanced distribution of species within the Ravine habitat. The evenness in Deep wetlands (0.57±0.35) is moderately high, indicating a relatively equitable distribution of species. Many resident birds and summer visitors (lesser whistling duck) contribute to the bird's population stability in the habitat. Similar to Deep wetlands, Agri-fields (0.57±0.24) also show moderate evenness, indicating a balanced distribution of species within Agricultural landscapes. Crops such as wheat and paddy provide food for herbivores and insectivorous birds therefore population of birds in this habitat remains quite stable. Swampy (0.51±0.15) and Plantation (0.51±0.12) both exhibit similar levels of evenness, suggesting a moderately balanced population of species in these habitats. Sandy (0.40±0.14) habitats have lower evenness compared to the previously mentioned habitats, indicating a less balanced abundance of species, with some species potentially dominating the habitat. The potential cause of low stability in bird population due to sand excavation and flood. Shallow Wetland (0.35±0.24) exhibits the lowest evenness among the habitats listed, indicating that species distribution within this habitat may be more skewed, with certain species dominating the environment. In the winter season, the shallow wetland has shown the highest species richness (105 species) as well as high evenness (0.62). The observation of low bird populations in summer and high populations in winter can be attributed to the presence of winter migratory birds. During winter, these migratory species come these habitats which significantly surges the overall bird population in HWS.

ANOVA

An Analysis of Variance (ANOVA) was conducted to examine the differences in species richness among habitat types in different seasons (Table 6.3). There is a significant change has been observed [ANOVA, $F (3, 20) = 4.94$, $P = 0.01$] in the species richness of avian species across the habitats of HWS, therefore failed to accept the null hypothesis. Significant changes in the species richness have been witnessed due to winter migration of birds in different habitat types of HWS. Harike wetland attracts many species from the family Anatidae. These birds feed on aquatic vegetation such as *Hydrilla verticillata, Vallisneria natans, Lemna minor* and *Azolla pinnata.*

Table 6.3: ANOVA for Variation in seasonal Species richness across habitats.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Summer	6.00	266.00	44.33	165.47		
Monsoon	6.00	275.00	45.83	148.97		
Post-monsoon	6.00	356.00	59.33	127.07		
Winter	6.00	398.00	66.33	110.27		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2044.13	3.00	681.38	4.94	0.01	3.10
Within Groups	2758.83	20.00	137.94			
Total	4802.96	23.00				

Seasonal changes play a crucial role in shaping the behavior and habitat utilization of bird communities across different types of habitats. Understanding the relationship between seasonal changes and bird communities is important for effective conservation and management of bird populations, particularly in the face of climate change and habitat loss. The present study aims to find out the communities of avian species across the habitat of HWS besides the role of avian species in cultural ecosystem services.

Seasonal change and relationship among bird communities across habitats

The behavior and habitat use of bird communities in a variety of habitat types is significantly influenced by seasonal changes. Birds adjust their behavior in response to changes in temperature, photoperiod, and the availability of food. The present study examines how seasonal variations impact the distribution and diversity of bird communities across various types of habitats in HWS. In Punjab, where the four distinct seasons are well described, the connection between seasonal changes and bird groups is particularly vibrant. As migrant birds return to their wintering refugee habitat in the spring. As temperatures rise, the availability of food resources such as rise in insect's and spider population, supports breeding population of birds. In the summer, when many species breed and raise young, bird groups are at their most diversified. Bird groups take advantage of this by foraging in a variety of habitats during this time when food supplies, such as seeds and fruit, are abundant. Some bird species, like woodpeckers, may switch to eating insects and larvae during the summer when they are more plentiful. Numerous bird species move to warmer areas in search of food and suitable breeding habitat as the weather cools and the number of daylight hours decreases. Additionally, during this time, social behavior increases as bird's flock together for safety and foraging. As seeds and nuts grow increasingly plentiful, some species, like finches, may begin to eat only them. For bird groups, winter may be a difficult time of year, especially in temperate areas where temperatures can drop below freezing. During this time, many bird species fly to warmer climates, but those that stay must adapt to survive. Others, like grouse, may rely on snow as a source of insulation and food. Some species, like chickadees and nut-hatcher, can stockpile food before the winter months. The relationship between seasonal changes and bird communities is also influenced by the type of habitat in which they live. For example, forest habitats provide shelter and food resources for many bird species, but the level of diversity and abundance of bird communities may vary depending on the type and age of the forest. Similarly, wetland habitats provide important breeding and foraging grounds for many waterbird species, but the availability of water and food resources may vary depending on seasonal changes.

Seasonal changes play a crucial role in shaping the behavior and habitat utilization of bird communities across different types of habitats. Understanding the relationship between seasonal changes and bird communities is important for effective conservation and management of bird populations, particularly in the face of climate change and habitat loss. The present study aims to find out the communities of avian species across the habitat of HWS besides the role of avian species in cultural ecosystem services.

Deep Wetland habitat

This habitat is part of the wetland habitat and the major part includes part of Beas Rivers in HWS. Meandering Beas River enters into Sanctuary from the north-east direction and form confluence with Sutlej River. Beas River adds a substantial amount of water into Harike Wetland. The island in the Beas River is dominated by a plant community comprised of *Phragmites karka* and some associate species like *Typha angustifolia*, *Ipomoea carnea*, some tree species such as *Terminalia arjuna, Syzygium cumini, Bombax ceiba* and *Vachellia nilotica.* Deep wetland area does not have submersed vegetation, however deep wetland receives free-floating vegetation such as *Eichhornia crassipes*, especially during monsoon season. Many reptile species have been recorded Frequent at the time of the bird survey and reptile species like checkered keelback (*Fowlea piscator*), Indian or oriental rat snake (*Ptyas mucosa*) and common Indian monitor (*Varanus bengalensis*) along the bank of Deep Wetland. The mammal species regularly seen along Beas River or Deep Wetland are the Golden jackal (*Canis aureus*), Nilgai (*Boselaphus tragocamelus*), smooth-coated otter (*Lutrogale perspicillata*), wild boar (*Sus scrofa*) and Jungle cat (*Felis chaus*) besides Deep Wetland also supports a population of fish species like Cat fish (*Clarius batrachus*), *Katla* (*Catla catla*) and Rhohu (*Labeo rohita*). The right bank of Beas River runs along the Ravine habitat in the Sanctuary.

Fig 6.10: Deep wetland habitat at HWS.

Diversity and abundance

Deep Wetland provides habitat to the avian community of resident as well as migratory species. The mean abundance of each species is estimated on a monthly basis. The avian community comprises 36 species that have been documented in different seasons, these species belong to 17 genera, 5 families, and 3 orders. Dominated birds species are from the family Anatidae (19 species), which are Bar-headed Goose (*Anser indicus*), Common Pochard (*Aythya ferina*), Greylag Goose (*Anser anser*), Indian Spot-billed Duck (*Anas poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*) and Red-crested Pochard (*Netta rufina*). There are 6 species including Black-headed Gull (*Chroicocephalus ridibundus*), Pallas's Gull (*Ichthyaetus ichthyaetus*), River Tern (*Sterna aurantia*), Brown-headed Gull (*Chroicocephalus brunnicephalus*) were from family Laridae and one species, Eurasian Coot (*Fulica atra Linnaeus*) from the family Rallidae. The birds of prey like Eurasian Marsh-Harrier (*Circus aeruginosus*) and Osprey (*Pandion haliaetus*) belongs to the family Accipitridae and Pandionidae, respectively.

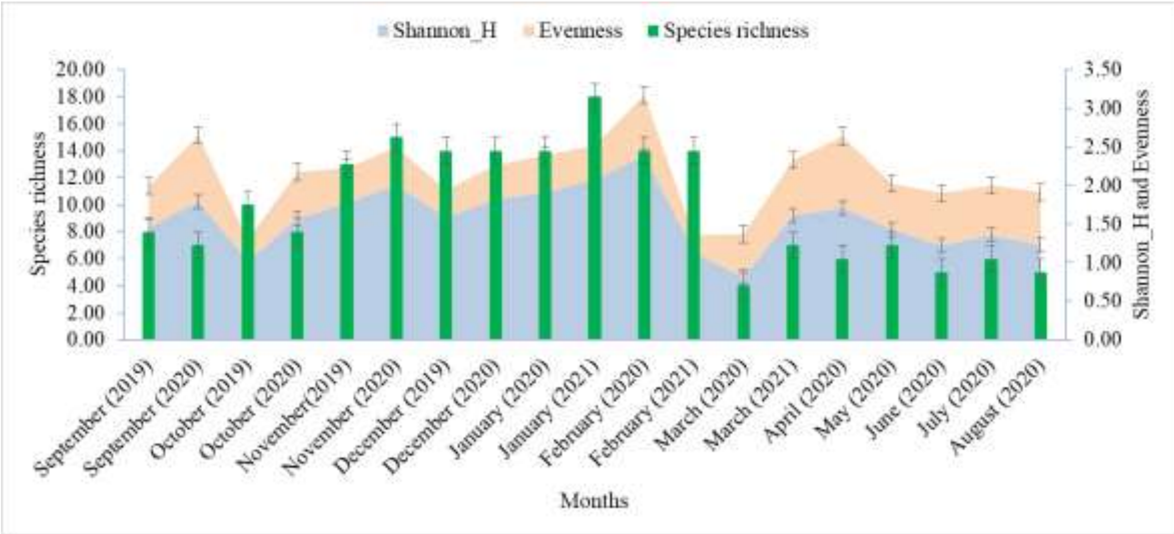


Fig 6.11: Pattern of avian diversity in Deep Wetland habitat across months.

The species richness (S), Evenness (J'), and Shannon-Weiner Diversity Index (H′) of bird species have been estimated for consecutively for 19 months. In summer season, mean temperature and humidity remain at 30.40 °C±3.25°C and 37.33%±6.51%, respectively. In the months of summer, resident bird species can be found in different habitats of HWS. The majority of resident birds start breeding in the months of summer. An increasing trend of species richness and Shannon-Weiner Diversity Index is observed from summer to post-monsoon till residing winter season with minor fluctuation in the monsoon season, however after the winter season there is a decreasing trend observed in species richness and Shannon-Weiner Diversity Index. The community composition of avian species in Deep Wetland habitat is estimated according to months from September 2019 to march 2021.

The abundance of species is an indicator of a healthy ecosystem besides indicating enough availability of resources for concerned species. The population of species in a community is measured by the abundance of particular species in the habitat type. In this study, mean abundance of each recorded species has been estimated per month in a particular season. The seasonal variation in a population of avian species in Deep Wetland habitat type is calculated for species richness (S), Evenness (J'), Shannon-Weiner Diversity Index (H′), and mean abundance. In the summer season during April 2020, (S= 6, H'=1.71, J'= 0.92), May 2020 (S=7, H'=1.43, J'=0.60), and June 2020 (S=5, H'=1.22, J'=0.68) with maximum mean abundance is recorded for Lesser Whistling-Duck (*Dendrocygna javanica*) with 46.67±29.37, followed by Little Cormorant (*Phalacrocorax fuscicollis*) 19±12.12, Indian Cormorant (*Phalacrocorax fuscicollis*) with 16.67±7.77, Common Moorhen (*Gallinula chloropus*) with

12.33±4.73, Garganey (*Spatula querquedula*) with 9±7.81, Oriental Darter (*Anhinga melanogaster*) with 4.33±2.08), and Little Grebe (*Tachybaptus ruficollis)* with 0.33 ±0.58.

Similarly for the Monsoon season community of ten species were recorded and calculated for species richness, diversity and evenness in the month of July 2020 (S=6, H'=1.36, J'=0.65), August 2020, (S=5, H'=1.23, J'=0.68), September 2019 (S=8, H'=1.46, J'=0.54), and September 2020 (S=7, H'=1.79, J'=0.86). Lesser Whistling-Duck (*Dendrocygna javanica*) with 23.75±18.08, were abundant followed by Little Cormorant (*Phalacrocorax fuscicollis*) with (16.25±19.2), Eurasian Coot (*Fulica atra*) with (14.25±28.50), Indian Cormorant (*Phalacrocorax fuscicollis*) with (12.00±4.32), Common Moorhen (*Gallinula chloropus*) with (10.25± 9.95), Indian Spot-billed Duck (*Anas poecilorhyncha*) with (5.75±7.23), Oriental Darter (*Anhinga melanogaster*) with (4.25±1.71), Little Grebe (*Tachybaptus ruficollis*) with (2.00±1.83), Great Cormorant (*Phalacrocorax carbo*) with (1.50±3.00).

In the case of post-monsoon, a community of 28 species was observed in the Deep wetland habitat type. Sapecies richness, diverity and evenness were calculated of birds in the month of October 2019 (S=10, H'=1.02, J'=0.28) and October 2020 (S=8, H'=1.57 J'=0.60), November 2019 (S=13, H'=1.77, J'=0.45), and November 2020 (S=15, H'=2.01, J'=0.50), December 2019 (S=14, H'=1.59 J'=0.35) and December 2020 (S=14, H'=1.82, J'=0.44) were calculated with highest mean abundance is recorded for Eurasian Coot (*Fulica atra*) with 141.67±77.02, followed by Little Cormorant (*Microcarbo niger*) with 32±19.05, Great Cormorant (*Phalacrocorax carbo*) with 24.17±24.79, Bar-headed Goose (*Anser indicus*) with 21.50±36.77, Greylag Goose (*Anser anser*) with 17.83±13.11 Indian Cormorant (*Phalacrocorax fuscicollis*) with 16.50±14.24, Gadwall (*Mareca strepera*) with 14.83±4 Common Moorhen (*Gallinula chloropus*) with 9±4.69, Oriental Darter (*Anhinga melanogaster*) with 3.50±1.71, Tufted Duck (*Aythya fuligula*) with 2.67±8, Mallard (*Anas platyrhynchos*) with 2.33±2.31, Brown-headed Gull (*Chroicocephalus brunnicephalus*) with 2±6, Ferruginous Duck (*Aythya nyroca*) with 1.67 ±3, Little Grebe (*Tachybaptus ruficollis*) with 1.50±1, Northern Pintail (*Anas acuta*) with 1.50±3, Common Shelduck (*Tadorna tadorna)* with 1.33±4, Eurasian Wigeon (*Mareca penelope*) with 1.33±1.5, River Tern (*Sterna aurantia*) with 1.33±1.5, Eurasian Marsh-Harrier (*Circus aeruginosus*) with 1.17±0.82, Caspian Gull (*Larus cachinnans*) with 1±3, Ruddy Shelduck (*Tadorna ferruginea*) with 1±3, Pallas's Gull (*Ichthyaetus ichthyaetus*) with 0.67±2.

Fig 6.12: Avian community of Deep wetland habitat. (1: Red-crested pochard, 2: Horned grebe, 3: Pallas's Gull, 4: Garganey, 5: Northern Shoveler, 6: Mallard, 7: Eurasian coot and Gadwal, 8: Northern pintail).

In the winter season, a community of total 27 species of avian species was found in the Deep wetland habitat. Species richness, diversity and evenness were calculated for birds in the month of January 2020 (S=14, H'=1.91, J'=0.48) and January 2021(S=18, H'=2.08, J'=0.44), February 2020 (S=14, H'=2.39, J'=0.78) and February 2021 (S=14, H'=1.14, J'=0.22), March 2020 (S=4, H'=0.81, J'=0.56) and March 2021 (S=7, H'=1.61, J'=0.72) were calculated with mean abundance of each species as follows Eurasian Coot (*Fulica atra*) with (112±134.2), Little Cormorant (*Microcarbo niger*) with (22.75±16.05), Great Cormorant (*Phalacrocorax carbo*) with (27.75±24.14), Bar-headed Goose (*Anser indicus*) with (44.75±69.82), Greylag Goose (*Anser anser*) with (36.25±32.44), Indian Cormorant (*Phalacrocorax fuscicollis*) with (13.75±10.2), Common Pochard (*Aythya ferina*) with (7±8.1), Gadwall (*Mareca strepera*) with (13±15), Common Teal (*Anas crecca*) with (2.5±5), Common Moorhen (*Gallinula chloropus*) with (10±4.69), Oriental Darter (*Anhinga melanogaster*) with (3.25±1.71), Tufted Duck (*Aythya fuligula*) with (18.5±23.17), Mallard (*Anas platyrhynchos*) with (0.75±1.50), Brown-headed Gull (*Chroicocephalus brunnicephalus*) with (2±4) Ferruginous Duck (*Aythya nyroca*) with (2±4), Ruddy Shelduck (*Tadorna ferruginea*) with (2±4), Red-crested Pochard (*Netta rufina*) with (2±4), Little Grebe, (*Tachybaptus ruficollis*) with (1.25±1.89), Common Shelduck

(*Tadorna tadorna*) with (1±2), River Tern (*Sterna aurantia*) with (2±2.83), Indian Spot-billed Duck (*Anas poecilorhyncha*) with (1.75±3.50), Caspian Gull (*Larus cachinnans*) with (1±2), Pallas's Gull (*Ichthyaetus ichthyaetus*) with (1.75±3.5), Northern Shoveler (*Spatula clypeata*) with (14±16.67), Common Tern (*Sterna hirundo*) with (0.75±1.50). Horned Grebe (*Podiceps auritus*) with (0.5±1), and Eurasian Marsh-Harrier (*Circus aeruginosus*) with (0.25±0.5). A crucial sign of an ecosystem's health and overall biodiversity is the number of birds present in it. Birds are critical for preserving the balance of an ecosystem since they are involved in many ecological processes, such as pollination, seed dissemination, and insect control. Monitoring bird populations and comprehending their abundance patterns can assist guide conservation efforts and offer important insights into environmental changes. We can guarantee continuing bird abundance and maintain the integrity of our ecosystems for future generations by protecting habitats, reducing human foot-fall, and supporting sustainable practices. The abundance of recorded species is given in Table 6.4.

Table 6.4: Structure of avian community and seasonal abundance in Deep Wetland habitat.

Species	Scientific name	Summer	Monsoon	Post-monsoon	Winter
Bar-headed Goose	*Anser indicus* (Latham, 1790)	-	-	21.5±36.77	44.75±69.82
Black-headed Gull	*Chroicocephalus ridibundus* (Linnaeus, 1766)	-	-	0.5±1.50	-
Brown-headed Gull	*Chroicocephalus brunnicephalus* (Jerdon, 1840)	-	-	2±6.00	2±4.00
Caspian Gull	*Larus cachinnans* (Pallas, 1811)	-	-	1±3.00	1 ±2.00
Comb Duck	*Sarkidiornis melanotos* (Pennant, 1769)	-	-	0.33 ±0.00	-
Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	12.33±4.73	10.25 ±9.95	9 ±4.69	10 ±4.69
Common Pochard	*Aythya ferina* (Linnaeus, 1758)	-	-	-	7 ±8.12
Common Shelduck	*Tadorna tadorna* (Linnaeus, 1758)	-	-	1.33 ±4.00	1 ±2.00
Common Teal	*Anas crecca* (Linnaeus, 1758)	-	-	-	2.5 ±5.00
Common Tern	*Sterna hirundo* (Linnaeus, 1758)	-	-	0.33 ±1.00	0.75 ±1.50
Cotton Pygmy-Goose	*Nettapus coromandelianus* (J.F. Gmelin, 1789)	-	-	0.5 ±1.50	-
Eurasian Coot	*Fulica atra* (Linnaeus, 1758)	-	14.25±28.50	141.67 ±77.02	112 ±134.22
Eurasian Marsh-Harrier	*Circus aeruginosus* (Linnaeus, 1758)	-	-	1.17 ±0.82	0.25 ±0.50
Eurasian Wigeon	*Mareca penelope* (Linnaeus, 1758)	-	-	1.33 ±1.50	
Ferruginous Duck	*Aythya nyroca* (Güldenstädt, 1770)	-	-	1.67 ±3.00	2 ±4.00
Gadwall	*Mareca strepera* (Linnaeus, 1758)	-	-	14.83 ±4.00	13 ±15.03
Garganey	*Spatula querquedula* (Linnaeus, 1758)	9 ±7.81	-	-	-
Great Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	-	1.5 ±3.00	24.17 ±24.79	27.75 ±24.14
Great Crested Grebe	*Podiceps cristatus* (Linnaeus, 1758)	-	-	0.33 ±0.50	-
Greylag Goose	*Anser anser* (Linnaeus, 1758)	-	-	17.83 ±13.11	36.25 ±32.44
Horned Grebe	*Podiceps auritus* (Linnaeus, 1758)	-	-	-	0.5 ±1.00
Indian Cormorant	*Phalacrocorax fuscicollis* (Stephens, 1826)	16.67 ±7.77	12 ±4.32	16.5 ±14.24	13.75 ±10.21
Indian Spot-billed Duck	*Anas poecilorhyncha* (J.R. Forster, 1781)	-	5.75 ±7.23	-	1.75 ±3.50

Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield, 1821)	46.67 ±29.37	23.75 ±18.08	-	-
Little Cormorant	*Microcarbo niger* (Vieillot, 1817)	19 ±12.12	16.25 ±19.02	32 ±19.05	22.75 ±16.05
Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	0.33 ±0.58	2 ±1.83	1.5 ±1.00	1.25 ±1.89
Mallard	*Anas platyrhynchos* Linnaeus, 1758	-	-	2.33 ±2.31	0.75 ±1.50
Northern Pintail	*Anas acuta* Linnaeus, 1758	-	-	1.5 ±3.00	-
Northern Shoveler	*Spatula clypeata* (Linnaeus, 1758)	-	-	-	14 ±16.67
Oriental Darter	*Anhinga melanogaster* Pennant, 1769	4.33 ±2.08	4.25 ±1.71	3.5 ±1.71	3.25 ±1.71
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	-	-	0.17 ±0.50	-
Pallas's Gull	*Ichthyaetus ichthyaetus* (Pallas, 1773)	-	1 ±2.00	0.67 ±2.00	1.75 ±3.50
Red-crested Pochard	*Netta rufina* (Pallas, 1773)	-	-	-	2 ±4.00
River Tern	*Sterna aurantia* J.E. Gray, 1831	-	-	1.33 ±1.50	2 ±2.83
Ruddy Shelduck	*Tadorna ferruginea* (Pallas, 1764)	-	-	1±3.00	2±4.00
Tufted Duck	*Aythya fuligula* (Linnaeus, 1758)	-	-	2.67 ±8.00	18.5 ±23.17

Shallow wetland habitat

The Shallow wetland habitat is ideal for many bird species viz. herons, egrets, ducks, geese, rails, coots, and songbirds are a few famous birds that inhabit shallow wetlands. Elegant wading birds like herons and egrets are frequently observed in marshes. They search for fish and other small aquatic organisms in shallow waters, where their large legs and beaks help them to catch prey. These birds often build their nests in trees that encircle wetland habitats. Waterfowl (ducks and geese) that inhabit wetlands throughout the year or during migration. They are well-equipped for swimming and diving with webbed feet and waterproof feathers. These birds feed on aquatic vegetation, insects, and small invertebrates. Rails and coots are small waterbirds that reside in wetlands. Rails are known for their secretive behavior, often hiding in dense vegetation, however Coots, on the other hand, have distinctive white bills and are adept for diving to forage. Both rails and coots feed on aquatic plants and invertebrates. Songbirds, though not entirely reliant on wetlands, can be found in the surrounding areas. These birds add their melodi calls and songs to the wetland ecosystem. They use wetlands as a source of water, food, and shelter, contributing to the overall biodiversity of the area.

Fig 6.13: A flock of Glossy ibis (*Plegadis falcinellus*) sitting along Shallow wetland habitat.

The shallow wetland support community of avian species with a total of 105 species throughout the year. In summer season, a total of 33 species of avians belonging to 9 orders and 18 families, and 30 genera. The species richness (S), Shannon-Weiner Diversity Index (H′), Evenness (J’) and mean abundance were calculated for the species observed. In the month of April 2020 (S=25, H’=2.75, J’=0.62), May 2020 (S=27, H’=2.81, J’=0.62) and June 2020 (S=27, H’=2.71, J'=0.55) the estimated mean abundance of noted species includes the Indian Spot-billed Duck (*Anas poecilorhyncha*) 168.33 ±17.56, followed by Lesser Whistling-Duck (*Dendrocygna javanica*) 161.33±101.87, Baya Weaver (*Ploceus philippinus*)135±76.97, Cattle Egret (*Bubulcus ibis*) 133±31.58, Black-crowned Night-Heron (*Nycticorax nycticorax*) 125±43.58, Rosy Starling (*Pastor roseus*) 110±32.79, Grey-headed Swamphen (*Porphyrio porphyrio*) 106.67±29.30, Common Moorhen (*Gallinula chloropus*) 78.33±12.58, Little Cormorant (*Microcarbo niger*) 65±10, Streaked Weaver (*Ploceus manyar*) 65±13.23, and Red-naped Ibis (*Pseudibis papillosa*) 63.33±58.38, where some species were observed very less such as Sind Sparrow (*Passer pyrrhonotus*) 5± 8.66, followed by Pied Kingfisher (*Ceryle rudis*) 4.33±4.51, Little Egret (*Egretta garzetta*) 3.33±5.77, Shikra (*Accipiter badius*) 3.33±1.53, Jacobin Cuckoo (*Clamator jacobinus*) 2.33±2.08, Purple Heron (*Ardea purpurea*) 2±3.46, and Rufous-vented Grass Babbler (*Laticilla burnesii*) 0.33±0.58. The mean abundance of each species is given in Table 6.5.

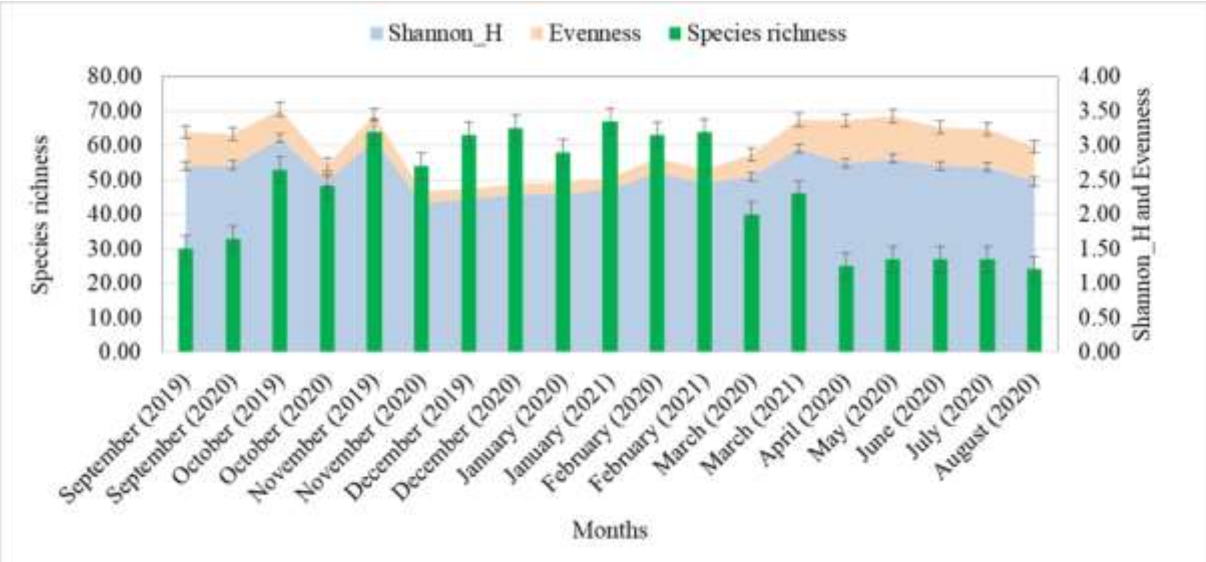


Fig 6.14: Seasonal variation in avian diversity at shallow wetland habitat.

In monsoon season a community of total 47 species belonging to 9 order 24 families and 42 genera were observed for species richness, diversity and evenness were calculated for avian species in the month of July 2020 (S=27, H'=2.69, J'=0.55), August 2020 (S=24, H'=2.48, J'=0.50), September 2019 (S=30, H'=2.70, J'=0.50, and September 2020 (S=33, H'=2.71, J'=0.46) were realised besides maximum mean abundance is observed for Little Cormorant (*Microcarbo niger*) 195.25±108.18, Cattle Egret (*Bubulcus ibis*) 195±86.63, Baya Weaver (*Ploceus philippinus*) 159.5±153.20,Lesser Whistling-Duck (*Dendrocygna javanica*) 156.25

±115.86, Eurasian Coot (*Fulica atra*)145±171.42, Rosy Starling (*Pastor roseus*)106.25 ±123.65, Great Cormorant (*Phalacrocorax carbo*) 91.25±106.33, Grey-headed Swamphen (*Porphyrio porphyria*) 88.50±19.47, Common Moorhen (*Gallinula chloropus*) 77.5±28.43, Indian Spot-billed Duck (*Anas poecilorhyncha)* 59.25±48.50, White-breasted Waterhen (*Amaurornis phoenicurus*) 54.5±24.28, Red-naped Ibis (*Pseudibis papillosa*) 34.5±28.24, Black-crowned Night-Heron (*Nycticorax nycticorax*) 30±60, Red-wattled Lapwing (*Vanellus indicus*) 26.75±7.68, Indian Cormorant (*Phalacrocorax fuscicollis*) 26.25±37.72, Streaked Weaver (*Ploceus manyar*) 26.25±20.56, and Painted Stork (*Mycteria leucocephala*) 20±40. Least mean abundance have been observed for avian species such as Common Pochard (*Aythya farina*) 2.75±3.20, Jacobin Cuckoo (*Clamator jacobinus*) 2.75±2.22, Scaly-breasted Munia (*Lonchura punctulata*) 2.5±5, Sind Sparrow (*Passer pyrrhonotus*) 2.5±5, Glossy Ibis (*Plegadis falcinellus*) 2±4, Purple Heron (*Ardea purpurea*) 1.25±2.5, Citrine Wagtail (*Motacilla citreola*) 1±2, Common Greenshank, (*Tringa nebularia*) 0.75±1.50, Eurasian Marsh-Harrier (*Circus aeruginosus*) 0.50±1.00, and Rufous-vented Grass Babbler (*Laticilla burnesii*) 0.25±0.5.

Fig 6.15: Avian community (Glossy ibis, Eurasian spoonbill, Intermediate egret, Red-wattled lapwing, Black-winged stilt, and Common Teal) in Shallow wetland habitat.

The volume of water in the shallow wetlands and the progressive drop in temperature may be seen during the post-monsoon season. In a community of 87 different bird species that inhabit shallow wetlands, in the shallow wetland there is modrate change in the species richness and diversity level of birds were observed, in the month of October 2019 (S=53, H'=3.10, J'=0.42), and October 2020 (S=48, H'=2.48, J'=0.25), November 2019 (S=64, H'=3.10, J'=0.35) and November 2020 (S=54, H'=2.17, J'=0.16), December 2019 (S=63, H'=2.22, J'=0.15) and December 2020 (S=65, H'=2.29, J'=0.15) were recorded and mean abundance is calculated as Eurasian Coot (*Fulica atra*) 2771.17±2190.85, followed by Greylag Goose (*Anser anser*) 1842.83±1904.50, Great Cormorant (*Phalacrocorax carbo*) 858±543.22, Gadwall (*Mareca strepera*) 515.33±685.71, Northern Shoveler (*Spatula clypeata*) 471.83±324.64, Bar-headed Goose (*Anser indicus*) 195.33±182.30, Common Teal (*Anas crecca*) 143.67±124.46, Little Cormorant (*Microcarbo niger*)139.67±82.56, Brown-headed Gull (*Chroicocephalus brunnicephalus)* 133.67±72.10, Red-crested Pochard (*Netta rufina*) 127.17±155.22, Cattle Egret (*Bubulcus ibis*) 106±30.93, Eurasian Spoonbill (*Platalea leucorodia*) 97.5±77.89, Pied Avocet (*Recurvirostra avosetta*) 94.33±47.81, Black-winged Stilt (*Himantopus himantopus*) 83.83±64.91, Common Pochard (*Aythya farina*) 78.17± 41.36, Northern Pintail (*Anas acuta*) 72.83±78.12, Grey-headed Swamphen (*Porphyrio porphyria*) 66.83±27.77, Indian Cormorant (*Phalacrocorax fuscicollis*) 64.17 ±38.45. Common Moorhen (*Gallinula chloropus*) 60.83 ±22.11, Glossy Ibis (*Plegadis falcinellus*) 59±46.85, Indian Spot-billed Duck (*Anas poecilorhyncha*) 57.83±43.33, Black-headed Gull (*Chroicocephalus ridibundus*) 54±38.54, White-breasted Waterhen (*Amaurornis phoenicurus*) 51.67±22.78, Ruddy Shelduck (*Tadorna ferruginea*) 44.83±34.91. Some avian species with mean abundance less than 2, includes Siberian Stonechat (*Saxicola maurus*) 1.83±2.79, Wood Sandpiper (*Tringa glareola*) 1.67±2.66, Caspian Gull (*Larus cachinnans*) 1.33±3.27, Spotted Redshank (*Tringa erythropus*) 1.33±3.27, Purple Heron (*Ardea purpurea*) 1.17±1.83, Great Egret (*Ardea alba*) 1±1.67, Barn Swallow (*Hirundo rustica*) 0.67±1.63, Cinnamon Bittern (*Ixobrychus cinnamomeus*) 0.67±0.82, Cotton Pygmy-Goose (*Nettapus coromandelianus*) 0.67±1.63, Zitting Cisticola (*Cisticola juncidis*) 0.50±1.22, Isabelline Shrike (*Lanius isabellinus*) 0.50±0.84, Osprey (*Pandion haliaetus*) 0.50±0.84, Great Crested Grebe (*Podiceps cristatus*) 0.50±0.84, Rufous-vented Grass Babbler (*Laticilla burnesii*) 0.33±0.52, Plumbeous water Redstart (*Rhyacornis fuliginosa*) 0.33±0.82, and Brown Crake (*Zapornia akool*) 0.33±0.82.

Fig 6.16: Winter visitors of avian community (Bar-headed goose, Brown-headed gull, and Common redshank) in Shallow wetland.

Due to winter migration a total of 93 avian species were recorded from shallow wetland in the winter season, highest species richness and diversity is witnessed in the month of January 2020 (S=58, H'=2.30, J'=0.17), January 2021 (S=67, H'=2.37, J'=0.16), February 2020 (S=63, H'=2.61, J'=0.22), February 2021 (S=64, H'=2.46, J'=0.18) March 2020 (S=40, H'=2.55, J'=0.32), and March 2021 (S=46, H'=2.95, J'=0.42) with mean abundance were calculated for various species and maximum mean abundance is found for species like Eurasian Coot (*Fulica atra*) 2651.5±1863.15, Greylag Goose (*Anser anser*) 1226.33±1082.52, Great Cormorant (*Phalacrocorax carbo*) 875.67±957.49, Northern Shoveler (*Spatula clypeata*) 567±430.94, Gadwall (*Mareca strepera*) 555.17±456.48, Bar-headed Goose (*Anser indicus*) 235±157.89, Northern Pintail (*Anas acuta*) 132.83±125.41, Red-crested Pochard (*Netta rufina*) 127.33±164.55, Eurasian Spoonbill (*Platalea leucorodia*) 112.17±72.16, Common Teal (*Anas crecca*) 108.33±121.16, Cattle Egret (*Bubulcus ibis*) 108.17±42.05, Little Cormorant (*Microcarbo niger*) 100.33±54.10, Pied Avocet (*Recurvirostra avosetta*) 79.5±70.05, Common Pochard (*Aythya farina*) 78.67±56.27, Tufted Duck (*Aythya fuligula*)72.33±80.50, Grey-headed Swamphen (*Porphyrio porphyria*) 67.83±28.86, Common Moorhen (*Gallinula chloropus*) 65.83±21.99, and Brown-headed Gull (*Chroicocephalus brunnicephalus*) 60.33±19.41. The least mean abundance have been observed for species like Great Crested Grebe (*Podiceps cristatus*) 0.83±2.04, Green Sandpiper (*Tringa ochropus*) 0.83±2.04, Purple Heron (*Ardea purpurea*) 0.67±1.63, Spotted Redshank (*Tringa erythropus*) 0.67±1.63, Gull-billed Tern (*Gelochelidon nilotica*) 0.67±1.63, Great Egret (*Ardea alba*) 0.50±0.84, Temminck's Stint (*Calidris temminckii*) 0.50±1.22, Marsh Sandpiper (*Tringa stagnatilis*) 0.33±0.82, Osprey (*Pandion haliaetus*) 0.33±0.52, Rufous-vented Grass Babbler *(Laticilla burnesii*) 0.33±0.82, and Horned Grebe (*Podiceps auritus*) 0.33±0.82. Mean abundance of avian community of Shallow wetland is given in table 6.5.

Table 6.5: Structure of avian community and seasonal mean abundance in Shallow wetland habitat.

Species		**Summer**	**Monsoon**	**Post-monsoon**	**Winter**
Common name	**Scientific name**	Mean	Mean	Mean	Mean
Asian Pied Starling	*Gracupica contra* (Linnaeus, 1758)	-	8± 16	6.33± 9.83	2± 4.9
Bank Myna	*Acridotheres ginginianus* (Latham, 1790)	-	-	-	17.17± 23.6
Bar-headed Goose	*Anser indicus* (Latham, 1790)	-	-	195.33± 182.3	235± 157.89
Barn Swallow	*Hirundo rustica* (Linnaeus, 1758)	-	-	0.67± 1.63	1.83± 2.99
Baya Weaver	*Ploceus philippinus* (Linnaeus, 1766)	135±76.97	159.5± 153.2	2.33± 5.72	-
Black-breasted Weaver	*Ploceus benghalensis* (Linnaeus, 1758)	5.33±9.24	5.5± 11	-	-
Black-crowned Night-Heron	*Nycticorax nycticorax (Linnaeus, 1758)*	125±43.58	30± 60	-	6.5± 15.92
Black-headed Gull	*Chroicocephalus ridibundus* (Linnaeus, 1766)	-	3.5± 7	54± 38.54	32.17± 27.75
Black-headed Ibis	*Threskiornis melanocephalus* (Latham, 1790)	-	-	3.83± 9.39	3± 7.35
Black-tailed Godwit	*Limosa limosa* (Linnaeus, 1758)	-	-	32.17± 24.56	93.33± 32.14
Black-winged Stilt	*Himantopus himantopus* (Linnaeus, 1758)	-	15± 17.8	83.83± 64.91	40.33± 47.34
Brahminy Starling	*Sturnia pagodarum* (J.F. Gmelin, 1789)	5±1	3.75± 7.5	-	-
Brown Crake	*Zapornia akool* (Sykes, 1832)	-	-	0.33± 0.82	1.67± 1.86
Brown-headed Gull	*Chroicocephalus brunnicephalus* (Jerdon, 1840)	-	16.25± 27.43	133.67± 72.1	60.33± 19.41
Caspian Gull	*Larus cachinnans* Pallas, 1811	-	-	1.33± 3.27	5.17± 6.34
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	133±31.58	195± 86.63	106± 30.93	108.17± 42.05
Cinnamon Bittern	*Ixobrychus cinnamomeus* (J.F. Gmelin, 1789)	-	-	0.67± 0.82	-
Citrine Wagtail	*Motacilla citreola* (Pallas, 1776)	-	1± 2	14.33± 9.85	16.83± 11.6
Comb Duck	*Sarkidiornis melanotos* (Pennant, 1769)	-	-	8.67± 9.61	9.5± 8.09

Common Greenshank	*Tringa nebularia (*Gunnerus, 1767)	-	0.75±1.5	3.83± 2.86	3.33± 1.97
Common Kingfisher	*Alcedo atthis* (Linnaeus, 1758)	-	-	2± 1.67	2.17± 1.47
Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	78.33±12.58	77.5±28.43	60.83± 22.11	65.83± 21.99
Common Pochard	*Aythya ferina* (Linnaeus, 1758)	-	2.75±3.2	78.17± 41.36	78.67± 56.27
Common Redshank	*Tringa totanus* (Linnaeus, 1758)	-	-	3± 0.89	3.83± 1.33
Common Sandpiper	*Actitis hypoleucos* (Linnaeus, 1758)	-	3±6	14.33± 9.16	15.17± 8.45
Common Shelduck	*Tadorna tadorna* (Linnaeus, 1758)	-	-	4.67± 7.26	6.83± 10.82
Common Teal	*Anas crecca* (Linnaeus, 1758)	-	-	143.67± 124.46	108.33± 121.16
Common Tern	*Sterna hirundo* (Linnaeus, 1758)	-	-	3± 5.02	3.5± 3.99
Cotton Pygmy-Goose	*Nettapus coromandelianus* (J.F. Gmelin, 1789)	-	-	0.67± 1.63	3± 4.69
Eurasian Coot	*Fulica atra* (Linnaeus, 1758)	-	145±171.42	2771.17± 2190.85	2651.5±1863.15
Eurasian Marsh-Harrier	*Circus aeruginosus* (Linnaeus, 1758)	-	0.5± 1	8.67± 3.98	13± 5.73
Eurasian Spoonbill	*Platalea leucorodia* (Linnaeus, 1758)	-	-	97.5± 77.89	112.17± 72.16
Eurasian Wigeon	*Mareca penelope* (Linnaeus, 1758)	-	-	24.83± 15.24	23± 14.83
Ferruginous Duck	*Aythya nyroca* (Güldenstädt, 1770)	-	-	26.83± 14.82	35.5± 27.6
Gadwall	*Mareca strepera* (Linnaeus, 1758)	-	-	515.33± 685.71	555.17± 456.48
Garganey	*Spatula querquedula* (Linnaeus, 1758)	20± 34.64	-	-	23.83± 36.96
Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	-	2± 4	59± 46.85	32.17± 33.14
Great Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	-	91.25± 106.33	858± 543.22	875.67± 957.49
Great Crested Grebe	*Podiceps cristatus* (Linnaeus, 1758)	-	-	0.5± 0.84	0.83±2.04
Great Egret	*Ardea alba* Linnaeus, 1758	-	-	1± 1.67	0.5±0.84
Greater Coucal	*Centropus sinensis* (Stephens, 1815)	155	14± 4.9	10± 2.19	7.33±4.97
Green Sandpiper	*Tringa ochropus* Linnaeus, 1758	-	-	3.33± 4.5	0.83±2.04

Grey Heron	*Ardea cinerea* Linnaeus, 1758	7.33± 2.52	6± 1.41	5.33± 2.16	5.67±2.34
Grey Wagtail	*Motacilla cinerea* Tunstall, 1771	-	-	2.33± 3.67	5±5.62
Grey-headed Swamphen	*Porphyrio porphyrio* (Linnaeus, 1758)	106.67± 29.3	88.5± 19.47	66.83± 27.77	67.83±28.86
Greylag Goose	*Anser anser* (Linnaeus, 1758)	-	-	1842.83± 1904.5	1226.33±1082.52
Gull-billed Tern	*Gelochelidon nilotica* (J.F. Gmelin, 1789)	-	-	-	0.67± 1.63
Horned Grebe	*Podiceps auritus* (Linnaeus, 1758)	-	-	-	0.33± 0.82
House Crow	*Corvus splendens* Vieillot, 1817	9.33±9.02	7.5± 8.66	4.67± 7.34	4.33± 5.13
Indian Cormorant	*Phalacrocorax fuscicollis* (Stephens, 1826)	16.67±15.28	26.25± 37.72	64.17± 38.45	26.5± 23.42
Indian Pond-Heron	*Ardeola grayii* (Sykes, 1832)	6.67± 2.89	15.25± 4.11	10.5± 2.95	11.17± 8.5
Indian Spot-billed Duck	*Anas poecilorhyncha* J.R. Forster, 1781	168.33± 17.56	59.25± 48.5	57.83± 43.33	42.33± 16.32
Intermediate Egret	*Ardea intermedia* Wagler, 1829	-	-	5.17± 4.31	2.83± 4.92
Isabelline Shrike	*Lanius isabellinus* Hemprich & Ehrenberg, 1833	-	-	0.5± 0.84	1.83± 2.23
Jacobin Cuckoo	*Clamator jacobinus* (Boddaert, 1783)	2.33± 2.08	2.75±2.22	-	-
Kentish Plover	*Charadrius alexandrinus* (Linnaeus, 1758)	-	-	7± 5.93	9.17± 8.57
Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield, 1821)	161.33± 101.87	156.25±115.8	2± 4.9	-
Little Cormorant	*Microcarbo niger (*Vieillot, 1817)	65 ± 10	195.25±108.2	139.67± 82.56	100.33± 54.1
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	3.33 ± 5.77	9.5±8.54	3.5±3.21	2.83± 2.56
Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	15± 8.66	14.25±4.35	12.33± 6.95	14.17± 7
Little Ringed Plover	*Charadrius dubius* (Scopoli, 1786)	-	-	2.83± 0.98	4± 0.63
Mallard	*Anas platyrhynchos* (Linnaeus, 1758)	-	-	5.5± 6.98	6.33± 10.31
Marsh Sandpiper	*Tringa stagnatilis* (Bechstein, 1803)	-	-	-	0.33± 0.82
Northern Pintail	*Anas acuta* (Linnaeus, 1758)	-	-	72.83± 78.12	132.83± 125.41
Northern Shoveler	*Spatula clypeata* (Linnaeus, 1758)	-	-	471.83± 324.64	567± 430.94

Oriental Darter	*Anhinga melanogaster* (Pennant, 1769)	18± 7.21	15.5±5.26	14± 7.56	15.67± 4.63
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	-	-	0.5± 0.84	0.33± 0.52
Painted Stork	*Mycteria leucocephala* (Pennant, 1769)	-	20±40	15.17± 16.87	15.5± 17.13
Pallas's Gull	*Ichthyaetus ichthyaetus* (Pallas, 1773)	-	10±12.25	19.5± 13.23	16.17 ± 15.47
Pheasant-tailed jacana	*Hydrophasianus chirurgus* (Scopoli, 1786)	19.33± 6.66	13.75± 10.84	-	1 ± 2.45
Pied Avocet	*Recurvirostra avosetta* (Linnaeus, 1758)	-	-	94.33 ± 47.81	79.5 ± 70.05
Pied Kingfisher	*Ceryle rudis* (Linnaeus, 1758)	4.33 ±4.51	4.25 ±3.3	3.33 ± 3.08	5 ± 1.79
Pheasant-tailed jacana	*Hydrophasianus chirurgus* (Scopoli, 1786)	13.6 ±0.5	9.6 ±8.73	-	1 ± 2.16
Plumbeous water Redstart	*Rhyacornis fuliginosa* (Vigors, 1831)	-	-	0.33 ± 0.82	-
Purple Heron	*Ardea purpurea* Linnaeus, 1766	2 ±3.46	1.25 ±2.5	1.17 ± 1.83	0.67 ± 1.63
Red-crested Pochard	*Netta rufina* (Pallas, 1773)	-	-	127.17 ± 155.22	127.33 ± 164.55
Red-naped Ibis	*Pseudibis papillosa* (Temminck, 1824)	63.33 ± 58.38	34.5 ±28.24	37.67 ± 39.05	16.33 ± 33.33
Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	40 ± 22.91	26.75 ±7.68	33.67 ± 27.96	27 ± 17.56
River Lapwing	*Vanellus duvaucelii* (Lesson, 1826)	-	-	-	1 ± 2.45
River Tern	*Sterna aurantia* (J.E. Gray, 1831)	-	-	10.67 ± 17.28	27.5 ± 18.57
Rosy Starling	*Pastor roseus* (Linnaeus, 1758)	110 ± 32.79	106.25 ±123.6	-	3 ± 7.35
Ruddy Shelduck	*Tadorna ferruginea* (Pallas, 1764)	-	-	44.83 ± 34.91	40.17 ± 41.43
Ruff	*Calidris pugnax* (Linnaeus, 1758)	-	-	18.67 ± 35.3	34.33 ± 55.23
Rufous-vented Grass Babbler	*Laticilla burnesii* (Blyth, 1844)	0.33 ± 0.58	0.25±0.5	0.33 ± 0.52	0.33 ± 0.82
Scaly-breasted Munia	*Lonchura punctulata* (Linnaeus, 1758)	7.33 ± 3.06	2.5 ± 5	5.83 ± 6.65	5 ± 6.03
Shikra	*Accipiter badius* (J.F. Gmelin, 1788)	3.33 ± 1.53	5 ± 1.41	4.67 ± 2.42	3.33 ± 1.03
Siberian Stonechat	*Saxicola maurus* (Pallas, 1773)	-	-	1.83 ± 2.79	2.17 ± 0.98
Sind Sparrow	*Passer pyrrhonotus (*Blyth, 1845)	5 ± 8.66	2.5 ± 5	3.33 ± 5.32	3.33 ± 5.32

Small Pratincole	*Glareola lactea (*Temminck, 1820)	-	-	-	2 ± 4.9
Spotted Dove	*Streptopelia chinensis* (Scopoli, 1786)	-	-	4.67 ± 7.34	-
Spotted Redshank	*Tringa erythropus* (Pallas, 1764)	-	-	1.33 ± 3.27	0.67 ± 1.63
Streaked Weaver	*Ploceus manyar* (Horsfield, 1821)	65± 13.23	26.25± 20.56	-	3.33 ± 8.16
Striated Babbler	*Argya earlei* (Blyth, 1844)	-	6.25± 12.5	9.33± 10.93	8± 19.6
Taiga Flycatcher	*Ficedula albicilla* (Pallas, 1811)	-	-	-	2.17 ± 2.4
Temminck's Stint	*Calidris temminckii* (Leisler, 1812)	-	-	-	0.5 ± 1.22
Tufted Duck	*Aythya fuligula* (Linnaeus, 1758)	-	-	33.5± 43.05	72.33 ± 80.5
Western Yellow Wagtail	*Motacilla flava (*Linnaeus, 1758)	-	-	2.67± 3.33	2.67 ± 4.84
White Wagtail	*Motacilla alba (*Linnaeus, 1758)	-		9.5 ± 9.07	6 ± 9.38
White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant, 1769)	50± 10	54.5 ± 24.28	51.67 ± 22.78	39.33 ± 13.05
White-browed Wagtail	*Motacilla maderaspatensis (*J.F. Gmelin, 1789)	-	-	5.33 ± 6.65	3.33 ± 5.32
White-tailed Lapwing	*Vanellus leucurus* (M.H.C. Lichtenstein, 1823)		-	5 ± 3.03	4.33 ± 5.13
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	8.33 ± 2.89	7.75 ± 5.5	8.5 ± 4.89	8.67 ± 3.98
Wire-tailed Swallow	*Hirundo smithii (*Leach, 1818)	-	6.25 ± 12.5	31.17 ± 38.47	12 ± 29.39
Wood Sandpiper	*Tringa glareola (*Linnaeus, 1758)	-	-	1.67 ± 2.66	3 ± 4.69
Woolly-necked Stork	*Ciconia episcopus* (Boddaert, 1783)	-	-	2.67 ± 4.13	2 ± 4.9
Zitting Cisticola	*Cisticola juncidis* (Rafinesque, 1810)		-	0.5 ±1.22	-

Sandy habitat

A Sandy habitat near a wetland is situated in the western region of HWS and is essential to the survival of birds. For diverse bird species, the region offer vital nesting locations, foraging possibilities, and refuge. The loose, well-drained nature of sandy soil allows birds to construct their nests securely, protecting their eggs and young from potential predators. Additionally, the presence of sand allows birds to engage in dust bathing, an important behavior for maintaining feather health and reducing parasites. Sandy habitats also harbor a diverse range of invertebrates, which serve as a crucial food source for birds, especially shorebirds and waterfowl. The Sandy habitat in HWS is primarily characterized by the dominance of two grass species, *Saccharum spontaneum* and *Saccharum munja*. Which thrive best in the sandy soil, forming dense stands that create a unique habitat. *Saccharum spontaneum*, commonly known as wild sugarcane, is a tall, perennial grass with stout stems and long, slender leaves. It adapts well to sandy conditions, with its deep root system effectively anchoring it in the loose soil. The grass can reach impressive heights, often exceeding three meters. Its foliage provides shade and shelter for various organisms living within the habitat.

Fig 6.17: Sandy habitat dominated by *Saccharum spontaneum* and *Saccharum munja*.

Saccharum munja, also called munj grass, shares many characteristics with *Saccharum spontaneum*. It is a tall, coarse grass with sturdy stems and narrow leaves. This species has evolved to thrive in sandy environments, displaying exceptional resilience to drought and high temperatures. Like its counterpart, *Saccharum munja* plays a crucial role in shaping the sandy habitat's structure and function. Together, these two dominant grass species create a dynamic and productive ecosystem. Their extensive root systems stabilize the sandy soil, preventing erosion and providing a foundation for other plant and animal species. The dense stands of grasses offer protection to a diverse range of organisms, including insects, reptiles, birds, and small mammals. Without the availability of sandy habitats within wetlands, the populations and ecological balance of numerous bird species would be significantly impacted.

Diversity and abundance of avian species

In the summer season a community of total 39 avian species were recorded. The abundance, species richness (S), Shannon-Weiner Diversity Index (H′) and Evenness (J') and of birds is also calculated for the month of April 2020 (S=31, H'=2.49, J'=0.39), May 2020 (S=26, H'=2.19, J'=0.34), and June 2020 (S=30, H'=2.58, J'=0.44) Mean abundance of bird species recorede which includes Cattle Egret (*Bubulcus ibis*) 68.67±20.26, followed by Indian Spot-billed Duck (*Anas poecilorhyncha*) 58.33±13.65, Little Cormorant (*Microcarbo niger*) 11.33±3.51, Baya Weaver (*Ploceus philippinus*) 9.33±6.43, Red-wattled Lapwing (*Vanellus indicus*) 6.33±2.08, Common Myna (*Acridotheres tristis*) 6±5.29, Painted Stork (*Mycteria leucocephala*) 6±4.36, House Sparrow (*Passer domesticus*) 5.33±2.08, Green Bee-eater (*Merops orientalis*) 4.67±2.52, Little Egret (*Egretta garzetta*) 4.33±1.53, Grey-throated Martin (*Riparia paludicola*) 4±3.61, and Indian Pond-Heron (*Ardeola grayii*) 4±1, Streaked Weaver (*Ploceus manyar*) 3.67±2.08, Ashy Prinia (*Prinia socialis*) 3±1, Oriental Darter (*Anhinga melanogaster*) 3±2, White-throated Kingfisher (*Halcyon smyrnensis*) 3±1, Black Drongo (*Dicrurus macrocercus*) 2.67±2.31, Lesser Whistling-Duck (*Dendrocygna javanica*) 2.67±3.06.

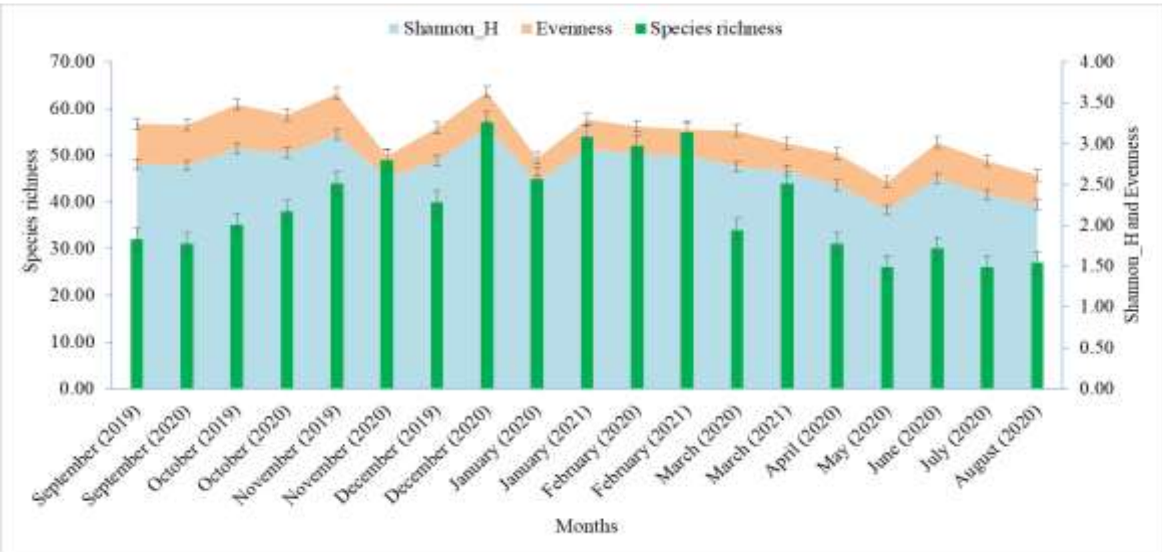


Fig 6.18: Pattern of avian diversity in Sandy habitat.

In the monsoon season, an assemblage of avian species in sandy wetlands includes 45 species and diversity of birds in July 2020 (S=26, H'=2.37, J'=0.41), August 2020 (S=27, H'=2.26, J'=0.35), September 2019 (S=32, H'=2.75, J'=0.49), September (2020) (S=31, H'=2.74, J'=0.50) were estimated based on systematic observation in the habitat, diversity. The maximum mean abundance is recorded for Cattle Egret (*Bubulcus ibis*) 56.25±18.30, followed by Little Cormorant (*Microcarbo niger*) 41.25±27.54, Indian Spot-billed Duck (*Anas poecilorhyncha*) 25±14.54, Baya Weaver (*Ploceus philippinus*) 24.25±17.33, Common Myna (*Acridotheres tristis*) 6±4.32, Indian Cormorant (*Phalacrocorax fuscicollis*) 6±3.74, White-throated Kingfisher (*Halcyon smyrnensis*) 5.5±2.52, Little Egret (*Egretta garzetta*) 4.75±2.06, Painted Stork (*Mycteria leucocephala*) 4.75±2.06, Green Bee-eater (*Merops orientalis*) 4.5±4.65, Brown-headed Gull (*Chroicocephalus brunnicephalus*) 4±5.23, Streaked Weaver (*Ploceus manyar*) 4±3.65, Black-headed Gull (*Chroicocephalus ridibundus*) 3.75±4.50, Indian Pond-Heron (*Ardeola grayii*) 3.75±1.50, Red-wattled Lapwing (*Vanellus indicus*) 3.00±1.63, Oriental Darter (*Anhinga melanogaster*) 2.75± 0.96, Ashy Prinia (*Prinia socialis*) 2.25±0.50, Grey-throated Martin (*Riparia paludicola*) 2.25±2.87, Paddyfield Pipit (*Anthus rufulus*) 2.25±2.22, Indian Silverbill (*Euodice malabarica*) 2±1.63, Plain Prinia (*Prinia inornata*) 1.75±0.96, House Sparrow (*Passer domesticus*) 1.5±3, Red-naped Ibis (*Pseudibis papillosa*) 1.50±1.91,Common Moorhen (*Gallinula chloropus*) 1.25±1.50.

Fig 6.19: Avian community of Sandy habitat (1: Little Cormorant, 2: Isabelline Shrike, 3: Indian Silverbill, 4: Brown Rock Chat, 5: Asian Woolly necked stork)

In the post- monsoon season community of total 76 species of birds were recorded from sandy habitats besides diversity indices were calculated for October 2019 (S=35, H'=2.94, J'=0.54), and October 2020 (S=38, H'=2.88, J'=0.47), November 2019 (S=44, H'=3.11, J'=0.51), and November 2020 (S=49, H'=2.58, J'=0.27), December 2019 (S=40, H'=2.79, J'=0.41), and December 2020 (S=57, H'=3.20, J'=0.43) In this season sandy habitat receives fresh layer of sand due to flood water. Floods also bring many aquatic vegetation and organism in the sandy habitat which are an addition to food stock for avian species. In the month of October, November, and December the highest mean abundance of avian species were found for Little Cormorant (*Microcarbo niger*) 58.67±55.42, Cattle Egret (*Bubulcus ibis*) 56.67±29.88, Greylag Goose (*Anser anser*) 42.83±52.99, Great Cormorant (*Phalacrocorax carbo*) 39.33±15.13, Eurasian Coot (*Fulica atra*) 30.5±14.38, Bar-headed Goose(*Anser indicus*) 23.00±26.22, Indian Spot-billed Duck (*Anas poecilorhyncha*) 11.17±10.57, Black-headed Gull (*Chroicocephalus ridibundus*) 10.83±5.34, Common Teal (*Anas crecca*) 8.33±12.93, Northern Shoveler (*Spatula clypeata*) 7.67±7, Brown-headed Gull (*Chroicocephalus brunnicephalus*) 7.50±3.08, Baya Weaver (Ploceus philippinus) 7.33±15.21, Common Myna (*Acridotheres tristis*) 6.33±5.01, Indian Cormorant (*Phalacrocorax fuscicollis*) 5.83±5.74, Pied Avocet (*Recurvirostra avosetta*) 5.67±5.16, Pallas's Gull (*Ichthyaetus ichthyaetus*) 5.5±6.32, Red-wattled Lapwing (*Vanellus indicus*) 5±2, Painted Stork (*Mycteria leucocephala*) 4.33±2.42.

In winter season a total of 80 species of birds were recorded in which there are many winter migrant utilise this habitat for couples of months, avian diversity in the month of January 2020 (S=45.00, H'=2.54, J'=0.28) and January 2021 (S=54.00, H'=2.94, J'=0.35), February 2020 (S=52.00, H'=2.87, J'=0.34), and February 2021 (S=55.00, H'=2.86, J'=0.32), March 2020 (S=34.00, H'=2.72, J'=0.44),and March 2021 (S=44.00, H'=2.67, J'=0.33) with mean abundance of birds like Little Cormorant (*Microcarbo niger*) 73.17±66.42 followed by Cattle Egret (*Bubulcus ibis*) 57.67±26.81, Greylag Goose (*Anser anser*) 54.33±52.51 Bar-headed Goose (*Anser indicus*) 47.33±50.85, Great Cormorant (*Phalacrocorax carbo*) 39.5±32.09, Indian Spot-billed Duck (*Anas poecilorhyncha*) 32.83±23.16, Black-tailed Godwit (*Limosa limosa*) 32.50 ±11.31 Eurasian Coot (*Fulica atra*) 32.5±24.50, Common Teal (*Anas crecca*) 31.00 ±56.82, Baya Weaver (*Ploceus philippinus*)17.33±27.95, Black-headed Gull (*Chroicocephalus ridibundus*) 14.33±16.60, Gadwall (*Mareca strepera*) 8.00 ±9.98,Northern Shoveler (*Spatula clypeata*) 6.5±5.82.

Table 6.6: Structure of avian community and seasonal abundance in Sandy habitat.

Common name	Scientific name	Summer	Monsson	Post-monsoon	Winter
Ashy Prinia	*Prinia socialis* Sykes, 1832	3 ±1.00	2.25 ± 0.50	2.67 ± 1.21	2.17 ± 1.17
Bar-headed Goose	*Anser indicus* (Latham, 1790)	-	-	23 ±26.22	47.33 ±50.85
Baya Weaver	*Ploceus philippinus* (Linnaeus, 1766)	9.33±6.43	24.25±17.33	7.33 ±15.21	17.33±27.95
Black Drongo	*Dicrurus macrocercus* Vieillot, 1817	2.67±2.31	0.5±1.00	3 ±1.26	1.33±1.03
Black Redstart	*Phoenicurus ochruros* (S.G. Gmelin, 1774)	-	-	0.17 ±0.41	0.33±0.52
Black-headed Gull	*Chroicocephalus ridibundus* (Linnaeus, 1766)	-	3.75±4.50	10.83 ±5.34	14.33±16.60
Black-headed Ibis	*Threskiornis melanocephalus* (Latham, 1790)	-	-	1.17 ±1.33	1±1.67
Black-tailed Godwit	*Limosa limosa* (Linnaeus, 1758)	-	-	6.5±5.43	32.5±11.31
Bluethroat	*Luscinia svecica* (Linnaeus, 1758)	-	-	0.5±0.84	0.33±0.82
Blyth's Reed Warbler	*Acrocephalus dumetorum* Blyth, 1849	-	0.25±0.50	0.17±0.41	00
Brown Rock Chat	*Oenanthe fusca* (Blyth, 1851)	0.67±1.15	0.75±0.96	1.5±1.64	1.17±0.98
Brown-headed Gull	*Chroicocephalus brunnicephalus* (Jerdon, 1840)	-	4±5.23	7.5±3.08	6.33±8.59
Caspian Gull	*Larus cachinnans* Pallas, 1811	-	-	-	0.83±1.33
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	68.67±20.26	56.25±18.30	56.67±29.88	57.67±26.81
Citrine Wagtail	*Motacilla citreola* Pallas, 1776	-	-	0.17±0.41	0.17±0.41
Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	2±2.00	1.25±1.50	2.67±2.25	3.33±2.80
Common Myna	*Acridotheres tristis* (Linnaeus, 1766)	6±5.29	6±4.32	6.33±5.01	4±3.16
Common Pochard	*Aythya ferina* (Linnaeus, 1758)	-	-	3.67±7.20	5.67±9.56
Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	1.33±1.53	0.5±0.58	1±1.10	0.5±0.55
Common Teal	*Anas crecca* Linnaeus, 1758	-	-	8.33±12.93	31±56.82
Common Tern	*Sterna hirundo* Linnaeus, 1758	-	-	0.17±0.41	0.33±0.82
Crested Lark	*Galerida cristata* (Linnaeus, 1758)	-	-	1±1.10	0.83±1.17
Eurasian Coot	*Fulica atra* Linnaeus, 1758	-	1±2.00	30.5±14.38	32.5±24.50
Eurasian Hoopoe	*Upupa epops* Linnaeus, 1758	1±1.00	1±0.82	1.17±1.17	1.33±1.21
Eurasian Marsh-Harrier	*Circus aeruginosus* (Linnaeus, 1758)	-	-	1±0.89	1.5±1.05
Eurasian Sparrowhawk	*Accipiter nisus* (Linnaeus, 1758)	-	-	-	0.17±0.41
Eurasian Wigeon	*Mareca penelope* (Linnaeus, 1758)	-	-	1.17±1.33	1.67±2.34
Eurasian Wryneck	*Jynx torquilla* Linnaeus, 1758	-	-	0.17±0.41	0.17±0.41

Gadwall	*Mareca strepera* (Linnaeus, 1758)	-	-	1±2.45	8±9.98
Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	-	-	2.17±1.60	2.67±2.50
Graceful Prinia	*Prinia gracilis* (M.H.C. Lichtenstein, 1823)	0.67±0.58	0.5±0.58	0.5±0.55	0.67±0.52
Great Cormorant	*Phalacrocorax carbo* (Linnaeus, 1758)	-	-	39.33±15.13	39.5±32.09
Green Bee-eater	*Merops orientalis* Latham, 1801	4.67±2.52	4.5±4.65	3.67±3.20	3.83±4.58
Grey Wagtail	*Motacilla cinerea* Tunstall, 1771	-	-	0.33±0.52	0.33±0.82
Greylag Goose	*Anser anser* (Linnaeus, 1758)	-	-	42.83±52.99	54.33±52.51
Grey-throated Martin	*Riparia paludicola* (Vieillot, 1817)	4±3.61	2.25±2.87	2±2.45	3.83±4.31
Gull-billed Tern	*Gelochelidon nilotica* (J.F. Gmelin, 1789)	-	-	-	0.17±0.41
House Sparrow	*Passer domesticus* (Linnaeus, 1758)	5.33±2.08	1.5±3.00	4±4.43	2.83±1.72
Indian Bushlark	*Mirafra erythroptera* Blyth, 1845	0.33±0.58	0.75±0.96	0.17±0.41	0.67±0.82
Indian Cormorant	*Phalacrocorax fuscicollis* Stephens, 1826	1±1.73	6±3.74	5.83±5.74	6.33±5.32
Indian Pond-Heron	*Ardeola grayii* (Sykes, 1832)	4±1.00	3.75±1.50	4.83±3.37	5.33±2.16
Indian Robin	*Saxicoloides fulicatus* (Linnaeus, 1766)	1.33±1.53	0.25±0.50	1±0.89	1.17±0.98
Indian Silverbill	*Euodice malabarica* (Linnaeus, 1758)	2±1.73	2±1.63	2±1.90	2.5±2.35
Indian Spot-billed Duck	*Anas poecilorhyncha* J.R. Forster, 1781	58.33±13.65	25±14.54	11.17±10.57	32.83±23.16
Intermediate Egret	*Ardea intermedia* Wagler, 1829	-	-	0.33±0.52	0.17±0.41
Isabelline Shrike	*Lanius isabellinus* Hemprich & Ehrenberg, 1833	-	-	0.83±0.98	0.67±0.52
Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield, 1821)	2.67±3.06	1±2.00	-	-
Little Cormorant	*Microcarbo niger* (Vieillot, 1817)	11.33±3.51	41.25±27.54	58.67±55.42	73.17±66.42
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	4.33±1.53	4.75±2.06	4.5±1.52	4.17±1.33
Little Grebe	*Tachybaptus ruficollis* (Pallas, 1764)	0.67±1.15	0.75±1.50	2±1.41	0.83±0.98
Long-tailed Shrike	*Lanius schach* Linnaeus, 1758	10	0.5±0.58	0.33±0.52	0.67±0.52
Northern Pintail	*Anas acuta* Linnaeus, 1758	-	-	3±2.83	3±5.02
Northern Shoveler	*Spatula clypeata* (Linnaeus, 1758)	-	-	7.67±7.00	6.5±5.82
Oriental Darter	*Anhinga melanogaster* Pennant, 1769	3±2.00	2.75±0.96	3.67±1.37	3.83±1.72
Oriental Magpie-Robin	*Copsychus saularis* (Linnaeus, 1758)	0.33±0.58	1.25±0.96	0.83±0.75	0.67±0.82
Oriental Skylark	*Alauda gulgula* Franklin, 1831	0.67±0.58	0.5±0.58	0.33±0.52	0.17±0.41
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	-	-	0.17±0.41	0.33±0.52
Paddyfield Pipit	*Anthus rufulus* Vieillot, 1818	0.33±0.58	2.25±2.22	1.83±1.60	1.5±1.05

Painted Stork	*Mycteria leucocephala* (Pennant, 1769)	6±4.36	4.75±2.06	4.33±2.42	2.67±1.75
Pallas's Gull	*Ichthyaetus ichthyaetus* (Pallas, 1773)	-	-	5.5±6.32	3±5.02
Pied Avocet	*Recurvirostra avosetta* Linnaeus, 1758	-	-	5.67±5.16	2.83±3.13
Pied Bushchat	*Saxicola caprata* (Linnaeus, 1766)	0.67±1.15	1±0.82	0.83±0.98	1.33±1.03
Plain Prinia	*Prinia inornata* Sykes, 1832	2.67±1.53	1.75±0.96	1.83±0.98	1.83±0.98
Purple Heron	*Ardea purpurea* Linnaeus, 1766	1±1.00	1±0.82	0.67±0.52	0.83±0.41
Red-crested Pochard	*Netta rufina* (Pallas, 1773)	-	-	0.33±0.82	-
Red-naped Ibis	*Pseudibis papillosa* (Temminck, 1824)	2±1.00	1.5±1.91	1.5±1.38	1.83±1.83
Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	6.33±2.08	3±1.63	5±2.00	5.5±2.88
River Tern	*Sterna aurantia* J.E. Gray, 1831	-	-	4.17±2.71	2.33±1.37
Ruddy Shelduck	*Tadorna ferruginea* (Pallas, 1764)	-	-	-	5±7.85
Rufous-fronted Prinia	*Prinia buchanani* Blyth, 1844	0.33±0.58	0.25±0.50	-	0.17±0.41
Sand Lark	*Alaudala raytal* (Blyth, 1845)	-	-	0.5±0.84	1.17±0.98
Scaly-breasted Munia	*Lonchura punctulata* (Linnaeus, 1758)	0.33±0.58	1.25±1.50	0.67±1.03	1.17±1.60
Siberian Stonechat	*Saxicola maurus* (Pallas, 1773)	-	-	0.5±1.22	0.5±0.84
Sind Sparrow	*Passer pyrrhonotus* Blyth, 1845	-	1±2.00	1±1.10	1.67±1.37
Steppe Eagle	*Aquila nipalensis* Hodgson, 1833	-	-	-	0.17±0.41
Streaked Weaver	*Ploceus manyar* (Horsfield, 1821)	3.67±2.08	4±3.65	1±1.67	1.67±2.07
Temminck's Stint	*Calidris temminckii* (Leisler, 1812)	-	-	0.67±1.03	0.67±0.82
Western Yellow Wagtail	*Motacilla flava* Linnaeus, 1758	-	0.5±1.00	0.33±0.52	0.67±0.82
White Wagtail	*Motacilla alba* Linnaeus, 1758	-	-	2.17±1.17	1.5±0.84
White-browed Wagtail	*Motacilla maderaspatensis* J.F. Gmelin, 1789	-	-	0.33±0.82	1.5±1.22
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	3±1.00	5.5±2.52	3.33±1.86	3.5±1.05
A.Woolly-necked Stork	*Ciconia episcopus* (Boddaert, 1783)	-	-	0.33±0.82	-
Yellow-bellied Prinia	*Prinia flaviventris* (Delessert, 1840)	1±1.00	0.5±0.58	0.17±0.41	0.83±0.41
Zitting Cisticola	*Cisticola juncidis* (Rafinesque, 1810)	-	-	-	0.17±0.41

Swampy habitat

Harike Wildlife Sanctuary is a refuge for avian aficionados and wildlife lovers, located in the rich plains of Punjab, India. This spectacular Sanctuary, which spans the junction of the Beas and Sutlej rivers, is home to a wide variety of bird species and provides a special environment for both resident and migratory birds. The common reed, Phragmites karka, and its marshy habitats, as well as the presence of trees that further increase the Sanctuary's biological significance, are some of the significant characteristics of Harike Wildlife Sanctuary. The trees and Swampy habitats are essential for maintaining the region's general biodiversity as well as the avian population. For birds, *Phragmites karka* dominance in the Swampy habitats of Harike Wildlife Sanctuary is of utmost significance. This tall, perennial grass grows in dense clumps that contribute to the creation of a sophisticated ecosystem within the Swamp. For many number of bird species, the reeds provide a places to nest. Purple Heron (*Ardea purpurea*) and Indian Pond Heron (*Ardeola grayii*) use *Phragmites karka* as nesting material. The reeds' dense growth screens the birds from disturbances and protects them from predators, enabling them to nest and raise their chicks in a safe environment.

Fig 6.20: Swampy habitat dominated by *Phragmites karka* along Beas River.

Furthermore, the swampy areas where *Phragmites* predominates offer an ample food source for bird occupants. Many bird species depend on the insects, tiny crustaceans, and other invertebrates that the reeds attract for their food. Additionally, the dense stands are home to a variety of plant species, including aquatic flora, which gives waterbirds like Common Moorhen (*Gallinula chloropus*) and Indian Spot-billed Duck (*Anas poecilorhyncha*) more foraging options. Bird populations are sustained year-round by the presence of such a productive ecosystem, ensuring their survival and enhancing the natural harmony of Harike Wildlife Sanctuary. The Sanctuary's trees add to the diversity of habitats and ecological value in addition to the Swampy habitats dominated by *Phragmites karka*. Within the Sanctuary, trees like Kikar (*Vachellia nilotica*), Neem (*Azadirachta indica*), and Shisham (*Dalbergia sissoo*) help to form a mosaic of habitats. For different bird species, these trees serve as perches, breeding locations, and roosting areas. Raptors like Oriental Honey-buzzard (*Pernis ptilorhynchus*), Indian Spotted Eagle (*Clanga hastata*) and Shikra (*Accipiter badius*) frequently use the trees as vantage points for hunting.

The Indian Grey Hornbill (*Ocyceros birostris*), which breeds in tree cavities, find places to nest among the big trees that line the riverbanks. Additionally, the trees at Harike Wildlife Sanctuary support the area's general ecological stability. They create microclimates that support a variety of understory plants by assisting in soil stabilization, preventing erosion, and offering shade. In turn, these understory plants draw insects and other invertebrates, which are a source of food for many different bird species. The combination of trees and other plant species within the Sanctuary produces a complex vegetation structure that maintains a healthy and balanced ecology, supporting a rich bird community. The Harike Wildlife Sanctuary's wetland ecosystems, which are dominated by *Phragmites karka* and trees, require long-term conservation efforts.

Diversity and abundance

The swampy habitat is one of the largest habitats in the HWS, the avian community is comprised of a total of 64 species, which accounts for 31% of the total avian species recorded during this study. Species richness (S), diversity (H')evenness (J') and mean abundance were calculated from field data for the months of summer season such as April 2020 (S=37, H'=2.81, J'=0.45), May 2020 (S=40, H'=2.92, J'=0.46), and June 2020 (S=39, H'=2.87, J'=0.45) and highest mean abundance in summer season is shown by Green Bee-eater (*Merops orientalis*) 126±44.19, followed by Cattle Egret (*Bubulcus ibis*) 77.33±4.93, Black-crowned Night-Heron (*Nycticorax nycticorax*) 75.67± 8.08, Baya Weaver *(Ploceus philippinus*) 69.00 ± 16.09, House Sparrow (*Passer domesticus*) 62.33±44.09, Common Moorhen (*Gallinula chloropus*) 37.33±26.16, Rose-ringed Parakeet (*Psittacula krameri*) 35±1, Rosy Starling (*Pastor roseus*) 34±27.22, Black-breasted Weaver (*Ploceus benghalensis*) 33.67±11.50, Red-vented Bulbul (*Pycnonotus cafer*) 30.33±14.19, Indian Silverbill (*Euodice malabarica*) 27.33±9.87, Red Munia (*Amandava amandava*) 25.33±15.37, Grey-headed Swamphen (*Porphyrio porphyria*)

22±3, Striated Babbler (*Argya earlei*) 20.67±6.81, Jungle Babbler (*Turdoides striata*) 12.33±4.04, Pheasant-tailed Jacana (*Hydrophasianus chirurgus*) 12.33±2.52, and Red-naped Ibis (*Pseudibis papillosa*) 12±5.

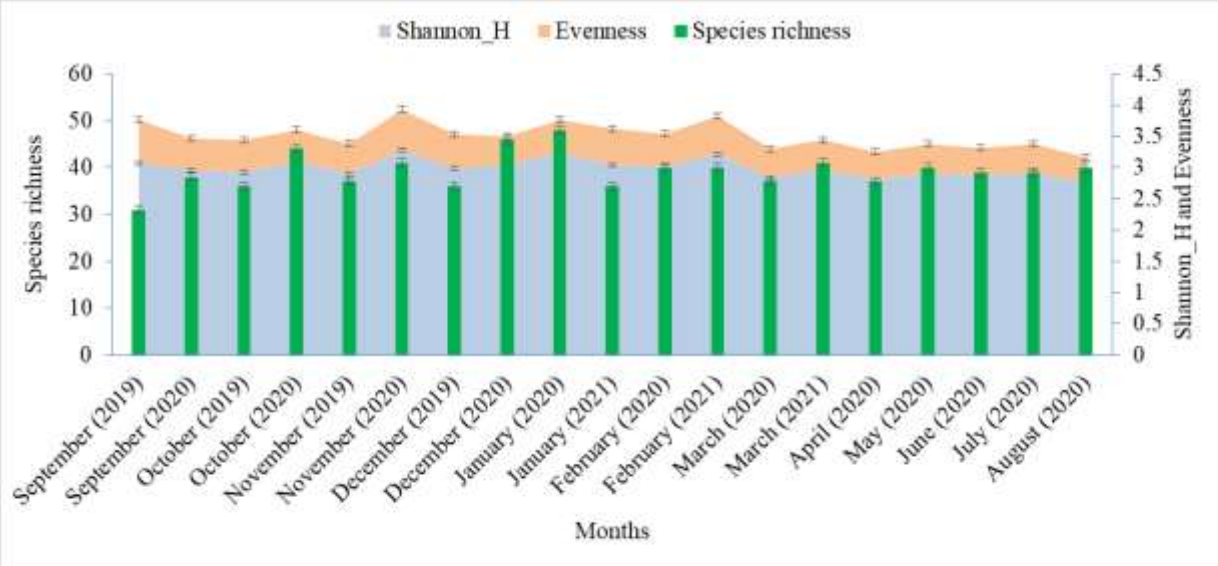


Fig 6.21: Seasonal variation in avian diversity at Swampy habitat.

In the monsoon season variation in the avian community can be seen. A total of 42 species of birds were documented from the files survey. It accounts for 20.48 % of the total avian species recoded in the HWS across the year. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for July 2020 (S=39, H’=2.91, J’=0.47), August 2020 (S=40, H’=2.77, J’=0.40) Highest mean abundance is recorded for Cattle Egret (*Bubulcus ibis*) 113.75±91.46, Green Bee-eater (*Merops orientalis*) 165.5±61.72, House Sparrow (Passer domesticus) 60.25 ±26.58, Black-crowned Night-Heron (*Nycticorax nycticorax*) 49.75±31.01, Baya Weaver (*Ploceus philippinus*) 38.75±2.53, Red Munia (*Amandava amandava*) 29.5±16.98, Some species with low mean abundance in monsoon season was observed, including species like Plain Prinia (*Prinia inornata*) 1±0.82, followed by Purple Heron (*Ardea purpurea*) 1±0.82, Jungle Prinia (*Prinia sylvatica*) 0.75±0.50, Yellow-bellied Prinia (*Prinia flaviventris*) 0.75±0.50 Graceful Prinia (*Prinia gracilis*) 0.5±0.58, and Blyth's Reed Warbler (*Acrocephalus dumetorum*) 0.25±0.50.

In the Post-monsoon season variation in the community composition of avian species had been recorded. A total of 58 bird species were observed in the post-monsoon season, it accounts for 28.29% of the total species observed in the present study across the habitat types in a year.

Fig 6.22: Bird's community in Swampy habitat (1: Eurasian marsh-harrier, 2: Purple Heron, 3: Cattle Egret, 4: Glossy Ibis, 5: Red Munia, 6: Greater Coucal, 7: Indian Pond-Heron)

Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for the post-monsoon month of October 2019 (S=36, H'=2.93, J'=0.52), and October 2020 (S=44, H'=3.10, J'= 0.50), November 2019 (S=37, H'=2.90, J'=0.49), and November 2020 (S=41, H'=3.28, J'=0.65), December 2019 (S=36, H'=2.99, J'=0.55) and December 2020 (S=46, H'=3.05, J'=0.46). The mean abundance of each species were recorded, maximum mean abundance is observed for Cattle Egret (*Bubulcus ibis*) 43.5±33.38, followed by House Sparrow (*Passer domesticus*) 39±19.24, Grey-headed Swamphen (*Porphyrio porphyria*) 28.67±11.52, Common Moorhen (*Gallinula chloropus*) 24.67±8.64, Rose-ringed Parakeet (*Psittacula krameri*) 21.67±5.79, Jungle Babbler (*Turdoides striata*) 17.33±4.27, Red Munia (*Amandava amandava*) 15±4.52, Indian Silverbill (*Euodice malabarica*) 14.67±7.58, Red-vented Bulbul (*Pycnonotus cafer*) 13.33±7.31, Striated Babbler (*Argya earlei*) 11.83±3.82, Rosy Starling (*Pastor roseus*) 11.5±16.69, Glossy Ibis (*Plegadis falcinellus*) 11.33±21.45, Baya Weaver(*Ploceus philippinus*) 11±21.61, Indian Spot-billed Duck (*Anas poecilorhyncha*) 10.33±5.16, Bank Myna (*Acridotheres ginginianus*) 7.5±4.28, Red-naped Ibis (*Pseudibis papillosa*) 7±1.10, and Green Bee-eater (*Merops orientalis*) 6±5.97 similarly some species with low mean abundance were recorded for Jungle Prinia (*Prinia sylvatica*) 0.33±0.52, followed by Osprey (*Pandion haliaetus*) 0.33±0.52, Rufous-fronted Prinia (*Prinia buchanani*) 0.33±0.52, Blyth's Reed Warbler (*Acrocephalus dumetorum*) 0.17±0.41, Clamorous Reed Warbler (*Acrocephalus stentoreus*) 0.17±0.41, and Graceful Prinia (*Prinia gracilis*) 0.17±0.41.

Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for the month of January 2020 (S=48, H'=3.23, J'=0.530), and January 2021 (S=36, H'=3.04, J'=0.58), February 2020 (S=40, H'=3.03, J'=0.52), and February 2021 (S=40, H'=3.21, J'=0.62), March 2020 (S=37, H'=2.84, J'=0.46), and March 2021 (S=41, H'=2.97, J'=0.48) diversity of birds were observed with mean abundance of recorded species like House Sparrow (*Passer domesticus*) 52.17±39.20, followed by Cattle Egret (*Bubulcus ibis*) 44.17±24.41, Grey-headed Swamphen (*Porphyrio porphyria*) 29.67±7.26, Baya Weaver (*Ploceus philippinus*) 24.17±34.16, Rose-ringed Parakeet (*Psittacula krameri*) 24±12.96, Common Moorhen (*Gallinula chloropus*) 21.83±9.64, Jungle Babbler (*Turdoides striata*) 17.17±5.95, Red Munia (*Amandava amandava*) 16.5±7.45, Red-vented Bulbul (*Pycnonotus cafer*) 16.17±6.94, Indian Spot-billed Duck (*Anas poecilorhyncha*) 15±11.26, Indian Silverbill (*Euodice malabarica*) 10.83±6.15, Black-crowned Night-Heron (*Nycticorax nycticorax*) 9.5±13.87, Red-naped Ibis (*Pseudibis papillosa*) 9.5±4.32, Details of mean abundance are given in Table 6.6

Table 6.7: Structure of avian community and seasonal abundance in Swampy habitat.

Common species	Scientific name	Summer	Monsoon	Post-monsoon	Winter
Ashy Prinia	*Prinia socialis* Sykes, 1832	4.33± 1.53	4± 1.15	3.33± 1.21	3.17± 0.98
Bank Myna	*Acridotheres ginginianus* (Latham, 1790)	2.67± 4.62	3± 3.56	7.5± 4.28	9.33± 4.46
Baya Weaver	*Ploceus philippinus* (Linnaeus, 1766)	69± 16.09	38.75± 32.53	11± 21.61	24.17± 34.16
Black Bittern	*Ixobrychus flavicollis* (Latham, 1790)	0.67± 0.58	1± 0.00	0.33± 0.52	0.17± 0.41
Black Drongo	*Dicrurus macrocercus* Vieillot, 1817	4.67± 1.53	4.75± 1.50	4.17± 1.33	3.83± 1.94
Black-breasted Weaver	*Ploceus benghalensis* (Linnaeus, 1758)	33.67± 11.50	4.25± 3.10	1.5± 2.74	-
Black-crowned Night-Heron	*Nycticorax nycticorax* (Linnaeus, 1758)	75.67± 8.08	49.75± 31.01	3.67± 6.50	9.5± 13.87
Black-headed Ibis	*Threskiornis melanocephalus* (Latham, 1790)	-	-	1.5± 1.76	2.5± 2.81
Blue-tailed Bee-eater	*Merops philippinus* Linnaeus, 1767	-	7± 7.02	-	-
Black-tailed Godwit	*Limosa limosa* (Linnaeus, 1758)	-	-	2± 2.53	2± 2.53
Bluethroat	*Luscinia svecica* (Linnaeus, 1758)	-	-	3.33± 2.80	3.83± 2.32
Blyth's Reed Warbler	*Acrocephalus dumetorum* Blyth, 1849	1± 0.00	0.25± 0.50	0.17± 0.41	0.33± 0.52
Booted Warbler	*Iduna caligata* (M.H.C. Lichtenstein, 1823)	-	-	-	0.5± 0.55
Brown Crake	*Zapornia akool* (Sykes, 1832)	0.67± 0.58	1± 0.00	1± 0.00	0.17± 0.41
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	77.33± 4.93	113.75± 91.46	43.5± 33.38	44.17± 24.41
Cinnamon Bittern	*Ixobrychus cinnamomeus* (J.F. Gmelin, 1789)	-	-	0.67± 0.52	0.33± 0.82
Clamorous Reed Warbler	*Acrocephalus stentoreus* (Hemprich & Ehrenberg,1833)	-	-	0.17± 0.41	0.5± 0.84
Common Babbler	*Argya caudata* (Dumont, 1823)	7± 1.00	3.75± 2.63	2.33± 2.73	3.5± 2.26
Common Chiffchaff	*Phylloscopus collybita* (Vieillot, 1817)	-	-	1.17± 0.75	0.33± 0.52
Common Moorhen	*Gallinula chloropus* (Linnaeus, 1758)	37.33± 26.16	22.5± 7.51	24.67± 8.64	21.83± 9.64
Common Snipe	*Gallinago gallinago* (Linnaeus, 1758)	-	-	0.33± 0.52	0.17± 0.41
Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	1.33± 0.58	1.75± 0.96	1.33± 1.37	1.67± 1.21
Eurasian Marsh-Harrier	*Circus aeruginosus* (Linnaeus, 1758)	-	-	3.67± 2.34	6.33± 3.39
Glossy Ibis	*Plegadis falcinellus* (Linnaeus, 1766)	-	-	11.33± 21.45	7.33± 5.85
Graceful Prinia	*Prinia gracilis* (M.H.C. Lichtenstein, 1823)	0.67± 0.58	0.5± 0.58	0.17± 0.41	0.5± 0.84

Greater Coucal	*Centropus sinensis* (Stephens, 1815)	4± 2.65	3.5± 1.91	2.83± 1.94	4± 2.37
Green Bee-eater	*Merops orientalis* Latham, 1801	126± 44.19	65.5± 61.72	6± 5.97	4± 9.80
Grey Heron	*Ardea cinerea* Linnaeus, 1758	5± 1.00	3.5± 2.08	3.5± 1.87	3.5± 1.52
Grey-headed Swamphen	*Porphyrio porphyrio* (Linnaeus, 1758)	22± 3.00	27.5± 12.15	28.67± 11.52	29.67± 7.26
House Sparrow	*Passer domesticus* (Linnaeus, 1758)	62.33± 44.09	60.25± 26.58	39± 19.24	52.17± 39.20
Hume's Leaf Warbler	*Abrornis humei* (W.E. Brooks, 1878	-	-	0.33± 0.52	0.17± 0.41
Indian Pond-Heron	*Ardeola grayii* (Sykes, 1832)	1.33± 0.58	4.75± 0.96	5.67± 1.97	3± 2.10
Indian Robin	*Saxicoloides fulicatus* (Linnaeus, 1766)	0.33± 0.58		1± 0.89	1.33± 1.03
Indian Silverbill	*Euodice malabarica* (Linnaeus, 1758)	27.33± 9.87	17.25± 7.04	14.67± 7.58	10.83± 6.15
Indian Spot-billed Duck	*Anas poecilorhyncha* J.R. Forster, 1781	5± 2.65	19± 9.42	10.33± 5.16	15± 11.26
Intermediate Egret	*Ardea intermedia* (Wagler, 1829)	-	-	1± 1.26	2.17± 1.17
Jerdon's Babbler	*Chrysomma altirostre* (Jerdon, 1862)	1.67± 2.08	-	1± 1.10	0.5± 1.22
Jungle Babbler	*Turdoides striata* (Dumont, 1823)	12.33± 4.04	16.5± 4.73	17.33± 4.27	17.17± 5.95
Jungle Prinia	*Prinia sylvatica* (Jerdon, 1840)	-	0.75± 0.50	0.33± 0.52	0.5± 0.55
Large Gray Babbler	*Argya malcolmi* (Sykes, 1832)	3.67± 1.15	6.25± 2.06	3.17± 1.17	5.33± 3.39
Lesser Whistling-Duck	*Dendrocygna javanica* (Horsfield, 1821)	7± 4.58	10.75± 10.87	-	-
Lesser Whitethroat	*Curruca curruca* (Linnaeus, 1758)	-	-	1± 0.63	1± 0.89
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	1.67± 0.58	3± 0.82	4± 1.79	3.33± 1.75
Oriental Turtle-Dove	*Streptopelia orientalis* (Latham, 1790)	-	-	-	6± 10.04
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	-	-	0.33± 0.52	-
Pheasant-tailed Jacana	*Hydrophasianus chirurgus* (Scopoli, 1786)	12.33± 2.52	4.75± 6.60	-	1.5± 2.51
Pied Bushchat	*Saxicola caprata* (Linnaeus, 1766)	4± 2.00	1.75± 0.50	1.33± 1.21	2± 1.10
Plain Prinia	*Prinia inornata* (Sykes, 1832)	1.33± 0.58	1± 0.82	1.33± 0.82	1.5± 1.05
Purple Heron	*Ardea purpurea* (Linnaeus, 1766)	1.33± 0.58	1± 0.82	1± 0.63	1± 0.00
Red Munia	*Amandava amandava* (Linnaeus, 1758)	25.33± 15.37	29.5± 16.98	15± 4.52	16.5± 7.45
Red-breasted Flycatcher	*Ficedula parva* (Bechstein, 1792)	-	-	0.67± 0.52	0.67± 0.52
Red-naped Ibis	*Pseudibis papillosa* (Temminck, 1824)	12± 5.00	6.5± 1.29	7± 1.10	9.5± 4.32
Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus, 1766)	30.33± 14.19	15± 6.98	13.33± 7.31	16.17± 6.94
Rose-ringed Parakeet	*Psittacula krameri* (Scopoli, 1769)	35± 1.00	25± 3.56	21.67± 5.79	24± 12.96

Rosy Starling	*Pastor roseus* (Linnaeus, 1758)	34± 27.22	27.25± 21.90	11.5± 16.69	
Rufous-fronted Prinia	*Prinia buchanani* (Blyth, 1844)	-	-	0.33± 0.52	-
Rufous-vented Grass Babbler	*Laticilla burnesii* (Blyth, 1844)	0.33± 0.58	-	0.17± 0.41	0.5± 0.84
Scaly-breasted Munia	*Lonchura punctulata* (Linnaeus, 1758)	7.33± 4.16	6.25± 4.35	3.83± 1.72	4.33± 2.25
Shikra	*Accipiter badius* (J.F. Gmelin, 1788)	1.67± 0.58	1.75± 0.96	1.5± 0.55	1.33± 0.52
Sind Sparrow	*Passer pyrrhonotus* (Blyth, 1845)	-	-	-	2.83± 2.32
Streaked Weaver	*Ploceus manyar* (Horsfield, 1821)	6.67± 5.51	14.5± 8.50	1± 2.45	0.5± 0.55
Striated Babbler	*Argya earlei* (Blyth, 1844)	20.67± 6.81	15.5± 5.97	11.83± 3.82	9.17± 3.43
Yellow-bellied Prinia	*Prinia flaviventris* (Delessert, 1840)	1± 0.00	0.75± 0.50	0.17± 0.41	0.33± 0.52
Yellow-eyed Babbler	*Chrysomma sinense* (J.F. Gmelin, 1789)	-	-	3± 2.53	2.67± 2.58
Zitting Cisticola	*Cisticola juncidis* (Rafinesque, 1810)	-	-	0.17± 0.41	0.33± 0.52

Plantation habitat

The presence of trees in an ecosystem not only contributes to its aesthetic beauty but also plays a crucial role in supporting various forms of wildlife. Among the numerous tree species *erminalia arjuna*, *Dalbergia sissoo*, *Leucaena leucocephala*, and *Syzygium cumini* are dominating species which supports the birds population. These tree species offer essential resources, including food, shelter and nesting sites, which are vital for the survival and proliferation of avian species. Many bird species rely on trees for nesting. Which provides a secure and elevated location for birds to build their nests, protecting them from ground-dwelling predators. Different bird species have adapted to nest in various parts of trees, such as tree cavities, branches, or dense foliage, depending on their specific requirements. Trees support avian survival by providing a diverse range of food sources. They bear fruits, nuts, seeds, and berries that serve as essential food for many bird species. Birds like finches, sparrows, and grosbeaks rely on seeds, while thrushes and orioles feed on fruits. Insects attracted to trees also serve as a vital food source for insectivorous birds. Trees offer shelter and protection from harsh weather conditions, such as wind, rain, and extreme temperatures. The dense foliage of trees provide cover from direct sunlight, helping birds to regulate their body temperature and avoid overheating. Trees also act as a physical barrier, shielding birds from strong winds and heavy rainfall. Birds need perches and roosting spots for resting and observing their surroundings. Trees provide sturdy branches and limbs where birds can perch during non-active periods. Many bird species gather in communal roosts during the night, using trees as safe and secure locations for resting and sleeping. The leaves, branches, and bark of trees offer excellent camouflage for birds, allowing them to blend into their surroundings and remain hidden from predators. This protective feature helps birds avoid detection, increasing their chances of survival. Trees play a vital role in the migration of many bird species. They act as markers and provide essential stopover points along migration routes. Trees with abundant food and water sources are crucial for migrating birds to rest, refuel, and recover their energy during long journeys. Plantation habitats support a wide range of organisms that form interconnected ecosystems. Birds contribute to pollination and seed dispersal, aiding in the regeneration and propagation of trees and other plant species. This symbiotic relationship between birds and trees helps maintain biodiversity and overall ecosystem health.

Diversity and abundance

In the summer season, a total of 43 species were found during the survey and repeated surveys in the habitat have been carried out to estimate mean abundance in the summer season. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for months of summer like April 2020 (S=37, H'=2.77, J'=0.43), May 2020 (S=34, H'=2.86, J'=0.52), June 2020 (S=38, H'=3.0, J'=0.53) besides species shown the highest mean abundance for Common Myna (*Acridotheres tristis*) 46.33±5.13, followed by Green Bee-eater (*Merops orientalis*) 46.00±16.37, Rose-ringed Parakeet (*Psittacula krameri*) 44.67±8.62, House Crow (*Corvus splendens*) 15.67±3.21, Eurasian Collared-Dove (*Streptopelia decaocto*) 14.33±1.53, Jungle Babbler (*Turdoides striata*) 8.67±2.08, Laughing Dove (*Streptopelia senegalensis*) 8.67±3.06, Rock Pigeon (*Columba livia*) 7.67±5.51, Cattle Egret (*Bubulcus ibis*) 6.33±1.53, Yellow-footed Green-Pigeon (*Treron phoenicopterus*) 6.33±1.53, Greater Coucal (*Centropus sinensis*) 5.33±2.08, Indian Silverbill (*Euodice malabarica*) 5.33±1.53, and Black Drongo (*Dicrurus macrocercus*) 5±1.

Fig 6.23: Avian community of plantation habitat at HWS. (1: Shikra, 2: Barn Owl, 3: Indian Paradise-Flycatcher, 4: Common Hawk-Cuckoo, 5: Spotted Owlet, 6: Brown-headed Barbet)

Some species recorded with low mean abundance in summer season includes Brahminy Starling (*Sturnia pagodarum*) 0.67±1.15, Indian Golden (*Oriole Oriolus*) 0.67±0.58, Oriental

Honey-buzzard (*Pernis ptilorhynchus*) 0.67±0.58, Barn Owl (*Tyto alba*) 0.33±0.58, Long-tailed Shrike (*Lanius schach*) 0.33±0.58, and Oriental Magpie-Robin (*Copsychus saularis*) 0.33±0.58. A bird's community with total 47 species were found in the plantation habitat during monsoon season, Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for the months of monsson like July 2020 (S=36, H'=2.99, J'=0.55), August 2020 (S=38, H'=3.12, J'=0.59), and September 2019 (S=38, H'=3.00, J'=0.53), and September 2020 (S=38, H'=2.76, J'=0.42) The mean abundance recorded like Rose-ringed Parakeet (*Psittacula krameri*) 48.25±4.19, followed by Green Bee-eater (*Merops orientalis*) 39.25±11.53, Common Myna (*Acridotheres tristis*) 29.25±16.64, Jungle Babbler (Turdoides striata) 13.75±6.65, Eurasian Collared-Dove (*Streptopelia decaocto*) 12±4.08, House Crow (*Corvus splendens*) 11±7.62, Oriental White-eye (*Zosterops palpebrosus*) 8.75±3.59, Greater Coucal (*Centropus sinensis*) 7.75±4.35, Laughing Dove (*Streptopelia senegalensis*) 6.5±4.43, Rock Pigeon (*Columba livia*) 5.75±1.50, Cattle Egret (*Bubulcus ibis*) 5.5±3, Yellow-footed Green-Pigeon (*Treron phoenicopterus*) 5.5±3.87, Grey Francolin (*Francolinus pondicerianus*) 5.25±2.22 and Spotted Owlet (*Athene brama*) 5.25±4.57.

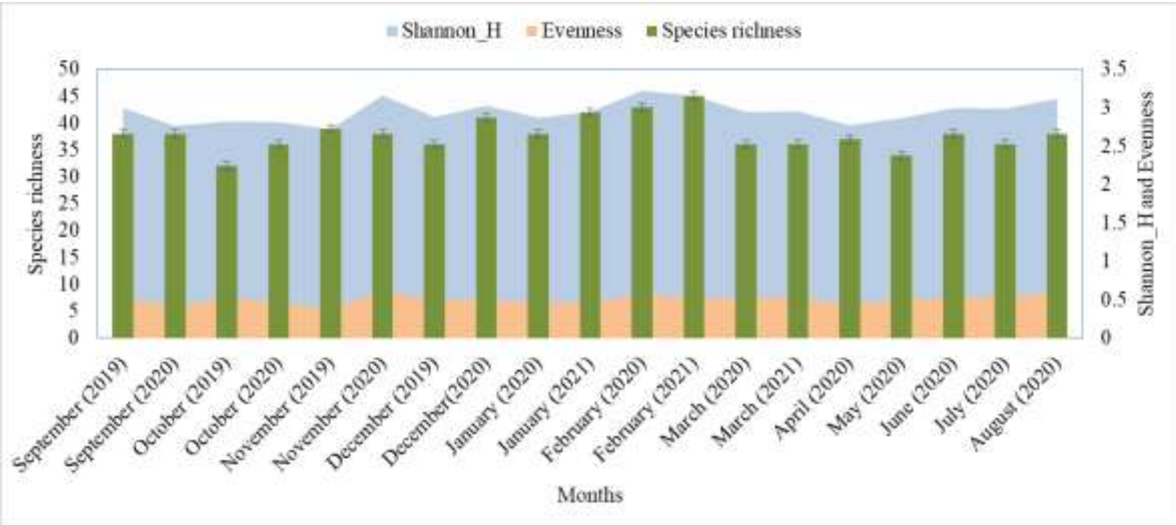


Fig 6.24: Seasonal variation in avian diversity at Plantation habitat.

In the post-monsoon season, a community with 63 bird species shares the plantation habitat for survival and breeding. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated, a little change was observed with respect to the diversity of avian species in October 2019 (S=32, H'=2.82, J'=0.53), October 2020 (S=36, H'=2.81, J'=0.46), November 2019 (S=39, H'=2.72, J'=0.39), and November 2020 (S=38, H'=3.16, J'=0.62), December 2019 (S=36, H'=2.88, J'=0.49), and December 2020 (S=41, H'=3.03, J'=0.50). The mean abundance were by Rose-ringed Parakeet (*Psittacula krameri*) 38.67±15.73 followed by Common Myna (*Acridotheres tristis*) 36.17±16.20, House Crow (*Corvus splendens*) 11.5±2.88, Jungle Babbler (*Turdoides striata*) 11.5±3.89, Green Bee-eater (*Merops orientalis*) 9.83±16.49, Rock Pigeon (*Columba livia*) 7.33±3.56, Eurasian Collared-Dove (*Streptopelia decaocto*) 7.17±2.14, Black Drongo (*Dicrurus macrocercus*) 6.17±3.60, Spotted Owlet (*Athene brama*) 5.67±1.63, Oriental White-eye (*Zosterops palpebrosus*) 5.17±5,Oriental Honey-buzzard (*Pernis ptilorhynchus*) 0.83±0.41.

The bird's migration can be experienced in the post-monsoon and winter seasons therefore variation can be seen in the composition of the bird's community in the plantation habitat. The mean abundance of 62 species was calculated. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for months of January 2020 (S=38, H'=2.87, j'= 0.46), January 2021 (S=42, H'=2.95, J'=0.45), February 2020 (S=43 ,H'=3.22, J'=0.58) February 2021 (S=45, H'=3.15, J'=0.52), March 2020 (S=36, H'=2.95. J'=0.53) and March 2021 (S=36 H'=2.95, J'=0.53) besides maximum mean abundance is recorded for species like Rose-ringed Parakeet (*Psittacula krameri*) 41±11.98, Common Myna (*Acridotheres tristis*) 33.33±10.07, Green Bee-eater (*Merops orientalis*) 21.83±21.21, Jungle Babbler (*Turdoides striata*) 13.67±5.09, House Crow (*Corvus splendens*) 12.17±5.85, Eurasian Collared-Dove (*Streptopelia decaocto*) 9.83±2.64, Oriental Turtle-Dove (*Streptopelia orientalis*) 8.50±6.66, Rock Pigeon (*Columba livia*) 6.5±3.33, Yellow-footed Green-Pigeon (*Treron phoenicopterus*) 6.50±3.39, and Black Drongo (*Dicrurus macrocercus*) 5.5±1.64. Species with low mean abundance include Common Tailorbird (*Orthotomus sutorius*) 2.33±0.52, Cinereous Tit (*Parus cinereus*) 2±0.89, House Sparrow (*Passer domesticus*) 2±4.90, Lesser Golden-backed Woodpecker (*Dinopium benghalense*) 2±1.10, Indian Grey Hornbill (*Ocyceros birostris*) 1.83±1.17, Laughing Dove (*Streptopelia senegalensis*) 1.83±1.72, Black-winged Kite (*Elanus caeruleus*) 1.67±0.82, Spotted Dove (*Streptopelia chinensis*) 1.67±2.66, Common Chiffchaff (*Phylloscopus collybita*) 1.5±1.05 and Lesser Whitethroat (*Curruca curruca*) 1.5±0.55. The mean abundance of each bird's species is estimated and shown in Table 6.7.

Table 6.8: Structure of avian community and seasonal abundance in Plantation habitat.

Common name	Scientific name	Summer	Monsoon	Post-monsoon	Winter
Alexandrine Parakeet	*Psittacula eupatria* (Linnaeus, 1766)	1± 1.00	1.75 ± 1.26	0.67±0.82	1.17 ±0.98
Asian Koel	*Eudynamys scolopaceus* (Linnaeus, 1758)	3.33 ± 1.53	3 ± 0.82	0.33±0.82	2.67±1.97
Asian Pied Starling	*Gracupica contra* (Linnaeus, 1758)	1.67 ± 1.53	2. 5± 1.91	3.5±2.43	3.33±2.16
Barn Owl	*Tyto alba* (Scopoli, 1769)	0.33 ± 0.58	-	0.33± 0.52	-
Black Drongo	*Dicrurus macrocercus* Vieillot, 1817	5 ± 1.00	4 ± 1.83	6.17 ± 3.60	5.5 ± 1.64
Black Kite	*Milvus migrans* (Boddaert, 1783)	-	0.75 ± 1.50	4 ± 4.43	3.33 ± 1.86
Black Redstart	*Phoenicurus ochruros* (S.G. Gmelin, 1774)	-	-	1.170.41	0.83 ±0.98
Black-throated Thrush	*Turdus atrogularis* Jarocki, 1819	-	-	0.170.41	0.330.52
Black-winged Kite	*Elanus caeruleus* (Desfontaines, 1789)	1.33 ± 0.58	0.75 ± 0.96	0.83 ± 0.75	1.67 ± 0.82
Blyth's Reed Warbler	*Acrocephalus dumetorum* Blyth, 1849	0.33 ± 0.58	-	0.33 ± 0.52	-
Booted Eagle	*Hieraaetus pennatus* (J.F. Gmelin, 1788)	-	-	-	0.33± 0.52
Booted Warbler	*Iduna caligata (*M.H.C. Lichtenstein, 1823)	-	0.25 ± 0.50	0.33 ± 0.52	0.17 ± 0.41
Brahminy Starling	*Sturnia pagodarum* (J.F. Gmelin, 1789)	0.67 ± 1.15	0.75 ± 0.96	0.17 ±0.41	-
Brown-headed Barbet	*Psilopogon zeylanicus* (J.F. Gmelin, 1788)	2.33 ± 1.53	3.75 ± 1.71	0.83± 0.98	0.67 ± 1.21
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	6.33 ± 1.53	5.5 ± 3.00	4.5 ± 2.26	5.33 ± 2.16
Cinereous Tit	*Parus cinereus* Vieillot, 1818	-	1± 2.00	1.17 ± 1.17	2 ± 0.89
Common Chiffchaff	*Phylloscopus collybita* (Vieillot, 1817)	-	-	2 ± 1.41	1.5 ± 1.05
Common Hawk-Cuckoo	*Hierococcyx varius* (Vahl, 1797)	-	-	0.17 ± 0.41	0.83 ± 0.75
Common Kestrel	*Falco tinnunculus* Linnaeus, 1758	-	-	0.17 ± 0.41	0.17 ± 0.41

Common Myna	*Acridotheres tristis* (Linnaeus, 1766)	46.33 ± 5.13	29.25 ± 16.64	36.17 ±16.20	33.33 ± 10.07
Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	2.67 ± 0.58	1.5 ± 0.58	2.5 ± 0.84	2.33 ± 0.52
Coppersmith Barbet	*Psilopogon haemacephalus* (Statius Muller, 1776)	4.67 ± 1.53	4.5 ± 1.29	1.5 ± 1.05	3.17 ± 2.48
Crested Serpent-Eagle	*Spilornis cheela* (Latham, 1790)	-	-	-	0.17 ± 0.41
Eurasian Collared-Dove	*Streptopelia decaocto* (Frivaldszky, 1838)	14.33 ± 1.53	12 ± 4.08	7.17 ± 2.14	9.83 ± 2.64
Eurasian Hoopoe	*Upupa epops* Linnaeus, 1758	2 ± 0.00	2 ± 0.82	3 ± 1.10	2.5 ± 1.05
Greater Coucal	*Centropus sinensis* (Stephens, 1815)	5.33 ± 2.08	7.75 ± 4.35	5 ± 1.10	5.33 ± 3.08
Greater Spotted Eagle	*Clanga clanga* (Pallas, 1811)	-	-	0.17 ± 0.41	0.33 ± 0.82
Green Bee-eater	*Merops orientalis* Latham, 1801	46 ± 16.37	39.25 ± 11.53	9.83± 16.49	21.83± 21.21
Grey Francolin	*Francolinus pondicerianus* (J.F. Gmelin, 1789)	2.33 ± 2.08	5.25 ± 2.22	3.67± 1.51	4.67± 2.34
Grey-headed Canary-Flycatcher	*Culicicapa ceylonensis* (Swainson, 1820)	-	-	1.33± 1.63	0.5± 1.22
House Crow	*Corvus splendens* Vieillot, 1817	15.67 ± 3.21	11± 7.62	11.5± 2.88	12.17± 5.85
House Sparrow	*Passer domesticus* (Linnaeus, 1758)	3 ± 2.65	2 ± 4.00	-	2± 4.90
Hume’s Leaf Warbler	*Abrornis humei* (W.E. Brooks, 1878	-	0.25 ± 0.50	0.17± 0.41	0.17± 0.41
Indian Golden Oriole	*Oriolus kundoo* Sykes, 1832	0.67± 0.58	0.25± 0.50	-	-
Indian Grey Hornbill	*Ocyceros birostris* (Scopoli, 1786)	2.33 ± 2.08	2.5 ± 1.29	1± 0.89	1.83± 1.17
Indian Paradise-Flycatcher	*Terpsiphone paradisi* (Linnaeus, 1758)	-	0.25± 0.50	-	-
Indian Roller	*Coracias benghalensis* (Linnaeus, 1758)	2.33 ± 0.58	1.5 ± 1.73	-	-
Indian Scops-Owl	*Otus bakkamoena* Pennant, 1769	-	-	0.17± 0.41	0.17± 0.41
Indian Silverbill	*Euodice malabarica* (Linnaeus, 1758)	5.33 ± 1.53	4.25 ± 1.71	1 ± 2.45	4 ± 2.28
Indian Spotted Eagle	*Clanga hastata* (Lesson, 1831)	-	-	-	0.17 ± 0.41
Jacobin Cuckoo	*Clamator jacobinus* (Boddaert, 1783)	1 ± 1.73	2 ± 1.63	-	-

Jungle Babbler	*Turdoides striata* (Dumont, 1823)	8.67 ± 2.08	13.75 ± 6.65	11.5 ± 3.89	13.67 ± 5.09
Kashmir Chiffchaff	*Phylloscopus sindianus* W.E. Brooks, 1880	-	-	0.17 ± 0.41	0.17 ± 0.41
Large Gray Babbler	*Argya malcolmi* (Sykes, 1832)	-	1± 1.15	0.17 ± 0.41	1.17 ± 1.33
Large-billed Crow	*Corvus macrorhynchos* Wagler, 1827	-	-	0.17 ± 0.41	0.17 ± 0.41
Laughing Dove	*Streptopelia senegalensis* (Linnaeus, 1766)	8.67 ± 3.06	6.5 ± 4.43	1.67 ± 2.07	1.83 ± 1.72
Lesser Golden-backed Woodpecker	*Dinopium benghalense* (Linnaeus, 1758)	1 ± 0.00	2.75 ± 1.26	1.5 ± 0.55	2 ± 1.10
Lesser Whitethroat	*Curruca curruca* (Linnaeus, 1758)			1.17 ± 0.75	1.5 ± 0.55
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	2± 1.00	2.5± 1.29	1.5 ± 1.52	0.83 ± 0.98
Long-legged Buzzard	*Buteo rufinus* (Cretzschmar, 1829)	-	-	0.17 ± 0.41	0.17 ± 0.41
Long-tailed Minivet	*Pericrocotus ethologus* Bangs & J.C. Phillips, 1914	-	-	0.33 ± 0.82	-
Long-tailed Shrike	*Lanius schach* Linnaeus, 1758	0.33 ± 0.58	0.75 ± 0.50	0.33 ± 0.52	0.5 ± 0.55
Northern Goshawk	*Accipiter gentilis* (Linnaeus, 1758)	-	-	0.17 ± 0.41	-
Orange-headed Thrush	*Geokichla citrina* (Latham, 1790)	-	-	0.17 ± 0.41	-
Oriental Honey-buzzard	*Pernis ptilorhynchus* (Temminck, 1821)	0.67 ± 0.58	1 ± 0.00	0.83 ± 0.41	0.5± 0.55
Oriental Magpie-Robin	*Copsychus saularis* (Linnaeus, 1758)	0.33 ± 0.58	0.25 ± 0.50	0.33 ± 0.82	0.5± 0.55
Oriental Turtle-Dove	*Streptopelia orientalis* (Latham, 1790)			1.33 ± 3.27	8.5± 6.66
Oriental White-eye	*Zosterops palpebrosus* (Temminck, 1824)	5 ± 0.00	8.75 ± 3.59	5.17 ± 5.00	3± 3.46
Osprey	*Pandion haliaetus* (Linnaeus, 1758)	-	-	-	0.33± 0.52
Purple Sunbird	*Cinnyris asiaticus* (Latham, 1790)	4.33 ± 1.53	4 ± 4.24	-	1± 2.45
Red Collared-Dove	*Streptopelia tranquebarica* (Hermann, 1804)	2 ± 2.00	-	-	
Red-breasted Flycatcher	*Ficedula parva* (Bechstein, 1792)	-	-	1 ± 0.63	0.67 ± 0.52
Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus, 1766)	4.33 ± 1.53	5 ± 2.16	3.17± 1.17	3 ± 0.63

Rock Pigeon	*Columba livia* J.F. Gmelin, 1789	7.67 ± 5.51	5.75 ± 1.50	7.33 ± 3.56	6.5 ± 3.33
Rose-ringed Parakeet	*Psittacula krameri* (Scopoli, 1769)	44.67 ± 8.62	48.25 ± 4.19	38.67 ± 15.73	41 ± 11.98
Rosy Starling	*Pastor roseus* (Linnaeus, 1758)	-	2.5 ± 3.00	-	-
Rufous Treepie	*Dendrocitta vagabunda* (Latham, 1790)	2 ± 1.00	2 ± 0.82	2.17 ± 0.98	2.67 ± 1.37
Shikra	*Accipiter badius* (J.F. Gmelin, 1788)	1.33 ± 0.58	1 ± 0.00	1.67 ± 0.82	1 ± 0.00
Spotted Dove	*Streptopelia chinensis* (Scopoli, 1786)	-	-	2.17 ± 2.86	1.67 ± 2.66
Spotted Owlet	*Athene brama* (Temminck, 1821)	4.33 ± 1.15	5.25 ± 4.57	5.67 ± 1.63	5.3 3± 1.21
Steppe Eagle	*Aquila nipalensis* Hodgson, 1833	-	-	-	0.17 ± 0.41
Taiga Flycatcher	*Ficedula albicilla* (Pallas, 1811)	-	-	0.33 ± 0.52	-
Tickell's Thrush	*Turdus unicolor* Tickell, 1833	-	-	0.17 ± 0.41	0.17 ± 0.41
White-browed Fantail	*Rhipidura aureola* Lesson, 1831	-	-	0.17 ± 0.41	-
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	2 ± 1.00	2.5 ± 1.29	1.5 ± 0.84	3.33 ± 1.21
Yellow-footed Green-Pigeon	*Treron phoenicopterus* (Latham, 1790)	6.33 ± 1.53	5.5 ± 3.87	3.67 ± 2.25	6.5 ± 3.39

Ravine habitat

Shrubs and grasses in a dry ravine habitat provide suitable nesting sites for a variety of bird species. The dense vegetation offers protection from predators and the elements, allowing birds to build their nests and raise their chicks in a secure environment. Ravine habitat with shrubs like *Capparis decidua*, *Lycium edgeworthii* and grasses such as *Saccharum spontaneum, Saccharum munja* and *Dichanthium annulatum*, often support a diverse range of plant species, which attract insects and other invertebrates. These invertebrates serve as a valuable food source for many bird species, especially during the breeding season when birds require high energy level to care for their offspring. The dense shrubs and grasses found in the dry ravine habitat offer birds ample cover to camouflage.

Fig 6.25: Various locations of Ravine habitat and a common babbler roosting on a dry shrub.

This is particularly important for ground-nesting species that rely on blending into their surroundings to avoid detection by predators. Many bird species undertake long-distance migrations and dry ravines with suitable vegetation provide important resting and stopover sites along their migratory routes. These sites offer birds a place to rest, refuel, and recover before continuing their journey, contributing to their overall survival during migration. The dry ravine habitat dominated by shrubs and grasses tend to support a diverse community of bird species. The different vegetation layers, from ground cover to shrubbery, attract a variety of birds with varying foraging and nesting preferences. This habitat diversity fosters a healthy ecosystem with intricate ecological relationships. Dry ravines are often located in areas prone to human disturbances, such as urbanization and agriculture. Preserving these habitats is of great importance for maintaining biodiversity and providing refuge for bird species facing habitat loss and fragmentation. The Ravine habitat dominated by shrubs and grasses is an essential ecosystem for birds. Which provides nesting sites, food resources, cover, resting and stopover sites and water sources. Protecting and conserving these habitats is crucial for the survival and well-being of numerous bird species, contributing to the overall health and balance of the ecosystems of HWS.

Diversity and abundance

The ravine habitat is supporting a community of birds with a total of 51 species in the summer season. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for month of April 2020 (S=42, H'=3.16, J'=0.56), May 2020 (S=42, H'=3.13, J'=0.54), and June 2020 (S=42, H'=3.17, J'=0.57) besides mean abundance was calculated for recorded species and maximum mean abundance was found for species like Green Bee-eater (*Merops orientalis*) 43±8.98, followed by Rosy Starling (*Pastor roseus*) 21.67±10.21, Baya Weaver (*Ploceus philippinus*) 18.33±11.90, Indian Silverbill (*Euodice malabarica*) 17.67±8.99, House Sparrow (*Passer domesticus*) 10±1.63, Cattle Egret (*Bubulcus ibis*) 9.67±2.36, Rose-ringed Parakeet (*Psittacula krameri*) 8±3.27, Jungle Babbler (*Turdoides striata*) 6.67±2.49, Eurasian Collared-Dove (*Streptopelia decaocto*) 6.33±1.70, Wire-tailed Swallow (*Hirundo smithii*) 6.33±1.25, Streaked Weaver (*Ploceus manyar*) 5.67±2.36, Grey-throated Martin (*Riparia paludicola*) 5±2.16, Common Myna (*Acridotheres tristis*) 4.67±1.25, Black Drongo (*Dicrurus macrocercus*) 4.33±1.25, Black-breasted Weaver (*Ploceus benghalensis*) 4±2.16, Common Babbler (*Argya caudate*) 3.67±1.25, Grey Francolin (*Francolinus pondicerianus*) 3.67±0.47, House Crow (*Corvus splendens*) 3.67±0.94, Ashy Prinia (*Prinia socialis*) 3.33±1.25, Asian Pied Starling (*Gracupica contra*) 3±1.41, Rufous-fronted Prinia (*Prinia buchanani*) 0.33±0.47, White-eyed Buzzard (*Butastur teesa*) 0.33±0.47, White-throated Kingfisher (*Halcyon smyrnensis*) 0.33±0.47.

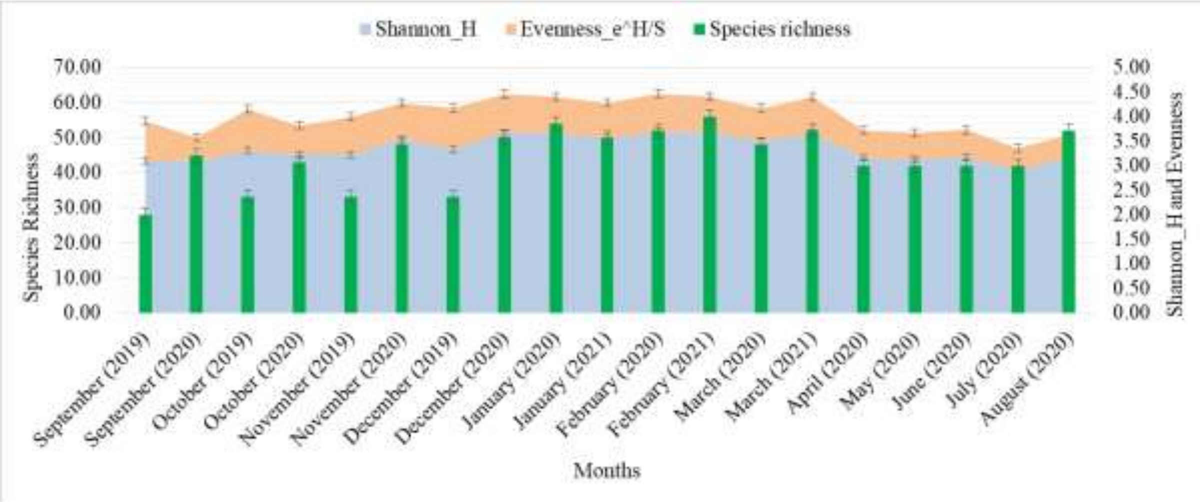


Fig 6.26: Seasonal variation in the diversity of avian species at Ravine habitat.

In the monsoon season, a community with a composition of 60 species can be observed. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for month of July 2020 (S=42, H'=2.92, J'=0.44), August 2020 (S=52, H'=3.17, J'=0.46), September 2019 (S=28, H'=3.11, J'=0.80), September 2020 (S=45, H'=3.09, J'=0.49) and abundance of species were recorded prominent species like Green Bee-eater (*Merops orientalis*) 55±30.36, Baya Weaver (*Ploceus philippinus*) 20.5±14.64 Indian Silverbill (*Euodice malabarica*) 11.5±8.14, Cattle Egret (*Bubulcus ibis*)11±8.54, Grey-throated Martin (*Riparia paludicola*) 8.25±2.28, Common Myna (*Acridotheres tristis*)7.5±1.12, Jungle Babbler (*Turdoides striata*) 7±3.39, Rose-ringed Parakeet (*Psittacula krameri*) 6.75±2.68, House Sparrow (*Passer domesticus*) 6.5±2.29 Eurasian Collared-Dove (*Streptopelia decaocto*) 5.5±1.66,Wire-tailed Swallow (*Hirundo smithii*) 4.75±3.49, Red Munia (*Amandava amandava*) 4.5±2.69, Red-wattled Lapwing (*Vanellus indicus*) 4.25 ±1.09, House Crow (*Corvus splendens*) 4.00 ± 1.22, Scaly-breasted Munia (*Lonchura punctulata*) 4.00 ±1.22, Streaked Weaver (*Ploceus manyar*) 4.00 ±4.06 and Ashy Prinia (*Prinia socialis*) 3.75±0.83, The species shown very low mean abundance incluses Black-winged Kite (*Elanus caeruleus*) 0.75 ± 0.83, Graceful Prinia (*Prinia gracilis*) 0.75 ± 0.43, followed by Large Gray Babbler (*Argya malcolmi*) 0.75 ± 0.43, Long-tailed Shrike (*Lanius schach*) 0.75 ± 1.30, Red Collared-Dove (*Streptopelia tranquebarica*) 0.75 ± 1.30 and Black Francolin (*Francolinus francolinus*) 0.50 ± 0.87.

Fig 6.27: House sparrow (*Passer domesticus*) roosting on *Capparis decidua*

In the post-monsoon season 66 species were recorded from the Ravine habitat. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for months, October 2019 (S=33, H’=3.31, J’=0.83), and October 2020 (S=43, H’=3.23, J’=0.59), November 2019 (S=33 H’=3.23, J’=0.76), November 2020 (S=48, H’=3.55, J’=0.73), December 2019 (S=33, H’=3.33, J’=0.85), December 2020 (S=50, H’=3.67, J’=0.79) with abundance of species seen for Rose-ringed Parakeet (*Psittacula krameri*) 9.67±4.37,Grey-throated Martin (*Riparia paludicola*) 9.17±7.4, Cattle Egret (*Bubulcus ibis*)7.33±9.29, Green Bee-eater (*Merops orientalis*) 6.83±13.45, House Sparrow (*Passer domesticus*) 6.5±2.26, Eurasian Collared-Dove (*Streptopelia decaocto*) 5.83±1.47, Indian Silverbill (*Euodice malabarica*) 5.±1.41, Common Myna (*Acridotheres tristis*) 4.83±1.47, Jungle Babbler (*Turdoides striata*) 4.33±1.63, Bank Myna (*Acridotheres ginginianus*) 4±2.53, Red-wattled Lapwing (*Vanellus indicus*) 4±1.55, Wire-tailed Swallow (*Hirundo smithii*) 3.67±3.27House Crow (*Corvus splendens*) 3.33±1.37, Red-vented Bulbul (*Pycnonotus cafer*), 3.17±0.75, Asian Pied Starling (*Gracupica contra*) 3±2.19, Alexandrine Parakeet (*Psittacula eupatria*) 2.83±0.98, Ashy Prinia (*Prinia socialis*) 2.83±1.33, Indian Robin (*Saxicoloides fulicatus*) 2.83±0.75, Striated Babbler (*Argya earlei*) 2.83±0.75, Black Drongo (*Dicrurus macrocercus*) 2.5±1.52, Laughing Dove (*Streptopelia senegalensis*) 2.5±1.05 and Scaly-breasted Munia (*Lonchura punctulata*), 2.5±0.84.

Fig 6.28: Short-toed snake eagle (*Circaetus gallicus*) hovering over Ravine habitat.

In winter season a total of 83 species were recorded in different months. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for January 2020 (S=54, H’=3.67, J’=0.73), and January 2021 (S=50, H’=3.57, J’=0.71), February 2020 (S=52, H’=3.69, J’=0.77), and February 2021 (s=56, H’=3.69, J’=0.72), March 2020 (S=48, H’=3.49, J’=0.68), and March 2021 (S=52, H’=3.66, J’=0.75) besides species abundance of species were seen for House Sparrow (*Passer domesticus*)10.83±6.59, Jungle Babbler (*Turdoides striata*) 9.5±5.50, Rose-ringed Parakeet (*Psittacula krameri*) 9.5±5.61, Indian Silverbill (*Euodice malabarica*) 7.83±3.49, Green Bee-eater (*Merops orientalis*) 6.5±6.44, Common Starling (*Sturnus vulgaris*) 6.17±5.95, Common Myna (*Acridotheres tristis*) 6±1.79, Eurasian Collared-Dove (*Streptopelia decaocto*) 4±2.61, Laughing Dove (*Streptopelia senegalensis*) 3.5±1.64, Red Munia (*Amandava amandava*) 3.5±1.22, Black Drongo (*Dicrurus macrocercus*) 3.33±1.37, Red-vented Bulbul (*Pycnonotus cafer*) 3±0.89, Jungle Prinia (*Prinia sylvatica*) 0.33 ± 0.52, Little Egret (*Egretta garzetta*) 0.33 ± 0.82, Oriental Skylark (*Alauda gulgula*) 0.33 ± 0.52, Hume’s Leaf Warbler (*Abrornis humei*) 0.17±0.4, Indian Roller (*Coracias benghalensis*) 0.17± 0.41, Kashmir Chiffchaff (*Phylloscopus sindianus*) 0.17±0.41, Peregrine Falcon (*Falco peregrinus*) 0.17±0.41, Rain Quail (*Coturnix coromandelica*) 0.17±0.41, Rufous-fronted Prinia (*Prinia buchanani*) 0.17±0.41, Steppe Eagle (*Aquila nipalensis*) 0.17±0.41, Tickell's Thrush (*Turdus unicolor*) 0.17±0.41 and White-throated Kingfisher (*Halcyon smyrnensis*) 0.17±0.4. Details are given in the table 6.8.

Table 6.9: Structure of avian community and seasonal mean abundance in Ravine habitat.

Common name	**Scientific name**	Summer	Monsoon	Post-monsoon	Winter
Alexandrine Parakeet	*Psittacula eupatria* (Linnaeus, 1766)	2.67 ± 0.47	2 ± 0.71	2.83 ±0.98	2.33 ±0.52
Ashy Prinia	*Prinia socialis* Sykes, 1832	3.33 ± 1.25	3.75 ±0.83	2.83 ±1.33	2.67 ±1.37
Asian Koel	*Eudynamys scolopaceus* (Linnaeus, 1758)	1.33 ±0.47	2 ±0.71	-	-
Asian Pied Starling	*Gracupica contra* (Linnaeus, 1758)	3 ±1.41	2.25 ±1.48	3 ±2.19	2.67 ±0.52
Bank Myna	*Acridotheres ginginianus* (Latham, 1790)	3 ±2.16	3.25 ±2.17	4 ±2.53	1.67 ±1.37
Barn Swallow	*Hirundo rustica* Linnaeus, 1758	-	-	0.5 ±0.84	0.67 ±1.03
Baya Weaver	*Ploceus philippinus* (Linnaeus, 1766)	18.33 ±11.90	20.5 ±14.64	1.5 ±2.35	-
Black Drongo	*Dicrurus macrocercus* Vieillot, 1817	4.33 ±1.25	3.25 ±1.64	2.5 ±1.52	3.33 ±1.37
Black Francolin	*Francolinus francolinus* (Linnaeus, 1766)	-	0.5 ±0.87	0.33 ±0.52	0.33 ±0.52
Black Kite	*Milvus migrans* (Boddaert, 1783)	-	1.5 ±2.60	1.5 ±1.76	4.67 ±1.37
Black Redstart	*Phoenicurus ochruros* (S.G. Gmelin, 1774)	-	0.25 ±0.43	0.17 ±0.41	0.67 ±0.52
Black-breasted Weaver	*Ploceus benghalensis* (Linnaeus, 1758)	4 ±2.16	-	-	0.33 ±0.52
Black-headed Ibis	*Threskiornis melanocephalus* (Latham, 1790)	-	-	0.83 ±1.33	0.67 ±1.03
Black-throated Thrush	*Turdus atrogularis* Jarocki, 1819	-	-	-	0.330.52
Black-winged Kite	*Elanus caeruleus* (Desfontaines, 1789)	1.67 ±0.47	0.75±0.83	1 ±1.10	1.67 ±1.03
Bluethroat	*Luscinia svecica* (Linnaeus, 1758)	-	-	1.5 ±1.76	4 ±1.55
Brahminy Starling	*Sturnia pagodarum* (J.F. Gmelin, 1789)	-	1.25±1.30	1 ±1.67	1±1.55
Cattle Egret	*Bubulcus ibis* (Linnaeus, 1758)	9.67 ±2.36	11 ±8.54	7.33 ±9.29	4±1.55
Citrine Wagtail	*Motacilla citreola* Pallas, 1776	-	0.25 ±0.43	0.5 ±0.55	1
Common Babbler	*Argya caudata* (Dumont, 1823)	3.67 ±1.25	3.75 ±0.83	1.67 ±1.51	2.5 ±0.55
Common Kestrel	*Falco tinnunculus* Linnaeus, 1758	-	-	-	0.33 ±0.52
Common Myna	*Acridotheres tristis* (Linnaeus, 1766)	4.67 ±1.25	7.5 ±1.12	4.83 ±1.47	6 ±1.79

Common Starling	*Sturnus vulgaris* Linnaeus, 1758	-	-	-	6.17 ±5.95
Common Tailorbird	*Orthotomus sutorius* (Pennant, 1769)	0.67 ±0.47	0.25 ±0.43	0.17 ±0.41	0.67 ±0.52
Crested Serpent-Eagle	*Spilornis cheela* (Latham, 1790)	-	-	-	0.17±0.41
Eurasian Collared-Dove	*Streptopelia decaocto* (Frivaldszky, 1838)	6.33 ±1.70	5.5 ±1.66	5.83 ±1.47	4 ±2.61
Eurasian Hoopoe	*Upupa epops* Linnaeus, 1758	0.67 ±0.94	0.5 ±0.87	1.17 ±1.17	1 ±1.26
Eurasian Sparrowhawk	*Accipiter nisus* (Linnaeus, 1758)	-	-	-	0.17 ±0.41
Graceful Prinia	*Prinia gracilis* (M.H.C. Lichtenstein, 1823)	-	0.75 ±0.43	0.5 ±0.84	1.17 ±0.75
Greater Coucal	*Centropus sinensis* (Stephens, 1815)	2 ±0.82	1 ±0.71	1.5 ±1.05	1.33 ±1.21
Greater Spotted Eagle	*Clanga clanga* (Pallas, 1811)	-	-	-	0.5 ±0.84
Green Bee-eater	*Merops orientalis* Latham, 1801	43 ±8.98	55 ±30.36	6.83 ±13.45	6.5 ±6.44
Grey Francolin	*Francolinus pondicerianus* (J.F. Gmelin, 1789)	3.67 ±0.47	2.75 ±0.83	2.17 ±0.98	2.67 ±1.21
Grey Wagtail	*Motacilla cinerea* Tunstall, 1771	-	-	1.33 ±1.51	2 ±1.90
Grey-throated Martin	*Riparia paludicola* (Vieillot, 1817)	5 ±2.16	8.25 ±2.28	9.17 ±7.41	6 ±4.34
Himalayan Bulbul	*Pycnonotus leucogenis* (J.E. Gray, 1835)	-	-	-	0.17 ±0.41
House Crow	*Corvus splendens* Vieillot, 1817	3.67 ±0.94	4 ±1.22	3.33 ±1.37	4.17 ±1.17
House Sparrow	*Passer domesticus* (Linnaeus, 1758)	10 ±1.63	6.5 ±2.29	6.5 ±2.26	10.83 ±6.59
Hume’s Leaf Warbler	*Abrornis humei* (W.E. Brooks, 1878)	-	-	0.17 ±0.41	0.17 ±0.41
Indian Peafowl	*Pavo cristatus* Linnaeus, 1758	1 ±1.41	0.5 ±0.87	0.5 ±1.22	0.33 ±0.82
Indian Robin	*Saxicoloides fulicatus* (Linnaeus, 1766)	2.67 ±0.94	3.25 ±1.30	2.83 ±0.75	2.83 ±0.98
Indian Roller	*Coracias benghalensis* (Linnaeus, 1758)	2.33 ±0.47	1.5 ±1.12	-	0.17 ±0.41
Indian Silverbill	*Euodice malabarica* (Linnaeus, 1758)	17.67 ±8.99	11.5 ±8.14	5 ±1.41	7.83 ±3.49
Indian Spotted Eagle	*Clanga hastata* (Lesson, 1831)	-	-	-	0.33 ±0.52
Jacobin Cuckoo	*Clamator jacobinus* (Boddaert, 1783)	0.33 ±0.47	1.5 ±1.12		-
Jungle Babbler	*Turdoides striata* (Dumont, 1823)	6.67 ±2.49	7 ±3.39	4.33 ±1.63	9.5 ±5.50
Jungle Prinia	*Prinia sylvatica* Jerdon, 1840	-	-	-	0.33 ±0.52

Kashmir Chiffchaff	*Phylloscopus sindianus* W.E. Brooks, 1880	-	-	0.17 ±0.41	0.17 ±0.41
Large Gray Babbler	*Argya malcolmi* (Sykes, 1832)	1±0	0.75 ±0.43	2 ±2.37	4.33 ±3.98
Laughing Dove	*Streptopelia senegalensis* (Linnaeus, 1766)	1.67 ±0.47	3.5 ±2.06	2.5 ±1.05	3.5 ±1.64
Little Egret	*Egretta garzetta* (Linnaeus, 1766)	1±1.41	1.25±1.30	1±1.26	0.33±0.82
Long-billed Pipit	*Anthus similis* (Jerdon, 1840)	-	-	-	0.67±1.03
Long-legged Buzzard	*Buteo rufinus* (Cretzschmar, 1829)	-	-	-	0.5±0.55
Long-tailed Shrike	*Lanius schach* Linnaeus, 1758	1±1.41	0.751.3	0.83±0.98	0.5±0.84
Oriental Magpie-Robin	*Copsychus saularis* (Linnaeus, 1758)	-	10.71	0.67±0.52	1±0.63
Oriental Skylark	*Alauda gulgula* Franklin, 1831	-	-	0.67 ±0.82	0.33±0.52
Paddyfield Pipit	*Anthus rufulus* Vieillot, 1818	-	0.50.5	0.5 ±0.55	0.83±0.41
Peregrine Falcon	*Falco peregrinus* Tunstall, 1771	-	-	0.17 ±0.41	0.17±0.41
Pied Bushchat	*Saxicola caprata* (Linnaeus, 1766)	10	1.250.43	0.83 ±0.41	0.67±0.52
Plain Prinia	*Prinia inornata* Sykes, 1832	1±0.82	1.250.43	1.67 ±1.37	1±1.26
Purple Sunbird	*Cinnyris asiaticus* (Latham, 1790)	3±0.82	2.251.48	-	1.67±1.63
Rain Quail	*Coturnix coromandelica* (J.F. Gmelin, 1789)		0.250.43	-	0.17±0.41
Red Collared-Dove	*Streptopelia tranquebarica* (Hermann, 1804)	0.67±0.94	0.751.3	-	-
Red Munia	*Amandava amandava* (Linnaeus, 1758)	2.33±2.05	4.52.69	1.83 ±1.6	3.5±1.22
Red-breasted Flycatcher	*Ficedula parva* (Bechstein, 1792)	-	-	0.17 ±0.41	0.67±0.52
Red-naped Ibis	*Pseudibis papillosa* (Temminck, 1824)	2±1.63	11	2.33 ±2.73	2.83±1.83
Red-vented Bulbul	*Pycnonotus cafer* (Linnaeus, 1766)	3±0.82	3.251.3	3.17 ±0.75	3±0.89
Red-wattled Lapwing	*Vanellus indicus* (Boddaert, 1783)	3±1.41	4.251.09	4 ±1.55	2.83±1.33
Rock Pigeon	*Columba livia* J.F. Gmelin, 1789	-	-	0.83 ±1.33	4.67±4.80
Rose-ringed Parakeet	*Psittacula krameri* (Scopoli, 1769)	8±3.27	6.752.68	9.67 ±4.37	9.5±5.61
Rosy Starling	*Pastor roseus* (Linnaeus, 1758)	21.67±10.21	-	2.33 ±3.67	-
Rufous Treepie	*Dendrocitta vagabunda* (Latham, 1790)	0.33±0.47	11.73	0.33 ±0.52	0.33±0.82

Rufous-fronted Prinia	*Prinia buchanani* Blyth, 1844	0.33±0.47	0.250.43	0.33 ±0.52	0.17±0.41
Scaly-breasted Munia	*Lonchura punctulata* (Linnaeus, 1758)	3±1.41	41.22	2.5 ±0.84	2.67±0.82
Shikra	*Accipiter badius* (J.F. Gmelin, 1788)	1±0	1±0	1±0	1±0
Short-toed Snake Eagle	*Circaetus gallicus* (J.F. Gmelin, 1788)	-	0.5±0.87	-	-
Siberian Stonechat	*Saxicola maurus* (Pallas, 1773)	-	-	0.67 ±0.82	1.67 ±0.52
Sind Sparrow	*Passer pyrrhonotus* Blyth, 1845	-	0.25 ±0.43	0.5 ±1.22	1.17 ±1.83
Spotted Dove	*Streptopelia chinensis* (Scopoli, 1786)	-	-	0.5 ±1.22	1.33 ±1.63
Steppe Eagle	*Aquila nipalensis* Hodgson, 1833	-	-	-	0.17 ±0.41
Streaked Weaver	*Ploceus manyar* (Horsfield, 1821)	5.67 ±2.36	4 ±4.06	-	1.33 ±2.16
Striated Babbler	*Argya earlei* (Blyth, 1844)	1±1.41	11.73	2.83 ±0.75	2.83±1.60
Taiga Flycatcher	*Ficedula albicilla* (Pallas, 1811)	-	-	0.17 ±0.41	0.33±0.52
Tickell's Thrush	*Turdus unicolor* Tickell, 1833	-	-	-	0.17±0.41
Tree Pipit	*Anthus trivialis* (Linnaeus, 1758)	-	-	-	1.5±1.76
White-breasted Waterhen	*Amaurornis phoenicurus* (Pennant, 1769)	2 ±0.82	31	2 ±0.63	2.17±1.17
White-eyed Buzzard	*Butastur teesa* (Franklin, 1831)	0.33 ±0.47	0.25 ±0.43	0.33 ±0.52	0.33±0.52
White-throated Kingfisher	*Halcyon smyrnensis* (Linnaeus, 1758)	0.33 ±0.47	0.5 ±0.5	0.17 ±0.41	0.17±0.41
Wire-tailed Swallow	*Hirundo smithii* Leach, 1818	6.33 ±1.25	4.75 ±3.49	3.67 ±3.27	1.83±1.60

Agricultural habitat

Agricultural field habitat is distributed in the Western part of the Sanctuary. This area has under encroached by locals. The agricultural field plays a crucial role in supporting bird populations and biodiversity. Agricultural fields provide habitat for many bird species. Birds rely on agricultural landscapes for nesting, foraging, and shelter. Different bird species have different habitat requirements, and agricultural areas can provide a range of habitats, including grasslands, wetlands, hedgerows, and forest edges, which attract a variety of bird species. Agricultural fields often offer a diverse and abundant food supply for birds. Grain crops, such as corn, wheat, and rice, provide a valuable food source for many bird species, including granivorous birds like sparrows, finches, and doves. Insects and invertebrates are also abundant in agricultural fields, attracting insectivorous birds such as swallows and flycatchers. Birds require suitable nesting sites to breed and raise their chicks.

Fig 6.29: Different locations of Agricultural habitat and Black-winged kite.

Agricultural landscapes with hedgerows, trees, or shrubs can provide nesting opportunities for various bird species. These features serve as nesting sites for birds that build their nests in trees, shrubs, or on the ground, supporting their reproductive success. Some agricultural practices, such as crop rotation or fallow fields, can provide seasonal cover for birds. For example, during winter or non-growing seasons, certain agricultural fields may be left uncultivated or contain leftover of crops, offering shelter and protection for birds during harsh weather conditions. Agricultural fields can act as connecting corridors or stepping stones between other natural habitats, enabling birds to move between different landscapes. This connectivity is crucial for migratory birds that rely on a network of suitable habitats during their long-distance journeys. Farmers and landowners can implement conservation practices within agricultural fields to benefit bird populations. These may include establishing wildlife-friendly farming techniques, planting cover crops, preserving or creating hedgerows and field margins, or managing wetlands. Such efforts can enhance the quality and availability of bird habitats within agricultural landscapes. Birds play an important role in ecosystem functioning and provide various ecosystem services, such as pest control by consuming insects and grass seeds. Having healthy bird populations in agricultural fields can contribute to reducing the need for chemical pesticides and maintaining a balanced ecosystem. The agricultural field provides vital resources and habitats that support bird species, promoting their survival, reproduction, and ecological functions. It is important to balance agricultural practices with conservation efforts to ensure the long-term coexistence of birds and agriculture.

Diversity and abundance

In the summer season a total of 47 species were recorded. Species richness (S), diversity (H') evenness (J') and mean abundance were calculated for the month of April 2020 (S=29, H'=2.63, J'=0.48), May 2020 (S=32, H'=2.57, J'=0.41), and June 2020 (S=33, H'=2.19, J'=0.27) with mean abundance across the season therefore for Green Bee-eater (*Merops orientalis*) 76.33±43.15, Baya Weaver (*Ploceus philippinus*) 75±35.09, Cattle Egret (*Bubulcus ibis*) 9.67±5.69, Little Egret (*Egretta garzetta*) 9±5.57, Common Myna (*Acridotheres tristis*) 8.33±3.51, Indian Silverbill (*Euodice malabarica*) 6±2, Jungle Babbler (*Turdoides striata*) 5.33±1.53, Rose-ringed Parakeet (*Psittacula krameri*) 5.33±4.16, Rosy Starling (*Pastor roseus*) 5.33±9.24, Streaked Weaver (*Ploceus manyar*) 5±5, Asian Pied Starling (*Gracupica contra*) 4.67±8.08, Indian Roller (*Coracias benghalensis*) 4.67±1.53, Grey Francolin (*Francolinus pondicerianus*) 4.33 ±1.53, Shikra (*Accipiter badius*) 0.33±0.58, White-eyed Buzzard (*Butastur teesa*) 0.33±0.58 and White-throated Kingfisher (*Halcyon smyrnensis*) 0.33±0.58.

Fig 6.30: Avian community in Agricultural field habitat (1: Cattle Egret, 2: Brown Rock Chat, 3: Oriental Magpie-Robin, 4: Ashy Prinia)

In the monsoon season a total of 49 species were seen in the habitat. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for July 2020 (S=33, H’=2.76, J’=0.48), August 2020 (S=31, H’=2.86, J’=0.56), September 2019 (S=27, H’=2.99, J’=0.74), September 2020 (S=29, H’=2.99, J’=0.69). maximum mean abundance observed for Green Bee-eater (*Merops orientalis*) 33.5±24.52, followed by Baya Weaver (*Ploceus philippinus*) 14.5±8.23, Blue-tailed Bee-eater (*Merops philippinus*) 10±12.88, Cattle Egret (*Bubulcus ibis*) 9±6.06, Common Myna (*Acridotheres tristis*) 8±16, Indian Silverbill (*Euodice malabarica*) 8±6.22, Asian Pied Starling (*Gracupica contra*) 7.75±7.50 Rose-ringed Parakeet (*Psittacula krameri*) 7.25±0.96, Red-naped Ibis (*Pseudibis papillosa*) 6.75±2.50, Bank Myna (*Acridotheres ginginianus*) 5.75±11.50 and Grey Francolin (*Francolinus pondicerianus*).

In the post-monsoon season, a total of 48 species were recorded. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for October 2019 (S=26, H’=2.94, J’=0.73), October 2020 (S=31, H’=2.89, J’=0.58), November 2019 (S=34, H’=3.16, J’=0.69), November 2020 (S=32, H’=2.94, J’=0.59, December 2019 (S=32, H’=2.98, J’=0.62), and December 2020 (S=36, H’=3.25, J’=0.72).

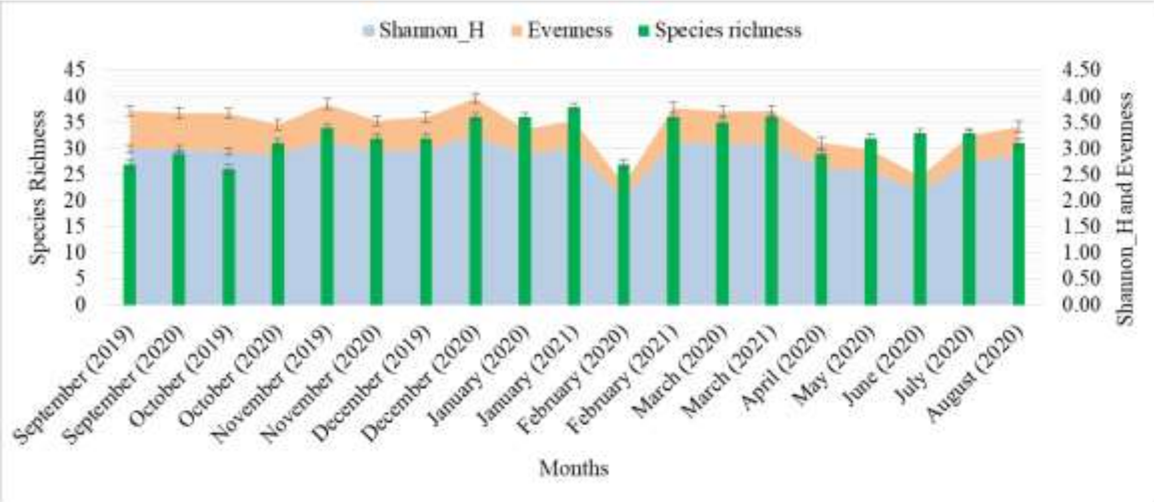


Fig 6.31: Seasonal variation in the diversity of avian species in Agricultural habitat.

The diversity was found between 2.89 to 3.25, therefore, the diversity of avian species remains healthy across the post-monsoon season, mean abundance of post-monsoon season calculated for Bar-headed Goose (*Anser indicus*)13.33±15.16, followed by Cattle Egret (*Bubulcus ibis*) 8.33±7.37, Common Myna (*Acridotheres tristis*) 8.33±13.87, Bank Myna (*Acridotheres ginginianus*) 8.17±5.56, Red-naped Ibis (*Pseudibis papillosa*) 6.83±9.06, Rose-ringed Parakeet (*Psittacula krameri*) 5±2.28, Streaked Weaver (*Ploceus manyar*) 4.67±4.68, Little Egret (*Egretta garzetta*) 4.33 ± 2.94, Grey Francolin (*Francolinus pondicerianus*) 4.17 ± 1.60, Eurasian Collared-Dove (*Streptopelia decaocto*) 4.00 ± 1.67, Indian Silverbill (*Euodice malabarica*) 4.00 ± 1.41, and Jungle Babbler (*Turdoides striata*) 4.00 ± 2.61. Species with low mean abundance are Sind Sparrow (*Passer pyrrhonotus*) 0.67 ± 1.63, Striated Babbler (*Argya earlei*) 0.67 ± 1.63, Black-headed Ibis (*Threskiornis melanocephalus*) 0.50 ± 1.22, Common Tailorbird (*Orthotomus sutorius*) 0.50 ± 0.55, Indian Robin (*Saxicoloides fulicatus*) 0.50 ± 0.84, Red-breasted Flycatcher (*Ficedula parva*) 0.50 ± 0.55, Barn Swallow (*Hirundo rustica*) 0.33 ± 0.82, Black Francolin (*Francolinus francolinus*) 0.33 ± 0.82, Citrine Wagtail (*Motacilla citreola*) 0.33 ± 0.82, Indian Roller (*Coracias benghalensis*) 0.17 ± 0.41 and Long-legged Buzzard (*Buteo rufinus*) 0.17 ± 0.41

A total of 62 species contribute to the community of birds in the winter season at Agricultural field habitats. Species richness (S), diversity (H’) evenness (J’) and mean abundance were calculated for January 2020 (S=36, H’=2.88, J’=0.49), January 2021 (S=38, H’=3.01, J’=0.53), February 2020 (S=27, H’=2.03, J’=0.28), February 2021 (S=36, H’=3.14, J’=0.64), March 2020 (S=35, H’=3.09, J’=0.63), March 2021 (S=36, H’=3.10, J’=0.62). Maximun mean abundance was calculated for Bar-headed Goose (*Anser indicus*) 47.17±49.85, followed by Baya Weaver (*Ploceus philippinus*) 11±18.18, Cattle Egret (*Bubulcus ibis*) 8.67±3.44, Red-naped Ibis (*Pseudibis papillosa*) 8.67±3.98, House Sparrow (*Passer domesticus*) 8.5±5.65, Rose-ringedParakeet (*Psittacula krameri*), 8.33±2.07, Little Egret (*Egretta garzetta*) 8±4.94, Indian Silverbill (*Euodice malabarica*) 7±4.34, Grey Francolin (*Francolinus pondicerianus*), 6.17±2.71, Common Myna (*Acridotheres tristis*)5.83±5.12, Bank Myna (*Acridotheres ginginianus*) 5.33±4.63, Green Bee-eater (*Merops orientalis*) 5.33±6.50, Asian Pied Starling (*Gracupica contra*) 4.67 ± 4.63, Scaly-breasted Munia (*Lonchura punctulata*) 4.17 ± 2.48, Black Drongo (*Dicrurus macrocercus*) 4.00 ± 1.41, Grey-throated Martin (*Riparia paludicola*) 3.67 ± 6.50, Eurasian Collared-Dove (*Streptopelia decaocto*) 3.50 ± 1.05, Red-vented Bulbul (*Pycnonotus cafer*) 3.17 ± 2.23, Jungle Babbler (*Turdoides striata*) 3.00 ± 2.53, Red-wattled Lapwing (*Vanellus indicus*) 3.00 ± 0.89. Least mean abundance are Tree Pipit (*Anthus trivialis*) 0.67 ±1.63, Long-legged Buzzard (*Buteo rufinus*) 0.50 ± 0.55, Plain Prinia (*Prinia inornata*) 0.50 ± 0.84, Black Francolin (*Francolinus francolinus*), 0.33 ± 0.52, Eurasian Marsh-Harrier (*Circus aeruginosus*) 0.33 ± 0.52. White-eyed Buzzard (*Butastur teesa*) 0.33 ± 0.52, Common Kestrel (*Falco tinnunculus*) 0.17 ± 0.41 and Taiga Flycatcher (*Ficedula albicilla*) 0.17 ± 0.41. Details for each species has given in the table 6.9.

Table 6.10 Structure of avian community and seasonal abundance in Agricultural field habitat.

Common name	**Scientific name**	Summer	Monsoon	Post-monsoon	Winter
Alexandrine Parakeet	*Psittacula eupatria*	3 ±3	2 ±1.41	1.67 ±1.97	2.17 ±1.33
Ashy Prinia	*Prinia socialis*	2 ±1	2.75 ±1.71	2.67 ±1.03	2.33 ±1.03
Asian Koel	*Eudynamys scolopaceus*	2 ±1	0.75 ±0.5	-	0.67 ±0.82
Asian Pied Starling	*Gracupica contra*	4.67 ±8.08	7.75 ±7.5	3.5 ±5.86	4.67 ±4.63
Bank Myna	*Acridotheres ginginianus*	1.33 ±2.31	5.75 ±11.5	8.17 ±5.56	5.33 ±4.63
Bar-headed Goose	*Anser indicus*	-	-	13.33 ±15.16	47.17 ±49.85
Barn Swallow	*Hirundo rustica*	-	-	0.33 ±0.82	-
Baya Weaver	*Ploceus philippinus*	75 ±35.09	14.5 ±8.23	2.83 ±6.01	11 ±18.18
Black Drongo	*Dicrurus macrocercus*	3.67 ±1.53	4.25 ±1.5	3.33 ±1.21	4 ±1.41
Black Francolin	*Francolinus francolinus*	0.33 ±0.58	0.75 ±0.96	0.33 ±0.82	0.33 ±0.52
Black-breasted Weaver	*Ploceus benghalensis*	4 ±6.93	3.25 ±3.95	1 ±1.67	0.5 ±1.22
Black-headed Ibis	*Threskiornis melanocephalus*	-	-	0.5 ±1.22	0.67 ±1.63
Black-winged Kite	*Elanus caeruleus*	1.67 ±0.58	1 ±0	1.33 ±0.52	1.33 ±0.52
Black-tailed Godwit	*Limosa limosa*	-	-	2.33 ±5.72	6.5 ±5.68
Blue-tailed Bee-eater	*Merops philippinus*	-	10 ±12.88	-	-
Brahminy Starling	*Sturnia pagodarum*	0.67 ±1.15	1.25 ±1.5	0.67 ±0.82	1.5 ±1.52
Brown Rock Chat	*Oenanthe fusca*		0.25 ±0.5	0.17 ±0.41	0.33 ±0.82
Cattle Egret	*Bubulcus ibis*	9.67 ±5.69	9 ±6.06	8.33 ±7.37	8.67 ±3.44
Citrine Wagtail	*Motacilla citreola*	-	-	0.33 ±0.82	0.33 ±0.52
Common Kestrel	*Falco tinnunculus*	-	-	-	0.17 ±0.41
Common Myna	*Acridotheres tristis*	8.33 ±3.51	81 ±6	8.33 ±13.87	5.83 ±5.12
Common Starling	*Sturnus vulgaris*	-	-	0.83 ±2.04	2.67 ±3.2
Common Tailorbird	*Orthotomus sutorius*	0.67 ±0.58	0.5 ±0.58	0.5 ±0.55	0.83 ±0.75

Eurasian Collared-Dove	*Streptopelia decaocto*	2 ±1	2.75 ±1.5	4 ±1.67	3.5 ±1.05
Eurasian Hoopoe	*Upupa epops*	0.67 ±1.15	1 ±1.41	0.67 ±0.52	1 ±1.26
Eurasian Marsh-Harrier	*Circus aeruginosus*	-	-	0.67 ±0.82	0.33 ±0.52
Eurasian Spoonbill	*Platalea leucorodia*	-	-	2.67 ±4.84	-
European Roller	*Coracias garrulus*	0.33 ±0.58	-	-	-
Glossy Ibis	*Plegadis falcinellus*	-	-	2.5 ±2.26	0.67 ±0.82
Graceful Prinia	*Prinia gracilis*	-	0.25 ±0.5	-	-
Greater Coucal	*Centropus sinensis*	2 ±1.73	2.75 ±0.5	1.83 ±1.17	1.5 ±0.55
Greater Spotted Eagle	*Clanga clanga*	-	-	0.67 ±1.03	0.33 ±0.52
Green Bee-eater	*Merops orientalis*	76.33 ±43.15	33.52 ±4.52	2.17 ±2.48	5.33 ±6.5
Grey Francolin	*Francolinus pondicerianus*	4.33 ±1.53	4.75 ±2.06	4.17 ±1.6	6.17 ±2.71
Grey-throated Martin	*Riparia paludicola*	-	3 ±6	0.33 ±0.82	3.67 ±6.5
House Crow	*Corvus splendens*	3.67 ±3.21	1.25 ±1.5	1 ±1.55	2 ±2.19
House Sparrow	*Passer domesticus*	2.67 ±4.62	3.75 ±4.79	3.17 ±4.75	8.5 ±5.65
Indian Golden Oriole	*Oriolus kundoo*	1 ±1	-	-	1.67 ±3.61
Indian Peafowl	*Pavo cristatus*	-	-	0.67 ±1.03	0.33 ±0.82
Indian Pond-Heron	*Ardeola grayii*	2 ±2.65	0.25 ±0.5	1 ±1.55	1.5 ±1.05
Indian Robin	*Saxicoloides fulicatus*	0.67 ±0.58	0.25 ±0.5	0.5 ±0.84	1.33 ±1.63
Indian Roller	*Coracias benghalensis*	4.67 ±1.53	2.75 ±1.71	0.17 ±0.41	-
Indian Silverbill	*Euodice malabarica*	6 ±2	8 ±6.22	4 ±1.41	7 ±4.34
Jacobin Cuckoo	*Clamator jacobinus*	0.67 ±1.15	0.75 ±0.96	-	-
Jungle Babbler	*Turdoides striata*	5.33 ±1.53	3.25 ±1.89	4 ±2.61	3 ±2.53
Laughing Dove	*Streptopelia senegalensis*	2 ±2	3 ±2.45	1 ±1.1	0.83 ±0.98
Little Egret	*Egretta garzetta*	9 ±5.57	4 ±2.71	4.33 ±2.94	8 ±4.94
Long-legged Buzzard	*Buteo rufinus*	-	-	0.17 ±0.41	0.5 ±0.55

Oriental Magpie-Robin	*Copsychus saularis*	0.33 ±0.58	0.25 ±0.5	0.33 ±0.52	0.33 ±0.52
Osprey	*Pandion haliaetus*	-	-	0.17 ±0.41	-
Paddyfield Pipit	*Anthus rufulus*	-	-	0.33 ±0.82	2.5 ±2.81
Pheasant-tailed jacana	*Hydrophasianus chirurgus (Scopoli, 1786)*	3.67 ±1.53	4.75 ±4.27	-	-
Pied Kingfisher	*Ceryle rudis*	0.67 ±0.58	1 ±0.82	1.17 ±0.75	2 ±0.89
Plain Prinia	*Prinia inornata*	1 ±1	0.25 ±0.5	0.67 ±0.82	0.5 ±0.84
Red-breasted Flycatcher	*Ficedula parva*	-	-	0.5 ±0.55	0.5 ±0.55
Red-naped Ibis	*Pseudibis papillosa*	3.67 ±1.53	6.75 ±2.5	6.83 ±9.06	8.67 ±3.98
Red-vented Bulbul	*Pycnonotus cafer*	1.33 ±2.31	1.5 ±1.73	2 ±2.45	3.17 ±2.23
Red-wattled Lapwing	*Vanellus indicus*	1.67 ±0.58	2.25 ±0.5	2.67 ±1.21	3 ±0.89
Rock Pigeon	*Columba livia*	3.67 ±3.21	0.75 ±1.5	3.33 ±4.84	2.5 ±4.18
Rose-ringed Parakeet	*Psittacula krameri*	5.33 ±4.16	7.25 ±0.96	5 ±2.28	8.33 ±2.07
Rosy Starling	*Pastor roseus*	5.33 ±9.24	3.57	-	24.9
Rufous Treepie	*Dendrocitta vagabunda*	0.67 ±1.15	1.5 ±1.73	0.33 ±0.52	0.67 ±1.03
Scaly-breasted Munia	*Lonchura punctulata*	2.33 ±2.52	3.5 ±1.29	3 ±2.83	4.17 ±2.48
Shikra	*Accipiter badius*	0.33 ±0.58	0.25 ±0.5	0.67 ±0.52	0.5 ±0.55
Sind Sparrow	*Passer pyrrhonotus*	-	-	0.67 ±1.63	-
Spotted Dove	*Streptopelia chinensis*	-	-	2.17 ±3.37	1.5 ±2.51
Streaked Weaver	*Ploceus manyar*	5 ±5	2.25 ±2.87	4.67 ±4.68	0.83 ±2.04
Striated Babbler	*Argya earlei*	-	-	0.67 ±1.63	-
Taiga Flycatcher	*Ficedula albicilla*	-	-	-	0.17 ±0.41
Tree Pipit	*Anthus trivialis*	-	-	-	0.67 ±1.63
White-browed Wagtail	*Motacilla maderaspatensis*	-	-	1.83 ±1.94	1.17 ±1.17
White-eyed Buzzard	*Butastur teesa*	0.33 ±0.58	0.25 ±0.5	0.33 ±0.52	0.33 ±0.52
White-throated Kingfisher	*Halcyon smyrnensis*	0.33 ±0.58	0.25 ±0.5	0.33 ±0.52	0.17 ±0.41
Wire-tailed Swallow	*Hirundo smithii*				12.45

Similarity among habitat types with reference to avian species in HWS

Diversity of habitat is important to possess a healthy avian community. In this study habitat similarity with respect to avian communities has been estimated. The presence and absence status of each species has been mentioned in the table. A total of 21 combinations of habitats were made to understand the nestedness of the avian community between the habitat types. The mean of common species in the different combinations of habitat types is 27.81±16.70 with the lowest 0 and highest 60 species whereas the mean Simpson similarity index is estimated at 0.36 ± 0.20 with the lowest value 0 and highest value 0.74. The maximum similarity (Fig 6.33) is found between the habitat Ravine *Vs* Agricultural field (SI=0.74, C= 60) with common species like Jacobin Cuckoo (*Clamator jacobinus*), Common Kestrel (*Falco tinnunculus*), Black Francolin (*Francolinus francolinus*),

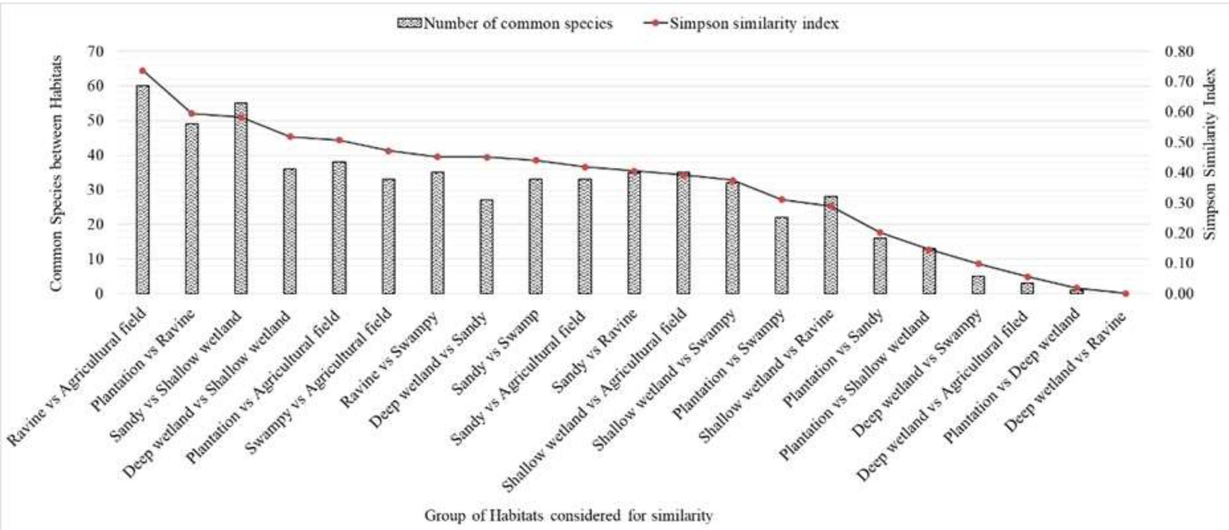


Fig 6.32: Simpson similarity index among various Habitat types.

Ashy Prinia (*Prinia socialis*), Graceful Prinia (*Prinia gracilis*), House Crow (*Corvus splendens*), Rufous Treepie (*Dendrocitta vagabunda*), Black Drongo (*Dicrurus macrocercus*), Barn Swallow (*Hirundo rustica*), Citrine Wagtail (*Motacilla citreola*), Indian Robin (*Saxicoloides fulicatus*), Red-breasted Flycatcher (*Ficedula parva*), House Sparrow (*Passer domesticus*), Black-breasted Weaver (*Ploceus benghalensis*), Rosy Starling (*Pastor roseus*), Alexandrine Parakeet (*Psittacula eupatria*), followed by Sandy *Vs* Shallow wetland habitat (SI=0.58, C=54) which are shared by community of avian species including some common species like Eurasian Marsh-Harrier (*Circus aeruginosus*), Common Pochard (*Aythya ferina*), Gadwall (*Mareca strepera*), Black-headed Gull (*Chroicocephalus ridibundus*), Common Tern

(*Sterna hirundo*), Pallas's Gull (*Ichthyaetus ichthyaetus*), Brown-headed Gull (*Chroicocephalus brunnicephalus*), Pied Avocet (*Recurvirostra avosetta*), Citrine Wagtail (*Motacilla citreola*), Painted Stork (*Mycteria leucocephala*), Great Cormorant (*Phalacrocorax carbo*) where Plantation Vs Ravine habitat (SI=0.59, C=49) provide support to common species like Crested Serpent-Eagle (*Spilornis cheela*), Long-legged Buzzard (*Buteo rufinus*), Greater Spotted Eagle (*Clanga clanga*), Indian Roller (*Coracias benghalensis*), Greater Coucal (*Centropus sinensis*), Jacobin Cuckoo (*Clamator jacobinus*), Common Kestrel (*Falco tinnunculus*), Grey Francolin (*Francolinus pondicerianus*), Common Tailorbird (*Orthotomus sutorius*), Black Drongo (*Dicrurus macrocercus*), Indian Silverbill (*Euodice malabarica*), Large Gray Babbler (*Argya malcolmi*). Between Plantation Vs Agricultural field habitat (SI=0.51, C=38) common species were recorded such as Black-winged Kite (*Elanus caeruleus*), Long-legged Buzzard (*Buteo rufinus*), Greater Spotted Eagle (*Clanga clanga*), Osprey (*Pandion haliaetus*), Eurasian Collared-Dove (*Streptopelia decaocto*), Spotted Dove (*Streptopelia chinensis*), Green Bee-eater (*Merops orientalis*), Asian Koel (*Eudynamys scolopaceus*), Greater Coucal (*Centropus sinensis*), Jacobin Cuckoo (*Clamator jacobinus*), Rufous Treepie (*Dendrocitta vagabunda*), Indian Silverbill (*Euodice malabarica*), Jungle Babbler (*Turdoides striata*), Indian Golden Oriole (*Oriolus kundoo*), Red-vented Bulbul (*Pycnonotus cafer*), and Rose-ringed Parakeet (*Psittacula krameri*). Between Deep wetland Vs Shallow wetland (SI=0.52, C=36) with some common species were Bar-headed Goose (*Anser indicus*), Common Pochard (*Aythya ferina*), Common Teal (*Anas crecca*), Eurasian Wigeon (*Mareca Penelope*), Ferruginous Duck (*Aythya nyroca*), Garganey (*Spatula querquedula*), Indian Spot-billed Duck (*Anas poecilorhyncha*), Mallard (*Anas platyrhynchos*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Tufted Duck (*Aythya fuligula*), Common Shelduck (*Tadorna tadorna*), River Tern (*Sterna aurantia*) and Brown-headed Gull (*Chroicocephalus brunnicephalus*). Where between Ravine Vs Swampy habitat (SI=0.46, C=35), Greater Coucal (*Centropus sinensis*), Rufous-fronted Prinia (*Prinia buchanani*), Jungle Prinia (*Prinia sylvatica*), Ashy Prinia (*Prinia socialis*),Graceful Prinia (*Prinia gracilis*), Black Drongo (*Dicrurus macrocercus*),Indian Silverbill (*Euodice malabarica*), Pied Bushchat (*Saxicola caprata*), Red-breasted Flycatcher (*Ficedula parva*), Bluethroat (*Luscinia svecica*), Hume's Leaf Warbler (*Abrornis humei*), Baya Weaver (*Ploceus philippinus*), Black-headed Ibis (*Threskiornis melanocephalus*).

The community comprises species like Eurasian Sparrowhawk (*Accipiter nisus*), White-throated Kingfisher (*Halcyon smyrnensis*), Oriental Skylark (*Alauda gulgula*), Common

Tailorbird (*Orthotomus sutorius*), Rufous-fronted Prinia (*Prinia buchanani*), Black Drongo (*Dicrurus macrocercus*), Grey-throated Martin (*Riparia paludicola*), Black Redstart (*Phoenicurus ochruros*), Indian Robin (*Saxicoloides fulicatus*), Pied Bushchat (*Saxicola caprata*), Siberian Stonechat (*Saxicola maurus*), Bluethroat (*Luscinia svecica*), Sind Sparrow (*Passer pyrrhonotus*), Streaked Weaver (*Ploceus manyar*), Little Egret (*Egretta garzetta*) were present between Sandy vs Ravine (SI=0.41, C=35) habitat. When we campaire Shallow wetland Vs Agricultural field (SI=0.39, C=34) then there were many common species including Black-tailed Godwit (*Limosa limosa*), Pied Kingfisher (*Ceryle rudis*), Scaly-breasted Munia, (*Lonchura punctulata*), Wire-tailed Swallow (*Hirundo smithii*), Striated Babbler (*Argya earlei*), Sind Sparrow (*Passer pyrrhonotus*), Brahminy Starling (*Sturnia pagodarum*), Indian Pond-Heron (*Ardeola grayii*), and Eurasian Spoonbill (*Platalea leucorodia*).When we see the Swampy Vs Agricultural field (SI=0.48, C=33) Habitat, a community of species like Eurasian Marsh-Harrier (*Circus aeruginosus*), Shikra (*Accipiter badius*), Blue-tailed Bee-eater (*Merops philippinus*), Green Bee-eater (*Merops orientalis*), Ashy Prinia (*Prinia socialis*), Graceful Prinia (*Prinia gracilis*), Black Drongo (*Dicrurus macrocercus*), Jungle Babbler (*Turdoides striata*), Indian Robin (*Saxicoloides fulicatus*), Red-breasted Flycatcher (*Ficedula parva*), Red-vented Bulbul (*Pycnonotus cafer*), Bank Myna (*Acridotheres ginginianus*), Rosy Starling (*Pastor roseus*), Indian Pond-Heron (*Ardeola grayii*), Red-naped Ibis (*Pseudibis papillosa*), and Rose-ringed Parakeet (*Psittacula krameri*). The community of common species between the habitat type Sandy Vs Agricultural field (SI=0.41, C=32) is Eurasian Marsh-Harrier (*Circus aeruginosus*), Eurasian Hoopoe (*Upupa epops*), Red-wattled Lapwing (*Vanellus indicus*), Scaly-breasted Munia (*Lonchura punctulata*), Indian Silverbill (*Euodice malabarica*), Grey-throated Martin (*Riparia paludicola*), Paddyfield Pipit (*Anthus rufulus*), Indian Robin (*Saxicoloides fulicatus*), Oriental Magpie-Robin (*Copsychus saularis*), Streaked Weaver (*Ploceus manyar*), Common Myna (*Acridotheres tristis*), Cattle Egret (*Bubulcus ibis*), Indian Pond-Heron (*Ardeola grayii*), Black-headed Ibis (*Threskiornis melanocephalus*), Glossy Ibis (*Plegadis falcinellus*), and Red-naped Ibis (*Pseudibis papillosa*). The habitat types along with wetland like Sandy Vs Swampy (SI=0.44, C=32) have common species like Indian Spot-billed Duck (*Anas poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*), Yellow-bellied Prinia (*Prinia flaviventris*), Zitting Cisticola (*Cisticola juncidis*), Black Drongo (*Dicrurus macrocercus*), Indian Robin (*Saxicoloides fulicatus*), Bluethroat (*Luscinia svecica*), Baya Weaver (*Ploceus philippinus*), Purple Heron (*Ardea purpurea*), and Black-headed Ibis (*Threskiornis melanocephalus*) similarly between Shallow wetland Vs Swampy (SI=0.37, C=31) habitat, common species are Eurasian Marsh-Harrier (*Circus aeruginosus*), Shikra (*Accipiter badius*), Greater Coucal (*Centropus sinensis*), Brown Crake (*Zapornia akool*), Scaly-breasted Munia (*Lonchura punctulata*), Sind Sparrow (*Passer pyrrhonotus*), Rufous-vented Grass Babbler (*Laticilla burnesii*), Black-breasted Weaver (*Ploceus benghalensis*), Black-crowned Night-Heron (*Nycticorax nycticorax*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Little Egret (*Egretta garzetta*), Purple Heron (*Ardea purpurea*), and Red-naped Ibis (*Pseudibis papillosa*). The habitat with wet and dry characters like Shallow wetland Vs Ravine (SI=0.29, C=28), some common species are Shikra (*Accipiter badius*), Jacobin Cuckoo (*Clamator jacobinus*), White-breasted Waterhen (*Amaurornis phoenicurus*), House Crow (*Corvus splendens*), Citrine Wagtail (*Motacilla citreola*), Siberian Stonechat (*Saxicola maurus*), Baya Weaver (*Ploceus philippinus*), Streaked Weaver (*Ploceus manyar*), Bank Myna (*Acridotheres ginginianus*), Rosy Starling (*Pastor roseus*), Brahminy Starling (*Sturnia pagodarum*), Black-headed Ibis (*Threskiornis melanocephalus*), and Red-naped Ibis (*Pseudibis papillosa*). Common species in the Deep wetland & Sandy (SI=0.45,C=27) habitat are Bar-headed Goose (*Anser indicus*), Eurasian Wigeon (*Mareca Penelope*), Lesser Whistling-Duck (*Dendrocygna javanica*), Northern Pintail (*Anas acuta*), Red-crested Pochard (*Netta rufina*), Ruddy Shelduck (*Tadorna ferruginea*), Eurasian Coot (*Fulica atra*), Common Moorhen (*Gallinula chloropus*), Oriental Darter (*Anhinga melanogaster*), Great Cormorant (*Phalacrocorax carbo*), Indian Cormorant (*Phalacrocorax fuscicollis*), Little Cormorant (*Microcarbo niger*), and Little Grebe (*Tachybaptus ruficollis*). The habitat is dominated by tree species and aquatic grasses such as Plantation Vs Swampy (SI=0.31, C=22) respectively, some common species that share these habitats are Shikra (*Accipiter badius*), Green Bee-eater (*Merops orientalis*), Booted Warbler (*Iduna caligata*), Blyth's Reed Warbler (*Acrocephalus dumetorum*), Common Tailorbird (*Orthotomus sutorius*), Jungle Babbler (*Turdoides striata*), Large Gray Babbler (*Argya malcolmi*), Red-breasted Flycatcher (*Ficedula parva*), Common Chiffchaff (*Phylloscopus collybita*), Little Egret (*Egretta garzetta*) and Rose-ringed Parakeet (*Psittacula krameri*). Common species between Plantation Vs Sandy (SI=0.20, C=16) Green Bee-eater (*Merops orientalis*) habitat are Steppe Eagle (*Aquila nipalensis*), Common Tailorbird (*Orthotomus sutorius*), Black Drongo (*Dicrurus macrocercus*), Indian Silverbill (*Euodice malabarica*), Long-tailed Shrike (*Lanius schach*), Black Redstart (*Phoenicurus ochruros*) Common Myna (*Acridotheres tristis*), and Cattle Egret (*Bubulcus ibis*). The common avian species belonging to habitat types Plantation Vs Shallow wetland (SI=0.15, C=13) are Shikra (*Accipiter badius*) Spotted Dove (*Streptopelia chinensis*), Greater Coucal (*Centropus *sinensis*), Jacobin Cuckoo (*Clamator jacobinus*), Rosy Starling (*Pastor roseus*), and Little Egret (*Egretta garzetta*). In the Comparison of Deep wetland Vs Swampy (SI=0.10, C=5) various species were found common including Eurasian Marsh-Harrier (*Circus aeruginosus*), Osprey (*Pandion haliaetus*), Indian Spot-billed Duck (*Anas poecilorhyncha*), Lesser Whistling-Duck (*Dendrocygna javanica*), and Common Moorhen (*Gallinula chloropus*). In the habitat types of Deep wetland Vs Agricultural filed (SI=0.06, C=3), Common species are Eurasian Marsh-Harrier (*Circus aeruginosus*), Osprey (*Pandion haliaetus*), and Bar-headed Goose (*Anser indicus*) where Osprey (*Pandion haliaetus*) is recorded as common species between Plantation Vs Deep wetland (SI=0.02, C=1). No common species have been found in the habitat of deep wetlands and ravines (SI=0.00, C=0).

Cultural ecosystem services with reference to avian diversity across habitat types

Cultural ecosystem services refer to the non-material benefits that humans derive from ecosystems, including their cultural, spiritual, and aesthetic values (Bieling and Plieninger, 2013; Chaudhary et al. 2019). Birds play a significant role in providing cultural ecosystem services, contributing to the overall well-being and quality of life for many people (Haines and Potschin, 2010; Summers et al. 2012; Green and Elmberg, 2014).

Fig 6.33: Cultural ecosystem services of birds recognized at HWS.

In the present study, cultural ecosystem services conveyed by birds were identified, and several significant aspects indicating the importance and relevance of these services were noted.

Cultural Ecosystem Services (CES) are generally accepted as being essential to human well-being. However, quantifying these non-material benefits is tricky, therefore they are frequently overlooked. This study has included field surveys and formal and informal talks with visitors and the forest department to understand the spatial distribution of various CES across the habitat types of HWS. During the assessment of all kinds of CES present at HWS, a total of 18 types of CES were recorded of which 7 types of cultural ecosystem services viz Recreational, nature education, Bird watching, content creation for social media, Inspiration for writers and poets, Wildlife photography, Pre-wedding shoot, and Research were identified that are supported by the avian community. Birds are often admired for their beauty, grace, and vibrant colors. They inspire artists, photographers, and nature enthusiasts, contributing to the aesthetic value of natural landscapes. Birdwatching and bird photography are popular recreational activities, promoting a deeper connection with nature and enhancing the overall cultural experience (Henderson and Vikander 2007). Birds have profound cultural and symbolic meanings in various societies around the world (Curran 2020). They are often associated with freedom, peace, wisdom, and spiritual beliefs. Birds feature prominently in folklore, myths, and religious traditions, enriching cultural heritage and fostering a sense of identity and belonging. Birds have long been a source of inspiration for poets, writers, and musicians. Their songs, calls, and behaviors have been integrated into literature, music, and storytelling across different cultures. Birds symbolize the beauty of nature and serve as metaphors for human emotions, aspirations, and experiences, thus enriching artistic expression. Birds attract ecotourists and nature enthusiasts from around the world. People travel to different regions to observe and appreciate unique bird species and their habitats. Birdwatching tours, bird festivals, and bird sanctuaries contribute to local economies, creating employment opportunities and supporting conservation efforts. Birds serve as ambassadors for broader environmental issues. Their presence and conservation need to raise awareness about the importance of protecting natural habitats and biodiversity. By studying birds, individuals gain insights into ecological processes, migration patterns, and the impacts of environmental changes, fostering a greater understanding of ecosystems and their interconnectedness. The presence of birds in urban and natural landscapes has a positive impact on human mental and emotional well-being. Birdsong has a calming effect and can reduce stress levels. Observing birds in their natural habitats promotes mindfulness and a sense of tranquility, providing a respite from the fast-paced urban environment. Indigenous and local communities often possess traditional ecological knowledge about birds, their behaviors, and their ecological roles. This knowledge is passed down through generations and contributes to cultural identity, resource management practices, and conservation efforts.

The utility level of habitats for providing cultural ecosystem services has been observed and are shown in Fig 6.34. All seven types of CES are available in Shallow wetland (21.87%) followed by plantation habitat (18.75%) with six types of CES except Pre-wedding shoot where swampy habitat (15.62%) is used for CES such as Wildlife Photography, Research, Recreation, Nature education, and Bird watching. The habitats like sandy and Agricultural fields are providing four types (12.5%) of CES except for Nature Education, Writing poetry, and Pre-wedding shoot. The Ravine habitat type (9.37%) is used for CES-like Wildlife Photography, Research and Bird watching. Similarly, the Deep wetland habitat type (9.37%) was seen delivering CES like Research, Recreation, and Bird watching.

Table 6.11: ANOVA table for seasonal change in the utility of CES provided by avian species.

Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Summer	6.00	40.00	6.67	12.27		
Monsoon	6.00	25.00	4.17	1.37		
Post-monsoon	6.00	35.00	5.83	3.37		
Winter	6.00	49.00	8.17	27.77		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	50.13	3.00	16.71	1.49	0.25	3.10
Within Groups	223.83	20.00	11.19			
Total	273.96	23.00				

According to One-way-ANOVA we failed to accept alternate hypothesis thus there is no significant change (Table 6.10) [ANOVA, $F_{(3, 20)} = 1.49$, $P = 0.25$] in utility of CES as seasons change in avian species besides other sub-variables like low temperature (15.37±4.37°C), accessibility, and sighing of migratory birds in a year are important for the utilization of CES. In January, and February total of 191 species can be found across the habitat of HWS which supports 7 types of CES. In March a total of 180 bird species were recorded due to return migration that leads to declining in species number. Onwards April month temperature increases and species richness decreases hence in April, steep decline had been observed in the species richness of different avian communities across the habitats of HWS which further makes a decline in CES, as for the month of April (96 species) with 4 types of CES, May (99 species)) with 4 types of CES, June (100 species)) with 4 types of CES, July (100 specie))with 4 types of CES and August (102 species) with 4 type of CES, species were recorded. The approaching post-monsoon season from September onwards starts receiving migratory species in various habitats. In the month of September total of 104 species providing 4 types of CES were recorded followed by October (131 species) with 4 types of CES, November (189 species) with 6 types of CES and December (190 species) with 7 types of CES.

Discussion

Avian species are important for the functing of ecosystems. Birds provide a number of ecosystem services. Ecosystems may be significantly impacted by the interactions between birds and plants that result in pollination and seed dissemination. A whopping 33% of bird species spread seeds, mostly by eating fruit, but also by scatter-hoarding nuts and conifer seed harvests (Vander Wall, 2001; Sekercioglu, 2006). The most well-known group of vertebrates, birds are found in almost all ecosystems on earth and offer a variety of benefits. (Sekercioglu 2006; Whelan et al, 2008). They are the perfect group to investigate in order to value ecosystem services. Surprisingly, not much ornithological study has been conducted in relation to ecological services. Perhaps as a result of the ease with which monetary value can be attributed to both fresh drinking water and agricultural products that require pollination, much ecosystem-services research has concentrated on watersheds and insect pollination (Kremen et al, 2007; Brenner et al, 2010). Some cultural and provisioning activities, like bird viewing and hunting, have economic aspects that have been quantified by Sekercioglu, (2002) and Poudel et al, (2008). However, the majority of the crucial ecological functions that birds perform include supporting and regulating services, such as seed dispersal and insect pest management, which are the most challenging to measure (Farber et al, 2006; Sekercioglu, 2006; Whelan et al, 2010).

The majority of the most crucial ecological services that birds offer are a direct outcome of their feeding habits. Birds contribute to the operation and resilience of ecosystems by acting as mobile linkages that move energy within and between ecosystems (Lundberg and Moberg, 2003). The difficulty is expressing the ecological significance of birds in ways that are now important to people. Insectivore birds play a vital role in controlling the pest in a natural ecosystem as well as Agricultural fields. In the present study, birds are recorded under different food guilds such as Insectivorous (87 species), Carnivorous (54 species including Piscivoure and meat-eater), Herbivorous (31 species), Granivorous (16 species), Omnivores (12 species), and Frugivorous (5 species). Pest control is an important ecosystem service provided by birds beside they also limit the outbreak of herbivorous insects in the natural and human ecosystems. The fact that the 1958 Chinese drive to eradicate the Eurasian Tree Sparrow (*Passer montanus*) resulted in bug pest outbreaks rather than higher rice yields shows indirectly that the crop benefited from the sparrows' ability to manage insects (Suyin 1959, Becker, 1996). Other trophic cascades involving birds may be advantageous to agriculture, although they are rarely researched. For instance, despite the fact that many raptors (both eagles and owls) eat mice and rats, Wenny, (2011) suggested there is no research that has looked at this predator-prey relationship in terms of its economic worth or trophic cascades. The outcomes of the few studies that have directly evaluated birds of prey as agricultural rodent-control agents are not entirely clear. Though Kay et al, (1994), recorded those perches built around soybean fields in Australia increased the number of diurnal raptors that flew over and over the fields, which in turn reduced the population density and population growth rate of house mice (*Mus musculus*) in the fields. The average number of species in the insectivore group was 30.14±13.23, followed by carnivores (20.43±7.39), piscivores (12.29 ±9.38), herbivores (12.14±7.36), meat-eaters (10.86 ±6.54), granivorous (7.43±3.91), omnivores (4.43 ±2.99), and frugivores (1.29±2.21) from HWS. Panda et al, (2021) recorded the number of bird species in the insectivorous guild (181 species), and the lowest in the omnivore guild (11 species) from Bhubaneswar, India. Kissling et al, (2012) investigated the variation in avian dietary guild species richness across latitudinal, environmental, and biogeographical scales. De Graaf, (1985) suggested classifying North American interior, coastal, and pelagic birds into foraging guilds. In order to classify 672 species of birds in both breeding and nonbreeding seasons, they classified using a three-part identification for each guild, namely the principal diet, feeding substrate, and foraging technique. Sohil and Sharma (2020) recorded 208 species for guild patterns in various land uses near Jammu, India. Ding et al, (2019) studied in the central Himalayas several avian feeding guilds' reactions to geographic and environmental conditions varied along an elevation gradient. This study has documented migratory birds, a total of 112 species were recorded as migratory species from the study area. Baidya and Bhagat, (2018) documented the migratory species from Goa, India. Kumar (2006) recorded mentioned migratory birds found in Bharathapuzha river basin, Kerala, India. Kaur and Brraich (2021) mentioned the abundance and diversity of threatened birds in Nangal Wetland, Punjab, India. Gupta et al. (2009), mentioned 21 species of migratory birds from Kurukshetra, Haryana, India.

In this study community of birds were recorded in each habitat and similarities among habitats with respect to bird communities have analyzed. Maximum similarity was found between the habitat Ravine *Vs* Agricultural field (SI=0.74, C= 60), and minimum similarity was recorded for Deep wetlands and Ravines (SI=0.00, C=0). Jokimäki and Kaisanlahti-Jokimäki (2003) also studied the similarity between bird community with seasonal variation. Tubelis and Cavalcanti, (2001) studied Central Brazilian Cerrado concerning Community similarity and abundance of bird species. Dos Anjos, and Bocon (1999) recorded Bird communities in a natural forest of southern Brazil.

Birds provide a number of cultural ecosystem services (Whelan et al, 2008; Belaire et al, 2015; Mahendiran and Azeez, 2018; Gaston et al, 2018). In this study cultural ecosystem services are documented such as Recreation, Bird watching, Educational tours, Pre-wedding shoots, Research, Wildlife Photography, and Writing poetry, these services are influenced by bird species richness. This study found that bird community play a singnificant role (R^2 =0.92) to generate cultural ecosystem services. Birds attract wildlife enthusiasts, birdwatchers, and ecotourists who like taking pictures of and viewing birds. This activity encourages ecotourism, outdoor enjoyment, and respect for natural environments. To draw tourists, promote local economies, and aid in conservation efforts, many areas have created birding trails, bird sanctuaries, and bird observatories. The preservation and restoration of natural habitats that support a variety of bird populations (Wehi and lord 2017) should be the main focus of conservation efforts. This comprises, among other things, wetlands, grasslands, and forests. To ensure the presence of different bird species by protecting these habitats, which opens up chances for birding, photography, and aesthetic pleasure. Effective conservation and management efforts require an understanding of the complex interplay between habitat diversity and bird foraging behavior. We can guarantee the continuing existence of these avian explorers and the ecosystems they inhabit by maintaining and restoring diverse habitats. Additionally, safeguarding bird habitats benefits other wildlife and advances the health of our world in general. Avian species in different habitats play integral roles in maintaining the balance and functionality of ecosystems. From seed dispersal and pest control to pollination and nutrient cycling, birds provide invaluable ecosystem services. Conservation efforts aimed at protecting avian species and their habitats are essential to ensure the continued improvement of these ecosystem services, benefiting both nature and human society. By recognizing and valuing the services provided by avian species, we can foster a greater understanding of the importance of birds and promote their conservation for a sustainable future.

Chapter 7

Discussion

Ecosystems are important for all species because they transform abiotic components into biotic matter, which generates life and allows a complex food chain to exist. They also give a variety of commodities and services to human civilizations for a long time. In today's sophisticated economic system, the monetary value of any consumable natural or manufactured product is determined. This economic system has a significant impact on people since it affects every aspect of their lives. The majority of the world's population is experiencing challenges as a result of environmental deterioration and loss. Climate change and water stress are major problems for future generations therefore several long-term commitments have been made and agreed upon by more than 150 nations. Since the last three decades, the value of ecosystem services has been employed to address the relevance of ecosystems. The current study aims to analyze the valuation of ecosystem services of Harike Wildlife Sanctuary by exploring diverse habitat types beside to assess the effect on ecosystem services, seasonal variation in plant species and bird species was also observed. A habitat's physical characteristics and biological variables are important elements in the creation of ecosystem services. The current study found that different habitats have varied levels of usefulness. The present study estimated the provisional ecosystem services such as Fuel-wood, Fodder, Edible-plants, Medicinal plants, Raw material, Water utilization by local people for agriculture and domestic purposes, and Water supply to Indira Gandhi Canal. In the field, 115 species across multiple use categories were counted. Diverse habitats contained these species. Across all use categories, the habitat types of the Sanctuary support populations of 48.5±20.95 species. The Plantation habitat contains 85 kinds of beneficial plants, with a mean number of 25.6±17.52 for each use category. There are 48 species of medicinal plants, followed by 28 species of fuel wood, 34 species of fodder, 16 species of edible plants, and 2 species of raw materials. The economic value of each use category is estimated for fuel-wood (₹70594.65/year), fodder (₹5656891.67/year), Medicinal plants (₹6000 to 10000/year), Edible plants (₹19,400/year), Raw-material (₹186528), and Agricultural production (₹306.930,922.82/per year) on another hand provisional service of abiotic component like Sand accounts for ₹1600800/year, Value of water supply to Indira Gandhi canal estimated ₹962,826,108,768/year, water consumption in the production of rice ₹23274020000, water consumption in the production of wheat ₹ 10579100000, water consumption for domestic purpose accounts for ₹799600682/year. Harike

Wetland provides several ecosystem services in case of cultural ecosystem services such as bird viewing, research, the concept of natural capital, and wildlife photography, which are available in all six habitat categories, others, like boating, birthday celebrations, and pre-wedding shoots in the current case, are exclusive to specific habitats. All the CES is estimated around ₹ 3894850.91 for a year. Valuation of supporting services is done by estimating biomass in different ecosystem habitats, according to the market value of biomass wetland provides supporting services worth of ₹7480698.58, Plantation habitat (₹22016520.96/year) Sandy (₹4687200/ year), Swampy (₹179897760/ year), Ravine (₹4577629.169/year), and Agricultural habitat (₹33695940). The valuation of regulatory ecosystem services is estimated up to ₹623012841.6 for flood protection through HWS in downstream. Valuation is an important tool for addressing the utility of an ecosystem for various benefits to society therefore such studies have been done across the globe. According to Uddin et al. (2013), the Sundarbans' primary provisioning resources include lumber, firewood, fish, thatching materials, honey, and waxes. And tourism is the primary cultural service. The Forest Department received an average of US $744,000 and US $42,000 per year in revenue from the Sundarbans' provisioning and cultural services.

The current study has identified some medicinal plants with significant efficacy in treating specific health issues. Informants acknowledged that a variety of important wild medicinal plants had been distributed throughout the HWS but these plants are now restricted to a few locations. Ethnobotanical indices such as the Use value, Relative Importance Index, and Fidelity level of wild medicinal plants also expanded on the effectiveness of medicinal plants for different ailments. The high fidelity level of any medicinal plant concerning a particular ailment indicates that people use that specific plant at large. Das et al. (2018) and Suwardi et al. (2020) have also shown how important it is to keep an inventory record of traditional ethnobotanical research for the conservation and sustainable consumption of wild medicinal plants.

Wetlands are dynamic ecosystems that fluctuate significantly all year long as a result of seasonal changes (Erwin 2009), Wetland habitats and plant communities are essential to a variety of ecosystem functions, such as the providing of habitat, water filtering, and carbon sequestration (Mitsch and Mander 2018). With a focus on the factors causing these changes and the significance of knowing them for wetland conservation and management, this debate attempts to analyze the seasonal changes in the plant population of wetland habitats. Wetland plant communities exhibit diverse seasonal patterns (Gorme et al. 2012) as a result of the interaction of many environmental elements like temperature, the availability of water, and light. These elements influence variations in species composition, phenology, and plant development, which cause dynamic alterations within the wetland community (Antala et al, 2012). Wetland plant communities flourish and produce more during the summer as temperatures rise and the days become longer. Early summer supports the growth of begin to emerge during this time. Before the tree canopy fully forms, these plants make use of the light and nutrients that are accessible. Wetlands are also essential for nesting and foraging during this time of year for migratory waterfowl and songbirds (Stewart 1982; Stewart 1996; Weller 1999; Webb et al. 2010). Wetland plant communities attain their highest biomass and variety levels in the summer. *Phragmites karka* and *Typha latifolia* two dominant emergent species, flourish in warm climates with plenty of water availability. The environment that these plants provide is crucial for a variety of animals, such as frogs, turtles, and ducks. The productivity and oxygenation of wetland ecosystems are also boosted by submerged aquatic plants like water *Ceratophyllum demersum, Hydrilla verticillata, Myriophyllum spicatum, Najas minor,* and *Potamogeton crispus*. Wetland plant communities shift noticeably as post-monsoon draws near. Numerous species of herbaceous plants begin to senesce and get ready for the next winter. Before dropping their leaves, wetlands plants like *Bombax ceiba, Dalbergia sissoo, Eucalyptus camaldulensis, Ficus benghalensis,* and *Ficus religiosa* exhibit bright foliage colors. The wetland ecosystem's water flow, sedimentation rates, and nutrient dynamics can all be affected by the reduction in plant biomass during this season (Chauhan and Gopal 2005). In wetland ecosystems, winter brings slumber and a comparatively low level of plant development (Tuboi and Hussain, 2018). Herbaceous species wither away, and deciduous plants lose their leaves. Some wetland species, such as *Ipomoea aquatica, Alternanthera paronychioides, Colocasia esculenta*, *Syzygium cumini, Terminalia arjuna*, and *Cuscuta reflexa* remain green all year long in HWS and offer important winter shelter for tiny animals and birds. Wetlands are important wintering sites for migratory species like waterfowl. The seasonal changes in wetland plant communities are influenced by a combination of abiotic and biotic factors such as water availability, including cycles of flooding and drought, has a significant impact on the dynamics of wetland plant communities. Changes in water levels have an impact on plant establishment, nutritional availability, and seed germination. Temperature variations control phenology, nitrogen cycling, and plant growth. Monsoon and summer temperatures that are warmer encourage plant growth, while fall and winter temperatures that are colder cause dormancy and leaf withering. The length and intensity of the day's sunshine have a significant impact on the diversity and productivity of wetland plant communities. The surrounding vegetation's canopy coverage and the wetland's water level both have an impact on the amount of light that is available. Natural and anthropogenic disturbances, such as fire, flooding, and human activities, can significantly impact wetland plant communities.

Within plantation settings, plant communities are dynamic and experience considerable seasonal changes. Numerous variables, including temperature, precipitation, sunshine availability, and soil conditions, have an impact on these changes. For effective management and protection of these ecosystems, it is essential to comprehend the patterns and dynamics of plant communities in plantations. Studies have shown that plant communities within plantation habitats exhibit distinct seasonal variations in species composition. The distribution of vegetation in India is greatly influenced by land surface temperature and rainfall during the monsoon (Sarkar and Kafatos 2004). Since vegetation needs moisture, rain, and favorable temperatures, the local climate may be characterized by it.

Aside from variations in phenological events like blooming, fruiting, and leaf senescence, seasonal changes in plant communities also affect how these events occur. These occurrences are frequently scheduled to maximize the use of resources and reproductive success. Bernier, 1988 suggests the level of individual plants to the level of entire ecosystems, phenology is a significant and much-disregarded part of plant ecology. For individuals and populations to produce the most seeds, the transition between the vegetative and reproductive stages, which take place concurrently with flowering, must be timed properly. Phenology may be more tuned to seasonal changes in precipitation and less susceptible to temperature and photoperiod in tropical environments (Sanchez et al. 2003; Morellato 2003). Due to their potential to intercept non-point source disturbances and maintain ecological integrity across a vast area, riparian zones are considered important. Makkeasorn et al. (2009) have carried out the seasonal change detection of riparian zones in a large semi-arid watershed to improve categorization and change detection of riparian buffers. Nilsson et al. (2013) advocated that the vegetation in riparian zones in boreal regions, such as wet landscapes on minerogenic soils, is diversified, prolific, and active, and it will respond quickly to climate change. Most of the boreal region is expected to experience various combinations of rising temperatures, and decreased seasonal variation in runoff, increasing temperatures will encourage the invasion of exotic species, although there is likely to be little loss of native species. The riparian zone will become more condensed as a result of the hydrologic changes, which will locally diminish the diversity of species.

Seasonal changes significantly impact bird communities, affecting their behavior, distribution, and composition (Karr 1976; Chettri et al. 2005; Caula et al. 2008; Katuwal et al. 2022). Birds are highly adaptable creatures, capable of adjusting to varying environmental conditions throughout the year. Different habitats provide distinct resources and climatic conditions, which result in diverse responses from avian populations. This discussion explores the seasonal changes in bird communities across various habitats and the factors that influence these fluctuations. Forests host a rich diversity of bird species, and their composition undergoes noticeable shifts with the changing seasons. During the breeding season, the forest is filled with the melodious songs of resident species establishing territories and attracting mates. Migratory birds, including warblers and thrushes, arrive in the spring to breed and contribute to the community's diversity. As autumn approaches, many migratory birds depart for warmer regions, resulting in a decline in overall bird abundance. However, some species, such as woodpeckers and resident birds, remain throughout the year, adapting to the forest's changing resources. Grasslands provide critical habitats for a variety of bird species, each exhibiting distinct seasonal patterns. During the breeding season, grasslands become a hub of activity as birds build nests, engage in courtship displays, and raise their young. Species like meadowlarks and sparrows are commonly associated with grasslands and exhibit strong seasonal fluctuations. In the winter, grassland bird communities often experience a decrease in diversity, as many species migrate to warmer regions or transition to alternative habitats. However, some winter-adapted species, such as raptors and northern harriers, continue to thrive in these open landscapes. Wetlands are highly dynamic ecosystems that experience pronounced seasonal changes, significantly influencing bird communities. During the spring and summer, wetlands attract a multitude of waterfowl, shorebirds, and wading birds, as they provide abundant food sources and suitable nesting sites. Migratory species such as ducks and geese use wetlands as stopover points during their long-distance journeys. In the winter, wetlands become vital refuges for waterbirds, as they provide open water and foraging opportunities when other habitats are frozen. However, wetlands may face challenges due to climate change and human disturbances, impacting bird populations that rely on them.

Several factors contribute to the seasonal changes observed in bird communities across habitats. Seasonal fluctuations in food availability, such as fruiting trees, flowering plants, or insect abundance, directly influence bird communities. Birds adapt their foraging behavior and may switch diets based on resource availability. Breeding seasons trigger changes in bird communities as resident and migratory species establish territories, build nests, and raise their young. Suitable nesting sites and resources play a crucial role in determining species composition. Climatic conditions affect bird migration patterns, with some species leaving habitats to avoid harsh winters or to take advantage of abundant resources in other regions. Human-induced changes to habitats, such as deforestation, urbanization, or wetland.

Multiple sources of pollution pollute aquatic systems where Wetlands are one of the world's most endangered ecosystems. Even low-level pollution of these habitats might have negative ecological consequences. (Hildebrandt et al. 2008). The natural habitats located near human habitation are potentially under various kinds of threats like a change of landform, invasive species, discharge of sewage, and seepage of synthetic fertilizers and pesticides. In the present scenario, Beas and Sutlej rivers are facing above mentioned threats and both Rivers accumulate water mixed with pesticides and sewage (Kaur 2017) even though Harike wetland supports a large number of resident and migratory birds. There might be the role of vegetation like *Eichhornia crassipes*, *Phragmites karka*, *Hydrilla verticillata,* and *Typha angustifolia,* in absorbing the toxic elements from water (Delgado et al. 1993; Windham et al. 2003; Panich-pat et al. 2005; Srivastava et al. 2011) besides this vegetation also helpful in decreasing Biochemical oxygen demand level, eventually helps in survival of aquatic animals and avian community. In HWS habitats like sandy and Ravine have very less area even though they support a community of 138 species of birds including resident and migratory birds whereas these habitats are facing anthropogenic pressure in the form of agricultural encroachment. The change in the composition of the avian community can impact various ecological functions, regulatory services in particular (Polis and Hurd 1996; Anderson and Polis 1999). The species richness of any area is an indicator of a healthy ecosystem for producing ecosystem services.

The relevance of cultural ecosystem services provided by birds lies in their ability to foster a sense of connection between humans and nature. They contribute to the overall cultural and social fabric of societies, promoting environmental awareness, supporting local economies, and enhancing the overall well-being of individuals. Recognizing and valuing the cultural significance of birds can aid in conservation efforts and sustainable management of ecosystems, ensuring their continued provision of cultural ecosystem services for future generations. Altaf et al. (2023) recorded 64 different bird species identified in the Khanki, Punjab, Pakistan area, also calculated the Shannon-wiener diversity index was 3.973, and Evenness 0.8306. The abundance and diversity of water bird assemblages were observed in the ponds of the district of Barnala, Punjab, India, by Kaur et al. (2018). They discovered a total of 36 species of birds, divided among 24 families and 13 orders. Additionally, they noted a notable variation in the avian population at various sites. Aquatic plants are a significant component in the assemblage of bird species, claim Kaur et al. in 2018. From 2009 to 2011, Bibi and Ali, 2013 measured the variety of bird species at the Taunsa Barrage Wildlife Sanctuary, Punjab, Pakistan. The study's goal was to determine the variety of birds in the Sanctuary and the primary risks to them. Data were gathered directly from censuses. A total of 58,598 bird species from 53 families and 171 different species were counted. The number of birds per acre was 6.9 birds. Simpson's Diversity Index (D) was 0.93, while Shannon-Weiner Diversity Index (H') was 3.39. 12 species were classified as very abundant, 19 as abundant, 62 as very common, 16 common, and 41 somewhat common in terms of local occurrence status. According to Gillies and Clair, 2010 birds provide: providing, regulatory, cultural, and sustaining functions. In this assessment, they largely focus on supporting services, birds have a variety of roles in ecosystems, such as predators, pollinators, scavengers, seed dispersers, predators of seeds, and ecosystem engineers. The two subcategories of these ecosystem services are those that result from behavior (such as eating agricultural pests) and those that result from bird products (such as nests and guano). From the perspective of ecosystem services, most birds are highly unique due to their unique characteristics. In the HWS Avian species are providing Cultural, supporting, and regulatory ecosystem services. HWS supports the breeding population of threatened species as well as refuses to many migratory birds therefore habitat must be conserved followed by some ecological intervention like desiltation and control of invasive species. During the study a floating invasive species (*Pistia stratiotes*) was seen in the shallow wetland habitat, this species has the potential to spread quickly and disrupt wetland ecosystem services (Reddy 2008). Avian communities are significant for cultural ecosystem services such as recreational services besides being important for educational, wildlife photography, and research opportunities to people. Conservation efforts for the avian population and their habitat are creating livelihood opportunities for local people. Climate change, anthropogenic pressures, and alien vegetation invasion could change the composition of avian communities. As an outcome, this study will be useful in detecting changes in avian communities in each habitat of HWS as well as keeping baseline data on the current distribution of avian communities among habitats.

Chapter 8

Conclusion and recommendations

The present study successfully achieved the objective of evaluating ecosystem services this study also documented seasonal variation of a total of 591 species including plants (386 species) and birds (205 species) in each habitat of HWS. The present study contains systematic methods for the quantification of ecosystem services and their economic valuation. The provisional ecosystem services such as Fuel-wood, Fodder, Edible plants, medicinal plants, Crops, and raw materials were assessed for economic valuation. A total of ₹ 312870337.1/year was estimated for provisional ecosystem services in biotic forms, where the valuation of Provisional ecosystem services of abiotic components estimated around ₹34654321482/year. The Harike wetland provides water worth ₹ 9,62,82,61,08,768/ year to IGC, which is considered as provisional ecosystem services in this study. The Harike wetland is crucial for western part of India as this wetland ensures the water supply up to 550km from Harike to Jaisalmer, Rajasthan.

The habitat diversity of HWS creates cultural ecosystem services. In the present study a total of 18 types of cultural ecosystem services were identified and considered for economic valuation, around 7500 people visited HWS in the year 2019 and 2020, this many people would have created cultural ecosystem services worth ₹ 3894850.91. In the case of supporting ecosystem services habitat of HWS stocks Biomass in different kind of plants therefore biomass estimation has been done for selected plants. HWS provides supporting services worth of ₹ 252355748.7/year. Harike wetland and sandy habitat found significant in flood protection downstream, HWS protects rice crops worth ₹ 623012841.6/year downstream up to 30km in Indian Territory.

Plants contribute to major resources for humankind right from food to medicine. A total of 386 species of plants were recorded among them 115 species are used by local people for different purposes besides 85 species were recorded as important concerning ethno botanical knowledge. Even though the study area also has access to contemporary healthcare services, the study found that numerous species are employed to treat a wide range of medical conditions. The species of wild medicinal plants that are common in various habitats have been identified through the current investigation. This study includes primary information on traditionally utilized wild medicinal plants and their distribution throughout the various habitat types of HWS in addition to information on conservation. The gene pool of medicinal plants enables the acquisition of germplasm for ex-situ or in-situ conservation on certain habitat types. The ideal period for germplasm extraction might be supported by the timeline chart of the medicinal plant. The documentation of plant uses in traditional medicine aids in the creation of accurate information about the customary healthcare culture. Traditional knowledge of medicinal plants among local people was recorded and well-documented for 40 types of ailments. The availability of medicinal plants is also recorded and a timeline chart is mentioned in this study. The mapping of some important plants was designed and mentioned in Chapter 5. The major six habitats were identified and mapped with pictures of different locations of the concerned habitat. Seasonal change in species richness of plants in each habitat has been documented besides plant community of each habitat with seasonal variation is mentioned in this study. Similarity among habitats was analysed through similarity in the plant community. Common species of plants among habitats were mentioned with plant community similarity percentage.

A total of 205 species were recorded from a mosaic of habitats. The avian community of each habitat with seasonal change was mentioned. Seasonal changes in the diversity of birds, species richness, and evenness have been analysed and documented in the present study. The avian community of each habitat is mentioned in Chapter 6. Similarity among the avian community of each habitat was documented with common species between habitats. The significance of bird sightings and cultural ecosystem services were analysed and According to One-way-ANOVA analysis has shown no significant effect [ANOVA, $F_{(3, 20)} = 1.49$, $P = 0.25$] of seasons on utility of CES associated with avian species besides other sub-variables like low temperature (15.37 ±4.37 °C), accessibility, and sighing of migratory birds in a year are important for the utilization of CES. Cultural ecosystem services in each habitat are mentioned in Chapter 6.

Habitat conservation plays a crucial role in promoting the creation of cultural ecosystem services through bird diversity. Cultural ecosystem services refer to the non-material benefits that human derive from ecosystems, such as recreational opportunities, aesthetic enjoyment, and cultural and spiritual connections. To maintain the efficiency of ecosystems for the generation of Ecosystem services habitats must be protected from degradation besides Restoration must be carried out for the functionality of Ecosystems. The present study identified the factors for improvement in HWS, Suggestions are mentioned below.

Recommendations

Ecological restoration of degraded habitats

Wetland habitat

Controlling *Eichhornia crassipes* and *Pistia stratiotes* growth in wetlands can be challenging, but there are several methods you can employ to manage and mitigate its spread. In the HWS major population of *Eichhornia crassipes* comes through the Sutlej River and get settled in low flow area or shallow wetland of Harike wetland. To control the lateral expansion and addition of *Eichhornia crassipes* in Harike wetland through Sutlej River can be done by construction of wetland on Sutlej River according to the natural drainage pattern. There is a need to construct a 30m wide vegetation belt across the river with species composition like *Phragmites karka, Typha angustifolia, Cyperus alternifolius, Cyperus papyrus, Ipomoea aquatic,* and *Arundo donax,* This vegetation belt will be followed by a wetlands that would be made by expanding selected area on either side of Sutlej River. The expanded area will impound more water during floods besides this expanded wetland will slow down the flow of water and it will also help in purifying water by absorption of heavy metals through vegetation (Shao and Chang 2004; Adelodun et al. 2020). Probably Harike Wetland and IGC will receive clean water after implementing the model (Fig 8.1).

Eichhornia crassipes is a free-floating vegetation that can be blocked by a vegetation belt. The collected *Eichhornia crassipes* can be harvested as Raw-material for organic manure. Mitigating the problem of the proliferation of *Eichhornia crassipes* can be done by manufacturing organic manure out of it. Crop output can be considerably increased by using organic materials to improve the physical, chemical, and microbiological qualities of cultivated soil (Steffen 1979; Darmody et al. 1983; Pera et al. 1983). Vidya and Girish (2014) found that considerable rise in the percentage of germination, fresh weight, dried weight, biomass, root, and shoot length of wheat crops by applying compost material made up of *Eichhornia crassipes.* They also suggest that compost of *Eichhornia crassipes* can be utilized as a good source of nutrients for crops because it is a good absorber of nitrogen, phosphate, and potassium through water. The many strategies for removing this "weed" have not been very successful in halting its spread. Therefore, the current study focus is on finding the particle solutions for the sustainable use of *Eichhornia crassipes* as organic manure.

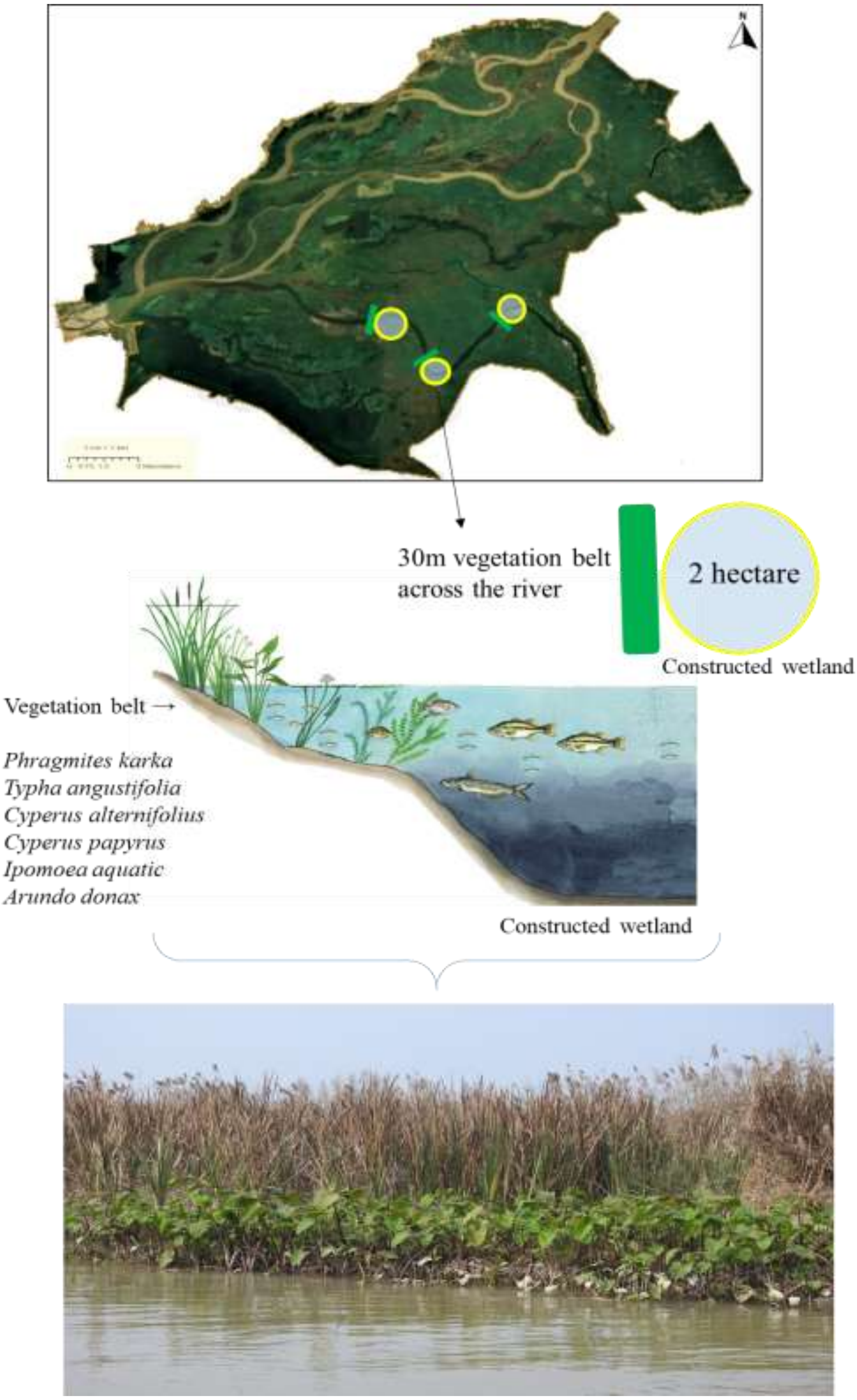


Fig 8.1: Model for controlling *Eichhornia crassipes* and water filtration.

Regular monitoring of the wetland is crucial to detect *Eichhornia crassipes* and *Pistia stratiotes* growth in its early stages. By identifying and addressing the problem early on, you can prevent the rapid expansion of the plants and implement appropriate control measures promptly.

Remember, the control methods you choose may depend on the specific conditions and regulations in your area. It is essential to consult with local environmental agencies, wetland experts, or specialists for guidance and to ensure that your efforts align with the conservation goals of the wetland ecosystem.

Shallow wetlands located adjacent to the village area are under threat of encroachment and the conversion of seasonal wetlands into the agricultural fields is happening, therefore, these areas must be identified and protected by the tree lines, species like *Terminalia arjuna, Syzygium cumini, Mitragyna parvifolia, Mallotus nudiflorus, Tamarix dioica, Phoenix sylvestris,* and *Vachellia nilotica*, in between trees clumps of *Phragmites karka, Typha angustifolia, Cyperus alternifolius, Cyperus papyrus,* and *Saccharum bengalense* should be planted. Try to plant big saplings and protect them with a tree guard because the area is under grazing of livestock.

	A shallow wetland (in Monsoon)
	Converted into Agricultural field. (in Winter)

Fig 8.2: Change in the land use in HWS

Ravine habitat

Beas River is under encroachment thus the landform is continuously changed into an agricultural field. To protect the Ravine habitat and restorative following things can be considered. Restoring a ravine habitat is an important step in preserving biodiversity and supporting the health of ecosystems. Here are some suggestions for the restoration of a ravine habitat:

1. Conduct a site assessment: Start by assessing the current condition of the ravine habitat. Identify factors such as soil quality, water sources, vegetation cover, and any potential sources of pollution or degradation. This assessment will help you develop an appropriate restoration plan.

2. Remove invasive species: Invasive plant species can outcompete native vegetation, reducing biodiversity and altering ecosystem dynamics. Remove any invasive plants from the ravine, using manual or mechanical methods. Be sure to properly dispose of the removed plants to prevent their reestablishment.

3. Plant native species: Select a variety of native plant species that are suitable for the ravine habitat. Consider the soil type, moisture levels, and light conditions when choosing plants. Planting a diverse range of species will enhance the habitat's resilience and support a wider array of wildlife.

4. Control erosion: Ravines are susceptible to erosion, which can lead to sedimentation in nearby water bodies. Implement erosion control measures such as installing erosion control blankets, using bioengineering techniques, or constructing retention ponds to capture excess sediment.

5. Establish buffers: Create buffer zones along the edges of the ravine to provide a transition between the habitat and surrounding areas. Buffers can help filter runoff, reduce pollution inputs, and protect the ravine from encroachment.

6. Promote natural regeneration: Encourage natural regeneration by allowing native plants to self-seed and propagate. This approach can help restore the ecological balance and reduce the need for extensive planting efforts.

7. Manage stormwater runoff: Develop a stormwater management plan to control the quantity and quality of runoff entering the ravine. Implement strategies such as rain

gardens, bioswales, or permeable pavement to capture and filter stormwater before it reaches the ravine.

8. Monitor and maintain: Regularly monitor the restored ravine habitat to assess its progress and address any emerging issues. Conduct ongoing maintenance activities such as weed control, pruning, and reseeding as needed to support the habitat's long-term health.
9. Educate and involve the community: Engage the local community and raise awareness about the importance of ravine restoration. Encourage community members to participate in volunteer activities, workshops, and educational programs to foster a sense of stewardship and long-term commitment.
10. Seek expert advice: If you are not familiar with habitat restoration techniques or lack the necessary expertise, consider consulting with local conservation organizations, environmental experts, or landscape professionals who specialize in ecological restoration. Their knowledge and experience can help ensure the success of the restoration project.

Ravine habitat restoration is a long-term endeavor, requiring ongoing dedication and resources. Patience, perseverance, and collaboration with stakeholders are key to achieving a thriving and resilient ravine ecosystem.

Plantation habitat

In the plantation habitat rapid growth of *Leucaena leucocephala* and *Prosopis juliflora* were observed, these species produce seeds in huge quantity that furether results in new germination of these species only which is limiting the grow of other plants including species of Hebs and trees. *Prosopis juliflora* can be harmfull for ecosystem because allapahy effect. If these species were not controlled, they will dominate the planation habitat and will significantly impact the funationality of ecosystems in HWS, thus systamaitc stratigies must be persude to control the pollifiration of *Leucaena leucocephala* and *Prosopis juliflora*.

Suggestion for improvement in CES

Developing and improving the cultural ecosystem of a wildlife Sanctuary can be achieved through several strategies, including:

1. **Engage with local communities:** To strengthen the cultural ecosystem of a wildlife Sanctuary, it is essential to engage with local communities. This can be done by organizing community events, workshops, and cultural festivals that celebrate the diverse cultural heritage of the region. Such initiatives can foster a sense of belonging and pride in the local culture and build a strong relationship between the Sanctuary and the surrounding communities.

2. **Interpretation and education:** Interpretation and education programs can be developed to provide visitors with a deeper understanding of the cultural significance of the Sanctuary. This can include guided tours, exhibits, and educational materials that highlight the cultural history of the area and its ecological importance. This can help visitors develop a greater appreciation for the cultural value of the Sanctuary.

3. **Preservation of cultural sites:** Cultural sites within the Sanctuary should be identified and protected. This can include traditional hunting grounds, sacred sites, and cultural artifacts. Such sites can be marked and interpreted to provide visitors with a deeper understanding of the cultural heritage of the area.

4. **Incorporation of traditional practices:** The incorporation of traditional practices such as sustainable agriculture, traditional medicine, and cultural arts and crafts can help to maintain cultural traditions and support the livelihoods of local communities. This can also create economic opportunities for local people, helping to build a sustainable future for the Sanctuary and its surrounding communities.

5. **Collaboration with local groups:** If the wildlife Sanctuary is located within the traditional lands of Indigenous groups, it is important to work collaboratively with these groups to ensure that their cultural heritage is respected and preserved. Such collaboration can include the involvement of indigenous groups in the management of the Sanctuary and the development of cultural tourism initiatives.

In conclusion, for enhancing the cultural ecosystem of a Harike wildlife sanctuary, it needs a comprehensive strategy that encompasses engaging local communities, educating visitors, preserving cultural sites, integrating traditional practices and collaborating with local communities. Through the implementation of these multifaceted approaches, a robust cultural ecosystem can be established, fostering biodiversity conservation and promoting the sustainable development of adjacent villages.

References

Abdar, M. R. (2014). Seasonal diversity of birds and ecosystem services in agricultural area of Western Ghats, Maharashtra state, India. Journal of Environmental Science, Toxicology and Food Technology, 8(1), 100-105.

Abe, R., & Ohtani, K. (2013). An ethnobotanical study of medicinal plants and traditional therapies on Batan Island, the Philippines. Journal of Ethnopharmacology, 145(2), 554-565.

Abson, D. J., & Termansen, M. (2011). Valuing ecosystem services in terms of ecological risks and returns. Conservation Biology, 25(2), 250-258.

Acharya, R. P., Maraseni, T., & Cockfield, G. (2019). Global trend of forest ecosystem services valuation–An analysis of publications. Ecosystem Services, 39, 100979.

Acreman, M., & Holden, J. (2013). How wetlands affect floods. Wetlands, 33, 773-786.

Adams, W. M. (1993). Indigenous use of wetlands and sustainable development in West Africa. Geographical journal, 209-218.

Adepoju, A. A., & Salau, A. S. (2007). Economic valuation of non-timber forest products (NTFPs).

Adhikari, B. S., & Babu, M. M. (2008). Floral diversity of Baanganga Wetland, Uttarakhand, India. Check List, 4(3), 279. https://doi.org/10.15560/4.3.279.

Ahmad, K. A. F. E. E. L., Khan, Z. I., Ashraf, M. U. H. A. M. M. A. D., Hussain, M., Ibrahim, M., & Valeem, E. E. (2008). Status of plant diversity at Kufri (Soone valley) Punjab, Pakistan and prevailing threats therein. Pak. J. Bot, 40(3), 993-997.

Akwee, P. E., Palapala, V. A., & Gweyi-Onyango, J. P. (2010). A comparative study of plant species composition of grasslands in Saiwa Swamp National Park and Kakamega Forest, Kenya. Journal of Biodiversity, 1(2), 77-83.

Albuquerque, C.A. & U.P. Albuquerque. 2005. Local perceptions towards biological conservation in the community of Vila Velha, Pernambuco, Brazil. Interciencia 30:453-459

Ali, M., Iqbal, I. M., Shabbir, A., Khan, Z. U. D., & Khan, M. T. A. (2020). Ethnomedicinal studies on aquatic plants of tehsil Shakargarh, Punjab, Pakistan. Journal of Medicinal Plants, 8(1), 15-19.

Allen, S. E., Carlisle, A., White, E. J., & Evans, C. C. (1968). The plant nutrient content of rainwater. The Journal of Ecology, 497-504.

Allison, S. K. (2012). Ecological restoration and environmental change: renewing damaged ecosystems. Routledge.

Altaf, M., Javid, A. R. S. H. A. D., Irfan, M. A., Munir, S. A., Iqbal, K. J., & Umair, M. (2013). Diversity, distribution and ecology of birds in summer season flathead Khanki, Punjab, Pakistan. Biologia (Pakistan), 59(1), 131-7.

Ambastha, K., Hussain, S. A., & Badola, R. (2007). Social and economic considerations in conserving wetlands of indo-gangetic plains: A case study of Kabartal wetland, India. Environmentalist, 27(2), 261–273. https://doi.org/10.1007/s10669-007-9003-1.

Anchang, J. Y., Prihodko, L., Ji, W., Kumar, S. S., Ross, C. W., Yu, Q., ... & Hanan, N. P. (2020). Toward operational mapping of woody canopy cover in tropical savannas using Google Earth Engine. Frontiers in Environmental Science, 8, 4.

Anderson, D. R., Laake, J. L., Crain, B. R., & Burnham, K. P. (1979). Guidelines for line transect sampling of biological populations. The Journal of Wildlife Management, 70-78. Annu. Rev. Plant Physiol. Plant Mol. Biol. 39, 175–219.

Anoop, P., & Suryaprakash, S. (2008). Estimating the Option Value of Ashtamudi Estuary in South India : a contingent valuation approach, 1–5.

Antala, M., Juszczak, R., van der Tol, C., & Rastogi, A. (2022). Impact of climate change-induced alterations in peatland vegetation phenology and composition on carbon balance. Science of the total environment, 154294.

Anthony, A., J. Atwood, P. August, C. Byron, S. Cobb, C. Foster, C. Fry, A. Gold, K. Hagos, L. Heffner, D. Q. Kellogg, K. Lellis-Dibble, J. J. Opaluch, C. Oviatt, A. Pfeiffer-Herbert, N. Rohr, L. Smith, T. Smythe, J. Swift, and N. Vinhateiro. 2009. Coastal lagoons and climate change: ecological and social ramifications in U.S. Atlantic and Gulf coast ecosystems. Ecology and Society 14(1): 8.

Anupama, N., Madhumitha, G., & Rajesh, K. S. (2014). Role of dried fruits of Carissa carandas as anti-inflammatory agents and the analysis of phytochemical constituents by GC-MS. BioMed Research International, 2014.

Asrat, G., & Seid, A. (2017). Allelopathic effect of meskit (Prosopis juliflora (Sw.) DC) aqueous extracts on tropical crops tested under laboratory conditions. Momona Ethiopian Journal of Science, 9(1), 32-42.

Assessment, M. E. (2003). Ecosystems and human well-being: a framework for assessment.

Assessment, M. E. (2005). Ecosystems and human well-being: wetlands and water. World Resources Institute.

Atkinson, G., Bateman, I., & Mourato, S. (2012). Recent advances in the valuation of ecosystem services and biodiversity. Oxford Review of Economic Policy, 28(1), 22-47.

Babu, C., Kumar, P., Prasad, L., & Agrawal, R. (2000). Valuation of Ecological Functions and Benefits: A Case Study of Wetland Ecosystems along the Yamuna River Corridors of Delhi Region. Irade.Org. Retrieved from http://www.irade.org/eerc/pdf/WB_FR_LallanPrasad.pdf.

Badola, R., & Hussain, S. A. (2005). Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India. Environmental Conservation, 32(1), 85–92. https://doi.org/10.1017/S0376892905001967.

Badola, R., Hussain, S. A., Mishra, B. K., Konthoujam, B., Thapliyal, S., & Dhakate, P. M. (2010). An assessment of ecosystem services of Corbett Tiger Reserve, India. The Environmentalist, 30, 320-329.

Badola, R., Ogra, M. V., & Barthwal, S. C. (2014). Ecodevelopment, gender and empowerment: Perspectives from India's Protected Area communities. In Global Perspectives on Gender and Space (pp. 200-223). Routledge.

Baidya, P., & Bhagat, M. (2018). A checklist of the birds of Goa, India. Indian Birds, 14(1), 1-31.

Báldi, A., Batáry, P., & Erdős, S. (2005). Effects of grazing intensity on bird assemblages and populations of Hungarian grasslands. Agriculture, ecosystems & environment, 108(3), 251-263.

Báldi, A., Batáry, P., & Erdős, S. (2005). Effects of grazing intensity on bird assemblages and populations of Hungarian grasslands. Agriculture, ecosystems & environment, 108(3), 251-263.

Bann, C. (1999). A contingent valuation of the mangroves of Benut, Johor State, Malaysia. Economy and Environment Programme for Southeast Asia (EEPSEA).
Barbier, E. B., Acreman, M., & Knowler, D. (1997). Economic valuation of wetlands: a guide for policy makers and planners. Gland, Switzerland: Ramsar Convention Bureau.

Barbier, E. B., Baumgärtner, S., Chopra, K., Costello, C., Duraiappah, A., Hassan, R., ... & Perrings, C. (2009). The valuation of ecosystem services. Biodiversity, ecosystem functioning, and human wellbeing: An ecological and economic perspective, 10.

Barbier, E. B., Baumgärtner, S., Chopra, K., Costello, C., Duraiappah, A., Hassan, R., ... & Perrings, C. (2009). The valuation of ecosystem services. Biodiversity, ecosystem functioning, and human wellbeing: An ecological and economic perspective, 10.

Bardgett, R.D. & Wardle, D.A. (2003) Herbivore-mediated linkages between aboveground and belowground communities. Ecology, 84, 2258– 2268.

Başkent, E. Z. (2021). Assessment and valuation of key ecosystem services provided by two forest ecosystems in Turkey. Journal of Environmental Management, 285, 112135.

Bayon, R., 2004. Making Environmental markets work: lessons from early experience with sulfur, carbon, wetlands, and other related markets. Forest Trends, Katoomba Group Meeting in Locarno, Switzerland, 2003.

Behera, M. C., & Nath, M. R. (2012). Financial valuation of non-timber forest products flow from tropical dry deciduous forests in Boudh district, Orissa. International Journal of farm sciences, 2(2), 83-94.

Belaire, J. A., Westphal, L. M., Whelan, C. J., & Minor, E. S. (2015). Urban residents' perceptions of birds in the neighborhood: Biodiversity, cultural ecosystem services, and disservices. The Condor: Ornithological Applications, 117(2), 192-202.

Bennett, B.C. and Prance, G.T. (2000) Introduced Plants in the Indigenous Pharmacopoeia of Northern South America. Economic Botany, 54, 90-102.

Bensizerara, D., Chenchouni, H., Bachir, A. S., & Houhamdi, M. (2013). Ecological status interactions for assessing bird diversity in relation to a heterogeneous landscape structure. Avian Biology Research, 6(1), 67-77.

Bensizerara, D., Chenchouni, H., Bachir, A. S., & Houhamdi, M. (2013). Ecological status interactions for assessing bird diversity in relation to a heterogeneous landscape structure. Avian Biology Research, 6(1), 67-77.

Bernier, G. (1988) The control of floral evocation and morphogenesis.

BESWS–Biodiversity and Ecosystem Service Work Stream (2010) Demystifying materiality: hardwiring biodiversity and ecosystem services into finance. UNEP FI CEO Briefing, Genf.

Beura, D. (2017). Depletion of water bodies due to urbanisation and its management. International Education and Research Journal, 3(6).

Bhandari, A. R., Khadka, U. R., & Kanel, K. R. (2018). Ecosystem services in the mid-hill forest of western Nepal: A case of Panchase protected forest. Journal of Institute of Science and Technology, 23(1), 10-17.

Bhardwaj, S. K. (2016). Impact of Climate Change on Ecosystem Services. International Journal of Economic Plants, 3(2), 61-66.

Bhattacharyya, S. C. (2006). Energy access problem of the poor in India: Is rural electrification a remedy?. Energy policy, 34(18), 3387-3397.

Bibby, C. J., & Burgess, N. D. Hill, DA & Mustoe, SH (2000). Bird census techniques.

Bibby, C. J., Burgess, N. D and Hills, D. A. (1992). Birds' Census Technique. Academic Press. London.

Bibby, C., Jones, M and Marsden, S. (1998). Expedition Field Techniques: Bird Surveys. Expedition Advisory Centre. Royal Geographical Society. London.

Bibi, F., & Ali, Z. (2013). Measurement of diversity indices of avian communities at Taunsa Barrage Wildlife Sanctuary, Pakistan. The Journal of Animal & Plant Sciences, 23(2), 469-474.

Bieling, C., & Plieninger, T. (2013). Recording manifestations of cultural ecosystem services in the landscape. Landscape Research, 38(5), 649-667.

Birgé, H. E., Allen, C. R., Garmestani, A. S., & Pope, K. L. (2016). Adaptive management for ecosystem services. Journal of Environmental Management, 183, 343-352.

Bli. (2008). State of the world’s birds: Indicators for Our Changing World. Bird Life International, Cambridge, UK. pp. 12-13.

Böhning-Gaese, K., & Lemoine, N. (2004). Importance of climate change for the ranges, communities and conservation of birds. Advances in Ecological Research, 35, 211-236.

Borad, C. K., & Parasharya, B. M. (2018). Community structure of birds in wheat crop fields of Central Gujarat. Journal of Entomology and Zoology, 6(5), 19-24.

Brauman, K. A., Daily, G. C., Duarte, T. K. E., & Mooney, H. A. (2007). The nature and value of ecosystem services: an overview highlighting hydrologic services. Annu. Rev. Environ. Resour., 32, 67-98.

Brenner, J., Jimenez, J. A., Sarda, R., & Garola, A. (2010). An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management, 53(1), 27-38.

Buckland, S. T., Borchers, D. L., Johnston, A., Henrys, P. A., & Marques, T. A. (2007). Line transect methods for plant surveys. Biometrics, 63(4), 989-998.

Cairns, M.A., Brown, S., Helmer, E.H. & Baumgardner, G.A. (1997). Root biomass allocation in the world’s upland forest. Oecologia, 111, 1-11.

Camacho-Valdez, V., Ruiz-Luna, A., Ghermandi, A., & Nunes, P. A. (2013). Valuation of ecosystem services provided by coastal wetlands in northwest Mexico. Ocean & Coastal Management, 78, 1-11.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P. et al. (2012) Biodiversity loss and its impact on humanity. Nature, 486, 59– 67.

Carpenter, S. R., DeFries, R., Dietz, T., Mooney, H. A., Polasky, S., Reid, W. V. and Scholes, R. J. (2006) ‘Millennium Ecosystem Assessment: Research needs’, Science, vol 314, pp257–258.

Carson, R. M., & Bergstrom, J. C. (2003). A review of ecosystem valuation techniques.

Carter, V. (1996). Wetland Hydrology, Water Quality. National water summary on wetland resources, 2425, 35.

Caula, S., Marty, P., & Martin, J. L. (2008). Seasonal variation in species composition of an urban bird community in Mediterranean France. Landscape and Urban Planning, 87(1), 1-9.

Chahal, S. S., & Chhabra, A. S. (2014). Crop biomass production and its utilization in Punjab: Some energy considerations. Economic Affairs, 59(4), 529.

Chakma, K. (2019). Extraction efficiency, quality and characterization of Typha latifolia L. fibres for textile applications (Master's thesis).

Chan, K. M. A., T. Satterfield, and J. Goldstein. 2012. Rethinking ecosystem services to better address and navigate cultural values. Ecological Economics 74:8-18.

Chan, K. M., & Ruckelshaus, M. (2010). Characterizing changes in marine ecosystem services. F1000 biology reports, 2.

Chatterjee, A., Adhikari, S., Pal, S., & Mukhopadhyay, S. K. (2020). Foraging guild structure and niche characteristics of waterbirds wintering in selected sub-Himalayan wetlands of India. Ecological Indicators, 108, 105693.

Chaudhary, S., McGregor, A., Houston, D., & Chettri, N. (2019). Spiritual enrichment or ecological protection?: A multi-scale analysis of cultural ecosystem services at the Mai Pokhari, a Ramsar site of Nepal. Ecosystem Services, 39, 100972.

Chauhan, M., & Gopal, B. (2005). Vegetation structure and dynamics of a floodplain wetland along a subtropical regulated river. River research and Applications, 21(5), 513-534.

Chave, J., Ḿechain, M.R., B́urquez A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., & Vielledent G. (2015). Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology, 20, 3177-3190. https://doi 10.1111/gcb.12629

Chee, Y. E. (2004). An ecological perspective on the valuation of ecosystem services. Biological conservation, 120(4), 549-565.

Chettri, N., Deb, D. C., Sharma, E., & Jackson, R. (2005). The relationship between bird communities and habitat. Mountain Research and Development, 25(3), 235-243.

Chopra R, Verma VK, Sharma PK (2001) Mapping, monitoring and conservation of Harike wetland ecosystem, Punjab, India through remote sensing. Int J Remote Sens 22:89–98.

Chopra, R. (2016). Environmental degradation in India: causes and consequences. International journal of applied environmental sciences, 11(6), 1593-1601.

Clarke, J. L., Welch, D., & Gordon, I. J. (1995). The influence of vegetation pattern on the grazing of heather moorland by red deer and sheep. I. The location of animals on grass/heather mosaics. Journal of Applied Ecology, 166-176.

Codesido, M., Zufiaurre, E., & Bilenca, D. (2015). Relationship between pest birds and landscape elements in the Pampas of central Argentina. Emu, 115(1), 80-84.

Collins, A.L., Walling, D.E., McMellin, G.K., Zhang, Y., Gray, J., McGonigle, D. and Cherrington, R. (2010). A preliminary investigation of the efficacy of riparian fencing schemes for reducing contributions from eroding channel banks to the siltation of salmonid spawning gravels across the south west UK. Journal of Environmental Management, 91(6): 1341-1349.

Cord, A. F., Bartkowski, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., ... & Volk, M. (2017). Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. Ecosystem services, 28, 264-272.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... & Van Den Belt, M. (1998). The value of ecosystem services: putting the issues in perspective. Ecological economics, 25(1), 67-72.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, G.R., Sutton, P., van der Belt, M., (1997). The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Costanza, R., De Groot, R., Sutton, P., Van der Ploeg, S., Anderson, S. J., Kubiszewski, I., ... & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global environmental change, 26, 152-158.

Croitoru, L. (2007). Valuing the non-timber forest products in the Mediterranean region. Ecological Economics, 63(4), 768-775.

Csurgó, B., & Smith, M. K. (2021). The value of cultural ecosystem services in a rural landscape context. Journal of Rural Studies, 86, 76-86.

Curran, G. (2020). Bird/monsters and contemporary social fears in the Central Desert of Australia. In Monster Anthropology (pp. 127-141). Routledge.

Daily, G. C. (1997). Introduction: what are ecosystem services? In: Daily, G. C. (ed.), Nature's services. Washington DC: Island Press, pp. 1–10.

Daily, G. C., Polasky, S., Goldstein, J., Kareiva, P. M., Mooney, H. A., Pejchar, L., & Ricketts, T. H. (2009). Ecosystem services in decision making: time to deliver. Frontiers in ecology and the environment, 7(1), 21-28.

Daly, H.E., (1997). Georgescu-Roegen versus Solow/Stiglitz. Ecological Economics 22, 261–266.

Das, A. (2018). Ethnobotanical uses of wild fruits of Santal paraganas (Jharkhand). Intl J Minor Fruits Med Aromatic Plants, 4(2), 31-38.

Das, S. (2013). Travel cost method for environmental valuation. Center of Excellence in Environmental Economics, Madras School of Economics, Dissemination Paper, 23.

Das, T. K., Moitra, B., Raychaudhuri, A., Jash, T., Ghosh, S., & Mukherjee, A. (2011). Degradation of Water Bodies and Wetlands in West Bengal: Interaction with Economic Development. Jadhavpur University, (Table 1), 49–52.

Daw, T., K. Brown, S. Rosendo, and R. Pomeroy. (2011). Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. Environmental Conservation 38:370-379.

De Bello, F., Lavorel, S., Díaz, S., Harrington, R., Bardgett, R., Berg, M. et al. (2010) Functional traits underlie the delivery of ecosystem services across different trophic levels. Biodiversity and Conservation, 143, 2873– 2893.

De Graaf, R. M., Tilghman, N. G., & Anderson, S. H. (1985). Foraging guilds of North American birds. Environmental Management, 9, 493-536.

De Groot, R. S., R. Alkemade, L. Braat, L. Hein, and L. Willemen. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7:260-272.

De Groot, R.S., (1987). Environmental functions as a unifying concept for ecology and economics. The Environmentalist 7 (2), 105–109.

De Lampe, M. G., Bergeron, Y., McNeil, R., & Leduc, A. (1992). Seasonal flowering and fruiting patterns in tropical semi-arid vegetation of northeastern Venezuela. Biotropica, 64-76.

Dee, L. E., Cowles, J., Isbell, F., Pau, S., Gaines, S. D., & Reich, P. B. (2019). When do ecosystem services depend on rare species?. Trends in Ecology & Evolution, 34(8), 746-758.

Delgado M, Bigeriego M, Guardiola E (1993) Uptake of Zn, Cr and Cd by water hyacinth. Water Res 27:269.

Ding, Z., Liang, J., Hu, Y., Zhou, Z., Sun, H., Liu, L., ... & Si, X. (2019). Different responses of avian feeding guilds to spatial and environmental factors across an elevation gradient in the central Himalaya. Ecology and Evolution, 9(7), 4116-4128.

Doxa, A., Bas, Y., Paracchini, M. L., Pointereau, P., Terres, J. M., & Jiguet, F. (2010). Low-intensity agriculture increases farmland bird abundances in France. Journal of Applied Ecology, 47(6), 1348-1356.

Dukes, J. S., & Mooney, H. A. (2004). Disruption of ecosystem processes in western North America by invasive species. Revista chilena de historia natural, 77(3), 411-437.

EC, European Commission, (2008). The economics of ecosystems and biodiversity. European Ecosystem Functioning, and Human Wellbeing: An Ecological and Economic Perspective, Oxford University Press, Oxford, UK, ch 18, pp248–262.

Eicken, H., A. L. Lovecraft, and M. L. Druckenmiller. (2009). Sea-ice system services: a framework to help identify and meet information needs relevant for Arctic observing networks. Arctic 62:119-136.

Ekka, A., & Pandit. (2012). Willingness to Pay for Restoration of Natural Ecosystem: A Study of. Arun Indian Journal of Agricultural Economics, 67(3).

Emlen, J. T. (1974). An urban bird community in Tucson, Arizona: derivation, structure, regulation. The Condor, 76(2), 184-197.

Engel, S., Pagiola, S., Wunder, S., (2008). Designing payments for environmental services in theory and practice: an overview of the issue. Ecological Economics 65, 663–674.

Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. Wetlands Ecology and management, 17(1), 71-84.

Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. Wetlands Ecology and management, 17(1), 71-84.

Faaborg, J., Holmes, R. T., Anders, A. D., Bildstein, K. L., Dugger, K. M., Gauthreaux Jr, S. A., ... & Warnock, N. (2010). Conserving migratory land birds in the New World: Do we know enough?. Ecological applications, 20(2), 398-418.

Farber, S. C., Costanza, R., & Wilson, M. A. (2002). Economic and ecological concepts for valuing ecosystem services. Ecological Economics, 41(3), 375-392.

Farhan, Y., Zregat, D., & Farhan, I. (2013). Spatial estimation of soil erosion risk using RUSLE approach, RS, and GIS techniques: a case study of Kufranja watershed, Northern Jordan. Journal of Water Resource and Protection, 5(12), 1247.

Fisher, B., Turner, R. K., Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics 68(3), pp. 643–653.

Fitter, A., Elmqvist, T., Haines-Young, R., Potschin, M., Rinaldo, A., Setala, H., ... & Murlis, J. (2010). An assessment of ecosystem services and biodiversity in Europe. Issues in Environmental Science and Technology, 30, 1-28.

Food and Agriculture Organization of the United Nations (FAO). (2006). Livestock's Long Shadow: Environmental Issues and Options.Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M., de Haan C. ed. FAO, Rome, Italy.

Friedman J, Yaniv Z, Dafni A, Palewitch D. (1986). A preliminary classification of the healing potential of medicinal plants, based on a rational analysis of an ethnopharmacological field survey among Bedouins in the Negev Desert, Israel. Journal of ethnopharmacology Ethnopharmacol.16:275–87.

Ganasri, B. P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geoscience Frontiers, 7(6), 953-961.

Gaston, K. J., Cox, D. T., Canavelli, S. B., García, D., Hughes, B., Maas, B., ... & Inger, R. (2018). Population abundance and ecosystem service provision: the case of birds. BioScience, 68(4), 264-272.

Gelagay, H. S., & Minale, A. S. (2016). Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia. International Soil and Water Conservation Research, 4(2), 126-136.

Gentry, D. J., Swanson, D. L., & Carlisle, J. D. (2006). Species richness and nesting success of migrant forest birds in natural river corridors and anthropogenic woodlands in southeastern South Dakota. The Condor, 108(1), 140-153.

Ghermandi, A., Sheela, A. M., & Justus, J. (2016). Integrating similarity analysis and ecosystem service value transfer: Results from a tropical coastal wetland in India. Ecosystem Services, 22(April), 73–82. https://doi.org/10.1016/j.ecoser.2016.09.014.

Gillies, C. S., & St. Clair, C. C. (2010). Functional responses in habitat selection by tropical birds moving through fragmented forest. Journal of applied ecology, 47(1), 182-190.

Ginantra, i. K., muksin, i. K., suaskara, i. B. M., & joni, m. (2020). Diversity and distribution of mollusks at three zones of mangrove in Pejarakan, Bali, Indonesia. Biodiversitas Journal of Biological Diversity, 21(10).

Gómez-Baggethun, E., Barton, D. N., Berry, P., Dunford, R., & Harrison, P. A. (2016). Concepts and methods in ecosystem services valuation. Routledge handbook of ecosystem services, 99-111.

Goodman, L. A. (1961). Snowball sampling. The annals of mathematical statistics, 148-170.

Gorme, J. B., Maniquiz, M. C., Lee, S., & Kim, L. H. (2012). Seasonal changes of plant biomass at a constructed wetland in a livestock watershed area. Desalination and water treatment, 45(1-3), 136-143.

Gosal, G. (2004). Physical geography of the Punjab. JPS, 11(1), 20.

Gould, R.K., Klain, S.C., Ardoin, N.M., Satterfield, T., Woodside, U., Hannahs, N., Daily, G.C., Chan, K.M., (2014). A Protocol for eliciting nonmaterial values through a cultural ecosystem services frame. Conserv. Biol. 29 (2), 575–586.

Goulder, L. H., & Kennedy, D. (1997). Valuing ecosystem services: philosophical bases and empirical methods (pp. 23-47). Island Press, Washington, DC.

Graf, D. F. (1984). Medism: the Origin and Significance of the Term. The Journal of Hellenic Studies, 104, 15-30.

Gray, S. B., & Brady, S. M. (2016). Plant developmental responses to climate change. Developmental biology, 419(1), 64-77.

Green, A. J., & Elmberg, J. (2014). Ecosystem services provided by waterbirds. Biological reviews, 89(1), 105-122.

Gregory, R. D., Gibbons, D. W., & Donald, P. F. (2004). Bird census and survey techniques. Bird ecology and conservation, 17-56.

Grimmett, R., C. Inskipp & T. Inskipp (2012). Birds of the Indian Subcontinent. Oxford University Press, Delhi, India, 384 pp.

Grover, D. K. (2019). Economic profile of rice cultivation in Punjab economic profile of rice cultivation in punjab. July.

Grunewald, K., & Bastian, O. (Eds.). (2015). Ecosystem services–concept, methods and case studies. Springer.

Guerry, A. D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G. C., Griffin, R., ... & Vira, B. (2015). Natural capital and ecosystem services informing decisions: From promise to practice. Proceedings of the National academy of Sciences, 112(24), 7348-7355.

Gupta, S. K., Kumar, P., & Malik, M. K. (2009). Avifaunal diversity in the university campus of Kurukshetra, Haryana. Journal of Threatened Taxa, 629-632.

Haber, W. (2007). Energy, food, and land—the ecological traps of humankind. Environmental Science and Pollution Research-International, 14, 359-365.

Haines-Young, R., & Potschin, M. (2010). The links between biodiversity, ecosystem services and human well-being. Ecosystem Ecology: a new synthesis, 1, 110-139.

Hamilton, A. C. (2004). Medicinal plants, conservation and livelihoods. Biodiversity & Conservation, 13(8), 1477-1517.

Haq SM, Yaqoob U, Calixto ES, Rahman IU, Hashem A, Abd_Allah EF, .Alakel MA, Alaqarwi AA, Addalla M, Hassan M,Bussmann, RW, Abbasi AM, Ur Rahman S, Ijaz F. (2021). Plant resources utilization among different ethnic groups of Ladakh in Trans-Himalayan Region. Biology 10(9):827.

Haque, A. E., Murty, M. N., & Shyamsundar, P. (2011). Environmental Valuation in South Asia. Cambridge University Press.

Haslem, A., & Bennett, A. F. (2008). Countryside elements and the conservation of birds in agricultural environments. Agriculture, Ecosystems & Environment, 125(1-4), 191-203.

Haslett, J. R., Berry, P. M., Bela, G., Jongman, R. H., Pataki, G., Samways, M. J., & Zobel, M. (2010). Changing conservation strategies in Europe: a framework integrating ecosystem services and dynamics. Biodiversity and Conservation, 19, 2963-2977.

He F. L., Jin H. X., Guo C. X., Ma J. M., Wu H. (2017). Vegetation composition and community similarity of Haloxylon ammodendron plantations at different degree of degradation on the edge of the minqin oasis. J. Desert Res. 37 (06), 1135–1141. doi: 10.7522/j.issn.1000-694X.2016.00109

Heather, C., & Jeffrey, S. D. (2007). Impacts of Invasive Species on Ecosystem Services. Biological Invasions, 193, 217–237. https://doi.org/10.1007/978-3-540-36920-2_13.

Heikkinen, R. K., Luoto, M., Virkkala, R., & Rainio, K. (2004). Effects of habitat cover, landscape structure and spatial variables on the abundance of birds in an agricultural–forest mosaic. Journal of Applied Ecology, 41(5), 824-835.

Heimlich, R. E., Wiebe, K. D., Claassen, R., Gadsby, D. M., & House, R. M. (1998). Agriculture and" No Net Loss" of Wetlands. Choices, 13(316-2016-6463).

Hema, M., & Devi, P. (2015). Economic valuation of mangrove ecosystems of Kerala, India. Journal of Environmental Professionals Sri Lanka, 4(1).

Henderson, B., & Vikander, N. (Eds.). (2007). Nature first: Outdoor life the friluftsliv way. Dundurn.

Hildebrandt A, Guillamon M, Lacorte S, Tauler R, Barcelo´ D (2008) Impact of pesticide used in agriculture and vineyards to surface and groundwater quality (North Spain). Water Res 42:3315–3326.

Hirons, M., Comberti, C., Dunford, R., (2016). Valuing cultural ecosystem services. Annu. Rev. Environ. Resour. 41, 545–574.

Hoffman, B., & Gallaher, T. (2007). Importance indices in ethnobotany. Ethnobotany Research and applications, 5, 201-218.

Holmes, R. T., & Sturges, F. W. (1975). Bird community dynamics and energetics in a northern hardwoods ecosystem. The Journal of Animal Ecology, 175-200.

Hossain, A., & Aditya, G. (2016). Avian diversity in agricultural landscape: records from Burdwan, West Bengal, India. In Proceedings of the Zoological Society (Vol. 69, pp. 38-51). Springer India.

Huang, K., Zhang, Y., Zhu, J., Liu, Y., Zu, J., & Zhang, J. (2016). The influences of climate change and human activities on vegetation dynamics in the Qinghai-Tibet Plateau. Remote Sensing, 8(10), 876.

Hutto, R. L., Pletschet, S. M., & Hendricks, P. (1986). A fixed-radius point count method for nonbreeding and breeding season use. Auk, 103(3), 593–602. Retrieved from http://silk.library.umass.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=boh&AN=BACD198682071455&site=ehost-live&scope=site.

Ibrar, M., Hussain, F., & Sultan, A. (2007). Ethnobotanical studies on plant resources of Ranyal hills, District Shangla, Pakistan. Pakistan Journal of Botany, 39(2), 329.

Ikinci, N., & Bayındır, N. (2019). Distribution and richness of aquatic plants of Bolu Province (Turkey). Fresenius Environmental Bulletin, 28(1), 244-256.

Jain KS, Sarkar A, Garg V (2008) Impact of declining trend of flow on Harike wetland. Water Res Manag 22:409–421.

Jain, A., Singh, R. S., & Singh, H. B. (2004). Economic evaluation of Lotus (Nelumbo nucifera Gaertn.) cultivation in Sanapat Lake, Manipur Valley.

James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). An introduction to statistical learning (Vol. 112, p. 18). New York: springer.

Jerath, N., Puja & J. Chadha (2006). Biodiversity in the Shivalik Ecosystem of Punjab. Punjab State Council for Science and Technology, 193pp.

Johansson, J., Bolmgren, K., & Jonzén, N. (2013). Climate change and the optimal flowering time of annual plants in seasonal environments. Global change biology, 19(1), 197-207.

Jokimäki, J., & Kaisanlahti-Jokimäki, M. L. (2003). Spatial similarity of urban bird communities: a multiscale approach. Journal of Biogeography, 30(8), 1183-1193.

Jones, G. A., Sieving, K. E., & Jacobson, S. K. (2005). Avian diversity and functional insectivory on north-central Florida farmlands. Conservation biology, 19(4), 1234-1245.

Jordan, F., Jelks, H. L., & Kitchens, W. M. (1997). Habitat structure and plant community composition in a northern Everglades wetland landscape. Wetlands, 17, 275-283.

Joshi, G., & Negi, G. C. (2011). Quantification and valuation of forest ecosystem services in the western Himalayan region of India. International Journal of Biodiversity Science, Ecosystem Services & Management, 7(1), 2-11.

Karr, J. R. (1976). Seasonality, resource availability, and community diversity in tropical bird communities. The American Naturalist, 110(976), 973-994.

Karr, J. R., & Roth, R. R. (1971). Vegetation structure and avian diversity in several New World areas. The American Naturalist, 105(945), 423-435.

Kassas, M., & Girgis, W. A. (1970). Habitat and plant communities in the Egyptian Desert: VII. Geographical facies of plant communities. The Journal of Ecology, 335-350.

Katuwal, H. B., Rai, J., Tomlinson, K., Rimal, B., Sharma, H. P., Baral, H. S., ... & Quan, R. C. (2022). Seasonal variation and crop diversity shape the composition of bird communities in agricultural landscapes in Nepal. Agriculture, Ecosystems & Environment, 333, 107973.

Kaul, R. B., Kantak, G. E., & Churchill, S. P. (1988). The Niobrara River Valley, a postglacial migration corridor and refugium of forest plants and animals in the grasslands of central North America. The Botanical Review, 54(1), 44-81.

Kaur J, Kaur R, Nagpal AK. (2017). Documentation of Traditional Knowledge on Medicinal Plants used by Local Population of Kapurthala, Punjab (India). Journal of Chemical and Pharmaceutical Research 9:351-5.

Kaur, B., Vatta, K., & Sidhu, R. S. (2015). Optimising irrigation water use in Punjab agriculture: Role of crop diversification and technology. Indian Journal of Agricultural Economics, 70(902-2016-68393), 307-318.

Kaur, J., Walia, H., Mabwoga, S. O., & Arora, S. (2017). Water quality monitoring of an international wetland at Harike, Punjab and its impact on biological systems. Applied Water Science, 7(3), 1107-1115.

Kaur, K., Sidhu, M. C., & Ahluwalia, A. S. (2017). Angiosperm diversity in Doaba region of Punjab, India. Journal of Threatened Taxa, 9(8), 10551–10564.

Kaur, R., & Brraich, O. S. (2021). Abundance and diversity of threatened birds in Nangal Wetland, Punjab, India. Journal of Threatened Taxa, 13(12), 19733-19742.

Kaur, S., Kler, T. K., & Javed, M. (2018). Abundance and diversity of water bird assemblages in relation to village ponds in Punjab. Journal of Entomology and Zoology Studies, 6(1), 1375-1380.

Kenter, J. O., T. Hyde, M. Christie, and I. Fazey. (2011). The importance of deliberation in valuing ecosystem services in developing countries — evidence from the Solomon Islands. Global Environmental Change 21:505-521.

Keune, H., Dendoncker, N., Popa, F., Sander, J., Kampelmann, S., Boeraeve, F., ... & Verboven, J. (2015). Emerging ecosystem services governance issues in the Belgium ecosystem services community of practice. Ecosystem services, 16, 212-219.

Khan S, Masoodi TH, Islam MA, Wani AA, Gattoo AA. 2022. Ethnomedicinal study of wild plants used by fringe communities in Temperate Forests of Himalayan Kashmir, India. Phytomedicine Plus 2(2):100251.

Khare CP. (2008). Indian medicinal plants: an illustrated dictionary. Springer Science & Business Media.

Kiester, A. R. (2013). Species diversity, overview.

Kiran, G. S., & Malhi, R. K. M. (2011). Economic valuation of forest soils. Current Science, 396-399.

Kissling, W. D., Sekercioglu, C. H., & Jetz, W. (2012). Bird dietary guild richness across latitudes, environments and biogeographic regions. Global Ecology and Biogeography, 21(3), 328-340.

Kontoleon, A., & Pascual, U. (2007). Incorporating Biodiversity into Integrated Assessments of Trade Policy in the Agricultural Sector. Volume II: Reference Manual. Chapter 7. Economics and Trade Branch, United Nations Environment Programme. Geneva.

Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology?. Ecology letters, 8(5), 468-479.

Kremen, C., Williams, N. M., Aizen, M. A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., & Ricketts, T. H. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. Ecology letters, 10(4), 299-314.

Küchler, A. W., & Zonneveld, I. S. (2012). Vegetation mapping (Vol. 10). Springer Science & Business Media.

Kumar, A. B. (2006). A checklist of avifauna of the Bharathapuzha river basin, Kerala. Zoos' Print Journal, 21(8), 2300-2355.

Kumar, A., Kumar, N., Baredar, P., & Shukla, A. (2015). A review on biomass energy resources, potential, conversion and policy in India. Renewable and sustainable energy reviews, 45, 530-539.

Kumar, P., Rai, D., & Gupta, S. K. (2016). Wetland bird assemblage in rural ponds of Kurukshetra, India. Waterbirds, 39(1), 86-98.

Kumar, R., Horwitz, P., Milton, G. R., Sellamuttu, S. S., Buckton, S. T., Davidson, N. C. & Baker, C. (2011). Assessing wetland ecosystem services and poverty interlinkages: a general framework and case study. Hydrological Sciences Journal, 56(8), 1602-1621.

Kumar, S. (2001). Flora of Haryana. Bishan Singh Mahendra Pal Singh Publications, Dehra Dun, India, 507pp.

Kumar, S., & Dhankhar, R. (2015). Assessment of floristic and avian faunal diversity of Bhindawas Wetland, Jhajjar (Haryana), India. Plant Archive, 15(2), 733–740.

Ladhar, S. S. (2002). Status of ecological health of wetlands in Punjab, India. Aquatic Ecosystem Health & Management, 5(4), 457-465.

Lal, R. (2020). Soil health and carbon management. Journal of Soil and Water Conservation, 75(5), 133A-137A.

Lal, R. (2020). Soil organic matter and water retention. Agronomy Journal, 112(5), 3265-3277.

Laldingliani, T. B. C., Thangjam, N. M., Zomuanawma, R., Bawitlung, L., Pal, A., & Kumar, A. (2022). Ethnomedicinal study of medicinal plants used by Mizo tribes in Champhai district of Mizoram, India. Journal of Ethnobiology and Ethnomedicine, 18(1), 1-29.

Lang, S., Pernkopf, L., Mairota, P., & Padoa-Schioppa, E. (2015). Earth observation for habitat mapping and biodiversity monitoring. International Journal of Applied Earth Observation and Geoinformation, 37, 1-160.

Lechowicz, M. J. (1984). Why do temperate deciduous trees leaf out at different times? Adaptation and ecology of forest communities. The American Naturalist, 124(6), 821-842.

Legowo, S., Hadihardaja, I. K., & Haji, T. S. (2019). Application of digital elevation method (DEM) for flood estimation on Upstream Ciliwung River, West Java, Indonesia. GEOMATE Journal, 17(59), 154-165.

Leitão, R. P., Zuanon, J., Villéger, S., Williams, S. E., Baraloto, C., Fortunel, C. & Mouillot, D. (2016). Rare species contribute disproportionately to the functional structure of species assemblages. Proceedings of the Royal Society B: Biological Sciences, 283(1828), 20160084.

Levine, J. M., Vila, M., Antonio, C. M. D., Dukes, J. S., Grigulis, K., & Lavorel, S. (2003). Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London. Series B: Biological Sciences, 270(1517), 775-781.

Li, J., Ren, Z., & Zhou, Z. (2006). Ecosystem services and their values: a case study in the Qinba mountains of China. Ecological Research, 21(4), 597-604.

Li, Y., Qian, F., Silbernagel, J., & Larson, H. (2019). Community structure, abundance variation and population trends of waterbirds in relation to water level fluctuation in Poyang Lake. Journal of Great Lakes Research, 45(5), 976-985.

Luck, G. W., & Daily, G. C. (2003). Tropical countryside bird assemblages: richness, composition, and foraging differ by landscape context. Ecological applications, 13(1), 235-247.

Lukasch, B., Frank, T., & Schulze, C. H. (2011). Short-term effects of recent land-use changes in Eastern Austria on farmland bird assemblages in a human-dominated landscape. Biodiversity and Conservation, 20, 1339-1352.

Mabwoga, S. O., & Thukral, A. K. (2014). Characterization of change in the Harike wetland, a Ramsar site in India, using landsat satellite data. SpringerPlus, 3(1), 1-11.

Madyise, T. (2013). Case studies of environmental impacts of sand mining and gravel extraction for urban development in Gaborone (Doctoral dissertation, University of South Africa).

Mahendiran, M., & Azeez, P. (2018). Ecosystem services of birds: a review of market and non-market values. Entomol Ornithol Herpetol, 7(209), 2161-0983.

Makkeasorn, A., Chang, N. B., & Li, J. (2009). Seasonal change detection of riparian zones with remote sensing images and genetic programming in a semi-arid watershed. Journal of Environmental Management, 90(2), 1069-1080.

Manfreda, S., & Samela, C. (2019). A digital elevation model based method for a rapid estimation of flood inundation depth. Journal of Flood Risk Management, 12, e12541.

Mao, L., Li, J., Ma, X. L., Quandahor, P., & Gou, Y. P. (2023). Effects of different plantation years on grassland plant community in Maxian Mountain area of the Loess Plateau. Frontiers in Plant Science, 14.

Martin, G. J. (2010). Ethnobotany: a methods manual. Routledge.

Marzluff, J. M., & Ewing, K. (2008). Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Urban ecology: An international perspective on the interaction between humans and nature, 739-755.

Mathur N, Bhatnagar P, Nagar P, Bijarnai MK (2005) Mutagenicity assessment of effluents from textile/dye industries of Sanganer, Jaipur (India): a case study. Ecotoxicol Environ Saf 61:106–113.

McKenzie, A. J., & Whittingham, M. J. (2009). Why are birds more abundant on organic farms. Journal of Food, Agriculture & Environment, 7(2), 807-814.

Meenakshi & M. Sharma (1985). Flora of Ropar District. Dev Publishers, Patiala, Punjab, India, 267pp.

Mensah, S., Veldtman, R., Assogbadjo, A. E., Ham, C., Kakaï, R. G., & Seifert, T. (2017). Ecosystem service importance and use vary with socio-environmental factors: A study from household-surveys in local communities of South Africa. Ecosystem Services, 23, 1-8.

Mg, S., & Thomas, K. J. (2007). Indigenous medicinal usages of some macrophytes of the Muriyad wetland in. Knowledge Creation Diffusion Utilization, 6(April), 365–367.

Mir AY, Yaqoob U, Hassan M, Bashir F, Zanit SB, Haq SM, Bussmann RW. (2021). Ethnopharmacology and phenology of high-altitude medicinal plants in Kashmir, Northern Himalaya. Ethnobotany Research and Applications 22:1-15.

Mitsch, W. J., & Gosselink, J. G. (2015). Wetlands. John Wiley & Sons.

Mitsch, W. J., & Mander, Ü. (2018). Wetlands and carbon revisited. Ecological Engineering, 114, 1-6.

Mitsch, W. J., Bernal, B., & Hernandez, M. E. (2015). Ecosystem services of wetlands. International Journal of Biodiversity Science, Ecosystem Services & Management, 11(1), 1-4.

Mitsch, W. J., Bernal, B., & Hernandez, M. E. (2015). Ecosystem services of wetlands. International Journal of Biodiversity Science, Ecosystem Services & Management, 11(1), 1-4.

Morellato, L. P. C. (2003). South America. Phenology: an integrative environmental science, 75-92.

Morissette, J. L., Kardynal, K. J., Bayne, E. M., & Hobson, K. A. (2013). Comparing bird community composition among boreal wetlands: is wetland classification a missing piece of the habitat puzzle?. Wetlands, 33(4), 653-665.

Mouillot, D., Bellwood, D. R., Baraloto, C., Chave, J., Galzin, R., Harmelin-Vivien, M., ... & Thuiller, W. (2013). Rare species support vulnerable functions in high-diversity ecosystems. PLoS biology, 11(5), e1001569.

Moza, U., & Mishra, D. N. (2008). Current Status of Harike Wetland Visa Visa its Ecology and Fishery. Taal 2007:The 12th World Lake Confrence:1470-1476, 1470–1476.

Mukherjee, S. (2008). Economic Valuation of a Wetland in West Bengal, India, (7068).

Mukhopadhyay, S., & Mazumdar, S. (2017). Composition, diversity and foraging guilds of avifauna in a suburban area of southern West Bengal, India. The Ring, 39(1), 103-120.

Müller, F., & Burkhard, B. (2007). An ecosystem based framework to link landscape structures, functions and services. In Multifunctional land use: Meeting future demands for landscape goods and services (pp. 37-63). Springer Berlin Heidelberg.

Muñoz-Sáez, A., Perez-Quezada, J. F., & Estades, C. F. (2017). Agricultural landscapes as habitat for birds in central Chile. Revista chilena de historia natural, 90.

Musacchio, L.R., (2013). Cultivating deep care: integrating landscape ecological research into the cultural dimension of ecosystem services. Landsc. Ecol. 28 (6), 1025–1038.

Muthu C, Ayyanar M, Raja N, Ignacimuthu S. (2006). Medicinal plants used by traditional healers in Kancheepuram District of Tamil Nadu, India. Journal of Ethnobiology and Ethnomedicine 2(1):1-10.

Nadeau, C. P., Conway, C. J., Smith, B. S., & Lewis, T. E. (2008). Maximizing detection probability of wetland-dependent birds during point-count surveys in northwestern Florida. The Wilson Journal of Ornithology, 120(3), 513-518.

Nagarajan, R., & Thiyagesan, K. (1996). Waterbirds and substrate quality of the Pichavaram wetlands, southern India. Ibis, 138(4), 710-721.

Nahlik, A.M., Kentula, M. E., Fennessy, M. S. and Landers, D. H. (2012) Where is the consensus? A proposed foundation for moving ecosystem service concepts into practice. Ecological Economics 77, pp. 27–35.

Nair, N.C. (1978). Flora of Punjab Plains. Botanical Survey of India, Howrah, 326 pp.

Naruse, t. (1976). A geomorphological study of the Punjab plains and the northern part of the Thar Desert in India. Journal of Geography (Chigaku Zasshi), 85(6), 311–328.

Narwade, S., & Fartade, M. M. (2011). Birds of Osmanabad District of Maharashtra, India. Journal of Threatened taxa, 1567-1576.

Negi, S. S. (1991). Himalayan rivers, lakes, and glaciers. Indus Publishing.

Newman DJ, Cragg GM. (2007). Natural products as sources of new drugs over the last 25 years. Journal of Natural Products 70(3):461-477.

Nilsson, C., Jansson, R., Kuglerová, L., Lind, L., & Ström, L. (2013). Boreal riparian vegetation under climate change. Ecosystems, 16, 401-410.

Ninan, K. N., & Inoue, M. (2014). Valuing forest ecosystem services: What we know and what we don't. Valuing Ecosystem Services, 189-226.

Nolan, K. A., & Callahan, J. E. (2006). Beachcomber biology: The Shannon-Weiner species diversity index. In Proc. workshop able (Vol. 27, pp. 334-338).

Nowak, D.J. (1994). Atmospheric carbon dioxide by Chicago's urban forest. In: Mc Pherson, E.G., Nowak, D.J., Rowntree, R.A. (Eds.), Chicago's Urban Forest Climate Project. USDA Forest Service General Technical Report NE-186, Radnor, PA, pp. 83-94.

O'Connell, T. J., Jackson, L. E., & Brooks, R. P. (2000). Bird guilds as indicators of ecological condition in the central Appalachians. Ecological Applications, 10(6), 1706-1721.

O'NEAL, B. J., Heske, E. J., & Stafford, J. D. (2008). Waterbird response to wetlands restored through the conservation reserve enhancement program. The Journal of Wildlife Management, 72(3), 654-664.

Owens, J. N., & Lund, H. G. (2009). Forests and forest plants. Owens, John N. and Lund, H. Gyde. Forests and Forest Plants, 1.

Oyebode O, Kandala NB, Chilton PJ, Lilford RJ. (2016). Use of traditional medicine in middle-income countries: a WHO-SAGE study. Health Policy and Planning, 31(8):984-991.

Pagag, K., & Borthakur, S. K. (2012). Wild edible wetland plants from Lakhimpur district of Assam, India.

Pagiola, S., Platais,G., (2007). Payments for Environmental Services: FromTheory to Practice. World Bank, Washington.

Panda, B. P., Prusty, B., Panda, B., Pradhan, A., & Parida, S. P. (2021). Habitat heterogeneity influences avian feeding guild composition in urban landscapes: evidence from Bhubaneswar, India. Ecological Processes, 10(1), 1-10.

Pandey, R. (2011). Consumption and valuation of livestock fodder under different forest types of Himalayas, India. Silva Lusitana, 19(2), 195-207.

Pandit, A., Ekka, A., Sharma, A. P., Bhattacharjya, B. K., Katiha, P. K., & Biswas, D. K. (2015). Economic valuation of natural ecosystems - an empirical study in a stretch of Bramhaputra River in Assam, North-east India. Indian Journal of Fisheries, 62(3), 107–112.

Panghal,M, Arya V, Yadav S, Kumar S, Yadav JP. (2010). Indigenous knowledge of medicinal plants used by Saperas community of Khetawas, Jhajjar District, Haryana, India. Journal of Ethnobiology and Ethnomedicine 6:1-11.

Panich-pat T, Srinives P, Kruatrachue M, Pokethitiyook P, Upathamd S, Lanzae GR (2005) Electron microscopic studies on localization of lead in organs of Typha angustifolia grown on contaminated soil. ScienceAsia 31:49–53.

Panigrahi, S., Rout, S., & Sahoo, G. (2021). Ethnobotany: A strategy for conservation of plant. Annals of the Romanian Society for Cell Biology, 25(6), 1370-1377.

Paramitha, I. G. P., Nasution, S. H., & Kurniawan, R (2014). The diversity of aquatic macrophyte, a habitat of ornamental fish in lake sentani, papua. Asia Pacific Centre for Ecohydrology-UNESCO Research Center for Limnology-Indonesian Institute of Sciences, 414.

Parvaiz M. (2014). Ethnobotanical studies on plant resources of Mangowal, district Gujrat, Punjab, Pakistan. Avicenna Journal of Phytomedicine 4(5):364.

Pascual, U., Corbera, E., Muradian, R. and Kosoy, N. (2010) 'Exploring the links between equity and efficiency in payments for environmental services: A conceptual approach', Special Section, Ecological Economics, vol 69, no 6, pp1237–1244

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., ... & Polasky, S. (2010). The economics of valuing ecosystem services and biodiversity. The economics of ecosystems and biodiversity: Ecological and economic foundations, 183-256.

Pascual, U., Muradian, R., Brander, L., Gómez-Baggethun, E., Martín-López, B., Verma, M., ... & Turner, R. K. (2012). The economics of valuing ecosystem services and biodiversity. In The economics of ecosystems and biodiversity: Ecological and economic foundations (pp. 183-256). Routledge.

Pathania, M. S., & Kumar, G. A. (2017). Economic Valuation and causes of degradation of pong dam wetland of Himachal Pradesh. International Journal of Social Sciences, 6(1), 21. https://doi.org/10.5958/2321-5771.2017.00003.5.

Patton, M. Q. (2008). Utilization-focused evaluation. Sage publications.

Paudel, S., & Vetaas, O. R. (2014). Effects of topography and land use on woody plant species composition and beta diversity in an arid Trans-Himalayan landscape, Nepal. Journal of Mountain Science, 11, 1112-1122.

Pausas, J. G., & Austin, M. P. (2001). Patterns of plant species richness in relation to different environments: an appraisal. Journal of Vegetation Science, 12(2), 153-166.

Perrings Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., ... & Depledge, M. H. (2015). Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. International journal of health geographics, 14(1), 1-17.

Perrings, C., Folke, C., Mäler, K.G., (1992). The ecology and economics of biodiversity loss: the research agenda. Ambio 21, 201–211.

Perrings, C., Jackson, L., Bawa, K., Brussaard, L., Brush, S., Gavin, T., Papa, R., Pascual, U. and de Ruiter, P. (2006) 'Biodiversity in agricultural landscapes: Saving natural capital without losing interest', Conservation Biology, vol 20, no 2, pp263–264

Perrins, C. M. (1970). The timing of birds 'breeding seasons. Ibis, 112(2), 242-255.

Plieninger, T., Bieling, C., Fagerholm, N., Byg, A., Hartel, T., Hurley, P., Van Der Horst, D., (2015). The role of cultural ecosystem services in landscape management and planning. Current Opinion in Environmental Sustainability 14, 28–33.

Plumptre, A. J. (2000). Monitoring mammal populations with line transect techniques in African forests. Journal of Applied Ecology, 37(2), 356-368.

Poudel, J., Munn, I. A., & Henderson, J. E. (2017). Economic contributions of wildlife watching recreation expenditures (2006 & 2011) across the US south: An input-output analysis. Journal of Outdoor Recreation and Tourism, 17, 93-99.

Praveen, J., R. Jayapal & A. Pittie (2016). A checklist of the birds of India. Indian Birds 11 (5&6): 113–172.

Prusty, B. A. K., Chandra, R., & Azeez, P. A. (2017). Wetland Science. Springer, New Delhi.

R Vasanthi, H., ShriShriMal, N., & K Das, D. (2012). Phytochemicals from plants to combat cardiovascular disease. Current medicinal chemistry, 19(14), 2242-2251.

Rai, D. & Vanita (2021). Community composition and status of avifaunal diversity in and around Ottu reservoir of Sirsa, Haryana, India. Journal of Applied and Natural Science 13(2): 593–606. https://doi. org/10.31018/jans.v13i2.2666

Rai, D. (2021). Community composition and status of avifaunal diversity in and around Ottu reservoir of Sirsa, Haryana, India. Journal of Applied and Natural Science, 13(2), 593-606.

Rai, V. (2008). Modeling a wetland system: The case of Keoladeo National Park (KNP), India. Ecological Modelling, 210(3), 247–252. https://doi.org/10.1016/j.ecolmodel.2007.07.031.

Raja Reddy, G., Baskaran, M., Kumara Swamy, G., & Adinalaia, D. (2013). Avian Diversity in around the Baitarani Reserve Forest of Joda, Keonjhar District Odisha, India. Newsletter for Birdwatchers, 53(5), 69-76.

Rajashekariah, K., Ghosh, N., Areendran, G., & Babu, S. (2015). Valuation of ecosystem services of Kunigal lake in Tumkur District, Karnataka, (September).

Ramachandra, R. R. T. V. (2004). Economic valuation of wetlands. Journal of Environmental Biology.

Ramachandra, T. V., Rajinikanth, R., & Ranjini, V. G. (2005). Economic valuation of wetlands. Journal of Environmental Biology, 26(2), 439.

Rao PV. (1991). Traditional Medicine Modern Perspectives (Proceedings of the World Federation of Proprietary Medicine Manufactures 10 General the Assembly) Self Medication: Progress Built on Tradition. Seoul, Korea.

Rapport, D. J. (1989). What constitutes ecosystem health?. Perspectives in biology and medicine, 33(1), 120-132.

Ratan, N., & Singh, U. N. (2013). Carrying capacity of three grassland ecosystems in Bundelkhand region (UP), India. Range Management and Agroforestry, 34(1), 58-61.

Reddy, C. S. (2008). Catalogue of invasive alien flora of India. Life science journal, 5(2), 84-89.

Redlich, S., Martin, E. A., Wende, B., & Steffan-Dewenter, I. (2018). Landscape heterogeneity rather than crop diversity mediates bird diversity in agricultural landscapes. PLoS One, 13(8), e0200438.

Reid, S., Cornelius, C., Barbosa, O., Meynard, C., Silva-García, C., & Marquet, P. A. (2002). Conservation of temperate forest birds in Chile: implications from the study of an isolated forest relict. Biodiversity & Conservation, 11, 1975-1990.

Reid, W. V., Mooney, H. A., Cropper, A., Capistrano, D., Carpenter, S. R., Chopra, K., ... & Zurek, M. B. (2005). Ecosystems and human well-being-Synthesis: A report of the Millennium Ecosystem Assessment. Island Press.

Reynolds, J. F., Virginia, R. A., Kemp, P. R., De Soyza, A. G., & Tremmel, D. C. (1999). Impact of drought on desert shrubs: effects of seasonality and degree of resource island development. Ecological Monographs, 69(1), 69-106.

Richardson, C. T., & Miller, C. K. (1997). Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin, 634-638.

Ricklefs, R. E., & Renner, S. S. (1994). Species richness within families of flowering plants. Evolution, 48(5), 1619-1636.

Rosadi, S. D., & Patria, M. P. (2018). Economic Valuation of Mangrove Forest at Taman Ayu Village, West Lombok Regency. In E3S Web of Conferences (Vol. 68, p. 02009). EDP Sciences.

Rosli, z., khan, w. R., ahmad, k. I., nawaz, m., rajpar, g. J. G., & alhassan, a. B. (2023). Avian diversity at highland conservation area of payeh maga, lawas, sarawak, malaysia. The malaysian forester, 86(1), 109-124.

Rossato, S.C., H.F. Leitao-Filho & A. Begossi. (1999). Ethnobotany of Caiçaras of the Atlantic Forest Coast (Brazil). Economic Botany 53:387-395.

Sachan, S., Singh, D., Kumar, N. V., & Student, B. S. (2020). Comparison of cost of cultivation of wheat in punjab , haryana and andhra. 7(11), 503–509.

Sahu, R., & Chandravanshi, S. S. (2018). Lotus cultivation under wetland: a case study of farmers innovation in chhattisgarh, India. Int. J. Curr. Microbiol. App. Sci. Special Issue-7, 4635-4640.

Salimi, S., Almuktar, S. A., & Scholz, M. (2021). Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. Journal of Environmental Management, 286, 112160.

Sanchez-Azofeifa, A., Kalacska, M. E., Quesada, M., Stoner, K. E., Lobo, J. A., & Arroyo-Mora, P. (2003). Tropical dry climates. Phenology: an integrative environmental science, 121-137.

Santapau, H. (1958). The floristic study in India. Memoirs: Indian Botanical Society 1: 117–121.

Sardans, J., & Peñuelas, J. (2013). Plant-soil interactions in Mediterranean forest and shrublands: impacts of climatic change. Plant and soil, 365, 1-33.

Sarkar S, Kafatos M (2004) Interannual variability of vegetation over the Indian sub-continent and its relation to the different meteorological parameters. Remote Sens Environ 90:268–280.

Sarkar, P., & Das, T. (2016). Wetland ecosystem services and its valuation with special reference to India—A review. Biodiversity and Environmental Conservation; Upadhaya, K., Ed.; Discovery Publishing House Pvt: New Delhi, India, 59-76.

Sarukhán, J., and A. Whyte, editors. (2005). Ecosystems and human well-being: Synthesis (Millennium Ecosystem Assessment). Island Press, World Resources Institute, Washington, D.C., USA.

Sathya, T., & Sekar, C. (2012). Mangrove Eco-system and their Multifunctionalities: An Analysis of the Provision of Economic and Environmental Livelihoods to the Fishermen Communities in the South-East Coast of India. Trends in Agricultural Economics. https://doi.org/10.3923/tae.2012.31.47.

Sayami, M., & Tamrakar, N. K. (2007). Status of sand mining and quality in northern Kathmandu, Central Nepal. Bulletin of the Department of Geology, 10, 89-98.

Schaafsma, M., Morse-Jones, S., Posen, P., Swetnam, R. D., Balmford, A., Bateman, I. J., ... & Turner, R. K. (2014). The importance of local forest benefits: Economic valuation of Non-Timber Forest Products in the Eastern Arc Mountains in Tanzania. Global Environmental Change, 24, 295-305.

Schippmann U, Leaman DJ, Cunningham AB. (2002). Impact of cultivation and gathering of medicinal plants on biodiversity: global trends and issues. Biodiversity and the ecosystem approach in agriculture, forestry and fisheries.Rome: FAO.

Schirpke, U., Timmermann, F., Tappeiner, U., Tasser, E., (2016). Cultural ecosystem services of mountain regions: modelling the aesthetic value. Ecol. Indicat. 69, 78–90.

Scullion, J., C. W. Thomas, K. A. Vogt, O. Pérez-Maqueo, and M. G. Logsdon. (2011). Evaluating the environmental impact of payments for ecosystem services in Coatepec (Mexico) using remote sensing and on-site interviews. Environmental Conservation 38:426-434.

Seber, G. A., & Lee, A. J. (2003). Linear regression analysis (Vol. 330). John Wiley & Sons.

Seccombe-Hett, T. (2000). Market-based Instruments. World Economics, 1(3), 101-126.

Sekercioglu, C. H. (2002). Impacts of birdwatching on human and avian communities. Environmental conservation, 29(3), 282-289.

Sekercioglu, C. H. (2006). Ecological significance of bird populations. Handbook of the Birds of the World, 11, 15-51.

Seppelt, R., C. F. Dormann, F. V. Eppink, S. Lautenbach, and S. Schmidt. (2011). A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. Journal of Applied Ecology 48:630-636.

Shannon, C.E. & W. Weaver. (1963). The Mathematical Theory of Communication. University of Illinois Press.

Sharma M. (1990). Punjab Plants-Check List. Bishen Singh Mahendra Pal Singh Publications, Dehra Dun, India, 115pp.

Sharma, B., Rasul, G., & Chettri, N. (2015). The economic value of wetland ecosystem services: Evidence from the Koshi Tappu Wildlife Reserve, Nepal. Ecosystem Services, 12, 84–93. https://doi.org/10.1016/j.ecoser.2015.02.007.

Sharma, D., Tiwari, B. K., Chaturvedi, S. S., & Diengdoh, E. (2015). Status, utilization and economic valuation of Non-timber Forest Products of Arunachal Pradesh, India. Journal of Forest and Environmental Science, 31(1), 24-37.

Sharma, G., Joshi, P. C., Kumar, R., & Vasu, D. (2009). Floral diversity and limnological studies in and around Dholbaha dam (Punjab Shivalik, India). Biological Forum–An International Journal, 1(1), 22–31.

Sharma, M. & K. Rajpal (1995). Flora of Punjab State- A phytogeographic assessment. Journal of the Bombay Natural History Society 92(2): 160–165.

Sharma, M. (1990). Punjab Plants-Check List. Bishen Singh Mahendra Pal Singh Publications, Dehra Dun, India, 115pp.

Sharma, M.L. & P.K. Khosla, (1989). The Grasses of Punjab and Chandigarh. Publication Bureau, Punjab University, Chandigarh, 296pp.

Sharma, P. D. (2012). Ecology and Environment. India: Rastogi Publications.

Sheng-Ji, P. (2001). Ethnobotanical approaches of traditional medicine studies: some experiences from Asia. Pharmaceutical biology, 39(sup1), 74-79.

Sidhu MC, Kaur K, Ahluwalia AS. (2012). Ethno-medicinal studies of plants in Jalandhar District of Punjab, India. International Journal of Plant Research·6016:187-150.

Sidhu, H.S. (2005). Production condition in contemporary Punjab Agriculture, Journal of Punjab Studies, 12(2): 197- 219.

Sidhu, M. C., Kaur, K., & Ahluwalia, A. S. (2011). The use of traditional plant remedies in Hoshiarpur district of Punjab, India. Journal of Phytology, 3(9).

Sidhu, M. C., Kaur, K., & Ahluwalia, A. S. (2012). Ethno-medicinal studies of plants in Jalandhar District of Punjab, India. International journal of plant research· December, 6016, 187-150.

Silva VA, Albuquerque UP. (2004). Técnicas para análise de dados etnobotânicos. Pp. 63-88 in Métodos e técnicas na pesquisa etnobotânica, org. Edited by UP. Albuquerque & RP. Lucena. Nupeea, Recif.

Sinclair, M., Ghermandi, A., & Sheela, A. M. (2018). A crowdsourced valuation of recreational ecosystem services using social media data: An application to a tropical wetland in India. Science of the Total Environment, 642, 356–365.

Smith, G. F., O'Donoghue, P., O'Hora, K., & Delaney, E. (2011). Best practice guidance for habitat survey and mapping. Heritage Council, Kilkenny.

Smith, M.K., Ram, Y., (2016). Tourism, landscapes and cultural ecosystem services: a new

Sogah, S. G. (2012). The effects of differences in agro-ecosystems on the diversity and distribution of avifauna in selected areas in the Eastern Region of Ghana (Doctoral dissertation).

Sohil, A., & Sharma, N. (2020). Assessing the bird guild patterns in heterogeneous land use types around Jammu, Jammu and Kashmir, India. Ecological Processes, 9, 1-15.

Srivastava S, Srivastava M, Suprasanna S, D'Souza F (2011) Phytofi ltration of arsenic from simulated contaminated water using Hydrilla verticillata in fi eld conditions. Ecol Eng 37:1937–194.

Stewart Jr, R. E. (1982). Technical aspects of wetlands. US Geological Survey Water-supply Paper, 49.

Stewart, R. W. (1996). Wetlands as bird habitat. US Geological Survey Water Supply Paper, 2425.

Su, K., Wei, D. Z., & Lin, W. X. (2020). Evaluation of ecosystem services value and its implications for policy making in China–A case study of Fujian province. Ecological Indicators, 108, 105752.

Subramanya, K. (2017). Engineering Hydrology. McGraw Hill, New York, United States.

Suepa, T., Qi, J., Lawawirojwong, S., & Messina, J. P. (2016). Understanding spatio-temporal variation of vegetation phenology and rainfall seasonality in the monsoon Southeast Asia. Environmental research, 147, 621-629.

Sukumaran, S, Sujin, R. M, Geetha, V. S, & Jeeva, S. (2021). Ethnobotanical study of medicinal plants used by the Kani tribes of Pechiparai Hills, Western Ghats, India. Acta Ecologica Sinica 41(5):365-376.

Summers, J. K., Smith, L. M., Case, J. L., & Linthurst, R. A. (2012). A review of the elements of human well-being with an emphasis on the contribution of ecosystem services. Ambio, 41, 327-340.

Suwardi AB, Navia ZI, Harmawan T, Syamsuardi S, Mukhtar E. (2020). Wild edible fruits generate substantial income for local people of the Gunung Leuser National Park, Aceh Tamiang Region. Ethnobotany Research and Applications 20:1-13.

Tallis, H., & Polasky, S. (2009). Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. Annals of the New York Academy of Sciences, 1162(1), 265-283.

TEEB–The economics of Ecosystems and Biodiversity (2009) An interim report. Europ. Comm., Brussels. 7 www.teebweb.org. Assessed 20 June 2013.

Tefera BN, Kim YD. (2019). Ethnobotanical study of medicinal plants in the Hawassa Zuria District, Sidama zone,Southern Ethiopia. Journal of Ethnobiology and Ethnomedicine 15:1-21.

Teklehaymanot, T., & Giday, M. (2007). Ethnobotanical study of medicinal plants used by people in Zegie Peninsula, Northwestern Ethiopia. Journal of ethnobiology and Ethnomedicine, 3(1), 1-11.

Tessfa, E., Ejigu, D., Degife, G., & Tassie, N. (2020). Diversity, relative abundance, and habitat association of avian species in Tara Gedam Monastery forest and adjacent habitats, Northwestern Ethiopia. Ethiopian Journal of Science and Technology, 13(1), 65-80.

Thakur, O., & Churpal, D. (2022). Cost-benefits analysis of water chestnut cultivation in Gariaband district of Chhattisgarh. Seed, 13500, 43-64.

Thomann, M., Imbert, E., Devaux, C., & Cheptou, P. O. (2013). Flowering plants under global pollinator decline. Trends in plant science, 18(7), 353-359.

Tiwana, N. S., Jerath, N., Saxena, S. K., & Sharma, V. (2008). 69-Conservation and Management of Wetlands in Punjab-Challenges & Opportunities.

Tiwana, N.S., N. Jerath, S.K. Saxena, P. Nangia & H.K. Parwana (2005). State of Environment Report: Punjab. Punjab State Council for Science and Technology, 315pp.

Tratalos, J.A., Haines-Young, R., Potschin, M., Fish, R., Church, A., (2016). Cultural ecosystem services in the UK: lessons on designing indicators to inform management and policy. Ecol. Indicat. 61, 63–73.

Treasure IO, Adjene JO, Odigie MO. (2020). Ethnobotanical survey of medicinal plants in Ughelli North Local Government Area of Delta State. Journal of Medicine: Study and Research 3(14):1-9.

Trierweiler, C., Klaassen, R. H., Drent, R. H., Exo, K. M., Komdeur, J., Bairlein, F., & Koks, B. J. (2014). Migratory connectivity and population-specific migration routes in a long-distance migratory bird. Proceedings of the Royal Society B: Biological Sciences, 281(1778), 20132897.

Tsutsumi, A., Jinno, K., & Berndtsson, R. (2004). Surface and subsurface water balance estimation by the groundwater recharge model and a 3-D two-phase flow model/Estimation de bilan hydrologique de surface et de subsurface à l'aide de modèles de recharge de nappe et d'écoulement diphasique 3-D. Hydrological Sciences Journal, 49(2).

Tubelis, D. P., & Cavalcanti, R. B. (2001). Community similarity and abundance of bird species in open habitats of a central Brazilian Cerrado. Ornitologia Neotropical, 12(1), 57-73.

Tuboi, C., & Hussain, S. A. (2018). Plant community structure of the floating meadows of a hypereutrophic wetland in the Indo-Burma Biodiversity Hotspot. Aquatic botany, 150, 71-81.

Uddin, M. S., van Steveninck, E. D. R., Stuip, M., & Shah, M. A. R. (2013). Economic valuation of provisioning and cultural services of a protected mangrove ecosystem: A case study on Sundarbans Reserve Forest, Bangladesh. Ecosystem Services, 5, 88-93.

Van Wilgen, B. W., Cowling, R. M., & Burgers, C. J. (1996). Valuation of ecosystem services. BioScience, 46(3), 184-189.

Vander Wall, S. B. (2001). The evolutionary ecology of nut dispersal. The Botanical Review, 67, 74-117.

Verma, M. (2001). Economic Valuation in the Lake Basin Management Decision Making Process : Lessons from Bhoj Wetland , India *. Wetlands.

Verma, M., & Negandhi, D. (2011). Valuing ecosystem services of wetlands — a tool for effective policy. Hydrolgoical Sciences Journal, 56(8), 1622–1639.

Verma, M., Bakshi, N., & Nair, R. P. (2001). Economic valuation of Bhoj Wetland for sustainable use. Unpublished project report for World Bank assistance to Government of India, Environmental Management Capacity-Building. Bhopal: Indian Institute of Forest Management, 35.

Verma, M., Bakshi, N., & Nair, R. P. K. (2001). Economic valuation of Bhoj wetland for sustainable use. EERC Working Paper Series, 35, 227. Retrieved from http://www.irade.org/eerc/pdf/WB_FR_MadhuVerma.pdf

Vieira, I. F. B., Rolim Neto, F. C., Carvalho, M. N., Caldas, A. M., Costa, R. C. A., Silva, K. S. D., ... & Pissarra, T. C. T. (2020). Water security assessment of groundwater quality in an anthropized rural area from the atlantic forest biome in Brazil. Water, 12(3), 623.

Vymazal, J. (2011). Enhancing ecosystem services on the landscape with created, constructed and restored wetlands. Ecological Engineering, 37(1), 1-5.

Wallace, K. J. 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 39:235-246.

Wang, J., Peng, J., Zhao, M., Liu, Y., & Chen, Y. (2017). Significant trade-off for the impact of Grain-for-Green Programme on ecosystem services in North-western Yunnan, China. Science of the Total Environment, 574, 57-64.

Webb, E. B., Smith, L. M., Vrtiska, M. P., & Lagrange, T. G. (2010). Effects of local and landscape variables on wetland bird habitat use during migration through the Rainwater Basin. The Journal of Wildlife Management, 74(1), 109-119.

Wehi, P. M., & Lord, J. M. (2017). Importance of including cultural practices in ecological restoration. Conservation biology, 31(5), 1109-1118.

Weller, M. W. (1999). Wetland birds: habitat resources and conservation implications. Cambridge University Press.

Wenny, D. G., Devault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D. F., & Whelan, C. J. (2011). The need to quantify ecosystem services provided by birds. The auk, 128(1), 1-14.

Westman, W., (1977). How much are nature's services worth? Science 197, 960–964.

Whelan, C. J., Wenny, D. G., & Marquis, R. J. (2008). Ecosystem services provided by birds. Annals of the New York academy of sciences, 1134(1), 25-60.

Whelan, C. J., Wenny, D. G., & Marquis, R. J. (2010). Policy implications of ecosystem services provided by birds. Synesis: A Journal of Science, Technology, Ethics & Policy, 1(1).

Wiener, C. S. W. (1949). The Mathematical Theory of Communication: Unknown Distance Function. Urbana, IL: Illinois Press.

Wilcove, D. S. (2010). Endangered species management: the US experience. Conservation Biology for All, 220-235.

Williams, T. O., Fernández-Rivera, S., & Kelley, T. G. (1997). The influence of socioeconomic factors on the availability and utilization of crop residues as animal feeds.

Willson, M. F. (1974). Avian community organization and habitat structure. Ecology, 55(5), 1017-1029.

Wilson, S., Mitchell, G. W., Pasher, J., McGovern, M., Hudson, M. A. R., & Fahrig, L. (2017). Influence of crop type, heterogeneity and woody structure on avian biodiversity in agricultural landscapes. Ecological Indicators, 83, 218-226.

Windham L, Weis JS, Weis P (2003) Uptake and distribution of metals in two dominant salt marsh macrophytes, Spartina alternifl ora (cordgrass) and Phragmites australis (common reed). Estuar Coast Shelf Sci 56:63.

Wu, B., Tian, F., Zhang, M., Piao, S., Zeng, H., Zhu, W., ... & Lu, Y. (2022). Quantifying global agricultural water appropriation with data derived from earth observations. Journal of Cleaner Production, 358, 131891.

Wu, G., Xiao, H., Zhao, J., Shao, G., & Li, J. (2002). Forest ecosystem services of Changbai Mountain in China. Science in China Series C: Life Sciences, 45(1), 21-32.

Wunder, S., (2005). Payments for environmental services: some nuts and bolts. Occasional paper No 42. CIFOR, Bogor.

Xu, W., Xiao, Y., Zhang, J., Yang, W. U., Zhang, L. U., Hull, V., ... & Ouyang, Z. (2017). Strengthening protected areas for biodiversity and ecosystem services in China. Proceedings of the National Academy of Sciences, 114(7), 1601-1606.

Yacob, M. R., Radam, A., Shuib, A., Samarahan, K., & Sarawak, M. (2009). A contingent valuation study of marine parks ecotourism: The case of Pulau Payar and Pulau Redang in Malaysia. Journal of Sustainable Development, 2(2), 95-105.

Yadav, R., Jangid, M., Rajpurohit, S., & Kamboj, R. D. (2019). Estimated quantification and valuation of fuelwood collected from forest areas of Narmada forest division of Gujarat state, India. Plant Archives, 19(2), 2459-2464.

Zacharias, I., Dimitriou, E., Dekker, A., & Dorsman, E. (2007). Overview of temporary ponds in the Mediterranean region: threats, management and conservation issues. Journal of environmental biology, 28(1), 1-9.

Zeleke, G. (2011). Preliminary survey on tsetse flies and trypanosomosis at grazing fields and villages in and around the Nech Sar National Park, Southern Ethiopia. Ethiopian Veterinary Journal, 15(1).

Zhang, Y., S. Singh, and B. R. Bakshi. (2010). Accounting for ecosystem services in life cycle assessment, Part I: a critical review. Environmental Science & Technology 44:2232-2242.

Zhou, L., Guan, D., Huang, X., Yuan, X., Zhang, M., 2020. Evaluation of the cultural ecosystem services of wetland park. Ecol. Indicat. 114, 106286.

Zoderer, B.M., Tasser, E., Erb, K., Stanghellini, P.S.L., Tappeiner, U., 2016. Identifying and mapping the tourists’ perception of cultural ecosystem services: a case study from an Alpine region. Land Use Pol. 56, 251–261.

Annexure - 1

Set of questionnaire

Questionnaire for cultural ecosystem services

1. Personal:

Name	Male	Female	Age	✓ Education				Village/ city
				Illiterate	Less than 12^{th}	Graduate	Maters and above	

Occupation:

Students	
Teachers	
State Government job	
Doctors	
Central Government job	
Entrepreneurs	
Forest official	
Researcher	
Photographer	
Poets	
Singers	
Farmer	
Journalist	

Annual income Group	Number of Individuals
Not earning yet	
Up to ₹ 2,50,000	
₹ 2,50,001 - ₹ 5,00,000	
₹ 5,00,001 - ₹ 10,00,000	
Above ₹ 10,00,000	

2. Travelling details:
   a. Type of vehicle you came by (ਤੁਸੀਂ ਕਿਹੜਾ ਵਾਹਨ ਵਰਤਿਆ ਹੈ) ………………
   b. How much Distance you travelled to reach here (ਤੁਸੀਂ ਇੱਥੇ ਪਹੁੰਚਣ ਲਈ ਕਿੰਨੀ ਦੂਰੀ ਤੈਅ ਕੀਤੀ ਹੈ)........km.
   c. Did you directly come for visiting HWS? (ਕੀ ਤੁਸੀਂ ਸਿੱਧੇ ਇੱਥੇ ਆਏ ਹੋ)

      Y/N...................

d. How was your road experience: (ਤੁਹਾਡਾ ਸੜਕ ਦਾ ਅਨੁਭਵ ਕਿਹੋ ਜਿਹਾ ਰਿਹਾ) Good/ Bad …………..

e. Expected cost on food and other (ਤੁਸੀਂ ਭੋਜਨ ਅਤੇ ਹੋਰ 'ਤੇ ਕਿੰਨਾ ਖਰਚ ਕੀਤਾ ਹੈ) Rs……………

3. Willingness to pay:

a. What you find more attractive: ………………
b. Do you want to see birds and animals? = Y/N
c. Do you want someone to explain about Wildlife? = Y/N
d. Would you like to walk for 2 km for nature trail? = Y/N
e. Should there be compulsory entry fee? Y/N
f. What should be the entry fee/ person ………….RS
g. How was your experience?

Satisfied	Unsatisfied	Neutral

Services	Services for which you can pay	How much can you afford to pay for an hour /person in Rs …√
Aesthetic		
Bird watching		
Birthday celebration		
Boating		
Celebrating important days for environment		
Content creation for social media		
Cycling		
Educational tour		
Painting		
Peace		
Pre-wedding shoot		
Singing practice		
Wildlife Photography		
Writing poetry		

Why you want to pay

✓ For conservation	✓ For creation of employment for locals	✓ Own Enjoyment	✓ For getting new information	✓ Time spent in nature with peace

Problems faced during visit:

Washroom	Y/N
Attacked by any animal	
Misbehaviour by other visitors	
Drinking water	
Needed someone to explain the wildlife	
Needed Binoculars to see birds	

Questionnaire for provisional ecosystem services

Fuel wood

Species	Total weight	Village	No of male	No of female

Fodder (Grazing)

Date	Habitat	Livestock	Number	Species used for grazing

Editable plants

Species	Month of harvest	Approx. Quantity (kg)

Raw-material

Date	Species	Number	Number of clumps	Market price/ piece

Questionnaire for Ethno botanical documentation

Personal information

Name	Male	Female	Age	✓ Education				Village/ city And location
				Illiterate	Less than 12th	Graduate	Maters and above	

Utility of medicinal plants

S.no	Species	Use for Aliments	Did you use it?	Method for preparing drug	Source of collection	How frequent you collect?	Do you collect it for sale?

Field survey for distribution of medicinal plants in the HWS

			Present or absent in the habitats					
S.no	Species	Habit	Wetland	Sandy	Swampy	Ravine	Agricultural field	Plantation

Data collection for vegetation across the habitats

Date: **Time:** **Location:**

Habitat type: **Transit distance:**

S.no	Species	Count	Flowering	Fruiting	Used for fulewood	Used for Fodder	Used as Raw matireal	Used as medicinal plants

Data collection for Biomass

Date: **Time:** **Location:**

Habitat type: **Plot no:**

S.no	Species	GBH (cm)	Height (m)	Conopy cover in %

Data collection for aquatic plants

Plot no (1m x 1m)	Species	Percentage in plot

Data collection for avian species

Date: **Time range:** **Location:**

Habitat type: **Point or Transit no:**

S.no	Species	Count	Activity	Food guild

Checklist of plant species recorded in various habitats of HWS

Habit: T, Trees; S, Shrubs; H, Herbs; Cl, Climbers; G, Grasses; Sv, Submerged vegetation; Fv, Floating vegetation; Fr, Ferns; Su, Succulent

Habitat: WL, wetland; SD, Sandy; PL, Plantation; RV, Ravine; SW, Swampy; AG, Agricultural field

Source: W, Wild; O, Ornamental; C, Cultivated

Occurrence: F, Frequent; OC, Occasional; R, Rare; VR, Very rare.

Voucher/Photograph No.	Species	Family	Habit	Habitat	Source	Occurrence
WII/HARIKE/SG/125	*Abelmoschus esculentus* (L.) Moench.	Malvaceae	H	AG	C	OC
WII/HARIKE/SG/298	*Abrus precatorius* L.	Leguminosae	Cl	PL,RV,SW	W	OC
WII/HARIKE/SG/126	*Abutilon indicum* (L.) Sweet	Malvaceae	H	SD, PL, RV, SW	W	R
WII/HARIKE/SG/002	*Acacia catechu* (L.f.) Willd	Leguminosae	T	PL, RV	W	OC
WII/HARIKE/SG/003	*Acacia tortilis* (Forsk.) Hayne	Leguminosae	T	PL, AG,RV	W	OC
WII/HARIKE/SG/001	*Acacia auriculiformis* Benth	Leguminosae	T	PL, AG,RV,SW	O	OC
WII/HARIKE/SG/127	*Achyranthes aspera* L.	Amaranthaceae	H	PL,AG,RV,	W	F
WII/HARIKE/SG/128	*Adenostemma platyphyllum* Cass	Compositae	H	WL,SW	W	VR
WII/HARIKE/SG/004	*Aegle marmelos* (L.) Correa	Rutaceae	T	PL	W	R
WII/HARIKE/SG/129	*Aerva javanica* (Burm.f.) Juss. ex Schult	Amaranthaceae	H	AG, RV,	W	F
WII/HARIKE/SG/383	*Agave sisalana* Perrine	Asparagaceae	Su	PL	O	OC
WII/HARIKE/SG/130	*Ageratum conyzoides* (L.) L	Compositae	H	WL, SD, PL, AG, RV, SW	W	F
WII/HARIKE/SG/005	*Ailanthus excelsa* Roxb.	Simaroubaceae	T	PL, RV. SW	W	OC
WII/HARIKE/SG/006	*Albizia lebbeck* (L.) Benth.	Leguminosae	T	PL. SD, AG, RV, SW	W	F
WII/HARIKE/SG/007	*Albizia procera* (Roxb.) Benth.	Leguminosae	T	PL, SW	W	F
WII/HARIKE/SG/131	*Alhagi maurorum* Medik	Leguminosae	H	AG,RV	W	OC

WII/HARIKE/SG/132	*Allium cepa* L.	Amaryllidaceae	H	AG	C	F
WII/HARIKE/SG/133	*Allium sativum* L	Amaryllidaceae	H	AG	C	F
WII/HARIKE/SG/008	*Alstonia scholaris* (L.) R. Br.	Apocynaceae	T	PL	O	OC
WII/HARIKE/SG/134	*Alternanthera paronychioides* A.St.-Hil.	Amaranthaceae	H	WL	W	F
WII/HARIKE/SG/135	*Alternanthera pungens* Kunth	Amaranthaceae	H	AG,RV	W	F
WII/HARIKE/SG/136	*Alysicarpus ovalifolius* (Schum.) Leonard	Leguminosae	H	AG	W	OC
WII/HARIKE/SG/137	*Alysicarpus vaginalis* (L.) DC	Leguminosae	H	PL,AG	W	OC
WII/HARIKE/SG/138	*Amaranthus viridis* L.	Amaranthaceae	H	PL	W	OC
WII/HARIKE/SG/139	*Ammannia baccifera* L.	Lythraceae.	H	AG	W	F
WII/HARIKE/SG/140	*Anagallis arvensis* L.	Primulaceae	H	WL,SD,PL,AG,RV,SW	W	F
WII/HARIKE/SG/141	*Anisomeles indica* (L.) Kuntze	Lamiaceae	H	PL,AG	W	VR
WII/HARIKE/SG/299	*Antigonon leptopus* Hook. & Arn	Polygonaceae	Cl	PL	O	OC
WII/HARIKE/SG/142	*Argemone mexicana* Sweet	Papaveraceae	H	RV	W	OC
WII/HARIKE/SG/331	*Aristida adscensionis* L.	Poaceae	G	RV	W	F
WII/HARIKE/SG/143	*Artemisia scoparia* Waldst. & Kitam.	Compositae	H	SD,PL,AG,RV,SW	W	F
WII/HARIKE/SG/009	*Artocarpus heterophyllus* Lam.	Moraceae	T	PL	C	R
WII/HARIKE/SG/332	*Arundo donax* L.	Poaceae	G	WL,SW	W	F
WII/HARIKE/SG/300	*Asparagus officinalis* L.	Asparagaceae	Cl	PL	W	VR
WII/HARIKE/SG/382	*Asplenium platyneuron* (L.) Britton, Sterns & Poggenb	Aspleniaceae	Fr	WL, SW	W	R
WII/HARIKE/SG/144	*Astragalus sinaicus* Boiss.	Leguminosae	H	RV	W	OC
WII/HARIKE/SG/333	*Avena sativa* L.	Poaceae	G	AG	W	F
WII/HARIKE/SG/010	*Azadirachta indica* A. Juss.	Meliaceae	T	PL, SD AG, RV,SW	W	OC
WII/HARIKE/SG/371	*Azolla pinnata* R. Br.	Salviniaceae	Fv	WL, SW	W	F
WII/HARIKE/SG/145	*Bacopa monnieri* (L.) Wettst.	Plantaginaceae	H	WL,SW	W	VR
WII/HARIKE/SG/301	*Basella alba* L	Basellaceae	Cl	PL	W	OC
WII/HARIKE/SG/011	*Bauhinia variegata* L.	Leguminosae	T	PL	W	R
WII/HARIKE/SG/146	*Berula erecta* (Huds.) Coville	Apiaceae	H	WL,SW	W	R

WII/HARIKE/SG/147	*Blumea lacera* (Burm.f.) DC	Compositae	H	AG,RV,	W	R
WII/HARIKE/SG/148	*Boerhavia diffusa* L.	Nyctaginaceae	H	PL,AG,RV,SW	W	F
WII/HARIKE/SG/149	*Boerhavia erecta* L.	Nyctaginaceae	H	RV	W	VR
WII/HARIKE/SG/012	*Bombax ceiba* L.	Malvaceae	T	PL, WL, SD, SW	W	OC
WII/HARIKE/SG/085	*Bougainvillea spectabilis* Willd.	Nyctaginaceae	S	PL	O	OC
WII/HARIKE/SG/334	*Brachiaria ramosa* (L.) Stapf	Poaceae	G	PL	W	F
WII/HARIKE/SG/151	*Brassica rapa* var. rapa L.	Brassicaceae	H	AG	C	F
WII/HARIKE/SG/150	*Brassica oleracea* L	Brassicaceae	H	AG	C	F
WII/HARIKE/SG/152	*Bryophyllum pinnatum* (Lam.) Oken	Crassulaceae	H	PL,	O	R
WII/HARIKE/SG/013	*Butea monosperma* (Lam.) Taub.	Leguminosae	T	PL	W	R
WII/HARIKE/SG/086	*Cajanus cajan* (Linn.) Millsp.	Leguminosae	S	AG	C	R
WII/HARIKE/SG/014	*Callistemon viminalis* (Sol. ex Gaertn.) G.Don	Myrtaceae	T	PL	W	R
WII/HARIKE/SG/087	*Calotropis procera* (Aiton) Dryand	Apocynaceae	S	PL, AG, RV,	W	F
WII/HARIKE/SG/153	*Cannabis sativa* L.	Cannabaceae	H	SD,PL,AG,RV,SW	W	F
WII/HARIKE/SG/088	*Capparis decidua* (Forssk.) Edgew	Capparaceae	S	RV	W	R
WII/HARIKE/SG/154	*Capsella bursa-pastoris* (L.) Medik.	Brassicaceae	H	PL,	W	OC
WII/HARIKE/SG/155	*Capsicum annuum* L.	Solanaceae	H	PL,	C	OC
WII/HARIKE/SG/156	*Cardamine hirsuta* L.	Brassicaceae	H	SD	W	R
WII/HARIKE/SG/302	*Cardiospermum halicacabum* L.	Sapindaceae	Cl	PL	W	VR
WII/HARIKE/SG/015	*Carica papaya* L	Caricaceae	T	PL	C	R
WII/HARIKE/SG/089	*Carissa spinarum* L	Apocynaceae	S	PL	O	VR
WII/HARIKE/SG/016	*Caryota urens* L.	Arecaceae	T	PL	O	R
WII/HARIKE/SG/090	*Cascabela thevetia* (L.) Lippold	Apocynaceae	S	PL	O	F
WII/HARIKE/SG/017	*Cassia fistula* L.	Leguminosae	T	PL, RV,SW	W	OC
WII/HARIKE/SG/018	*Casuarina equisetifolia* L	Casuarinaceae	T	PL	O	R
WII/HARIKE/SG/157	*Catharanthus roseus* (L.) G.Don	Apocynaceae	H	PL	O	OC
WII/HARIKE/SG/303	*Cayratia trifolia* (L.) Domin	Vitaceae	Cl	PL,AG	W	VR

WII/HARIKE/SG/019	*Ceiba pentandra* L.	Malvaceae	T	PL	O	VR
WII/HARIKE/SG/335	*Cenchrus ciliaris* L.	Poaceae	G	PL,AG,RV	W	F
WII/HARIKE/SG/158	*Centella asiatica* (L.) Urb.	Apiaceae	H	WL,SW	W	VR
WII/HARIKE/SG/364	*Ceratophyllum demersum* L	Ceratophyllaceae	Sv	WL	W	F
WII/HARIKE/SG/091	*Cestrum nocturnum* L	Solanaceae	S	PL	O	R
WII/HARIKE/SG/159	*Chenopodium album* L.	Chenopodiaceae	H	PL,AG	W	F
WII/HARIKE/SG/160	*Chenopodium murale* L.	Chenopodiaceae	H	PL	W	F
WII/HARIKE/SG/336	*Chloris barbata* Sw.	Poaceae	G	PL	W	VR
WII/HARIKE/SG/337	*Chrysopogon zizanioides* (L.) Roberty	Poaceae	G	WL,SD,SW	W	OC
WII/HARIKE/SG/020	*Chukrasia tabularis* A. Juss.	Meliaceae	T	PL	O	OC
WII/HARIKE/SG/161	*Cirsium arvense* (L.) Scop.	Asteraceae	H	PL,AG,RV,	W	F
WII/HARIKE/SG/304	*Citrullus colocynthis* (L.) Schrad.	Cucurbitaceae	Cl	RV	W	R
WII/HARIKE/SG/092	*Citrus aurantifolia* (Christm) Sw.	Rutaceae	S	AG	C	R
WII/HARIKE/SG/162	*Cleome viscosa* L	Cleomaceae	H	PL	W	OC
WII/HARIKE/SG/093	*Clerodendrum inerme* (L.) Gaertn	Lamiaceae	S	PL	O	OC
WII/HARIKE/SG/094	*Clerodendrum phlomidis* L.f.	Lamiaceae	S	RV	W	VR
WII/HARIKE/SG/305	*Clitoria ternatea* L.	Leguminosae	Cl	PL	W	OC
WII/HARIKE/SG/306	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	Cl	PL,SW	W	F
WII/HARIKE/SG/307	*Cocculus hirsutus* (L.) W.Theob	Menispermaceae	Cl	RV	W	VR
WII/HARIKE/SG/308	*Cocculus pendulus* (J.R.Forst. & G.Forst.) Diels	Menispermaceae	Cl	PL,RV,	W	R
WII/HARIKE/SG/163	*Colocasia esculenta* (L.) Schott.	Araceae	H	WL	C	R
WII/HARIKE/SG/164	*Commelina benghalensis* L.	Commelinaceae	H	PL,AG,RV	W	OC
WII/HARIKE/SG/165	*Commelina erecta* L.	Commelinaceae	H	RV	W	VR
WII/HARIKE/SG/309	*Convolvulus arvensis* L.	Convolvulaceae	Cl	WL,SD,PL,AG,RV,SW	W	F
WII/HARIKE/SG/310	*Convolvulus prostratus* Forssk	Convolvulaceae	Cl	RV	W	R
WII/HARIKE/SG/166	*Corchorus aestuans* L	Malvaceae	H	SD	W	F
WII/HARIKE/SG/021	*Cordia myxa* L.	Boraginaceae	T	PL,AG, RV,SW	W	F

WII/HARIKE/SG/167	*Coriandrum sativum* L.	Apiaceae	H	AG	C	F
WII/HARIKE/SG/022	*Crateva religiosa* G.Forst.	Capparaceae	T	PL	W	OC
WII/HARIKE/SG/168	*Crinum asiaticum* L.	Amaryllidaceae	H	RV	O	R
WII/HARIKE/SG/169	*Crotalaria burhia* Benth.	Leguminosae	H	RV	W	VR
WII/HARIKE/SG/170	*Crotalaria medicaginea* Lam	Leguminosae	H	PL,AG,RV	W	R
WII/HARIKE/SG/171	*Croton bonplandianus* Baill.	Euphorbiaceae	H	AG	W	F
WII/HARIKE/SG/311	*Cucumis melo var.* callosus Rot	Cucurbitaceae	Cl	AG	W	OC
WII/HARIKE/SG/312	*Cucumis sativus* L.	Cucurbitaceae	Cl	AG	C	OC
WII/HARIKE/SG/313	*Cucurbita maxima* Duchesne.	Cucurbitaceae	Cl	AG	C	R
WII/HARIKE/SG/172	*Curcuma longa* L.	Zingiberaceae	H	RV	C	R
WII/HARIKE/SG/314	*Cuscuta reflexa* Roxb	Convolvulaceae	Cl	PL	W	F
WII/HARIKE/SG/173	*Cyathula prostrata* (L.) Blume	Amaranthaceae	H	WL,SD	W	VR
WII/HARIKE/SG/023	*Cycas revoluta* Thunb	Cycadaceae	T	PL	O	VR
WII/HARIKE/SG/338	*Cymbopogon martini* (Roxb.) W.Watson	Poaceae	G	RV	W	VR
WII/HARIKE/SG/339	*Cynodon dactylon* (L.) Pers.	Poaceae	G	SD,PL,AG,RV,SW	W	F
WII/HARIKE/SG/174	*Cyperus michelianus* (L.) Delile	Cyperaceae	H	WL,SD,AG,SW	W	F
WII/HARIKE/SG/175	*Cyperus rotundus* L.	Cyperaceae	H	PL	W	F
WII/HARIKE/SG/340	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae	G	PL,AG	W	F
WII/HARIKE/SG/024	*Dalbergia sissoo* DC.	Leguminosae	T	PL, WL, SD, SW, RV	W	F
WII/HARIKE/SG/176	*Datura metel* L.	Solanaceae	H	PL,AG,RV	W	OC
WII/HARIKE/SG/177	*Datura stramonium* L.	Solanaceae	H	AG	W	OC
WII/HARIKE/SG/178	*Daucus carota* L.	Apiaceae	H	PL,AG	C	F
WII/HARIKE/SG/025	*Delonix regia* (Hook.) Raf.	Leguminosae	T	PL	O	OC
WII/HARIKE/SG/341	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	G	PL	W	R
WII/HARIKE/SG/342	*Desmostachya bipinnata* (L.) Stapf	Poaceae	G	SD,PL,AG,RV	W	F
WII/HARIKE/SG/343	*Dichanthium annulatum* (Forssk.) Stapf	Poaceae	G	AG	W	OC
WII/HARIKE/SG/026	*Dichrostachys cinerea* (L.) Wight & Arn.	Leguminosae	T	PL, SW	W	VR
WII/HARIKE/SG/179	*Digera muricata* (L.) Mart.	Amaranthaceae	H	SD,PL,AG	W	F

WII/HARIKE/SG/344	*Digitaria ciliaris* (Retz.) Koeler	Poaceae	G	PL	W	F
WII/HARIKE/SG/027	*Diospyros montana* Roxb	Ebenaceae	T	PL	W	R
WII/HARIKE/SG/380	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae	Fr	WL, SW	W	F
WII/HARIKE/SG/180	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	Chenopodiaceae	H	SD	W	OC
WII/HARIKE/SG/345	*Echinochloa colona* (L.) Link	Poaceae	G	AG	W	OC
WII/HARIKE/SG/181	*Echinops echinatus* Roxb	Compositae	H	RV,	W	VR
WII/HARIKE/SG/182	*Eclipta prostrata* (L.) L	Compositae	H	WL,SD,SW	W	F
WII/HARIKE/SG/028	*Ehretia laevis* (Rottler ex G. Don) Roxb.	Boraginaceae	T	PL,SD,AG, RV, SW	W	F
WII/HARIKE/SG/372	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Fv	WL, SW	W	F
WII/HARIKE/SG/346	*Eleusine indica* (L.) Gaertn	Poaceae	G	PL,AG	W	F
WII/HARIKE/SG/183	*Emex spinosa* (L.) Campd.	Polygonaceae	H	PL,	W	F
WII/HARIKE/SG/381	*Equisetum ramosissimum* Desf	Equisetaceae	Fr	WL, SW, PL,SD	W	R
WII/HARIKE/SG/347	*Eragrostis amabilis* (L.) Wight & Arn.	Poaceae	G	SD,PL,RV,	W	F
WII/HARIKE/SG/348	*Eragrostis minor* Host	Poaceae	G	AG	W	F
WII/HARIKE/SG/184	*Erigeron canadensis* L.	Compositae	H	PL,AG	W	OC
WII/HARIKE/SG/029	*Erythrina variegata* L.	Leguminosae	T	PL	W	R
WII/HARIKE/SG/030	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	T	PL, WL, SD, SW, RV	W	F
WII/HARIKE/SG/095	*Euphorbia cotinifolia* L	Euphorbiaceae	S	PL	O	VR
WII/HARIKE/SG/185	*Euphorbia cyathophora* Murray	Euphorbiaceae	H	PL,	W	VR
WII/HARIKE/SG/186	*Euphorbia helioscopia* L.	Euphorbiaceae	H	WL,	W	OC
WII/HARIKE/SG/187	*Euphorbia hirta* L.	Euphorbiaceae	H	SD,PL,AG,RV,	W	F
WII/HARIKE/SG/096	*Euphorbia milii* Des Moul	Euphorbiaceae	S	PL	O	OC
WII/HARIKE/SG/188	*Euphorbia prostrata* Aiton	Euphorbiaceae	H	PL,RV	W	F
WII/HARIKE/SG/189	*Euphorbia thymifolia* L.	Euphorbiaceae	H	PL,AG	W	F
WII/HARIKE/SG/190	*Euphorbia tithymaloides* L.	Euphorbiaceae	H	PL	O	R
WII/HARIKE/SG/191	*Evolvulus nummularius* (L.) L.	Convolvulaceae	H	PL	W	R
WII/HARIKE/SG/192	*Fagonia indica* Burm.f.	Zygophyllaceae	H	RV	W	VR

WII/HARIKE/SG/031	*Ficus benghalensis* L.	Moraceae	T	PL, WL, SD, SW	W	OC
WII/HARIKE/SG/032	*Ficus benjamina* L.	Moraceae	T	PL	O	OC
WII/HARIKE/SG/033	*Ficus carica* L.	Moraceae	T	PL	W	R
WII/HARIKE/SG/034	*Ficus palmata* Forssk.	Moraceae	T	PL,AG, RV, SW	W	F
WII/HARIKE/SG/035	*Ficus racemosa* L.	Moraceae	T	PL	W	R
WII/HARIKE/SG/036	*Ficus religiosa* L.	Moraceae	T	PL, WL, SD, SW, RV	W	F
WII/HARIKE/SG/037	*Ficus virens* Aiton	Moraceae	T	AG	W	R
WII/HARIKE/SG/193	*Foeniculum vulgare* Mill.	Apiaceae	H	PL	C	R
WII/HARIKE/SG/194	*Fumaria indica* (Hausskn.) Pugsley	Papaveraceae	H	SD,PL,AG	W	OC
WII/HARIKE/SG/195	*Galium aparine* L.	Rubiaceae	H	PL	W	F
WII/HARIKE/SG/196	*Geranium rotundifolium* L	Geraniaceae	H	PL	W	VR
WII/HARIKE/SG/197	*Glandularia pulchella* (Sweet) Tronc	Verbenaceae	H	PL	W	VR
WII/HARIKE/SG/038	*Gmelina arborea* Roxb	Lamiaceae	T	RV	W	R
WII/HARIKE/SG/198	*Gnaphalium pensylvanicum* Willd.	Compositae	H	SD,PL,AG,SW	W	OC
WII/HARIKE/SG/199	*Gomphrena celosioides* Mart	Amaranthaceae	H	PL	W	OC
WII/HARIKE/SG/097	*Gossypium arboreum* L	Malvaceae	S	AG	C	R
WII/HARIKE/SG/039	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	T	PL	W	OC
WII/HARIKE/SG/098	*Grewia tenax* (Forssk.) Fiori	Malvaceae	S	PL, RV	W	R
WII/HARIKE/SG/099	*Hamelia patens* Jacq	Rubiaceae	S	PL	O	OC
WII/HARIKE/SG/200	*Heliotropium bacciferum* Forssk.	Boraginaceae	H	RV	W	VR
WII/HARIKE/SG/201	*Heliotropium strigosum* Willd	Boraginaceae	H	RV	W	VR
WII/HARIKE/SG/202	*Herniaria hirsuta* L	Caryophyllaceae	H	RV	W	VR
WII/HARIKE/SG/100	*Hibiscus mutabilis* L.	Malvaceae	S	PL	O	R
WII/HARIKE/SG/101	*Hibiscus rosa-sinensis* L.	Malvaceae	S	PL	O	OC
WII/HARIKE/SG/040	*Holoptelea integrifolia* Planch	Ulmaceae	T	PL	W	OC
WII/HARIKE/SG/315	*Humulus scandens* (Lour.) Merr.	Cannabaceae	Cl	PL,AG	W	F
WII/HARIKE/SG/365	*Hydrilla verticillata* (L.f.) Royle	Hydrocharitaceae	Sv	WL, SW	W	F
WII/HARIKE/SG/203	*Indigofera spicata* Forssk.	Leguminosae	H	RV	W	R

WII/HARIKE/SG/316	*Ipomoea aquatica* Forssk	Convolvulaceae	Cl	WL,SD,SW	W	F
WII/HARIKE/SG/317	*Ipomoea cairica* (L.) Sweet	Convolvulaceae	Cl	SW	W	F
WII/HARIKE/SG/102	*Ipomoea carnea* Jacq.	Convolvulaceae	S	WL,SD, SW	W	F
WII/HARIKE/SG/318	*Ipomoea nil* (L.) Roth	Convolvulaceae	Cl	PL,SW	W	F
WII/HARIKE/SG/319	*Ipomoea pes-tigridis* L.	Convolvulaceae	Cl	PL,SW	W	R
WII/HARIKE/SG/041	*Jacaranda mimosifolia* D.Don	Bignoniaceae	T	PL	O	OC
WII/HARIKE/SG/103	*Jasminum sambac* (L.) Sol	Oleaceae	S	PL	O	R
WII/HARIKE/SG/104	*Jatropha curcas* L.	Euphorbiaceae	S	AG	C	VR
WII/HARIKE/SG/105	*Jatropha gossypiifolia* L	Euphorbiaceae	S	PL	W	R
WII/HARIKE/SG/106	*Jatropha integerrima* Jacq	Euphorbiaceae	S	PL	O	R
WII/HARIKE/SG/204	*Juncus bufonius* L.	Juncaceae	H	SD	W	R
WII/HARIKE/SG/107	*Justicia adhatoda* L.	Acanthaceae	S	RV	W	R
WII/HARIKE/SG/205	*Justicia adhatoda* L.	Acanthaceae	H	PL	W	R
WII/HARIKE/SG/206	*Kalanchoe daigremontiana* Raym.-Hamet & H. Perrier	Crassulaceae	H	PL	O	R
WII/HARIKE/SG/042	*Kigelia africana* (Lam.) Benth.	Bignoniaceae	T	PL	W	F
WII/HARIKE/SG/044	*Lagerstroemia indica* L.	Lythraceae	T	PL, SD, RV, AG,SW	O	R
WII/HARIKE/SG/045	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	T	PL	O	OC
WII/HARIKE/SG/108	*Lantana camara* L.	Verbenaceae	S	PL, RV	W	F
WII/HARIKE/SG/207	*Launaea procumbens* (Roxb.) Ramayya & Rajagopal	Compositae	H	PL,AG	W	F
WII/HARIKE/SG/043	*Lawsonia inermis* L.	Lythraceae	T	PL	O	R
WII/HARIKE/SG/370	*Lemna minor* L.	Lemnaceae	Fv	WL, SW	W	F
WII/HARIKE/SG/208	*Lepidium didymum* L.	Brassicaceae	H	PL,AGSW	W	F
WII/HARIKE/SG/046	*Leucaena leucocephala* (Lam.) de Wit	Leguminosae	T	PL	W	F
WII/HARIKE/SG/209	*Leucas cephalotes* (Roth) Spreng.	Lamiaceae	H	PL,AG	W	VR
WII/HARIKE/SG/210	*Ludwigia adscendens* (L.) H.Hara	Onagraceae	H	WL,SD	W	OC
WII/HARIKE/SG/211	*Ludwigia hyssopifolia* (G.Don) Exell	Onagraceae	H	PL	W	R

WII/HARIKE/SG/212	*Ludwigia perennis* L.	Onagraceae	H	WL	W	R
WII/HARIKE/SG/320	*Luffa cylindrica* (L.) M. J. Roem.	Cucurbitaceae	Cl	AG	C	OC
WII/HARIKE/SG/109	*Lycium edgeworthii* Miers	Solanaceae	S	RV	W	VR
WII/HARIKE/SG/213	*Lycopersicon esculentum* Mill.	Solanaceae	H	AG	C	R
WII/HARIKE/SG/047	*Madhuca longifolia* var. latifolia (Roxb.) A.Chev.	Sapotaceae	T	AG	C	R
WII/HARIKE/SG/049	*Mallotus nudiflorus* (L.) Kulju & Welzen	Euphorbiaceae	T	PL	W	R
WII/HARIKE/SG/214	*Malva parviflora* L.	Malvaceae	H	PL,AG,RV,SW	W	F
WII/HARIKE/SG/215	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae	H	PLRV	W	F
WII/HARIKE/SG/048	*Mangifera indica* L.	Anacardiaceae	T	PL	W	F
WII/HARIKE/SG/216	*Marsilea quadrifolia* L.	Marsileaceae	H	WL,SW	W	F
WII/HARIKE/SG/217	*Mazus pumilus* (Burm.f.) Steenis	Phrymaceae	H	PL,AG	W	F
WII/HARIKE/SG/218	*Mecardonia procumbens* (Mill.) Small	Plantaginaceae	H	SD	W	R
WII/HARIKE/SG/219	*Medicago polymorpha* L.	Leguminosae	H	PL	W	OC
WII/HARIKE/SG/220	*Medicago sativa* L.	Leguminosae	H	AG	W	R
WII/HARIKE/SG/050	*Melia azedarach* L.	Meliaceae	T	PL, SD, AG, RV, SW	W	F
WII/HARIKE/SG/221	*Melilotus indicus* (L.) All.	Leguminosae	H	PL,AG	W	OC
WII/HARIKE/SG/222	*Melochia corchorifolia* L.	Malvaceae	H	PL	W	R
WII/HARIKE/SG/223	*Mentha × piperita* L.	Lamiaceae	H	AG	C	R
WII/HARIKE/SG/321	*Merremia hederacea* (Burm. f.) Hallier f	Convolvulaceae	Cl	SW	W	R
WII/HARIKE/SG/051	*Millettia peguensis* Ali	Leguminosae	T	PL	O	R
WII/HARIKE/SG/224	*Mimosa pudica* L.	Leguminosae	H	PL	O	R
WII/HARIKE/SG/052	*Mimusops elengi* L.	Sapotaceae	T	PL	W	OC
WII/HARIKE/SG/225	*Mirabilis jalapa* L.	Nyctaginaceae	H	PL	O	R
WII/HARIKE/SG/226	*Mollugo nudicaulis* Lam.	Molluginaceae	H	SD	W	R
WII/HARIKE/SG/322	*Momordica charantia* L.	Cucurbitaceae	Cl	AG	C	R
WII/HARIKE/SG/053	*Moringa oleifera* Lam	Moringaceae	T	PL, AG	W	R
WII/HARIKE/SG/054	*Morus alba* L	Moraceae	T	PL,SD, AG, RV, SW	W	OC

WII/HARIKE/SG/323	*Mukia maderaspatana* (L.) M.Roem	Cucurbitaceae	Cl	PL,RV,SW	W	F
WII/HARIKE/SG/110	*Murraya koenigii* (L.) Spreng	Rutaceae	S	PL	W	R
WII/HARIKE/SG/111	*Murraya paniculata* (L.) Jack	Rutaceae	S	PL	O	VR
WII/HARIKE/SG/055	*Musa × paradisiaca* L	Musaceae	T	WL	C	R
WII/HARIKE/SG/366	*Myriophyllum spicatum* L	Haloragaceae	Sv	WL	W	F
WII/HARIKE/SG/367	*Najas minor* All.	Hydrocharitaceae	Sv	WL,SW	W	F
WII/HARIKE/SG/373	*Nelumbo nucifera* Gaertn.	Nymphaeaceae	Fv	WL, SW	W	F
WII/HARIKE/SG/056	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	T	PL	O	OC
WII/HARIKE/SG/112	*Nerium oleander* L.	Apocynaceae	S	PL	O	OC
WII/HARIKE/SG/227	*Nicotiana plumbaginifolia* Viv.	Solanaceae	H	SD, PL, AG	W	F
WII/HARIKE/SG/057	*Nyctanthes arbor-tristis* L	Oleaceae	T	PL	O	R
WII/HARIKE/SG/374	*Nymphaea nouchali* Burm.f	Nymphaeaceae	Fv	WL	W	R
WII/HARIKE/SG/375	*Nymphoides cristata* (Roxb.) Kuntze	Menyanthaceae	Fv	WL	W	VR
WII/HARIKE/SG/228	*Ocimum basilicum* L.	Lamiaceae	H	PL	O	OC
WII/HARIKE/SG/229	*Ocimum tenuiflorum* L.	Lamiaceae	H	PL	O	OC
WII/HARIKE/SG/349	*Oplismenus burmannii* (Retz.) P.Beauv.	Poaceae	G	PL	W	F
WII/HARIKE/SG/385	*Opuntia dillenii* (Ker Gawl.) Haw.	Cactaceae	Su	RV	W	R
WII/HARIKE/SG/350	*Oryza sativa* L.	Poaceae	G	AG	C	F
WII/HARIKE/SG/230	*Osteospermum fruticosum* (L.) Norl	Compositae	H	PL	O	R
WII/HARIKE/SG/231	*Oxalis corniculata* L.	Oxalidaceae	H	WL, SD, PL, AG, RV, SW	W	F
WII/HARIKE/SG/324	*Oxystelma esculentum* (L. f.) Sm	Apocynaceae	Cl	PL,AG,RV,SW	W	F
WII/HARIKE/SG/351	*Panicum virgatum* L.	Poaceae	G	PL	W	F
WII/HARIKE/SG/232	*Papaver rhoeas* L	Papaveraceae	H	PL	W	R
WII/HARIKE/SG/058	*Parkinsonia aculeata* L	Leguminosae	T	PL,RV	W	F
WII/HARIKE/SG/233	*Parthenium hysterophorus* L.	Compositae	H	PL, RV	W	F
WII/HARIKE/SG/352	*Paspalum distichum* L.	Poaceae	G	WL,SD,SW	W	F
WII/HARIKE/SG/234	*Pedalium murex* L.	Pedaliaceae	H	PL	W	VR
WII/HARIKE/SG/235	*Peganum multisectum* (Maxim.) Bobrov	Nitrariaceae	H	RV	W	R

WII/HARIKE/SG/353	*Pennisetum typhoides* Rich.	Poaceae	G	AG	C	OC
WII/HARIKE/SG/325	*Pentatropis nivalis* (J.F.Gmel.) D.V.Field & J.R.I.Wood	Apocynaceae	Cl	RV	W	F
WII/HARIKE/SG/326	*Pergularia daemia* (Forssk.) Chiov.	Apocynaceae	Cl	PL,AG,SW	W	F
WII/HARIKE/SG/236	*Peristrophe bicalyculata* (Retz.)	Acanthaceae	H	PL,AG	W	F
WII/HARIKE/SG/237	*Persicaria barbata* (L.) H.Hara	Polygonaceae	H	WL	W	F
WII/HARIKE/SG/238	*Persicaria glabra* (Willd.) M.Gómez	Polygonaceae	H	WL	W	F
WII/HARIKE/SG/239	*Persicaria lanigera* (R.Br.) Soják	Polygonaceae	H	WL	W	R
WII/HARIKE/SG/354	*Phalaris minor* Retz.	Poaceae	G	AG	W	F
WII/HARIKE/SG/059	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	T	WL, SD, SW	W	OC
WII/HARIKE/SG/355	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae	G	WL,SD,SW	W	F
WII/HARIKE/SG/240	*Phyla nodiflora* (L.) Greene	Verbenaceae	H	WL,SDSW	W	F
WII/HARIKE/SG/060	*Phyllanthus emblica* L	Phyllanthaceae	T	PL	W	VR
WII/HARIKE/SG/241	*Phyllanthus niruri* L	Phyllanthaceae	H	AG	W	R
WII/HARIKE/SG/242	*Physalis minima* L.	Solanaceae	H	PL,AG	W	OC
WII/HARIKE/SG/376	*Pistia stratiotes* L.	Araceae	Fv	WL, SW	W	F
WII/HARIKE/SG/243	*Pisum sativum* L.	Leguminosae	H	AG	C	OC
WII/HARIKE/SG/061	*Pithecellobium dulce* (Roxb.) Benth.	Leguminosae	T	PL	W	R
WII/HARIKE/SG/113	*Platycladus orientalis* (L.) Franco	Cupressaceae	S	PL	O	R
WII/HARIKE/SG/244	*Pluchea lanceolata* (DC.) C.B.Clarke	Compositae	H	RV	W	R
WII/HARIKE/SG/245	*Plumbago zeylanica* L.	Plumbaginaceae	H	PLRV	W	R
WII/HARIKE/SG/114	*Plumeria obtusa* L	Apocynaceae	S	PL	O	R
WII/HARIKE/SG/356	*Poa annua* L	Poaceae	G	PL	W	F
WII/HARIKE/SG/062	*Polyalthia longifolia* (Sonn.) Thwaites	Annonaceae	T	PL	O	OC
WII/HARIKE/SG/246	*Polygonum plebeium* R.Br.	Polygonaceae	H	SD	W	R
WII/HARIKE/SG/357	*Polypogon monspeliensis* (L.) Desf.	Poaceae	G	AG	W	OC
WII/HARIKE/SG/063	*Pongamia pinnata* (L.) Pierre	Leguminosae	T	PL, AG,RV, SW	W	F
WII/HARIKE/SG/064	*Populus deltoides* Marshall	Salicaceae	T	WL, SD	C	F

WII/HARIKE/SG/247	*Portulaca grandiflora* Hook.	Portulacaceae	H	SD,PL,	W	R
WII/HARIKE/SG/248	*Portulaca oleracea* L	Portulacaceae	H	SD	W	F
WII/HARIKE/SG/249	*Portulaca pilosa* L.	Portulacaceae	H	SD	W	R
WII/HARIKE/SG/368	*Potamogeton natans* L	Potamogetonaceae	Sv	WL	W	R
WII/HARIKE/SG/065	*Prosopis cineraria* (L.)Druce	Leguminosae	T	PL. RV	W	VR
WII/HARIKE/SG/066	*Prosopis juliflora* (Sw.) DC.	Leguminosae	T	PL, SD, PL, AG, SW	W	F
WII/HARIKE/SG/067	*Psidium guajava* L.	Myrtaceae	T	PL	C	OC
WII/HARIKE/SG/068	*Pterospermum acerifolium* Willd	Malvaceae	T	PL	C	VR
WII/HARIKE/SG/250	*Pulicaria undulata* (L.) C.A.Mey.	Compositae	H	RV	W	VR
WII/HARIKE/SG/115	*Punica granatum* L.	Punicaceae	S	AG	C	VR
WII/HARIKE/SG/251	*Pupalia lappacea* (L.) Juss	Amaranthaceae	H	RV	W	R
WII/HARIKE/SG/069	*Putranjiva roxburghii* Wall	Putranjivaceae	T	PL	O	OC
WII/HARIKE/SG/252	*Ranunculus sceleratus* L.	Ranunculaceae	H	WL,SDSW	W	F
WII/HARIKE/SG/253	*Raphanus sativus* L.	Brassicaceae	H	AG	C	OC
WII/HARIKE/SG/327	*Rhynchosia minima* (L.) DC	Leguminosae	Cl	PL	W	OC
WII/HARIKE/SG/116	*Ricinus communis* L.	Euphorbiaceae	S	PL	W	F
WII/HARIKE/SG/117	*Rosa alba* L.	Rosaceae	S	PL	O	R
WII/HARIKE/SG/254	*Rumex dentatus* L.	Polygonaceae	H	SD,PL,AG	W	F
WII/HARIKE/SG/358	*Saccharum officinarum* L.	Poaceae	G	,SD,AG,RV,SW	C	R
WII/HARIKE/SG/359	*Saccharum bengalense* Retz	Poaceae	G	,SDAG,RV,SW	W	F
WII/HARIKE/SG/360	*Saccharum spontaneum* L	Poaceae	G	PL,AG,RV,	W	F
WII/HARIKE/SG/255	*Sagittaria sagittifolia* L	Alismataceae	H	WL	W	R
WII/HARIKE/SG/070	*Salix alba* L	Salicaceae	T	PL, WL, SD	W	F
WII/HARIKE/SG/256	*Salvia plebeia* R.Br.	Lamiaceae	H	SDSW	W	R
WII/HARIKE/SG/377	*Salvinia natans* (L.) All.	Salviniaceae	Fv	WL, SW	W	R
WII/HARIKE/SG/384	*Sansevieria aethiopica* Thunb	Asparagaceae	Su	PL	O	F
WII/HARIKE/SG/071	*Schleichera oleosa* (Lour.) Oken.	Sapindaceae	T	PL	W	VR
WII/HARIKE/SG/257	*Scoparia dulcis* L.	Plantaginaceae	H	SD	W	R

WII/HARIKE/SG/072	*Senegalia modesta* (Wall.) P.J.H. Hurter	Leguminosae	T	RV	W	VR
WII/HARIKE/SG/118	*Senna alata* (L.) Roxb.	Leguminosae	S	PL	O	R
WII/HARIKE/SG/258	*Senna occidentalis* (L.) Link	Leguminosae	H	PL,AG,RV,	W	F
WII/HARIKE/SG/073	*Senna siamea* (Lam.) H.S.Irwin & Barneby	Leguminosae	T	PL	W	OC
WII/HARIKE/SG/259	*Senna tora* (L.) Roxb.	Leguminosae	H	PL,AG	W	R
WII/HARIKE/SG/260	*Sesamum indicum* L.	Pedaliaceae	H	AG	C	R
WII/HARIKE/SG/361	*Setaria viridis* (L.) P.Beauv	Poaceae	G	AG	W	F
WII/HARIKE/SG/261	*Sida cordifolia* L.	Malvaceae	H	PL,AG	W	F
WII/HARIKE/SG/262	*Sida acuta* Burm.f.	Malvaceae	H	PL,AG	W	F
WII/HARIKE/SG/263	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	H	PL	W	F
WII/HARIKE/SG/264	*Sida rhombifolia* L.	Malvaceae	H	PL	W	F
WII/HARIKE/SG/265	*Sisymbrium irio* L.	Brassicaceae	H	SD,PL,AG,RV,	W	F
WII/HARIKE/SG/266	*Solanum melongena* L.	Solanaceae	H	AG	C	R
WII/HARIKE/SG/267	*Solanum nigrum* L	Solanaceae	H	PL,AG,RV,	W	F
WII/HARIKE/SG/268	*Solanum villosum* Mill.	Solanaceae	H	PL	W	R
WII/HARIKE/SG/269	*Solanum virginianum* L.	Solanaceae	H	PL,AG	W	OC
WII/HARIKE/SG/270	*Sonchus oleraceus* (L.) L.	Compositae	H	PL,AG	W	F
WII/HARIKE/SG/362	*Sorghum halepense* (L.) Pers.	Poaceae	G	AG	W	R
WII/HARIKE/SG/271	*Spergula arvensis* L	Caryophyllaceae	H	SD	W	F
WII/HARIKE/SG/272	*Sphenoclea zeylanica* Gaertn	Sphenocleaceae	H	SD	W	R
WII/HARIKE/SG/378	*Spirodela polyrrhiza* (L.) Schleid	Araceae	Fv	WL, SW	W	F
WII/HARIKE/SG/273	*Stellaria media* (L.) Vill.	Caryophyllaceae	H	WL,SD,PL,AGSW	W	F
WII/HARIKE/SG/074	*Syzygium cumini* var. cumini	Myrtaceae	T	PL, WL, SD, SW, AG, RV	W	F
WII/HARIKE/SG/119	*Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult.	Apocynaceae	S	PL	O	R
WII/HARIKE/SG/274	*Tagetes erecta* L	Compositae	H	PL	O	OC
WII/HARIKE/SG/075	*Tamarix dioica* Roxb. ex Roth	Tamaricaceae	T	AG	W	VR
WII/HARIKE/SG/076	*Tecoma stans* var. stans	Bignoniaceae	T	PL	O	R

WII/HARIKE/SG/077	*Tectona grandis* L.f.	Lamiaceae	T	PL	W	VR
WII/HARIKE/SG/275	*Tephrosia purpurea* (L.) Pers.	Leguminosae	H	PL	W	R
WII/HARIKE/SG/079	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	T	PL, WL, SD, SW,AG	W	F
WII/HARIKE/SG/078	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	T	PL	W	R
WII/HARIKE/SG/328	*Tinospora cordifolia* (Willd.) Miers	Menispermaceae	Cl	PL,AG,SW	W	OC
WII/HARIKE/SG/080	*Toona ciliata* M.Roem	Meliaceae	T	PL	W	VR
WII/HARIKE/SG/379	*Trapa natans* L.	Lythraceae	Fv	WL	W	R
WII/HARIKE/SG/276	*Trianthema portulacastrum* L.	Aizoaceae	H	PL,AG	W	F
WII/HARIKE/SG/277	*Tribulus terrestris* L.	Zygophyllaceae	H	PL,RV,	W	OC
WII/HARIKE/SG/329	*Trichosanthes dioica* Roxb	Cucurbitaceae	Cl	AG	C	R
WII/HARIKE/SG/278	*Tridax procumbens* (L.) L.	Compositae	H	PL,AG,RV	W	F
WII/HARIKE/SG/279	*Trifolium alexandrinum* L.	Leguminosae	H	AG	C	F
WII/HARIKE/SG/280	*Trifolium dubium* Sibth	Leguminosae	H	PL	W	OC
WII/HARIKE/SG/281	*Trifolium repens* L.	Leguminosae	H	PL	W	R
WII/HARIKE/SG/282	*Trifolium resupinatum* L.	Leguminosae	H	AG	W	R
WII/HARIKE/SG/283	*Trigonella foenum-graecum* L.	Leguminosae	H	AG	C	F
WII/HARIKE/SG/363	*Triticum aestivum* L.	Poaceae	G	PL,AG	C	F
WII/HARIKE/SG/284	*Triumfetta rhomboidea* Jacq.	Malvaceae	H	PL,AG	W	OC
WII/HARIKE/SG/285	*Typha angustifolia* L	Typhaceae	H	WL,SW	W	F
WII/HARIKE/SG/286	*Urena lobata* L.	Malvaceae	H	PL,SW	W	OC
WII/HARIKE/SG/287	*Urtica urens* L.	Urticaceae	H	PL	W	VR
WII/HARIKE/SG/081	*Vachellia farnesiana* (L.) Wight & Arn	Leguminosae	T	SW	W	VR
WII/HARIKE/SG/082	*Vachellia leucophloea* (Roxb.) Maslin, Seigler & Ebinger	Leguminosae	T	RV	W	VR
WII/HARIKE/SG/083	*Vachellia nilotica* (L.) P.J.H. Hurter & Mabb	Leguminosae	T	PL, WL, SD, SW, AG, RV	W	F
WII/HARIKE/SG/369	*Vallisneria natans* (Lour.) H.Hara	Hydrocharitaceae	Sv	WL	W	F
WII/HARIKE/SG/288	*Verbascum thapsus* L.	Scrophulariaceae	H	WL,SD,AG	W	R

WII/HARIKE/SG/289	*Verbesina encelioides* (Cav.) Benth. & Hook.f. ex A.Gray	Compositae	H	SD,PL,AG,RV,	W	F
WII/HARIKE/SG/330	*Vernonia elaeagnifolia* DC.	Asteraceae	Cl	PL	O	VR
WII/HARIKE/SG/120	*Vernonia amygdalina* Delile	Compositae	S	PL	O	R
WII/HARIKE/SG/290	*Vernonia cinerea* (L.) Less.	Compositae	H	PL	W	OC
WII/HARIKE/SG/292	*Veronica anagallis-aquatica* L.	Plantaginaceae	H	WL	W	R
WII/HARIKE/SG/291	*Veronica agrestis* L.	Plantaginaceae	H	PL	W	R
WII/HARIKE/SG/293	*Veronica persica* Poir.	Plantaginaceae	H	AG	W	OC
WII/HARIKE/SG/294	*Vicia sativa* L	Leguminosae	H	PL	W	R
WII/HARIKE/SG/121	*Vigna mungo* (L.) Hepper	Leguminosae	S	AG	C	R
WII/HARIKE/SG/122	*Withania coagulans* (Stocks) Dunal	Solanaceae	S	AG	W	VR
WII/HARIKE/SG/295	*Withania somnifera* (L.) Dunal	Solanaceae	H	PL	W	VR
WII/HARIKE/SG/296	*Xanthium strumarium* L.	Compositae	H	PL,SW	W	F
WII/HARIKE/SG/386	*Yucca filamentosa* L	Asparagaceae	Su	PL	O	VR
WII/HARIKE/SG/297	*Zaleya pentandra* (L.) C.Jeffrey	Aizoaceae	H	PL,RV	W	VR
WII/HARIKE/SG/123	*Zamia furfuracea* L.f. ex Aiton	Zamiaceae	S	PL	O	R
WII/HARIKE/SG/084	*Ziziphus mauritiana* Lam	Rhamnaceae	T	PL, AG, RV	W	F
WII/HARIKE/SG/124	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Rhamnaceae	S	RV	W	OC

Community composition of avian species across the habitat type of HWS

(Feeding behavior: CA- Carnivore, HV-Harbivore, IN- Insectivore, FU-Fogivore, OM-Omnivore, and GR: Grainivore.)

(IUCN status: LC- Least concern, VU-Vulnarable, NT-Near-threatened, EN-Endanged)

(Migratory status: R-Resident, SV-Summer visitor, WV-Winter visitor)

(1-Observered and 0- Not bservered)

Order	Scientific name	Family	Common name	Feeding behaviour	Plantation	Deep wetland	Sandy	Shallow wetland	Ravine	Swampy	Agricultural field	Habitat association (Number)	IUCN (Red list vesion 2021)	Migratory status
Accipitriformes	*Elanus caeruleus* (Desfontaines, 1789)	**Accipitridae**	Black-winged Kite	CA	1	0	0	0	1	0	1	3	LC	R
	Hieraaetus pennatus (J.F. Gmelin, 1788)	**Accipitridae**	Booted Eagle	CA	1	0	0	0	0	0	0	1	LC	WV
	Spilornis cheela (Latham, 1790)	**Accipitridae**	Crested Serpent-Eagle	CA	1	0	0	0	1	0	0	2	LC	WV
	Circus aeruginosus (Linnaeus, 1758)	**Accipitridae**	Eurasian Marsh-Harrier	CA	0	1	1	1	0	1	1	6	LC	WV
	Accipiter nisus (Linnaeus, 1758)	**Accipitridae**	Eurasian Sparrowhawk	CA	0	0	1	0	1	0	0	2	LC	WV
	Clanga hastata (Lesson, 1831)	**Accipitridae**	Indian Spotted Eagle	CA	1	0	0	0	1	0	0	2	VU	WV
	Buteo rufinus (Cretzschmar, 1829)	**Accipitridae**	Long-legged Buzzard	CA	1	0	0	0	1	0	1	3	LC	WV
	Pernis ptilorhynchus (Temminck, 1821)	**Accipitridae**	Oriental Honey-buzzard	CA	1	0	0	0	0	0	0	1	LC	R
	Accipiter badius (J.F. Gmelin, 1788)	**Accipitridae**	Shikra	CA	1	0	0	1	1	1	1	5	LC	R
	Aquila nipalensis (Hodgson, 1833)	**Accipitridae**	Steppe Eagle	CA	1	0	1	0	1	0	0	3	EN	WV
	Butastur teesa (Franklin, 1831)	**Accipitridae**	White-eyed Buzzard	CA	0	0	0	0	1	0	1	2	LC	R
	Milvus migrans (Boddaert, 1783)	**Accipitridae**	Black Kite	CA	1	0	0	0	1	0	0	2	LC	WV
	Clanga clanga (Pallas, 1811)	**Accipitridae**	Greater Spotted Eagle	CA	1	0	0	0	1	0	1	3	VU	WV
	Circaetus gallicus (J.F. Gmelin, 1788)	**Accipitridae**	Short-toed Snake Eagle	CA	0	0	0	0	1	0	0	1	LC	SV
	Accipiter gentilis (Linnaeus, 1758)	**Accipitridae**	Northern Goshawk	CA	1	0	0	0	0	0	0	1	LC	WV

	*Pandion haliaetus (*Linnaeus, 1758)	**Pandionidae**	Osprey	CA	1	1	1	1	0	1	1	7	LC	WV
Anseriformes	*Anser indicus* (Latham, 1790)	**Anatidae**	Bar-headed Goose	HV	0	1	1	1	0	0	1	4	LC	WV
	Sarkidiornis melanotos (Pennant, 1769)	**Anatidae**	Comb Duck	HV	0	1	0	1	0	0	0	2	LC	WV
	Aythya ferina (Linnaeus, 1758)	**Anatidae**	Common Pochard	HV	0	1	1	1	0	0	0	3	VU	WV
	Anas crecca Linnaeus, 1758	**Anatidae**	Common Teal	HV	0	1	1	1	0	0	0	3	LC	WV
	*Nettapus coromandelianus (*J.F. Gmelin, 1789*)*	**Anatidae**	Cotton Pygmy-Goose	HV	0	1	0	1	0	0	0	2	LC	WV
	Mareca penelope (Linnaeus, 1758)	**Anatidae**	Eurasian Wigeon	HV	0	1	1	1	0	0	0	3	LC	WV
	Aythya nyroca (Güldenstädt, 1770)	**Anatidae**	Ferruginous Duck	HV	0	1	0	1	0	0	0	2	NT	WV
	Mareca strepera (Linnaeus, 1758)	**Anatidae**	Gadwall	HV	0	1	1	1	0	0	0	3	LC	WV
	*Spatula querquedula (*Linnaeus, 1758)	**Anatidae**	Garganey	HV	0	1	0	1	0	0	0	2	LC	WV
	Anser anser (Linnaeus, 1758*)*	**Anatidae**	Greylag Goose	HV	0	1	1	1	0	0	0	3	LC	WV
	Anas poecilorhyncha J.R. Forster, 1781	**Anatidae**	Indian Spot-billed Duck	HV	0	1	1	1	0	1	0	5	LC	R
	Dendrocygna javanica (Horsfield, 1821)	**Anatidae**	Lesser Whistling-Duck	HV	0	1	1	1	0	1	0	4	LC	SV
	Anas platyrhynchos Linnaeus, 1758	**Anatidae**	Mallard	HV	0	1	0	1	0	0	0	2	LC	WV
	Anas acuta Linnaeus, 1758	**Anatidae**	Northern Pintail	HV	0	1	1	1	0	0	0	3	LC	WV
	Spatula clypeata (Linnaeus, 1758)	**Anatidae**	Northern Shoveler	HV	0	1	1	1	0	0	0	3	LC	WV
	Netta rufina (Pallas, 1773)	**Anatidae**	Red-crested Pochard	HV	0	1	1	1	0	0	0	3	LC	WV
	Tadorna ferruginea (Pallas, 1764)	**Anatidae**	Ruddy Shelduck	HV	0	1	1	1	0	0	0	3	LC	WV
	Aythya fuligula (Linnaeus, 1758)	**Anatidae**	Tufted Duck	HV	0	1	0	1	0	0	0	2	LC	WV
	Tadorna tadorna (Linnaeus, 1758)	**Anatidae**	Common Shelduck	HV	0	1	0	1	0	0	0	2	LC	WV
Bucerotiformes	*Ocyceros birostris* (Scopoli, 1786)	**Bucerotidae**	Indian Grey Hornbill	FU	1	0	0	0	0	0	0	1	LC	R
	Upupa epops Linnaeus, 1758	**Upupidae**	Eurasian Hoopoe	IN	1	0	1	0	1	0	1	4	LC	R
Charadriiformes	*Charadrius alexandrinus* Linnaeus, 1758	**Charadriidae**	Kentish Plover	IN	0	0	0	1	0	0	0	1	LC	WV
	Charadrius dubius Scopoli, 1786	**Charadriidae**	Little Ringed Plover	IN	0	0	0	0	0	0	0	1	LC	WV
	Vanellus indicus (Boddaert, 1783)	**Charadriidae**	Red-wattled Lapwing	IN	0	0	1	1	1	0	1	5	LC	R
	Vanellus duvaucelii (Lesson, 1826)	**Charadriidae**	River Lapwing	IN	0	0	0	1	0	0	0	1	LC	WV
	Vanellus leucurus (M.H.C. Lichtenstein, 1823)	**Charadriidae**	White-tailed Lapwing	IN	0	0	0	1	0	0	0	2	LC	WV

	Glareola lactea Temminck, 1820	**Glareolidae**	Small Pratincole	IN	0	0	0	1	0	0	0	1	LC	WV
	Chroicocephalus ridibundus (Linnaeus, 1766)	**Laridae**	Black-headed Gull	CA	0	1	1	1	0	0	0	3	LC	WV
	Sterna hirundo Linnaeus, 1758	**Laridae**	Common Tern	CA	0	1	1	1	0	0	0	4	LC	WV
	Ichthyaetus ichthyaetus (Pallas, 1773)	**Laridae**	Pallas's Gull	CA	0	1	1	1	0	0	0	3	LC	WV
	Sterna aurantia J.E. Gray, 1831	**Laridae**	River Tern	IN	0	1	1	1	0	0	0	3	NT	WV
	Chroicocephalus brunnicephalus (Jerdon, 1840)	**Laridae**	Brown-headed Gull	CA	0	1	1	1	0	0	0	3	LC	WV
	Gelochelidon nilotica (J.F. Gmelin, 1789)	**Laridae**	Gull-billed Tern	CA	0	0	1	1	0	0	0	2	LC	WV
	Larus cachinnans Pallas, 1811	**Laridae**	Caspian Gull	CA	0	1	1	1	0	0	0	3	LC	WV
	Himantopus himantopus (Linnaeus, 1758*)*	**Recurvirostridae**	Black-winged Stilt	IN	0	0	0	1	0	0	0	2	LC	R
	Recurvirostra avosetta Linnaeus, 1758	**Recurvirostridae**	Pied Avocet	IN	0	0	1	1	0	0	0	3	LC	WV
	*Tringa nebularia (*Gunnerus, 1767)	**Scolopacidae**	Common Greenshank	IN	0	0	0	1	0	0	0	2	LC	WV
	*Tringa totanus (*Linnaeus, 1758)	**Scolopacidae**	Common Redshank	IN	0	0	0	1	0	0	0	2	LC	WV
	Actitis hypoleucos (Linnaeus, 1758)	**Scolopacidae**	Common Sandpiper	IN	0	0	0	1	0	0	0	2	LC	WV
	Gallinago gallinago (Linnaeus, 1758)	**Scolopacidae**	Common Snipe	IN	0	0	0	0	0	1	0	2	LC	WV
	Calidris pugnax (Linnaeus, 1758)	**Scolopacidae**	Ruff	IN	0	0	0	1	0	0	0	2	LC	WV
	Tringa erythropus (Pallas, 1764)	**Scolopacidae**	Spotted Redshank	CA	0	0	0	1	0	0	0	2	LC	WV
	*Calidris temminckii (*Leisler, 1812)	**Scolopacidae**	Temminck's Stint	IN	0	0	1	1	0	0	0	3	LC	WV
	Tringa glareola Linnaeus, 1758	**Scolopacidae**	Wood Sandpiper	IN	0	0	0	1	0	0	0	2	LC	WV
	Limosa limosa (Linnaeus, 1758)	**Scolopacidae**	Black-tailed Godwit	IN	0	0	1	1	0	1	1	4	NT	WV
	Tringa ochropus Linnaeus, 1758	**Scolopacidae**	Green Sandpiper	IN	0	0	0	1	0	0	0	2	LC	WV
	Tringa stagnatilis (Bechstein, 1803)	**Scolopacidae**	Marsh Sandpiper	IN	0	0	0	1	0	0	0	2	LC	WV
	Hydrophasianus chirurgus (Scopoli, 1786)	**Jacanidae**	Pheasant-tailed jacana	OM	0	0	0	1	0	1	1	2	LC	SV
Columbiformes	*Streptopelia decaocto (*Frivaldszky, 1838)	**Columbidae**	Eurasian Collared-Dove	HV	1	0	0	0	1	0	1	3	LC	R
	Streptopelia senegalensis (Linnaeus, 1766)	**Columbidae**	Laughing Dove	HV	1	0	0	0	1	0	1	3	LC	R
	Streptopelia orientalis (Latham, 1790)	**Columbidae**	Oriental Turtle-Dove	GR	1	0	0	0	0	1	0	2	LC	WV
	Streptopelia tranquebarica (Hermann, 1804*)*	**Columbidae**	Red Collared-Dove	GR	1	0	0	0	1	0	0	2	LC	SV

	Columba livia J.F. Gmelin, 1789	**Columbidae**	Rock Pigeon	GR	1	0	0	0	1	0	1	3	LC	R
	Streptopelia chinensis (Scopoli, 1786)	**Columbidae**	Spotted Dove	GR	1	0	0	1	1	0	1	4	LC	WV
	Treron phoenicopterus (Latham, 1790)	**Columbidae**	Yellow-footed Green-Pigeon	FU	1	0	0	0	0	0	0	1	LC	R
Coraciiformes	*Alcedo atthis (*Linnaeus, 1758)	**Alcedinidae**	Common Kingfisher	CA	0	0	0	1	0	0	0	1	LC	WV
	Halcyon smyrnensis (Linnaeus, 1758)	**Alcedinidae**	White-throated Kingfisher	CA	1	0	1	1	1	0	1	6	LC	R
	Ceryle rudis (Linnaeus, 1758)	**Alcedinidae**	Pied Kingfisher	CA	0	0	0	1	0	0	1	3	LC	R
	Coracias benghalensis (Linnaeus, 1758)	**Coraciidae**	Indian Roller	IN	1	0	0	0	1	0	1	3	LC	SV
	Coracias garrulus Linnaeus, 1758	**Coraciidae**	European Roller	IN	0	0	0	0	0	0	1	1	LC	SV
	Merops philippinus Linnaeus, 1767	**Meropidae**	Blue-tailed Bee-eater	IN	0	0	0	0	0	1	1	3	LC	SV
	Merops orientalis Latham, 1801	**Meropidae**	Green Bee-eater	IN	1	0	1	0	1	1	1	5	LC	R
Cuculiformes	*Eudynamys scolopaceus* (Linnaeus, 1758*)*	**Cuculidae**	Asian Koel	FU	1	0	0	0	1	0	1	3	LC	R
	Hierococcyx varius (Vahl, 1797)	**Cuculidae**	Common Hawk-Cuckoo	IN	1	0	0	0	0	0	0	1	LC	WV
	Centropus sinensis (Stephens, 1815)	**Cuculidae**	Greater Coucal	CA	1	0	0	1	1	1	1	5	LC	R
	Clamator jacobinus (Boddaert, 1783)	**Cuculidae**	Jacobin Cuckoo	OM	1	0	0	1	1	0	1	4	LC	SV
Falconiformes	*Falco tinnunculus* Linnaeus, 1758	**Falconidae**	Common Kestrel	CA	1	0	0	0	1	0	1	3	LC	WV
	Falco peregrinus Tunstall, 1771	**Falconidae**	Peregrine Falcon	CA	0	0	0	0	1	0	0	1	LC	WV
Galliformes	*Francolinus francolinus* (Linnaeus, 1766*)*	**Phasianidae**	Black Francolin	HV	0	0	0	0	1	0	1	2	LC	R
	*Francolinus pondicerianus (*J.F. Gmelin, 1789)	**Phasianidae**	Grey Francolin	HV	1	0	0	0	1	0	1	3	LC	R
	Pavo cristatus Linnaeus, 1758	**Phasianidae**	Indian Peafowl	OM	0	0	0	0	1	0	1	2	LC	R
	Coturnix coromandelica (J.F. Gmelin, 1789)	**Phasianidae**	Rain Quail	HV	0	0	0	0	1	0	0	1	LC	R
Gruiformes	*Fulica atra* Linnaeus, 1758	**Rallidae**	Eurasian Coot	HV	0	1	1	1	0	0	0	3	LC	WV
	*Porphyrio porphyrio (*Linnaeus, 1758*)*	**Rallidae**	Grey-headed Swamphen	HV	0	0	0	1	0	1	0	3	LC	R
	Amaurornis phoenicurus (Pennant, 1769)	**Rallidae**	White-breasted Waterhen	HV	0	0	0	1	1	0	0	3	LC	R
	Zapornia akool (Sykes, 1832*)*	**Rallidae**	Brown Crake	CA	0	0	0	1	0	1	0	2	LC	R
	Gallinula chloropus (Linnaeus, 1758)	**Rallidae**	Common Moorhen	HV	0	1	1	1	0	1	0	5	LC	R
Passeriformes	*Iduna caligata* (M.H.C. Lichtenstein, 1823)	**Acrocephalidae**	Booted Warbler	IN	1	0	0	0	0	1	0	2	LC	R

	Acrocephalus stentoreus (Hemprich & Ehrenberg,1833)	**Acrocephalidae**	Clamorous Reed Warbler	IN	0	0	0	0	0	1	0	1	LC	WV
	Acrocephalus dumetorum Blyth, 1849	**Acrocephalidae**	Blyth's Reed Warbler	IN	1	0	1	0	0	1	0	3	LC	R
	Mirafra erythroptera Blyth, 1845	**Alaudidae**	Indian Bushlark	GR	0	0	1	0	0	0	0	1	LC	R
	Alaudala raytal (Blyth, 1845)	**Alaudidae**	Sand Lark	GR	0	0	1	0	0	0	0	1	LC	R
	Galerida cristata (Linnaeus, 1758)	**Alaudidae**	Crested Lark	GR	0	0	1	0	0	0	0	1	LC	WV
	Alauda gulgula Franklin, 1831	**Alaudidae**	Oriental Skylark	GR	0	0	1	0	1	0	0	2	LC	R
	Pericrocotus ethologus Bangs & J.C. Phillips, 1914	**Campephagidae**	Long-tailed Minivet	IN	1	0	0	0	0	0	0	1	LC	WV
	*Orthotomus sutorius (*Pennant, 1769)	**Cisticolidae**	Common Tailorbird	IN	1	0	1	0	1	1	1	5	LC	R
	Prinia inornata Sykes, 1832	**Cisticolidae**	Plain Prinia	IN	0	0	1	0	1	1	1	4	LC	R
	Prinia buchanani Blyth, 1844	**Cisticolidae**	Rufous-fronted Prinia	IN	0	0	1	0	1	1	0	3	LC	R
	Prinia flaviventris (Delessert, 1840*)*	**Cisticolidae**	Yellow-bellied Prinia	IN	0	0	1	0	0	1	0	2	LC	R
	*Cisticola juncidis (*Rafinesque, 1810)	**Cisticolidae**	Zitting Cisticola	IN	0	0	1	1	0	1	0	3	LC	WV
	Prinia sylvatica Jerdon, 1840	**Cisticolidae**	Jungle Prinia	IN	0	0	0	0	1	1	0	2	LC	R
	Prinia socialis Sykes, 1832	**Cisticolidae**	Ashy Prinia	IN	0	0	1	0	1	1	1	4	LC	R
	Prinia gracilis (M.H.C. Lichtenstein, 1823)	**Cisticolidae**	Graceful Prinia	IN	0	0	1	0	1	1	1	4	LC	R
	Corvus splendens Vieillot, 1817	**Corvidae**	House Crow	OM	1	0	0	1	1	0	1	4	LC	R
	Corvus macrorhynchos Wagler, 1827	**Corvidae**	Large-billed Crow	OM	1	0	0	0	0	0	0	1	LC	R
	*Dendrocitta vagabunda (*Latham, 1790)	**Corvidae**	Rufous Treepie	IN	1	0	0	0	1	0	1	3	LC	R
	Dicrurus macrocercus Vieillot, 1817	**Dicruridae**	Black Drongo	IN	1	0	1	0	1	1	1	6	LC	R
	Lonchura punctulata (Linnaeus, 1758)	**Estrildidae**	Scaly-breasted Munia	GR	0	0	1	1	1	1	1	5	LC	R
	Euodice malabarica (Linnaeus, 1758*)*	**Estrildidae**	Indian Silverbill	GR	1	0	1	0	1	1	1	5	LC	R
	Amandava amandava (Linnaeus, 1758)	**Estrildidae**	Red Munia	GR	0	0	0	0	1	1	0	2	LC	R
	Hirundo rustica Linnaeus, 1758	**Hirundinidae**	Barn Swallow	IN	0	0	0	1	1	0	1	4	LC	WV
	Riparia paludicola (Vieillot, 1817)	**Hirundinidae**	Grey-throated Martin	IN	0	0	1	0	1	0	1	4	LC	R
	Hirundo smithii Leach, 1818	**Hirundinidae**	Wire-tailed Swallow	IN	0	0	0	1	1	0	1	4	LC	R
	Lanius isabellinus Hemprich & Ehrenberg, 1833	**Laniidae**	Isabelline Shrike	IN	0	0	1	1	0	0	0	2	LC	WV

	Lanius schach Linnaeus, 1758	**Laniidae**	Long-tailed Shrike	CA	1	0	1	0	1	0	0	3	LC	R
	*Argya caudata (*Dumont, 1823)	**Leiothrichidae**	Common Babbler	OM	0	0	0	0	1	1	0	2	LC	R
	Turdoides striata (Dumont, 1823)	**Leiothrichidae**	Jungle Babbler	OM	1	0	0	0	1	1	1	4	LC	R
	*Argya malcolmi (*Sykes, 1832)	**Leiothrichidae**	Large Gray Babbler	IN	1	0	0	0	1	1	0	3	LC	R
	Argya earlei (Blyth, 1844)	**Leiothrichidae**	Striated Babbler	OM	0	0	0	1	1	1	1	4	LC	R
	Terpsiphone paradisi (Linnaeus, 1758)	**Monarchidae**	Indian Paradise-Flycatcher	IN	1	0	0	0	0	0	0	1	LC	SV
	Motacilla citreola Pallas, 1776	**Motacillidae**	Citrine Wagtail	IN	0	0	1	1	1	0	1	5	LC	WV
	Motacilla cinerea Tunstall, 1771	**Motacillidae**	Grey Wagtail	IN	0	0	1	1	1	0	0	4	LC	WV
	Anthus rufulus Vieillot, 1818	**Motacillidae**	Paddyfield Pipit	IN	0	0	1	0	1	0	1	3	LC	R
	Motacilla flava Linnaeus, 1758	**Motacillidae**	Western Yellow Wagtail	IN	0	0	1	1	0	0	0	3	LC	WV
	Motacilla alba Linnaeus, 1758	**Motacillidae**	White Wagtail	IN	0	0	1	1	0	0	0	3	LC	WV
	Motacilla maderaspatensis J.F. Gmelin, 1789	**Motacillidae**	White-browed Wagtail	IN	0	0	1	1	0	0	1	4	LC	WV
	Anthus trivialis (Linnaeus, 1758*)*	**Motacillidae**	Tree Pipit	IN	0	0	0	0	1	0	1	2	LC	WV
	Anthus similis (Jerdon, 1840)	**Motacillidae**	Long-billed Pipit	IN	0	0	0	0	1	0	0	1	LC	WV
	Phoenicurus ochruros (S.G. Gmelin, 1774)	**Muscicapidae**	Black Redstart	IN	1	0	1	0	1	0	0	3	LC	WV
	*Oenanthe fusca (*Blyth, 1851)	**Muscicapidae**	Brown Rock Chat	IN	0	0	1	0	0	0	1	2	LC	R
	Saxicoloides fulicatus (Linnaeus, 1766)	**Muscicapidae**	Indian Robin	IN	0	0	1	0	1	1	1	4	LC	R
	*Saxicola caprata (*Linnaeus, 1766)	**Muscicapidae**	Pied Bushchat	IN	0	0	1	0	1	1	0	3	LC	R
	Ficedula parva (Bechstein, 1792)	**Muscicapidae**	Red-breasted Flycatcher	IN	1	0	0	0	1	1	1	4	LC	WV
	Saxicola maurus (Pallas, 1773*)*	**Muscicapidae**	Siberian Stonechat	IN	0	0	1	1	1	0	0	3	LC	WV
	*Ficedula albicilla (*Pallas, 1811)	**Muscicapidae**	Taiga Flycatcher	IN	1	0	0	1	1	0	1	4	LC	WV
	Luscinia svecica (Linnaeus, 1758)	**Muscicapidae**	Bluethroat	IN	0	0	1	0	1	1	0	3	LC	WV
	Copsychus saularis (Linnaeus, 1758*)*	**Muscicapidae**	Oriental Magpie-Robin	IN	1	0	1	0	1	0	1	4	LC	R
	Rhyacornis fuliginosa (Vigors, 1831)	**Muscicapidae**	Plumbeous water Redstart	IN	0	0	0	1	0	0	0	1	LC	WV
	Cinnyris asiaticus (Latham, 1790)	**Nectariniidae**	Purple Sunbird	HV	1	0	0	0	1	0	0	2	LC	SV
	Oriolus kundoo Sykes, 1832	**Oriolidae**	Indian Golden Oriole	OM	1	0	0	0	0	0	1	2	LC	SV
	Parus cinereus Vieillot, 1818	**Paridae**	Cinereous Tit	IN	1	0	0	0	0	0	0	1	LC	WV

	Passer domesticus (Linnaeus, 1758)	**Passeridae**	House Sparrow	GR	1	0	1	0	1	1	1	5	LC	R
	Passer pyrrhonotus Blyth, 1845	**Passeridae**	Sind Sparrow	GR	0	0	1	1	1	1	1	5	LC	R
	Laticilla burnesii (Blyth, 1844)	**Pellorneidae**	Rufous-vented Grass Babbler	IN	0	0	0	1	0	1	0	2	NT	R
	Phylloscopus sindianus W.E. Brooks, 1880	**Phylloscopidae**	Kashmir Chiffchaff	IN	1	0	0	0	1	0	0	2	LC	WV
	Abrornis humei (W.E. Brooks, 1878	**Phylloscopidae**	Hume’s Leaf Warbler	IN	1	0	0	0	1	1	0	3	LC	WV
	Phylloscopus collybita (Vieillot, 1817*)*	**Phylloscopidae**	Common Chiffchaff	IN	1	0	0	0	0	1	0	2	LC	WV
	*Ploceus philippinus (*Linnaeus, 1766)	**Ploceidae**	Baya Weaver	GR	0	0	1	1	1	1	1	5	LC	R
	Ploceus manyar (Horsfield, 1821)	**Ploceidae**	Streaked Weaver	GR	0	0	1	1	1	1	1	5	LC	R
	Ploceus benghalensis (Linnaeus, 1758)	**Ploceidae**	Black-breasted Weaver	GR	0	0	0	1	1	1	1	4	LC	R
	Pycnonotus cafer (Linnaeus, 1766)	**Pycnonotidae**	Red-vented Bulbul	OM	1	0	0	0	1	1	1	4	LC	R
	Pycnonotus leucogenis (J.E. Gray, 1835*)*	**Pycnonotidae**	Himalayan Bulbul	OM	0	0	0	0	1	0	0	1	LC	WV
	Rhipidura aureola Lesson, 1831	**Rhipiduridae**	White-browed Fantail	IN	1	0	0	0	0	0	0	1	LC	WV
	*Culicicapa ceylonensis (*Swainson, 1820*)*	**Stenostiridae**	Grey-headed Canary-Flycatcher	IN	1	0	0	0	0	0	0	1	LC	WV
	Gracupica contra (Linnaeus, 1758)	**Sturnidae**	Asian Pied Starling	IN	1	0	0	1	1	0	1	4	LC	R
	Acridotheres ginginianus (Latham, 1790)	**Sturnidae**	Bank Myna	IN	0	0	0	1	1	1	1	4	LC	R
	Acridotheres tristis (Linnaeus, 1766)	**Sturnidae**	Common Myna	OM	1	0	1	0	1	0	1	4	LC	R
	*Pastor roseus (*Linnaeus, 1758)	**Sturnidae**	Rosy Starling	IN	1	0	0	1	1	1	1	5	LC	SV
	*Sturnia pagodarum (*J.F. Gmelin, 1789*)*	**Sturnidae**	Brahminy Starling	IN	1	0	0	1	1	0	1	4	LC	R
	Sturnus vulgaris Linnaeus, 1758	**Sturnidae**	Common Starling	IN	0	0	0	0	1	0	1	2	LC	WV
	Curruca curruca (Linnaeus, 1758)	**Sylviidae**	Lesser Whitethroat	IN	1	0	0	0	0	1	0	2	LC	WV
	Chrysomma sinense (J.F. Gmelin, 1789)	**Sylviidae**	Yellow-eyed Babbler	IN	0	0	0	0	0	1	0	2	LC	R
	Chrysomma altirostre Jerdon, 1862	**Sylviidae**	Jerdon's Babbler	IN	0	0	0	0	0	1	0	1	VU	R
	*Geokichla citrina (*Latham, 1790)	**Turdidae**	Orange-headed Thrush	IN	1	0	0	0	0	0	0	1	LC	WV
	Turdus unicolor Tickell, 1833	**Turdidae**	Tickell's Thrush	IN	1	0	0	0	1	0	0	2	LC	WV
	Turdus atrogularis Jarocki, 1819	**Turdidae**	Black-throated Thrush	IN	1	0	0	0	1	0	0	2	LC	WV
	Zosterops palpebrosus (Temminck, 1824)	**Zosteropidae**	Oriental White-eye	IN	1	0	0	0	0	0	0	1	LC	R
Pelecaniformes	*Anhinga melanogaster* Pennant, 1769	**Anhingidae**	Oriental Darter	CA	0	1	1	1	0	0	0	3	NT	R

	Nycticorax nycticorax (Linnaeus, 1758)	**Ardeidae**	Black-crowned Night-Heron	CA	0	0	0	1	0	1	0	3	LC	R
	Bubulcus ibis (Linnaeus, 1758)	**Ardeidae**	Cattle Egret	CA	1	0	1	1	1	1	1	7	LC	R
	Ixobrychus cinnamomeus (J.F. Gmelin, 1789)	**Ardeidae**	Cinnamon Bittern	CA	0	0	0	1	0	1	0	2	LC	R
	Ardea alba Linnaeus, 1758	**Ardeidae**	Great Egret	CA	0	0	0	1	0	0	0	2	LC	WV
	Ardea cinerea Linnaeus, 1758	**Ardeidae**	Grey Heron	CA	0	0	0	1	0	1	0	3	LC	R
	Ardeola grayii (Sykes, 1832*)*	**Ardeidae**	Indian Pond-Heron	CA	0	0	1	1	0	1	1	5	LC	R
	Egretta garzetta (Linnaeus, 1766)	**Ardeidae**	Little Egret	CA	1	0	1	1	1	1	1	7	LC	R
	Ardea purpurea Linnaeus, 1766	**Ardeidae**	Purple Heron	CA	0	0	1	1	0	1	0	4	LC	R
	*Ixobrychus flavicollis (*Latham, 1790)	**Ardeidae**	Black Bittern	CA	0	0	0	0	0	1	0	1	LC	R
	Ardea intermedia Wagler, 1829	**Ardeidae**	Intermediate Egret	CA	0	0	1	1	0	1	0	4	LC	WV
	Mycteria leucocephala (Pennant, 1769)	**Ciconiidae**	Painted Stork	CA	0	0	1	1	0	0	0	3	NT	R
	*Ciconia episcopus (*Boddaert, 1783)	**Ciconiidae**	Woolly-necked Stork	CA	0	0	1	1	0	0	0	3	NT	WV
	Phalacrocorax carbo (Linnaeus, 1758)	**Phalacrocoracidae**	Great Cormorant	CA	0	1	1	1	0	0	0	4	LC	WV
	Phalacrocorax fuscicollis Stephens, 1826	**Phalacrocoracidae**	Indian Cormorant	CA	0	1	1	1	0	0	0	3	LC	R
	Microcarbo niger (Vieillot, 1817)	**Phalacrocoracidae**	Little Cormorant	CA	0	1	1	1	0	0	0	3	LC	R
	Threskiornis melanocephalus (Latham, 1790)	**Threskiornithidae**	Black-headed Ibis	IN	0	0	1	1	1	1	1	6	NT	WV
	Platalea leucorodia Linnaeus, 1758	**Threskiornithidae**	Eurasian Spoonbill	CA	0	0	0	1	0	0	1	3	LC	WV
	*Plegadis falcinellus (*Linnaeus, 1766)	**Threskiornithidae**	Glossy Ibis	IN	0	0	1	1	0	1	1	5	LC	WV
	Pseudibis papillosa (Temminck, 1824*)*	**Threskiornithidae**	Red-naped Ibis	IN	0	0	1	1	1	1	1	6	LC	R
Phoenicopteriformes	*Podiceps cristatus* (Linnaeus, 1758)	**Podicipedidae**	Great Crested Grebe	CA	0	1	0	1	0	0	0	2	LC	WV
	Tachybaptus ruficollis (Pallas, 1764)	**Podicipedidae**	Little Grebe	CA	0	1	1	1	0	0	0	3	LC	R
	*Podiceps auritus (*Linnaeus, 1758)	**Podicipedidae**	Horned Grebe	CA	0	1	0	1	0	0	0	2	VU	WV
Piciformes	*Dinopium benghalense (*Linnaeus, 1758*)*	**Indicatoridae**	Lesser Golden-backed Woodpecker	IN	1	0	0	0	0	0	0	1	LC	R
	Jynx torquilla Linnaeus, 1758	**Picidae**	Eurasian Wryneck	IN	0	0	1	0	0	0	0	1	LC	WV
	*Psilopogon zeylanicus (*J.F. Gmelin, 1788)	**Ramphastidae**	Brown-headed Barbet	FU	1	0	0	0	0	0	0	1	LC	R

	Psilopogon haemacephalus (Statius Muller, 1776)	**Ramphastidae**	Coppersmith Barbet	FU	1	0	0	0	0	0	0	1	LC	R
Psittaciformes	*Psittacula eupatria* (Linnaeus, 1766)	**Psittaculidae**	Alexandrine Parakeet	HV	1	0	0	0	1	0	1	3	NT	R
	Psittacula krameri (Scopoli, 1769)	**Psittaculidae**	Rose-ringed Parakeet	HV	1	0	0	0	1	1	1	4	LC	R
Strigiformes	*Otus bakkamoena* Pennant, 1769	**Strigidae**	Indian Scops-Owl	CA	1	0	0	0	0	0	0	1	LC	R
	Athene brama (Temminck, 1821)	**Strigidae**	Spotted Owlet	CA	1	0	0	0	0	0	0	1	LC	R
	Tyto alba (Scopoli, 1769)	**Tytonidae**	Barn Owl	CA	1	0	0	0	0	0	0	1	LC	R
Sum →					76	36	84	105	89	66	74			

Annexure II

Table 4.7: Details of medicinal plants mentioned by informants are given below

ADM: Mode of Administration of medicinal plants (O: oral. T: Topical)

Parts used: (Lf: Leaves, Rt: Roots, Sm: Stem, Rz: Rhizome, Wp: Whole plants, Fl: Flowers, Lx: Latex, Sd: Seeds, Fr: Fruits, Oi: Oil, Br: Bark)

Habit: (H: Herbs, T: Trees, S: Shrubs, C: Climbers, G: Grasses)

Family	Species		Habit	Use	Parts used	Method	ADM	Use value	Relative Importance	Voucher No
Acanthaceae	*Justicia adhatoda* L.	Baykr, Vasaakaa	H	Diabetes, asthma, cold and cough	Lf	Decoction of leaves is used for ailments	O	0.86	1.17	WII/HARIKE/SG/107
Amaranthaceae	*Achyranthes aspera* L.	Puth kanda	H	liver disorder, Toothache, periodontitis and Cough	Rt, Lf, Sm	Decoction of leaves is used for a liver disorder, roots for toothache, and stem used for cough	O	0.76	1.17	WII/HARIKE/SG/127
	Beta vulgaris L.	Chakunder	H	Anemia, hair loss and constipation,	Rz, Lf	Raw form and Juice are used, and fresh leaves are cooked	O	0.27	1.03	
Amaryllidaceae	*Allium cepa* L.	Pyaz, gannda	H	Eye irritation and Asthma	Rz	Fresh juice with honey is used for Asthma and some drops of fresh juice are used for eye irritation	O,T	0.40	0.69	WII/HARIKE/SG/132

	Allium sativum L.	Lehsen	H	Blood pressure, Diabetes, sexual disorder, cold, cough, indigestion, and gastric	Rz	The raw form is used, and two or three cloves are taken with honey for erectile dysfunction.	O	1.15	2	WII/HARI KE/SG/133
Anacardiaceae	*Mangifera indica* L	Amb	T	Heatstroke and constipation	Fr	The unripe fruit is boiled with water for eating and a paste of leaves is applied on the body for heatstroke	O ,T	0.25	0.69	WII/HARI KE/SG/048
Apiaceae	*Centella asiatica* (L.) Urb.	Brahmi - buti	H	Heatstroke, headache, and stomachache	W p	Fresh juice is used for headaches and heatstroke	O	0.47	1.03	WII/HARI KE/SG/158
	Coriandrum sativum L.	Dhania	H	Heatstroke, urinary tract infections	W p	Fresh juice with drops of lemon juice is used for urinary tract infections	O	0.38	0.69	WII/HARI KE/SG/167
	Trachyspermum ammi (L.) Sprague	Ajwain	H	Diarrhoea, cold and cough	Sd	Seeds are taken with water.	O	0.44	0.83	
Apocynaceae	*Catharanthus roseus* (L.) G.Don	Sadaba har	H	Diabetes	Lf, Fl	Fresh leaves and flowers are used	O	0.09	0.34	WII/HARI KE/SG/157
	Nerium oleander L.	Laal kanire	S	Toothache and periodontitis	Sm	Soft twigs are chewed for clean teeth	T	0.27	0.49	WII/HARI KE/SG/112
	Calotropis procera (A iton) Dryand.	Akk, Akha	S	Body pain and Arthritis	Lf, Lx	leaves are heated with mustard oil and tied up joints	T	0.15	0.49	WII/HARI KE/SG/087

Arecaceae	*Phoenix sylvestris* (L.) Roxb.	Desi Khajur	T	Body pain, Anemia	Fr	Fruit is used	O	0.18	0.69	WII/HARI KE/SG/059
Asparagaceae	*Asparagus officinalis* L.	Shataav ari	H	Weakness and sexual disorder	Rt	Powdered roots are used	O	0.19	0.69	WII/HARI KE/SG/300
Asteraceae	*Ageratum conyzoides* L.	Knar	H	Cut and wound	Lf	Leaves juice is applied to cut to block the bleeding	T	0.17	0.49	WII/HARI KE/SG/130
Bignoniaceae	*Kigelia Africana* L.	Balum Kheera	T	Piles, stomachache, and constipation	Fr	A powdered form of dried fruit is used	O	0.16	0.83	WII/HARI KE/SG/042
Boraginaceae	*Cordia myxa* L.	Lasoda a	T	Constipation and periodontitis	Fr	Fresh fruits are used for periodontitis	O	0.22	0.69	WII/HARI KE/SG/021
Brassicaceae	*Raphanus sativus* L.	Muli	H	Constipation and Jaundice	Rt	Fresh juice and raw form is used	O	0.16	0.69	WII/HARI KE/SG/253
	Brassica campestris Hook.f. & Thoms.	Saro	H	Body pain, Skin diseases, cuts, cold, and cough	Sd, Oi, Lf	Oil is used for various ailments	O	0.53	1.17	WII/HARI KE/SG/151
	Sisymbrium irio L	khubak alan	H	Asthma	W p, Sd	The fresh plant is cooked for use.	O	0.08	0.34	WII/HARI KE/SG/265
Cannabaceae	*Cannabis sativa* L.	Phang	H	Insomnia, mental disorders	Lf	Leaves are smoked and leave juice is used.	O	0.06	0.49	WII/HARI KE/SG/153
Caricaceae	*Carica papaya* L	Papita	T	Constipation and Dengue	Lf, Fr	Fresh juice of leaves and ripe fruits are used.	O	0.24	0.69	WII/HARI KE/SG/015

Chenopodiaceae	*Chenopodium ambrosioides* L.	Chandan bathua	H	Piles and Stomachache	Lf	Decoction of leaves is used for Stomachache.	O	0.15	0.69	WII/HARIKE/SG/180
Cleomaceae	*Cleome viscosa* L	Bagra, Hulhul	H	Fever, constipation, lung infection and cough	Lf, Sd	The decoction is used.	O	0.12	1.37	WII/HARIKE/SG/162
Combretaceae	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Arjun	T	Cardiovascular disease, diabetes, Fever	Br	Decoction of bark is used.	O	0.16	1.03	WII/HARIKE/SG/079
	Terminalia bellirica (Gaertn.) Roxb	Bahera	T	Diabetes, constipation, Indigestion	Fr	The powdered form of dried fruit is used.	O	0.15	0.83	WII/HARIKE/SG/078
Compositae	*Eclipta prostrata* (L.) L.	Bhringraz	T	Hair loss and cut	Wp	Boiled with olive oil to apply to hair	T	0.21	0.69	WII/HARIKE/SG/182
Convolvulaceae	*Cuscuta reflexa* Roxb.	Amarvalli	H	Hair loss	Wp	Boiled in mustard oil and applied to hair.	T	0.11	0.94	WII/HARIKE/SG/314
Crassulaceae	*Bryophyllum pinnatum (*Lam.) Oken	Patherchatta	H	Kidney stone, cut, and wound	Lf	Raw leaves are used for kidney stones.	O	0.75	0.83	WII/HARIKE/SG/152
Cucurbitaceae	*Momordica charantia* L.	Karela	C	Diabetes	Fr	Fresh juice is used.	O	0.06	0.34	WII/HARIKE/SG/322
	Lagenaria siceraria (Molina) Standl.	Loki	C	Diabetes	Fr	Fresh juice is used.	O	0.19	0.34	WII/HARIKE/SG/313
Euphorbiaceae	*Euphorbia hirta* L.	Dudhi	H	Diarrhoea, Piles , and stomachache	Wp	The raw form is taken empty stomach for Piles.	O	0.89	0.83	WII/HARIKE/SG/187
	Euphorbia prostrata Aiton	Choti dudhi	H	Piles, Diarrhea and Stomachache	Wp	The raw form is taken empty stomach for Piles.	O	0.26	0.83	WII/HARIKE/SG/188

	Ricinus communis L.	Arand	S	Constipation	Oi	Seed oil with water is used for Constipation.	O	0.69	0.34	WII/HARI KE/SG/116
Lamiaceae	*Mentha piperita* L.	Putna	H	Indigestion and gastric	W p	Fresh juice mixed with water for drinks.	O	0.18	0.49	
	Ocimum basilicum L	Ram Tulsi	H	Indigestion, Stomachache and bad breath	Lf	Fresh leaves and decoction are used.	O	0.49	0.83	WII/HARI KE/SG/228
	Ocimum tenuiflorum L.	Tulsi	H	Cold and cough, lung infection	Lf	A decoction is used.	O	0.55	0.83	WII/HARI KE/SG/229
Lauraceae	*Cinnamomum verum* J .Presl	Dalchin i	T	Cold and cough	Bk	Decoction of bark is used for colds and coughs.	O	0.8	0.69	
Fabaceae	*Abrus precatorius* L.	Ghunch i	C	Sexual disorder	Rt	Powder of roots is used.	O	0.15	0.34	WII/HARI KE/SG/298
	Pongamia pinnata (L.) Pierre	Karanj, Sukhch ain	T	Toothache and periodontitis	Sm	Soft twigs are chewed for cleaning teeth.	O	0.12	0.49	WII/HARI KE/SG/063
	Trigonella foenum-graecum L	Methi	H	Diabetes	Sd	Seeds are soaked in water for ten hours, water is used for drinking after filtering seeds.	O	0.26	0.34	WII/HARI KE/SG/283
	Vachellia nilotica (L.) P.J.H. Hurter & Mabb	Babool	T	Arthritis, periodontitis and toothache	Fr, Sd	The powdered form of dried fruit is used.	O	0.15	0.83	WII/HARI KE/SG/083
Lythraceae	*Punica granatum* L.	Annar	S	Anaemia, dengue, malarial and headache	Fr	Fresh juice and raw form are used.	O	0.24	1.37	WII/HARI KE/SG/115

	Lawsonia inermis L.	Mehdi	S	Hair loss	Lf	A paste of leaves is applied to the scalp.	T	0.12	0.34	WII/HARI KE/SG/043
Malvaceae	*Abutilon indicum* (L.) Sweet	Kangi	H	Weakness and sexual disorder	Lf	Raw leaves are used.	O	0.18	0.69	WII/HARI KE/SG/126
	Hibiscus rosa-sinensis L.	Gudhal	S	Hair loss	Fl	Flowers are boiled in mustard oil and then applied to hair.	T	0.14	0.34	WII/HARI KE/SG/101
Meliaceae	*Azadirachta indica* A. Juss.	Neem	T	Stomachache, Diabetes, Fever, periodontitis, wound, and ulcer	Rt, Lf, Sm, Fr, Bk	Raw leaves, fruits, bark, and root decoction are used.	O .T	0.88	1.85	WII/HARI KE/SG/010
	Melia azedarach L.	Bakain	T	Diabetes	Lf	Fresh leaves are chewed.	O	0.10	0.34	WII/HARI KE/SG/050
Menispermaceae	*Tinospora cordifolia* (Willd.) Miers	Giloya	C	Malaria, dengue, lung infection, and fever	Bk	Decoction of bark is used for various ailments.	O	1.80	1.17	WII/HARI KE/SG/328
Moraceae	*Ficus benghalensis* L.	Bod	T	Azoospermia	Lx	Latex is used.	O	0.18	0.34	WII/HARI KE/SG/031
	Ficus palmata Forssk.	Anjiri	T	Skin diseases	Rt, Lx	Mixtures of latex with milk are used.	T	0.04	0.34	WII/HARI KE/SG/034
Moringaceae	*Moringa oleifera* Lam	Sojna	T	liver disorder, diabetes, and indigestion	Lf, Fr, Sd	Leaves are cooked, and powdered seed and decoction of the fruit are used.	O	0.15	1.03	WII/HARI KE/SG/053
Musaceae	*Musa x paradisiaca*	Kela	T	Diarrhea	Fr	Fruit is used with curd.	O	0.39	0.34	WII/HARI KE/SG/055

Myrtaceae	*Psidium guajava* L.	Amrood	T	Diarrhea, constipation, and periodontitis	Fr, Lf	Fruits and leaves are used.	O	0.16	0.83	WII/HARIKE/SG/067
	Syzygium cumini var. cumini	Jamun	T	Diabetes, asthma, liver disorder	Sd, Fr	Fresh fruits and powdered forms of dried seeds are used.	O	0.19	1.03	WII/HARIKE/SG/074
	Syzygium aromaticum (L.) Merr. & L.M.Perry	Long	H	Periodontitis, toothache, and cough	Fl	Decoction and raw form are used.	O	0.37	0.83	
Nyctaginaceae	*Boerhavia diffusa* L.	Itsit	H	Weakness, kidney stones, and sexual disorder	Rt, Lf	Powder from roots and fresh juice from leaves is used.	O	0.37	1.03	WII/HARIKE/SG/148
Oleaceae	*Nyctanthes arbor-tristis* L.	Harsingar	T	Fever and dengue	Lf	A decoction is used.	O	0.25	0.69	WII/HARIKE/SG/057
Oxalidaceae	*Oxalis corniculata* L	Tinpatiyaa, Khatti Buti	H	Diarrhea, wound, bee sting, and heatstroke	Wp	Paste of the whole plant is used.	O	0.23	1.37	WII/HARIKE/SG/231
Papaveraceae	*Argemone mexicana* L.	Kandiali	H	Skin disease	Lx	Fresh juice is applied to the skin.	T	0.11	0.34	WII/HARIKE/SG/142
	Fumaria indica (Haussknecht) Pugsley	Pittapaaparaa	H	Constipation, fever, and blood infection	Wp	A decoction is used for fever.	O	0.9	1.03	WII/HARIKE/SG/194
	Papaver rhoeas L	Laal Posta	H	Mental disorders	Sd	A paste of seeds is used.	O	0.05	0.34	WII/HARIKE/SG/232
Pedaliaceae	*Pedalium murex* L.	Brihatgokshura	H	Sexual disorder	Fr	A powdered form with milk is used.	O	0.09	0.034	WII/HARIKE/SG/234

		, Bda Gokhru								
Phyllanthaceae	*Phyllanthus emblica* L.	Amla	T	Hair loss, indigestion, and constipation	Fr	Fresh fruits and powdered forms of dried fruit are used.	O	0.20	0.83	WII/HARIKE/SG/060
	Phyllanthus niruri L	Bhui Aaamalaa	H	Jaundice	Wp	Fresh juice is used.	O	0.06	0.34	WII/HARIKE/SG/241
Piperaceae	*Piper longum* L.	Maga	C	Cold and cough, lung infection	Fr	Fruit Powder with honey is used for dry cough.	O	1.16	0.83	
	Piper nigrum L.	Kali-mirch	C	Cold and cough	Sd	A decoction is used.	O	0.75	0.49	
Plantaginaceae	*Bacopa monnieri* (L.) Wettst.	Choti-bhrami	H	Heatstroke and memory loss	Wp	Raw form and Juice are used.	O	0.25	0.69	WII/HARIKE/SG/145
Poaceae	*Chrysopogon zizanioides* (L.) Roberty	Khas	G	Stomachache and heatstroke	Rt	Fresh juice is used for heatstroke.	O	0.10	0.89	WII/HARIKE/SG/337
	Cynodon dactylon (L.) Pers.	Dup	G	Diarrhea	Wp	Decoction is used.	O	0.07	0.34	WII/HARIKE/SG/339
Rhamnaceae	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Jharberi, Choti beri	S	Body pain, constipation, and diarrhea	Fr	Fresh fruits are used.	O	0.13	0.83	WII/HARIKE/SG/124
Rutaceae	*Aegle marmelos* (L.) Correa	Bael	T	Diarrhea and fever	Fr	Fresh juice of the fruit is used.	O	0.15	0.69	WII/HARIKE/SG/004
	Citrus aurantium L.	Nimbu	S	Heatstroke, headache, and stomachache	Fr	Fresh juice is used for ailments.	O	0.30	1.03	WII/HARIKE/SG/092
	Murraya koenigii (L.) Spreng	Karipattaa	S	Liver disorder, diabetes, indigestion,	Lf	Fresh leaves are cooked.	O	0.47	1.17	WII/HARIKE/SG/110

				and constipation						
Sapotaceae	*Mimusops elengi* L.	Mulshri	T	Periodontitis	Sm	A paste of soft twigs is applied to the gums.	T	0.11	0.34	WII/HARI KE/SG/052
Solanaceae	*Datura metel* L.	Kala-Datura	H	Mental disorders, Insomnia	Sd	Three to four seeds with water are taken.	O	0.03	0.49	WII/HARI KE/SG/176
	Solanum virginianum L.	Kateri	H	Cold and cough and liver disorder	Rt	A decoction is used.	O	0.06	0.83	WII/HARI KE/SG/269
	Withania somnifera (L .) Dunal	Akksen	H	Malarial, stomachache, asthma and sexual disorder	Lf, Rt	Raw leaves with turmeric and ginger are chewed to control high fever.	O	0.77	1.37	WII/HARI KE/SG/295
Theaceae	*Camellia sinensis* (L.) Kuntze	Chai	S	Diarrhoea	Lf	Dry leaves mixed with sugar are taken with water.	O	0.29	0.34	
Verbenaceae	*Phyla nodiflora* (L.) Greene	Gorakh mundi	H	Piles and Stomachache	W p	Paste form is used.	O	0.09	0.49	WII/HARI KE/SG/240
Xanthorrhoeac eae	*Aloe vera* (L.) Burm.f.	Kuwar	H	Diarrhoea, indigestion, skin disease and constipation	Lf	Leaves juice is used.	O	0.42	0.97	
Zingiberaceae	*Amomum subulatum* R oxb.	Bari ilaichi	H	Indigestion	Fr	A decoction made from fruits with milk is taken.	O	0.16	0.34	
	Curcuma longa L.	Haldi	H	Body pain, fever, skin disease, cold and cough,	Rz	Powdered and decoction form is used.	O	1.79	1.51	WII/HARI KE/SG/172

	Zingiber officinale Ro scoe	Adrak	H	Blood pressure, cold and cough, Indigestion and gastric	Rz	Raw form and decoction is used.	O	1.00	1.31	
Zygophyllacea e	*Tribulus terrestris* L.	Pakhda	H	Diarrhoea, a sexual disorder	Fr	A powdered form of dried fruit is used.	O	0.13	0.83	WII/HARI KE/SG/277

Oral presentation given in the conferences

International Conference

On

BIODIVERSITY:

Exploration, Exploitation And Conservation For Sustainable Development

(ICB-01)

(On Blended Mode)

Ref.: Cert/ICB01/PDUAMB/2022

Certificate of Participation

This is to certify that

Sameer Gautam

of

Forest Research Institute (Deemed to be) University, with research center Wildlife Institute of India, Dehradun

has participated and presented a research paper (oral) entitled

Habitat diversity contributing plant-based provisioning ecosystem services at Harike Wildlife Sanctuary, Punjab, India

in the International Conference on Biodiversity: Exploration, Exploitation and Conservation for Sustainable Development (ICB-01), organized by the Department of Botany, Pandit Deendayal Upadhyaya Adarsha Mahavidyalaya -Behali, Assam, India in association with ECO-CLUB (MoEFC, Govt. of India and ASTEC, Assam) on 5th January, 2022.

DR. DEBOJIT BARUAH	DR. SHAFIQUL ISLAM BHUYAN	DR. MOFIDUL ISLAM	MS. HEENA AGARWAL
Principal and Chairperson, ICB-01	Organizing Secretary, ICB-01	Joint Organizing Secretary, ICB-01	Joint Organizing Secretary, ICB-01

All is Vain Without God - Psalm 127:1

DEPARTMENT OF BIOTECHNOLOGY & BIOINFORMATICS

BISHOP HEBER COLLEGE (Autonomous)

(Nationally Reaccredited with 'A' grade by NAAC with a CGPA of 3.58 out of 4)
(Recognised by UGC as "College of Excellence")
Tiruchirappalli – 620017

INTERNATIONAL VIRTUAL CONFERENCE ON

BIOLOGICAL INNOVATIONS & COMPUTATIONAL EXPLORATION FOR PANDEMIC CHALLENGES (BICPAC'22)

सत्यमेव जयते

24th & 25th February, 2022

Sponsored by

Department of Biotechnology
&
Council of Scientific and Industrial Research
Ministry of Science & Technology Government of India

CERTIFICATE OF APPRECIATION

This is to certify that

Mr. Sameer gautam
Research Scholar
Habitat Ecology, Wildlife Institute of India
Forest Research Institute (Deemed to be University)
with Research Center Wildlife Institute of India,
Dehradun, Uttarakhand

DBT
DBT/CTEP/01/20211051992

CSIR
Ref No. SYM/10715/21-HRD

has presented a paper / poster entitled

Economic valuation of cultural ecosystem services for a Ramsar site: an assessment from Harike Wildlife Sanctuary, Punjab, India

in **BICPAC" 22**

Dr. R. JASMINE
Associate Professor & UG Head
Co-Convener, BICPAC" 22

Dr. D. PAUL DHAYABARAN
Principal & Patron
BICPAC" 22

Dr. M. VINEETH
Assistant Professor & Organising Secretary
BICPAC" 22

Mr. J. DINESH RAJA
Assistant Professor & Organising Secretary
BICPAC" 22

Publication from the present study

Ethnobotanical documentation of Harike Wildlife Sanctuary (Ramsar Site), Punjab, India: A case study

Sameer Gautam and B.S. Adhikari

Research

Abstract

Background

Floral diversity across habitat types of Harike Wildlife Sanctuary, Punjab, India

ABSTRACT

1. INTRODUCTION