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Tree species diversity and stand structure in the inner and the outer zone of the North Zamari Wildlife Sanctuary, Myanmar

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Abstract

The North Zamari Wildlife Sanctuary (NZWS) is a well-known protected area in Myanmar for its diverse flora and fauna. Nowadays, it has been under severe threat due to illegal logging, charcoal making, fuel-wood collecting, and various anthropogenic pressures from surrounding communities and there is an urgent need to conserve the flora and fauna of the NZWS. Therefore, the study on species diversity, stand structure, and regeneration status of the mixed deciduous forests at the NZWS is crucial for formulating an appropriate management plan to fully protect wildlife and plant communities inside and outside of the sanctuary. In this study, forest inventory was conducted on 1.8 hectares in the inner zone and the outer zone. Square sample plots of 30 m × 30 m quadrats were laid out in each forest type by simple random sampling method and the basic factors such as tree species, forest structure, and biodiversity were studied. The research results can provide a scientific basis for formulating appropriate protection policies and make positive contributions to promoting the sustainable development of protected areas. In the NZWS, valuable tree species are threatened due to forest degradation and unsustainable resource extraction. Appropriate and proper management systems should be adopted based on the nature of forests to systematically and sustainably manage different types of forests. The distribution of tree species and the diversity results in the study will provide a good database for park managers to manage and conserve Myanmar's protected areas effectively and efficiently.

Key Words: Species diversity, Stand Structure, NZWS, Distribution patterns, Natural regeneration

မြောက်ဇာမရီဘေးမဲ့တောအတွင်းနှင့် အပြင်ဧရိယာများ၌ ပေါက်ရောက်လျက်ရှိသည့် သစ်တောသစ်ပင်များ ကွဲပြားမှုနှင့် ပေါက်ရောက်ပျံ့နှံ့မှုများအားလေ့လာခြင်း

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စာတမ်းအကျဉ်း

ပဲခူးတိုင်းဒေသကြီးအတွင်းရှိ မြောက်ဇာမရီ တောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တော၏ အတွင်းဇုန်နှင့် အပြင်ဘက်ဇုန်ရှိ (၁.၈) ဟက်တာစီ တွင် (30 m×30 m) လေးထောင့်နမူနာကွက်များကို Simple Random Sampling နည်းလမ်းဖြင့် နမူနာကွက်များချ၍ အပင်မျိုးစိတ်ဆိုင်ရာ အချက်အလက်များ၊ ပေါက်ရောက်မှုပုံစံဆိုင်ရာ အခြေခံအချက်အလက်များကို လေ့လာ စာရင်းကောက်ယူခဲ့ပါသည်။ ရရှိလာသည့်သုတေသနရလဒ်များသည် ဇီဝမျိုးစုံမျိုးကွဲများ ကာကွယ်ထိန်းသိမ်းရန်အတွက် သင့်လျော်သော စီမံခန့်ခွဲမှုဆိုင်ရာ မူဝါဒများချမှတ်ရန် အတွက် သိပ္ပံနည်းကျအချက်အလက်များကို ပံ့ပိုးပေးနိုင်ပြီး သဘာဝထိန်းသိမ်းရေးနယ်မြေများ ရေရှည်တည်တံ့ ခိုင်မြဲနိုင်ရေးအတွက် မြှင့်တင်ရာတွင် အပြုသဘောဆောင်သော ပံ့ပိုးကူညီမှု များ ရရှိစေပါသည်။ မြောက်ဇာမရီတောရိုင်း တိရစ္ဆာန်ဘေးမဲ့တော၌ သစ်တောပြုန်းတီးမှု နှင့် ရေရှည်တည်တံ့မှုမရှိသည့် သယံဇာတထုတ်ယူမှုများကြောင့် အဖိုးတန် အပင်မျိုးစိတ်များ ခြိမ်းခြောက်ခံနေရလျက်ရှိပါသည်။ အမျိုးအစားစုံလင်လှသည့် အပင်မျိုးစိတ်များနှင့် သစ်တော အမျိုးအစားများကို စနစ်တကျနှင့် ရေရှည်တည်တံ့ခိုင်မြဲစေရန် စီမံနိုင်ရန်အတွက် သင့်လျော် မှန်ကန်သည့် လုပ်ငန်းစီမံချက်များရေးဆွဲချမှတ်၍ စီမံအုပ်ချုပ်ရမည်ဖြစ်ပါသည်။ ယခု သုတေသနလေ့လာမှုမှ ရရှိခဲ့သည့်ရလဒ်များသည် သဘာဝထိန်းသိမ်းရေး နယ်မြေများအား စီမံအုပ်ချုပ်လုပ်ကိုင်နေသည့် သစ်တောဝန်ထမ်းများအတွက် မြန်မာ့သဘာဝ ထိန်းသိမ်းရေး နယ်မြေများကို ထိထိရောက်ရောက် စီမံအုပ်ချုပ်နိုင်ရန်အတွက် အရေးကြီးသည့်အခြေခံ အချက်အလက်များကိုပံ့ပိုးပေးပါသည်။

Tree Species Diversity And Stand Structure In The Inner And The Outer Zone Of The North Zamari Wildlife Sanctuary, Myanmar

1. Introduction

1.1 Background Information and Ecological Importance of Myanmar's Forests

Forests play an enormously important role in the global ecosystem. Naturally, forests provide a wide range of ecosystem services. Conservation of forests is not only a cost-effective way to mitigate climate change but also means that many other benefits including biodiversity, soil and water resources, and pollination are provided to local communities and wider society[1].Nowadays, forests are increasingly threatened by a wide range of pressures, including deforestation, land-use change, agricultural expansion, invasion of alien species, severe droughts, and wildfires [2], [3], resulting in a decline in both the quantity and quality of forest resources [4].Myanmar is one of the largest countries in mainland Southeast Asia with an area of 676,577 km^2. Forest resources dominate large areas of Myanmar between latitudes9 ° 58'N - 28 ° 29'N and longitudes 92 ° 10'E - 101 ° 10'E [5], [6].There are various types of forests such as mangrove forests, tropical evergreen forests, mixed deciduous forests, dry forests, deciduous Dipterocarp, hill and temperate evergreen forest, and scrub and grassland[7]. The forest types vary depending on topographic, edaphic, and climatic conditions.

Myanmar is best known as the natural home of teak (*Tectona grandis*), which is regarded worldwide as one of the most valuable wood [8]–[11]. It is one of the hardwood species and the highest quality wood in the world [12], [13]. Due to the high global demand, teak was the most harvested species in the Bago Yoma [14].The Bago Yoma is mainly composed of mixed deciduous forests and it is the main forest type in Myanmar that encourages commercial logging [10], [15], [16]. In Bago Yoma, teak is a prominent species with other commercial hardwood species such as Binga *(Mitragyna rotundifolia)*, HtaukKyant*(Terminalia tomentosa)*, Pyinkado *(Xylia xylocarpa)*Than-de *(Stereospermumneuranthum)*, Dalbergia species, and Dipterocarpus species are also grown [10], [17]–[19]. Teak is also associated with bamboo species and the high bamboo percentage is a sign of deforestation [17],[20]. The Myanmar Selection System (MSS) was formulated from 1880 to 1920 and the MSS has been the major forest management system used in Myanmar's natural forest management system since 1856 [3], [15], [17]. MSS is a selective logging protocol that involves the felling of the most desirable and valuable natural forest species and residual trees are maintained until the next felling period [10], [21]. However, the proportion of quality teak and other commercial hardwoods has been decreasing continuously [21], [22]. At present, the MSS protocol is no longer used in Bago Yoma.

Quantitative sampling provides the information needed for planning and sustainable biodiversity conservation and floristic inventory is a necessary prerequisite for much fundamental research in tropical community ecology [23], [24].Characteristics of tree species and forest stand conditions can be useful in planning activities aimed at conserving biodiversity [21].Hence, the main objective of this study was to analyze the species composition, richness, and diversity of different forest stands to support the sustainable forest management of Myanmar.

1.2 Role of Protected Area in Biodiversity Conservation

Protected areas provide tangible solutions to species loss issues and climate change adaptation issues [25]–[27]. The UNEP World Conservation Monitoring Center found that protected areas in the study countries accounted for 3% of tropical forest loss between 2000 and 2005, significantly less than unprotected areas [28]. Protected areas are the cornerstone of all national and regional biodiversity conservation strategies, as well as environmental conservation [29], [30]. Protected areas are needed to address biodiversity loss and to maintain vital ecosystem services of the nation because the earth's ecosystem is being destroyed [31], [32]. Besides, protected areas subjected to international and national agreements must resolve their acquired responsibilities to maintain their legal status [31].The expansion of protected areas is a good indicator of environmental performance [33]. Therefore, there is a growing focus on protected area management, as it is one of the key aspects needed for the effective conservation of protected areas.

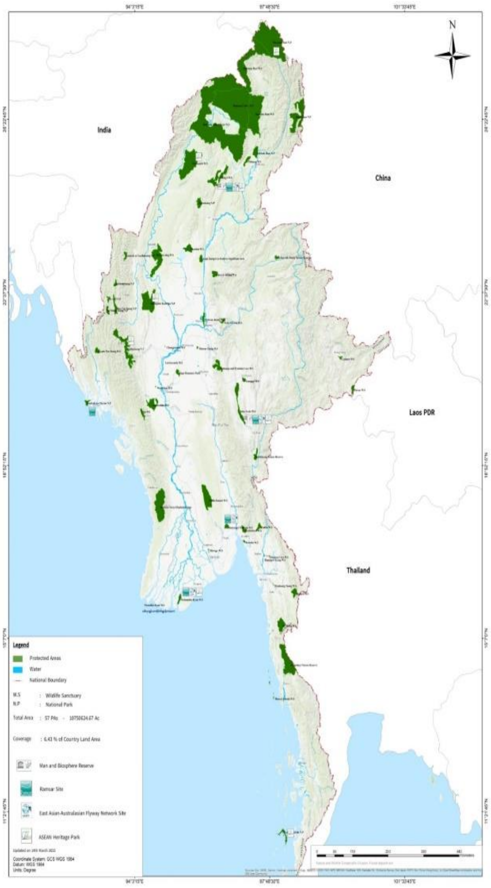

Figure 1:Protected areas in Myanmar

(Source: Nature and Wildlife Conservation Division, Myanmar Forest Department)

Protected Areas are used to conserve biodiversity and it is the most important tool for protecting ecosystem services and preserving cultural landscapes in Myanmar [34].Under the IUCN protected area management categories, Myanmar has six management categories for protected areas [35], and these areas are managed for science or wilderness protection, wilderness protection, ecosystem protection and recreation, the conservation of specific natural features, conservation through management intervention, landscape/seascape conservation or recreation and the sustainable use of natural resources[36].

1.3 Forest Cover and Distribution of Myanmar

Myanmar possesses one of the richest biodiversity in the Indo-Pacific region and has one of the highest proportions of forest cover in mainland Southeast Asia[37]. Myanmar's forests vary in species composition and stand structure, and constitute a valuable ecosystem due to their wide extent, varied topography, and different climatic conditions. Myanmar's forests, covering 42.92% [38]of the country's area, stabilize the ecosystems, sustain a rich variety of biodiversity, maintain the environment, preserve soil and water resources and ameliorate climate which are the key attributes to ensuring viable agriculture on which the economy of the country is based. A great variation in rainfall, temperature, soil, and topography results in many forest types in Myanmar. Major forest types of Myanmar are mangrove forest, hills and temperate evergreen forest, tropical evergreen forest, mixed deciduous forest, deciduous indaing (Dipterocarp) forest, dry forest, and scrubland (Figure 2). The percentage of Myanmar Forest area is as follows;

Table 1: Forest types and forest area of Myanmar[38]

No	Major Forest Types	ha	% of Forest Area
1	Mangrove Forest	325,259.20	1.12
2	Tropical Evergreen Forest	5024,093.00	17.30
3	Mixed Deciduous Forest	11,093,662.00	38.20
4	Dry Forest	2,904,100.00	10.00
5	Deciduous Dipterocarp	1,237,146.60	4.26
6	Hill and Temperate Evergreen	7817,837.20	26.92
7	Scrub and Grass Land	638,902.00	2.20
	Total Forest Area	**29,041,000.00**	**100.00**

According to the Myanmar Forest Department (2019), the extent of PFE and PAs is shown in Table 2.

Table 2: Current status of Reserved Forests, Protected Public Forests, and Protected Area System in Myanmar

Legal classification	Area (Acre)	% of land area
Reserved Forest (RF)	29,702,095.99	17.77%
Protected Public Forest (PPF)	12,909,460.99	7.72%
Total RF & PPF	42,611,556.98	25.49%
Protected Area (PA)	9,783,684.42	5.85%

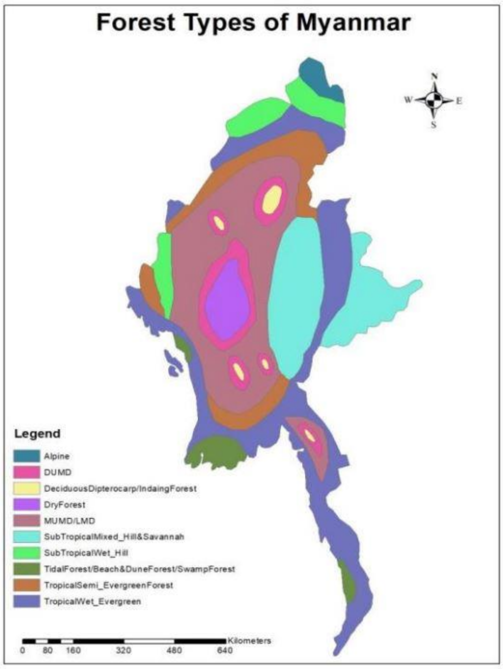

Figure 2:Different forest types in Myanmar

(Source: GIS section, Myanmar Forest Department)

1.4 Problem Statement

Like other tropical timber-producing countries, forest loss and degradation remain a major challenge faced by Myanmar's forestry [3], [10]as a result of social and economic development. Approximately 20% of natural tropical forests are classified as production forests and tropical production forests supply both timber and non-timber forest products. According to Global Forest Resources Assessment (2015), 546,000 hectares (1.7 %) of forest areas have been lost, and the biodiversity of these forests has been lost since 2010.The major threats to Myanmar's forests are charcoal making and illegal logging not only in nature reserves but also in national parks, shifting cultivation, improper land use for agriculture, and illegal encroachment into the forests. Forest ecosystems across Myanmar were devastated when forest areas are converted to other land-use systems; as a result, biodiversity conservation is threatened. Forests in Myanmar are being lost by illegal logging and shifting cultivation[11].Current status and quantitative data and knowledge of forests in each forest type should be collected to rehabilitate degraded land areas and conserve the remaining forests.

A large amount of teak and other hardwood has been illegally cut and exported from Myanmar[13].Illegal harvesting of timber and charcoal making inside and adjacent PA is having negative impacts on a wildlife sanctuary. The absence of management plans in the long term makes biodiversity conservation and restoration ineffective. Most protected areas in Myanmar lack the staffing and basic infrastructure [39]and therefore consequently suffer from threats of encroachment, illegal logging, and over-harvesting of non-timber forest products. There is a strong correlation between the threat status of protected areas and adequate well-trained staff who have access to adequately patrol[36].To restore the remnant forests, it is essential to assess the species composition, stand structure, and regeneration status[34]. Moreover, the study on natural regeneration also is important to assess the forest dynamics and structure that help in the management and monitoring of environmental changes. This study is critical to enhancing understanding of the conservation needs of deciduous forest ecosystems in Myanmar.

The main objective of this study was to investigate the species composition, richness, diversity, and growth condition of different forest stands to support the sustainable forest management of Myanmar. This study furthermore provides important information for the planning of management systems and it supports the recommendation of sound silvicultural practices in forest restoration and rehabilitation procedures as well as in the provision of critical data for conservation activities.

1.5 Scope and Limitations

The study is conducted in a short period which covers the species composition, richness, diversity, and growth condition of different forest stands in North Zamari Wildlife Sanctuary. However, the study area was chosen within one community, but the zonation was different because of some preventative measures of Covid-19 diseases, time constraints, and political situation, so it is hard to make it in more detail. Therefore, I did not measure some environmental factors such as soil, pH, elevation, and slope gradient due to the limitation of time during the study period. The study is more on field data such as diameter at breast height, height, and basal area. In addition, human disturbance in the North Zamari Wildlife Sanctuary did not study in this research. Due to the Covid-19 outbreak in Myanmar, a social survey to assess human disturbance in the North Zamari Wildlife Sanctuary did not conduct in the study area.

1.6 Objectives

The main objective of this study was to investigate the species composition, richness, diversity, and growth condition of different forest stands to support the sustainable forest management of Myanmar. The specific objectives of the North Zamari Wildlife Sanctuary are mentioned as follows:

- To know the current ecological status of tree species at two selected sites
- To compare the species composition, diversity, and stand structure in the inner and the outer zone of the NZWS
- To analyze growth conditions of natural regeneration species
- To provide effective information for future PA management system.

2. Literature Review

2.1 Tropical Forest and its Deforestation

According to FAO (2020),forests currently cover about 4.06 billion hectares, with tropical forests accounting for about 1.8 billion hectares or 45% of the forest area of the world[40]and natural tropical forests are home to more than half of the world's estimated 10 million plants, animal, and insect species[41], [42], two-thirds of terrestrial living species, and contain the highest terrestrial biodiversity [43]. About 50% of tropical forests are still primary forests, while only 36% of the world's forests are primary and only 12% are included in legally protected areas. A tropical forest plays an important role in climate management and the global carbon cycle and receives 2.2 to 2.7 Giga-ton of carbon per year[44]. The ecosystems which hold some of the richest biodiversity, in the tropics are vital components of a healthy. For people living in the tropics, forests provide shelter, food, and medicine. Since the beginning of the first biological expeditions at the end of the 18th century, tropical forests have played an important role in the conceptual establishment of biodiversity[45].

Tropical deciduous forests are lush and green in the rainy seasons and lose their leaves in the dry season. Depending on average rainfall, there are two main types of forests: tropical dry deciduous forest and moist deciduous forest. Tropical dry deciduous forests are called dry monsoon forests; woodland savanna or open dry forests in different regions consist mainly of hardwoods, which shed their foliage during the dry season [46]. Tropical dry deciduous forests extend into South and Southeast Asia, Africa and Madagascar, and central and South America. Moist deciduous tropical forests are mainly found in the neighborhood of tropical rainforests. Large areas of tropical moist deciduous forest can be found in India, Nepal, Bhutan, Bangladesh, Myanmar, Thailand, Laos, Cambodia, Vietnam, and Indonesia. The teak forests of India, Myanmar, Laos, and Thailand are good examples of this forest type [47].Tropical rainforests, deciduous, and savannas are the main component of the earth's ecosystem and they are home to 50 % of plant species [48].

The tropical rainforest is one of the major vegetation types in the world because of its abundant, inspiring, and constant source of new scientific discoveries[49]. The three main regions of the rainforest separated by the oceans are Southeast Asia, Central Africa, and Amazonia, each with different species and structures[47]. Tropical forests are needed for the global climate ecosystems to function properly and the tropical forests are key climate regulators, absorbing and storing carbon to ameliorate climate change. They also supply a variety of additional ecosystem services, including food, freshwater, raw materials, and medicinal resources[50].

In tropical forest countries, poverty is a cause of deforestation resulting in increased demand for fuel-wood and agricultural land[51].The livelihoods of rural people in the tropics are significantly dependent on forest resources and this situation leads to over-exploitation of forest resources resulting in deforestation and degradation of the forest ecosystems [52]. According to World Bank 2001, roughly 1.6 billion people rely on forests for their livelihoods with 350 million people who live in or near dense forests relying on them to a high degree. The conversion of forest land is becoming more frequent because of the increasing demand for agricultural land [53].If the world's forest area continues to decline by 5.2 million hectares per year, it will take 115 years for the world's forests to be lost [54].This seems to be enough time for action to slow or stop global deforestation.

Large areas of tropical forest, regardless of whether they are the under protection or the control of local communities, are still being harvested in an unsustainably or even unlawfully destructive manner through logging, hunting, or the collection of non-timber forest products [55].The major causes of deforestation and forest degradation in Myanmar are legal and illegal forest logging, fuel-wood collection, charcoal making, shifting cultivation, encroachment, forest fires, agricultural expansion, hydropower development, mining and infrastructure development, and forest grazing and the expansion of the road and transportation network. Timber exploitation, infrastructure development, and plantation expansion are boosting Myanmar's economy; however, they can cause significant deforestation, resulting in losses of carbon sequestration, watershed, and biodiversity services [56]. If deforestation and forest degradation continue at high levels in Myanmar, the future of Myanmar’s forest ecosystem is in jeopardy.

2.2 Tropical Mixed Deciduous Forest in Myanmar

In Myanmar, tropical mixed deciduous forests play a vital role in the country’s economy. It provides the best quality of teak and other commercially important timber species [16]. According to the Myanmar Forest Department, a total area of 12.16 million hectares of these forest types is largely distributed in the Bago Yoma, a low range of hill, and also extends across the westward of the Ayeyarwaddy River in northern Myanmar. The mixed deciduous forests of Bago Yoma are often referred to as the Home of Teak in Myanmar. Mixed deciduous forests of Myanmar are further divided into three types based on their common species composition, rainfall distribution, and characteristic bamboo species. They are moist upper mixed deciduous forests (MUMD), Dry upper mixed deciduous forests (DUMD), and Lower mixed deciduous forests (LMD) [7]. Teak (*Tectona grandis*), Pyinkado (*Xylia xylocarpa*), Htauk-kyant (*Terminalia tomentosa*), Yone (*Anogeissus acuminata*), and Myauk-chaw (*Homaliumtomentosum*) are common species found in all three types while other different timber and bamboo species confined to the respective forest types as characterizing species [7].

Teak is the most important and characterizing species of mixed deciduous forests, grows well in warm, moist tropical regions with annual rainfall between 1250 mm and 2500 mm [57]. From the ecological point of view, tropical forest is a subjective process of successional change. When the annual rainfall exceeds 2450 mm and with no biotic interference, MUMD undergoes a gradual process of successional change to a semi-evergreen forest where teak is incapable of regeneration. Consequently, there is little or no natural generation of teak by a lack of teak seedlings, saplings, and poles, only bigger size teak trees predominate together with other invasive evergreen species [57]. Teak is a light-demanding species and species that need light will gradually disappear under such natural succession. The best type of MUMD teak forests are found in an area of annual rainfall ranging from 1650 mm to 2030 mm [57]**.** The growth rate of teak varies according to site condition and strongly correlates with precipitation [19].

2.3 Major Threats to Biodiversity in Protected Area

Protected Areas are one of the most important tools for biodiversity conservation, safeguarding ecosystems services, and preserving cultural landscapes[34].According to the Myanmar Forest Department (2020),Myanmar possesses 57 (6.43%) protected areas. Among them, thirty-five sites were designated in the period 1918-2010. Differences in size are largely reflected by the different years of establishment [58].Old protected areas were very small in size because they aimed at protecting specific resources. Older protected areas appear to be subject to a greater number of incompatible activities than recently created protected areas. Later established protected areas are larger to protect entire landscapes and ecosystems and wide-ranging species[59].Most of the protected areas are important water catchment regions, but illicit logging, forest farming, and plant and large mammal poaching are threatening their significance as ecological regions[60].

There are many causes of biodiversity loss in protected areas, some of which are direct and some indirect. Many protected areas possess insufficient staff, management plans, and basic infrastructure[34].They consequently suffer from threats of illegal logging, encroachment, mining, poaching, and over-harvesting of non-timber forest products. Indirect dangers include the country's economic structure and policies; unsustainable resource exploitation and a weak management system; gaps in spatial information and a lack of public awareness, etc. Direct dangers include illegal logging, habitat destruction, land-use change, and the introduction of invasive alien species.

Deforestation and poaching have led to significant declines in wildlife populations[61]. Increased human population in the area of protected areas has caused a strong demand for land, causing tremendous strain on wildlife and other biodiversity kinds in protected areas. This rapid population growth, combined with increased demand for fuel-wood and construction materials, puts excessive pressure on the protected areas. This rapid population growth, combined with increased demand for fuel-wood and construction materials, puts excessive pressure on the protected areas [62].Tourism also destroys ecosystems, threatens biodiversity, and degrades ecological services. The development of tourism has led to increased exploitation of forest resources such as charcoal, fire-wood, and other raw materials and increased waste disposal. Consequences include forest degradation, soil erosion, and ecological disruption in the protected areas [63].

According to the Myanmar Forest Department (2022), illegal logging, mining, illegal hunting, NTFP collecting, intentionally polluting soil and water, disposing of toxic objectives or mineral wastes, using chemical or explosive materials in the water, trespassing within the protected area, land encroachment and destroying natural conditions are key issues to the degradation of protected area ecosystem in the North Zamari Wildlife Sanctuary. In addition to all of these activities and intensive resource use, the vegetation of the protected area changes over time [64].

2.4 Protected Area Management in Myanmar

Myanmar, the largest country in South East Asia, is part of the Sundaic sub-region of the Indo-Malayan Realm. Due to the combination and interaction of geography, topography, climate, pattern of seasonal rainfall, presence of high mountains and major rivers, Myanmar presents a great variety of different habitats and ecosystems supporting a rich biodiversity [58].Myanmar has 14 major eco-regions, or relatively large areas of land or water which each contain characteristic, geographically distinct assemblages of plants and animals[34].

The North Zamari Wildlife Sanctuary has been designated as a protected area on 22nd May 2014 (Myanmar Forest Department, 2022). Protected areas are essential for the conservation of biodiversity and sustaining the fundamental services provided by natural systems [65].Protected areas are a well-known strategy for preserving wildlife in situ. Monitoring and managing resource utilization has always been a significant challenge for the management of protected areas [66].Management zoning is one strategy for increasing the direct advantages of protected areas to nearby people. Zoning facilitates the division of protected areas into core protection areas for exclusionary conservation, buffer zones for local usage that alleviate pressure on core areas, and transition or development regions where local people can have full management authority [67].Appropriate conservation strategies must be put in place to conserve protected areas and their valuable resources [65].Conservation efforts in national parks can be made more efficient and effective if the government provides effective control and lawful, financial, and political support to the regional states and local communities where the real protection and management activities take place [68].Organizations outside of the government can help raise awareness about the state of natural resources and educate rural populations about environmental ethics [60].

2.5 Deforestation outside the Wildlife Sanctuary

Forests outside the wildlife sanctuary are causing deforestation due to population pressures and rising demand for forest products. Most people living in the vicinity of the wildlife sanctuary are poor and rely heavily on the forest to support their daily lives. As a result, illegally harvesting valuable timber and selling it to timber traders has become one of their major sources of income. Forests are also threatened by land clearing for agriculture and pasture and by harvesting wood for fuel or industrial uses. In the practice of clear-cutting, all the trees are removed from the land, which destroys the forest. In some cases, however, even partial logging and accidental fires thin out the trees enough to change the forest structure dramatically.

Deforestation is caused by a combination of multiple factors. Some major driving forces of deforestation in the outside of the wildlife sanctuary as identified by the Myanmar Forest

Department are shifting cultivation, over-exploitation of timber, encroachment, natural disasters, developments, population pressure and consequent demand of forest products.

3. Research Methodology

3.1 General Description of the Study Area

3.1.1 Study Area

A case study will be conducted in the North Zamari Wildlife Sanctuary (Figure 3) because of the sites where any research on the above-mentioned topic has not been conducted yet. The North Zamari Wildlife Sanctuary covers 242938.48 acres (379.59 sq. miles) and is largely comprised of mixed deciduous and dry deciduous forests. Wildlife Sanctuary is richly endowed with diverse flora, which contributes habitat for wildlife (especially it is a home for *Elephas maximus*) and many kinds of birds.

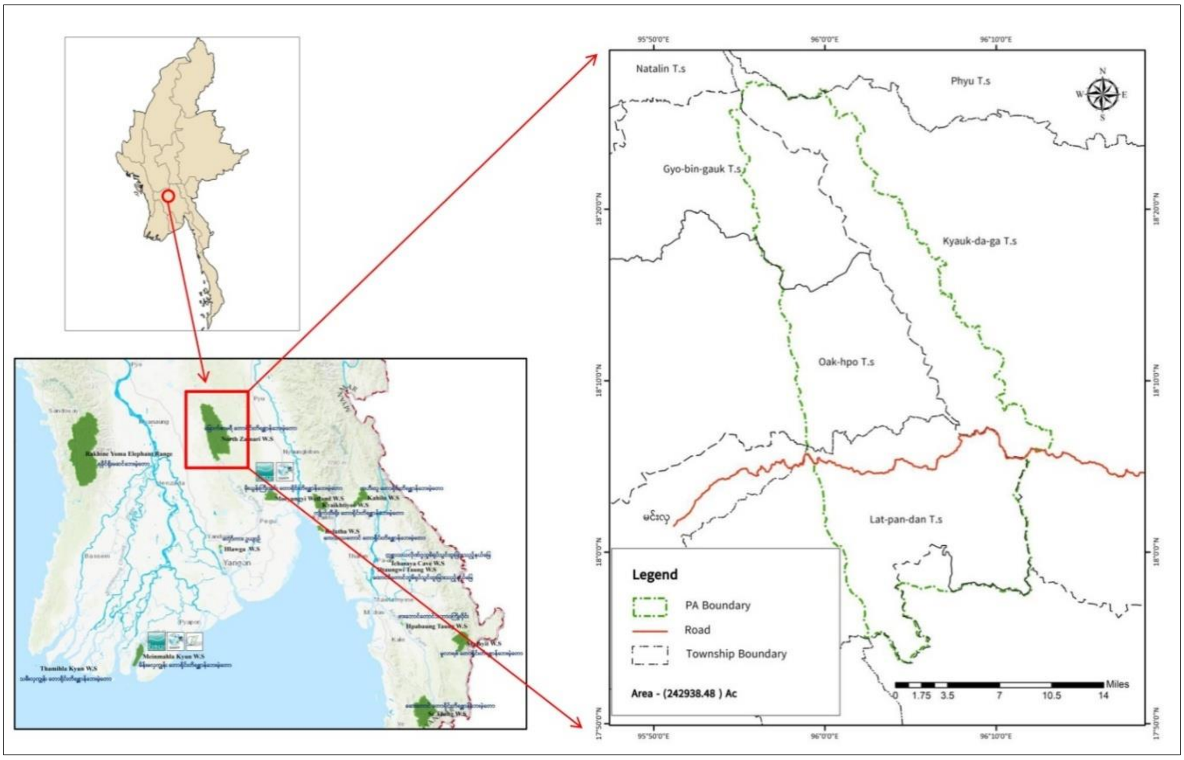

Figure 3: Study area map of the North Zamari Wildlife Sanctuary

(Source: Nature and Wildlife Conservation Division, Myanmar Forest Department)

3.1.2 Topography, Geology and Soil Types

North Zamari Wildlife Sanctuary is generally a hilly region and the elevation is about 420 meters above sea level except for some particular places such as the riverside and shoreline of Bago River. Generally, the ridges stretch in the west to the watershed areas in the eastern part.

3.1.3 Climate

The climate diagram of the study area was formulated according to De Martonne'smonthly aridity index[69]and it was calculated by using the following formula to categorize the dry months.

$$A_j = N\,(mm) / T_j + 10 \text{ (yearly)}$$

$$A_m = 12\,(n) / T_m + 10 \text{ (monthly)}$$

Where, A^j = annual aridity index

A^m = the monthly aridity index (A_m below 20 = dry month)

N = mean annual precipitation (mm)

n = the mean monthly rainfall in millimeters

T_m = the mean annual temperature in ˚C

Table 3: Monthly mean rainfall and temperature (2010-2020) and De Martonne's aridity index for Tharyarwaddy Township, 2020

Month	Rainfall (mm)	Temperature (°C)	Aridity
January	5.92	23.75	2.10
February	2.36	24.58	0.82
March	2.62	29.86	0.79
April	22.40	31.64	6.46
May	146.41	31.35	42.49
June	330.07	29.22	100.99
July	335.58	27.78	106.59
August	274.27	27.75	87.18
September	211.13	28.55	65.72
October	172.33	28.47	53.75
November	25.47	27.28	8.20
December	7.98	24.35	2.79

According to De Martonne's monthly aridity index of the study area, the dry season is from November to April. A dry month can be defined as one with a monthly aridity index (A_m) of less than 20 or a rainfall curve that falls under the temperature curve in the climate diagram [70]. The climate diagram demonstrates that there are seven humid months in the study area.The general description of climatic data of the study sites were shown in the following diagram (Figure 4).

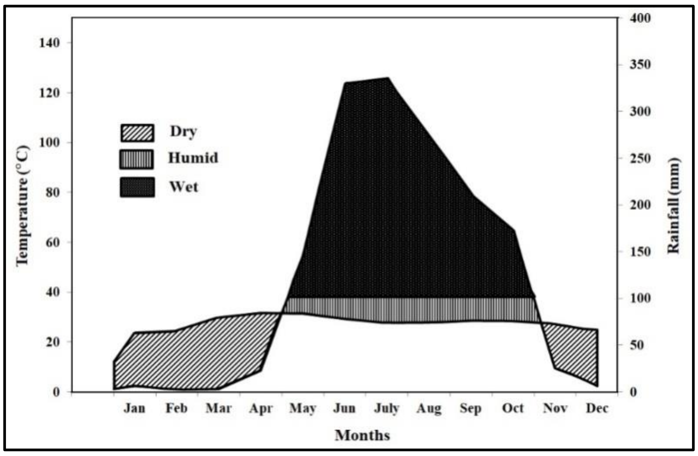

Figure 4: Climate diagram of the study sites (data recorded from 2010 to 2020)

3.2 Experiment Design

To collect the required data from the forests and to fulfill the set objectives, two different sites (the inner and the outer zone of the North Zamari Wildlife Sanctuary) were chosen. In this study, a simple random sampling method was used to lay the sample plots in the inner and outer zones of the North Zamari Wildlife Sanctuary. The simple random sampling method isa fair method of choosing a sample from a particular population, as each member is given an equal chance of selection [71]. Twenty sample plots (30 m x 30 m) was constructed in each site (a total of 40 sample plots) and it will refer to as A. Within each plot, a sub-plot measuring (10 m x 10 m) was established and it will refer to as B. Within the sub-plot, four (5 m x 5 m) plots were established and will refer to as C1, C2, C3 and C4 (Fig 5).

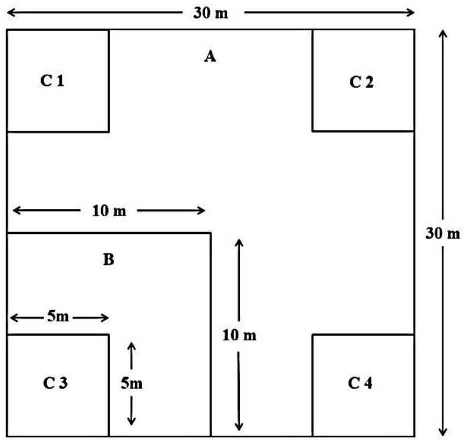

Figure 5: Sample Plot Design

3.3. Measurement and Calculation of Investigation Parameters

3.3.1 Measurement of Tree Diameter at Breast Height (DBH)

The numbers of the species with the diameter at breast height (DBH ≥ 5 cm) for adult trees were measured in each 30 m x 30 m plots (Table 4). The measurement of DBH for leaning and abnormal trees followed the methods of Van Larr & Akca,2007 [72].

3.3.2.Measurement of Tree Height

In 30 m x 30 m plots, the total height of all trees, of which their diameters had already been recorded, will be measured. The tree height was measured by using Suunto Clinometer. Small trees were measured by using a normal stick.

3.3.3 Natural Regeneration

The trees with DBH lower than 5 cm to greater or equal than 2 cm and height greater or equal than 1.3 m to lower or equal than 4 m were regarded as young sapling and were counted. Within the sub-plot measuring (10 m x 10 m), the numbers of the species for saplings were measured. Within four (5 m x 5 m) plots, heights lower than 1.3 m to greater or equal than 0.3m and DBH lower than 2 cm were measured for seedlings (Table 4).

Table 4: Measurement of tree's DBH, height, and natural regenerations within plots

Classification	Side length	Area	What to measure	Notes
Plot (A)	30 m x 30 m	900 m^2	Adult Trees	DBH ≥ 5 cm
Plot (B)	10 m x 10 m	100 m^2	Saplings	Height ≥ 1.3 m to ≤ 4 m DBH < 5 cm to ≥ 2 cm
Plot (C) C1 to C4	5 m x 5 m	25 m^2	Seedlings	Height ≥ 0.3 m to <1.3 m DBH < 2 cm

3.3.4 Species

Tree species were identified in the field with the support of local experts and expert staff from the North Zamari Wildlife Sanctuary. In the case of unidentifiable trees, "Standard Nomenclature of Forest Plants, Myanmar, U Hote Linn" was referenced.

3.3.5 Species-Area Curve

The species-area curve is an important estimation tool and is the best way to determine the minimum research area[73].It applies to a variety of research works and it can be used to determine the representativeness of the sample. Moreover, it is applied as criteria to calculate a minimum area of a community and it serves as a quick identification tool in community descriptions. As the survey area expands, the species-area curve could represent the number of new species found and as the survey area extends, the number of new species were discovered[74]. It is acceptable if the increase of species per unit area remains less than 10% while the area expands by 10%. The species-area curve was formulated by using trees with a height of ≥ 1.3 m and a diameter ≥ 5cm DBH on 20 plots (1.8 ha).

3.3.6 Floristic Composition

The calculation of the relative density, relative frequency, and relative dominance of observed tree species are all components of the important value of observed tree species. In this study, the importance value index (IVI) was used as an indicator of species rank. This index, proposed by Curtis, 1951[75]was applied to describe species composition in the following manner:

$$IVI = R_{dom} + R_{den} + R_{freq} \quad (1)$$

Where, R_{dom} = relative dominance, R_{den} = relative abundance,

R_{freq} = relative frequency.

The three indices were calculated using the following equations:

$$R_{dom} = \frac{\sum Gi}{\sum Gij} \times 100\ \% \quad (2)$$

$$G = \pi \times (DBH/2) \quad (3)$$

Where, $\sum Gi$ = total basal area for each species, $\sum Gij$ = total basal area for all species,

G = basal area, DBH = diameter at breast height.

$$R_{den} = \frac{N_i}{\sum N_{ij}} \times 100\ \% \quad (4)$$

Where, N_i = the number of individuals of a species,

$\sum N_{ij}$ = total number of individuals of all species.

$$R_{freq} = \frac{F_i}{\sum F_{ij}} \times 100\ \% \quad (5)$$

Where, F_i = the frequency of a species, $\sum F_{ij}$ = a sum frequency of all species.

Furthermore, the Family Importance Value (FIV) is calculated from the sum of the relative abundance, relative dominance, and relative frequency of each family. According to Mori et al., (1983), FIV is used to determine the dominance of woody taxa in the plant community [76].

$$FIV = R_{dom} + R_{den} + R_{freq} \quad (6)$$

Where, FIV = Family important value, R_{dom} = relative dominance,

R_{den} = relative density, R_{freq} = relative frequency.

The composition of tree species is the variety of communities found in a forest, as measured by the occurrence of species and the diversity index. Therefore, a family important value for the ecological dimension is required to evaluate the species composition of the plant community at the family level.

3.3.7 Diversity Indices

In this study, Simpson's (1-D′), Shannon-Weaver (H′), and the Pielou's Evenness(J′) indices were applied for their widespread use and low-to-moderate sensitivity to sample size. Simpson (1949) calculated both richness and evenness. In comparison to the Shannon-Weaverindex, Simpson's index of variation is more influenced by evenness than richness. The Simpson index gives the probability of any two individuals of different species drawn at random from an infinitely large community [77].Simpson’s index value is usually between 0 and 1; the higher the value, the more diverse the sample. This index is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness. The Simpson index was calculated according to Magurran,1988[78].

$$1\text{-}D = 1 - \sum \frac{ni(ni-1)}{N(N-1)} \quad (7)$$

Where, D = Simpson index of dominance, n = number of individuals of each species,
N = the total number of individuals of all species.

The Shannon-Weaverindex is the most widely used index for comparing diversity between habitats [79].The Shannon-Weaver index is mainly used to quantify the degree of uncertainty associated with a certain category within a given community set. These indices are also influenced by the number of species present and their distribution homogeneity. Shannon diversity index values are normally between 1.5 and 3.5, seldom reaching 4.5 [80].The Shannon-Wiener index is defined as:

$$H' = -\sum_{i=1}^{s} p_i \times \mathrm{Ln}\, p_i \quad (8)$$

Where, p_i = the proportion of individuals of species i in community,
S = the total number of species in the sample,
i =the total number of individuals in one species.

Species diversity depends not only on the number of species found but also on their numbers in an area. The Evenness index will be used to know how evenly individuals are distributed among different species. Pielou's evenness index (J) is the most widely used measure that has the greatest coverage for a larger sample. These estimations appear to indicate that when a single 29 species dominate the population, evenness values tend to zero, and when species' abundance are relatively close together, evenness values tend to one [81]. Equitability is supposed to be a value between 0 and 1, with 1 indicating that the distribution is completely even. The Evenness index expresses how evenly individuals are distributed among different species and was calculated according to Pielou, 1966 [82].

$$J' = \frac{H'}{\ln(s)} \quad (9)$$

Where, H′ = Shannon Weaver diversity, S = the total number of species in a sample.

3.3.8 Species Similarity

Forest habitats are characterized by their similarity in species composition. The coefficients of Sörensen (1948) and Lamprecht (1989) were applied to compare the similarity of tree species composition in this study. Sörensen’s index is based on the presence or absence of species. To determine the degree of species similarity between two forest stands, Sörensen’s index was applied [83].Sörensen’s index was calculated using the following equation:

$$K_s = \left(\frac{2c}{a+b}\right) \times 100\,\% \quad (10)$$

Where, Ks = Sörensen’s coefficient of similarity between the two stands,
a = total number of tree species of the first stand,
b = total number of tree species of the second stand,
c = total number of common species between the two stands.

The similarity of tree species could also be assessed using Lamprecht's coefficient, which involves comparing the number of species with the number of dominance that belonged to the species.

$$K_d = \left(\frac{\sum c_d}{\sum a_d + \sum b_d}\right) \times 100\,\% \quad (11)$$

Where, K_d = similarity coefficient modified by Lamprecht,
$\sum a_d$ = total dominant (basal area) of survey A,

$\sum b_d$ = total dominant (basal area) of survey B,

$\sum c_d$ =total of the dominants of both surveys A and B.

3.3.9 Diameter Distribution

Tree diameter distribution gives us a lot of the information needed for sustainable management, and it can also be predicted with a high degree of accuracy [84]. Uneven-aged stands, particularly in natural forests, contain a variety of diameter classes and a J-shaped distribution pattern, with a large number of trees falling into the smaller diameter classes [85]. Many mathematical equations may be used to approximate the diameter distribution of uneven-aged natural forests, but the negative exponential function is the one that is the most frequently used and best-fitted model in this study. The negative exponential function can be described by the following equation:

$$n = k * e\ (a * d) \qquad (12)$$

Where, n = number of stems per ha, k, a = constant, d = DBH of trees.

3.3.10 Frequency Percent

The frequency percent of trees and their class classification is shown in Table 5.

Table 5: Frequency percent of trees and its classification in the study

Frequency Percent	Frequency Class
1-20%	I
20.1-40%	II
40.1-60%	III
60.1-80%	IV
80.1-100%	V

3.3.11 Height Curves

Table 6: The fitted height-diameter functions for all species in the inner zone and the outer zone of the NZWS

Source	Equation
(Van Larr & Akça, 2007)	$H = 1.3 + d^2 / b_0 + b_1 \times DBH + b_2 \times DBH^2$
(Van Larr & Akça, 2007)	$H = b_0 + b_1 \times DBH + b_2 \times DBH^2$
(Van Larr & Akça, 2007)	$H - 1.3 = b_1 \times DBH + b_2 \times DBH^2$
(Van Larr & Akça, 2007)	$H = b_0 + b_1 \times \ln (DBH)$
(Van Larr & Akça, 2007)	$\ln(H) = b_0 + b_1 \times \ln (DBH)$
(Van Larr & Akça, 2007)	$H = b_1 \times (1 - e^{-b_2} \times DBH)$

Where, H = the total height, DBH = the diameter at breast height,

b0, b1, b2 = the parameters of the regression.

Communities of the study sites were assessed using height-diameter relationships based on stand density, basal area, and site index. Stem diameter at breast height (DBH) and tree height (H) are regularly used measurements of tree growth [86]. Stand height is necessary for calculating the volume of the stand, determining the site, forecasting future growth, and conducting silvicultural experiments [72]. The slope of the height curve is also determined by the quality of the site; a high-quality site has a steep curve on the right-hand side of the graph. The relationship between the DBH and height was constructed by using several applied models [72]. The following equation was the best-fitted model to show the relationship between DBH and height for all types of forests in this study.

$$H = b_0 + b_1 \times \ln (DBH) \qquad (13)$$

Where, H = the total height, DBH = the diameter at breast height,

b0, b1, b2 = the parameters of the regression

3.3.12 Height Layer Classification

The height distribution of a stand is critical in determining its vertical structure. When height layer classification is considered for species distribution, it contributes to the definition of species behavior, i.e., as an upper - (dominant), middle, or understory tree species. The vertical structure was classified according to IUFRO's classification scheme defined by Leibundgut (1958)[87] as an upper layer (tree height > 2/3 top height), middle layer (tree height < 2/3 and > 1/3 of the top height), and lower layer (tree height < 1/3 of the top height)[87], [88].

3.4 Data Analysis

All data were entered into Microsoft Excel 2010 spreadsheets for statistical analysis. Species-area curve was formulated based on Cain's method. To explore the species composition of tree species, the family importance value index (FIV) and the Importance Value Index (IVI)were calculated. To explore the species richness and equitability among the species, Simpson's index of dominance, the Shannon-Weaver index, and Shannon's measure of evenness were calculated. Two types of similarity methods based on Sörensen's coefficient of similarity and Lamprecht coefficient similarity were calculated. To compare the structural parameters, nonparametric statistical analyses, such as the Mann-Whitney U test was used in SPSS software(e.g., species richness, diversity indices, densities, diameter at breast height, tree height, basal area) among the forest types. Furthermore, R software was also used to construct the height-diameter distribution curve.

4. Results

4.1 Species Area Curve

As shown in Figure 6, the trends for the inner and outer zones continue to increase as the sample area expands. The inner zone had a higher number of species than the outer zone. There were 52 species in the inner zone and 40 species in the outer zone. It was found that the curve of the inner zone increased dramatically from 900 m^2 to 45,00 m^2 and then stabilized until it reached 72,000 m^2, after which it gradually increased to 13,500 m^2 and remained stable until 18,000 m^2. For the outer zone, the number of species increased gradually from 900 m^2 to 17,100 m^2, and the curve pattern plateaued until 18,000 m^2. As a result, the trend curves proved that 1.8 hectaresper community were a representative area for evaluating the status of the North Zamari Wildlife Sanctuary flora and these areas were used as the sample for the study. Species-area curves of the collected stands in the inner zone and the outer zone of the North Zamari Wildlife Sanctuary were formulated based on 1.8 ha and shown in Figure.

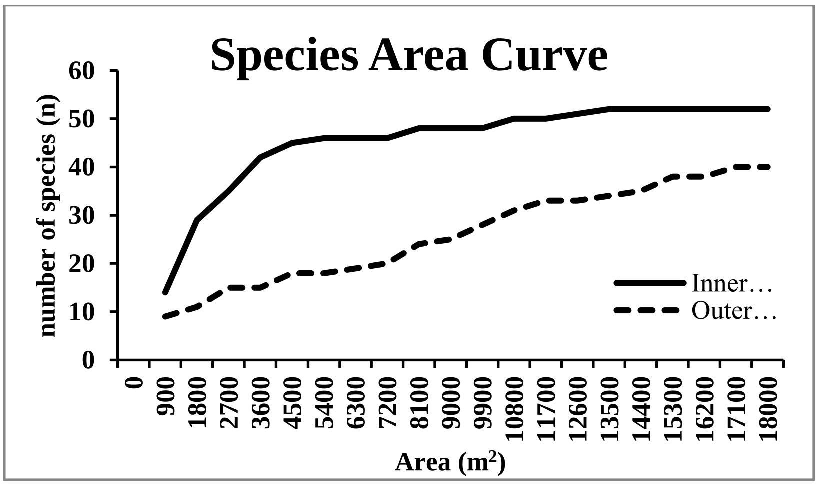

Figure 6: Species-area curve (accumulated number of tree species in the study) for the inner zone and outer zone of the NZWS

4.2 Tree Species Composition and Diversity

4.2.1 Species Composition

In this study, 26 families were found from the inner zone and 22 families were found from the outer zone. Family Importance Value (FIV) was obtained from the sum of the relative dominance, the relative density, and the relative frequency of all the stand families. The families of the inner zone and the outer zone may be different due to human disturbance in this area. Moreover, to find an ecologically important or structurally dominant family, the FIV value was also calculated at the family level. Family Importance Value (FIV) was calculated based on 1.8 ha and the results are shown in Table 7.

For the inner zone, the family with the highest FIV value was Combretaceae (38.90%), with an absolute dominance of 7.93 m^2 per 1.8 ha, and it was followed by Fabaceae, the second-highest family in terms of importance value (32.37%), with a dominance of 6.61 m^2 per 1.8 ha and the third-highest family is Rubiaceae (27.24%) with a dominance of 6.08 m^2 per 1.8 ha. Furthermore, the most abundant family in the inner zone was Combretaceae (256 individuals), the second most abundant family is Fabaceae (200 individuals) and the third is Rubiaceae (146 individuals). Then, the top ten families account for 213.95% of the total FIV, while the top three comprise 98.51%. The total number of families remaining in the inner zone was 16 familieswhich had a low FIV value. Among the top three families, there were five species in Combretaceae, six species in Fabaceae, and three species in the Rubiaceae family.The species in the Combretaceae were *Terminalia chebula*,*Terminalia tomentosa*, *Terminalia phillyreifolia*, *Anogeissus acuminate*,and *Bauhinia acuminata*. The species in the Fabaceae were *Dalbergia cultrata*, *Dalbergia ovate*, *Dalbergia muliflora*, *Dalbergia kurzii*, *Dalbergia fusca*and *Millettia pendula*. The species in the Rubiaceae were *Mitragyna rotundifolia*, *Naucleaorientalis*, and *Hymenodictynoexcelsum*. The other families in the top ten were Lamiaceae, Lythraceae, Mimosaceae, Flacourtiaceae, Euphorbiaceae,Bignoniaceae, and Sterculiaceae.

For the outer zone, the highest family importance value (FIV) was (56.76%) with a basal area of 8.89 m^2 per 1.8 ha for Combretaceae, followed by Fabaceae (41.91%) with a basal area of 4.64 m^2 per 1.8 ha and Bombacaceae (23.13%) with a basal area of 2.27 m^2 per 1.8 ha. The outer zone had Combretaceae (168 individuals) with the highest number of individuals, followed by Fabaceae (166 individuals) and Bombacaceae (70 individuals), respectively. The four types of families found in the inner zone such as Apocynaceae, Ebenaceae, Hypericaceae, and Theaceae were not found in the outer zone.

Table 7: The most important families in the inner and outer zone of the NZWS (all stems with a DBH ≥ 5cm)

Rank	Family	Absolute Abundance (no. of trees)	Dominance (basal area-m^2)	Frequency* (%)	FIV (%)
Inner Zone					
1	Combretaceae	256	7.93	100	38.90
2	Fabaceae	200	6.61	95	32.37
3	Rubiaceae	146	6.08	85	27.24
4	Lamiaceae	137	2.49	100	20.32
5	Lythraceae	114	3.16	90	19.58
6	Mimosaceae	110	5.74	90	24.63
7	Flacourtiaceae	88	2.93	85	17.16
8	Euphorbiaceae	58	0.80	70	9.91
9	Bignoniaceae	56	2.45	90	14.53
10	Sterculiaceae	54	0.62	70	9.31
11	16 other families	387	9.86		86.03
	Total	**1606**	**48.67**		**300.00**
Outer Zone					
1	Combretaceae	168	8.89	95	56.76
2	Fabaceae	166	4.64	95	41.91
3	Bombacaceae	70	2.27	85	23.13
4	Euphorbiaceae	67	0.98	80	17.90
5	Lamiaceae	66	1.07	85	18.59
6	Lythraceae	66	1.48	75	19.04
7	Mimosaceae	65	2.16	90	22.73
8	Bignoniaceae	63	1.72	80	20.05
9	Flacourtiaceae	58	1.44	50	15.66
10	Tiliaceae	45	0.33	50	10.52
11	12 other families	166	3.97		53.72
	Total	**1000**	**28.96**		**300.00**

*Frequency means the percentage of the plots in which the families was represented.

These three leading families constitute 121.8% of the total FIV (300%). Moreover, the combination of the FIV value of these top ten families was 246.29%. The total number of remaining families in the outer zone was 12 which had a low FIV value. Then, three species in Combretaceae, four species in Fabaceae, and two species in Bombacaceaewere observed. The species in the Combretaceae were *Anogeissus acuminata*, *Terminalia chebula*, and *Terminalia tomentosa*. The species in the Fabaceae were *Dalbergia kurzii*, *Dalbergia ovate*, *Dalbergia cultrata*, and *Millettia pendula* and then the species in Bombacaceae were *Bombax ceiba* and *Bombax insigne*. The other families in the top ten were Euphorbiaceae, Lamiaceae, Lythraceae, Mimosaceae, Bignoniaceae, Flacourtiaceae, and Tiliaceae were the dominant families in the inner zone, but Combretaceae and Fabaceae were the most dominant families in the outer zone.

The contribution of each tree species to the forest stand is regarded as tree species composition and it shows the major dominant species and their important ecological characteristic in a forest. To compare the ecological importance of tree species composition in the inner and the outer zone, the Importance Value Index (IVI) is applied to determine the overall importance of each tree species in the vegetation analysis. To know the ecologically important, the Importance Value Indices of species levels in the inner and the outer zone were calculated and are shown in Table 8.

Table 8 showed that the highest important value index (IVI) recorded from the inner zone was (18.36%) for *Tectona grandis*with a basal area of 2.49 m^2 per 1.8 ha, followed by *Terminalia tomentosa*and *Xylia xylocarpa* with an IVI of (19.83%) and (19.24%) respectively. The dominance for *Terminalia tomentosa*and *Xylia xylocarpa*were 3.87 m^2 and 4.91 m^2 per 1.8 ha. These top three species held the total IVI value of (57.43%). *Tectona grandis*had 137 individuals and *Terminalia tomentosa* showed 119 individuals. Therefore these species could be considered the most ecologically important species on this site. Furthermore, the species such as *Xylia xylocarpa*, *Lagerstroemia speciosa*,and *Mitragyna rotundifolia* were also assumed as the most dominant tree species for all investigated stands. Likewise, the highest relative frequencies were also recorded by *Tectona grandis* (100%), *Terminalia tomentosa* (95%), and *Xylia xylocarpa* (90%). Additionally, the top ten leading species constitute (139.71%) of the total IVI (300%).

For the outer zone, the highest IVI value was (43.86%) with a basal area of 6.95 m^2 per 1.8 ha for *Terminalia tomentosa*, followed by *Dalbergia kurzii*(28.55%) with a basal area of 3.41 m^2 per 1.8 ha and *Tectona grandis* (17.15%) with a basal area of 1.07 m^2 per 1.8 ha. The highest frequencies were recorded in *Terminalia tomentosa*(90%), *Dalbergia kurzii*(85%), and *Tectona grandis* (85%). Additionally, *Terminalia tomentosa* species had 126 individuals, *Dalbergia kurzii* showed 99 individuals and *Tectona grandis* species had 66 individuals. Moreover, the IVI value of the top ten species showed (193.26%) and 30 other species constituted the rest.

Table 8: The most important value index in the inner and outer zone of the NZWS (all stems with a DBH ≥ 5cm)

Rank	Species	Absolute			
		Abundance (no. of trees)	Dominance (basal area-m^2)	Frequency* (%)	IVI (%)
Inner Zone					
1	*Tectona grandis*	137	2.49	100	18.36
2	*Terminalia tomentosa*	119	3.87	95	19.83
3	*Xylia xylocarpa*	79	4.91	90	19.24
4	*Lagerstroemia speciosa*	77	2.50	85	13.93
5	*Mitragyna rotundifolia*	76	4.58	60	16.96
6	*Dalbergia kurzii*	70	3.18	55	13.49
7	*Anogeissus acuminata*	66	2.13	65	11.54
8	*Naucleaorientalis*	63	1.24	35	8.12
9	*Homaliumtomentosum*	62	2.01	75	11.52
10	*Dalbergia ovata*	41	0.77	55	6.72
11	42 other species	816	20.99		160.29
	Total	**1606**	**48.67**		**300.00**
Outer Zone					
1	*Terminalia tomentosa*	126	6.95	90	43.86
2	*Dalbergia kurzii*	99	3.41	85	28.55
3	*Tectona grandis*	66	1.07	85	17.15
4	*Croton oblongifolius*	62	0.87	75	15.25
5	*Xylia xylocarpa*	57	2.00	90	19.86
6	*Lagerstroemia speciosa*	54	1.23	75	15.71
7	*Bombax insigne*	53	1.79	70	17.11
8	*Stereospermumneuranthum*	39	1.52	55	13.60
9	*Anogeissus acuminata*	35	1.34	50	12.17
10	*Duabanga grandiflora*	35	0.83	45	10.00
11	30 other species	374	7.94		106.74
	Total	**1000**	**28.96**		**300.00**

*Frequency means the percentage of the plots in which the species was represented.

According to the result of the study performed in the field, the most dominant species were *Tectona grandis* in the inner zone and *Terminalia tomentosa* in the outer zone. Due to human disturbance and the different sites, the most dominant species were not the same. The result showed 52 species in the inner zone and 40 species in the outer zone.

4.2.2 Diversity Indices of Tree Species

In the study, diversity indices are important to clearly understand community structure. The tree species diversity of each forest zone was determined using the Shannon-Wiener index, Simpson's index, and Shannon's measure of evenness. The tree species richness and diversity indices of the inner and outer zone are given in Table 9. The inner zone had the higher species richness (52 species) and the outer zone had the lower species richness(40 species).

Table 9: Diversity indices (Simpson, Shannon- Weiner, and Evenness) in the inner and outer zone of the North Zamari Wildlife Sanctuary (all trees with DBH ≥ 5 cm)

Study Site	Species (n)	Diversity indices		
		Simpson (1-D')	Shannon-Wiener (H')	Evenness (J')
Inner Zone	52	0.965	3.641	0.493
Outer Zone	40	0.945	3.239	0.469

According to the result, the Shannon-Wiener index (H') was 3.641 for the inner zone and 3.239 for the outer zone. These results show that the inner zone was the most complex in terms of species diversity, whereas the outer zone was the simplest community in terms of species composition. The Simpson index (1-D') ranged from 0.945 to 0.965. The Evenness index (J') was 0.493 for the inner zone and 0.469 for the outer zone. The Evenness, Shannon-Wiener, and Simpson indices obtained in the inner zone were higher than those of the outer zone.

Table 10: Statistical results of the diversity indices between two zones of the study area (Mann-Whitney U Test)

Mann-Whitney U Test						
Diversity indices	Zone	Mean Rank	Sum of Ranks	U	Z	p-value
Simpson (1-D')	Inner	24.30	486.00	124.500	-2.056	0.042
	Outer	16.70	334.00			
Shannon-Wiener (H')	Inner	28.30	566.50	177.500	-2.220	0.002
	Outer	12.70	254.50			
Evenness (J')	Inner	21.66	433.00	44.000	-3.057	0.434
	Outer	18.35	387.00			

In this study, non-parametric statistical analysis (Mann-Whitney U test) was employed to evaluate diversity indices as an additional measure of diversity and the results are shown in Table 10. According to the results, all p-value is less than 0.05 (all p-values < 0.05), and therefore the Simpson, Shannon-Weiner, and Evenness indices were significantly different between the inner and outer zone.

4.2.3 Similarity Index

Table 11: The Sörensen's similarity coefficient (K_s) and the Lamprecht's similarity coefficient (K_d) among the inner and the outer zone (all stands with DBH ≥ 5cm based on 1.8 ha)

Zone	Inner (%)	Outer (%)
The Sörensen's similarity coefficient (K_s)		
Inner	……	86.96
Outer	86.96	……
The Lamprecht's similarity coefficient (K_d)		
Inner	……	93.97
Outer	93.97	……

The results of the similarity index of the Sörensen and the Lamprecht similarity coefficient for all stands among the study sites based on 1.8 ha were given in Table 11.For the Sörensen index, the coefficient of similarity was 86.96%. Sörensen's similarity values showed a species similarity of 86.96% between the inner and outer zone. For the Lamprecht's index, the coefficient of similarity was 93.97%. As the same result, the value of the Sorensen similarity index showed the same pattern as the Sörensen index.

4.2.4 Density of Species

The inner zone had not only a higher number of 52 tree species and 26 families but also a higher number of tree density and the results are shown in Table 12.However, the mean diameter of the inner zone (16.35cm) and the outer zone (16.47cm) was shown to be almost identical. The outer zone had a lower number of 40 tree species and 22 families and a lower number of tree densities. Furthermore, a statistical analysis such as the Mann-Whitney U test was performed to analyze the variations between the inner and outer zone based on 1.8 ha. When a non-parametric Mann-Whitney U test was used (all p values < 0.05), the diameter at breast height (p values < 0.008) and height (p values < 0.447) were significantly different between the inner zone and outer zone.

Table 12: Tree density of all species in the inner and outer zones based on 1.8 ha in NZWS

Zone	Species (n)	Family (n)	Tree Density (n)	DBH Mean ± SD (cm)	H Mean ± SD (m)	Total BA (m^2)
Inner Zone	52	26	1606	$16.35^{a} \pm 10.89$	11.8 ± 6.0	48.69
Outer Zone	40	22	1000	$16.47^{b} \pm 9.87$	11.7 ± 5.4	28.95

Difference letters indicate significant differences. (DBH= diameter at breast height, H=height, BA=basal area)

4.3 Horizontal Stand Structure

4.3.1 Diameter Distribution

Diameter distributions were often used to illustrate stand structure. It can be used to predict the future growth potential of the stand [89]. This parameter shows whether the density of smaller trees in a forest is sufficient to replace the current population of large trees. Stand structure was defined in terms of species richness and tree abundance, which were categorized according to their diameter classes.

4.3.1.1 Tree Abundance Based on Diameter Class (All Species)

The reverse J-shape pattern of diameter distribution indicates a sustainable distribution and a stable species composition in forest management [90]. Figures 7 and 8show the size classes based on the diameter distribution of individuals with a 10 cm interval between each class.

For the inner zone, the highest number of individuals was found in the diameter classes between 5 cm to 14.9 cm with 905 individualstree (Figure 7). The most abundant tree species such as *Tectona grandis*, *Xylia xylocarpa*, *Terminalia tomentosa*, and *Lagerstroemia speciosa* were found in the smallest diameter classes while *Dalbergia ovate*, *Dalbergia cultrata*, *Dalbergia kurzii*, *Tectona grandis*, *Mitragyna rotundifolia*, and *Anogeissus acuminata* were found in the second smallest diameter classes (15-24.9 cm). The species with 2 individuals of *Xylia xylocarpa* and *Lagerstroemia speciosa* were found in the second-largest diameter classes (55-64.9 cm) and the only tree species with one individual of *Dalbergia kurzii* which was found in the largest DBH classes (65-74.9 cm).

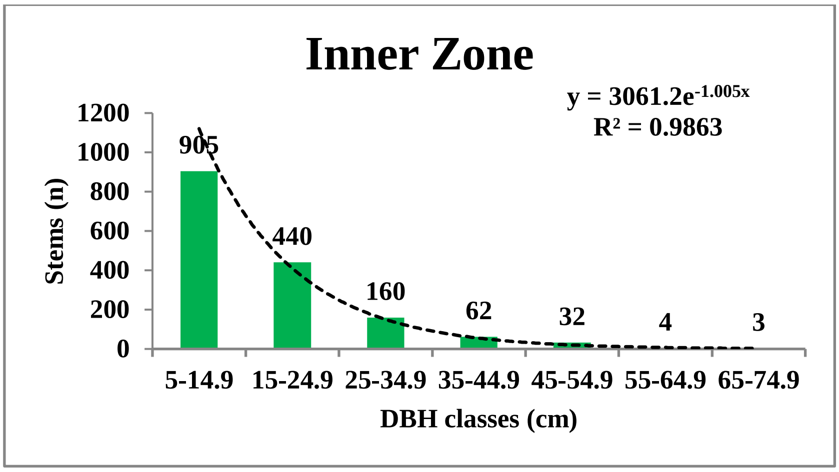

Figure 7: Diameter distribution of all tree species in the inner zone of the NZWS

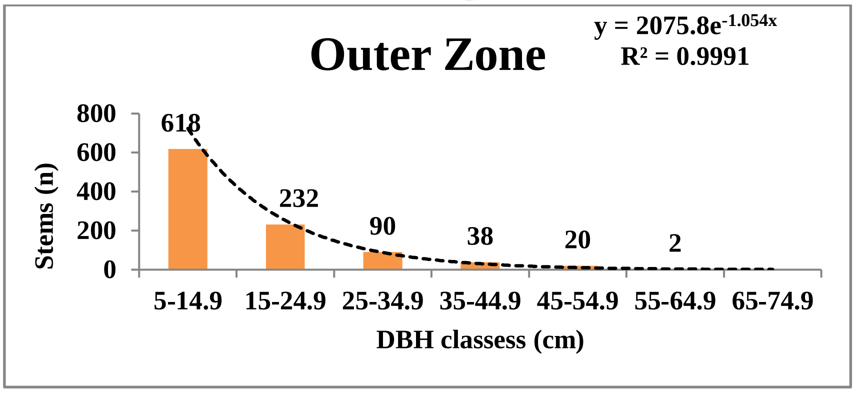

Figure 8: Diameter distribution of all tree species in the outer zone of the NZWS

For the outer zone, the largest numbers of 618 individuals were identified in the smallest diameter class 5 cm to 14.9 cm (Figure 8). The most abundant tree species such as *Terminalia tomentosa*,*Dalbergia kurzii*, and *Tectona grandis* were found in the smallest diameter classes while*Xylia xylocarpa*, *Croton oblongifolius*, *Bombax insigne*, and *Lagerstroemia speciosa* were found in the second smallest diameter classes (15-24.9 cm) and only one tree species with one individual of *Dalbergia kurzii*which was found in the second largest DBH classes (55-64.9 cm). Notably, the curves of both zones were approximately reverse J-shaped. Lamprecht (1989) determined that forest stands are reverse J-shaped and have a certain natural sustained yield, owing to the presence of an adequate number of small-diameter trees to compensate for the loss of larger diameter trees.

4.3.1.2 Species Richness Based on Diameter Classes

In this study, 52 species were found from the inner zone and 40 species were found from the outer zone.

Table 13: Stand table for the inner and outer zones of the NZWS (DBH ≥ 5 cm classes per 1.8 ha)

DBH classes (cm)	Inner Zone	Outer Zone
5-14.9	52	39
15-24.9	46	37
25-34.9	36	21
35-44.9	23	11
45-54.9	11	5
55-64.9	3	1
65-74.9	1	

4.3.1.3 Diameter Distribution of the Most Common Commercial Tree Species in the Study Area

The stand diameter distributions of the most common commercial tree species were also observed in both zones as these are critical species to conserve in the North Zamari Wildlife Sanctuary. Figure 9 indicates the diameter frequency distribution for both zones of the most common commercial species. As a result, none of the three tree species (*Tectona grandis*, *Xylia xylocarpa*, and *Terminalia tomentosa*) followed the reverse J-shaped pattern entirely. The diameter distributions of *Tectona grandis* (5 - 39.9 cm), *Xylia xylocarpa* (5 - 59.9 cm), and *Terminalia tomentosa* (5 - 54.9 cm) were observed in the inner zone. *Xylia xylocarpa* had the widest range of DBH classes, whereas *Tectona grandis* had the smallest range of diameter classes. The diameter distributions of *Tectona grandis* (5 - 29.9 cm), *Xylia xylocarpa* (5- 59.9 cm), and *Terminalia tomentosa* (5 - 54.9 cm) were found in the outer zone. Based on field observations and information from local people, both zones have been illegally logged, practically tree species such as *Tectona grandis*, *Xylia xylocarpa*, *Dalbergia cultrata*, *Mitragyna rotundifolia*, *Dalbergia fusca*, *Dalbergia kurzii*, *Dalbergia muliflora*, *Dalbergia ovate*, *Lagerstroemia speciosa*, *Lagerstroemia tomentosa*, *Lagerstroemia villosa*, and *Millettia pendula*.

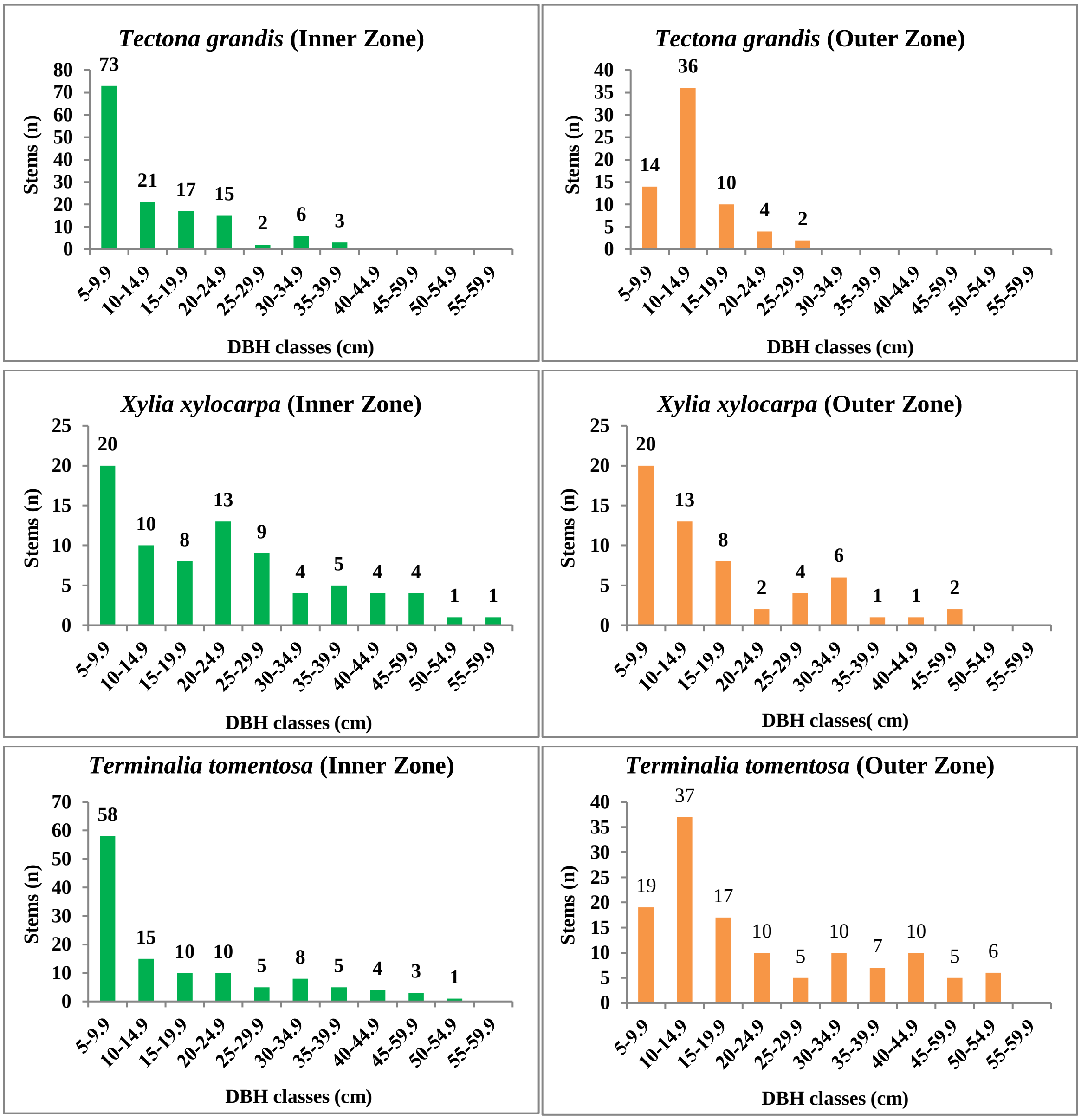

Figure 9: Diameter distribution of the most common commercial tree species in the study area

4.3.2 Frequency Percent

The frequency classifications of all stands were determined using their absolute frequencies. The numbers of species occurring in both zones were categorized into five classes. The absolute frequency (81-100%) is regarded as class V, (61-80%) as class IV, (41-60%) as class III, (21-40%) as class II, and (1-20%) as class I. The inner zone showed a high frequency of occurrences in classes II and III however a low frequency showed in the classes IV and V (Figure 10). There were 10 species in class I, 22 species in class II, 11 species in class III, 5 species in class IV, and only 4 species in class V.The class V species for the inner zone were *Tectona grandis*, *Xylia xylocarpa*, *Terminalia tomentosa*, and *Lagerstroemia speciosa*. The outer zone showed a high frequency of occurrences in class I only but a low frequency showed in all other classes. There were 22 species in class I, 7 species in class II, 4 species in class III, 3 species in class IV and only 4 species in class V. The class V species for the inner zone were *Tectona grandis*, *Xylia xylocarpa*, *Terminalia tomentosa*,and *Dalbergia kurzii*.

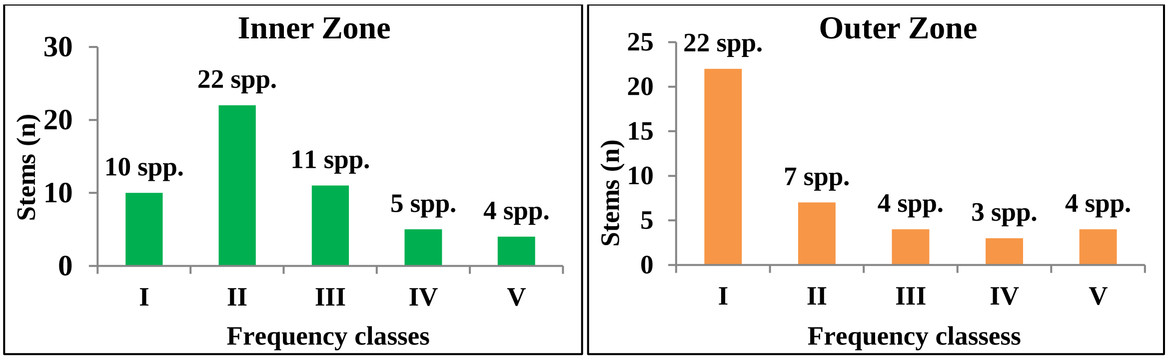

Figure 10: Frequency diagram of the inner zone and the outer zone of the NZWS

4.4 Vertical Stand Structure

4.4.1 Height Curve Fitting

According toVan Larr &Akca (2007)[72], the relationship between diameter at breast height and height was formulated by using the best-fitted model for the inner and the outer zone. The height curves were formulated using a data set of all tree species with a diameter at breast height ≥ 5 cm per 1.8 hectares in this study. Height curves on good sites are comparatively steeper and higher than the height curves on poor sites[91]. Height curves give a steep slope in young stands due to the greatest of the early stage growth height while lower gradients are obtained in old stands due to slow growth of height with age[92].The regression function was chosen based on the forms and trends of the curves over the range of observed diameters, as well as on the statistical characteristics (coefficient of determination [r^2] and regression coefficient [r]) [93].

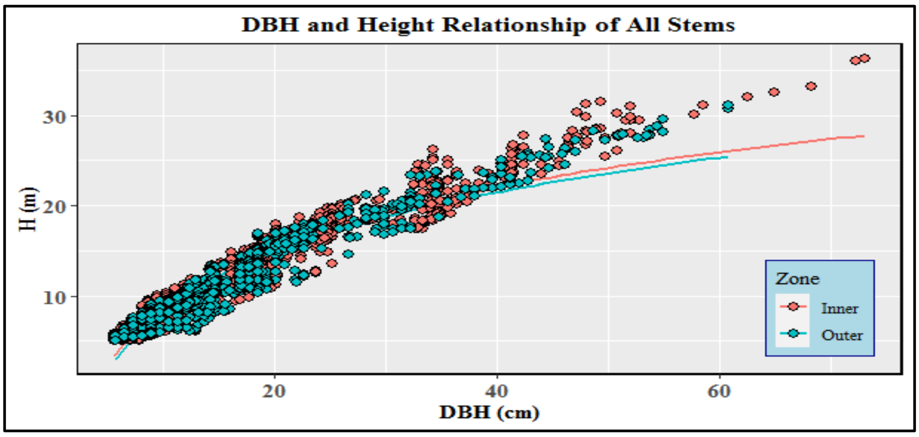

Figure 11: The height and DBH relationship of all stems with a DBH ≥ 5 cm in the inner zone and the outer zone of the NZWS

Figure 11showed the relationship between diameter at breast height and height for the inner zone and the outer zone of the North Zamari Wildlife Sanctuary. The curves of both zones showed the same trends but the height curve of the inner zone showed steeper than the outer zone. In this study, the biggest diameter at breast height for the inner zone was 73cm and the outer zone was 60.8 cm. Based on the shape of those curves, it can be concluded that height can increase with a larger diameter in both stands and the curves reach the constant level at the highest diameters.

The relationship between diameter at breast height and height of the *Tectona gradis* at both zones is illustrated in Figure (12-a). For *Tectona gradis*, the numbers of stands were 137 in the inner zone and 66 in the outer zone. The range of the diameter in *Tectona gradis* was (5.7 cm – 36.4cm) in the inner zone and (5.5 cm – 32.3cm) in the outer zone. The range of the height was (5.1 cm – 23.5m) in the inner zone and (5.6 cm – 32.3m) in the outer zone. The curves of both zones showed the same trends but the height curve of the inner zone showed steeper than the outer zone.

The relationship between diameter at breast height and height of the *Xylia xylocarpa* in both zones is illustrated in Figure (12-b). For *Xylia xylocarpa*, the numbers of stands were 79 in the inner zone and 57 in the outer zone. The range of the diameter in *Xylia xylocarp* was (6.2 cm to 62.5 cm) in the inner zone and (5.6 cm to 54.9 cm) in the outer zone. The range of the height was (5.3 cm to 32 m) in the inner zone and (5.6 cm to 29.6 m) in the outer zone. The curves of both zones showed the same trends but the height curve of the inner zone showed steeper than the outer zone.

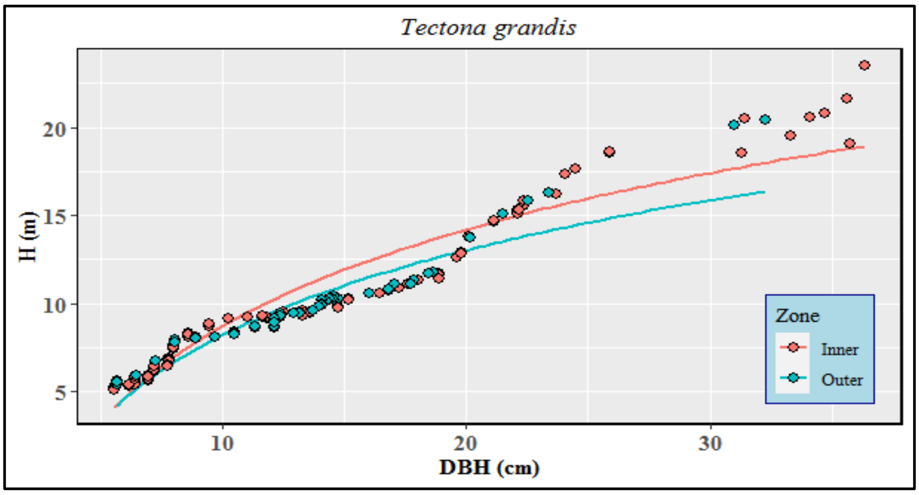

Figure 12-a: The height and DBH relationship of*Tectona gradis* with a DBH ≥ 5 cm in the inner zone and the outer zone of the NZWS

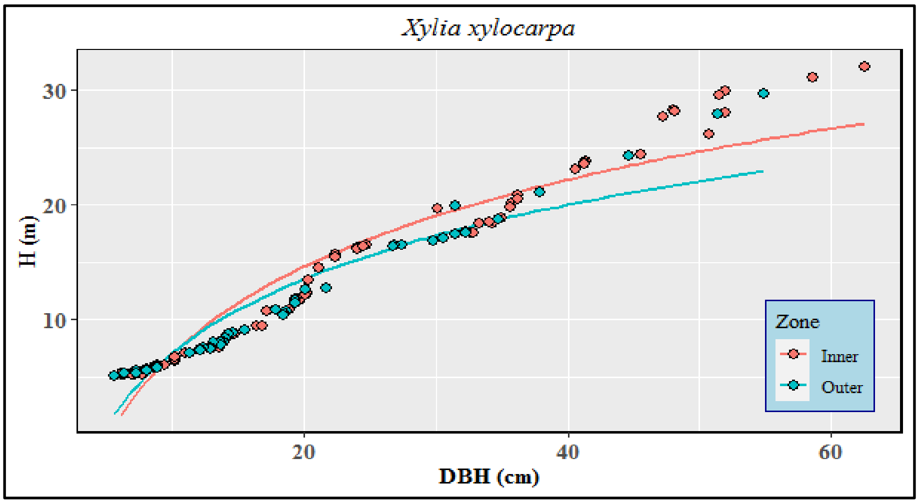

Figure 12-b: The height and DBH relationship of *Xylia xylocarpa* with a DBH ≥ 5 cm in the inner zone and the outer zone of the NZWS

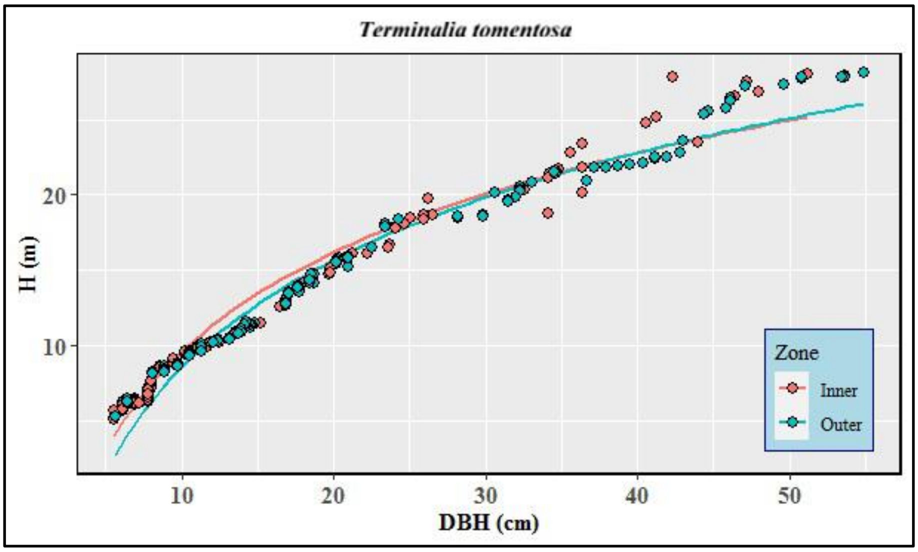

Figure 12-c: The height and DBH relationship of *Terminalia tomentosa* with a DBH ≥ 5 cm in the inner zone and the outer zone of the NZWS

The relationship between diameter at breast height and height of the *Terminalia tomentosa* at both zones is illustrated in Figure (12-c). For *Terminalia tomentosa*, the numbers of stands were 119 in the inner zone and 127 in the outer zone. The range of the diameter in*Terminalia tomentosa* was (5.6 cm to 51.2cm) in the inner zone and (5.5 cm to 54.9cm) in the outer zone. The range of the height was (5.1 cm to 28m) in the inner zone and (5.3 cm to 28.1m) in the outer zone.The curves of both zones showed the same trends. *Terminalia tomentosa* is different from *Tectona gradis* and *Xylia xylocarpa*, the height curve of the outer zone showed steeper than the inner zone and the number of stands found in the outer zone is higher than the inner zone.

4.4.2 Vertical Floristic Component

The vertical floristic component of the forest layers based on 1.8 ha was given in Table 14.

Table 14: Classification on the number of stems and species of all stems with a DBH ≥ 5 with canopy layers in the inner and the outer zone of the NZWS

Canopy Layer	Inner Zone		Outer Zone	
	Individuals (n)	Species (n)	Individuals (n)	Species (n)
Lower	493	43	236	28
Middle	560	49	529	39
Upper	553	38	235	31
Total	**1606**		**1000**	

According to the table, the tree density of the inner zone was 493 stems (31%) of the total abundance recorded in the lower canopy layer and 560 stems (35%) of the total abundance were found in the middle canopy layer. In the upper canopy layer, 553 stems (34%) of the total abundance were recorded. The tree density of the outer zone was 236 stems (24%) of the total abundance recorded in the lower canopy layer and 529 stems (53%) of the total abundance were found in the middle canopy layer. In the upper canopy layer of the outer zone, 235 stems (23%) of the total abundance were recorded. The results showed that the percentage of the middle canopy layer is the highest and the percentage of the upper canopy layer is the smallest for both zones.

4.5 Natural Regeneration

4.5.1 Density and Structure of Natural Regeneration

In this study, natural regenerations were measured for both zones. There were 40 square subplots (10 m x 10 m) for saplings and 160 square subplots (5 m x 5 m) for seedlings. The total area of 2000 m^2 for saplings and seedlings was measured in both zones. The number of regenerations was multiplied by 5 to express regenerations on a per hectare basis. The densities of natural regeneration are given in the following table (Table 15). According to the results, the number of seedlings and saplings in the outer zone was higher than in the inner zone.

Table 15: The abundance of natural regenerations in the inner and outer zone of the NZWS

Zone	Abundance		Total
	Saplings(n)	Seedlings(n)	
Inner Zone	265	1870	2135
Outer Zone	305	2135	2440

4.5.2 Species Composition in Natural Regeneration

Table 16: The number of species and families of the natural regenerations in the inner and outer zone of the NZWS

Zone	Total NR*		Saplings		Seedlings	
	Species (n)	Family (n)	Species (n)	Family (n)	Species (n)	Family (n)
Inner Zone	39	22	30	16	39	22
Outer Zone	36	20	32	15	36	20

*Total NR is the sum of the same species and families of the seedlings and saplings

Table 16 showed the numbers of species and families of the regenerations in the inner and outer zone of the North Zamari Wildlife Sanctuary. According to the result, the total numbers of species in the regenerations of the outer zone were higher than in the inner zone. However, 22 families of the regenerations in the inner zone were higher than in the outer zone. The numbers of regenerations were higher in the outer zone because the outer zone had several gaps that favor the light on the natural regenerations.Most of the species found in the study area are light-demanding species. In terms of saplings,*Tectona grandis*, *Dalbergia kurzii*,*Dalbergia cultrata*, *Terminalia tomentosa*and *Xylia xylocarpa*were the most abundant species in the inner zone and *Terminalia tomentosa*,*Dalbergia kurzii*, *Tectona grandis*, *Millettia pendula* and*Dalbergia cultrata*were the most abundant species in the outer zone. In terms of seedlings,*Tectona grandis*,*Millettia pendula*, *Xylia xylocarpa*, *Mitragyna rotundifolia*,and*Lagerstroemia speciosa*werethe most abundant species in the inner zone and *Tectona grandis*,*Millettia pendula*,*Terminalia tomentosa*, *Xylia xylocarpa*, and*Mitragyna rotundifolia*were the most abundant species in the outer zone (Table 17).

Table 17: The ten most abundant species of saplings and seedlings

Rank	Saplings		Rank	Seedlings	
	Scientific Name	n/ha		Scientific Name	n/ha
Inner Zone					
1	*Tectona grandis*	40	1	*Tectona grandis*	190
2	*Dalbergia kurzii*	25	2	*Millettia pendula*	160
3	*Dalbergia cultrata*	20	3	*Xylia xylocarpa*	145
4	*Terminalia tomentosa*	15	4	*Terminalia tomentosa*	110
5	*Xylia xylocarpa*	15	5	*Lagerstroemia speciosa*	95
6	*Lagerstroemia speciosa*	10	6	*Mitragyna rotundifolia*	90
7	*Dalbergia ovata*	10	7	*Bombax insigne*	70
8	*Anogeissus acuminata*	10	8	*Dalbergia cultrata*	50
9	*Mitragyna rotundifolia*	10	9	*Dalbergia ovata*	50
10	*Bombax insigne*	10	10	*Bridelia retusa*	40
11	20 other species	100	11	29 other species	870
	Total	**265**		**Total**	**1870**

Outer Zone					
1	*Terminalia tomentosa*	50	1	*Tectona grandis*	220
2	*Dalbergia kurzii*	30	2	*Millettia pendula*	180
3	*Tectona grandis*	30	3	*Terminalia tomentosa*	155
4	*Millettia pendula*	15	4	*Xylia xylocarpa*	135
5	*Dalbergia cultrata*	15	5	*Mitragyna rotundifolia*	125
6	*Dalbergia ovata*	15	6	*Dalbergia kurzii*	110
7	*Xylia xylocarpa*	10	7	*Bombax insigne*	95
8	*Bombax insigne*	10	8	*Dalbergia cultrata*	70
9	*Croton oblongifolius*	10	9	*Croton oblongifolius*	65
10	*Dalbergia fusca*	10	10	*Dalbergia fusca*	55
11	22 other species	110	11	26 other species	925
	Total	**305**		**Total**	**2135**

4.5.3 Tree Species With and Without Natural Regeneration

Table 18showed the comparison of the number of species with and without regeneration of the investigated stands for both zones. The total number of tree species found in the study area was 52 for the inner zone and 40 for the outer zone. However, 39 tree species for the inner zone and 36 tree species for the outer zone were observed with regenerations and 13 tree species for the inner zone and 4 tree species for the outer zone were observed without regenerations.

Table 18: Number of tree species with and without natural regeneration in the inner and the outer of NZWS

Total number of species found	Inner Zone	Outer Zone
Total number of species	52	40
Total number of species with regeneration	39	36
Total number of species without regeneration	13	4

4.5.4 Floristic Similarity of the Natural Regeneration

Table 19 showed the similarity of the species composition by using Sörensen's index. For the species level,Sörensen's similarity index of natural regenerations was calculated by80% between the inner zone and the outer zone. At the family level,Sörensen's similarity index was 90.32%between the inner zone and the outer zone.

Table 19: Sörensen's index on floristic similarity for the inner and the outer zone of NZWS

Zone	Sörensen's Similarity Index			
	Species level (%)		Family level (%)	
	Inner	Outer	Inner	Outer
Inner	……	80	……	90.32
Outer	80	……	90.32	……

5. Discussion

5.1 Discussion

The species-area curve was applied as an important parameter to determine the minimal area of a community [94]and it was also the best criterion for the contribution of the minimum study area [73]. The trend in the species-area curve showed that as the number of plots increases, more the number of species appear, and it also indicates that 1.8 ha for the inner and the outer zone of the North Zamari Wildlife Sanctuary was a representative area to access tree species in forest communities. The total study area (1.8 ha) had a listing of 52 species (26 families) for the inner zone and 40 species (22 families) for the outer zone.

The tree species recorded in the North Zamari Wildlife Sanctuary are comparable to the other studies in mixed deciduous forest types of Myanmar, India, and Thailand. In this study, 26 families were found from the inner zone and 22 families were found from the outer zone.

Khamyong et al., (2018)listed71 species in 31 families in a 1 ha plot in Doi Suthep-Pui National Park, Chaing Mai, Thailand[95].Narayan (2015)reported38 tree species in 21 families on the 4 ha study site in the western part of the Bokaro district, India[96].Sein and Aung (2015)listed34 species in 10 families from 1 ha of dry upper mixed deciduous forest type in the AlaungdawKathapa National Park, Sagaing Region, Myanmar[97].Therefore, the North Zamari Wildlife Sanctuary can be considered rich in biodiversity.

The Family Importance Value Index (FIV) showed that Combretaceae, Fabaceae, and Rubiaceae were the most dominant families in the inner zone and Combretaceae, Fabaceae, and Bombacaceae were the most dominant families in the outer zone. The results of this study showed that the floristic diversity of the North Zamari Wildlife Sanctuary was not very much different from other mixed deciduous forests because Narayan (2015)reported Combretaceae and Fabaceae were the most dominant families in the western part of the Bokaro district, India[96]. Khamyong et al., (2018) found thatFabaceae and Combretaceae were the dominant families in the upper mixed deciduous forest of Doi Suthep-Pui National Park, Chaing Mai, Thailand[95]and Sein & Aung (2015)also stated that Euphorbiaceae and Fabaceae were the most dominant families in the AlaungdawKathapa National Park, Sagaing Region, Myanmar[97].

At the species level, the most dominant species in the North Zamari Wildlife Sanctuary are*Tectona grandis*,*Xylia xylocarpa*, and*Terminalia tomentosa*in the inner zone, and *Tectona grandis*, *Terminalia tomentosa*,and *Dalbergia kurzii*in the outer zone. This result also revealed that the floristic diversity of the North Zamari Wildlife Sanctuary at the species level was notdifferent from other mixed deciduous forests. When compared with another study in Bago Yoma, T. N. OO and D. K. Lee (2007)found that*Tectona grandis*, *Xylia xylocarpa*, and*Mitragyna rotundifolia*were the most dominant species[21].Myo et al., (2016) stated that *Tectona grandis*, *Xylia xylocarpa*, and *Milettia pendula* were the most dominant species in the mixed deciduous forest, Madan watershed, Myanmar [98]. Marod et al., (2017) enumerated that *Shoreasiamensis*, *Dillenia parviflora*, and *Xylia xylocarpa* are the dominant species in the mixed deciduous forest at the Mae Klong Watershed research station in Thailand [99]. Moreover, Podong&Krivutthinun (2018) found that *Tectona grandis*, *Dalbergia cultrata*, and *Strychnos nux-blanda* were the dominant species in the mixed deciduous forest of Ban-Khum, Lab-Lare district, Thailand [100].

According to the results of the diversity indices, all forest types had a great variety of species. Non-parametric statistical analysis (Mann-Whitney U test) was employedto assess variance across the inner and outer zone. When using the Mann-Whitney U test, the Simpson, Shannon Weiner, and Evenness indices were significantly different between the inner and outer zone.The diversity indices in the North Zamari Wildlife Sanctuary revealed more diversethan the finding of Myo et al., (2016)inthe deciduous dipterocarp forest of Myanmar's Madan Watershed[98]and the finding of Podong&Krivutthinun (2018)ina mixed deciduous forest in Thailand's Thung Saleng Laung National Park [100]however less diverse than the finding of Shwe Zin (2017)inthe moist evergreen forest of Myanmar's Tanintharyi Nature Reserve[101]. In this study, most of the species found in the inner zone and the outer zone were quite similar.

The results of the similarity index of the Sörensen and the Lamprecht similarity coefficient were 86.96% and 93.97% respectively. Moreover, the inner zone had a higher basal area of 48.67 m^2 (1606 stems) per size and the outer zone had 28.96 m^2 (1000 stems) per size. Many trees with small diameters are found in both zones due to dense human disturbances.

When viewed from the whole set of population structures in the study, the distribution of tree species in different size classes showed the reverse J-shaped pattern for diameter distributions. The pattern of diameter distributions of tree species was calculated based on the inner and the outer zone and the results showed the reverse J-shaped pattern, resulting in good shape forests and growth conditions. Moreover, the reversed J-shaped distribution pattern showed that the forest is on the status of favorable regenerations potentials. This result was like the findings of Myo et al., (2016) in the deciduous forest of Myanmar [98]. The stand diameter distributions of the most common commercial tree species (*Tectona grandis*, *Xylia xylocarpa*, and *Terminalia tomentosa*) were also observed for both zones and none of the three tree speciesfollowed the reverse J-shaped pattern entirely. The commercial tree species are very useful to the local people living around the North Zamari Wildlife Sanctuary and the numbers of commercial tree species were declining largely due to illegal logging.

In the present study, the species which had the maximum height was *Dalbergia kurzii* (Thit-pok) for both zones; 36.3min the inner zone and 31.1m in the outer zone. It was greater than 23.94m found in dry dipterocarp forest at the Doi Suthep-Pui National Park in Nothern Thailand [95].The result of the maximum height recorded in this study was lower than the maximum height of 40m reported byT. N. OO and D. K. Lee (2007) in the moist deciduous forest of Bago Yoma [21].The height curve of the inner zone was steeper than the outer zone and therefore it showed that the growth conditions of tree species in the inner zone were better than in the outer zone. Furthermore, the height curves for both zones were observed with an increase in diameter, which is consistent with the findings of Shwe Zin (2017) [101]. For vertical floristic structure, the young stage of trees in the lower storey was less than in the middle and upper storey and this result followed the observations of T. N. OO and D. K. Lee (2007) [21]and Gyi K.K. and Tint K. (1998)[102]in Bago Yoma.

According to the result, 39 tree species for the inner zone and 36 tree species for the outer zone were observed with regenerations and 13 tree species for the inner zone and 4 tree species for the outer zone were observed without regenerations. Therefore, 75% of the adult trees in the inner zone had regeneration and 90% of the adult trees had regeneration in the outer zone. Conversely, 25% of the adult trees in the inner zone had without regeneration and 10% of the adult trees had without regeneration in the outer zone due to the effects of climatic factors such as rainfall, temperature, pH, and human-induced disturbances.

6. Conclusion and Recommendations

6.1 Conclusion

Most of the valuable tree species are depleted and degraded at an alarming rate in Myanmar due to forest degradation and unsustainable resource extraction, such as illegal logging, fuel-wood collection, and charcoal making. Commercial tree species in the North Zamari Wildlife Sanctuary are also threatened due to illegal logging, charcoal making, and growing population pressure from the surrounding community. Detailed information about the growth characteristics and distribution of tree species in the North Zamari Wildlife Sanctuary is rare and specific detailed research is needed. Therefore, the focus of this study was on tree species by analyzing the distribution pattern and growth conditions of the mixed deciduous forests in the North Zamari Wildlife Sanctuary.

The study was conducted in February 2022 at the North Zamari Wildlife Sanctuary, Min Hla Township, and Lat Pa Dan Township, Tharrawaddy District of Sagaing Region in central Myanmar. The 52 species in 26 families and 40 species in 22 familiesper 1.8 ha(DBH $\geq$ 5 cm and H $\geq$ 1.3 m) were found in the inner zone and the outer zone of the North Zamari Wildlife Sanctuary. In the North Zamari Wildlife Sanctuary, the inner zone had more species richness than the outer zone. Combretaceaeand Fabaceae were the most abundant families in both zones. *Tectona grandis* was the most dominant species in the inner zone and *Terminalia tomentosa* was the most dominant species in the outer zone.

The forest structure of the inner zone had a high degree of floristic heterogeneity and diversity of species based on the diversity indices. When using the non-parametric statistical analysis (Mann-Whitney U test), all p-values are less than 0.05, and therefore the Simpson, Shannon Weiner, and Evenness indices were significantly different between the inner and outer zone. For species similarity, Sörensen’s similarity values showed a species similarity of 86.96% and Lamprecht showed 93.97% between the inner and outer zone. The diameter at breast height and height were significantly different between the inner zone and outer zone. The mean diameter of the inner zone (16.35 cm) and the outer zone (16.47 cm) was shown to be almost identical. However, the basal area of 48.67m^2 of the inner zone was higher than the basal area of 28.96 m^2 of the outer zone due to the presence of large diameter and abundant species.

The diameter distribution curves of both zones followed the regular (reverse J-shaped) pattern. *Tectona grandis*, *Terminalia tomentosa*, and *Xylia xylocarpa*were the highest trees in the inner zone and *Terminalia tomentosa*, *Dalbergia kurzii*, and *Tectona grandis* were the highest trees in the outer zone however human disturbances and illegal logging activities were found in both zones. For both zones, the highest number of individuals was found in the diameter classes between 5 cm to 14.9 cm. The only tree species with one individual of *Dalbergia kurzii*was found in the largest DBH classes (65-74.9 cm) in the inner zone. The inner zone discovered 52 species (100%) and the outer zone discovered 39 species (75%) of the total species in the 5 cm to 14.9 cm DBH class and the inner zone discovered 3 species (5.76%) and the outer zone discovered only one species (1.92%)in the 55 cm to 64.9 cm DBH class. Only one species (*Dalbergia kurzii*) for 1.92% of the species richness was detected with DBH classes 65 cm to 74.9 cm in the inner zone, none was found in the outer zone.

The stand diameter distributions of the most common commercial tree species (*Tectona grandis*, *Xylia xylocarpa*, and *Terminalia tomentosa*) were also observed in both zones as these are critical species to conserve in the North Zamari Wildlife Sanctuary and none of the three tree species followed the reverse J-shaped pattern entirely due to illegal logging activities. For frequency percent, the most dominant tree species for the inner zone is *Tectona grandis* and the outer zone is *Xylia xylocarpa*.The heightcurves of both zones showed the same trends but the height curve of the inner zone showed steeper than the outer zone. In this study, the biggest diameter at breast height for the inner zone was 73 cm and the outer zone was 60.8 cm.The height curves of *Tectona grandis* and *Xylia xylocarpa* in the inner zone showed steeper than in the outer zone but the height curve of *Terminalia tomentosa* in the outer zone showed steeper than in the inner zone.

The tree density of the inner zone was493 stems (31%)of the total abundance recorded in the lower canopy layer, 560 stems (35%) in the middle canopy layer, and 553 stems (34%) in the upper canopy layer. The tree density of the outer zone was236 stems (24%)recorded in the lower canopy layer,529 stems (53%) in the middle canopy layer, and 235 stems (23%) in the upper canopy layer. The percentage of the middle canopy layer is the highest and the percentage of the upper canopy layer is the smallest for both zones. Moreover, the total numbers of species in the regenerations of the outer zone were higher than in the inner zone.

6.2 Recommendations

In Myanmar, valuable tree species are threatened due to forest degradation and unsustainable resource extraction. Different forest types have different compositions, structures, and environments. Even within the same forest type, the structure and composition of the forest can be different on the bases of the elevation, climatic conditions, and other environmental factors. The vegetation assessment of the North Zamari Wildlife Sanctuary revealed that most valuable tree species are threatened because of illegal logging, fuel-wood collection, and charcoal making. The Myanmar Forest Department and other related conservation organizations are trying to get more optimum for the reforestation program and the real status of Myanmar’s forest conditions is crucial for reforestation activities. Appropriate and proper management systems should be adopted based on the nature of forests to systematically and sustainably manage different types of forests. Therefore, the study explored the following recommendations:

1. Law enforcement and strict regulations should be conducted to prevent encroachment and illegal logging activities in the North Zamari Wildlife Sanctuary.

2. Forest Rangers should be increased to carry out adequate patrols for effective habitat protection in the North Zamari Wildlife Sanctuary.
3. Many comprehensive inventories should be conducted to cover the whole area of the North Zamari Wildlife Sanctuary.
4. Enrichment planting should be carried out in the open gaps of natural forests and the existing young regenerations should be conserved in the gaps.
5. The silvicultural operations such as thinning, weeding, improvement felling, and climber cuttings should be carried out in time.
6. A systematic management plan should be formulated in the North Zamari Wildlife Sanctuary.
7. Fuel-wood plantations should be established near villages around the North Zamari Wildlife Sanctuary and local stakeholders should be encouraged to reduce their fuel-wood consumption.
8. The awareness program for people's participation is important in reforestation activities and promoting awareness is essential to support the livelihood of local communities.

Finally, the distribution of tree species and the patterns of diversity in the study will provide a good database for park managers to manage and conserve Myanmar’s protected areas effectively and efficiently.

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