CHAPTER 1

INTRODUCTION

1.1 Background to Phytosociology

Phytosociology is considered a specific domain of vegetation science that significantly focuses on recent plant assemblages at a spatial shape and volume of grain of vegetation stand (Dengler, 2016). The key goals of phytosociology are the characterization and demarcation of types of vegetation depending on species or floristic composition of a forest or particular place (Dengler, 2016). Phyto-coenoses in this specific regard is floristically identical concrete stands, depicted by releves or particular plot records and both the stated variables and/or entities, therefore, get combined into types of abstract vegetation (Dengler, 2016). However, this method or approach does not work similar to plant taxonomy; rather it places units of vegetation in a hierarchical order depending on differing extents of floristic identity (Biondi, 2011). The history and evolution of phytosociology is very interesting and will be discussed in subsequent sections.

The key ideas, approaches, and terminology associated with principle and discipline of phytosociology were primarily developed by Josias Braun-Blanquet, a Swiss-French Botanist. The framework was developed in the year 1920 and since that time, further development and modification is taking place on the model or framework (Biondi, 2011). Combination of standardized sampling of communities of vegetation or plan on unit area or plots, identification of 'species-by-plot' matrices, demarcation and terminology of plant types and their positioning into hierarchical ladder was performed by Josias Braun-Blanquet at that time (Ewald, 2003). This approach is often known by the name of Josias; for example, in literature it is also known as the 'Braun-Blanquet Approach' (Westhoff and Maarel, 1978). However, significant differences are there between the approach developed initially by the author and the model that is used currently. All the changes and modification in this model is majorly due to technological upgrade and methodological developments. However, despite all the changes, the framework of the model is still based on same concepts as before.

The time when emergence of plot-based vegetation characterization was noticed as a scientific approach, specifically in the 1920s-1930s' time period, some regional schools/institutes were there at that time with methodologies which were not similar to that of the approach/framework shared by Braun-Blanquet (Pott, 2011). The approach initially was more prevalent and widely used in southern as well as central Europe (Pott, 2011). Specifically in the scientific realm of the Anglo-American, the meaning or integration of a typology of communities of plant was questioned fundamentally during this time period, depending on a concept of individualistic community (Dengler, 2016). Retrospectively, evidence was also there that phytosociology significantly managed to develop comprehensive as well as widely implemented characterizations of types of vegetation, specifically for broader spatial regions, while the other frameworks or procedures ceased to exist even regionally. Currently, a significant change is there in terms of the utilization of phytosociology approach where it is mainly considered a conventional or mainstream approach all over Europe and is also implemented in various parts of Africa, northern Asia and Latin America (Dengler, 2016). However, the implementation of this approach in North America is still very limited. The United States National Vegetation Classification (USNVC) was released a few years before, which specifically admit the relevance and advantages of a consistent 'hierarchical classification patterns' and also adopts concepts of this approach in a modified manner (Faber-Langendoen et al., 2007). In the next section, some important determinants and factors associated with phytosociology approach including placement and plots size, phytosociological releves, phytosociological classification and phytosociological databases will be discussed.

At the phase of development, the traditional phytosociologists considered that representation of a patch or whole stand of vegetation could be done by one with a single 'typical' releve (Werger and Sprangers, 1982). However, on the contrary, the current approach of phytosociology is considered as a modern tool based on statistical measures that specifically focus on characterizing or identifying types of vegetation by the combined data collected from multiple plots (Dengler, 2016). Hence, it is usually better to obtain samples from many small areas or plots than to obtain or collect samples from few large plots. The strategies for sampling in this specific aspect specifically aim at encompassing the complete variability of plants or vegetation within the confined ecological and geographical region or extent of a particular study, while reducing the heterogeneity within the plot (Dengler, 2016). The two stated targets can be met specifically by a spatially random sampling approach as there is a chance that vegetation of geographically restricted types would be missed, which, therefore, may place a different and distinct area in a given ecological region (Chytrý, 2001). According to current understanding, as statistical inference around the geographic regions is commonly not the main objective of phytosociological sampling, most of the time, specialists prefer subjective plots' placement and stratified random sampling (Dengler, 2016).

Earlier, most of the phytosociologists believed that one could also ordain a 'minimal area' for every type of vegetation above which the amount of species does not enhance further (Concenço et al., 2013). In this specific regard, vegetation sampling on plots analogous to or greater than the particular minimal area would provide comparable outcomes, despite having varying plot sizes (Concenço et al., 2013). On the other hand, according to current understanding and theoretical comprehension, richness of mean species enhances monotonously with region and a minimal area is a complete flimflam mainly the result of a non-linear type of relationship between species and area (Dengler, 2016). As most methods and frameworks for vegetation classification are considered very sensitive to varying plot sizes, it is usually recommended to implement uniform or identical plot sizes within some structurally limited or confined formations. In the following section of this chapter, some essential determinants that are associated with phytosociology will be discussed.

1.2 Definition of Parameters in Phytosociology

Characteristics of phytosociology such as density, frequency, and abundance were affected by anthropogenic, climatic, and biotic pressures present at the three research locations (Concenço et al., 2013). When it comes to frequency, density, and abundance, rainy season is the best time of year for all of the species studied. In 1985, Walter G. Rosen invented the phrase "biodiversity" a shortened term for "biological diversity" (Sarkar, 2002). However, the notion has been around for a long time. It is well-known that invasive species, pollution, and over-exploitation by humans, and global warming are causing changes in ecosystems throughout the planet. Most individuals now understand the value of preserving genetic variety, diversity of species, and biological community variety (Biondi, 2011). The term "community" refers to a group of organisms that share the same environment and time. Phytosociology is a branch of ecology that focuses on the study of plants and their interactions with each other (Biondi, 2011). Species that share environmental tolerances create a community when they dwell together in the same habitat.

It's not true that most of these organisms are crucially significant; rather, there are a small number of dominating species whose size and growth alter the environment and regulate the development of many other species in the community (Biondi, 2011). Plant sociology or phytosociology is the science of the organization of plant communities. Paczoski invented the term "phytosociology" to describe the study of plant social connections, and this research is critical to understanding how communities work (Maycock, 1967). Understanding the structure and composition of a plant community is essential to its research. It was estimated by Stone and Frayer (1935) that the 'complexity index' was calculated using plant heights, basal areas, densities, and species numbers (Maycock, 1967). The vegetation complex changes annually as well as seasonally, and the variation shows that each species population responds to the incoming warmth, humidity, and light as adjusted by the plants. Rivers, lakes, and ponds, as well as the marginal wetlands that surround them have been studied extensively in terms of pollutant characteristics and biodiversity. Despite the importance of macrophyte richness and phytosociology in drainage and their construction to ecologists, it has been overlooked so far. As a result, the current study provides a solid foundation for future research into the composition, organization, species diversity, developmental stages, and evolution of plant communities.

Definitions of some parameters including abundance, density, dominance, frequency, relative frequency, relative density, and relative dominance associated with phytosociological analysis will be discussed in detail in this section (Johnson, Mason and Raven, 1968).

$$\textbf{Frequency} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total numberof quadrats studied}} \times 100$$

$$\textbf{Relative Frequency } (\%) = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100$$

$$\textbf{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$$

$$\textbf{Relative Density } (\%) = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \times 100$$

$$\textbf{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occurred}} \times 100$$

$$\textbf{Relative Dominance } (\%) = \frac{\text{Basal area of a species}}{\text{Basal area of all species}} \times 100$$

$$\textbf{Importance Value Index (IVI)} = \text{Relative Frequency} + \text{Relative Density} + \text{Relative Dominance}$$

Species density in plant ecology is described as the amount of specimens of a specific species found in a given survey population or research region (Johnson, Mason and Raven, 1968). In a vegetation assessment, density is frequently used to indicate the position of a species in vegetation types. According to the given formula, density of a population in a given region can be identified considering the total amount of species individuals and total number of quadrats that have been studied in an experiment (Johnson, Mason and Raven, 1968). In this specific regard, it can be stated that, density of a given species in a given region can be identified dividing the total number of species individuals and total number of quadrats studied. It is the proportional representation of an organism in a particular environment that is measured by local abundance in ecological terms. It is often described as the amount of persons discovered in a given sample.

Relative species abundances are calculated as the proportion of the richness of one creature to the richness of one or other organisms that coexist in an environment (MacArthur, 1960). Abundance of a population of a specific species in a given region is identified considering total number of individuals of a particular species and total number of quadrats studied (MacArthur, 1960). In this specific regard, it can be stated that, abundance of a population of a given species can be calculated estimating the total number of the given species dividing with number of quadrats studied and then multiplying the value with 100. It significantly helps in plant species and/or vegetation analysis in a given region.

The next parameter in phytosociology is frequency of a population (Takahata, Ishii and Matsuda, 1975). The frequency of occurrence of a species in a given region is the vegetative attribute that reflects the likelihood of encountering that species. The calculation is performed depending on the existence or absence of a certain type in a set of sample units (Takahata, Ishii and Matsuda, 1975). According to the formula to determine frequency of a population, one must consider total quadrats where species existed and total number of quadrats studied in the assessment. Frequency of a population can be accounted dividing the total number of quadrats where species exist by total number of quadrats studied and then multiplying the value with 100.

In ecology, environmental dominance refers to the level toward which one or more organisms have a significant impact over the other organisms in their ecosystems (due to their enormous size, number, productivity, or other relevant criteria) or account for a greater proportion of the biomass (Takahata, Ishii and Matsuda, 1975). Apart from the relevance of density in ecology, relative density is also considered essential in terms of its relevance in population biology and ecology. According to the formula mentioned above, the overall number of individuals in a species is used to find the density of a species. It is possible to compute relative density by dividing the volume by the total of the densities of all taxa and multiplying the result by 100 (Southwood et al., 1974).

Apart from relative density two other important parameters used in population ecology are relative dominance and relative frequency (Southwood et al. 1974). It is possible to compute relative frequency by dividing the rate of one species by the total of the rates of all species and multiplying the result by 100 (Southwood et al., 1974). Lastly, relative dominance states that it is common to express relative values, such as relative density, frequency, and dominance, where relative density is the amount of a particular species conveyed as a proportion of the total population of living species, and relative frequency is the frequency of a particular species expressed as a proportion of the total population of living species, and relative dominance is the basal region of the quadrat under investigation. The overall population in a species is used to calculate the density of a species (Southwood et al., 1974).

In the next section of the chapter, the quadrat method of vegetation analysis will be discussed.

1.3 Quadrat analysis method

A quadrat is a framework that is built up to delineate a specific region of a population that will be sampled for research purposes. In the quadrat framing method, the presence of vegetation is recorded to use an effective method of abundance to determine their relative abundance (Thomas, 1977).

Quadrats can be square, rectangular, or circular in shape, and they can have any size that is acceptable (Thomas, 1977). The quadrat technique may be used to estimate the vegetation cover in practically any form of vegetation, regardless of the vegetation type. While certain plant species are best surveyed using other approaches (e.g., a point-frame method for grasslands or a point-quarter method for forests), others are best sampled using a combination of techniques. Multiple quadrat samples are obtained since a single quadrat cannot be anticipated to effectively sample a population in a single visit (Thomas, 1977). As a general rule, the community is broken up into subareas based on topography, aspect, and other physical factors – as well as evident floristic variations – and each of these subareas is sampled independently; within each subarea, quadrats are randomly placed inside each area. This sort of sampling strategy guarantees that a representative sample of the various physical and floristic characteristics of the community is obtained (Thomas, 1977). Stratified random sampling is the term used to describe this form of sampling. Once the data has been obtained, the sample data from all quadrats is combined together and determined to be an appropriate sample of the general population. When vegetation is sampled using quadrats, several metrics of abundance can be measured in order to estimate the effect or "importance" of each species within the quadrat under consideration. A simple count of the amount of persons belonging to a species is known as counting (Thomas, 1977). Coverage is the percentage (%) of a quadrat's total area that is covered by a species of plants. Density is calculated by calculating the amount of individuals within a species living in a given unit of land. The percentage of quadrats collected wherein the taxa are present is referred to as the incidence. As shown on the left side of Table 1.1, the overall cover, density, and frequency estimates for each species are then derived from the complete dataset by putting all of the transects together, as shown on the right side of the Table 1.1 (Allen and Wyleto, 1983). Comparative cover, density, and frequency distribution values may be calculated to estimate the proportionate representation of each species in relation to the overall plant community (right-hand side of Table 1.1). According to the definition given above, relative cover is the proportionate cover of an individual species stated as a percentage of total native vegetation; hence, it is expressed as percentage, with the range being 0–100 percent (Allen and Wyleto, 1983). "Importance" is indeed a measure of such a plant species' total effect on the community in which it grows. For each species in a community, a Significance Value (IV) is calculated based on the overall impact of the individual's relative cover, density, and relative abundance in the community (Allen and Wyleto, 1983). Its important values range from 0 to 300 since it takes into account relative cover, density, and frequency of appearance. The quadrat technique yields the following major quantitative community metrics, which are summarized in Table 1.1.

Table 1.1: Quadrat Analysis Method

Abundance (A_i) = total number of individuals of species *i*	
Cover (C_i) = Total % cover of species *i*	Relative cover (RC_i) = $\frac{\text{Cover of species } i}{\text{Total plant cover}}$
Density (D_i) = $\frac{A_i}{\text{Area}}$	Relative density (RD_i) = $\frac{D_i}{\text{Total plant density}}$
Frequency (F_i) = $\frac{\text{\# of quadrats with species } i}{\text{Total \# of quadrats sampled}}$	Relative frequency (RF_i) = $\frac{F_i}{\text{Total plant frequency}}$
Importance value (IV) = $RC_i + RD_i + RF_i$	IV ranges between 0 - 300

Quadrats can be found in a variety of shapes, including square, rectangle, and circle. Each has its own set of benefits and limitations. When choosing the appropriate quadrat shape to use for analysis, there are two important aspects to keep in mind. The first is the edge effect wherein researchers make subjective opinions about if a species is regarded as "in" or "out" of the quadrat, which is the foremost of the two aspects (Allen and Wyleto, 1983). The reliability of the collection is reduced as a result of this bias. Quadrats with a round shape have the lowest border to interior ratio and hence the lowest bias. In addition, they are simple to define inside the field. However, in dense natural vegetation, this form may not be as helpful as it appears. Quadrats that are square or rectangular in shape are often easier to define than quadrats that are round or oval in shape, because tape measures may be threaded through dense plant stands. In general, rectangular quadrats are regarded a suitable balance since they have a lower border to inner area ratio than square quadrats and may record a greater linear distance along the ground than square quadrats (Weaver, 1918). When compared to square quadrats, this distance feature is more successful in capturing environmental variance. Using a disproportionately small number of quadrats may result in an inadequate or erroneous depiction of all the different species. Using an excessive number of them will be a waste of effort (Weaver, 1918). The species area curve may be used to calculate the number of samples that are required. To accomplish this, the total number of species that have been added with each subsequent quadrat sampled should be noted (Weaver, 1918). When the curve reaches a point of equilibrium, the number of samples collected is sufficient. Therefore, considering the above mentioned facts and findings it can be stated that quadrat analysis method is significant for studying or assessing vegetation distribution in various reserve forests.

1.4 Saraswati Wildlife Sanctuary

The 11,003-acre Saraswati Wildlife Sanctuary in Haryana lies between the districts of Kurukshetra and Kaithal at 76° 33' E latitude and 29° 56' - 30° N longitude. The region has a subtropical climate with alkali soil and a semi-arid climate. The area receives 516 mm of rainfall per year, and the mean temperature is 32.4°C in the region. Saraswati Wildlife Sanctuary is home to "Sub–group 5B tropical deciduous forest," which describes the forest's flora (Kumar and Malhotra, 2014). As the most intriguing facet of biology, species diversity encompasses a wide range of living things from many different habitats, including underground, marine and other aquatic ecosystems as well as ecosystem in general to which they belong (Kumar and Malhotra, 2014). It also encompasses the diversity found within species and ecosystems themselves. Every level of organization, from cell to ecosystem, is affected by biodiversity. This includes all sorts of living things that live on land or in the oceans, as well as those that live in the atmosphere. Located at the crossroads of three bio-geographical regions — temperate Eurasia, tropical Africa and the East Asian continent — India has a diverse biological legacy, making it one of the world's 12 super diversity nations (Kumar and Malhotra, 2014). As a result, there are presently seventeen countries classified as "mega diversity." In total, 7 percent of the world's fauna and flora may be found in the Indian subcontinent, with more than 45,000 species of plants and

65,000 animal species. In India, the flora is among the most diverse in the world because of the nation's vast diversity of climates (Kumar and Malhotra, 2014). Dry forest area and thorny bushes cover much of Haryana mostly during monsoon season. Indo-Himalayan (South and Southeast Asia), Pale arctic (Northern Asia and Europe) and Afro-tropical (Africa) are the three major bio-geographic domains that make up India's biodiversity zone. According to the World Biodiversity Assessment of the UNEP of 1995, the overall diversity of plants documented so far is 1.75 million. India covers just 2.4% of the world's geographical area, but its commitment to the earth's biodiversity is around 8%. About 335 circulatory species of plants, including Gymnosperms (4 species), Angiosperms (300 species) and Pteridophytes (31 species) from 236 genera and 103 families, 187 herbs, 73 shrubs, and 21 climbers, were documented from the 'Calicut University campus', located in Kerala, India (Kumar and Malhotra, 2014). Multiple number of vegetation species have been documented in this campus, for example, *Acacia eburnea, Acacia chundra, Aegle marmelos, Acacia nilotica, Barringtonia acutangula, Atalantia racemosa, Bombax ceiba, Bauhinia purpurea, Bauhinia racemosa, Cassia fistula, Buchanania axillaris, Butea monosperma, Cochlospermum religiosum, Chukrasia tabularis, Hibiscus platanifolius, Gyrocarpus asiaticus, Ficus tinctoria, Mimusops elengi, Melia azedarach, Ochna obtusata, Morinda pubescens, Sterculia urens, Strychnos potatorum, Cynodon dactylon, Cymbopogon coloratus, Chloris virgata,* grasses and sedges, *Vitex altissima, Terminalia chebula,* and *Saccharum spontaneum,* and shrubs and herbs likely *Artabotrys hexapetalus, Barleria buxifolia, Asparagus racemosus, Breynia vitis-idaea, Capparis zeylanica, Calycopteris floribunda, Crotalaria retusa, Clerodendrum inerme, Carissa carandas, Grewia tenax, Helicteres isora, Murraya paniculata, Mimosa intsia, Solanum trilobatum, Rauvolfia tetraphylla, Tarenna asiatica,* and *Helicteres isora, Jasminum cuspidata, Indigofera aspalathoides, Lawsonia inermis,* and *Crotalaria retusa* (Kumar and Malhotra, 2014).

In the field work conducted in this study, the plant species that were found in the Saraswati Wildlife Sanctuary included *Morus alba*, *Acacia nilotica*, *Ziziphus jujuba*, *Eucalyptus globulus*, *Cannabis sativa*, *Urena lobata*, *Capparis sepiaria*, *Chenopodium album*, *Chenopodium murale*, *Pongamia pinnata*, *Sida cordifolia*, *Cynodon dactylon*, and *Abutilon indicum*.

The existence of the above-mentioned plant elements in the Saraswati Wildlife Sanctuary significantly rely on the environment and atmosphere of the place and has direct and indirect relationship with characteristics of other biotic and abiotic factors in the land that includes existence of animals, birds, insects and many more. The wildlife sanctuary is a matter of concrete ecological and geological research as many archeologists till date have obtained many historical and architectural products from this place. In this specific regard, further phytosociological analysis will significantly help in drawing contribution of India in global biodiversity and also identifying some endangered plant species (Kumar and Malhotra, 2014). As the soil structure of the land is getting changed over time and global warming is eliciting its drastic impact on fauna and flora, a proper phytosociological analysis will be very helpful in this specific aspect to draw attention of Indian government and forest ministry if any conservation system needs to be promoted to rescue and ensure wellbeing of some specific plant vegetation or other living beings in Saraswati Wildlife Sanctuary. Drawing a conclusive point on existence of plant species in the land is very challenging as the land comprises many different types of plants as already stated above; however, long-term study and observational and survey analysis will help in characterizing and/or investigating the traits of the plants present there and their relation with eco-geological perspectives (Kumar and Malhotra, 2014).

According to current evidence, carbon stock has a huge impact on dispersion and growth of plant vegetation in Saraswati Wildlife Sanctuary (Bhalla and Gupta, 2013). In this section of the chapter, the impact of carbon stock will be discussed. In this aspect, it can be stated that in forests, carbon management and plantation of tree and vegetation plays a very significant role with rapidly growing organisms having direct as well as indirect impact on the regional frequency of carbon sequestration by carbon incorporation into biomass of plant and improvement of organic matter of soil (Bhalla and Gupta, 2013). Soil organic matter is considered a renewable source and it also can be maintained at a sustainable rate if restoration of degraded ecosystem is possible in this regard. Organic matter of soil is also considered a very essential source of nutrients that plant vegetation requires most often. The maintenance of soil productivity significantly depends on soil carbon that makes the management system of soil very resilient as well as sustainable and also capable to prohibit degradation (Bhalla and Gupta, 2013). Sequestration of soil carbon in this regard, considered as the procedure by which consumption of atmospheric carbon dioxide takes place by plant species and they synthesize and accumulate biomass performing photosynthesis (Bhalla and Gupta, 2013). In Saraswati Wildlife Sanctuary, different tree plantations and soil organic carbon elicited signficiant decrease with enhance in soil depth. Therefore, it can be stated that when depth of soil is increased in the land, it significantly decreases the amount of organic carbon of soil. Three different plant species were highlighted in an experiment that includes *Prosopis juliflora, Eucalyptus tereticornis*, and *Dendrocalamus hamiltonii*. In all the stated plant species, significant differences were noticed in term of biomass production as well as amount of soil carbon source. The next important determinant that was followed in this specific aspect was the amount of soil inorganic carbon where soil surface layer was found to accumulate less inorganic carbon in comparison with sub-surface layers. In case of different plantation, the amount of soil inorganic carbon and their presence in different soil levels differ significantly (Bhalla and Gupta, 2013). For example, in case of *Prosopis juliflora* plantation, in comparison with *Eucalyptus tereticornis* and *Dendrocalamus hamiltonii* plantations, the amount of inorganic matter was significantly higher. In Saraswati Wildlife Sanctuary, the highest amount of inorganic carbon in soil is present in carbonates' form. Total soil carbon stock is another major determinant that significantly helps in understanding growth and development of plantation in the chosen land and relation with soil type. The largest elevation in soil inorganic carbon material was significantly noticed at around 45 to 60 cm of soil depth in three different tree plantations (Bhalla and Gupta, 2013). A total amount of carbon stock in *Prosopis juliflora* was lesser than *Eucalyptus tereticornis* but higher than *Dendrocalamus hamiltonii.* The next important determinant or soil factor that regulates plant growth and development is considered as aggregate composition of soil. In this specific aspect, it can be stated that in the three chosen plant species of Saraswati reserve forest, only a few amount of macroaggregates were obtained from soils up to around 0 to 35 cm of soil depth. The amount of large macroaggregates was significantly higher in *Eucalyptus tereticornis* and found to be lowest in *Prosopis juliflora*. The proportion of small macroaggregates, on the other hand, was found in varying amounts in different vegetations (Bhalla and Gupta, 2013). While specifically focusing on the context of soil structure and pattern, it has been found that the concentration of carbon was significantly higher in case of macroaggregates in comparison with microaggregates. The concentration of carbon in macroaggregates significantly differed in range from around 0.20 to 0.85% specifically in *Eucalyptus tereticornis* vegetation and in case of *Prosopis juliflora* the range was 0.21 to around 0.80% (Bhalla and Gupta, 2013).

Aggregates of soil are the fundamental unit of structure of soil influencing many biological as well as physical processes of the soil. In this specific regard, soil aggregation is a very essential process of sequestration of carbon. In the observed plantations of trees, it was significantly found that concentration of organic carbon reduced from macroaggregates to microaggregates at several depths of soil. The macroaggregates of soil are stabilized specifically by currently deposited residues as well as carbohydrates which enrich plant debris or root occluded within aggregates (Bhalla and Gupta, 2013). Macroaggregates in this very specific aspect are very sensitive to disturbance of soil, but microaggregates are commonly more stable as well as very resistant to any type of disturbance. The amount of organic carbon in soil in microaggregates is considered to be significantly protected from degradation and is also significant for the process of sequestration of soil carbon (Bhalla and Gupta, 2013). The frequency of loss of carbon from macroaggregates is considered way faster than microaggregates mainly because of lower protective impacts of both chemical and biophysical processes.

Considering all the above mentioned facts and findings, hence, it can be stated that plantations of trees have significant potential in sequestration of carbon by developing structure of soil and enhancing soil carbon in multiple fractions of soil aggregates. Plantations of tree on degraded lands could be considered a very effective approach in this aspect for restoration of forest and sequestration of carbon over both long and short term. In the tree plantations soil in Saraswati Wildlife Sanctuary, clay, silt, and micro aggregates-associated fractions of soil formed a large amount of soil aggregation and provided protection to most of organic carbon in the soil. Therefore, while further proceeding with phytosociological analysis, it is very essential to consider plantation, vegetation, and soil structure of Saraswati Wildlife Sanctuary. An in-depth study will help in developing a direct relation between available nutrients in soil, biomass synthesis, and accumulation and growth and development of different types of plants species.

1.5 Summary

This chapter provided an introduction to phytosociological analysis in context of the Saraswati Wildlife Sanctuary in Haryana. It described the quadrat method of analysis and parameters that can be measured using this method of analysis in detail. It also listed the plant species that have been identified in this and other reserve forests across India and globally. It also described specific soil and environmental characteristics that determine the type and numbers of plant species that grow in a particular region.

1.6 Aims and Objectives of the Study

The central aim of the dissertation is to carry out a phytosociological analysis of the Saraswati Wildlife Sanctuary in Haryana using the quadrat method of analysis. Hence, the following objective has been made for the present study:

- To characterize the floristic composition and analytical characteristics of vegetation in Saraswati Wildlife Sanctuary, Haryana, India

CHAPTER 2

REVIEW OF LITERATURE

2.1 Background

Phytosociology, according to the Oxford English Dictionary, is the study of natural vegetation, its structure and growth, and the connections among the species that make up such populations. Phytosociology or vegetation sociology, as described by Blanquet (1932), is the study of natural vegetation or flora in its broadest sense, including all factors that have an impact on plants' social lives. Using basic field procedures, it is an important tool for conducting vegetation surveys and determining the properties of forest ecosystems (Rieley and Page, 1990). It is critical to know the operation of the community since it requires knowledge of the community's composition and structure (Singh and Singh, 2010). Phytosociology is a science of vegetation types, and organization or characteristics of communal connections of plants. Native plants are studied in terms of their structure, origin, organization, and growth. Plant ecology identifies and describes plant communities based on the content and organization of such communities (Hargreaves, 2008). In order to identify plant diversity, phytosociology analyses a large set of numerical and qualitative properties of natural vegetation, as well as their multilateral interactions to each other and to environmental factors. When a group of species populating a certain area get together at the same time and location, it is called a community, and this group has a strong bond or kinship with some other species (Mueller-Dombois and Ellenberg, 1974). The architecture of a habitat is determined by its vegetation types, which differs from location to location depending on the area's ecological heterogeneity (Kukshal et al., 2009). Ecologically determining or recognising a species' relationship has significant consequences. The relevance of an organism and its behaviour in a group may be gleaned through phytosociological research in plants. A community's organization, content, and feeding structure may all be gleaned from a plant's phytosociological properties. A community's genetic diversity and ability to adapt may be gauged by looking at the diversity of its species (Odum, 1963). Statistical metrics of species abundance, dispersal, frequency, and predominance are employed in phytosociology to define community composition and analyze its movements through time and space. The density-diameter scattering is used to assess the demographic behaviour of forestry ecosystem component species, especially woody species. This emergent trait is typically referred to by researchers as a J-shaped comprising of multiple (Robertson et al., 1978), as well as an approximate negative potential dispersion (Manion and Griffin, 2001; Hitimana et al., 2004). In order to develop a strategy for habitat protection and/or exploitation, all this information will be useful for identifying habitat structures (Das and Lahiri, 1997). Phytosociology is a branch of biology that studies plant variety in various environments and geographies around the world (Loidi, 2004). Most commonly, this culture can be described at the environmental level by biodiversity, which is a geographical form of textural variety and is studied both in the growth of plant communities as well as in their dynamic processes of change (Maarel, 1988). Plant sociological (also known as phytosociology or plant sociology) is described as the study of flora as a whole, including its structure and distribution, according to numerous writers. It aids our knowledge of the forest's plant communities and state of biodiversity (Phillips et al., 2003). Phytosociological research takes into account the current vegetation structure, biodiversity, and soil plant relationships, resulting in data on annual and cyclical variations (Malik et al., 2007).

Understanding the population trends of every species in an area may be done through data analysis in phytosociological study. The species composition of vegetation types is the most essential feature to investigate. Changes in the abiotic circumstances of the environment, as shown by the species diversity, may have generated instabilities in the social dynamics, which in turn were reflected in the species diversity. The term "community" refers to a grouping of species populations that exist at the very same moment and in the same area and exhibit a clear connection to one another (Mueller-Dombois and Ellenberg, 1974). The prevalence of specific species of different girth classes, their connection, the structure of dispersal, and numerous measures of variety are essential to understanding the organization of forest communities (Longman and Jenik, 1987). Different groups of plants from various living forms exist in forest ecosystems, each playing a comparable role (Richards, 1996). The architecture of a community is made up of these many kinds of organization. In order to fully understand community organization, scientists might use the phytosociological technique to examine the variety of plants. Conservation, environmental management, and landscape design all benefit from data gleaned through plant surveys and habitat analyses (Haila and Margules, 1996).

2.2 Diversity concept

As a general rule, diversity is regarded as a characteristic of both natural and man-made communities (Hairston, 1964). Species culture can be described as the sum of abundance and species richness (Molles, 1999). Biodiversity may be defined by the amount of species, but this is the most frequent and straightforward way of doing so (Peet, 1974). The trend of species diversity may be traced back to a variety of variables, including rivalry, geography, development, and environmental elements (Criddle and colleagues, 2003). The species richness is a measure of a species' overall population density. There has been research on the relationship between plant diversity and a metric called species evenness (Rentch et al., 2005). It might be useful to compare species abundance and diversity indexes to get insight into the variety of a community (Magurran, 1988) based on population abundance estimate.

2.3 Indices of diversity

These indices have been presented to help clarify the phytosociology of forest communities (Fisher et al., 1943; Sorensen, 1948; Simpson, 1949 and Margaleff, 1958). Some authors have focused their emphasis on the dispersal of people among a society's various species populations. These include Preston (1948, 1962); Margalev (1958); Hairston (1959, 1964); and Lloyd and Ghelardi (1964). According to Gause (1936), an abundance-to-rareness ratio that can be quantified is the most significant structural attribute for any given society. For the comparison of the population resemblance scores, several alternative metrics have been created by various authors (Whittaker, 1952; Bray and Curtis, 1957; Austin and Orloci, 1966). The range of an organism within a population is an essential consideration. In a community, the organisms' distribution may be dispersed in clumped, uniformly, or randomly (Odum, 1971). When doing phytosociological research in mountain locations, altitude is a crucial factor to consider. It is one of the most important elements in determining the geographical distribution of species (Zimmerman and Kienast, 1999; Lomolino, 2001). Species diversity composition and ecosystem processes alter with elevation (Sakya and Bania, 1998). Warmth and precipitation patterns are affected by the area's height, which in turn impacts the area's climatic behaviour (Arora, 1995). Tree species abundance and dispersion patterns are influenced by the elevation and slope of mountainous terrains (Ellu and Obua, 2005). Kharkwal et al., (2005) found that biodiversity decreased as altitude increased.

2.4 Classification of life form

Vegetation study also requires knowledge of the plant species' life forms. For example, it is a clear indicator of macro and micro-environmental circumstances and the vegetation's ability to respond to these circumstances (Shimwell, 1971). For the first time, Raunkiaer (1934) provided a workable criterion for describing greenery. Perennial buds, which are located at a certain distance from the ground, are responsible for producing new growth in the following year. Plant characteristics in a favourable season were added later by Mueller-Dombois and Ellenberg (1974). Seedling and sapling renewal behaviour, particularly that of native trees, has a significant impact on forest community population dynamics. Restoration will be effective if there is an adequate community of saplings (Saxena and Singh, 1984; Khan et al., 1987). Tree community pattern and regenerative behaviour have been studied in many forest environments by (Veblen et al., 1979; Cao et al., 1996; Uma Shankar et al., 1998; Bhuyan et al., 2003; Pokhriyal et al., 2010; Comita and Engelbrecht 2014) among many others.

2.5 Previously accomplished phytosociological studies

The middle Amazonian rain forest's architecture and species diversity makeup were explored by Klinge and Rodrigues (1971). Klinge et al (1977) and Klinge (1978) studied the ecosystem of the Venezuelan Caatinga woodland in the San Carlos de Rio Negro area of Venezuela. This rain forest's architecture was studied by Christopher and Murphy for the San Carlos area (1981). Bekele (1994) studied the flora and fauna of the tropical rain forests of western Ethiopia and their environmental interactions. Colorado's Rocky Mountain Nature Reserve is where Johnson (1996) conducted a phytosociological and gradient analysis. The river forest in Eastern Mato Grosso, Brazil, was examined by Marimon et al., (2002) using stratified sampling. Kerinci Seblat National Park at Sumatra was studied by Linkie et al. (2004), who examined the satellite imagery map of forest loss. According to Lovett et al. (2006), the tropical forest vegetation in Tanzania's Udzungwa Mountain National Park has changed significantly since their study was conducted. In three Nigerian farmlands that had been abandoned, Ebenezer et al. (2008) investigated the phytosociology of weed flora. Pitman (1999) investigated the Amazonian forest's tree diversity. Vegetation in South Africa's Highveld National Park was the subject of a study by Daemane (2010). An unusual form of phytocenoses was discovered by Indreica and Kelemen (2011) in the oak and fir woodland of southern eastern Transylvanian. The phytosociology of various sinuous vegetation types in the Dominican Republic was studied using the Braun-Blanquet approach by Cano et al. (2014), who discovered three distinct forest types. The richness and species richness of the damaged Takamanda Rainforest in Cameroon were also examined by Ndah et al. (2013).

Colorado's Rocky Mountain National Park provided Johnson (1996) with the opportunity to conduct a phytosociological and gradation analysis of plants. In Eastern Mato Grosso, Brazil, Marimon et al. (2002) used stratified sampling to study the stream forest. Sumatra's Kerinci Seblat National Park's forest decline was studied by Linkie and colleagues (2004) using satellite photography. In Tanzania's Udzungwa Mountain National Park, Lovett et al. (2006) examined how climate change affected the tropical forest flora. The phytosociology of weed flora was investigated by Ebenezer et al. (2008) in three Nigerian farmlands that had been abandoned. Amazonian forest tree distribution was analyzed by Pitman (1999). In South Africa's Highveld National Park, Daemane (2010) researched the ecology of plant groups. When Indreica and Kelemen (2011) looked at the phytosociology of the oak and spruce forest in southern Transylvania, they found a unique sort of phytocenoses. Using the Braun-Blanquet approach, Cano et al. (2014) explored the phytosociology of several Dominican serpentine plant communities and discovered three distinct forest types. Similarly, Ndah et al. (2013) investigated the species richness and diversity in the Cameroonian Takamanda Rainforest. Research on the phytosociology and biodiversity of flora in Palestine was conducted by Ighbareyeh et al. (2014).

2.6 Previous studies performed in Asia

The phytosociology and vegetation biodiversity of Asia's landmass have also been the subject of several studies. Geomorphological evolution of Western Malaysia and lowland forest in the quaternary period was studied by Ashton (1972). The little basic mountain in Sabah, Malaysia, was studied by Proctor (1988). Tropical rainforest trends and biodiversity were studied by Phillips (1994). The floristic content and vegetation structure of Lok Kawi's lowland forest were studied by Adam et al. (2007). Tropical forest flora in China's south-west province of Xishuangbanna was examined by Cao and Zhang (1997). Tibetan alpine woods in the northern and southern were studied by Winkler (1998), who analyzed their dispersion and breakup patterns. In China's highland redwood grove, Li Ping et al. (2011a) investigated the elements that influence the structure and function. Phytosociology of subalpine coniferous forests in Korea was researched by Song (1991). Studying the rain forest vegetation communities on Mount Kinabalu in Borneo, Aiba and Kitayama looked at the architecture, structure, and diversity of species (1999). *Picea jezoensis* phytosociology in Far Eastern Japanese woods was examined by Krestov and Nakamura (2002). An extensive study by Shimono et al. (2010) looked at the patterns of plant variety on the Tibetan plateau at high altitudes. Phytosociological sampling, structure, age, and development rates of pine forests in the Dangam province of Afghanistan were studied by Wahab et al. (2008). In Pakistan's Chhumbi Surla wildlife sanctuary, Chaudhry et al. (2001) conducted phytosociological research. Ahmed et al. (2006a) measured the vegetation status in Pakistan's major climatic zones. In the north Pakistani valley of Chagharzai, researchers Sher and Khan (2007) counted 223 different types of plants. Similar to Sobuj & Rahman (2011), Khadimnagar National Park in Bangladesh was studied for its plant variety. In Bangladesh's Chittagong Hill Tracts Forest Division, Nath et al. (2000) investigated the tree species diversity in the Sitaphar Forest Reserve. An investigation of the Himalayan height gradient in Nepal was carried out by Vetaas and Grytnes (2002). A subtropical altitude variation in Eastern Nepal was examined by Bhattarai and Vetaas (2003) for its effect on the diversity of plant species. In Nepal's Trans Himalayan Plateau, Panthi et al. (2007) evaluated the link between plant diversity and elevation between altitudes of 3000 and 4000 m. The phytosociology of East Asian Beech forests was researched by Hukusima et al. (2013).

2.7 Previous studies in the subcontinent of India

In the Indian subcontinent, several forest ecosystems have been studied for decades for their vegetation analysis, diversity of species, and ecosystem processes. In the Pir Chinasi hills of Jammu and Kashmir, Malik et al. (2007) examined the phytosociological characteristics of several plant groups. The Sarsawa Hills in Jammu and Kashmir were studied by Nazir et al. (2012), who conducted phytosociological investigations of the flora in relation to environmental factors and human impacts. For the study of contaminated environments in Jaipur, Sharma and colleagues (2001) recorded 74 species of plants. Sharma and Pandey did research on the phytosociology of a few specific dry locations of the Thar Desert (2010). This decade has seen a flurry of activity in the Western Himalayan areas. In the Himalayan Mountain alpine meadows, researchers Nautiyal et al. (2001) looked at phenology and the dispersion of growth forms. Kala and Mathur (2002) studied the dispersal of plants in the Trans-Himalayan area of Ladakh, India, along an altitude gradient. In northern Indian tropical dry deciduous woods, Sagar and Singh (2004) investigated the reproductive fragility of native trees. The vegetation diversity of the Kuther watershed in Himachal Pradesh was studied by Gupta et al. (2014). According to Chawla et al. (2008), 313 species of plants were found in the Bhabha Valley's altitude gradient. A study conducted by Gairola et al. (2008) examined the structure of vegetation cover along an elevational variation in the west Himalaya's sub-alpine zone. In the subtropical Northwest Himalaya area, between 1100 and 1400 metres above sea level, Kukshal et al. (2009) conducted phytosociological research and life form patterns investigation on grazing land.

Khan et al. (2012) investigated the relationship between topography and climatic variability on the Western Himalayan vegetation change. Jaykumar and Nair studied the diversity of species and tree rejuvenation patterns in the Western Ghats tropical forests (2013). Andhra Pradesh's Srikakulam district is home to 129 tree species, 96 genera, and 46 families, according to Rao et al. (2013), who studied the phytosociological patterns of native trees in the tropical forest. Tree stands in the tropical Eastern Ghats of northern Andhra Pradesh were examined by Reddy et al. (2011). As an example, at the red sand dunes near Bhimili in Visakhapatnam, researchers conducted research on phytosociology, soil protection, and economic factors. Ray and George studied the phytosociology of an environmentally tolerant roadside community in Kerala (2009). Aside from those areas, the variety of Indian Region has been examined by previous researchers in places like the Madhumalai deciduous forest (Sukumar et al., 1992) and the Western Ghats wet evergreen forest (Parthasarathy et al., 1992; Pascal and Pelissier, 1996). In the Western Ghats tropical rain forest, Visalakshi investigated the floral variety (1995). Mohanan and Sivadasan took on the task of cataloguing the flora of Agasthyamala (2002). Various forest populations in the middle Himalayas were researched by Singh and Singh (1986). Numerous projects have been undertaken in the Eastern Himalayan area during the past few decades. The eastern Himalayan woods were examined by Nath and Banerjee (1986) for their phytosociology and soil properties. Bankoti et al. examined tree species composition and community composition in the Kumaon Himalaya's altitudinal gradient (1986). Floristic richness and availability to frequency ratio of woods, bushes and herbs in tropical forests of Garhwal Himalaya were examined by Kumar and Bhatt (2006). Tree species richness and geographic distribution in tropical forests of Garo Hills were studied by Kumar et al., (2006). *Anogeissus latifolius* hybrid forests of the Garhwal Himalayas were researched by Todaria et al., 2009, as well. Tree species were studied by Devlal and Sharma (2008), who found that *Quercus leucotricophora* was the most common in the Garhwal Himalayan range. In the Kumaon Himalaya, Hussain et al. (2008) studied the species diversity and ecosystem functioning of several forest stands between the altitudes of 1500 and 3000 above mean sea level. Analysis of plant communities and soil properties of Garhwal Himalayan Oak and Pine forests by Singh et al., (2009) Research by Uniyal and colleagues in the Himalayan watershed Garhwal Himalaya examined the plant variety of two different forest types. Raturi (2012) studied the forest community composition in the Rudraprayag area of the Garhwal Himalaya and identified four distinct forest types based on the elevational gradient. Forests in Uttarakhand's temperate forests between 1900 and 2200 metres altitude were examined by Rawat and Chandra (2012). Orissa's Eastern Ghats rainforests differ in composition, variety, and structure, according to a study by Reddy et al. (2007). The flora of Sambalpur was studied in depth by Panda and Das (2004). The Gangotri Valley's natural woods were studied by Kumar et al., (2008), who looked at their regeneration capacity and community structure.

2.8 Previous studies in North-East India

Researchers like Jamir & Pandey (2003), Chatterjee et al. (2006), and Mao et al. (2007) conducted floristic diversity research in the region's north-eastern corner (2009). Bora and Kumar (2003) worked on the fauna of Assam, whereas Barooah & Borthakur (2009) investigated the variety and dispersion of bamboos in Assam (2003). Ghosh et al. examined the pteridophytic vegetation of Eastern India (2004). Plants and fern-allies of the state of Arunachal Pradesh were studied by Singh and Panigrahi (2005). Utilizing remote sensing techniques from the Eastern Himalayas, Behera and Roy (2005) studied the biodiversity of Arunachal Pradesh. In Manipur's tropical quasi forest, Devi and Yadava (2006) examined the flora. According to Rana and

Gairola (2009), the forest population structure in Lohit district of Arunachal Pradesh was analyzed along an altitude gradient. Research conducted by Tripathi et al. (2010a) examined species of trees in the Northeast India's scattered sub tropical humid forest. Hajra and Verma conducted research of Sikkim's flora (1996). Sikkim Himalayan plant diversity was studied by Singh and Chauhan (1997). The Kanchenjunga Biosphere Reserve in Sikkim was studied by Maity and Maiti (2007). Pangolakha Wildlife Sanctuary in Sikkim's Lepcha (2010) studied and elaborated on its virgin flora. The Khangchendzonga landscape in Sikkim Himalaya was investigated by Tambe and Rawat (2010). Biodiversity distribution on the Indian subcontinent is discussed in seven chapters in the Flora of India (Hajra et al., 1993-2000) by the Botanical Survey of India. According to Hooker's "Flora of British India" (1872–1879), the provincial floras are presented in more detail. Numerous forests have been documented in floras such as Brandis' 1906 and Talbot's 1909-11 and Parkinson's 1918 and Osmaston and Gamble's 1984.

2.9 Previous studies in West Bengal

Roxburgh, on the other hand, has identified no earlier publications on West Bengal's floristic effort (1814). Roxburgh's "Hortus Benghalensis," published in 1814, included 3500 plant species grown at the Calcutta Botanic Garden. Bengali flora was the subject of many significant publications by Long (1857-59) around this time period. As "Bengal Plants," Prain described the vegetation of the Bengal Plains in two volumes in 1903. Several decades of renewed interest in floristics have been spurred by a resurgence of botanical activism. Sanyal (1994) made a significant contribution to our understanding of Bankura's forest flora. The vegetation of Murshidabad district was studied by Bakshi (1984). Some other floristic accounts of this research include Malick (1966), Sikdar and Samanta (1983), the greenery of Institutes district by Sikdar, and Krishna, and Dutta (1983), the vegetation of Malda district by Krishna, and Chowdhury (2009), the framework of the vegetative cover in the Malda district wetlands by Chowdhury. Plant identification was done in Burdwan and Jalpaiguri districts by Bhattacharya (1986), Mukherjee (1965). Birbhum district's flora was studied by Guha (1968), Dutta and Majumdar (1966), Banerjee (1968) and Banerjee and Pal (1974) for the Indian Botanic Garden, Maji and Sikdar (1983) for Bankura district and Guha (1968) for Birbhum district. The phytosociology of Biharinath hill in West Bengal was examined by Basu (2009), who found 118 species there. The phytosociology of medicinal conservation zones in the Duars area was examined by Das et al. (2010). Selections of Durgapur woodlands were studied by Bauri et al. (2013) for their phytosociology. Chilapata reserve forest in the mono tropical region of Duars, West Bengal, was studied by Shukla et al. (2014) for its plant variety. In addition to the numerous floral studies conducted by botanists, the province Bengal has seen the discovery of numerous new taxa and differential records.

2.10 Previous studies in Darjeeling

Botanical investigations in the Darjeeling hills began in 1872, when Gamble visited North Bengal and became attracted by the variety of woods found across Darjeeling (Gamble, 1875). He compiled a comprehensive and lengthy inventory of the town's more than 800 trees, bushes, and woody climber species. That list was bolstered by Cowan and Cowan (1929). Hooker's historical voyage from Darjeeling to Sikkim through Darjeeling and the Singalila Mountain provided a wonderful account of the Himalayan flora from the foothills to the highest point at Tonglo (Hooker, 1849). While on the lowlands and up to 1600 metres, he decided that all flora was tropical, while above this point to 3600 metres it was moderate. He also made extensive specimens in the Darjeeling area, and published significant observations on this botanically rich valley, Clarke (1876, 1885). From Darjeeling through Tonglo, and on up to Sandakphu, he mainly described his findings. Forest kinds of Darjeeling Himalayan range from North tropical quasi forest to Eastern sub-montane semi-evergreen forest, North Indian moist trees and shrubs eastern hill Sal forest, North Indian moist trees and shrubs forest, North Indian moist deciduous Eastern bhabar Sal forest, Eastern Himalayan sub-tropical wet temperate forest, Eastern Himalayan sub-tropical wet hill forest, Montane forest, and Dash (1947) categorized the Darjeeling hills' Darjeeling forest into three distinct types based on altitude: Lower, Middle, and Upper.

2.11 Summary

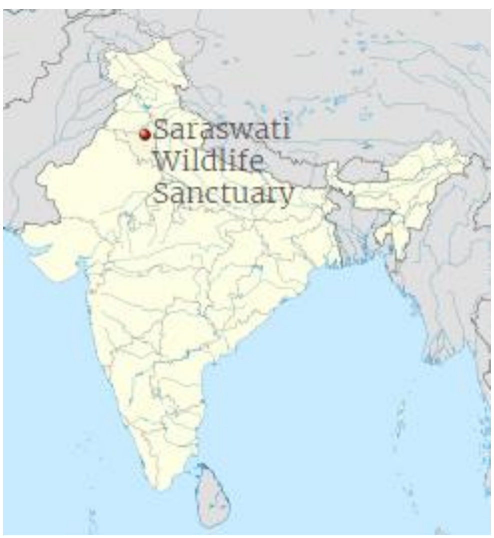
Considering all the above mentioned facts and findings it can be stated that, in this literature review section the evolutionary context of phytosociology has been discussed. The journey was initiated with naming of the term ‘phytosociology’ and after that this section of plant ecology was completely integrated to biodiversity and population ecology where plant biologists and ecologists prefer using spatial characteristics of plant species in different forests and eco-geological regions. In this regard, as the main objective of this research is to investigate phytosociology of Saraswati Wildlife Sanctuary, it is considered very essential to develop good understanding and idea on previous work that has already been accomplished by other authors and researchers in other forest regions across the world. Considering the context, in this study, specific focus has been given to previous research that has been placed in different Asians countries such as China, India, Malaysia, Korea, and Japan. Considering the findings, it has been suggested that India is extremely diverse in its’ biotic fauna and flora. Different climatic regions of the country contains different plant species where the diversity is mainly dependent on some major determinants including soil structure, climate, altitude, soil activity, water activity, precipitation, and human activities. Specific focus on plant diversity in Indian sub-continent, West Bengal, Darjeeling, and North-Bengal has significantly increased the essence of the study.

Chapter 3

Materials and Methods

3.1 Study site

The study was carried out at the Saraswati Wildlife Sanctuary, also called the Seonsar forest, which is located in the Kaithal district of Haryana, India (Figure 3.1). It falls between 29˚59'34" North latitude and 76˚21'24" East longitude, and covers an area of 4452.85 hectares. The altitude of the study site is 215 m above mean sea level. It is the third largest forest in Haryana after the Kalesar National Park and Morni Hills. The Saraswati Wildlife Sanctuary is located at a distance of 10 km from Pehowa, 40 km from Kurukshetra, 60 km from Kaithal along the Pehowa-Cheeka-Patiala Road, 62 km from Patiala, 66 km from Ambala, 108 km from Chandigarh, 150 km from Hisar, 67 km from Karnal, and 200 km from Delhi. It is just 30 km from the Bir Gurdialpura Wildlife Sanctuary located in Patiala District, Punjab.

(a) 

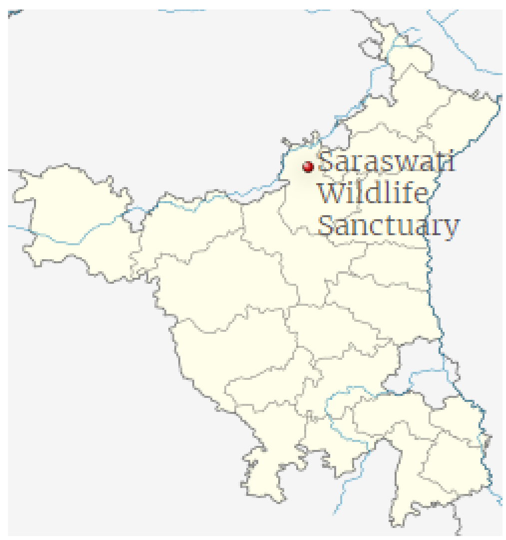
(b) 

Figure 3.1: Location of the Saraswati Wildlife Sanctuary in (a) India, and (b) Haryana

The climate of the site is tropical monsoonal and semi-arid. There are 3 different climatic divisions in a typical year at the site – a warm wet period or the rainy season that lasts from June to September, a cool dry period or the winter season that lasts from October to February, and a hot dry period or the summer season that lasts from March to May (Bhalla and Gupta, 2013).

The annual rainfall in the location is 516 mm, and the mean temperature is 32.4˚C (Kumar, 2014). The vegetation of the Saraswati Wildlife Sanctuary has been classified as "Sub-group 5B tropical deciduos forest" (Dagar et al., 2001). The soil at the study site is old alluvium having a sandy-loam texture. The pH of the soil is between 7.44 and 8.11, and the electric conductivity of the soil is between 1.17 and 1.80 dSm^{-1}, indicating that the soil is slightly alkaline in nature (Bhalla and Gupta, 2013).

3.2 Quadrat method of phytosociological analysis

Phytosociology is the relationship between plant communities and the characteristics and classification of the vegetation in a given location. It helps in providing meaning to a biodiversity analysis by enabling the quantification of the structural parameters of plant communities. In this study, the quadrat method of analysis was used wherein the vegetation of any location is sampled by dividing the entire site into plots of equal sizes. This method allows the researcher to acquire the maximum possible information about plant communities in minimum time and with the least amount of efforts (Roy et al., 1993).

In order to carry out a phytosociological analysis of the Saraswati Wildlife Sanctuary, the entire study area was divided into three different sizes of quadrats based on the type of vegetation analyzed as represented in Table 3.1. These quadrats were used to collect data of trees, shrubs, and herbs to assess the predominant species, and the richness and diversity of species. A total of 10 quadrats of 10 x 10 square meter each were used to carry out the analysis in the study site at altitude 257 meters above mean sea level (AMSL). Stratified random sampling was used to analyze the entire vegetation composition in the study site. Each of the quadrats was fixed on the vegetation map and located on the ground using GPS (Global Positioning System). Using the census quadrat method (Oosting, 1956), a 5 x 5 square meter plot in the centre of each quadrat was used for the analysis of shrubs and a 1 x 1 square meter plot in the corners of each quadrat was used for the analysis of herbs. The location of each of the ten quadrats is given in Table 3.2.

Table 3.1: Plant categories analyzed and their corresponding number and size of quadrats

Plant category	Number and size of quadrats
Trees	10 quadrats; 20 x 20 square meter each
Shrubs	5 quadrats; 5 x 5 square meter each
Herbs	5 quadrats; 1 x 1 square meter each

Table 3.2: Location coordinates of quadrats used for phytosociological analysis of trees

Quadrat	Location coordinates
Q1	N 29˚ 58’ 59” E 76˚ 29’ 15”
Q2	N 29˚ 59’ 26” E 76˚ 29’ 41”
Q3	N 29˚ 59’ 9” E 76˚ 29’ 35”
Q4	N 29˚ 59’ 8” E 76˚ 29’ 57”
Q5	N 30˚ 0’ 25” E 76˚ 30’ 28”
Q6	N 29˚ 59’ 22” E 76˚ 30’ 22”
Q7	N 30˚ 0’ 12” E 76˚ 30’ 9”
Q8	N 30˚ 0’ 32” E 76˚ 30’ 8”
Q9	N 30˚ 1’ 27” E 76˚ 31’ 50”
Q10	N 25˚ 59’ 81” E 76˚ 29’ 17”

In each of the respective quadrats, the names of each species of trees, herbs, and shrubs was recorded along with its number and the CBH (Circumference at Breast Height) or DBH (Diameter at Breast Height). Trees having a CBH greater than 31.5 cm and a height greater than 1.37 m above ground were measured for girth. Analysis of shrubs was carried out by enumerating the total number of tillers for each species. The equipment that was used for carrying out the measurements is given in Table 3.3.

Table 3.3: Equipment used for measurements for phytosociological analysis

Equipment	Use
Measuring tape	Layout of quadrats
Vernier Caliper	Measurement of CBH / DBH
Rope	Framing around the quadrats

3.3 Analysis of phytosociological parameters – Floristic composition

The quantitative analysis of the plant species in terms of frequency, density, and abundance was carried out using the methods of Misra (1968) and Ambasht (1969). The analysis of relative frequency, relative density, and relative dominance were carried out using the methods of Phillips (1959), Tansley (1946), and Oosting (1956). The various phytosociological parameters that were calculated for each individual species found in the quadrats are given below:

3.3.1 Density

This parameter provides an indication of the numerical strength of a plant species in a vegetation community. In common words, it is the number of individuals of species per unit area of land. It can be calculated using the following formula:

$$\text{Density} = \frac{\text{Number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

3.3.2 Frequency

Frequency refers to the number of sampling units where a particular species occurs thereby expressing the dispersion or distribution of species in a vegetation community. It gives the percentage occurrence of a species in a given area. It is obtained using the following formula:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which species occur}}{\text{Total number of quadrats studied}} \times 100$$

3.3.3 Abundance

This parameter provides an appreciation of the total number of individuals of various species in a vegetation community in each quadrat. It refers to the number of individuals of a species per unit of occurrence. It is expressed as plants per unit area. It can be calculated using the following formula:

$$\text{Abundance} = \frac{\text{Number of individuals of a species in all quadrats}}{\text{Number of quadrats in which species occur}}$$

3.3.4 Relative abundance

This presents the proportion of abundance of a species to the abundance of all species in the community. It can be calculated using the following formula:

$$\text{Relative abundance (\%)} = \frac{\text{Abundance of one species}}{\text{Sum of abundance of all species}} \text{ X } 100$$

3.3.5 Basal area

Basal area provides an index of the dominance of a given species. Lower the basal area, lesser the dominance, and vice versa. It is usually calculated using the average circumference of the plant at breast height with the help of the following formula:

$$\text{Basal area} = \frac{(\text{CBH})^2}{4\pi}$$

3.3.6 Relative density

Relative density refers to the numerical strength of a given species in comparison to the total number of individuals of all the species found in all analyzed quadrats. It is the proportion of density of a single species to all the species. It can be obtained using the following formula:

$$\text{Relative density (\%)} = \frac{\text{Density of one species}}{\text{Sum of densities of all the species}} \times 100$$

3.3.7 Relative frequency

This parameter indicates the proportion of the frequency of each individual species to that of all the species together. It is calculated using the following formula:

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of one species}}{\text{Sum of frequency of all species}} \times 100$$

3.3.8 Relative dominance

This value gives the proportion of the basal area of each individual species to the basal area of all species in all the quadrats analyzed. It is obtained using the following formula:

$$\text{Relative dominance (\%)} = \frac{\text{Total basal cover of a species}}{\text{Total basal cover of all the species}} \times 100$$

3.3.9 Importance Value Index (IVI)

The frequency parameter gives an indication of species distribution in a given area, the density parameter indicates the numerical strength of a species, and the dominance parameter indicates the basal cover of a species. When the percentage values of all these 3 parameters, i.e. relative frequency, relative density, and relative dominance, are added together, it gives the IVI value out of 300, which represents the overall ecological status of each individual species in a given vegetation community (Curtis and McIntosh, 1950; Misra, 1968). This value gives a complete picture of the sociological structure of each species in a vegetation community by enabling the researcher to compare the vegetational structure of the entire community and also, changes in the vegetational structure over time. The following formula is used to calculate IVI.

IVI = Relative frequency + Relative density + Relative dominance

3.3.10 Ni/N

This parameter gives the proportion of the number of individuals in each species to the number of individuals in all species in a given community. It can be obtained using the following formula:

$$Ni/N = \frac{\text{Total number of individuals of a species}}{\text{Total number of individuals of all species}}$$

3.4 Analysis of phytosociological parameters – Diversity Indices

One of the most direct ways to measure ecosystem fitness is by using community diversity. Diversity is a measure of the variation of species under different ecological circumstances. A diversity index can be used to indicate the relative significance of the factors that affect the entire population balance (Prasad, 2015). There are two distinct components of diversity – the total number of species in a given vegetation community and the distribution of abundance data among the species. The first component indicates the species richness and the second component indicates the equitability or species evenness. In general, diversity is considered as the function of relative distribution of individuals of a species in a given community (Prasad, 2015). In this study, the phytosociological parameters calculated using the above formulae were used to derive the values for three different diversity indices as described below:

3.4.1 Simpson's index

The Simpson's diversity index (Simpson, 1949) gives the index of dominance of the vegetation community. It is a measure of the degree of concentration of a particular species. Smaller values of the index indicate higher diversity and larger index values indicate lower diversity. The Simpson's index was calculated using the following formula:

Simpson's index (C) = $(Ni/N)^2$

where, Ni is the total number of individuals in a given species, and

N is the total number of individuals of all species

3.4.2 Shannon and Weiner diversity index

The Shannon-Weiner diversity index or information index (Shannon and Weiner, 1963) provides data regarding the evenness of distribution of individuals among the species. A maximum value of the index indicates that all species are equally abundant in the community. This index was calculated using the following formula:

Shannon-Weiner index (H) = - Σ (Ni/N) log2 (Ni/N)

where, Ni is the total number of individuals in a given species, and

N is the total number of individuals of all species

3.4.2 Pielou's index

The Pielou's index of evenness (Pielou, 1966) quantifies the equality in the number of each individual species in a vegetation community. High level of species evenness is indicated by a high value of the index and vice versa. It is calculated by making use of the Shannon-Weiner index value in the following formula:

Pielou's index (J) = H/ln(S)

where, H is the Shannon-Weiner diversity index value, and

S is the total number of species in the community

All the above mentioned phytosociological parameters and diversity indices were calculated for all identified species of trees, shrubs, and herbs across all quadrats and the results were tabulated.

Chapter 4

Results

4.1 Phytosociological Analyses

Using the quadrat method, the phytosociological attributes and diversity indices of trees, shrubs, and herbs of the Saraswati Wildlife Sanctuary were calculated. Among the quantitative attributes, density, frequency, abundance, relative abundance, basal area, relative density, relative frequency, relative dominance, importance value index (IVI), and Ni/N were calculated. Among the diversity indices, the Simpson, Shannon, and Pileou indices were calculated. The results of both floristic composition and diversity indices for trees, shrubs, and herbs are described below.

4.2 Floristic Composition of Trees

Table 4.1 provides the values of the phytosociological attributes of trees in the Saraswati Wildlife Sanctuary. A total of 8 species of trees were identified in the analyzed quadrats, 3 belonging to the Fabaceae family, 2 to the Myrtaceae family, 2 to the Moraceae family, and 1 to the Meliaceae family. Out of these, the highest density (about 50%) was contributed by *Prosopis juliflora* (237.5) out of a total density of all species being 437.5. The second highest density was shown by *Eucalyptus* sp. at 120. The remaining tree species showed smaller densities with *Acacia nilotica* at 25, *Morus alba* at 22.5, *Pongamia pinnata* at 12.5, *Melia azadirachta* at 10, and *Syzgium cumini* and *Ficus religiosa* at 5 each. The highest frequency was demonstrated by *Prosopis juliflora* at 90%, the second highest frequency was shown by *Eucalyptus* sp. at 70%, and the third highest frequency was contributed by *Morus alba* at 40%. All the rest of the species were present at 10% frequency in the analyzed quadrats. Out of a total abundance of 42.662, the highest was contributed by *Prosopis juliflora* (10.555), closely followed by *Acacia nilotica* (10). The third highest abundance was shown by *Eucalyptus* sp. (6.857). The minimum abundance was shown by *Syzgium cumini* and *Ficus religiosa* (2). The total basal area of all the tree species was found to be 40.545, out of which the maximum was contributed by *Ficus religiosa* (24.21). This was followed by *Eucalyptus* sp. at 10.533, *Morus alba* at 2.579, and *Prosopis juliflora* at

1.775. The basal area of all the remaining species was below 1.0, with the lowest being at 0.0008 demonstrated by *Syzgium cumini*.

Considering the relative abundance, the maximum was contributed by *Prosopis juliflora* at 24.743, closely followed by *Acacia nilotica* at 23.441. The next highest relative abundance was shown by *Eucalyptus* sp. at 16.074 and *Pongamia pinnata* at 11.721. All the remaining species had a relative abundance below 10, with the lowest being shown by *Syzgium cumini* and *Ficus religiosa* at 4.688 each. Comparing the relative densities, the highest was demonstrated by *Prosopis juliflora* (54.286) followed by *Eucalyptus* sp. (27.429). All the remaining species showed very less relative densities, with the lowest being shown by *Syzgium cumini* and *Ficus religiosa* at 1.142 each. The maximum relative frequency was shown by *Prosopis juliflora* at 36, followed by *Eucalyptus* sp. at 28 and *Morus alba* at 16. All the remaining species contributed a relative frequency of 4 each. With respect to the relative dominance, the maximum was contributed by *Ficus religiosa* (59.719) followed by *Eucalyptus* sp. (25.982). The rest of the species had a relative dominance of less than 10, with the least being shown by *Syzgium cumini* (0.002).

The importance value index (IVI) of *Prosopis juliflora* was highest at 94.664, followed by *Eucalyptus* sp. at 81.41 and *Ficus religiosa* at 64.862. *Morus alba* had an IVI value of 27.504, *Acacia nilotica* had an IVI of 11.789, *Melia azadirachta* had an IVI of 7.542, and *Pongamia pinnata* had an IVI of 7.097. The lowest IVI value was obtained for *Syzgium cumini* at 5.145. Considering the Ni/N value, the highest was shown by *Prosopis juliflora* (0.316), *Eucalyptus* sp. (0.271), and *Ficus religiosa* (0.216). The remaining species had low Ni/N values, with the lowest being 0.017 demonstrated by *Syzgium cumini*.

Table 4.1: Floristic composition of trees in the Saraswati Wildlife Sanctuary using the quadrat method of analysis (D – Density; F – Frequency; A – Abundance; RA – Relative Abundance; BA – Basal Area; RD – Relative Density; RF – Relative Frequency; Rdom – Relative Dominance; IVI – Importance Value Index)

S No	Plant Name	Family	D	F (%)	A	RA	BA	RD	RF	RDom	IVI	Ni/N
1.	*Morus alba*	Moraceae	22.5	40	2.25	5.274	2.579	5.143	16	6.362	27.504	0.092
2.	*Melia azadirachta*	Meliaceae	10	10	4	9.376	0.51	2.286	4	1.257	7.542	0.025
3.	*Prosopis juliflora*	Fabaceae	237.5	90	10.555	24.743	1.775	54.286	36	4.378	94.664	0.316
4.	*Eucalyptus* sp.	Myrtaceae	120	70	6.857	16.074	10.533	27.429	28	25.982	81.41	0.271
5.	*Acacia nilotica*	Fabaceae	25	10	10	23.441	0.841	5.714	4	2.074	11.789	0.039
6.	*Pongamia pinnata*	Fabaceae	12.5	10	5	11.721	0.097	2.857	4	0.24	7.097	0.024
7.	*Syzgium cumini*	Myrtaceae	5	10	2	4.688	0.0008	1.143	4	0.002	5.145	0.017
8.	*Ficus religiosa*	Moraceae	5	10	2	4.688	24.21	1.143	4	59.719	64.862	0.216
Total			**437.5**	**250**	**42.662**	**100**	**40.545**	**100**	**100**	**100**	**300**	

4.3 Diversity Indices of Trees

Table 4.2 provides the values of diversity indices of the tree species found in the analyzed quadrats of the Saraswati Wildlife Sanctuary. As is evident from the table, the values of Simpson's index range from 0.0003 (*Syzgium cumini*) to 0.0996 (*Prosopis juliflora*) with the other species following between these values. Overall, the values of Simpson's index are low, indicating that there is high species diversity in the vegetation community at the Saraswati Wildlife Sanctuary. The values of Shannon's index range from 0.0697 (*Syzgium cumini*) to 0.364 (*Prosopis juliflora*) indicating that the equality in abundance of all species in the community is low. Furthermore, the values of Pielou's index range from 0.0317 (*Syzgium cumini*) to 0.1656 (*Prosopis juliflora*), indicating that the species evenness in the community is low.

Table 4.2: Diversity indices of trees in the Saraswati Wildlife Sanctuary using the quadrat method of analysis

S No	Plant Name	Family	Simpson's Index	Shannon's Index	Pielou's Index
1.	*Morus alba*	Moraceae	0.0084	0.2191	0.0998
2.	*Melia azadirachta*	Meliaceae	0.0006	0.0926	0.0421
3.	*Prosopis juliflora*	Fabaceae	0.0996	0.364	0.1656
4.	*Eucalyptus* sp.	Myrtaceae	0.0736	0.3539	0.1611
5.	*Acacia nilotica*	Fabaceae	0.0015	0.1271	0.0579
6.	*Pongamia pinnata*	Fabaceae	0.0006	0.0886	0.0403
7.	*Syzgium cumini*	Myrtaceae	0.0003	0.0697	0.0317
8.	*Ficus religiosa*	Moraceae	0.0467	0.3311	0.1507

4.4 Floristic Composition of Shrubs

Table 4.3 provides the values of the phytosociological attributes of shrubs in the Saraswati Wildlife Sanctuary. A total of 6 species of shrubs were identified in the analyzed quadrats, 2 belonging to the Malvaceae family, and each of the others belonging to the Apocynaceae, Capparaceae, Asteraceae, and Lythraceae families respectively. Out of these, the highest density (572.5 out of 777.5) was contributed by *Parthenium hysterophorus*, of the Asteraceae family. The second highest density was shown by *Capparis sepiaria* at 97.5 and the third highest density was contributed by *Abitilon indicum* at 57.5. The remaining shrub species showed comparatively lower densities with *Urena lobata* at 35, *Calotropis procera* at 10, and *Punica granatum* at 5.

The highest frequency was demonstrated by *Capparis sepiaria* at 60%, the second highest frequency was shown by *Parthenium hysterophorus* at 50%, and the third highest frequency was contributed by *Abitilon indicum* at 40%. The frequencies of the rest of the species were *Urena lobata* at 30%, *Calotropis procera* at 20%, and *Punica granatum* at 10%. Out of a total abundance of 65.717, the highest was contributed by *Parthenium hysterophorus* (45.8). The remaining shrub species showed very low abundance with *Capparis sepiaria* at 6.5, *Abitilon indicum* at 5.75, *Urena lobata* at 4.667, *Punica granatum* at 2, and *Calotropis procera* at 1. The total basal area of all the shrub species was found to be 2.349, out of which the maximum was contributed by *Capparis sepiaria* (1.571). This was followed by *Punica granatum* at 0.753, *Parthenium hysterophorus* at 0.021, *Abitilon indicum* at 0.002, and *Urena lobata* at 0.001. The basal area of *Calotropis procera* was lowest at 0.0004.

Considering the relative abundance, the highest was contributed by *Parthenium hysterophorus* at 69.7. All the remaining shrub species had a relative abundance of less than 10 with *Capparis sepiaria* at 9.892, *Abitilon indicum* at 8.751, *Urena lobata* at 7.102, *Punica granatum* at 3.044, and *Calotropis procera* at 1.522. Comparing the relative densities, the highest was demonstrated by *Parthenium hysterophorus* at 73.633. Similar to relative abundance, all the remaining species showed very less relative densities, with *Capparis sepiaria* at 12.54, *Abitilon indicum* at 7.395, *Urena lobata* at 4.502, *Calotropis procera* at 1.286, and *Punica granatum* at 0.643. The maximum relative frequency was shown by *Capparis sepiaria* at 28.571, followed by *Parthenium hysterophorus* at 23.81 and *Abitilon indicum* at 19.048. All the remaining species contributed a relative frequency of less than 15, with *Urena lobata* at 14.286, *Calotropis procera* at 9.524, and *Punica granatum* at 4.762. With respect to the relative dominance, the maximum was contributed by *Capparis sepiaria* (66.893) followed by *Punica granatum* (32.063). The rest of the species had a relative dominance of less than 1, with *Parthenium hysterophorus* at 0.898, *Abitilon indicum* at 0.085, *Urena lobata* at 0.045, and *Calotropis procera* at 0.016.

The importance value index (IVI) of *Capparis sepiaria* was highest at 108.005, followed by *Parthenium hysterophorus* at 98.341. The remaining shrub species had lower IVI values with *Punica granatum* at 37.468, *Abitilon indicum* at 26.528, and *Urena lobata* at 18.832. The lowest IVI value was obtained for *Calotropis procera* at 10.826. Considering the Ni/N value, the highest was shown by *Capparis sepiaria* (0.36), followed by *Parthenium hysterophorus* (0.328), and *Punica granatum* (0.125). The remaining species had low Ni/N values, with *Abitilon indicum* at 0.088, *Urena lobata* at 0.063, and *Calotropis procera* at 0.036.

Table 4.3: Floristic composition of shrubs in the Saraswati Wildlife Sanctuary using the quadrat method of analysis (D – Density; F – Frequency; A – Abundance; RA – Relative Abundance; BA – Basal Area; RD – Relative Density; RF – Relative Frequency; Rdom – Relative Dominance; IVI – Importance Value Index)

S No	Plant Name	Family	D	F (%)	A	RA	BA	RD	RF	RDom	IVI	Ni/N
1.	*Abitilon indicum*	Malvaceae	57.5	40	5.75	8.751	0.002	7.395	19.048	0.085	26.528	0.088
2.	*Calotropis procera*	Apocynaceae	10	20	1	1.522	0.0004	1.286	9.524	0.016	10.826	0.036
3.	*Capparis sepiaria*	Capparaceae	97.5	60	6.5	9.892	1.571	12.54	28.571	66.893	108.005	0.36
4.	*Parthenium hysterophorus*	Asteraceae	572.5	50	45.8	69.7	0.021	73.633	23.81	0.898	98.341	0.328
5.	*Punica granatum*	Lythraceae	5	10	2	3.044	0.753	0.643	4.762	32.063	37.468	0.125
6.	*Urena lobata*	Malvaceae	35	30	4.667	7.102	0.001	4.502	14.286	0.045	18.832	0.063
Total			**777.5**	**210**	**65.717**	**100**	**2.349**	**100**	**100**	**100**	**300**	

4.5 Diversity Indices of Shrubs

Table 4.4 provides the values of diversity indices of the shrub species found in the analyzed quadrats of the Saraswati Wildlife Sanctuary. As is evident from the table, the values of Simpson's index range from 0.001 (*Calotropis procera*) to 0.13 (*Capparis sepiaria*) with the other species following between these values. Overall, the values of Simpson's index are low, indicating that there is high species diversity in the vegetation community at the Saraswati Wildlife Sanctuary. The values of Shannon's index range from 0.12 (*Calotropis procera*) to 0.368 (*Capparis sepiaria*) indicating that the equality in abundance of all species in the community is low. Furthermore, the values of Pielou's index range from 0.067 (*Calotropis procera*) to 0.205 (*Capparis sepiaria*), indicating that the species evenness in the community is low.

Table 4.4: Diversity indices of shrubs in the Saraswati Wildlife Sanctuary using the quadrat method of analysis

S.No.	Plant Name	Family	Simpson's Index	Shannon's Index	Pielou's Index
1.	*Abitilon indicum*	Malvaceae	0.0078	0.2145	0.1197
2.	*Calotropis procera*	Apocynaceae	0.0013	0.1199	0.0669
3.	*Capparis sepiaria*	Capparaceae	0.1296	0.3678	0.2053
4.	*Parthenium hysterophorus*	Asteraceae	0.1075	0.3656	0.2041
5.	*Punica granatum*	Lythraceae	0.0156	0.2598	0.145
6.	*Urena lobata*	Malvaceae	0.0039	0.1738	0.097

4.6 Floristic Composition of Herbs

Table 4.5 provides the values of the phytosociological attributes of herbs in the Saraswati Wildlife Sanctuary. A total of 27 species of herbs were identified in the analyzed quadrats, 6 belonging to the Amaranthaceae family, 4 to the Asteraceae family, 3 each to the Poaceae and Malvaceae families, 2 to the Solanaceae family, and 1 each to the Nyctaginaceae, Cannabaceae, Menispermaceae, Convolvulaceae, Brassicaceae, Oxalidaceae, Acanthaceae, Polygonaceae, and Caryophyllaceae families. Out of these, the highest density (more than 50%) was contributed by *Cynodon dactylon* (10,702.5) out of a total density of all species being 19,410. The second highest density was shown by *Chenopodium album* at 2060, and the third highest density was contributed by *Cannabis sativa* at 1982.5. The remaining herb species showed smaller densities with 8 species having densities between 100 and 1000, and the remaining 16 species having densities less than 100. The lowest density was demonstrated by *Boerhavia diffusa* at 7.5. The frequencies of the herb species ranged from 10% to 90%, with the highest frequency demonstrated by *Chenopodium album* (90%) and the lowest frequency demonstrated by *Sida cordifolia* (10%). All the remaining species had frequencies between this range with 12 species showing 20% frequency each, 6 species showing 30% frequency each, 2 species showing 40% frequency each, 1 species showing 50% frequency, 2 species showing 60% frequency each, and 1 species showing 70% and 80% frequencies each. Out of a total abundance of 1,368.523, the highest was contributed by *Cynodon dactylon* (535.15), followed by *Coronopus didymus* (162.5) and *Cannabis sativa* (158.6). All the remaining herb species had an abundance value of less than 100. The minimum abundance was shown by *Boerhavia diffusa* (1). The total basal area of all the herb species was found to be 0.132, out of which the maximum was contributed by *Cannabis sativa* (0.0385) and the minimum was contributed by *Alternanthera pungens* (0.00002), with all other species falling within this range.

Considering the relative abundance, the maximum was contributed by *Cynodon dactylon* at 39.103, followed by *Coronopus didymus* and *Cannabis sativa* at 11.874 and 11.589 respectively. All the remaining species had a relative abundance below 7, with the lowest being shown by *Boerhavia diffusa* at 0.073. Comparing the relative densities, the highest was demonstrated by *Cynodon dactylon* at 55.139, followed by *Chenopodium album* at 10.613 and *Cannabis sativa* at 10.214. All the remaining species showed very low relative densities that were lesser than 5, with the lowest being shown by *Boerhavia diffusa* at 0.039. The maximum relative frequency was shown by *Chenopodium album* at 9.783, followed by *Cynodon dactylon* at 8.696 and *Achyranthes aspera* at 7.609. All the remaining species had lower relative frequencies with the lowest being contributed by *Sida cordifolia* at 1.087. With respect to the relative dominance, the maximum was contributed by *Cannabis sativa* (29.195), followed by *Rumex dentatus* (27.148) and *Chenopodium album* (20.171). The rest of the species had a relative dominance of less than 10, with the least being shown by *Alternanthera pungens* (0.015).

The importance value index (IVI) of *Cynodon dactylon* was highest at 69.947, followed by *Cannabis sativa* at 44.844, *Chenopodium album* at 40.567, and *Rumex dentatus* at 35.024. All the remaining species had an IVI value of less than 15, with the lowest value shown by *Sida cordifolia* at 1.816. Considering the Ni/N value, the highest was shown by *Cynodon dactylon* (0.233) and the lowest was shown by *Sida cordifolia* (0.006). All the remaining species had Ni/N values within this range.

Table 4.5: Floristic composition of herbs in the Saraswati Wildlife Sanctuary using the quadrat method of analysis (D – Density; F – Frequency; A – Abundance; RA – Relative Abundance; BA – Basal Area; RD – Relative Density; RF – Relative Frequency; Rdom – Relative Dominance; IVI – Importance Value Index)

S No	Plant Name	Family	D	F (%)	A	RA	BA	RD	RF	RDom	IVI	Ni/N
1.	*Achyranthes aspera*	Amaranthaceae	677.5	70	38.714	2.829	0.002	3.49	7.609	1.517	12.616	0.042
2.	*Achyranthes bidantary*	Amaranthaceae	30	20	6	0.438	0.0002	0.155	2.174	0.136	2.465	0.008
3.	*Alternanthera pungens*	Amaranthaceae	12.5	20	2.5	0.183	0.00002	0.064	2.174	0.015	2.253	0.008
4.	*Amaranthus* sp.	Amaranthaceae	15	30	2	0.146	0.0001	0.077	3.261	0.076	3.414	0.011
5.	*Blumea loma*	Asteraceae	45	30	6	0.438	0.0005	0.232	3.261	0.341	3.834	0.013
6.	*Boerhavia diffusa*	Nyctaginaceae	7.5	30	1	0.073	0.00004	0.039	3.261	0.027	3.327	0.011
7.	*Cannabis sativa*	Cannabaceae	1982.5	50	158.6	11.589	0.039	10.214	5.435	29.195	44.844	0.149
8.	*Echinopus echinatus*	Asteraceae	72.5	20	14.5	1.06	0.0004	0.374	2.174	0.288	2.836	0.009
9.	*Chenopodium album*	Amaranthaceae	2060	90	91.56	6.69	0.027	10.613	9.783	20.171	40.567	0.135
10.	*Chenopodium murale*	Amaranthaceae	522.5	60	34.833	2.545	0.003	2.692	6.522	2.571	11.784	0.039
11.	*Cirsium arvensis*	Asteraceae	52.5	20	10.5	0.767	0.001	0.27	2.174	0.773	3.218	0.011
12.	*Cissampelos pareira*	Menispermaceae	15	20	3	0.219	0.00009	0.077	2.174	0.07	2.321	0.008
13.	*Convolvulus arvensis*	Convolvulaceae	32.5	20	6.5	0.475	0.00004	0.167	2.174	0.028	2.369	0.008
14.	*Coronopus didymus*	Brassicaceae	812.5	20	162.5	11.874	0.001	4.186	2.174	0.849	7.209	0.024
15.	*Cynodon dactylon*	Poaceae	10,702.5	80	535.15	39.103	0.008	55.139	8.696	6.112	69.947	0.233
16.	*Echinacea angustifolia*	Asteraceae	52.5	30	7	0.512	0.0004	0.27	3.261	0.304	3.835	0.013
17.	*Malvastrum coromandelianum*	Malvaceae	270	40	27	1.973	0.0009	1.391	4.348	0.66	6.399	0.021
18.	*Malva parviflora*	Malvaceae	40	20	8	0.585	0.002	0.206	2.174	1.221	3.601	0.012
19.	*Oxalis corniculata*	Oxalidaceae	457.5	30	61	4.457	0.0003	2.357	3.261	0.205	5.823	0.019
20.	*Peristrophe bicalyculata*	Acanthaceae	37.5	20	7.5	0.548	0.0003	0.193	2.174	0.195	2.562	0.009
21.	*Phalaris minor*	Poaceae	555	30	74	5.407	0.0006	2.859	3.261	0.47	6.59	0.022

22.	*Rumex dentatus*	Polygonaceae	685	40	68.5	5.006	0.036	3.529	4.348	27.148	35.024	0.117
23.	*Saccharum munja*	Poaceae	145	60	9.666	0.706	0.008	0.747	6.522	6.377	13.646	0.045
24.	*Sida cordifolia*	Malvaceae	35	10	14	1.023	0.0007	0.18	1.087	0.548	1.816	0.006
25.	*Solanum xanthocarpum*	Solanaceae	15	20	3	0.219	0.0003	0.077	2.174	0.205	2.456	0.008
26.	*Solanum nigrum*	Solanaceae	27.5	20	5.5	0.402	0.0005	0.142	2.174	0.364	2.68	0.009
27.	*Spergula arvensis*	Caryophyllaceae	50	20	10	0.731	0.0002	0.258	2.174	0.133	2.565	0.009
Total			**19,410**	**920**	**1368.523**	**100**	**0.132**	**100**	**100**	**100**	**300**	

4.7 Diversity Indices of Herbs

Table 4.6 provides the values of diversity indices of the herb species found in the analyzed quadrats of the Saraswati Wildlife Sanctuary. As is evident from the table, 10 species have a Simpson's index of greater than 1, while the others have a Simpson's index of less than 1, and the values of the index range from 0.000115 (*Cirsium arvensis*) to 8.93E-05 (*Echinopus echinatus*). Overall, the values of Simpson's index have a broad range with a good representation of low and high values indicating that the species diversity in the vegetation community at Saraswati Wildlife Sanctuary is high. The values of Shannon's index range from 0.0309 (*Sida cordifolia*) to 0.3395 (*Cynodon dactylon*) indicating that the equality in abundance of all species in the community is low. Furthermore, the values of Pielou's index range from 0.0094 (*Sida cordifolia*) to 0.103 (*Cynodon dactylon*), indicating that the species evenness in the community is low.

Table 4.6: Diversity indices of herbs in the Saraswati Wildlife Sanctuary using the quadrat method of analysis

S.No.	Plant Name	Family	Simpson's Index	Shannon's Index	Pielou's Index
1.	*Achyranthes aspera*	Amaranthaceae	0.0018	0.1333	0.0404
2.	*Achyranthes bidantary*	Amaranthaceae	6.75E-05	0.0394	0.012
3.	*Alternanthera pungens*	Amaranthaceae	5.64E-05	0.0367	0.0111
4.	*Amaranthus* sp.	Amaranthaceae	0.0001	0.0509	0.0155
5.	*Blumea loma*	Asteraceae	0.0002	0.0558	0.0169
6.	*Boerhavia diffusa*	Nyctaginaceae	0.0001	0.0499	0.0151
7.	*Cannabis sativa*	Cannabaceae	0.0223	0.2841	0.0862
8.	*Echinopus echinatus*	Asteraceae	8.93E-05	0.0441	0.0134
9.	*Chenopodium album*	Amaranthaceae	0.0183	0.2706	0.0821
10.	*Chenopodium murale*	Amaranthaceae	0.0015	0.1272	0.0386
11.	*Cirsium arvensis*	Asteraceae	0.0001	0.0486	0.0148
12.	*Cissampelos pareira*	Menispermaceae	5.98E-05	0.0376	0.0114
13.	*Convolvulus arvensis*	Convolvulaceae	6.24E-05	0.0382	0.0116
14.	*Coronopus didymus*	Brassicaceae	0.0006	0.0896	0.0272
15.	*Cynodon dactylon*	Poaceae	0.0544	0.3395	0.103

16.	*Echinacea angustifolia*	Asteraceae	0.0002	0.0557	0.0169
17.	*Malvastrum coromandelianum*	Malvaceae	0.0005	0.0821	0.0249
18.	*Malva parviflora*	Malvaceae	0.0001	0.0531	0.0161
19.	*Oxalis corniculata*	Oxalidaceae	0.0004	0.0765	0.0232
20.	*Peristrophe bicalyculata*	Acanthaceae	7.29E-05	0.0407	0.0123
21.	*Phalaris minor*	Poaceae	0.0005	0.0839	0.0254
22.	*Rumex dentatus*	Polygonaceae	0.0136	0.2507	0.0761
23.	*Saccharum munja*	Poaceae	0.0021	0.1406	0.0427
24.	*Sida cordifolia*	Malvaceae	3.66E-05	0.0309	0.0094
25.	*Solanum xanthocarpum*	Solanaceae	6.7E-05	0.0393	0.0119
26.	*Solanum nigrum*	Solanaceae	7.97E-05	0.0421	0.0128
27.	*Spergula arvensis*	Caryophyllaceae	7.3E-05	0.0407	0.0123