Ph.D. THESIS

COMMUNITY STRUCTURE AND HABITAT USE BY VERTEBRATES IN THE SACRED FORESTS OF KERALA

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Contents

List of figures iv

List of tables vi

Chapter 1

GENERAL INTRODUCTION 1-12

1.1 Introduction 1

1.2 Distribution 2

1.3 Area and zone wise distribution 6

1.4 Deities associated with sacred groves in Kerala 7

1.5 History of sacred groves in Kerala 8

1.6 Ecological and biological significance 9

Chapter 2

REVIEW OF LITERATURE 13-27

2.1 International studies 13

2.2 Studies in India 15

2.3 Studies in the Western Ghats 22

2.4 Regional studies/studies in Kerala 24

Chapter 3

STUDY SITE SELECTION AND METHODOLOGY 29-48

3.1 Selection of study sites and study site description 29

3.2 Methodology 41

3.2.1 Vertebrate species richness and diversity 41

3.2.2 Vegetation sampling 45

3.2.3 Microhabitat documentation..45
3.2.4 Public survey..47

Chapter 4

DIVERSITY AND SPECIES ABUNDANCE OF VERTEBRATES… 49-72

4.1 Birds...49
4.2 Reptiles..55
4.3 Amphibians 60
4.4 Mammals..63

Chapter 5

FACTORS AFFECTING THE DISTRIBUTION AND DIVERSITY OF VERTEBRATES……………………………………………73-104

5.1 Area or size of the sacred groves 74
5.2 Ownership and Management policies 77
5.3 Religious rituals and beliefs among public and people's attitude........................82
5.4 Climatic and topographic factors 85
5.5 Seasonal variations...96
5.6 Proximity towards the reserve forest predicts the vertebrate diversity 99

Chapter 6

MICHROHABITATS IN THE SACRED GROVES................................... 105-122

6.1 Arboreal microhabitats as indicators...107
6.2 Microhabitat use by vertebrates 113

Chapter 7

VERTEBRATE FAVORABLE SACRED GROVES AND THREATS ... 123-148

7.1 Based on Shannon index 124

7.2 People's attitude 130

7.3 Vegetation cover.. 132

7.4 Threats recorded in sacred groves.. 141

7.5 Strategies to promote conservation in sacred groves 145

Chapter 8

CONCLUSION AND RECOMMENDATIONS 149-155

8.1 Major outcomes.. 150

8.2 Recommendations 154

REFERENCES.. 156-163

PLATES 164-165

APPENDIX.. 167-176

List of figures

Figure 1 Zone- Wise Distribution of Sacred Groves in Kerala 6

Figure 2 Year Wise Publication of Studies in Sacred Groves 21

Figure 3 Trends in Publication Growth 21

Figure 4 Map showing the selected study sites 32

Figure 5 Distribution of Birds Across Different Sacred Groves 50

Figure 6 Representation of Bird Orders Recorded from the Sacred Groves 51

Figure 7 Shannon Diversity Index of Birds Across Different Sacred Groves 52

Figure 8 Simpson Diversity Index of Birds Across Different Sacred Groves 53

Figure 9 Dominant Index of Birds Across Different Sacred Groves 54

Figure 10 Distribution of Reptiles Across Different Sacred Groves 56

Figure 11 Shannon Index of Reptiles Across Different Sacred Groves 57

Figure 12 Simpson Diversity of Reptiles Across Different Sacred Groves 58

Figure 13 Dominance Index of Reptiles Across Different Sacred Groves 59

Figure 14 Evenness Index of Reptiles Across Different Sacred Groves 60

Figure 15 Distribution of Amphibians Across Different Sacred Groves 61

Figure 16 Shannon Index of Amphibians Across Different Sacred Groves 62

Figure 17 Species Accumulation Curve of Amphibians 63

Figure 18 Distribution of Mammals Across Different Sacred Groves 64

Figure 19 Shannon Index Results of mammals 65

Figure 20 Dominance Index of Mammals Across Different Sacred Groves 66

Figure 21 Shannon Index of Vertebrates Across Different Sacred Groves 67

Figure 22 Berger Parker Index of Vertebrates Across Different Sacred Groves 68

Figure 23 Equitability index of vertebrates 69

Figure 24 Dominance Index of Vertebrates Across Different Sacred Groves 70

Figure 25 Correlation of Vertebrate Diversity Among Selected Sacred Groves.... 71

Figure 26 Bray Curtis analysis of Vertebrate Diversity.. 72

Figure 27 The Species Area Relationship Observed in Different Sacred Groves .. 74

Figure 28 Correlation Between Species Diversity and Area of Sacred Groves...... 77

Figure 29 Correlation between Management policies and Shannon index............. 81

Figure 30 Species Richness Across Sacred Groves during the Pre-Monsoon........... 97

Figure 31 Alpha Diversity during Pre- Monsoon Across Sacred Groves................ 97

Figure 32 Species richness during Post-Monsoon 98

Figure 33 Alpha diversity during Post -Monsoon.. 98

Figure 34 Lollipop Chart of Microhabitats Across the Study Sites..................... 108

Figure 35 Dot Plot showing Composition of Microhabitats 109

Figure 36 Microhabitat Composition Across Selected Sacred Grove Study Sites.... 110

Figure 37 Relationship Between Microhabitat Abundance and Shannon Diversity. 113

Figure 38 Comparison of Available and Used Microhabitats by Vertebrates 114

Figure 39 Venn diagram of Vertebrates Sharing the Microhabitats 118

Figure 40 Heat map of Microhabitat Uses by Vertebrates...................................... 120

Figure 41 Species Richness of Vertebrate Groups Across Selected Sacred Groves . 124

Figure 42 Potential Key Biodiversity Area of Sacred Groves 127

Figure 43 K-Means Clustering of Study Sites…………………………………...128

List of Tables

Table 1 Area Covered by the Sacred Groves Across Different Regions 7

Table 2 Description of Selected Study Sites 30-31

Table 3 Site-wise Distribution of Point Count Stations used for Bird Counts 43

Table 4 Sampling effort and Percentage of Area Covered for Microhabitat Documentation ……………75

Table 5 Scores of Different Parameters 80

Table 6 Mean Scores for all the Study Sites 83

Table 7 Regression Analysis..84

Table 8 Correlation between Bird Shannon Index and Humidity Percentage……….92

Table 9 Correlation between Reptile Shannon Index and Humidity Percentage…….93

Table 10 Correlation between Amphibian Shannon index and Humidity Percentage …93

Table 11 Correlation between Mammal Shannon index and Humidity Percentage….94

Table 12 Aerial Distance between Sacred Groves and Nearest Reserve Forest..........100

Table 13 Regression analysis of Aerial Distance and Shannon index 101

Table 14 Regression analysis of Microhabitats and Shannon index..........................111

Table 15 Standardized Residual Analysis of Microhabitats.......................................116

Table 16 Z score of Different Study Sites..125

Table 17 Representative Floral Elements Recorded from Sacred Groves 134-138

Table 18 Area of Encroachment in Selected Sacred Groves.....................................142

1. General introduction

1.1 Introduction

The Earth has undergone continuous evolutionary changes, leading to speciation and the emergence of a vast diversity of living organisms, each adapted to specific habitats and ecological niches. To ensure their conservation, various strategies have been developed, which can be broadly classified into in situ and ex situ approaches. Ex situ conservation involves the protection and management of species outside their natural habitats, such as zoos, botanical gardens, and museums. In contrast, in situ conservation focuses on protecting species within their natural ecosystems through the establishment of protected area networks, including national parks, wildlife sanctuaries and biosphere reserves, governed by specific management frameworks and regulations.

However, protected areas worldwide are insufficient to conserve all critical habitats and species (Bhagwat & Rutte, 2006). It is estimated that only approximately 23% of tropical forest patches fall within protected area categories, raising serious concerns about the conservation of species occurring outside these areas. Consequently, the conservation of species beyond formally protected area networks has gained increasing global importance. Landscapes such as urban forests, mountains, lakes and rivers support a wide range of species; however, their conservation significance is often overlooked and many of these ecosystems remain outside formal protection frameworks. One such landscape that lacks formal protection, yet holds significant conservation value is the sacred grove.

Sacred forests, commonly referred to as sacred groves, are patches of relatively undisturbed natural vegetation that are closely associated with local deities and cultural traditions and are conserved primarily because of their religious and spiritual significance. Sacred groves vary in size from a few cents to several hectares, and their occurrence has been recorded since the pre-agricultural period (Gadgil & Vartak, 1975) that became a part of human civilizations. A distinctive feature of sacred groves is the presence of an idol or deity, around which the landscape is revered and worshiped through religious rituals. These beliefs often restrict human interference, as local communities consider such areas sacred and avoid entering or disturbing the natural resources within them, thereby indirectly ensuring their preservation. Although these ecosystems are not formally protected, they are deeply embedded in cultural practices and have become an integral part of human life, contributing to the preservation of native biota. Religious practices and beliefs associated with sacred groves vary across cultures; however, a range of myths and traditional narratives—often unexplained, yet widely accepted—play a crucial role in reinforcing protection and sustaining these ecologically significant patches.

The Earth is currently experiencing an unprecedented biodiversity crisis, largely driven by human-induced environmental changes, such as habitat loss and species extinction. In this context, sacred groves play a crucial role in conserving biodiversity, particularly in regions where the establishment of large, formally protected areas is impractical or lacks local support. Networks of sacred groves can effectively preserve significant portions of regional biodiversity by integrating conservation with cultural and spiritual values. As the global conservation community increasingly seeks resilient and community-based models, sacred groves have gained recognition as important conservation strategies. Sacred groves may be conceptually aligned with IUCN Category III protected areas, particularly where culturally protected natural features are conserved through traditional belief systems(Dudley, 2008; IUCN, 2017).

1.2 Distribution

Although sacred groves are distributed globally, they are widely distributed across Asia, Africa and Europe. Although these patches are known by different names, their conservation significance is considerable and has been extensively studied from both ecological and cultural perspectives.

1.2.1 Global distribution

Sacred groves have been reported in Cote d' Ivoire (Sanogo, 1983), Japan, Turkey, Syria, Nigeria (Tiwari et al., 1998), Ghana (Campbell, 2005), Philippines (Rebancos & Buot, 2007). Several sacred groves have been reported in Nepal (Ingles, 1990). The Dubla Island sacred grove which harbors well-developed vegetation (Islam et al.,1998) is present in the Sundarbans mangrove forests of Bangladesh.

1.2.2 Distribution in India

India places significant importance on cultural heritage and is enriched with sacred groves. The presence of these landscapes has been recorded in Vedic literature and is believed to date back to the pre-Vedic period, approximately 3000–5000 BC.

The estimated number of sacred groves in India is approximately 13,720 (Gokhale et al., 2001). However, a comprehensive assessment of the exact number of sacred groves across the country is still lacking. Several studies have reported the occurrence of sacred groves in Indian states. A recent review of studies on sacred groves in India reported their presence in 25 states (Warrier et al., 2023). This study addresses floristic composition as well as the distribution of sacred groves across different states of India

Sacred groves in India are known by different local names across various states, reflecting regional cultural diversity. In Andhra Pradesh, they are called *Pavithravanams*, while in Arunachal Pradesh they are referred to as *Gomba forest areas*. In Assam, they are known as *Than*, and in Bihar and Jharkhand as *Sarnas*. In Chhattisgarh, the local names include *Matagudi* and *Devgudi*, whereas in Goa they are called *Devrai*, *Devran*, or *Pann*. In Jammu and Kashmir, they are known as *Banis* and in Karnataka as *Devarkadu* or *Kans*. In Madhya Pradesh, they are referred to as *Deogudi* or *Sarnas*, while in Maharashtra they are known as *Devrai* or *Devrahati*. In Manipur, sacred groves are called *Umanglai*, and in Meghalaya as *Law Lyngdoh* or *Law Niam*. In Odisha, they are known as *Jahera* or *Thakurnama*, whereas in Puducherry they are referred to as *Kovil Kodugal* and *Ayyappan Kavu*. In Rajasthan, they are known by various names such as *Vani*, *Oran*, *Kenkri*, *Shamlat Deh*, and *Devbani*. In Sikkim, they are associated with Buddhist monasteries and are known as *Gumba forest areas*. In Tamil Nadu, they are called *Koil Kadu*, *Swami Thopu*, or *Swami Sholai*. In Uttarakhand, they are referred to as *Deo Bhumi* and *Bugyal*, while in Uttar Pradesh they are known as *Dev Van*. In Kerala, sacred groves are commonly known as *Kavu* in the regional language.

1.2.3 Distribution in Kerala

The documentation of sacred groves in Kerala follows a decentralized publication model. Initiated by the Institution of Foresters Kerala (IFK) in 2012, the project produced 14 district-specific reports between 2013 and 2022. This comprehensive inventory revealed a much higher density of sacred groves than previously recorded. For instance, in Alappuzha, the survey documented 2,242 groves, in contrast to earlier estimates of approximately 100. By 2022, the finalized state-wide database provided a detailed registry of thousands of sites, each assigned a unique ID and land survey number, effectively categorizing them as Sacred Natural Sites (SNS) within the state's conservation framework (Institution of Foresters Kerala, 2022).

According to the latest official records published in the *Forest Statistics 2022-23*, there are currently 10,742 documented sacred groves in Kerala, covering a total extent of 1,208.74 hectares (Kerala Forest Department, 2023)

In Kerala, sacred groves are typically associated with private temples and, in some cases, with homesteads. A large proportion of these groves is owned and managed by private temple trustees, often involving local communities. Some groves are under the control of the Devaswom Board and are managed by the Kerala Government, while a few are associated with homesteads, and are maintained by family members.

Most sacred groves contain water sources, either in the form of ponds or in close proximity to rivers and streams, which contribute to enhanced biodiversity. Cultural practices associated with sacred groves also vary across regions, with noticeable differences in offerings observed among northern, central, and southern parts of Kerala. Similarly, slight variations exist in the rules and regulations governing individual sacred groves. These groves are largely protected by numerous unwritten and informal rules that have significantly contributed to their conservation; however, a single, uniform set of regulations applicable to all sacred groves in Kerala is not evident.

1.3 Area and zone wise distribution.

The distribution of sacred groves in Kerala, based on surveys conducted by the Kerala Forest Department (Kerala Forest Department, 2023), can be categorized into three regions: northern Kerala (Kasaragod, Kannur, Wayanad, Kozhikode, and Malappuram), central Kerala (Palakkad, Thrissur, Ernakulam, Idukki, and Kottayam), and southern Kerala (Alappuzha, Pathanamthitta, Kollam, and Thiruvananthapuram). Among these regions, the highest number of sacred groves is recorded in southern Kerala (Figure 1).

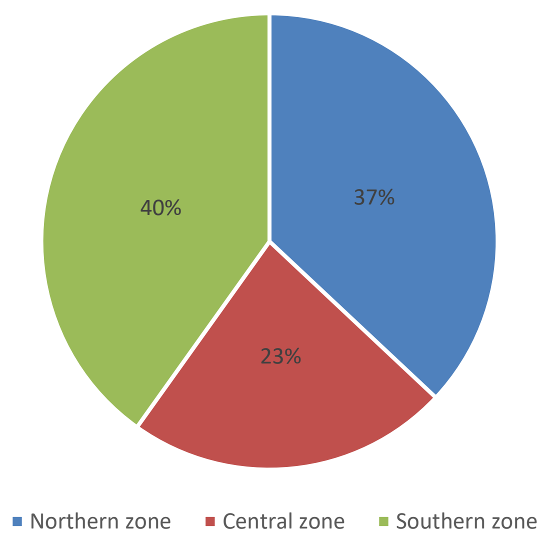


Figure 1. *Zone- Wise Distribution of Sacred Groves in Kerala*

However, when considering the total area or extent of vegetation, the northern region has a larger area than the other regions, according to the report (Table 1). While southern Kerala records a higher number of sacred groves, the northern region covers a larger total area, indicating a distinct geographical pattern in their distribution.

Table 1
Area Covered by the Sacred Groves Across Different Regions

Zone	Extent of wooded area (Ha)
Northern zone	1053
Central zone	155
Southern zone	383

1.4 Deities associated with sacred groves in Kerala

A distinctive feature of sacred groves is the presence of idols that are venerated by local communities, with offerings made based on informal and unwritten rules. Each sacred grove typically contains one or more idols. The majority of sacred groves in Kerala are associated with the Naga (snake) deity. As a result, snakes receive a high level of protection, as they are considered sacred and are often linked to mythological beliefs.

In addition to snake deities, other gods and goddesses are worshipped in sacred groves. Most idols are placed within temples, while some are located beneath individual trees. Religious practices and beliefs vary among different sacred groves. In many cases, the Bhagavathi (Durga) is the principal deity worshipped in Kerala. In larger sacred groves such as Kamadam Kavu and Iringole Kavu, the primary deity is Durga. In Kamadam Kavu, idol worship is not practiced within the grove itself, and the temple is located approximately one kilometre away (personal observation). Entry of priests into the grove is restricted to once a year, and public access is also limited, which contributes to conservation.

In some cases, snake idols are placed beneath a single tree, and such areas are locally considered sacred groves, although they were not included in the present study.

Many folk traditions are associated with sacred groves, particularly in northern Kerala, where the ritual art form *Theyyam* is widely practiced. During festival seasons, *Theyyam* performances are conducted in or near sacred groves, and the performer is regarded as a manifestation of the deity and worshipped accordingly.

In addition to these religious and cultural practices, sacred groves also perform important ecological functions, which have been highlighted in several studies.

1.5 History of sacred groves in Kerala

When examining the intrinsic relationship between sacred groves and society, it is evident that these landscapes are closely associated with human culture and daily life in Kerala. In northern Kerala, different caste groups traditionally maintain their own sacred groves, each managed through informal rules established by the respective custodians to protect these areas. These groves were associated with idols, and the performance of religious rituals led to the development of cultural art forms such as *Theyyam*, which are regarded by local communities as representations of deities and are worshipped accordingly.

Although many strict religious practices and customary laws have declined over time, these cultural traditions continue to be practiced, and people still consider such art forms divine. This belief system in northern Kerala contributes to conserving native vegetation within sacred groves. Sacred groves were also closely linked to the traditional joint family system in Kerala, where a portion of family land was preserved as sacred. However, with the increasing demand for land and the decline of joint family structures, many sacred groves associated with homesteads have diminished, particularly in central and southern Kerala.

In addition, the practice of tree worship has contributed to the formation and conservation of small natural patches as sacred groves. The existence and importance of sacred groves have been documented since the Vedic period (Gadgil & Vartak, 1975), where references to nature worship and sacred landscapes are evident. Sacred groves became an integral part of human culture with the development of agriculture. Even today, sacred groves retain a sense of mystery among local communities, with various myths and traditional beliefs continuing to circulate, further supporting their conservation.

1.6 Ecological and biological significance

Religious rituals and customary practices are among the primary factors contributing to the conservation of sacred groves, although regional variations can be observed among communities. People's attitudes toward these groves have changed over time, particularly in southern Kerala, where such changes have directly influenced and altered the landscape. In contrast, in northern Kerala, community attitudes remain more conservative and protective compared to those in the southern region. Most people exhibit an inherent reluctance to enter sacred groves unnecessarily and refrain from extracting or utilizing natural resources, which has significantly contributed to their preservation.

Sacred groves perform important ecological functions as they harbour rich biodiversity. The largest sacred grove in Kerala is Kammadam Kavu, located in Kasaragod district, covering approximately 60 acres and supporting evergreen floral species. A stream flowing through this grove supports a diverse range of amphibians and reptiles, along with microhabitats such as rock crevices.

Other large sacred groves in northern Kerala include Theyyottu Kavu (18 hectares) and Aravanchal Kavu (16 hectares), where public entry is strictly restricted, contributing to the conservation of evergreen flora, including many medicinally important native plant species. A notable feature of some sacred groves is the presence of Myristica swamps, observed in Kammadam Kavu (Kasaragod) and Vallikkattu Kavu (Kozhikode), which play an important role in maintaining hydrological balance.

The second largest sacred grove, Iringole Kavu, is located in Ernakulam district in central Kerala and covers approximately 20 hectares. This grove supports evergreen vegetation and provides habitat for numerous birds and butterflies, although relatively lower reptile diversity has been reported. Despite the high level of urbanization in this region, the natural resources within this sacred grove remain well -preserved.

Most sacred groves are located adjacent to agricultural fields, where they provide habitat for natural predators of agricultural pests, such as owls and amphibians, thereby contributing to biological pest control. For instance, species such as the Jungle Owlet and Brown Hawk Owl, observed in the Iringole sacred grove, feed on pests in nearby agricultural fields. Similarly, the Vallikkattu sacred grove in Kozhikode serves as a habitat for biological pest controllers such as herons and egrets, which help reduce pest populations in the surrounding fields.

The White-bellied Sea Eagle, a coastal species that feeds along seashores, has been recorded in the Edayilekad sacred grove in Kannur district. Its presence was first reported in 2000 (Palot, 2011), and it continues to use this grove as a roosting site, highlighting the importance of sacred groves for species conservation. The Brahminy Kite, another coastal species, also uses sacred groves as roosting sites. For example, Poil Kavu, a coastal sacred grove with an area of 4.4 ha, supports more than ten individuals of this species.

Sacred groves of North Malabar harbour a high diversity of rare and endemic plant species. More than 80% of the total flora recorded in these groves are medicinally important, while over 11% of the species are endemic (Prasad & Raveendran, 2012). Notably, the vegetation in the Kammadam sacred grove has remained largely undisturbed for many generations, providing stable microhabitats for various invertebrates and vertebrates.

Species such as *Ficus benghalensis* and *Alstonia scholaris* are considered sacred by local communities, who avoid cutting them due to cultural beliefs. These trees are often found in sacred groves and may have idols placed beneath them.

In addition to their role in biodiversity conservation, sacred groves contribute to ecosystem services such as water conservation, particularly in central and northern India (Ray, Chandran, et al., 2014). The presence of these groves can be traced back to the Vedic period, during which they became an integral part of human life and culture. In the present era, sacred groves continue to function as reservoirs of biodiversity, although many have undergone landscape alterations.

Beyond sacred groves, community-based conservation practices are also evident in other natural features such as sacred trees, mountains, and water bodies. Individual trees are often considered sacred, especially when associated with temples; in Kerala, *Ficus benghalensis* is commonly regarded as a sacred tree and is frequently found near temples. Similarly, Agasthyarkoodam is considered a sacred mountain by local communities, while the Pamba River is regarded as a sacred river.

Community-based conservation has long been a traditional approach for protecting natural resources. Sacred groves, which range in size from small patches to several hectares, are relatively easy to manage because of their limited extent, thereby supporting the conservation of native species with minimal intervention. Owing to their ecological and cultural importance, sacred groves have attracted considerable research attention, resulting in numerous studies and publications. These are discussed in detail in the following chapter.

2. Review of literature

Numerous studies have been conducted on sacred groves, addressing various aspects of their ecological, cultural, and social significance. Most of these studies have focused on the cultural and social dimensions, particularly the role of community-based conservation in protecting these landscapes.

For this review, relevant publications were collected from academic databases such as Google Scholar, JSTOR, ScienceDirect, Web of Science, Shodhganga, Academia, ResearchGate, and Semantic Scholar using keywords including “sacred groves,” “conservation,” “flora,” and “fauna.” The collected studies were subsequently categorized into three groups: international, national, and regional studies.

2.1 International studies

The concept of sacred groves has global significance, as many countries practice forms of spiritually guided conservation. Their occurrence has been reported across Africa, Europe, North America, and Asia. Although these groves are generally conserved through informal rules and customary practices, their management systems, landscape characteristics, rituals, and associated deities vary across regions.

Several studies from the Africa highlight the importance of sacred groves for conservation. community-based conservation of natural resources has been widely reported in Nigeria (Rim-Rukeh et al., 2013). In Cameroon and Benin, sacred groves hold historical significance and demonstrate a close relationship between humans and nature (Juhé-Beaulaton & Salpeteur, 2017). In Ghana, sacred groves reflect human-mediated conservation practices, with approximately 2,000–3,000 groves reported, serving as refuges for rare species and preserving vegetation in relatively undisturbed conditions (Nganso et al., 2012).

Sacred groves also contribute to *in situ* biodiversity conservation in the forest zones of southwestern Nigeria (Onyekwelu & Olusola, 2014). This study reported that sacred groves may support higher tree species diversity than primary and degraded forests, emphasizing that their conservation status is strongly influenced by local community interactions. Recent studies hjave further highlighted the role of sacred groves as important conservation units in Africa (Imarhiagbe & Ogwu, 2022). Similarly, in West Africa, wooded shrine rituals have been identified as key factors in vegetation conservation (Fournier, 2011).

Recent research in Ghana has focused on mapping sacred groves and assessing their biodiversity (Batame et al., 2023). These studies emphasize the need for strengthened conservation measures, as many groves are increasingly affected by anthropogenic disturbances. In addition, studies have examined community attitudes and management practices that support sustainable forest conservation in these areas (Kofi Sarfo-Adu et al., 2022). Overall, sacred groves in Africa function as important repositories of local biodiversity, highlighting their ecological and cultural significance (Sinthumule, 2024).

Studies from different parts of the world have further highlighted the conservation value of sacred groves. The role of sacred groves in conserving local flora has been well documented in the Philippines (Rebancos & Buot, 2007). A similar pattern has been reported in Italy, where the establishment of shrines contributes to the conservation of large trees and associated vegetation (Frascaroli et al., 2016). In Tanzania, studies have shown that species richness in sacred groves is higher than that in state forest reserves (Mgumia & Oba, 2003). Sacred groves have also been reported in North America, where research has primarily focused on their spiritual and cultural significance (Brown, 2018).

2.2 Studies in India

Numerous studies have been published on sacred groves in India, highlighting their ecological and cultural significance. Sacred groves are believed to have existed since the pre-agricultural period, and many of them continue to conserve relatively undisturbed vegetation (Gadgil & Vartak, 1975). One of the earliest documented studies on sacred groves in India was published in 1975, providing detailed descriptions of these landscapes. Since then, many studies have been conducted, covering various aspects of sacred groves.

For the present review, the collected studies have been categorized into five groups based on their primary focus: (i) spiritual and cultural beliefs, (ii) features, management, and ecosystem services, (iii) distribution, review, and disturbance, (iv) floral composition and diversity, and (v) faunal diversity and species richness. The details of the studies in each of these categories are discussed in the following sections.

2.2.1 Spiritual and cultural beliefs

Sacred groves are primarily maintained through religious beliefs and customary rules. Numerous studies have focused on their spiritual and cultural aspects. In southern India, several studies have examined religious practices associated with sacred groves, highlighting the role of taboos and customary laws in their conservation (Chandran & Hughes, 1997; Boraiah et al., 2003; Kushalappa & Raghavendra, 2012; Narasimha, 2015).

Similarly, studies from other regions of India have emphasized the spiritual aspects of sacred groves (Sharma & Devi, 2014; Kandari et al., 2014; Chaudhry & Murtem, 2015; Notermans et al., 2016; Singh et al., 2017). Some studies consider the environment itself as a sacred space, where sacred groves form an integral component along with rivers, pilgrimage sites, and *Shakti Peethas* (Olsen & Timothy, 2021). These studies highlight the close relationship between humans and nature, which plays a significant role in conservation.

In addition, certain studies have emphasized that belief systems, including reverence and fear of deities, contribute to the protection of sacred groves (Onyekwelu, 2021). Overall, these studies demonstrate that cultural beliefs, myths, taboos, and informal religious rules vary across regions but collectively support the conservation of sacred groves.

2.2.2 Features, management and ecosystem services

A large proportion of the available literature on sacred groves in India focuses on their general features, including topography, conservation status, management practices, and ecological roles. Rather than addressing a single aspect, several studies have provided a comprehensive overview of sacred groves, covering their floral composition, resource availability, associated deities, and historical background.

One of the earliest detailed studies on sacred groves was conducted by Gadgil and Vartak, who documented their presence in the Western Ghats and highlighted their importance as socio-cultural and ecological landscapes (Gadgil & Vartak, 1975). Over time, numerous studies have expanded this understanding by examining the rituals, vegetation composition, ecological characteristics, and ecosystem services associated with sacred groves (Boraiah et al., 2003; Bhagwat et al., 2005; Bhagwat, 2009; Ray & Ramachandra, 2010; Ormsby & Bhagwat, 2010; Ray, Chandran, et al., 2014).

These studies emphasize the ecological significance of sacred groves, demonstrating that, irrespective of their size and location, they contribute to important functions such as carbon storage (Parthasarathy & Naveen Babu, 2021).

Several studies have examined the key features of sacred groves, focusing on their physical composition and emphasizing landscape management practices influenced by the cultural and emotional values of local communities (Pruthi & Burch, 2009; Blicharska et al., 2013; Upadhyay et al., 2019). Hydrological importance is another aspect that has been widely studied, with findings indicating that water sources within sacred groves play a significant role in supporting biodiversity (Ray et al., 2015).

In addition, many studies have focused on the distribution and conservation of medicinal plant species within sacred groves (Duggal et al., 2017; Maru & Patel, 2013; Savithramma et al., 2014; Chanda & Ramachandra, 2019).

2.2.3 Distribution, review and disturbance

Several studies have focused on the distribution and number of sacred groves in India. For instance, Gokhale et al. (2001) documented the number of sacred groves in different Indian states. However, this documentation has changed over time, particularly in Kerala. Earlier studies reported approximately 2,000 sacred groves in the state, but many of these have since been modified into temple structures, resulting in the loss of natural vegetation.

Some studies have reviewed the vegetation characteristics of sacred groves across India (Chanda & Ramachandra, 2019). In addition, several researchers have examined the impact of anthropogenic disturbances on these ecosystems. For example, a study in West Bengal highlighted the effects of human activities on plant diversity within sacred groves (Sen, 2018), while another study reported the response of woody species to human disturbance (Upadhaya et al., 2008). Similarly, research from Rajasthan has identified the causes of biodiversity degradation and its impact on wildlife in sacred groves (Choudhary & Gupta, 2016).

Although a few studies have addressed disturbances in sacred groves, this aspect has not received sufficient attention to date. Understanding the nature and extent of these disturbances is essential for developing effective conservation strategies for the management of these ecosystems.

2.2.4 Floristic composition and diversity in sacred groves

Most of published studies on sacred groves focus on floral characterization, along with the medicinal and ecological importance of plant species. These studies range from taxonomic descriptions to detailed analyses of plant diversity in sacred groves. Some studies have highlighted the conservation significance of sacred groves in protecting endemic and endangered plant species (Prasad & Raveendran, 2012; Rajendraprasad et al., 2000).

Several researchers have documented the floral composition and structure of sacred groves (Page et al., 2009; Hangarge et al., 2016; Sukumaran et al., 2018; Prasad & Raveendran, 2012). Sacred groves are often considered repositories of native flora, including a wide range of medicinally important plants, making them a major focus of ecological research alongside their cultural importance.

Recent studies have focussed on the analysis of floral diversity. Some studies have focused on tree diversity within individual sacred groves (Koda et al., 2021; Baidya et al., 2022), while others have reported the conservation of endangered species, such as dipterocarps, within these ecosystems (Sanil et al., 2022). A study from Kerala reported a new species of liverwort from a sacred grove (Manju et al., 2023), and research from Pune has examined the ethnobotanical aspects of sacred groves (Mahabaleshwarkar et al., 2023). Additionally, studies on pteridophyte composition and conservation status have been conducted in the sacred groves of West Bengal (Uday & Bhakat, 2021).

A review of studies conducted on sacred groves in India indicates that the flora is the extensively studied component. Many studies have primarily focused on documenting diversity and composition of plants. The importance of flora in ecosystem functioning has been well established in these studies. However, the ecological role of fauna is equally important and requires greater research attention.

2.2.5 Species richness and diversity of fauna in the sacred groves

A review of studies conducted in India indicates that research focusing specifically on fauna associated with sacred groves is limited. Available literature suggests that faunal studies constitute only a minor proportion of sacred grove research compared with floristic and cultural studies. In Kerala, a study highlighted the role of sacred groves in conserving small mammals (Padmanabhan, 2007), while another study examined ground-dwelling insects within these ecosystems (Imam et al., 2016). New species have also been reported, including an anuran species from a sacred grove in Meghalaya (Das, 2010) and a millipede species from a sacred grove in Kerala (Aswathy & Sudhikumar, 2022).

Several studies have documented the faunal diversity of sacred groves across India. For example, bird diversity has been studied in the sacred groves of North Malabar, Kerala (Jyothi et al., 2015), and land mollusk abundance has been reported in sacred groves in Karnataka (Mumbrekar & Madhyastha, 2006). In Tamil Nadu, a study recorded 72 bird species from a single sacred grove (Rajesh et al., 2021). Similarly, avifaunal diversity in sacred groves of the Aravalli Range has been examined in relation to elevation and proximity to human settlements (Kumar & Koli, 2025). A study from Pune documented a wide range of fauna, including birds, mammals, butterflies, and amphibians, highlighting the biodiversity of these landscapes (Mahabaleshwarkar et al., 2023).

Despite these studies, comprehensive research on faunal diversity, habitat use, and ecological roles in sacred groves remains limited. Fauna play a crucial role in maintaining ecosystem balance, and therefore, detailed studies on faunal associations are essential for the effective conservation and management of sacred groves.

2.2.6 Year wise publication of sacred groves studies in India

The earliest known publication on sacred groves dates back to 1975. Subsequently, several studies were published in the 1990s. Of the total of 322 publications, details of 175 studies are presented in Figure 2, which illustrates a progressive increase in the number of publications over the decades. The graph clearly indicates that sacred groves have become an important area of research in recent years (Figure 2).

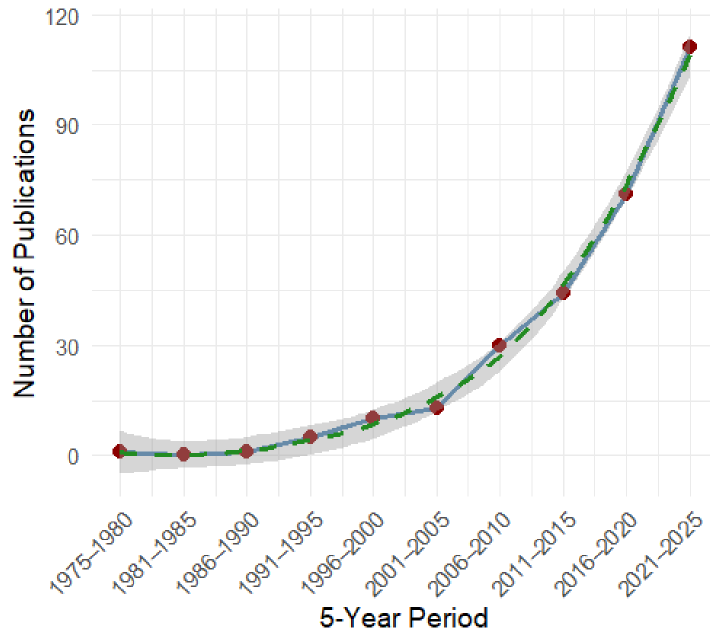


Figure 2. *Year Wise Publication of Studies in Sacred Groves From 1975 to 2025*

The analysis of five-year publication trends indicated an increase in the number of studies in recent decades (Figure 3).

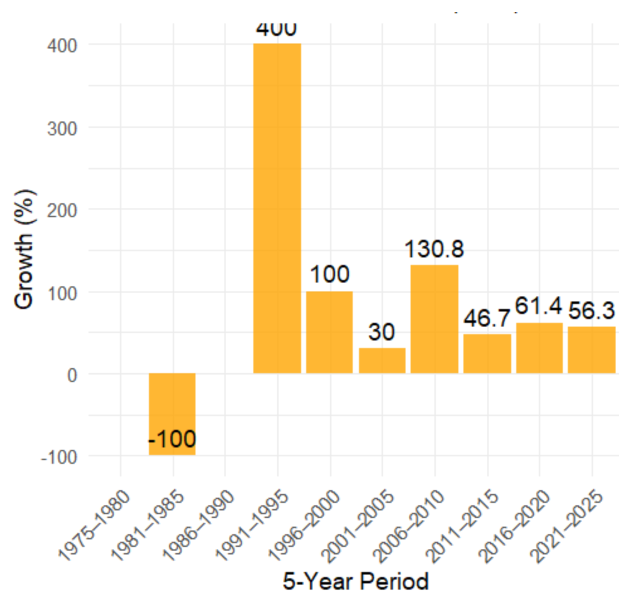


Figure 3. *Trends in Publication Growth*

2.3. Studies in the Western Ghats

The Western Ghats, also known as the Sahyadri mountain range, extends over an area of approximately 160,000 km^2 along a stretch of about 1,600 km parallel to the western coast of the Indian peninsula. It traverses the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala, and Tamil Nadu and is recognized as one of the 36 global biodiversity hotspots in the world. The presence of sacred groves has been widely reported in the Western Ghats, and their distribution, status, and ecological significance have been extensively studied.

A study on plant diversity in sacred grove fragments of the Western Ghats compared vegetation in sacred groves with that in surrounding forests, highlighting the effects of fragmentation on plant communities (Page et al., 2009). Community-based conservation of natural resources has also been identified as an important research focus in sacred groves of the Western Ghats (Narasimha, 2015).

Several studies have emphasized the role of sacred groves in biodiversity conservation. For example, in the southern states of India, a sacred grove in Agastheeswaram, Tamil Nadu, covering an area of approximately 2.6 ha, was reported to contain 98 species of angiosperms, of which 80.6% were medicinally important (Sukumaran & Jeeva, 2008). Another study from the Bhor region of the Western Ghats in Maharashtra examined soil organic carbon in sacred groves, highlighting their ecological importance (Hangarge et al., 2015).

The conservation of sacred groves is strongly influenced by the attitudes of local communities toward customary rules and beliefs. A study examining people's perceptions and attitudes toward snakes in northern Kerala and Kodagu (Karnataka) found that snakes are considered sacred and are therefore not harmed, highlighting the role of sacred groves as important refuges for these species (Yuan et al., 2020).

The Kodagu district in Karnataka, where sacred groves are abundant, has been a major focus of research on community-based conservation (Kushalappa & Raghavendra, 2012). Other studies from this region have emphasized the role of sacred groves in plant species conservation (Tambat et al., 2005). In addition, studies from South India have highlighted the overall conservation significance of sacred groves (Chandran & Hughes, 2000). Sacred groves also contribute to reforestation through culturally driven conservation practices (Bhagwat et al., 2014).

A study reported that informally protected sacred groves support higher plant species richness compared to reserve forests (Boraiah et al., 2003). Another study estimated the floral composition of a sacred grove in Tamil Nadu (Anbarashan et al., 2011). In addition, studies have highlighted the role of informally protected areas, such as sacred groves, in maintaining biodiversity in the Western Ghats (Bhagwat et al., 2005; Bhagwat & Rutte, 2006).

The biodiversity and ecosystem services of sacred groves have been widely discussed in the literature (Blicharska et al., 2013). Studies on lichen diversity in sacred groves of the central Western Ghats have recorded 53 species of epiphytic lichens belonging to 30 genera and 15 families, including newly identified species (Dudani et al., 2015).

Research in Maharashtra has documented the distribution of tree species within sacred groves (Kulkarni et al., 2014). Similarly, the Ammanaghata Sacred Reserve Forest in Karnataka, covering an area of approximately 376 hectares, has been reported to support 149 plant species, including 58 tree species, 48 herbs, 26 climbers, and 23 shrubs (Kekuda et al., 2016).

The distribution of medicinal and aromatic plants in sacred groves of the Western Ghats has also been extensively studied. The Western Ghats region supports a large number of sacred groves compared to other parts of India, and several studies have highlighted their importance in the conservation of endemic species.

2.4 Regional studies/ studies in Kerala

Kerala, located in the south-western part of the Indian peninsula and forming part of the Western Ghats, covers an area of 38,864 km^2. The climate of Kerala is tropical, humid, warm, and monsoonal, with relatively stable temperature and humidity throughout the year. Several studies have been published from the state, with a major focus on floral diversity.

One of the earliest records of sacred groves in Kerala is found in the *Memoir of the Survey of Travancore and Cochin States* by Ward and Conner, which reported the existence of approximately 15,000 sacred groves in the Thiruvananthapuram district (Ward & Conner, 1891). In Kerala, sacred groves are locally known as *Kavu* in the Malayalam language.

Several publications, including those in regional languages, describe sacred groves in Kerala, focusing on their religious practices, rituals, and customary laws. Folk traditions and temple-associated art forms linked to sacred groves have also attracted research interest in recent years. In addition, studies have examined the floral composition of selected sacred groves in the state.

Chandrashekara and Sankar (1998) studied the ecology and management of sacred groves in Kerala. In central Kerala, particularly in the Palakkad district, studies have highlighted the functional importance of sacred groves in altered landscapes, emphasizing their role in conservation (Rajasri et al., 2017). Other studies have explored the socio-cultural aspects of sacred groves, including the worship of snake deities, demonstrating a close relationship between humans and nature.

Research has also focused on the medicinal uses of plant species in sacred groves. For example, a study in central Kerala examined how local communities utilize plant resources for medicinal purposes (Nair & Mathew, 2024), while another study reported pharmacologically important plant species from sacred groves (Athira et al., 2023).

Studies on fauna are relatively limited in number. However, some studies have documented the conservation of small mammals in sacred groves (Padmanabhan, 2007), and bird diversity studies in northern Kerala have recorded 107 species across selected sacred groves (Jyothi et al., 2015). Despite these efforts, detailed studies on the faunal diversity in the sacred groves of Kerala remain limited.

The sacred groves of North Malabar serve as important refuges for endemic and medicinal plant species (Prasad & Raveendran, 2012). Vegetation characterization of sacred groves has also been a focus of research, with studies examining their structure and composition (Rajendraprasad et al., 2000).

For example, a sacred grove in Thrissur, covering an area of 1.73 ha, was reported to contain 57 species of angiosperms, including several endemic species (Deepa et al., 2017). In Kerala, some sacred groves are located in coastal regions, where studies have highlighted the presence of threatened plant species in these habitats.

The Single Large or Several Small (SLOSS) debate has global significance in conservation biology, as it addresses whether conserving a single large habitat or several smaller patches is more effective for species conservation. SLOSS-based inferences have been widely applied to conservation decision-making (Fahrig, 2017). Although many studies have examined this debate, the biogeographical factors underlying variations in SLOSS outcomes are not yet fully understood (Deane et al., 2020).

The SLOSS concept is particularly relevant in fragmented landscapes. A study comparing the importance of patch size reported that the protection of larger habitat fragments is often expected to support a greater proportion of species (Fahrig, 2020). However, several studies have shown that species conservation outcomes can vary depending on landscape structure and patch distribution.

In a review of 157 comparisons, 72% of the studies reported that several small patches supported more species than a single large habitat, whereas only 6% of the studies found that a single large patch supported more species than multiple smaller patches (Fahrig, 2020).

Since sacred groves occur as habitat patches of varying sizes within modified landscapes, the SLOSS framework provides a useful theoretical basis for examining whether larger groves or networks of smaller groves better support vertebrate diversity. In Kerala, sacred groves represent ecologically significant forest fragments with well-recognized cultural and historical importance; however, scientific understanding of their role in supporting vertebrate communities remains limited. In particular, little attention has been given to patterns of species composition, microhabitat utilization, and the influence of ecological factors such as grove size, disturbance regimes, climatic conditions, and management practices on vertebrate diversity.

Sacred groves in Kerala are culturally protected forest fragments embedded within increasingly human-dominated landscapes. Although their floristic, cultural, and ethnobotanical significance has been widely documented, comparatively little is known about their role in sustaining vertebrate communities. Existing studies have largely emphasized plant diversity, medicinal flora, ritual practices, and socio-cultural values, while vertebrate diversity, habitat use, microhabitat dependence, and responses to grove size and disturbance remain poorly understood. This gap limits the integration of sacred groves into broader landscape-level conservation planning.

Therefore, a comprehensive assessment of vertebrate diversity, community structure, and habitat utilization across sacred groves of varying sizes and disturbance gradients is essential for effective conservation. The present study aims to address this research gap by systematically investigating these ecological patterns, thereby contributing to a more informed understanding of the conservation significance of sacred groves.

Based on these research gaps, the present study tests the following hypotheses;

H1: Larger sacred groves support higher vertebrate species richness and exhibit more complex community structure compared to smaller groves.

H2: Sacred groves subjected to lower levels of anthropogenic disturbance support a greater abundance of habitat-specialist and endemic species.

H3: Microhabitat characteristics, including the presence of water bodies, dense understorey vegetation, and canopy continuity, significantly influence habitat utilization by the vertebrates

H4: Vertebrate assemblages differ significantly among sacred groves located in Northern, Central, and Southern Kerala, reflecting variations in cultural practices, landscape fragmentation, and grove management regimes.

To test these hypotheses, the following objectives were formulated and addressed using appropriate methodologies.

Objectives

1. To document the species richness, abundance, and community composition of vertebrates in selected sacred groves of Kerala.

2. To assess the influence of grove area, proximity to forest, disturbance level, water availability, and vegetation structure on vertebrate distribution.

3. To examine the relationship between sacred grove size and vertebrate diversity.

4. To document microhabitat availability and evaluate its use by birds, amphibians, reptiles, and mammals.

5. To assess local community attitudes, cultural practices, and perceptions towards sacred grove conservation.

6. To evaluate the influence of ownership and management practices on biodiversity conservation.

7. To propose site-specific and landscape-level strategies for conserving vertebrate diversity in sacred groves of Kerala.

The initial procedure for this study was the selection of study sites. For this, many criteria were taken into consideration such as ownership, landscape, vegetation, disturbance level and proximity to forest. The primary focus was on the area of the sacred groves.

The next chapter will discuss the study area and methodologies for achieving the above-mentioned objectives.

3. STUDY SITE SELECTION AND METHODOLOGY

3.1 Selection of study sites and study site description

The study sites were selected to represent sacred groves of different size classes, ownership types, disturbance levels and geographical zones across Kerala. A preliminary reconnaissance survey was conducted to identify potential groves and assess accessibility, ownership, vegetation condition, water availability and permission status. The data were collected from official sources, including the Kerala Forest Department and the Kerala Biodiversity Board.Based on grove area, the selected sites were grouped into five size classes: 0.01–1 ha, 1–3 ha, 3–5 ha, 5–10 ha and >10 ha. Sites were further categorized into northern, central and southern Kerala based on district location to examine regional variation in vertebrate assemblages, as follows:

Southern Kerala (Thiruvananthapuram, Kollam, Alappuzha, Kottayam and Pathanamthitta).

Central Kerala (Idukki, Ernakulam, Thrissur and Palakkad).

Northern Kerala (Malappuram, Kozhikode, Wayanad, Kannur and Kasaragod).

From the 0.01–1 ha category, three study sites were selected from different zones. From the 1–3 ha category, seven study sites were selected. From the 3–5 ha category, two sacred groves were selected. From the 5–10 ha category, six study sites were selected. From the category above 10 ha, two sacred groves were selected.

The details of the selected sacred groves are provided below.

Table 2

Description of Selected Study Sites

Study Sites in the 0.01 ha - 1 ha Category

Name of sacred grove	Area (in ha)	District	Water source	Neighboring area	Latitude	longitude
Athipatta mana	0.8	Palakkad	River	Homesteads	10.920035	76.340091
Kizhakkombu kavu temple	0.2	Ernakulam	Stream	Fields	9.864192	76.574192
Kulathoopuzha temple	0.6	Kollam	River	Urban area and homesteads	8.900803	77.059148

Study Sites in the 1-3 ha Category

Name of sacred grove	Area	District	Water source	Neighboring area	Latitude	Longitude
Mannampuram	3	Kasaragod	Pond	Homesteads	12.258608	75.132317
Chandana kavu	2.1	Malappuram	Nil	Homesteads	10.905598	75.998811
Mookuthala temple	2.8	Malappuram	Well	Fields	10.72931	76.010373
Pathirikunath mana	2.4	Palakkad	Pond	Fields	10.84409	76.282728
Vettikode temple	1.6	Alappuzha	Nil	Fields	9.170278	76.584151
Saranga kavu	1.7	Pathanamthitta	River	Homesteads	9.244174	76.631501
Raloor kavu	2.1	Thiruvananthapuram	Pond	Homesteads	8.749471	76.857985

Study Sites in the 3-5 ha Category

Name of sacred grove	Area	District	Water source	Neighboring area	Latitude	Longitude
Poil kavu	4.45	Kozhikode	Nil	Homestead	11.408626	75.71358
Pambumekkattu	4.4	Thrissur	Pond	Homestead	10.257168	76.265141

Study Sites in the 5 - 10 ha category

Name of sacred grove	Area	District	Water source	Neighboring Area	Latitude	Longitude
Karakkayil temple	6	Kasaragod	Pond	Homesteads	12.190213	75.166295
Kayyath nagam	6.1	Kannur	River	Homestead	12.009116	75.349348
Neliar kottam	6.4	Kannur	Well	Homestead	11.985404	75.363928
Vallikattu kavu	6.3	Kozhikode	Pond	Agricultural fields	11.38834	75.786571
Edayilekkad kavu	5.2	Kannur	Nil	Homestead	12.131795	75.159621
Mannarasala	5.28	Alappuzha	Pond	Homestead	9.289417	76.445665

Study Sites More Than 10 ha

Name of sacred grove	Area	District	Water source	Neighboring area	Lacassiatitude	Longitude
Kammadam	24	Kasaragod	Stream	Fields, plantations	12.311202	75.31602
Iringole kavu	20	Ernakulam	Pond	Fields	10.108107	76.491459

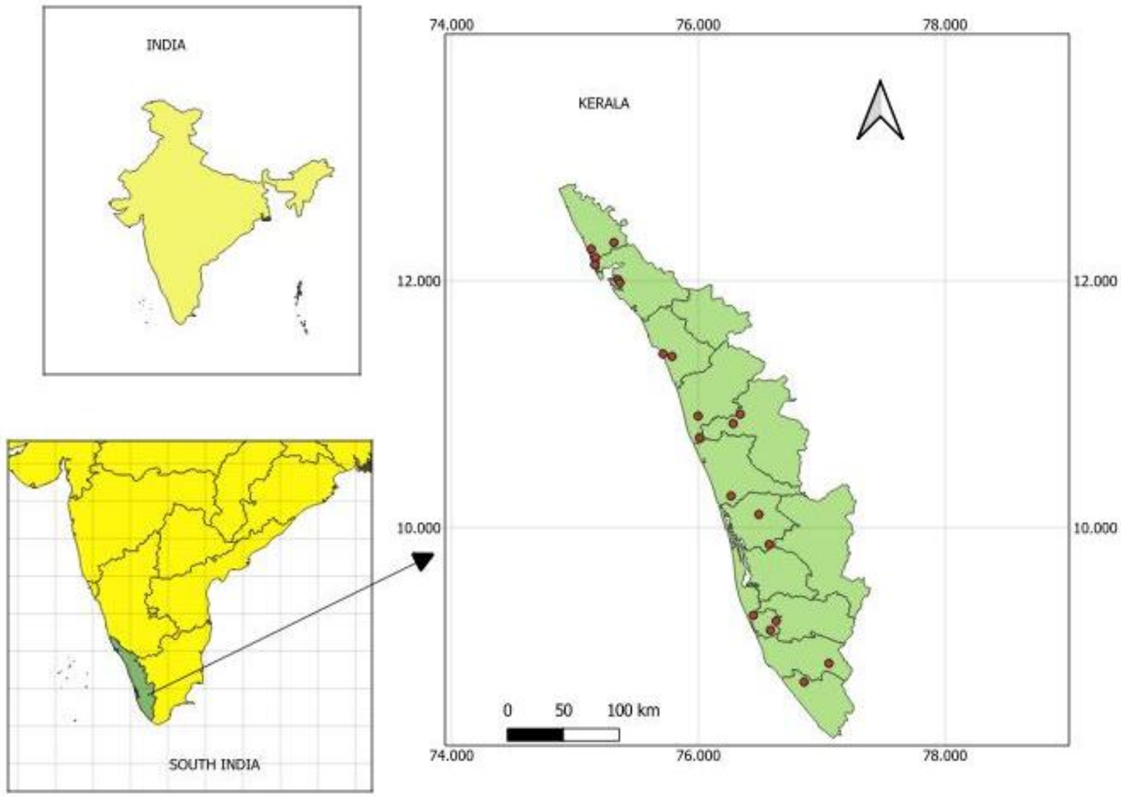


Figure 4. *Map Showing the Selected Study Sites*

Permissions were obtained from the respective owners of each sacred grove to conduct vertebrate surveys over a period of two years. During the study, several sacred groves were visited to seek permission; however, some owners declined due to religious beliefs and traditions, which restrict even their own entry into these groves.

In certain selected sacred groves, entry was restricted during nighttime. In such cases, indirect evidence such as faeces and spines was collected to document vertebrate species richness.

A brief district-wise description of the selected study sites is provided below;

Kasaragod

Kammadam Kavu

Kammadam Kavu sacred grove is located in Kasaragod district and covers an area of 24 hectares. It is owned and managed by the Devaswom Board under the Kerala government. This is the largest sacred grove in Kerala, located in the northern region. A stream flows through the grove but dries up during the summer season (April–May). The canopy cover is dense, and public entry into the sacred grove is restricted.

Mannampuram temple sacred grove

This sacred grove is located near an urban setting and covers an area of approximately three hectares. It is owned and managed by the temple authorities. A public pathway runs through the grove and is frequently used by local people. Additionally, a pond is situated adjacent to the grove.

Karakkayil temple

This is situated near an urban area owned and managed by the private temple trust. Proper fencing is absent, resulting in frequent entry of local people for collecting fallen branches and for leisure purposes. The deity associated with it is Lord Bhagwathi. A temple is situated within the sacred grove. It has an area of six hectares.

Kannur

Edayilekkad sacred grove

This is a sacred grove located on the seashore, owned by the private trustee where the local people are the members. There is no temple associated with this patch, and it has only a small area where the idol is placed. This has an area of 5.2 hectares, and the canopy cover is prominent. The entry of local people is prohibited, and the religious activity is relatively low compared to other sacred groves. The grove is located near a lake and homesteads.

Kayyath Nagam sacred grove

This sacred grove differs from other groves in terms of its spatial distribution, as it is situated on a hill. An idol is located at the hilltop, where religious rituals are performed, and a temple is also present nearby. Access to the hill is restricted. The grove covers an area of six hectares and is characterized by a dense canopy, with minimal anthropogenic disturbance. It is located near the Kutikkol River and includes a pond that serves as a water source. The grove is owned by a private temple trust.

Neliar kottam sacred grove

This sacred grove covers an area of 6.4 hectares and is managed by a private trustee. A public pathway passes through the grove and is regularly used by local residents for walking. In certain areas, vegetation is being cleared by temple authorities to accommodate religious activities. Nevertheless, the grove, situated within a matrix of homestead and urban landscapes, continues to support a diverse assemblage of faunal species.

Kozhikode

Vallikkatu kavu sacred grove

This sacred grove is located near Cheekilode, a small village in Kozhikode with dense vegetation. It is managed by the Malabar Devaswom Board under the Government of Kerala and covers an area of 6.3 hectares. A stream flows through the grove and does not dry up even during the summer season. Public entry is strictly prohibited, and temple constructions are minimal. This patch represents a typical sacred grove, where both high species diversity and religious rituals are maintained. It is surrounded by agricultural fields and hills, with limited human habitation in the vicinity.

Poil Kavu

This 4.45-hectare urban sacred grove is located adjacent to homesteads in a human-dominated landscape. Managed by a private temple trustee, it is subjected to significant anthropogenic disturbance, including waste dumping and tree cutting for household use, which have degraded the natural vegetation.

Malappuram

Chandana Kavu

This sacred grove, covering an area of 2.1 hectares, is located adjacent to homesteads and a public road and is owned by a private temple trustee. The grove is enclosed by a compound wall, with public entry permitted only during temple worship hours. Owing to effective management by the owners, the grove is well maintained and retains its ecological integrity.

Mookuthala temple

This is an urban sacred grove owned by a private temple trust, with a well-developed canopy cover. The canopy is dense and prominent, and the grove is adjacent to agricultural fields. The owners also plant trees within the grove. A custom known as 'Nakshatravana' is practiced here, wherein individuals plant a tree within the temple premises on their birthdays, thereby promoting conservation and biodiversity. The grove covers an area of 2.8 hectares, and a well serves as a water source. Public entry into the sacred grove is limited.

Palakkad

Pathirikunnath Mana

This is one of the widely recognised sacred groves in Kerala, where people from different regions of the state visit for worship. The snake deity is prominent here, and devotees offer rituals associated with serpent worship. The grove is owned by members of the Pathirikunnath Mana family and is located within the boundaries of this joint family property, covering an area of 2.4 hectares. The idol is placed within the household premises, and public entry is restricted. The grove has a well-developed canopy; however, some vegetation is being cleared by the owners for temple purposes, which is adversely affecting the biodiversity conserved there. It is adjacent to agricultural fields and contains a pond that serves as a water source.

Athipatta mana

This is a small sacred grove located on the foothills of Silent Valley National Park, covering an area of 0.8 hectares and is on a river bank. Owned by private family trust where the public entry is restricted.

Thrissur

Pambumekkattu Mana

This is a well-known snake temple in Kerala where snakes are considered sacred. Numerous mythological beliefs, religious taboos, and stories are associated with this site. A snake idol is placed within the household premises, and public entry into the house is prohibited. The site is managed by members of the Pambumekkattu Mana family. It is characterized by sparse vegetation and low canopy cover, covering an area of 4.4 hectares. Entry into the grove is restricted. The area is being modified to meet human requirements. Temple priests conduct various religious practices related to snake worship for devotees. Although this site is considered a sacred grove, it currently has limited canopy cover and offers minimal habitat complexity for vertebrate biodiversity due to anthropogenic disturbance. However, the implementation of appropriate biodiversity conservation measures could enhance its ecological significance.

Ernakulam

Iringole Kavu

This is an urban sacred grove and is the second largest sacred grove in Kerala covering an area of 20 hectares. The vegetation cover is extensive and supports numerous species. This is under the management of Travancore Devaswom Board, under Government of Kerala. A temple is located within the grove, and human entry is permitted only within the designated areas. Surrounded by agricultural fields, the grove plays a significant role in biodiversity conservation.

Plate1. *Kayyath Nagam sacred grove, Kannur*

Kizhakkombu Kavu

This is a small sacred grove covering only 0.2 hectares. This is adjacent to agricultural fields, owned by Travancore Devaswom board. The idol is located beneath a single tree, and the site is subject to anthropogenic disturbance

Alappuzha

Mannarasala temple

This is a well-known sacred grove in Kerala where snake deities are worshipped. It is managed by a private temple trust and experiences frequent public entry. Although the grove has a total area of 5.28 hectares, vegetation cover occupies only a limited portion, as a large part of the area is used for temple-related constructions and associated facilities.

Vettikkode temple

This sacred grove, covering an area of 1.6 hectares, is located adjacent to agricultural fields and human habitations, with public entry to the grove strictly restricted. A temple situated at the centre of the grove is managed by a private temple trust. Restricted human access has contributed to the preservation of the grove's vegetation and habitat quality.

Pathanamthitta

Saranga Kavu

This is on the Achankovil riverbank and is owned by a private trust. Human activity is prominent in this area. The vegetation cover is well developed and remains largely undisturbed by human activities or constructions. The site covers an area of 1.7 hectares. A boundary wall has been constructed around this patch to restrict direct human entry, which aids in the conservation of natural vegetation. Since the site is located along a riverbank, it also serves as a roosting site for many bird species.

Kollam

Kulathoopuzha temple sacred grove

This is one of the smallest sacred groves that has only 0.6 ha. It comprises of a snake deity.

Thiruvananthapuram

Raloor kavu

This sacred grove is owned and managed by a private temple trust. Although it covers an area of 2.1 ha, a major portion of the site has been converted into temple-related constructions, resulting in alteration of the natural vegetation. Biodiversity in the area is highly impacted by religious activities

The subsequent chapter presents a detailed account of the specific methodologies employed in the present study.

3.2 Methodology

3.2.1 Vertebrate species richness and diversity

The diversity of vertebrates such as birds, amphibians, reptiles and mammals in the selected sacred groves is documented based on the following methodologies.

3.2.1.a Birds

The point-count method was followed to determine bird species diversity and richness across the 20 selected sacred groves. A standardized sampling protocol was applied in all study sites to ensure consistency in documenting avian diversity. Sampling points were established across each grove at 25 m intervals with a fixed detection radius of 15 m. A relatively shorter inter-point distance was adopted because sacred groves are small, highly fragmented habitat patches with limited spatial extent, unlike larger continuous forest landscapes where wider spacing (50–100 m) is typically employed. The reduced spacing ensured adequate spatial representation of habitat heterogeneity within each grove while maintaining a standardized sampling protocol across all study sites. Although the 25 m spacing between points may allow limited overlap of detection zones, double counting was minimized by conducting sequential counts, recording only individuals within the fixed radius, and avoiding repeated recording of the same moving individuals. Point-count surveys were carried out for three hours after sunrise, coinciding with peak bird activity and each sampling point was observed for a standardized duration of 5 minutes. The methodology followed parameters adopted for bird surveys in fragmented forests (Raman et al., 2005). The study extended over a period of two years, covering all seasons except the monsoon period (June–July), in each selected sacred grove. Each grove was surveyed for 5–10 days annually, depending on its area, with larger groves receiving proportionately greater sampling effort. Survey visits were distributed across different seasons, and the same sampling protocol was repeated in the second year to ensure consistency in observations. The number of point-count stations varied among sacred groves according to grove size and habitat heterogeneity, with larger groves receiving greater sampling effort, while smaller groves were sampled intensively to ensure adequate spatial representation of avian assemblages. The site-wise distribution of point-count stations used for bird surveys in the selected sacred groves is presented in Table 3. During each survey, both the number of individuals and the number of species observed were recorded to estimate species richness and diversity.

Table 3

Site-wise Distribution of Point-Count Stations Used for Avian Surveys in Sacred Groves

Sacred grove	Area (ha)	Number of point count stations
Athipatta mana	0.8	8
Kizhakkombu kavu	0.2	3
Kulathoopuzha	0.6	4
Mannampuram	3	28
Chandana kavu	2.1	19
Mookuthala temple	2.8	25
Pathirikunath mana	2.4	20
Vettikode temple	1.6	10
Saranga kavu	1.7	10
Raloor kavu	2.1	18
Poil kavu	4.45	36
Pambumekkattu	4.4	36
Karakkayil temple	6	58
Kayyath nagam	6.1	58
Neliar kottam	6.4	60
Vallikattu kavu	6.3	60
Edayilekkad kavu	5.2	54
Mannarasala	5.28	53
Kammadam	24	170
Iringole kavu	20	148

Birds were observed by using binoculars of 10x50 dimensions. Most of the birds are identified in the field by using the field guides (Grimmet et al., 2016). Photographs were also taken using camera Canon 90D with 600 mm lens.

The recorded vocalization was captured using a Sony ICD-PX 470 digital voice recorder. Subsequent identification of the acoustic data was conducted in consultation with expert ornithologists from the Kerala Forest Research Institute (KFRI), Thrissur, Kerala and Salim Ali Centre for Ornithology and Natural History (SACON)- South India Centre of WII Coimbatore, Tamil Nadu.

3.2.1.b. Amphibian, reptile and mammal species richness and diversity

A Visual Encounter Survey (VES), a time-constrained method following Crump and Scott (1994), was employed to document vertebrate species diversity, excluding birds. The same standardized protocol was consistently applied across all selected sacred groves. Each study site was divided into 20 × 20 m quadrats (0.04 ha), and surveys were conducted within these plots. A total of nine hours per day was spent sampling each site. All vertebrates encountered within the quadrats were recorded and photographed for identification, while physical collection of specimens was deliberately avoided to minimize disturbance. The photographed specimens were subsequently identified with the assistance of experts in the respective taxonomic groups. Indirect evidence such as faeces and spines, along with acoustic recordings of amphibians and mammals, was used to detect species presence. Species were identified using standard field guides, including Das (2015), Daniels (2005), Grewal *et al.* (2017), and Menon (2023).

3.2.2 Vegetation sampling

The survey design adopted for this study was based on standard sampling methods used in fragmented forest ecosystems to assess plant species distribution within sacred groves. The quadrat method was employed, wherein each sampling unit consisted of a 20 × 20 m plot (0.04 ha) for documenting adult trees. All plots were randomly established, maintaining a minimum distance of 25 m between adjacent plots, following the methodology of Osuri et al. (2017). Trees with a girth at breast height (GBH) of ≥ 15 cm were selected for documentation. The number of plots established varied among the study sites in proportion to their area. The trees were identified with the help of Botanists of Tropical Botanic Garden and Research Institute, Thiruvananthapuram and Kerala Forest Research Institute, Thrissur.

Canopy cover was estimated using a modified mirror method. A flat mirror with a marked grid was held horizontally at sampling points, and the reflected canopy was observed. The proportion of the mirror surface covered by vegetation was visually estimated as percentage canopy cover. Observations from multiple points were averaged to obtain the canopy cover value for each sacred grove.

3.2.3 Microhabitat documentation

Microhabitats were documented using the same sampling approach employed for vegetation assessment. Randomly placed quadrats of 20 × 20 m (0.04 ha) were established across each study site to record the occurrence of microhabitats at both ground and arboreal levels. The number of plots varied among study sites in proportion to their area, ensuring adequate representation of microhabitat diversity. A standardized methodology was consistently applied across all selected sacred groves. Arboreal microhabitats were identified using binoculars and through direct inspection of trees where feasible. Photographic documentation was carried out using a Canon EOS 90D to facilitate accurate identification.

In this study, complete enumeration of all sampling units within each sacred grove was not feasible due to logistical constraints and the ecological nature of the study. Sampling was carried out using a plot-based approach, with quadrats of 20 × 20 m (0.04 ha) established across each selected sacred grove. The number of plots varied among sites and was determined based on the area, habitat heterogeneity, and accessibility of each grove. Smaller sacred groves, due to their limited spatial extent and lower microhabitat diversity, required fewer sampling plots to adequately represent their ecological characteristics. In contrast, larger groves, which exhibited greater structural complexity and habitat variability, were sampled more intensively to capture the diversity of microhabitats and associated fauna (Table 4).

Table 4

Sampling Effort and Percentage Area Covered for Microhabitat Documentation

Sacred grove	Area (ha)	Plots	Percentage of Area Covered
Athipatta mana	0.2	4	80.00%
Kizhakkombu kavu	0.6	6	66.67%
Kulathoopuzha	0.6	6	66.67%
Mannampuram	3	24	32.00%
Chandana kavu	2.1	27	51.43%
Mookuthala temple	2.8	31	44.29%
Pathirikunath mana	2.4	24	40.00%
Vettikode temple	1.6	10	25.00%
Saranga kavu	1.7	10	23.53%
Raloor kavu	2.1	15	28.57%
Poil kavu	4.45	78	70.11%
Pambumekkattu	4.4	35	31.82%
Karakkayil temple	6	68	45.33%
Kayyath nagam	6.1	69	45.25%
Neliar kottam	6.4	118	73.75%
Vallikattu kavu	6.3	95	60.32%
Edayilekkad kavu	5.2	87	66.92%
Mannarasala	5.28	53	40.15%
Kammadam	24	285	47.50%
Iringole kavu	20	218	43.60%

3.2.4. Public Survey

Sacred groves are closely associated with human communities, where religious practices, cultural beliefs, and informal regulations play a crucial role in their conservation. Considering this strong human–nature relationship, a questionnaire-based survey was conducted to assess local knowledge, perceptions, and attitudes toward sacred groves, as well as to identify perceived threats and existing conservation practices. The survey targeted local residents residing near the selected sacred groves, along with frequent visitors and individuals regularly associated with or dependent on these groves. A total of 200 respondents, comprising both male and female participants aged above 35 years, were included in the study, with 10 respondents surveyed from each sacred grove. Data were collected through in-person interviews using a structured questionnaire consisting of 12 pre-defined statements rated on a five-point Likert scale. Prior to each interview, respondents were informed about the purpose of the study, assured of confidentiality, and verbal informed consent was obtained. The standardized questionnaire format ensured consistency in data collection and enabled quantitative assessment of community perceptions toward sacred grove conservation. Scores obtained for each parameter were summed, and the mean value was calculated for each sacred grove based on responses from the 10 participants surveyed.

A major limitation of this study was the inability to conduct nocturnal surveys within the study sites due to religious norms and regulations imposed by the respective authorities. All surveys were therefore carried out in accordance with the guidelines and permissions granted by the custodians of each selected sacred grove. Consequently, the sampling of nocturnal species was limited. The presence of nocturnal species was primarily inferred using indirect evidence such as feathers, spines and faeces. Despite these constraints, the study systematically documented and analyzed vertebrate diversity across all selected sites, as detailed in the subsequent chapters.

4. Diversity and species richness of vertebrates

4.1 Birds

Birds were recorded using the point-count method in each selected sacred grove were recorded and analyzed to assess species richness and composition. A total of 105 species were documented across the 20 study sites. Field observations suggest that several northern Kerala groves retained comparatively lower disturbance levels, possibly due to stricter adherence to traditional rules and restricted access. This pattern may be attributed to relatively lower levels of anthropogenic disturbance compared to groves in Central and Southern Kerala. The recorded species were categorized based on their conservation status according to the International Union for Conservation of Nature, as well as their residency status (resident or migratory). Although the majority of the recorded species are categorized as Least Concern, a substantial number of bird species exhibited a strong dependence on sacred groves. Behavioral observations, including roosting, perching, foraging and nesting, indicate that these groves function as critical microhabitats supporting avian communities. In fragmented landscapes, such patches likely serve as refugia, offering essential resources such as food, shelter, and nesting sites. This highlights the ecological significance of sacred groves in maintaining local biodiversity and sustaining bird populations despite increasing anthropogenic pressures in surrounding areas.

4.1.1 Bird species richness in individual sacred groves

As we move from Northern Kerala to Southern Kerala, the species composition of birds at individual study sites varies. The largest sacred grove in Kerala, the Kammadam Kavu, located in northern Kerala, recorded the highest bird species richness (Figure 5). The number of species varies in every selected sacred grove. The lowest number of birds found in Kulathoopuzha sacred grove has an area of 0.6 ha. The species composition in individual sacred groves is depicted in Figure 5.

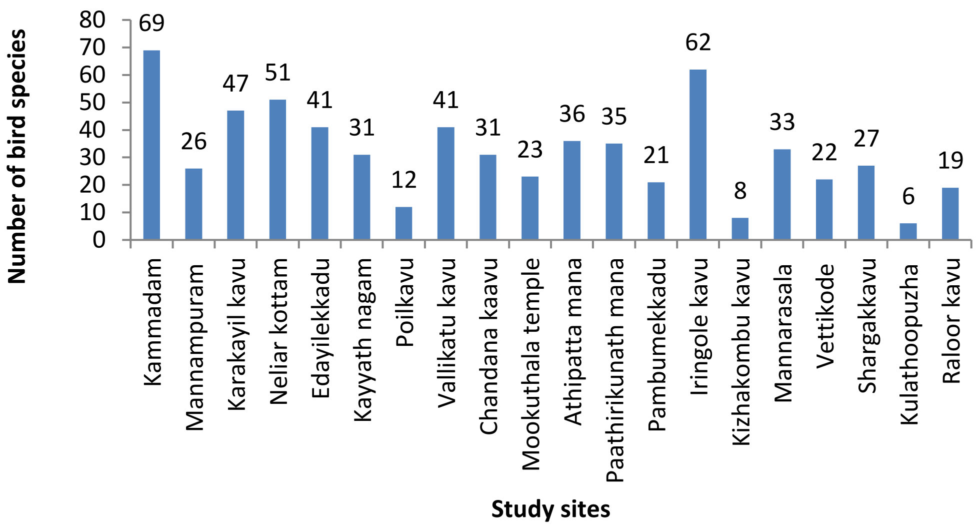


Figure 5. *Distribution of Birds Across Different Sacred Groves*

4.1.2 Order wise distribution of observed birds

The recorded birds belonged to 14 orders in which Passeriformes was the dominant order (Figure 6)

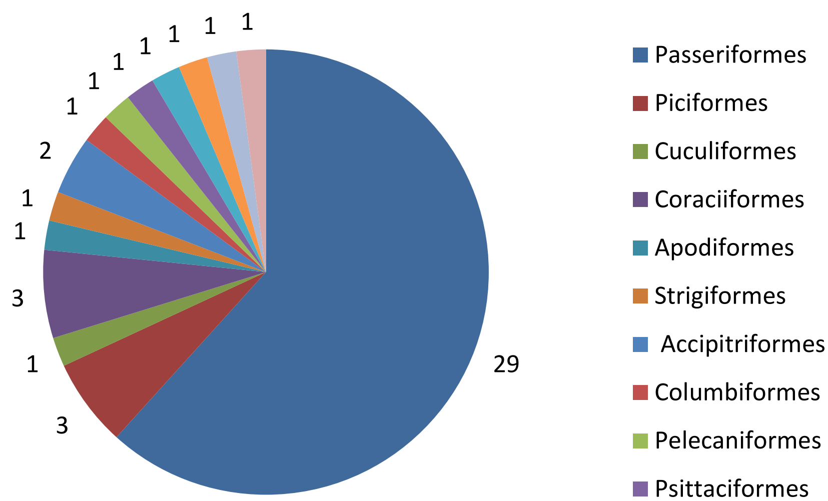


Figure 6. *Representation of Bird Orders Recorded from the Sacred Groves*

4.1.3 Statistical analysis

Bird data were analyzed to report on the diversity of species, species richness and similarity indices. Microsoft Excel 2011, R software, Biodiversity Pro and PAST software were used to describe the species abundance as well as association of birds with the studied patches. The following diversity indices were used ;

Shannon index

The Shannon index (H′) is a measure of species diversity in an ecosystem and is widely used to compare diversity across different ecosystems or study sites. The value of the Shannon index typically ranges from 0 upwards, with higher values indicating greater species diversity. Values around 1 generally represent low to moderate diversity, whereas values above 2 or 3 indicate higher levels of species diversity

The bird species associated with all selected sacred groves are analyzed using the Shannon index value. (Figure 7)

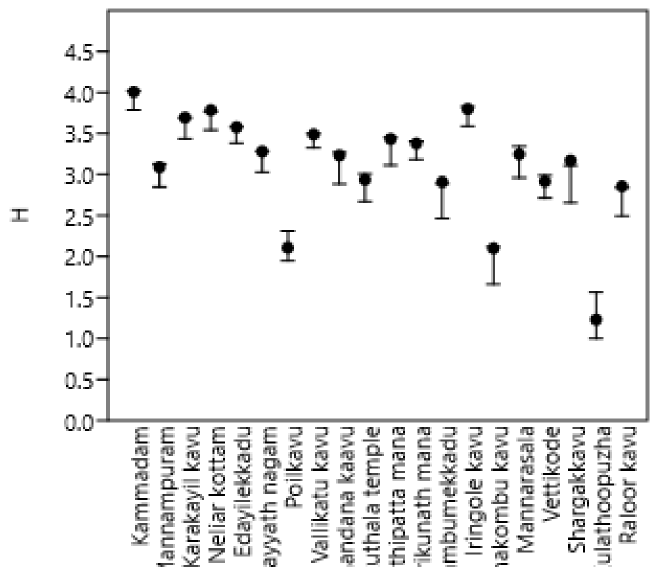


Figure 7. *Shannon Diversity Index of Birds Across Different Sacred Groves*

The values are further confirmed by analyzing the species richness using the R

software that also produced the same Shannon index value.

Among the surveyed sacred groves, the largest patch, Kammadam Kavu (24 ha), exhibited the highest Shannon index value (H′ = 3.99), indicating that it has a higher bird species diversity compared to the other study sites. In contrast, the lowest Shannon index value was recorded in the Kulathoopuzha sacred grove, the smallest site selected for the study (0.6 ha; H′ = 1.5).

Although lower, this value is still greater than 1, highlighting the ecological significance of even small sacred groves in conserving birdlife.

Simpson diversity index

The obtained data were used to calculate the Simpson diversity index. Values closer to 1 (in the case of 1 − D) indicate higher species diversity. In this study, Kammadam Kavu exhibited a Simpson diversity value close to 1, indicating that this site is more diverse in terms of bird composition than the other selected study sites. In contrast, the smallest sacred grove, Kulathoopuzha, showed the lowest Simpson diversity value, which was considerably lower than 1 (Figure 8).

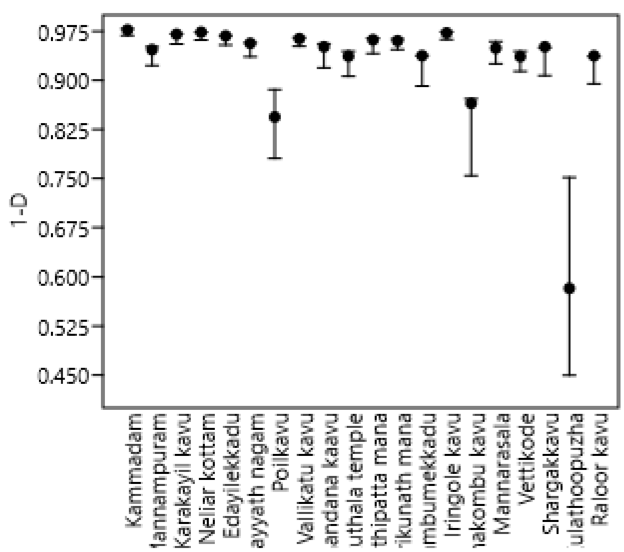


Figure 8. *Simpson Diversity Index of Birds Across Different Sacred Groves*

Both diversity indices showed that the selected study sites support avian assemblages and highlights the habitat dependency of birds in the sacred groves.

Dominance index

The dominance index was used to determine whether any individual bird species dominated the assemblage within the study patches. The dominance values were calculated for each selected study site and plotted using PAST software. The results indicate that most study sites exhibited similar dominance values (Figure 9), although three sites showed noticeable deviation from the overall pattern.

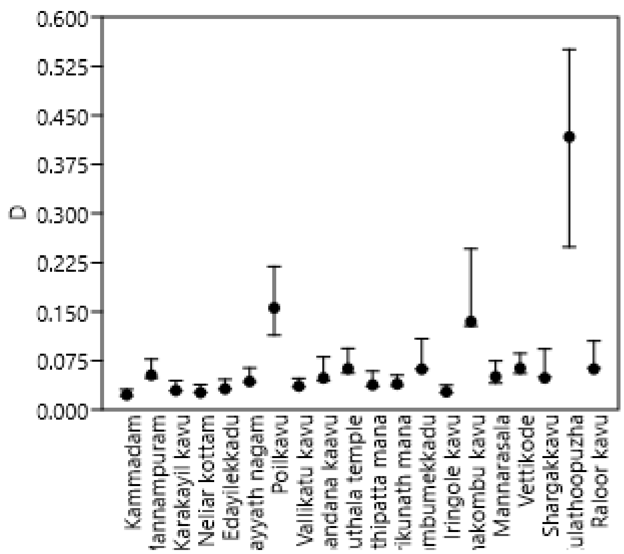


Figure 9. *Dominance Index of Birds Across Different Sacred Groves*

The dominance values suggest that no single bird species showed overwhelming dominance in most study sites; however, site-wise variation was evident and should be interpreted cautiously.

It can be concluded that, although sacred groves are distributed across different regions of Kerala, they exhibit similarities in bird species diversity. Although most of the recorded bird species fall under the Least Concern category according to the International Union for

Conservation of Nature, sacred groves play a significant role in their conservation across the state. Further studies in additional sacred groves would help to better elucidate the conservation value of these ecosystems. The present study indicates that sacred groves support a considerable number of bird species, irrespective of area.

4.2 Reptiles

4.2.1 Species diversity and abundance

As nocturnal surveys could not be conducted due to religious and access restrictions, the recorded amphibian and reptile richness should be interpreted as a conservative estimate. Reptile species diversity was assessed using the time-constrained visual encounter method, with surveys conducted for nine hours per day. Quadrats measuring 20 × 20 m were established in each selected sacred grove. Surveys were conducted between 09:00 and 18:00 h. The same methodology was applied across all selected sacred groves. Each quadrat was systematically walked and searched for the presence of reptiles in available microhabitats, including beneath leaf litter, within rock crevices, under stones, in tree cavities, and in fissures. All observed reptiles were photographed using a Canon EOS 1500D. Species identification was carried out with the help of experts at the Kerala Forest Research Institute and through the iNaturalist platform.

A total of 15 reptile species were recorded in the study. 15 species included seven species of skinks and lizards and eight species of snakes. Snakes included both venomous and non-venomous snakes.

4.2.2 Reptile species richness in individual sacred grove

Reptile species richness showed a declining trend from Southern Kerala to Northern Kerala in the selected sacred groves. Among the study sites, the Vallikattu Kavu Sacred Grove recorded the highest number of reptile species in the present study. (Figure 10). Snakes such as *Naja naja*, *Ahaetulla dispar*, *Bungarus caeruleus* reported from the site.

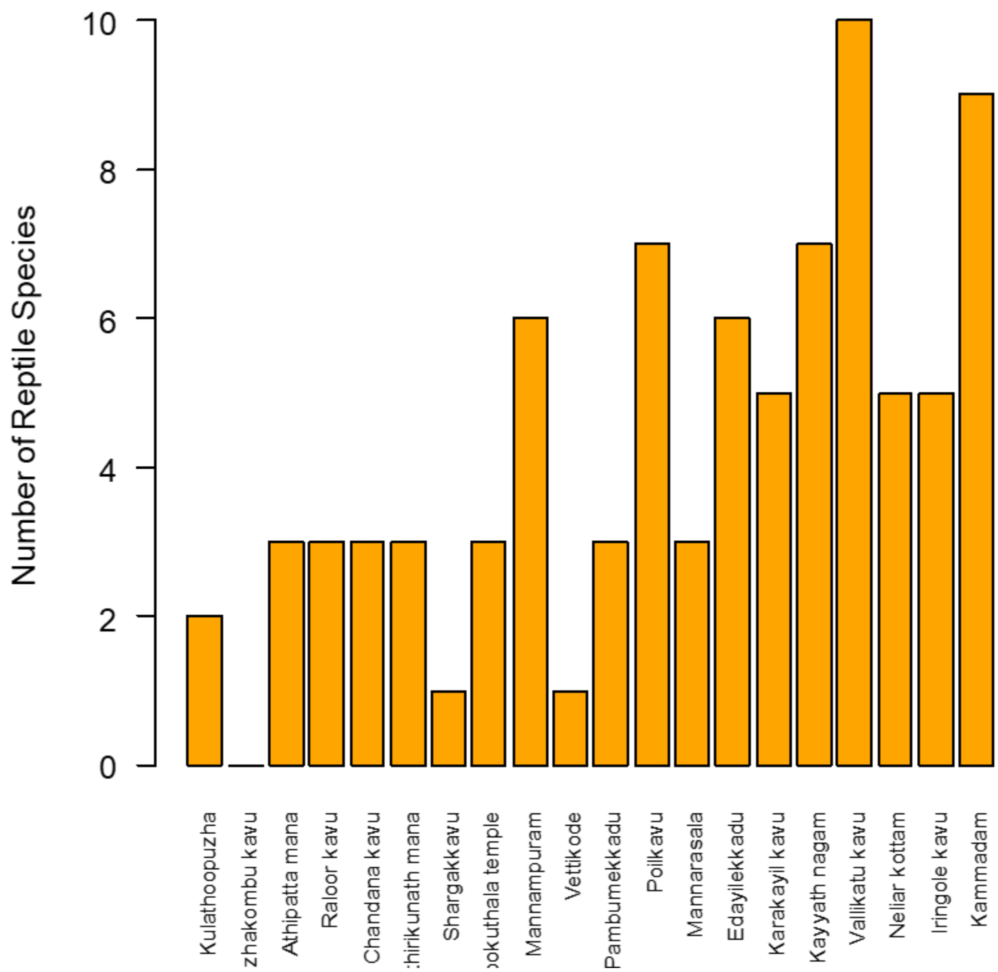


Figure 10. *Distribution of Reptiles Across Different Sacred Groves*

4.2.3 Species diversity analysis

To estimate the species diversity of reptiles, Shannon index is calculated by using the R software (Figure 11). Low values of the Shannon diversity index indicate reduced species diversity in three of the sacred groves. Across the surveyed sites, Shannon index values ranged from 0.1 to 2.5, suggesting variation in species diversity among the selected groves. This pattern is further supported by the Simpson index, with most values ranging between 0.5 and 0.9, indicating moderate to high dominance within the communities. The study site showing 0.5 Simpson diversity value is less diverse in reptile species composition (Figure 12).

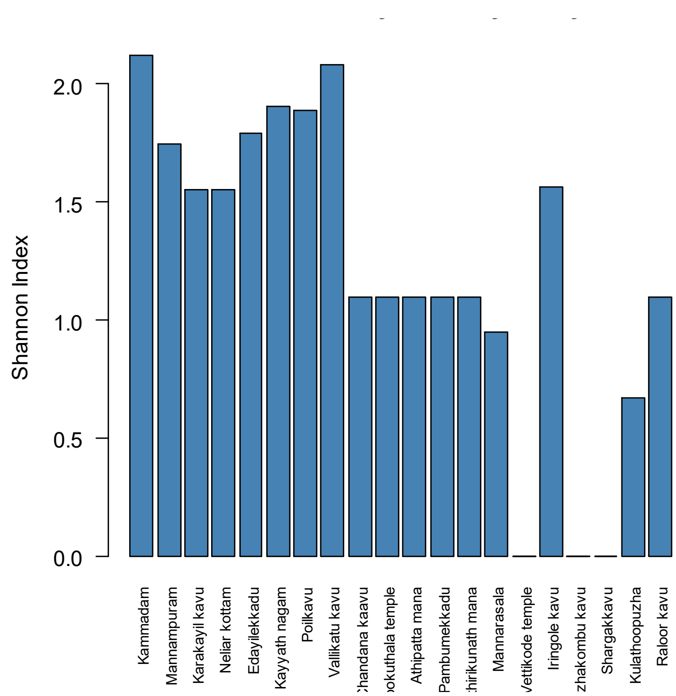


Figure 11. *Shannon Index of Reptiles Across Different Sacred Groves*

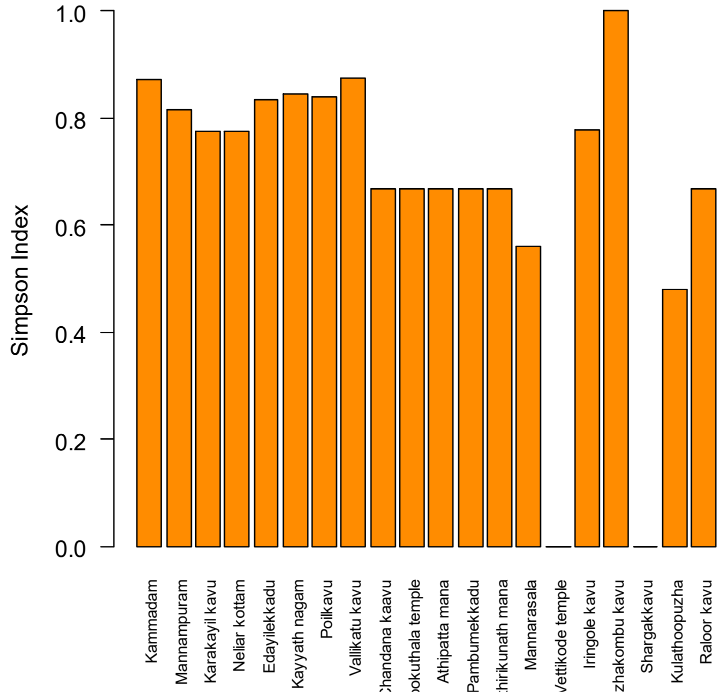


Figure 12. *Simpson Diversity of Reptiles Across Different Sacred Groves*

The dominance index was calculated to assess the extent to which particular species dominate within the communities. In three of the selected sacred groves, only a single species was recorded, resulting in higher dominance index values compared to other study sites. In contrast, the remaining sites exhibited a more even distribution of species, indicating lower dominance and greater community evenness. (Figure 13).

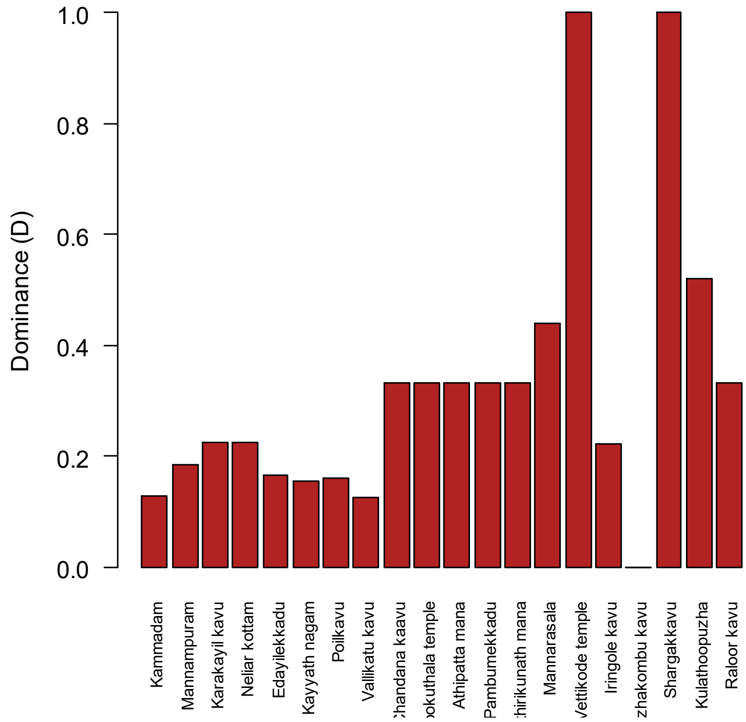


Figure 13. *Dominance Index of Reptiles Across Different Sacred Groves*

Evenness index

The Evenness Index measures how evenly individuals are distributed among the species within a community. The index ranges from 0 (low evenness) to 1 (high evenness), with values closer to 1 indicating a more uniform distribution of individuals among species, and values closer to 0 indicating dominance by a few species. The results suggest that most of the selected sacred groves support a relatively even distribution of reptile species. (Figure 14)

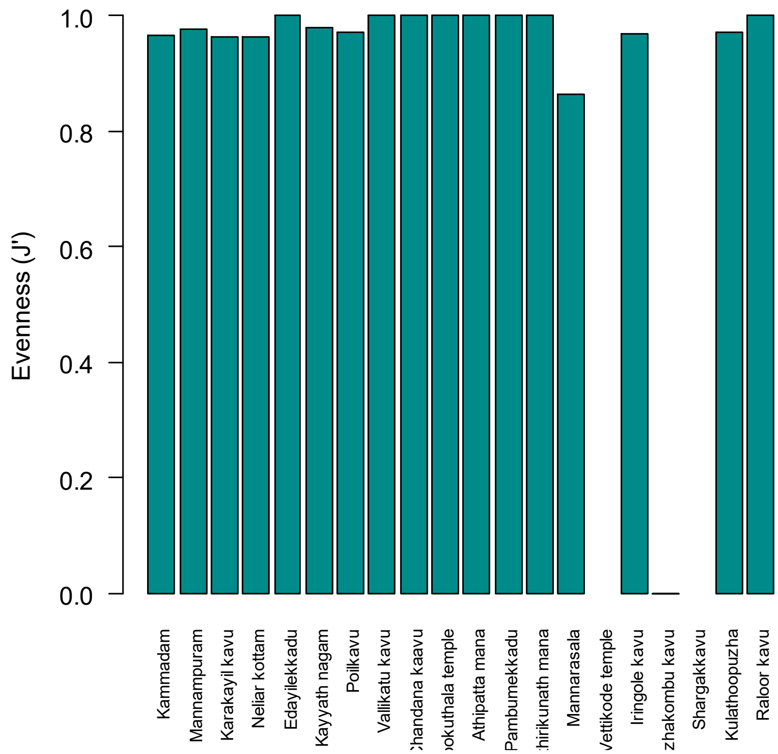


Figure 14. *Evenness Index of Reptiles Across Different Sacred Groves*

4.3 Amphibians

4.3.1 Species diversity and abundance

Amphibian diversity was documented using a combination of visual encounter surveys and acoustic monitoring. Individuals were recorded based on direct sightings as well as vocalizations, particularly during periods of peak activity. Surveys were conducted between 09:00 h and 18:00 h. These measurements are used in all the selected sacred groves for the survey. All the observed amphibians were photographed by using canon EOS1500 D. They were identified with the help of taxonomic experts of Kerala Forest Research Institute and using the citizen -science platform iNaturalist.

A total of six amphibian species were documented across the 20 study sites. However, the lack of nocturnal surveys may have resulted in an underestimation of the actual species richness within these sacred groves.

4.3.2 species richness in individual sacred grove

The number of amphibian species associated with the selected sacred groves showed a decreasing trend. (Figure 15). Among the study sites, the Kammadam Sacred Grove recorded the highest number of amphibian species in the present study

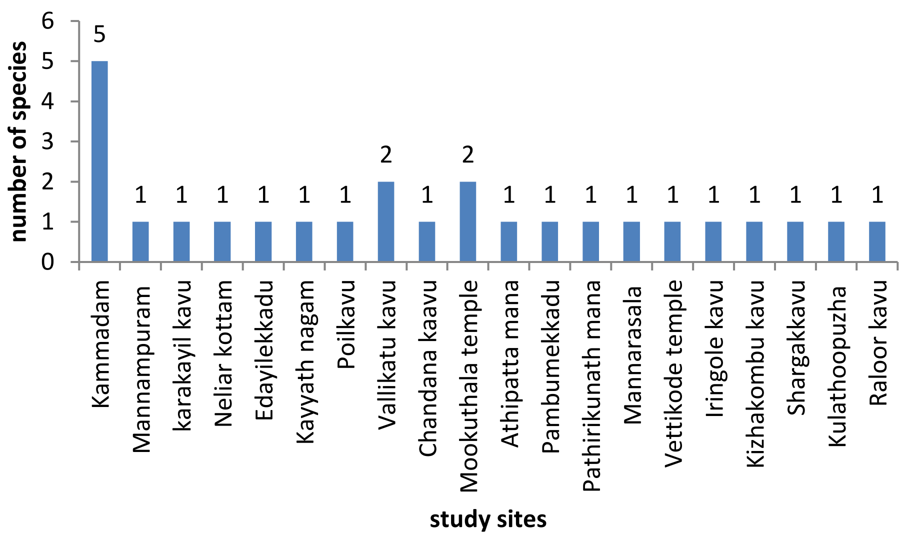


Figure 15. *Distribution of Amphibians Across Different Sacred Groves*

4.3.3 Species diversity analysis

Species diversity was estimated using the Shannon diversity index calculated with PAST software. According to the Shannon analysis (Figure 16), amphibian diversity was highest in the Kammadam Sacred Grove. Lower Shannon index values recorded in three sacred groves indicate reduced species diversity in those sites. Across the surveyed study sites, Shannon index values ranged from 0.1 to 2.5, suggesting variation in amphibian diversity among the selected groves.

As nocturnal surveys could not be conducted due to permission constraints, the recorded species richness is likely an underestimation of the actual diversity present. This limitation is further supported by the species accumulation curve, which indicates that additional sampling would likely yield more species. To illustrate this, a species accumulation curve was plotted (Figure 17).

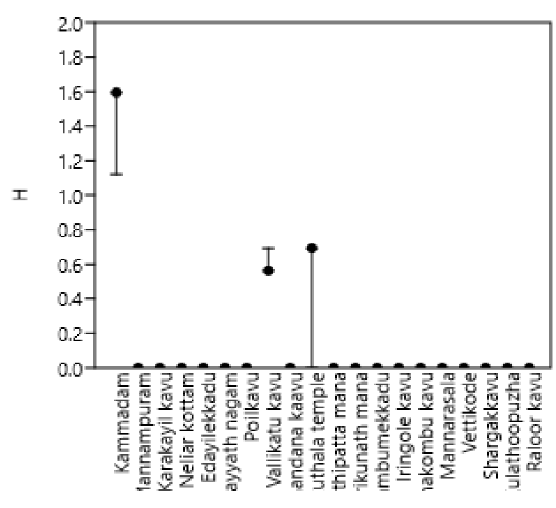


Figure 16. *Shannon Index of Amphibians Across Different Sacred Groves*

The species Accumulation Curve did not reach an asymptote indicating that more surveys may record a greater number of species that also signifies the conservation value of these patches.

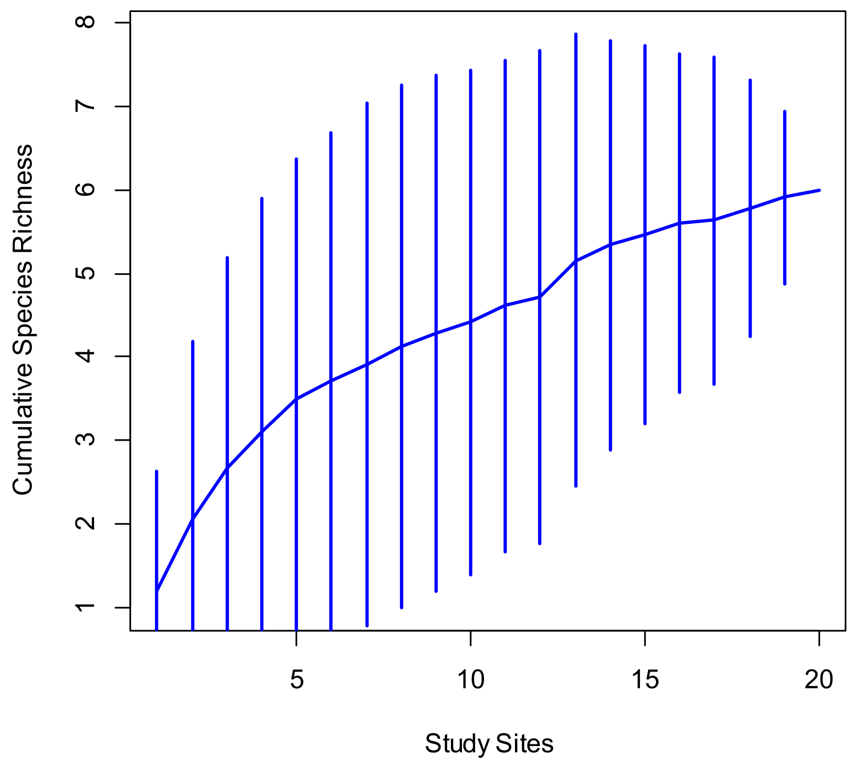


Figure 17. *Species Accumulation Curve of Amphibians Across Different Sacred Groves*

4.4 Mammals

4.4.1 Species diversity

The species diversity and abundance of mammals were estimated by visual encounter method. A sampling effort was implemented to record the species. Spent 9 hours per day to observe the presence of mammals and indirect signs such as spines and faeces were collected to determine the presence of mammals. The observed mammals were photographed by using canon EOS1500 D. The absence of camera trapping and nocturnal surveys may have resulted in under-detection of cryptic and nocturnal mammals. The mammals were identified with the help of experts of Kerala Forest Research Institute and using the website iNaturalist, and by using the field guide (Menon.,2003).

Nine species of mammals were identified from the surveyed sacred groves. Mammal species richness exhibited a declining trend from Northern Kerala to Southern Kerala.

4.4.2 Species richness in individual sacred groves

The highest number of mammal species was recorded in the Kammadam Sacred Grove (Figure 18), which is one of the largest sacred groves in Kerala.

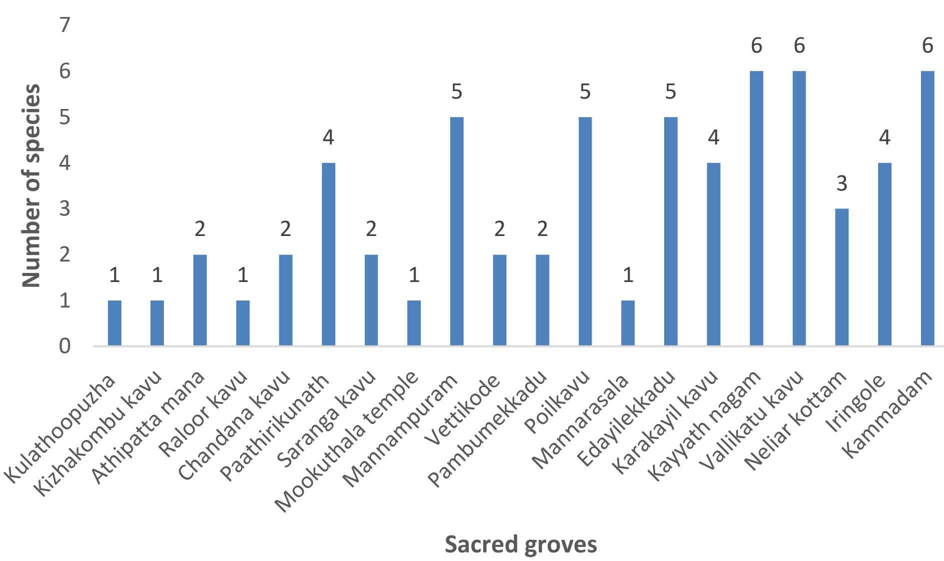


Figure 18. *Distribution of Mammals Across Different Sacred Groves*

4.4.3. Species diversity indices

The Shannon and Simpson diversity indices were used to assess species diversity across individual study sites, indicating that most of the selected sacred groves support relatively high mammal species diversity (Figure 19).

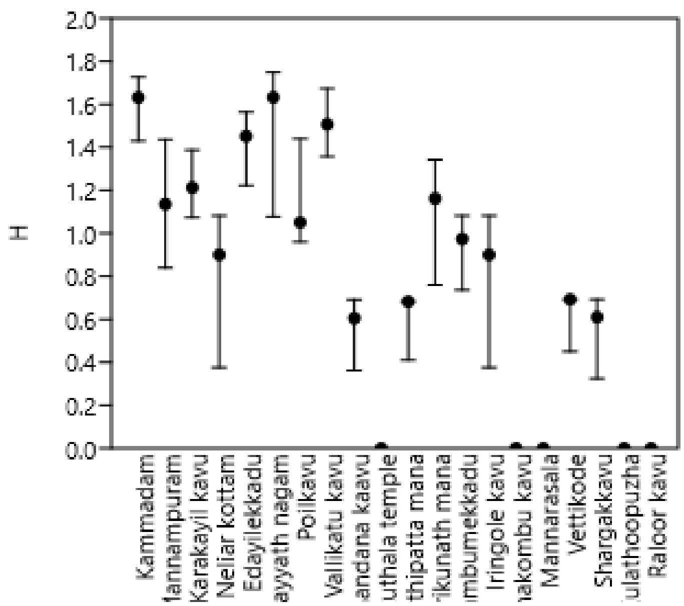


Figure 19. *Shannon Index Results of Mammals Across Different Sacred Groves*

The dominance index was calculated to assess the extent to which individual species dominate within the community composition. The results indicate a high degree of dominance by a single species in certain study sites, whereas in others, species are more evenly distributed. This variation suggests differences in mammal species distribution and community structure among the selected sacred groves. (Figure 20).

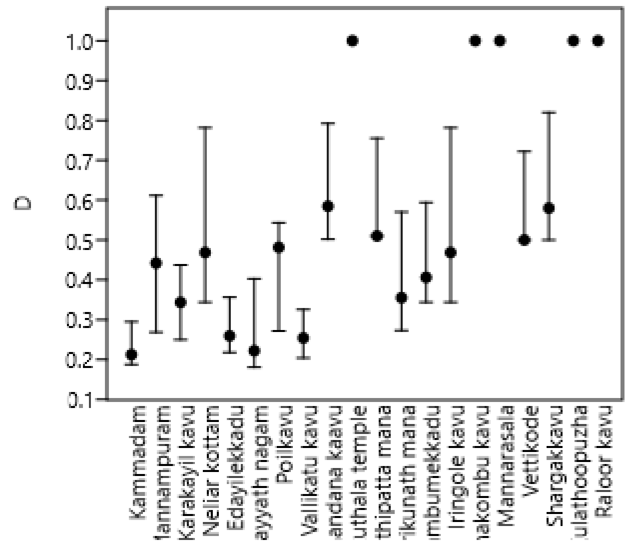


Figure 20. *Dominance Index of Mammals Across Different Sacred Groves*

The present study highlights that sacred groves support considerable mammal diversity despite their relatively small size and increasing anthropogenic pressure. Although the absence of nocturnal surveys may have led to an underestimation of total species richness, the recorded diversity underscores the ecological value of these groves as important refugia for mammals in the fragmented landscapes. The presence of both dominant and evenly distributed species across sites further reflects the differences in community structure and habitat conditions.

4.5 Vertebrate diversity and species richness in the selected sacred groves in Kerala

The selected twenty study sites located in three zones of Kerala show considerable diversity of vertebrate species. Overall, 136 species of vertebrates obtained from the surveyed sacred groves. The largest sacred grove in Kerala, the Kammadam Kavu has a greater number of vertebrate species

The diversity and species richness of all vertebrates in sacred groves analyzed by PAST software shows that the sacred groves have a considerable diversity of vertebrates. The Shannon index shows the same. (Figure 21)

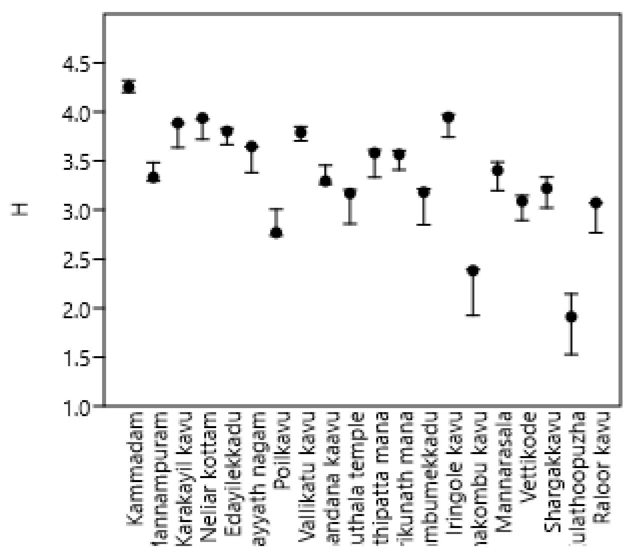


Figure 21. *Shannon Index of Vertebrates Across Different Sacred Groves*

The Berger–Parker index (Figure 22) and Pielou's equitability index were calculated for all study sites to assess species dominance and evenness. The results indicate that species are evenly distributed in most of the selected sacred groves, whereas in some sites, species distribution is uneven. In these cases, a single species exhibited dominance over others in terms of distribution and habitat use, irrespective of the size of the study sites. This pattern was particularly evident in smaller sacred groves with an area of less than one hectare. Overall, the findings highlight the importance of sacred groves in providing essential habitat and resources for the survival of vertebrate species.

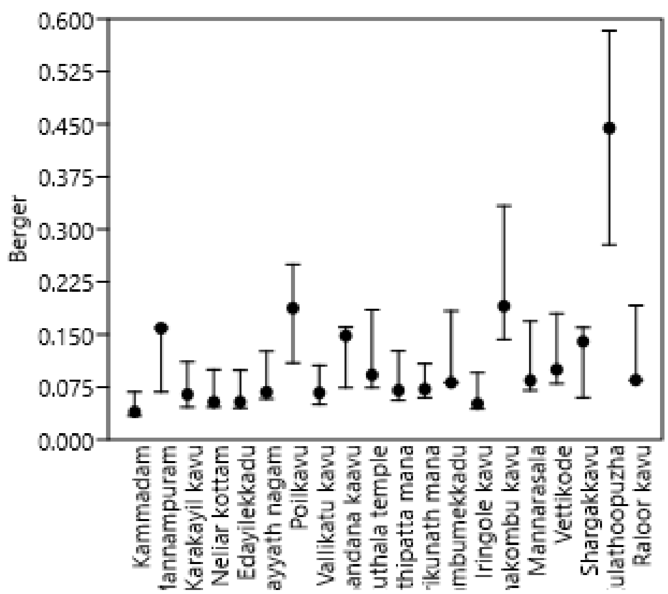


Figure 22. *Berger Parker Index of Vertebrates Across Different Sacred Groves*

The equitability index indicated that most of the study sites exhibited a relatively uniform pattern of species distribution (Figure 23). However, slight variation was observed in Poil Kavu Sacred Grove, which recorded an evenness value of 0.86. Although this value is marginally lower than sites with values closer to 1, it still reflects a high level of evenness. Notably, one site showed a comparatively lower evenness value (~0.80) with greater variability. The observed patterns suggest relatively balanced resource utilization among species; however, direct inferences regarding interspecific competition cannot be made based on this index alone.

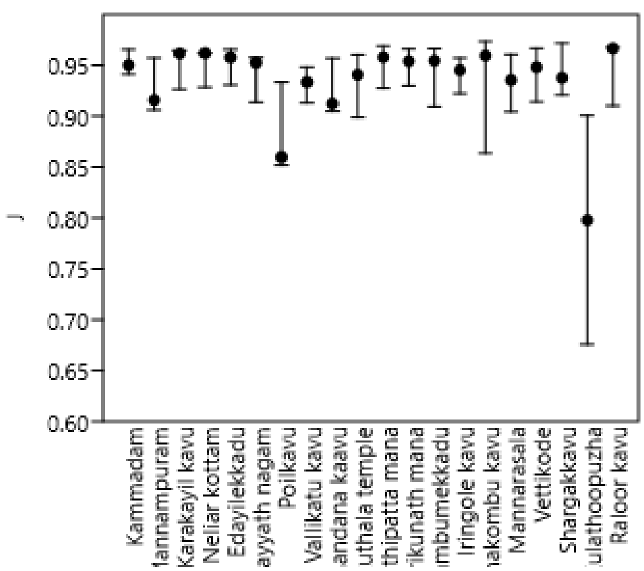


Figure 23. *Equitability Index of Vertebrates Across Different Sacred Groves*

This pattern of evenness is further supported by the Dominance Index (Figure 24). However, variation is observed in three out of the twenty sacred groves, where higher dominance values indicate the presence of species dominance in these sites.

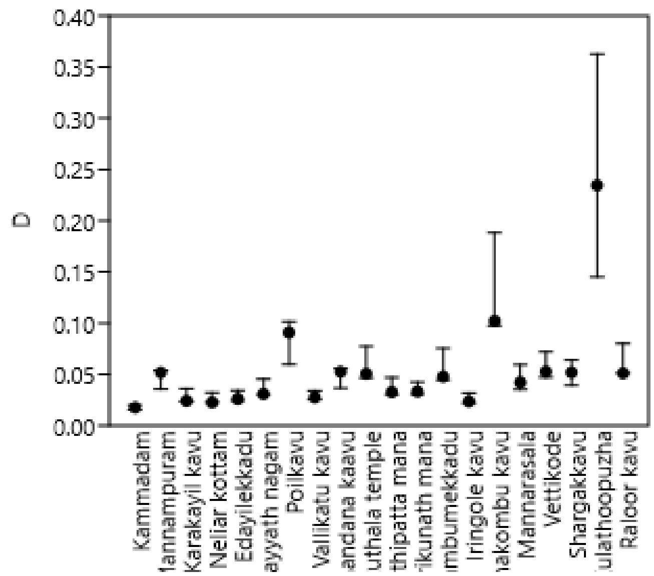


Figure 24. *Dominance Index of Vertebrates Across Different Sacred Groves*

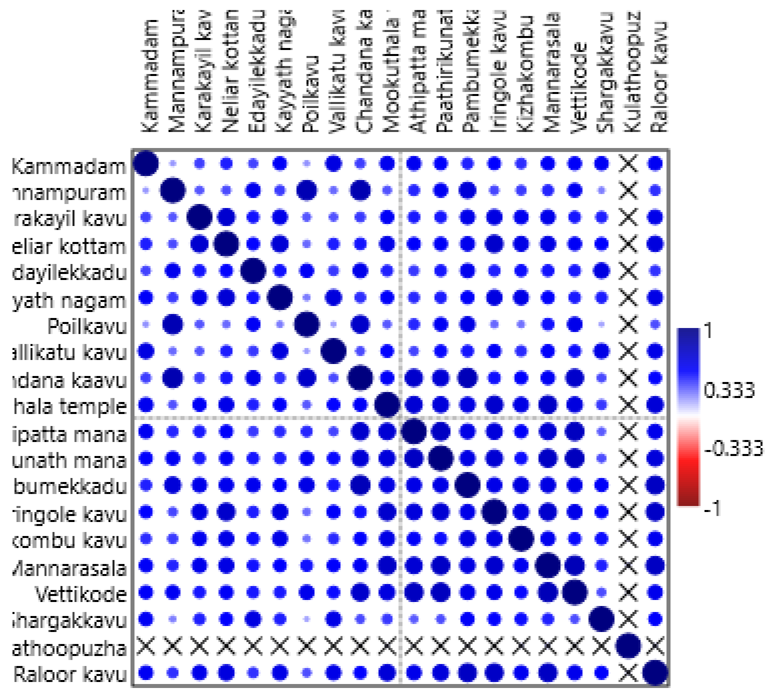


Figure 25. *Correlation of Vertebrate Diversity Among Selected Sacred Groves*

A correlation analysis was performed to examine the relationships among sacred groves based on vertebrate species richness and abundance. The results revealed predominantly positive correlations among the majority of study sites, indicating similarities in vertebrate composition patterns (Figure 25). This suggests that sacred groves, despite differences in area, are capable of supporting comparable levels of vertebrate diversity. These findings further emphasize the ecological and conservation significance of even small habitat patches.

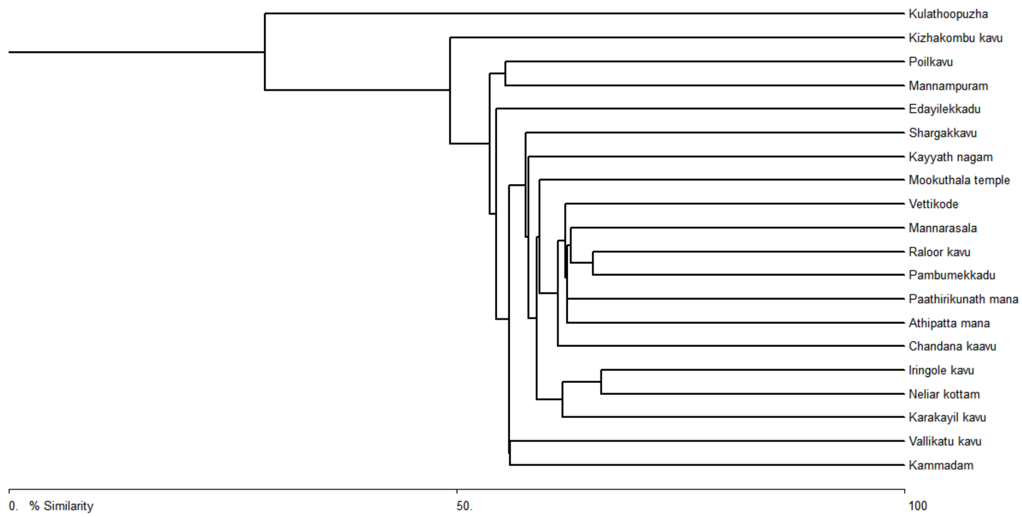


Figure 26. *Bray–Curtis Similarity Analysis of Vertebrate Diversity Among Different Sacred Groves*

This pattern is further supported by similarity analysis using the Bray–Curtis index in Biodiversity Pro software, which shows that most of the study sites exhibit more than 50% similarity in their vertebrate species composition (Figure 26). The study examined the factors responsible for vertebrate diversity, which are discussed in the next chapter.

5. Factors affecting the distribution and diversity of vertebrates

The diversity and species richness of vertebrates in the selected sacred groves are dependent on various factors such as their habitat requirements, resource availability landscape, water source, vegetation type are the common factors that decide the species diversity.

Sacred groves are informally protected landscapes for generations. There are some unique factors that directly influence the diversity of species. Apart from other ecosystems, vertebrates enjoy conservation and utilize the natural resources in these patches since anthropogenic disturbances are limited. A major factor, which is unique in these patches is religious rituals and unexplainable myths and beliefs that directly preserve the natural vegetation while also providing ecosystem for several faunal species. A major advantage of this landscape is its area. Usually, sacred groves are small in area, compared to other ecosystems, whose area ranges from cents to hectares, so that these habitats are easy to manage. A minimal effort for management ensures maximum conservation of natural resources for generations. The conservation of endemic and endangered species at minimum management policies highlights the conservational value of these patches.

The vertebrate species diversity in the selected sacred groves is influenced by several factors. Some of the factors are follows.

5.1 Area or size of the sacred groves

The selected sacred groves exhibited considerable variation in their spatial extent, with some occupying areas below one hectare while the majority exceeded one hectare. Among the study sites, the largest sacred grove, Kammadam Kavu in northern Kerala, covered an area of 24 hectares, whereas the smallest, Kulathoopuzha sacred grove, extended only 0.6 hectares. Despite these differences in area, all groves supported appreciable vertebrate species diversity, although the level of species diversity varied among sites.

To assess the influence of area on species diversity, a species–area relationship was examined by plotting the logarithm of species richness on the Y-axis against the logarithm of the area of the study sites on the X-axis. (Figure 27)

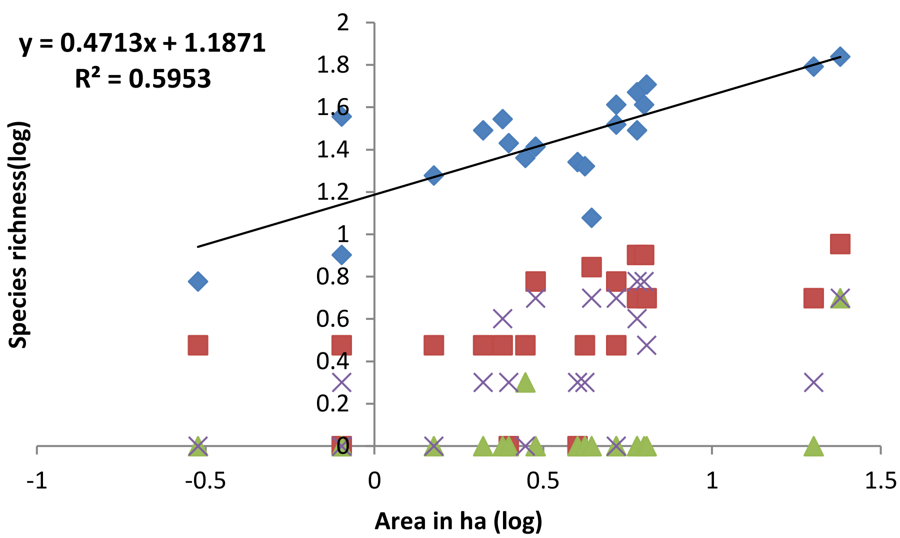


Figure 27. *The Species Area Relationship Observed in Different Sacred Groves*

This figure illustrates the relationship between the area of sacred groves and vertebrate species richness. A positive relationship is observed, indicating that larger sacred groves tend to support a higher number of species. However, the strength of this relationship varies among different vertebrate groups. Birds show a strong positive correlation with area, while reptiles and mammals exhibit moderate relationships. In contrast, amphibians show a weak or no clear relationship with area. These patterns suggest that, although area influences species richness, other ecological factors may also play an important role in determining vertebrate diversity in sacred groves. The Pearson's correlation value is given below:

Birds- 0.8

Reptiles- 0.57

Amphibians- 0.63

Mammals- 0.52

The correlation analysis indicates a strong relationship between the area of the sacred groves and bird species diversity. The correlation coefficient (r = 0.8) suggests a strong positive association, implying that an increase in the area of the study site is accompanied by a corresponding increase in the number of bird species. For the other vertebrate groups, moderate positive correlations (greater than 0.50) were observed. Correlation coefficients should be interpreted along with significance values and sample size. Without p-values, these results indicate association but not statistical confirmation.

Overall, the results demonstrate that the area of a habitat patch plays a significant role in determining species diversity. The consistently positive correlations observed across all vertebrate groups indicate that larger sacred groves tend to support higher vertebrate diversity compared to smaller ones.

Species diversity of vertebrates was quantified using the Shannon–Wiener diversity index across all selected sacred groves. The relationship between diversity (Shannon–Wiener index values) and grove area was evaluated using correlation analysis, and the results were graphically represented using PAST software. (Figure 28).

In this figure, the correlation value between Shannon wiener index and area of patches is more than 0.33 but not close to 1. This suggests that species diversity tends to increase with increasing patch area. The graph indicates a moderate positive relationship between the area of sacred groves and species diversity. The largest sacred grove in the study supported the highest number of species. However, the second and third largest groves exhibited nearly similar Shannon–Wiener index values. Although larger groves generally supported higher species richness, several smaller groves also retained considerable vertebrate diversity, suggesting that habitat patch area alone does not determine species diversity; ecological factors such as habitat quality, water availability, disturbance level, and landscape context also significantly influence species richness and diversity.

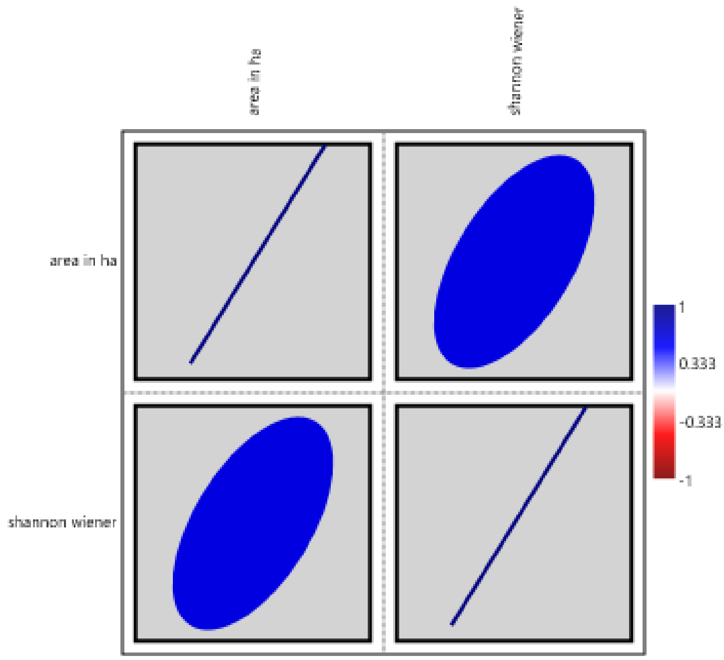


Figure 28. *Correlation Between Species Diversity and Area of Selected Sacred Groves*

5.2 Ownership and management policies

Out of the 20 selected sacred groves, 15 are owned by private temple trusts, where local communities act as the managing authorities. Three groves are managed by family members, as they are located within homestead boundaries, while the remaining two are managed by Devaswom Boards under the Government of Kerala. Management practices vary among sacred groves, with each following its own set of customary rules. These differences in management are reflected in the varying levels of species conservation observed across the groves.

To analyze management practices, nine parameters were formulated under management policies. Each parameter was assigned a score of 5 (Table 4). The total score for each sacred grove was calculated and correlated with the Shannon diversity index of the selected study sites. The nine parameters considered are listed below.

1. Presence and maintenance of compound wall
2. Public pathway management
3. Entry into groves by owners
4. Adopting religious rules and regulations
5. Vegetation maintenance
6. Maintenance of patch in its natural form
7. Prevention of public entry into groves
8. Not doing temple constructions
9. Prevention of public malpractices such as throwing waste into the patch

The presence of a well-maintained concrete compound wall was assigned a score of 5 (Table 5). If no compound wall was present, a score of 0 was assigned. A score of 1 indicated a severely damaged or largely incomplete wall; scores of 2-3 indicated moderate structural integrity with noticeable damage or gaps; a score of 4 indicated a mostly intact wall with minor deterioration; and a score of 5 represented a fully intact and well-maintained compound wall.

A score of 5 was assigned to sacred groves with a well-maintained designated pathway, as such pathways minimize disturbance to natural vegetation while facilitating access for devotees. In contrast, sacred groves lacking a proper pathway, where movement occurred through random routes within the vegetation, were assigned a score of 0. Intermediate scores (1-4) were assigned based on the extent, condition, and effectiveness of the pathway in regulating movement and minimizing disturbance to the surrounding vegetation. Frequent entry of landowners or other individuals into the interior of the sacred grove was considered a potential source of disturbance to the natural habitat and was assigned a score of 0. In contrast, sacred groves where access to the core area was restricted were assigned the maximum score (5) for this parameter. Intermediate scores (1-4) were assigned based on the frequency and extent of human access to the grove interior.

All nine defined parameters were evaluated using a standardized scoring framework, and scores were assigned to each selected sacred grove based on field observations and observed site conditions. The total score obtained reflects the effectiveness of management practices in each sacred grove. To minimize observational bias, all the parameters were assessed using predefined standardized scoring criteria, and the same evaluation framework was consistently applied across all selected sacred groves. Scores were assigned based on direct field observations made during repeated site visits, and assessment by a single observer throughout the study minimized inter-observer variation, thereby ensuring consistency in scoring across sites.

Table 5
Scores of Different Parameters

Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Compound wall	0	4	2	4	3	0	1	0	4	5	3	3	4	4	1	4	3	3	4	3
Proper pathway	3	3	2	3	3	4	1	4	4	5	4	4	2	5	2	4	4	4	2	3
Prohibition of owner entry	4	1	3	3	3	2	2	4	2	2	2	2	1	3	2	4	4	2	1	2
Adopting religious rules	5	1	3	5	5	3	1	5	4	4	5	5	5	4	3	5	5	2	3	3
Vegetation maintenance	5	3	5	3	5	5	2	5	5	5	5	2	3	5	4	5	4	3	5	1
Prevention of public entry	5	1	4	5	5	5	2	5	4	4	5	4	5	3	3	2	5	4	2	3
Maintenance of patch	5	4	5	3	4	4	3	5	4	4	4	1	2	3	3	4	5	3	1	1
Not doing temple constructions	5	4	4	2	4	4	4	5	4	4	3	1	2	5	4	4	4	2	4	0
Prevention of public malpractices	5	2	2	3	4	4	1	4	5	5	4	4	5	4	3	5	4	4	1	2

In table 3, 1 represents Kammadam, 2 Mannampuram kavu, 3 Karakkayil temple, 4 Neliar kottam, 5 Edayilekkad kavu, 6 Kayyath nagam kavu, 7 Poil kavu, 8 Vallikkatu kavu, 9 Chandana kavu, 10 Mookuthala kavu, 11 Athipatta mana, 12 Pathirikkunnath, 13 Pambumekkatu mana, 14 Iringole kavu, 15 Kizhakkomb kavu, 16 Mannarasala, 17 Vettikkode , 18 Sarangakavu, 19 Kulathoopuzha , 20 Raloor kavu

The total score obtained for each sacred grove was correlated with the Shannon diversity index of the respective sites to examine the relationship between management practices and species diversity. The analysis revealed a moderate positive correlation (Figure 29), indicating that sacred groves with higher management scores generally tended to support greater species diversity. However, the moderate strength of this relationship suggests that species diversity is also influenced by additional ecological and environmental factors beyond management practices alone. The findings further highlight the potential threats and disturbances affecting sacred groves, particularly anthropogenic activities, which may adversely influence their structural integrity and overall conservation status.

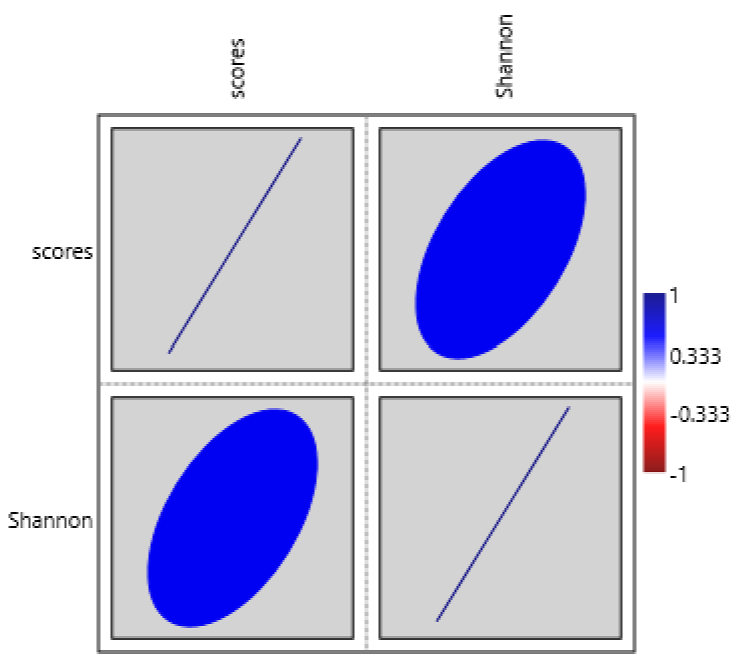


Figure 29. *Correlation Between Management Policies and Shannon Index of Different Sacred Groves*

In the figure, the blue ellipse indicates a moderate positive correlation between the variables, suggesting that effective management and community stewardship practices are positively associated with species diversity and the conservation status of sacred groves.

5.3 Religious rituals and beliefs among public and people's attitude

Since sacred groves are located adjacent to human habitations and have long been an integral part of cultural life, religious rituals, traditional beliefs, and community stewardship have contributed substantially to maintaining these groves in their natural form across generations. The mean composite perception scores obtained for the 20 selected sacred groves (Table 6) were analyzed in relation to the Shannon–Wiener diversity index of the respective study sites using regression analysis performed in Microsoft Excel (2011 version) and R software. The results (Table 7) revealed a statistically significant positive relationship between community stewardship scores and species diversity ($p < 0.05$), suggesting that positive community attitudes, cultural beliefs, and associated religious practices may contribute to the ecological integrity and faunal diversity of sacred groves.

Table 6
Mean Scores for All the Study Sites

Parameters	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Do not entering into forest	5	3	4	3	5	4	1	5	3	5	5	4	5	4	3	5	5	4	3	3
Do not taking fallen wood	5	4	5	5	4	5	1	5	4	5	4	5	5	5	4	5	5	4	4	4
Conserving the fauna	5	4	5	4	5	4	4	5	4	5	5	4	5	5	5	4	4	4	4	5
Do not use grove as public pathway	5	1	5	3	5	5	4	5	5	5	5	5	5	4	5	5	5	5	5	4
Do not dump waste in grove	5	3	3	3	4	4	2	4	4	4	4	4	4	4	3	5	4	4	2	3
Follow temple instructions	5	3	4	3	4	4	3	4	5	5	5	5	5	4	3	4	4	4	4	3
Provide offerings to sacred groves	3	4	4	4	3	4	2	4	4	4	4	4	4	4	4	5	4	4	4	3
Visit temple for worship	4	4	3	4	2	4	4	5	5	3	2	3	2	4	3	5	4	3	2	2
Observe the species	3	3	3	3	4	3	3	4	3	3	3	3	2	4	2	3	2	3	2	2
Promote other people to follow rules	5	4	4	4	4	5	4	5	5	4	3	4	5	4	4	5	5	3	3	2
Aware about myths and stories of temple	4	3	3	4	3	4	3	5	4	3	3	5	5	4	3	5	4	3	3	3
Aware about flora of the groves	3	3	3	3	3	3	3	3	3	3	2	2	2	4	2	2	2	3	2	2

[2] In table 4, 1 represents Kammadam, 2 Mannampuram kavu, 3 Karakkayil temple, 4 Neliar kottam, 5 Edayilekkad kavu, 6 Kayyath nagam kavu, 7 Poil kavu, 8 Vallikkatu kavu, 9 Chandana kavu, 10 Mookuthala kavu, 11 Athipatta mana, 12 Pathirikkunnath, 13 Pambumekkatu mana, 14 Iringole kavu, 15 Kizhakkomb kavu, 16 Mannarasala, 17 Vettikkode , 18 Sarangakavu, 19 Kulathoopuzha , 20 Raloor kav

Table 7
Regression Analysis

Regression Statistics	
Multiple R	0.59
R Square	0.35
Adjusted R Square	0.31
Observations	20

ANOVA

	Df	*SS*
Regression	1	2.13
Residual	18	3.94
Total	19	6.07

	Coefficients	*Standard Error*
Intercept	0.62	0.87
X Variable 1	0.05	0.01

5.4 Climatic and topographic factors

The climatic factors have a crucial role in determining the species diversity in an ecosystem. The climatic factors include temperature, rainfall, humidity and precipitation influences the species distribution and habitat use

5.4.1 Temperature

The study period extended to two years, 2021 and 2022. In 2021, the mean annual temperature ranged from 16.59°C (minimum) to 37.44°C (maximum), whereas in 2022 it ranged from 17.46°C to 36.9°C. The data is collected from the official website of the State Meteorological Department, Kerala. The diversity in sacred groves is influenced by the temperature.

Effect of temperature on Bird diversity

The monthly temperature of the largest study site, Kammadam Kavu, showed a negative correlation with the monthly Shannon diversity index of birds ($r = -0.24$), indicating a weak inverse relationship between temperature and species diversity. Similarly, Mannampuam Kavu, another site in Kasaragod district, also exhibited a stronger negative correlation ($r = -0.74$), suggesting a comparatively higher decline in diversity with increasing temperature.

In the second-largest sacred grove located in Ernakulam district, monthly temperature ranged between 27°C and 28°C, while the Shannon diversity index varied from 3.872 to 3.213. This site also showed a moderate negative correlation ($r = -0.55$), indicating a decline in species diversity with increasing temperature.

A similar negative correlation pattern was observed across other selected sacred groves. Overall, the analysis suggests an inverse relationship between temperature and bird species diversity across the study sites, where higher temperatures are generally associated with lower diversity. Overall, the study indicates a consistent negative relationship between temperature and bird diversity, suggesting that higher temperatures are associated with reduced species diversity in the selected sacred groves.

Effect of temperature on reptile diversity

The highest reptile diversity was recorded in Vallikattu Kavu, Kozhikode, with a Shannon diversity index of 2.3. In this site, monthly temperature ranged between 28°C and 31°C and showed a moderate positive correlation with reptile diversity ($r = 0.52$), indicating that reptile diversity tends to increase with rising temperature.

Similarly, Poil Kavu, another site in Kozhikode district, also exhibited a positive correlation between temperature and reptile diversity ($r = 0.35$), although the relationship was relatively weaker compared to Vallikattu Kavu.

In Kasaragod district, where the monthly average temperature ranged between 28°C and 29°C during 2022, a positive correlation was observed ($r = 0.50$). Mannampuram Kavu, with a Shannon diversity index of 1.74, also showed a weak positive correlation with temperature ($r = 0.15$), indicating a relatively less pronounced relationship.

In Ernakulam district, the second-largest study site, Iringole Kavu, recorded a positive correlation between temperature and reptile diversity ($r = 0.53$), with monthly temperatures ranging between 26°C and 28°C.

Nelliarkottam in Kannur district, covering an area of 6.4 hectares and having a Shannon diversity index of 1.7, also exhibited a positive correlation ($r = 0.61$) between temperature and reptile diversity, where temperatures ranged from 27°C to 31°C.

Overall, the analysis across all study sites indicates a consistent positive association between temperature and reptile species diversity, suggesting that reptile diversity tends to increase with rising temperature within the observed range.

Plate2. *Stream inside Kammadam sacred grove, Kasaragod*

Across all the study sites, temperature showed a consistent positive correlation with reptile diversity, indicating a positive association between temperature and species diversity. The results suggest that reptile diversity tends to increase with a slight rise in temperature within the observed range in the selected study sites.

Effect of temperature on amphibian diversity

The diversity of amphibians across the selected sacred groves was comparatively low when compared to other vertebrate groups. In several study sites, only a single amphibian species was recorded. The highest amphibian diversity was observed in Kammadam Kavu, where the Shannon diversity index was 1.59, indicating relatively low diversity. In this site, a moderate negative correlation was observed between temperature and amphibian diversity ($r = -0.41$), suggesting that amphibian diversity tends to decrease with increasing temperature.

Similarly, Vallikkattu Kavu in Kozhikode district showed a negative correlation between temperature and amphibian diversity ($r = -0.48$), with monthly mean temperatures ranging from 26°C to 29°C. Mookuthala sacred grove in Malappuram district also exhibited a negative correlation ($r = -0.38$), where the mean monthly temperature ranged from 26°C to 31°C.

Across the remaining study sites, amphibian diversity was very low, with most sites supporting only a single recorded species. It is also important to note that nocturnal surveys could not be conducted due to restrictions imposed by temple authorities, which may have influenced the recorded diversity, as many amphibian species are nocturnal in habit.

Effect of temperature on mammal diversity

The relationship between mammal diversity and mean annual temperature showed varying degrees of correlation across the selected sacred groves. In Kammadam Kavu, a weak negative correlation was observed ($r = -0.26$), where the Shannon diversity index for mammals was 1.7, with lower values recorded during warmer periods (1.65). This suggests a slight decrease in mammal diversity with increasing temperature in this site.

Similarly, Karakkayil sacred grove exhibited a moderate negative correlation ($r = -0.42$), while Edayilekkad Kavu showed a strong negative correlation ($r = -0.81$), indicating a more pronounced decline in mammal diversity with increasing temperature. Vallikkattu Kavu also recorded a strong negative correlation ($r = -0.82$). In contrast, Kayyath Nagam Kavu showed a weak positive correlation ($r = 0.16$), indicating a slight increase in diversity with temperature in that particular site.

Overall, the results indicate that mammal diversity across most of the selected sacred groves tends to show a negative association with temperature, suggesting higher diversity under relatively cooler conditions. However, the variation among sites, including a weak positive correlation in one location, indicates that other local environmental or habitat-related factors may also influence mammal diversity.

These contrasting patterns highlight that the response to temperature is taxon-specific, likely reflecting differences in physiological tolerance, habitat preferences, and ecological requirements among vertebrate groups. Thus, temperature appears to be an important environmental factor associated with vertebrate diversity in sacred groves, although its influence varies across taxonomic groups and may interact with other ecological and habitat-related factors, making causal interpretations difficult without controlled long-term data.

5.4.2 Humidity

The influence of humidity on vertebrates is analyzed. The annual relative humidity in Kerala is 82.5 and 81.5 in 2021and 2022 respectively. The humidity percentage varies region wise in Kerala. The diversity of the diverse species in selected sacred groves differs to each other which is correlated with the local humidity percentage to obtain the effect of humidity.

Effect of humidity on bird diversity

The correlation between the Shannon diversity index of birds and humidity percentage was analyzed for selected sacred groves with comparatively higher bird species richness among the 20 study sites (Table 8). The results showed weak to moderate negative correlations across the sites. Kammadam Kavu exhibited a very weak negative correlation (r = -0.044), indicating almost no relationship between humidity and bird diversity. Karakkayil Kavu (r = -0.25), Nelliarkottam (r = -0.36), Vallikkattu Kavu (r = -0.24), and Iringole Kavu (r = -0.33) showed weak to moderate negative correlations.

Overall, these findings suggest a slight negative association between humidity and bird species diversity in the selected high-diversity sites. However, the relatively low correlation values indicate that humidity may not be a strong factor influencing bird diversity in these sacred groves.

Based on the present analysis, a weak to moderate negative relationship was observed between humidity and bird species diversity across the selected sacred groves. However, as this study was conducted over a relatively short period of two years, these findings should be interpreted with caution. The limited temporal scale may not fully capture long-term climatic variability and its potential influence on bird diversity. Therefore, humidity alone may not be a strong determinant of bird diversity in these sacred groves, and longer-term studies incorporating additional environmental variables are required for more conclusive insights.

Table 8
Correlation Between Bird Shannon Index and Humidity Percentage in Sacred Groves

Kammadam Kavu	Karakkayil kavu	Neliar kottam	Vallikkatu Kavu	Iringole
-0.044	-0.25	-0.36	-0.24	-0.33

Effect of humidity on reptile diversity

he correlation between the Shannon diversity index of reptiles and humidity percentage was analyzed for selected sacred groves with relatively higher reptile species richness among the study sites. The results indicate a consistent negative association between humidity and reptile species diversity across the study sites, suggesting that higher humidity levels are generally associated with lower reptile diversity within the observed range. (Table 9).

Table 9

Correlation Between Reptile Shannon Index and Humidity Percentage in Sacred Groves

Vallikkatu Kavu	Kammadam Kavu	Iringole kavu	Kayyath nagam	Neliar kottam
-0.75	-0.77	-0.26	-0.61	-0.69

Effect of humidity on amphibian diversity

The correlation between the Shannon diversity index of amphibians and humidity percentage was analyzed for selected sacred groves with relatively higher amphibian species richness. The results showed very weak and inconsistent relationships across the sites, with Kammadam Kavu (r = -0.07) and Vallikkattu Kavu (r = -0.025) exhibiting negligible negative correlations, and Mookuthala Kavu showing a weak positive correlation (r = 0.20). (Table 10).

Overall, no clear association between humidity and amphibian diversity was observed in the selected study sites, possibly due to low sample size and absence of nocturnal surveys.

Table 10

Correlation Between Amphibian Shannon Index and Humidity Percentage in Sacred Groves

Kammadam Kavu	Vallikkatu Kavu	Mookuthala Kavu
-0.07	-0.025	0.20

Effect of humidity on mammal diversity

The correlation between the Shannon diversity index of mammals and humidity percentage was analyzed for selected sacred groves (Table 11). The results showed mixed relationships across the study sites. Kammadam Kavu (r = 0.40), Edayilekkad Kavu (r = 0.24), and Vallikkattu Kavu (r = 0.47) exhibited moderate positive correlations, suggesting a tendency for mammal diversity to increase with higher humidity. In contrast, Kayyath Nagam Kavu showed a moderate negative correlation (r = -0.52), indicating a decrease in diversity with increasing humidity. Karakkayi Kavu displayed a negligible negative correlation (r = -0.039), suggesting almost no relationship.

Overall, the findings indicate an inconsistent pattern in the relationship between humidity and mammal diversity across the selected study sites. The variation in both the strength and direction of correlation suggests that humidity alone may not be a determining factor influencing mammal diversity, and that other ecological or habitat-related factors may play a more significant role.

Table 11
Correlation Between Mammal Shannon Index and Humidity Percentage in Sacred Groves

Kammadam Kavu	Karakkayi Kavu	Edayilekkad Kavu	Kayyath Nagam Kavu	Vallikkatu Kavu
0.40	-0.039	0.24	-0.52	0.47

Overall, the study demonstrates that climatic factors, particularly temperature and humidity, exhibit varying and taxon-specific associations with vertebrate diversity across the selected sacred groves. Temperature showed a more consistent pattern, with bird, amphibian, and mammal diversity generally exhibiting negative relationships, indicating a tendency for reduced diversity under higher temperatures. In contrast, reptile diversity showed a positive association with temperature, suggesting increased diversity with rising temperature within the observed range.

Humidity, on the other hand, showed less consistent patterns across vertebrate groups. Bird and reptile diversity generally exhibited negative associations with humidity, whereas mammal diversity showed mixed responses across different sites. Amphibians did not display any clear relationship with humidity, likely due to the limited number of recorded species and constraints in sampling, particularly the absence of nocturnal surveys.

Taken together, these findings suggest that temperature may play a relatively more consistent role than humidity in shaping vertebrate diversity patterns in the selected sacred groves. However, both factors exhibit group-specific responses and are likely to interact with other ecological variables such as habitat structure, resource availability, and anthropogenic disturbances. Therefore, climatic variables alone cannot fully explain the observed patterns of vertebrate diversity in the study area.

Compared to humidity, temperature exhibited a relatively more consistent relationship with vertebrate diversity, suggesting that temperature may play a more prominent role than humidity in shaping species distribution patterns in the selected sacred groves. The contrasting responses observed between reptiles (positive association with temperature) and birds and mammals (negative association) suggest that differences in thermoregulatory strategies may influence their response to temperature. Ectothermic organisms such as reptiles may benefit from higher temperatures within a certain range, whereas endothermic groups such as birds and mammals may show reduced diversity under warmer conditions.

Overall, the relationships observed between environmental variables (such as temperature and humidity) and vertebrate diversity across the sacred groves were generally weak or moderate. While these patterns provide useful insights into potential ecological influences, the study was conducted over a relatively short period of two years, which may not adequately capture long-term environmental variability and species responses. Therefore, the observed correlations should be interpreted as indicative of short-term trends rather than definitive ecological relationships. Long-term monitoring, along with the inclusion of additional habitat and ecological factors, is necessary to better understand the drivers of vertebrate diversity in these sacred groves.

5.5 Seasonal variations

The results indicate that species richness and the number of individuals were generally higher during the post-monsoon season compared to the pre-monsoon and monsoon periods (Figure 30, Figure 32). Similarly, alpha diversity was observed to be relatively higher in the post-monsoon season, particularly in birds, as indicated by the Rényi diversity profiles (Figure 31, figure 33).

In contrast, other vertebrate groups did not exhibit marked seasonal variation in their distribution, suggesting that seasonal effects on diversity are more pronounced in birds than in other taxa.

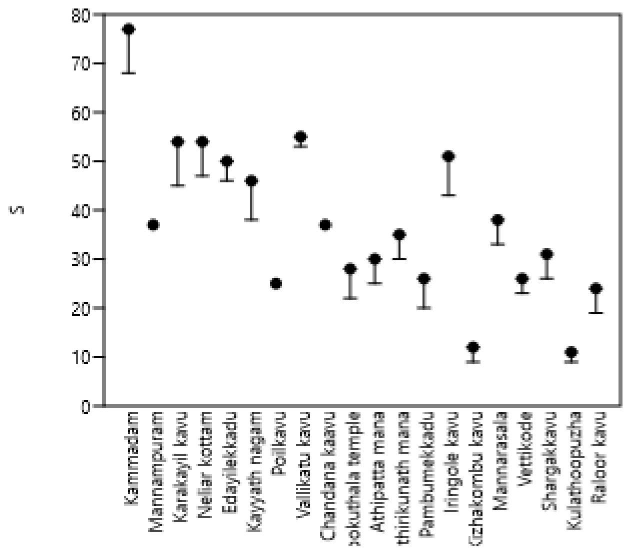


Figure 30. *Species Richness Across Sacred Groves During the Pre-monsoon*

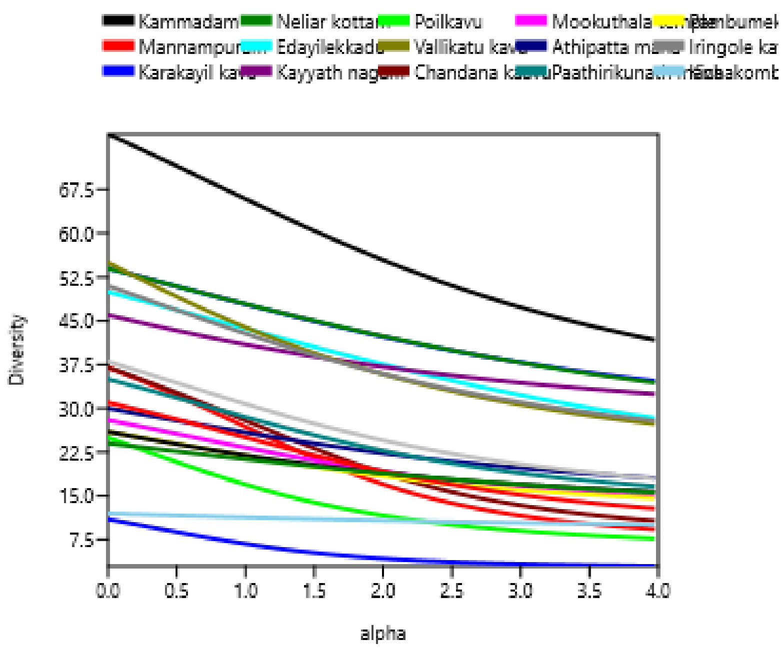


Figure 31. *Alpha Diversity During the Pre-Monsoon across Different Sacred Groves*

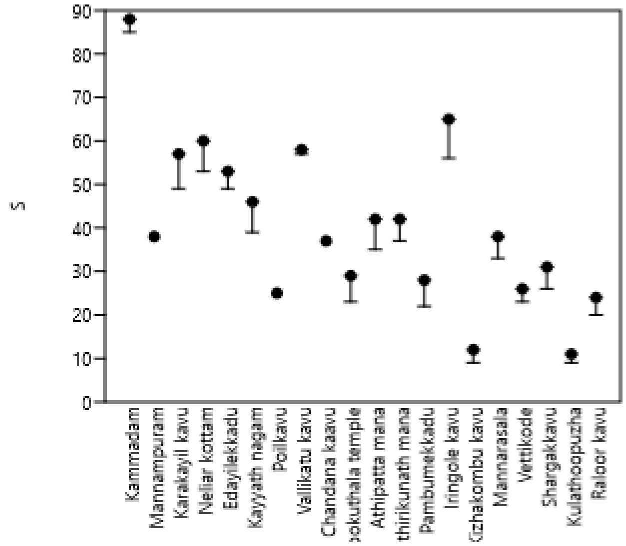


Figure 32. *Species Richness During Post- Monsoon Across Different Sacred Groves*

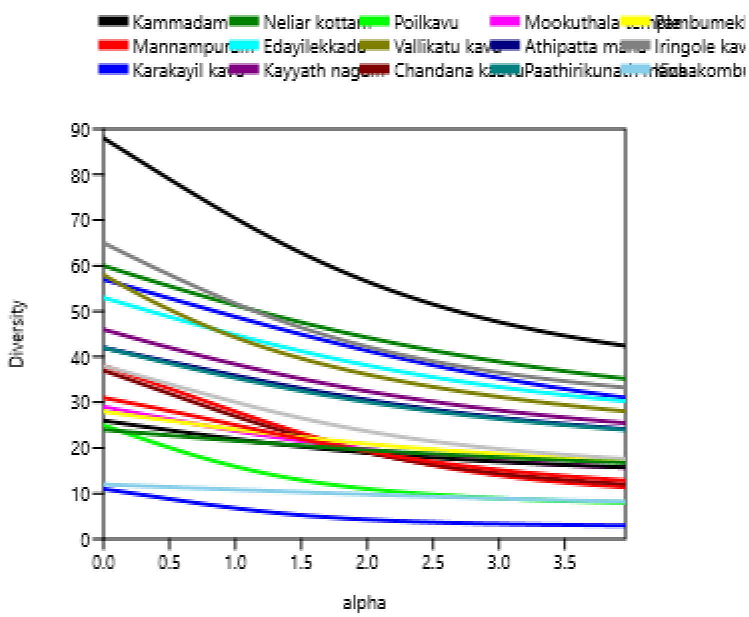


Figure 33. *Alpha Diversity during Post- Monsoon Across Different Sacred Groves*

5.6 Proximity to the reserve forest predicts the vertebrate diversity

Sacred groves function as small repositories of locally endemic flora and fauna. The species composition within these landscapes may be influenced by their proximity to nearby forests, wetlands, and other aquatic ecosystems. This influence is particularly evident in bird species, which may move between forests and adjacent vegetation. Therefore, an attempt was made to assess whether the proximity of nearby forests has any significant effect on species diversity within the selected sacred groves

For that, the precise location of the sacred groves is noted by the GPS device. The aerial distance between the selected sacred groves and the nearby forest is measured using the ArcGIS software (Table 12).

Table 12

Aerial Distance Between Selected Sacred Groves and the Nearest Reserve Forest

Sacred grove	Latitude	Longitude	Nearest reserve Forest	Aerial distance (Kms)	Shannon index
Mannampuram	12.258608	75.132317	Bheemanadi RF	30	3.332
Kammadam	12.311202	75.31602	Bheemanadi RF	11	4.204
Karakkayil temple	12.190213	75.166295	Bheemanadi RF	32	3.871
Edayilekkad	12.13581	75.15641	Bheemanadi RF	37	3.785
Kayyath nagam	12.009116	75.349348	Brahmagiri WLS	36	3.628
Neliar kottam	11.985404	75.363928	Brahmagiri WLS	36	3.924
Vallikattu kavu	11.38834	75.786571	Malabar WLS	26	3.75
Chandana kavu	10.905598	75.998811	Silent Valley NP	49	3.259
Athipatta mana	10.920035	76.340091	Silent Valley NP	18	3.581
Pathirikunath mana	10.84409	76.282728	Silent Valley NP	35	3.566
Pambumekkattu	10.257168	76.265141	Chimmony WLS	31	3.145
Iringole Kavu	10.108107	76.491459	Thattekkad WLS	21	3.927
Saranga Kavu	9.244174	76.631501	Ranni RF	59	3.186
Raloor Kavu	8.749471	76.857985	Agasthyamala RF	35	3.072

Abbreviations: RF-Reserve Forest; WLS- Wild Life Sanctuary; NP-National Park

A regression analysis was performed to examine the relationship between the aerial distance between sacred groves and their Shannon diversity index values. The results are presented in Table 13. The regression analysis shows that the p-value (0.025) is less than 0.05, indicating a statistically significant relationship between the aerial distance from the reserve forest and species diversity. The negative regression coefficient (−0.017) further indicates that species diversity decreases with increasing distance from the reserve forest. The model explains approximately 35.3% of the variation in species diversity ($R^2 = 0.353$).

Table 13

Regression Analysis of Aerial Distance and Shannon index of Sacred Groves

Regression Statistics	
Multiple R	0.59
R Square	0.35
Adjusted R Square	0.29
Standard Error	0.28
Observations	14

ANOVA		*SS*			
	Df	0.547801	*MS*	*F*	*Significance F*
Regression	1	1.004	0.54	6.54	0.025
Residual	12	1.55	0.083		
Total	13				

		Standard Error						
	Coefficients	0.230299	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept X	4.14	0.0066	17.98	4.79	3.640977	4.64	3.64	4.64
Variable 1	-0.017		-2.55	0.025	-0.03155	-0.0025	-0.0315	-0.0025

Proximity to forest appears to be an important factor associated with species diversity in sacred groves. The regression analysis yielded an R^2 value of 0.35, indicating that proximity to forest explains 35% of the observed variation in species diversity among the selected study sites, while the remaining variation is likely influenced by other ecological and habitat-related factors. The observed negative relationship between distance from reserve forest and species diversity suggests that proximity to forested areas appears to be an important factor associated with biodiversity maintenance in sacred groves. Sacred groves located closer to reserve forests may support higher species diversity due to greater habitat connectivity and increased opportunities for species movement and colonization. In contrast, groves situated farther away may experience reduced species exchange, which could be associated with lower diversity. These findings are consistent with the Island Biogeography Theory, which proposes that species richness is influenced by habitat isolation and proximity to source populations.

Among the selected study sites, the largest sacred grove Kammadam sacred grove spans about 24 hectares and is only 11 kilometers from the reserve forest. It has the highest Shannon diversity value. In this site, the study spotted some forest birds such as Malabar whistling thrush, Malabar Trogon and Malabar Grey hornbill. These birds chose Kammadam Kavu as their roosting site.

Breeding activity was also recorded in these sacred groves. A pair of White-bellied Sea Eagles (*Haliaeetus leucogaster*) was observed selecting the Edayilekad sacred grove as a breeding site. Although this species is classified as 'Least Concern' according to the IUCN, it is not commonly observed in Kerala. This indicates that the Edayilekad sacred grove serves as an important refuge for the species, even under adverse conditions. Breeding of the Brahminy Kite (*Haliastur indus*) was also recorded in this grove. Similarly, the Poil Kavu sacred grove, despite having a relatively lower Shannon diversity index compared to other study sites, functions as a breeding habitat for the Brahminy Kite.

The second-largest sacred grove in Kerala, located in the Ernakulam district, exhibited a relatively high Shannon diversity index (3.92) and is situated approximately 21 km from the Thattekad Wildlife Sanctuary. Despite being surrounded by urbanized and human-dominated landscapes, this study site continues to support diverse faunal communities. The relatively high diversity observed may be attributed to both its larger area and its proximity to forested habitats, as indicated by the present study. Additionally, breeding activity of the White-bellied Treepie was recorded in this sacred grove.

One of the study sites, Athipatta Mana sacred grove, with an area of only 0.8 hectares, exhibited a relatively high Shannon diversity index (3.5), exceeding that of several larger sacred groves. This small sacred grove is located in the foothills of the Silent Valley National Park, approximately 18 km from the park. Additionally, it is situated along the banks of the Kunthi River, which originates from Silent Valley National Park. The relatively high species diversity observed in this site may be attributed to its proximity to forested habitats and associated ecosystems, as indicated by the findings of the present study.

The adjacent vegetation and surrounding landscape features of the selected sacred groves also play a significant role in influencing species diversity. Some study sites are located near paddy fields, while others are situated along riverbanks. Additionally, two coastal study sites, namely Edayilekkad and Poil Kavu sacred groves, exhibit distinct variations in species composition. Coastal habitats support the presence of species such as eagles and kites, which are adapted to foraging in shoreline environments. In contrast, sacred groves located near paddy fields are associated with species such as owls and kraits. These observations indicate that species diversity within sacred groves is strongly influenced by the availability of adjacent habitat resources and landscape context.

As stated in the objectives, nocturnal surveys were not conducted in this study due to restricted access to the sacred groves, as imposed by temple authorities based on religious rules and regulations. Consequently, nocturnal species, including certain mammals, reptiles, and amphibians, were not documented. However, indirect evidence such as faecal matter and spines of vertebrates was observed in several study sites, particularly in Kammadam, Iringole, and Vallikkatu sacred groves. These observations suggest the possible presence of nocturnal fauna and highlight the conservation value of sacred groves within human-dominated landscapes.

In conclusion, sacred groves can play an important role in conserving biodiversity, particularly in fragmented and human-dominated landscapes. Species diversity in these groves is influenced by factors such as proximity to reserve forests, area, and surrounding habitat characteristics. The significant decline in diversity with increasing distance highlights the importance of habitat connectivity. Variations in species composition further reflect the influence of adjacent ecosystems. Despite certain limitations, the findings emphasize the ecological and conservation value of sacred groves as important refugia, underscoring the need for their continued protection and sustainable management.

As observed in the study, sacred groves support a wide range of vertebrate species and comprise diverse microhabitats that sustain faunal life. The available microhabitats in all study sites were documented using specific methodologies, which are explained in the following chapter.

6. Microhabitats in the sacred groves

Tree-related microhabitats are distinct, well-delineated structures occurring on living or standing dead trees. They constitute specific and essential substrates for individual species, species communities, or life stages, supporting activities such as development, feeding, sheltering, and breeding (Larrieu et al., 2018). These microhabitats include both tree-originating modifications as well as elements of external origin that are physically associated with the tree (Larrieu et al., 2018). In addition to tree-related microhabitats, ground microhabitats such as burrows and rock crevices are also present within ecosystems. Numerous studies examining the relationship between vertebrates and microhabitats have demonstrated that microhabitat availability strongly influences species diversity (Garda et al., 2013). Microhabitats within ecosystems have also been identified as important indicators of bird and bat communities (Regnery et al., 2013).

The availability of microhabitats enables animals to buffer against climatic extremes (Scheffers et al., 2014). Tree microhabitats can be surveyed throughout the year, although surveys are generally preferred during leafless and snow-free periods (Asbeck et al., 2021).

Larrieu et al. (2018) classified tree microhabitats into 15 types. In the present study, however, microhabitats were surveyed using the quadrat method, resulting in the following categories:

Broadly, microhabitats are divided into two- Arboreal and terrestrial microhabitats

Arboreal microhabitats include the following:

- Cavities- holes or shelters formed in the wood either by cavity builders, decay processes.
- Crown dead wood- dead branches at the top of tree.
- Fungal fruiting bodies- visible parts of saprophytic fungi.

- Epiphytes- wide variety of structures in which the tree is merely the physical support on which the microhabitats are located.
- Hollow branch- rot hole in a large branch resulting in tubular shelter which is often horizontally oriented.
- Dendrotelm- cup shaped concavity that due to its shape, retains water until it dries out by evaporation.
- Bark pocket- space between peeled off bark and sapwood forming a pocket possibly and containing mould.
- Dead branches- located in the canopy.
- Ferns- growing directly on a part of a tree.
- Vertebrate nest- nest built by birds or squirrels.
- Root buttress cavities- natural cavity at the base of tree trunk formed by roots.
- Cracks and scars- line shaped injury through the bark into the sapwood, exposing cambium.
- Micro soil- crown micro soil and bark micro soil, results from epiphytic mosses, lichens or algae. It also depends on debris and litter fall from the crowns and bark.

Terrestrial microhabitats

- Burrows- holes in the ground.
- Termite mounds- mound made by the termites.
- Rock crevices- scars beneath or in the rocks where reptiles especially skinks are inhabiting.
- Fallen leaves-beneath the trees where amphibians mostly inhabit.

The definitions of each microhabitat were adapted from a study in temperate and Mediterranean European forests (Larrieu et al., 2018) and from microhabitat catalogue. Although the classification framework was originally developed for temperate and Mediterranean forests, it was adapted here to suit tropical sacred grove conditions by including locally relevant terrestrial microhabitats such as rock crevices, burrows, termite mounds and fallen leaf litter.

6.1 Arboreal microhabitats as indicators

In forest biodiversity studies, numerous elements are considered indicators of ecological health. Various frameworks classify different components as indicators (Mace & Baillie, 2007), ranging from single keystone species to broader faunal assemblages. Tree microhabitats are also recognized as important indicators of ecosystem health. The presence of microhabitats such as deadwood within a forest enhances its conservation significance, thereby serving as a valuable ecological indicator (Lassauce et al., 2011). Furthermore, tree microhabitats, classified as "temporal and structural indicators," are particularly relevant at the stand scale (Garda et al., 2013).

Both invertebrates and vertebrates inhabit microhabitats. Arthropods are the largest cavity using species in some reports (Larrieu et al., 2018).

Microhabitats recorded from the study sites showed a dominance of cracks and crevices, followed by tree cavities (Figure 34). Among the individual sites, Kammadam Kavu recorded the highest number of microhabitats. In total, 4,893 microhabitats were documented across all selected study sites. However, it is likely that sites such as Kammadam Kavu and Iringole Kavu support a higher number of microhabitats than recorded in the present study.

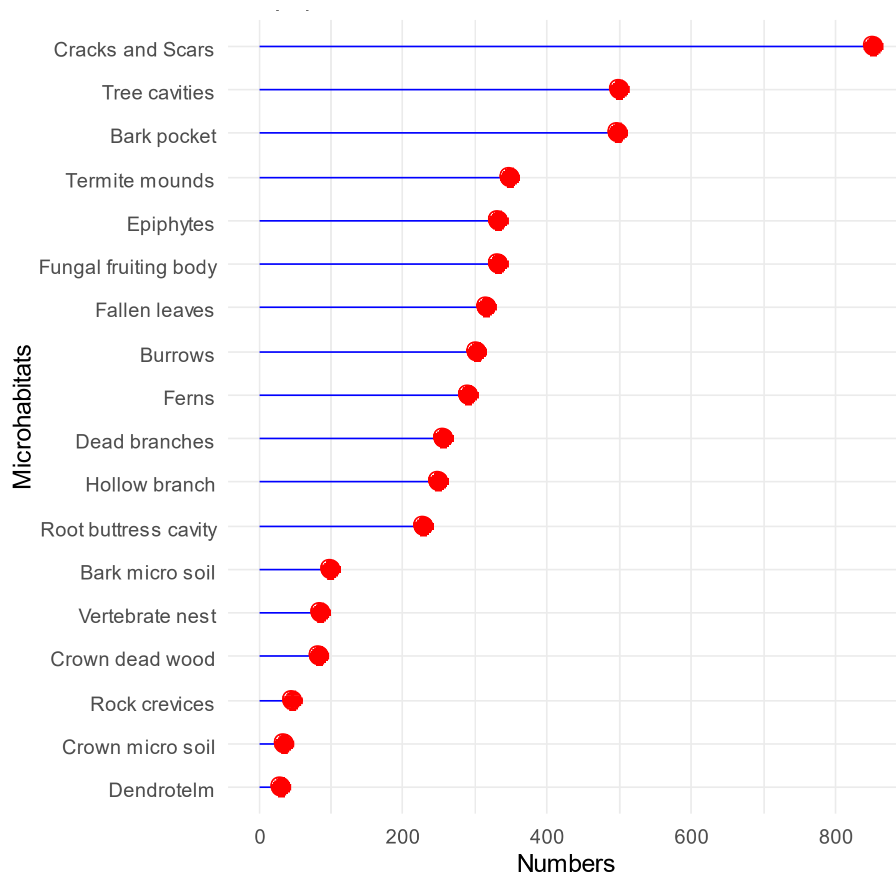


Figure 34. *Lollipop Chart Showing the Total Number of Microhabitats Across All Study Sites*

The number of microhabitat types recorded across the selected sacred groves ranged from 4 to 18 (Figure 35). Most of the study sites exhibited a high number of microhabitats (15–18), indicating substantial habitat heterogeneity. Sacred groves such as Kammadam, Iringole Kavu, and Neliar Kottam recorded the highest number of microhabitat types, reflecting their structural complexity and ecological integrity.

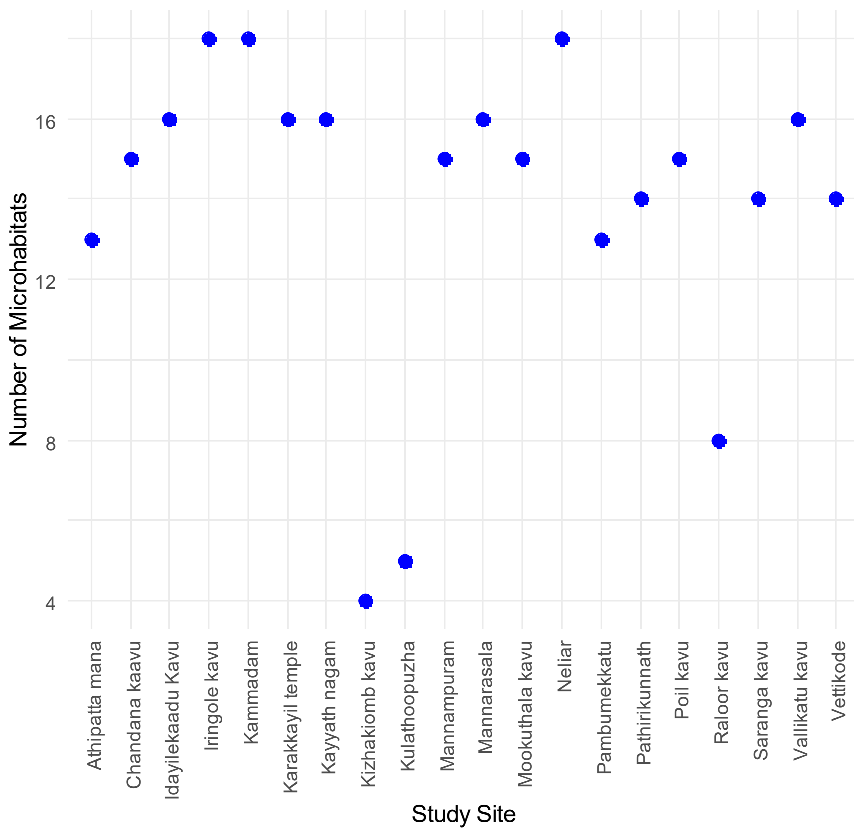


Figure 35. *Dot Plot Showing Individual Composition of Microhabitats Across Study Sites*

In contrast, a few sites, including Kizhakkombu Kavu and Kulathoopuzha, exhibited considerably lower microhabitat diversity, suggesting limited habitat complexity. The remaining sites showed moderate values, indicating intermediate levels of habitat heterogeneity. Overall, the variation in microhabitat distribution among sacred groves suggests that factors such as vegetation structure, management practices, and disturbance levels play a significant role in determining habitat complexity.

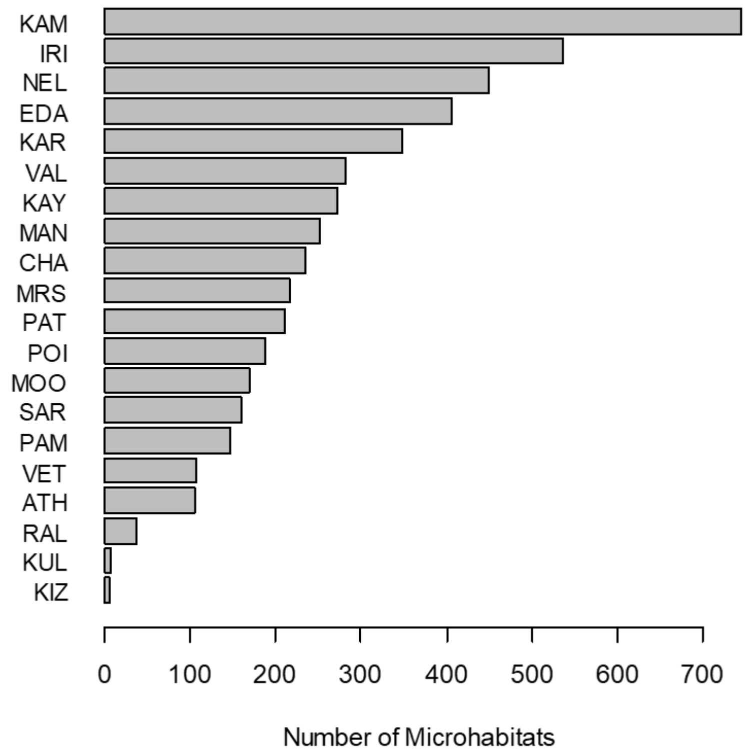


Figure 36. *Microhabitat Composition Across Selected Sacred Grove Study Sites.*

Abbreviations: KAM – Kammadam Kavu; IRI – Iringole Kavu; NEL – Neliar Kottam; EDA – Edayilekkad Kavu; KAR – Karakkayil Kavu; VAL – Vallikkatu Kavu; KAY – Kayyath Nagam; MAN – Mannampurath Temple; CHA – Chandana Kavu; MRS – Mannarasala; PAT – Pathirikkunnath Mana; POI – Poil Kavu; MOO – Mookuthala Kavu; SAR – Saranga Kavu; PAM – Pambumekkatu Mana; VET – Vettikode Temple; ATH – Athipatta Mana; RAL – Raloor Kavu; KUL – Kulathoopuzha Kavu; KIZ – Kizhakkomb Kavu.

The distribution of microhabitats across the selected sacred groves showed considerable variation, with a few sites contributing a disproportionately high number of microhabitats (Figure 36). Kammadam recorded the highest number (745), followed by Iringole Kavu (536) and Neliar (449), indicating high structural complexity and habitat heterogeneity in these groves. In contrast, sites such as Kizhakomb Kavu and Kulathoopuzha exhibited very low microhabitat availability, reflecting limited habitat complexity and smaller spatial extent.

The sampling intensity across the study sites ranged from approximately 23% to 74% of the total area, with variations influenced by grove size, habitat heterogeneity, accessibility, and the distribution of available microhabitats. Smaller groves required fewer plots due to their limited spatial extent, whereas medium and larger groves were sampled more intensively to capture greater habitat complexity and ecological variability. This effort-based sampling approach ensured adequate representation of the range of microhabitats present within each sacred grove, thereby providing a robust basis for assessing biodiversity patterns across all sites.

However, the observed patterns also suggest that microhabitat distribution is not solely dependent on area. While larger groves generally supported more microhabitats, certain medium-sized groves also exhibited high microhabitat richness, indicating the influence of additional factors such as vegetation structure, management practices, and disturbance levels. These findings highlight the ecological importance of structurally complex sacred groves as key habitats that support biodiversity within fragmented landscapes.

The ANOVA results indicate that the regression model is highly statistically significant ($F = 32.03$, $p < 0.001$), demonstrating that microhabitat availability is strongly associated with vertebrate species richness and diversity in the studied sacred groves (Table 14).

Table 14

Regression Analysis of Microhabitats and Shannon Index in Different Sacred Grove

Regression Statistics	
Multiple R	0.80
R Square	0.64
Adjusted R Square	0.62
Standard Error	0.34
Observations	20

ANOVA					
	Df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.88	3.88	32.02	2.28E-05
Residual	18	2.18	0.12		
Total	19	6.07			

The relationship between Shannon diversity and the number of microhabitats indicates a positive association (Figure 37), suggesting that greater microhabitat availability may support higher species diversity.

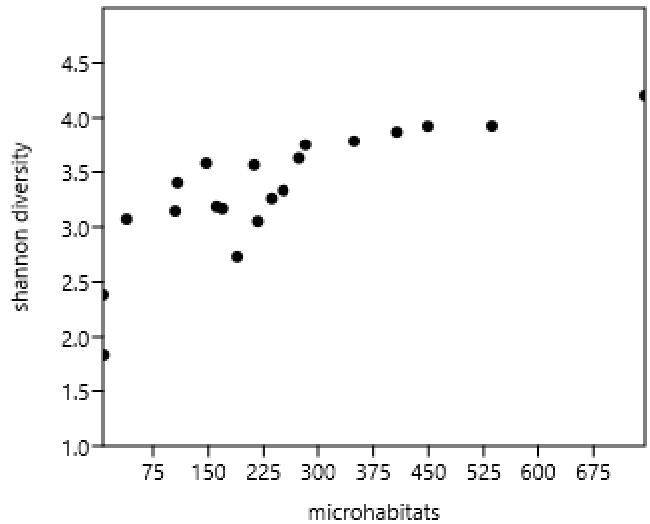


Figure 37. *Relationship Between Microhabitat Abundance and Shannon Diversity Across All Sacred Groves*

6.2 Microhabitat use by vertebrates

A total of 18 microhabitat types were included in the study based on their availability across the selected sacred groves. The objective was not only to document occupied microhabitats but also to assess the overall availability and utilization patterns of different microhabitat types. Therefore, all identified microhabitats were considered, irrespective of their occupancy status.

Including unoccupied microhabitats is essential to understand habitat preference, as it allows comparison between available and utilized microhabitats. This approach provides a more comprehensive assessment of habitat use and helps in identifying selective utilization patterns by vertebrates.

The relationship between total microhabitats and occupied microhabitats shows a positive trend (Figure 38), indicating that sites with a higher number of microhabitats tend to support greater occupancy by vertebrates. However, only a proportion of the available microhabitats is utilized, suggesting selective usage. The variation in occupancy across sites further indicates that factors other than microhabitat availability may influence vertebrate distribution. Amphibians inhabited root buttress cavities and under the fallen leaves whereas *Cnemaspis* found in the cracks, cavities and in cracks. Geckos inhabited beneath the rock crevices in Kammadam Kavu which is frequently observed.

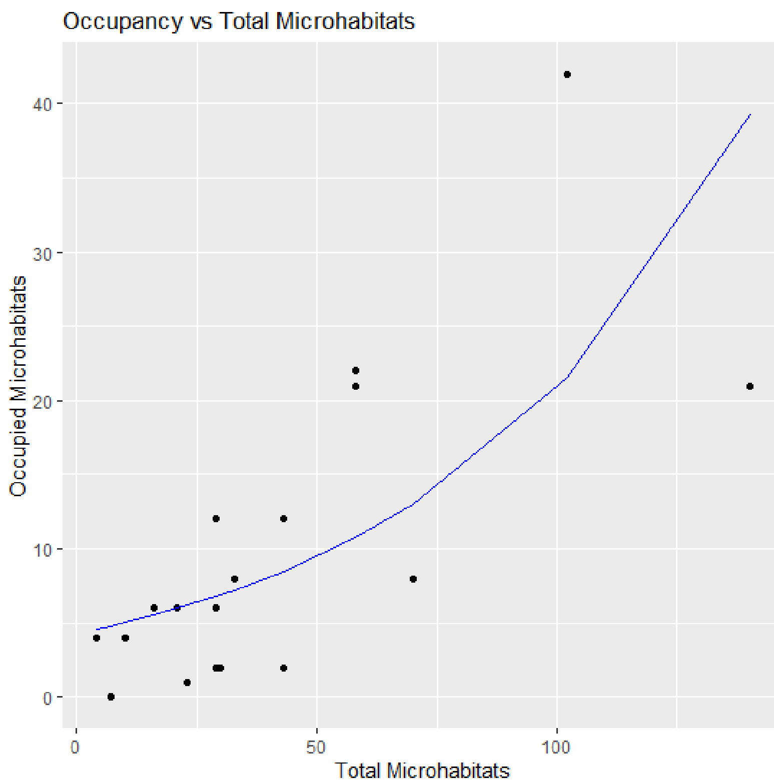


Figure 38. *Comparison of Available and Utilized Microhabitats by Vertebrates in Sacred Groves*

The occupancy of microhabitats by vertebrates was analyzed using a chi-square test in R, which indicated a significant deviation between observed and expected frequencies (Table 15). This suggests that vertebrates do not utilize microhabitats randomly. Standardized residual analysis further revealed that microhabitats such as tree cavities, vertebrate nests, rock crevices, hollow branches, fallen leaves, and root buttress cavities were significantly associated with higher vertebrate occupancy, whereas termite mounds, ferns, epiphytes, fungal fruiting bodies, bark pockets, and crown micro soil were associated with significantly lower occupancy. These findings demonstrate that vertebrates exhibit selective utilization of available microhabitats within the sacred groves.

Table 15

Standardized Residual Analysis of Microhabitats Recorded in Sacred Groves

Microhabitats	Occuppied	Unoccupied
Tree cavities	11.90	-11.90
Crown dead wood	-0.94	0.94
Fungal fruiting body	-3.5	3.58
Epiphytes	-5.01	5.011
Hollow branch	3.5	-3.59
Dendrotelm	0.97	-0.97
Bark pocket	-2.84	2.84
Dead branches	-0.71	0.71
Ferns	-5.90	5.90
Vertebrate nest	7.65	-7.65
Root buttress cavity	2.61	-2.61
Cracks and scars	-0.85	0.85
Crown micro soil	-2.08	2.08
Bark micro soil	-1.56	1.56
Burrows	-0.22	0.22
Termite mounds	-6.34	6.34
Rock crevices	4.00	-4.00
Fallen leaves	2.78	-2.78

A chi-square goodness-of-fit test revealed that vertebrate occupancy of available microhabitats differed significantly from random expectation ($\chi^2 = 294.57$, df = 17, $p < 0.001$). Standardized residual analysis indicated strong positive associations for tree cavities (SR = 11.90), vertebrate nests (SR = 7.65), rock crevices (SR = 4.00), hollow branches (SR = 3.50), root buttress cavities (SR = 2.61), and fallen leaves (SR = 2.78), indicating greater occupancy than expected. In contrast, termite mounds (SR = −6.34), ferns (SR = −5.90), epiphytes (SR = −5.01), and fungal fruiting bodies (SR = −3.58) showed negative associations with vertebrate occupancy, indicating lower utilization than expected. Overall, the results indicate selective, non-random use of available microhabitats by vertebrates, with sheltered and structurally complex microhabitats being preferentially occupied.

The habitat dependency of vertebrates is illustrated using a Venn diagram, which highlights the overlap in microhabitat usage among different groups. Reptiles occupied the greatest number of microhabitats, indicating their broad habitat adaptability (Figure 39). Four microhabitats were shared among all four vertebrate groups, suggesting that certain habitats support multiple taxa. The greatest overlap was observed between reptiles and amphibians, indicating similar habitat preferences. In contrast, birds showed minimal overlap with other groups, reflecting more specific habitat requirements. Mammals exhibit a comparatively limited distribution across microhabitats. These patterns are further supported by the heat map, which reveals similar trends.

According to the Venn diagram, reptiles are associated with the most unique microhabitats among vertebrate groups (3), indicating the broad use of multiple microhabitats.

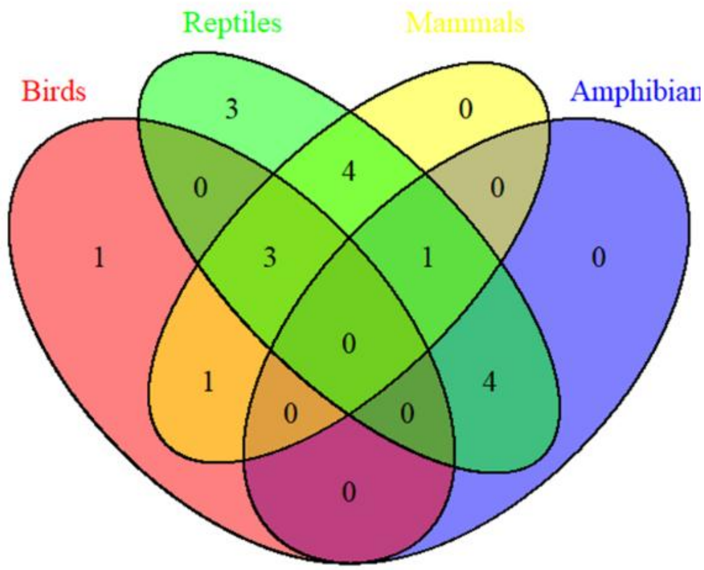


Figure 39. *Venn Diagram Showing Microhabitat Sharing Among Vertebrates in Sacred Groves.*

Reptiles use multiple microhabitats that account for their survival under different climatic conditions. The evolution pattern or phylogenetic deviation of reptiles is more closely related to microhabitats than to climate. (Bars-Closel et al., 2017) reveals the importance of microhabitats for the reptile adaptations. Reptiles inhabit a wide range of microhabitats, demonstrating their adaptability to multiple ecological conditions. Their broad pattern of microhabitat use enables them to occupy arboreal, semi-arboreal, as well as terrestrial environments. Microhabitat availability is a crucial factor that influences species distribution and density within ecosystems. Previous studies have shown that reptiles can occupy numerous microhabitat types, including both habitat specialists and generalists (Jins et al., 2022).

Microhabitat selection varies among reptile species, even within the same ecosystem. Different species tend to utilize distinct microhabitats, reflecting their diverse ecological adaptations and contributing to overall species diversity (Westaway et al., 2024). In the present study, reptiles were observed occupying multiple microhabitats. For instance, *Dussumier's forest skink* was found in fallen leaves, rock crevices, and root buttress cavities, whereas the *Indian monitor lizard* utilized burrows, and *table 21* was observed in tree cavities as well as cracks and scars.

Reptiles also exhibited a relatively broader use of epiphytes as microhabitats compared to other vertebrate groups, indicating their higher ecological flexibility.

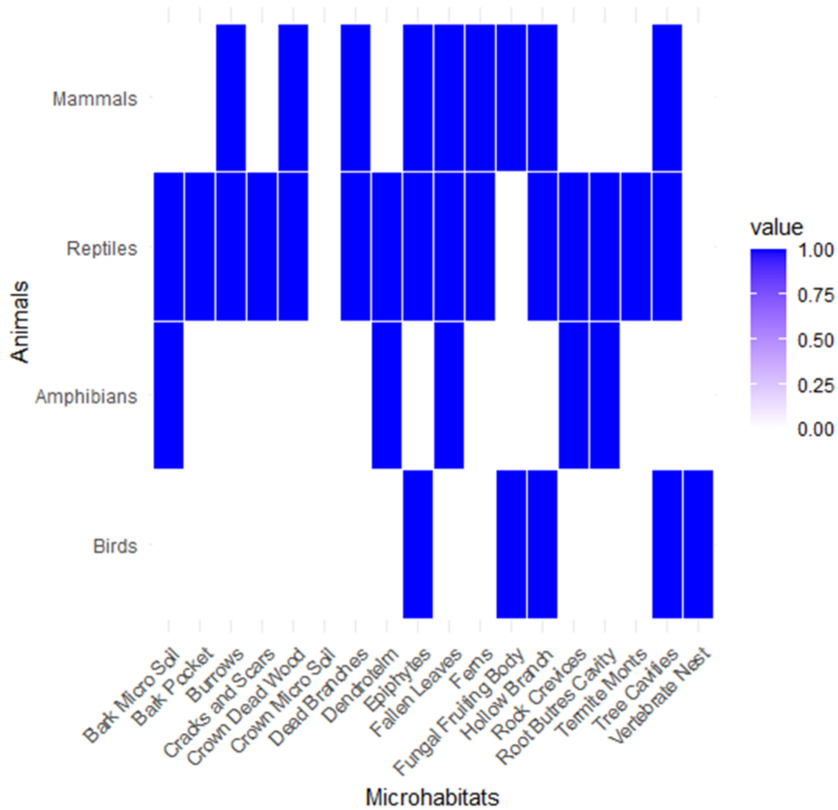


Figure 40. *Heat Map of Microhabitat Use by Vertebrates in Sacred Groves*

The heat map (Figure 40) illustrates the utilization of multiple microhabitats by vertebrates and highlights the broader range of microhabitat use by reptiles compared with other groups. Amphibians are largely restricted to terrestrial microhabitats, whereas birds are primarily associated with arboreal microhabitats. Mammals are distributed across both terrestrial and arboreal microhabitats. In contrast, reptiles exhibit a wider distribution, occupying both terrestrial and arboreal microhabitats extensively.

Among reptiles, species such as Russell's viper and the common rat snake were observed inhabiting burrows, while the vine snake was associated with epiphytes. This demonstrates the broad microhabitat utilization and ecological adaptability of reptiles.

Amphibians also utilize multiple microhabitats; however, in this study, most amphibian species were predominantly distributed in terrestrial microhabitats such as beneath fallen leaves, root buttress cavities, and rock crevices. A considerable overlap in the use of these terrestrial microhabitats was observed among amphibian species. Similar patterns of microhabitat utilization have been reported in other studies (Decena et al., 2023). This restricted yet overlapping use of terrestrial microhabitats by amphibians is consistent with the heat map and Venn diagram results.

The Wayanad bush frog, *Pseudophilautus wynaadensis*, an endemic species of the Western Ghats that is classified as Endangered by the IUCN, was recorded in this study inhabiting fallen leaves and root buttress cavities. This finding highlights the conservation significance of sacred groves as important refugia for threatened amphibian species.

Mammals, particularly the *Funambulus palmarum* and *Pteropus medius*, primarily utilize arboreal microhabitats. The *Pteropus medius* was observed roosting in tree cavities across five sacred groves, whereas the *Funambulus palmarum* was recorded in all selected study sites, indicating its adaptability to a wide range of ecosystems. The *Paradoxurus hermaphroditus* was observed inhabiting crown dead wood in Poil kavu sacred grove.

Birds, in contrast, utilize both arboreal and certain terrestrial microhabitats, with a strong preference for arboreal structures such as tree cavities, vertebrate nests, and cracks and scars. Some bird species occupy natural tree cavities and hollow branches, while others are cavity excavators, actively creating their own nesting sites.

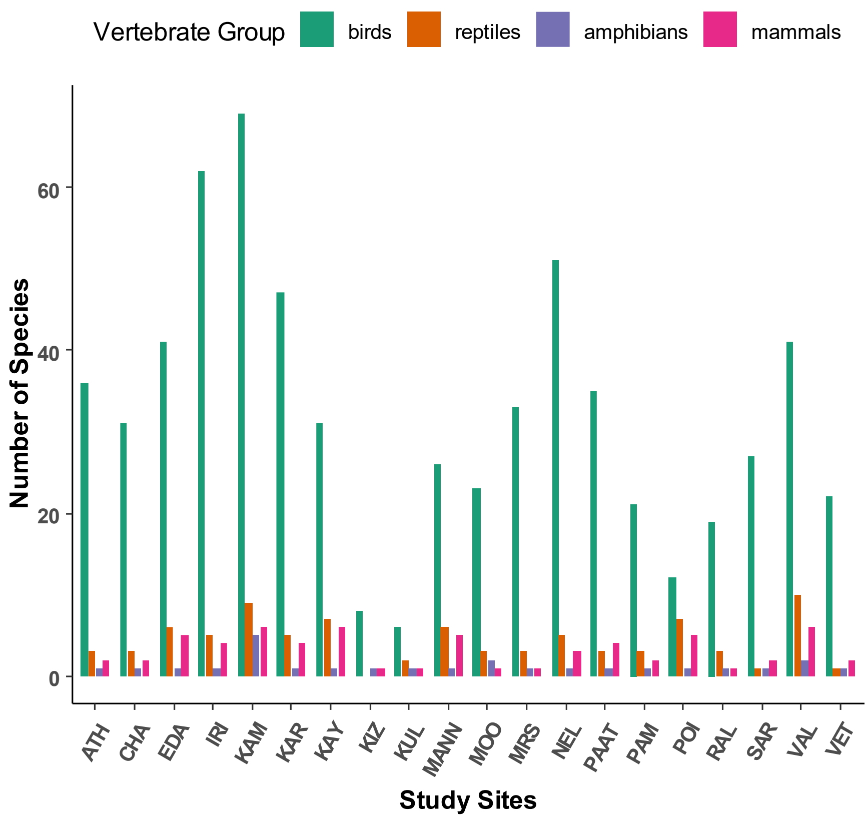
Among the vertebrates, reptiles utilize a wide range of microhabitats, as observed in the present study, and the availability of diverse microhabitats contributes to increased vertebrate species diversity.

The selected sacred groves collectively supported 4,893 recorded microhabitats, indicating substantial structural heterogeneity across the study sites. Cracks and scars, tree cavities, fallen leaf litter, root buttress cavities and rock crevices were among the most ecologically important microhabitat types. Kammadam Kavu, Iringole Kavu and Neliar Kottam recorded relatively high microhabitat availability, reflecting their greater structural complexity. However, because sampling intensity varied among sites, comparisons of microhabitat abundance should be interpreted cautiously or standardized per unit area or per plot.

Based on the observed species richness and analysis, sacred groves that provide more suitable ecosystems for vertebrates have been identified and are discussed in the following chapter.

7. Vertebrate favorable sacred groves and threats

The survey, conducted over two years, identified several sacred groves that serve as favourable habitats for vertebrate species. The vertebrate assemblages recorded across the study sites exhibited considerable species diversity (Figure 41). Birds showed the highest species richness across most sites, particularly in Kammadam (KAM), Iringole (IRI), and Neliar (NEL), whereas reptiles, amphibians, and mammals displayed comparatively lower and variable distributions among the study sites.



Abbreviations: ATH – Athipatta Mana; CHA – Chandana Kavu; EDA – Edayilekkad Kavu; IRI – Iringole Kavu; KAM – Kammadam Kavu; KAR – Karakkayil Kavu; KAY – Kayyath Nagam; KIZ – Kizhakkomb Kavu; KUL – Kulathoopuzha Kavu; MANN – Mannampurath Temple; MOO – Mookuthala Kavu; MRS – Mannarasala;NEL – Neliar Kottam; PAAT – Pathirikkunnath Mana; PAM – Pambumekkatu Mana; POI – Poil Kavu; RAL – Raloor Kavu; SAR – Saranga Kavu; VAL – Vallikkatu Kavu; VET – Vettikode Temple.

Figure 41. *Species Richness of Vertebrate Groups Across Selected Sacred Groves*

7.1 Based on Shannon index

Based on Shannon diversity, the sacred groves that are important for vertebrate diversity are identified using the Z-score method. (Table 16). This score predicts the study sites which are important for the diversity of species.

Table 16
Z Scores of Different Study Sites

Study site	z score
Kammadam	1.5277462
Mannampuram	-0.0145028
Neliar kottam	1.0325286
Kayyath nagam	0.5090129
Edayilekkad	0.7866885
Karakkayil Kavu	0.938791
Vallikkatu Kavu	0.7247863
Poil Kavu	-1.0792206
Chandana Kavu	-0.1436131
Mookuthala Kavu	-0.3045588
Pathirikunnath	0.3993576
Athipatta mana	0.4258871
Pambumekaatu	-0.3452374
Iringole kavu	1.0378345
Kizhakkonmb	-1.691168
Mannarasala	0.1110702
Vettikode	-0.5097204
Saranga kavu	-0.2727234
Kulathoopuzha	-2.6586108
Raloor kavu	-0.4743477

- Z-score > 1

Three sacred groves—Kammadam Sacred Grove, Neliar Kottam Sacred Grove, and Iringole Sacred Grove—recorded z-scores greater than 1, indicating vertebrate richness substantially above the overall mean. These sites represent relatively species-rich habitats within the study area and may be associated with favorable habitat structure, greater vegetation cover, and higher microhabitat availability.

- Z-score between 0 and 1

Seven sacred groves—Vallikkatu Kavu, Kayyath Nagam, Edayilekkad, Karakkayil Kavu, Pathirikunnath, Athipatta Mana, and Mannarasala Sacred Grove—showed above-average vertebrate richness, although not as high as the leading sites. These groves nevertheless contribute meaningfully to overall vertebrate diversity and appear to provide moderately favorable habitat conditions.

- Negative Z-score (< 0)

The remaining ten sacred groves recorded vertebrate richness below the overall mean, indicating comparatively lower species richness relative to other study sites. This pattern may be associated with differences in vegetation cover, habitat heterogeneity, and overall ecosystem complexity among sites.

- Z-score < −2

Kulathoopuzha Sacred Grove recorded a markedly low z-score (−2.66), indicating vertebrate richness substantially below the study mean. Given its small area (0.6 ha), limited vegetation structure, and sparse herbaceous cover, the low richness observed at this site may reflect reduced habitat complexity, highlighting the importance of habitat enrichment and conservation attention.

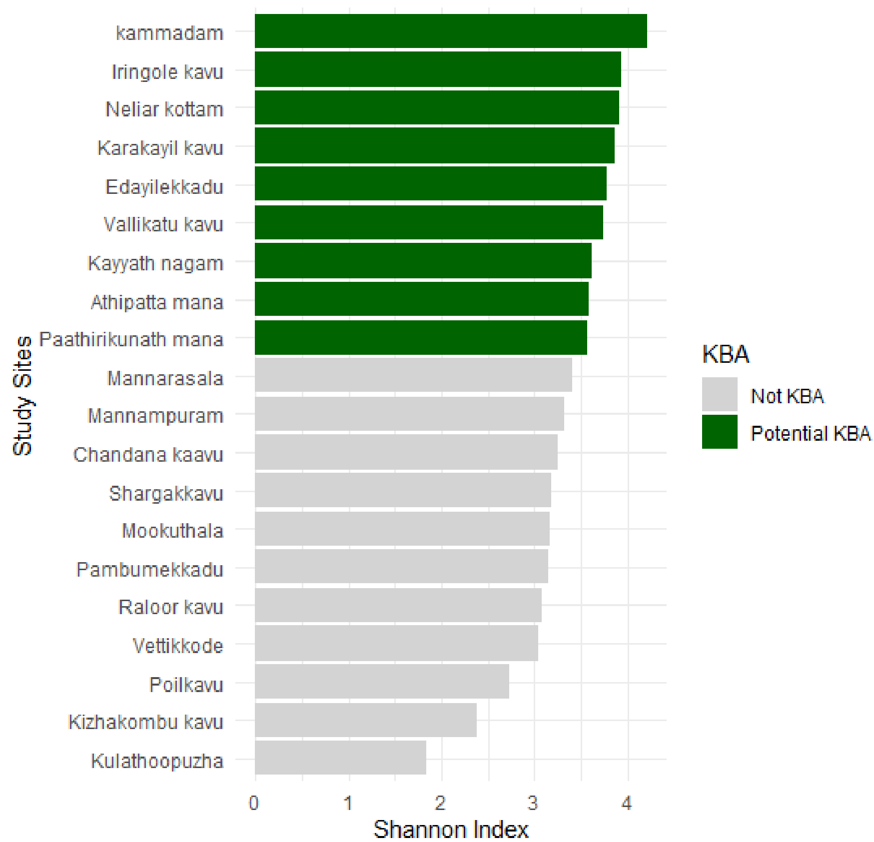


Figure 42. *Potential Key Biodiversity Areas Based on the Shannon Index of Sacred Groves.*

Based on the Shannon diversity index, a graph was plotted to identify sacred groves that can be considered potential key biodiversity areas (Figure 42). The graph indicates that nine sacred groves exhibit relatively high vertebrate diversity. These sites require greater conservation attention to preserve ecosystem integrity. The selected study sites were characterized by abundant vegetation, high microhabitat availability, and suitable niche conditions that support vertebrate distribution.

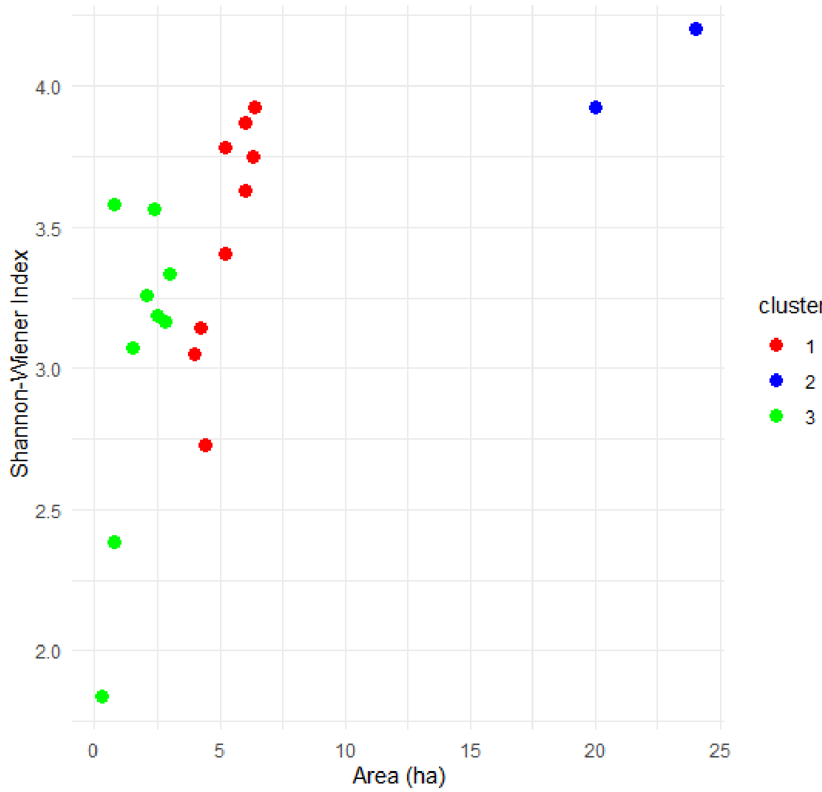


Figure 43. *K-Means Clustering of Study Sites.*

K-means clustering analysis was performed using R software to classify the selected sacred groves into ecologically meaningful groups based on two variables, namely grove area (ha) and Shannon–Wiener diversity index. A cluster number of K = 3 was chosen as it provided a clear separation of the study sites into three distinct groups representing small-sized groves with variable diversity, medium-sized groves with relatively high diversity, and large groves characterized by extensive area and comparatively high diversity. The clustering pattern revealed that medium-sized sacred groves (red cluster) supported relatively high vertebrate diversity, indicating that moderate habitat area combined with favorable ecological conditions can sustain rich vertebrate assemblages. The blue cluster, comprising the two largest sacred groves, exhibited high diversity values and represents ecologically important habitats with greater spatial extent and habitat complexity. The green cluster consisted predominantly of smaller sacred groves showing variable diversity levels, suggesting that habitat patch size alone does not determine vertebrate diversity, and that other factors such as vegetation structure, habitat quality, and microhabitat availability also play important roles in shaping vertebrate assemblages. These findings highlight the ecological significance of sacred groves of varying sizes and emphasize the need for site-specific conservation and management strategies.

Habitat area is one of the important ecological factors associated with species diversity. As observed from the K-means clustering analysis, sacred groves with an area ranging from 3 to 6 hectares generally exhibited relatively high vertebrate diversity, suggesting that medium-sized habitat patches can support stable and diverse vertebrate assemblages under favorable ecological conditions. However, Poil Kavu, despite covering an area of 4.4 hectares, recorded comparatively lower Shannon diversity, indicating that habitat area alone does not determine biodiversity patterns. This suggests that other ecological factors, such as habitat quality, vegetation structure, disturbance level, and microhabitat availability, may strongly influence vertebrate diversity within sacred groves. Nevertheless, Poil Kavu possesses considerable potential for biodiversity enhancement, as it supports diverse microhabitats and vegetation capable of sustaining vertebrate communities. With appropriate conservation measures and site-specific management strategies, the vertebrate diversity of this grove may be further improved.

Poil Kavu remains an important sacred grove in northern Kerala, particularly due to its coastal location. The site has recorded the presence of raptors such as the Brahminy kite and shore-associated species such as the brown fish owl. In addition, species such as the *Paradoxurus hermaphroditus* (inhabiting crown dead wood), vine snake, and monitor lizard were observed in this grove.

Although the current analysis does not classify Poil Kavu as a crucial site for vertebrate diversity, its ecological potential highlights the importance of implementing targeted conservation strategies to enhance and sustain its biodiversity.

The analysis of sacred groves revealed that both area and habitat quality play important roles in determining vertebrate diversity. Larger groves generally support higher biodiversity owing to greater habitat availability; however, this pattern is not consistent across all sites. For instance, Poil Kavu, despite having a moderate area (4.4 hectares), exhibited low Shannon diversity, indicating that area alone does not determine species richness.

In contrast, several smaller groves demonstrated considerable vertebrate diversity. Out of the 20 sacred groves studied, six small patches supported a notable number of species, as reflected by their moderate Shannon index values. Notably, Athipatta Mana, with an area of only 0.6 hectares, was identified as a potential key biodiversity area. Located in the foothills of the Silent Valley National Park, this grove supports diverse vertebrate communities despite its limited size.

These findings suggest that factors such as microhabitat availability, vegetation complexity, and ecological conditions may be more critical than area alone in shaping vertebrate diversity. Therefore, even small sacred groves hold significant conservation value and should be included in biodiversity management and conservation planning.

7.2 People's attitude

Various factors influence species distribution within sacred groves, as observed in the present study. One of the most distinctive features of these ecosystems is the strong socio-cultural relationship between local communities and the sacred groves. This relationship has served as the foundation for their conservation over long historical periods.

In the current scenario, although socio-economic conditions and land-use priorities have changed considerably, these groves continue to be protected through religious beliefs and traditional practices. The present study highlights that management practices adopted by local custodians contribute to maintaining these patches in a relatively undisturbed condition, although additional scientific management strategies may further enhance their conservation.

Religious rules and practices are more strictly followed in the sacred groves of northern Kerala than in the southern region, contributing to their better preservation. Many northern groves remain largely undisturbed, as human interference is minimal, allowing for the conservation of endemic species in these areas.

The occurrence of the endangered Wayanad Bush frog (*Pseudophilautus wynaadensis)* in Kammadam Kavu and the documented roosting of the *white-bellied sea eagle* in Idayilekadu Kavu (recorded in 2003) further support the observations of the present study, highlighting the ecological and conservation significance of these groves.

Local communities in this region consider these patches as sacred and refrain from engaging in activities that may harm them. This study also assessed the attitudes of people residing near the groves and found a generally positive response toward their conservation. The correlation between community attitude and Shannon diversity showed a positive relationship, indicating the influence of human perception on conservation of biodiversity.

Based on these observations, the study concludes that, when comparing the religious practices across the three regions of Kerala, sacred groves in the northern region remain relatively more undisturbed than those in central and southern Kerala.

7.3 Vegetation cover

The documentation of flora in the selected sacred groves was carried out to understand the structural components contributing to microhabitat formation rather than to provide a comprehensive floristic inventory. As the primary focus of the present study is on vertebrate distribution in relation to microhabitats, the recording of plant species was conducted in a representative manner using the quadrat method.

The listed species reflect the dominant and commonly occurring vegetation within the study sites, which play a significant role in shaping available microhabitats. However, a detailed and exhaustive survey of flora across all sacred groves was beyond the scope of this study.

Despite this, the documented vegetation provides valuable insights into habitat complexity and its influence on vertebrate diversity**.** This approach ensures that the vegetation data is contextually relevant to the study objectives while acknowledging its limitations in terms of taxonomic completeness.

The vegetation of the selected sacred groves can be classified into three types: evergreen, semi-evergreen, and moist deciduous. The vegetation cover of Iringole sacred grove comprises a climber, *Rhaphidophora pertusa*, which is common in semi evergreen forest, *Naringi crenulata*, a small evergreen tree, *Macaranga peltata,* an evergreen tree in Kammadam sacred grove. Apart from this, presence of species such as *Tectona grandis, Ficus religiosa, Plumeria rubra, Hopea ponga* resembles a semi evergreen and deciduous type forest. The tree strata of trees, shrubs and herbs, climbers and stragglers, epiphytes and parasites are the floristic elements of a grove. This stratification is prominent in Kammadam sacred grove too. The presence of myristica swamps in

Kammadam Kavu and Vallikkatu Kavu were also observed. The concept of '*nakshathravana*' is adopted in the Mookuthala sacred grove in the Malappuram district where they promote planting species on their birthdays, a custom followed as a part of religious beliefs. This procedure further reveals the socio-ecological relationship between people and sacred groves.

The largest sacred grove, Kammadam Kavu, exhibited a high percentage of canopy cover, similar to Iringole Kavu. The vegetation of sacred groves in Kerala has been well documented in previous studies; however, the primary objective of the present study is not focused on vegetation composition. Instead, this study emphasizes how microhabitats associated with vegetation influence vertebrate distribution.

The types of flora present in the selected study sites were recorded using the quadrat method, and their structural characteristics were also documented. (Table 17). These vegetation features contribute to the formation of diverse microhabitats that support vertebrate communities.

Table 17
Representative Floral Elements Recorded from Selected Sacred Groves

Common Name	Scientific Name	Family	Plant group
Parasol leaf tree	*Macaranga peltata*	Euphorbiaceae	Angiosperm
Scholar tree	*Alstonia scholaris*	Apocynaceae	Angiosperm
Wild Turmeric	*Curcuma oligantha*	Zingiberaceae	Herb
Ashoka tree	*Saraca asoca*	Fabaceae	Angiosperm
Comb Rungia	*Rungia pectinata*	Acanthaceae	Herb
South-Indian Vatica	*Vatica chinensis*	Dipterocarpaceae	Angiosperm
Indian prickly ash	*Zanthoxylum rhetsa*	Rutaceae	Angiosperm
Wild jack	*Artocarpus hirsutus*	Moraceae	Angiosperm
Wild cinnamon	*Cinnamomum malabatrum*	Lauraceae	Angiosperm
Rose Sandalwood	*Olea dioica*	Oleaceae	Angiosperm
Wild mussaenda	*Mussaenda frondosa*	Rubiaceae	Shrub
Rough bindweed	*Smilax aspera*	Smilacaceae	Shrub
Hydnocarpus Oil Tree	*Hydnocarpus pentandra*	Achariaceae	Angiosperm

Common Name	Scientific Name	Family	Plant group
Black Varnish Tree	*Holigarna arnottiana*	Anacardiaceae	Angiosperm
Banyan tree	*Ficus benghalensis*	Moraceae	Angiosperm
Indian Pavetta	*Pavetta indica*	Rubiaceae	Angiosperm
Indian mulberry	*Morinda citrifolia*	Rubiaceae	Angiosperm
Indian beech	*Pongamia pinnata*	Fabaceae	Angiosperm
Sticky Desmodium	*Pseudarthria viscida*	Fabaceae	Small shrub
Nux vomica	*Strychnos nux-vomica*	Loganiaceae	Angiosperm
Neem	*Azadirachta indica*	Meliaceae	Angiosperm
Indian thorny bamboo	*Bambusa bambos*	Poaceae	Angiosperm
Indian laburnum	*Cassia fistula*	Fabaceae	Angiosperm
Royal Poinciana	*Delonix regia*	Fabaceae	Angiosperm
Gin Berry	*Glycosmis pentaphylla*	Rutaceae	Angiosperm
Shiral	*Grewia nervosa*	Malvaceae	Shrub
Indian Mulberry	*Morinda pubescens*	Rubiaceae	Shrub

Common Name	Scientific Name	Family	Plant group
Ceylon Oak	*Schleichera oleosa*	Sapindaceae	Angiosperm
Quaker button	*Strychnos nux-vomica*	Loganiaceae	Angiosperm
Kindal Tree	*Terminalia paniculata*	Combretaceae	Angiosperm
Creat	*Andrographis paniculata*	Acanthaceae	Herb
Willow-leaved Justicia	*Justicia gendarussa*	Acanthaceae	Shrub
Teak	*Tectona grandis*	Lamiaceae	Angiosperm
Indian long pepper	*Piper longum*	Piperaceae	Shrub
Malabar nutmeg	*Myristica malabarica*	Myristicaceae	Angiosperm
Large-flowered bay tree	*Persea macrantha*	Lauraceae	Angiosperm
Sandalwood	*Santalum album*	Santalaceae	Angiosperm
Indian Cherry	*Cordia wallichii*	Boraginaceae	Angiosperm
Kerala heliotrope	*Heliotropium keralense*	Boraginaceae	Herb
Obscure morning glory	*Ipomoea obscura*	Convolvulaceae	Angiosperm
Turkey berry	*Solanum torvum*	Solanaceae	Angiosperm

Common Name	Scientific Name	Family	Plant group
Wishbone Flower	*Torenia bicolor*	Linderniaceae	Herb
Indian pennywort	*Bacopa monnieri*	Plantaginaceae	Herb
Jungle geranium	*Ixora coccinea*	Rubiaceae	Shrub
Chinese Salacia	*Salacia reticulata*	Celastraceae	Shrub
Chunna Berry	*Ziziphus rugosa*	Rhamnaceae	Shrub
Bandicoot Berry	*Leea indica*	Vitaceae	Shrub
Black Oil Plant	*Celastrus paniculatus*	Celastraceae	Shrub
Kerala Kunstleria	*Kunstleria keralensis*	Fabaceae	Shrub
Travancore Cane	*Calamus travancoricus*	Arecaceae	Palm
Candy Corn plant	*Moullava spicata*	Fabaceae	Shrub
Indian Sarsaparilla	*Hemidesmus indicus*	Apocynaceae	Shrub
Golden Bulbophyllum	*Bulbophyllum aureum*	Orchidaceae	Herb
Derris	*Derris brevipes*	Fabaceae	Shrub
Ixora	*Ixora johnsonii*	Rubiaceae	Shrub

Common Name	Scientific Name	Family	Plant group
Indian Copal Tree	*Vateria indica*	Dipterocarpaceae	Angiosperm
Travancore Top-Fruit Tree	*Nothopegia travancorica*	Anacardiaceae	Angiosperm
Fragrant Cherry Nutmeg	*Polyalthia fragrans*	Annonaceae	Angiosperm

The evergreen vegetation cover of Kammadam Kavu, Iringole Kavu and Neliar Kottam sacred grove provide more terrestrial microhabitats for the vertebrates. The Mannarasala sacred grove has discontinuous vegetation cover where in between the patches, some buildings are made for temple purposes which directly affected the avian assemblagesbird as this patch witnessed nesting of Red Whiskered bulbul, coppersmith barbet and other cavity users. Human habitation, along with disturbance to the natural habitat within the grove, may reduce habitat suitability for cavity-nesting birds, whereas Iringole Kavu, that resembles an evergreen type of forest which is undisturbed and has continuous vegetation with high canopy cover supports avian assemblages.

The variation observed among sacred groves in terms of vegetation structure and management practices appears to have a significant influence on vertebrate diversity. The Pambumekkatu sacred grove exemplifies a highly disturbed system, where vegetation clearance has been carried out to accommodate temple-related activities and management preferences. Although the grove spans approximately 4.4 hectares, only about 2.5 hectares retain vegetation cover, with the remaining area being altered for anthropogenic use. Such modifications have likely contributed to the reduced vertebrate diversity observed in this site. Despite restrictions on public entry, the persistence of anthropogenic disturbances indicates that protection measures alone may not be sufficient to maintain ecological integrity.

A comparison with Poil Kavu, a sacred grove of similar spatial extent, further highlights the importance of vegetation cover. With nearly 3.7 hectares under vegetation and a moderate canopy structure, Poil Kavu supports relatively better habitat conditions. However, ongoing anthropogenic disturbances in this grove suggest a gradual decline in vegetation quality, which may have long-term implications for faunal diversity if not effectively managed.

The condition of smaller sacred groves provides additional insight into the relationship between habitat structure and species diversity. Groves such as Kulathoopuzha and Kizhakomb, each occupying less than one hectare, are dominated by shrubs and herbaceous vegetation, resulting in limited availability of terrestrial microhabitats. This structural limitation is reflected in their comparatively lower vertebrate diversity. In contrast, Athipatta Mana sacred grove, despite its small size (0.8 hectares), supports a relatively higher number of species. This can be attributed to its moderate canopy cover, which enhances habitat complexity and resource availability.

Overall, these observations emphasize that vegetation cover, particularly canopy structure and habitat complexity, plays a crucial role in sustaining vertebrate diversity in sacred groves. The findings also indicate that anthropogenic disturbances, even at low or moderate levels, can significantly alter habitat quality and subsequently affect faunal distribution. Therefore, effective conservation of sacred groves should prioritize the maintenance of vegetation integrity alongside cultural and religious practices.

The patterns observed in vertebrate diversity across sacred groves can also be interpreted in the context of the Island Biogeography Theory, which explains species distribution based on habitat size and isolation. According to this theory, larger habitat patches tend to support higher species richness due to increased habitat heterogeneity and resource availability, while smaller and more isolated patches support fewer species due to limited resources and higher local extinction rates.

In the present study, larger sacred groves such as Pambumekkatu and Poil Kavu generally exhibit greater potential to support higher species diversity compared to smaller groves. However, the findings indicate that habitat quality, particularly vegetation cover and canopy structure, plays an equally important role alongside area. For instance, despite its relatively large size, Pambumekkatu sacred grove shows reduced vertebrate diversity due to habitat modification and anthropogenic disturbances. In contrast, Athipatta Mana sacred grove, although small in size, supports a comparatively higher number of species, likely due to better vegetation structure and moderate canopy cover.

This suggests that while the predictions of the Island Biogeography Theory are partially supported, they are modified by local habitat conditions. Disturbances and vegetation degradation can reduce the effective habitat area, thereby lowering species richness even in larger patches. Conversely, structurally complex habitats in smaller groves can enhance resource availability and microhabitat diversity, support more species than expect based solely on area.

Therefore, the results of this study highlight that both patch size and habitat quality must be considered together when evaluating species diversity in sacred groves. The applicability of the Island Biogeography Theory in this context is evident, but it is influenced by anthropogenic factors and vegetation structure, which ultimately determine the ecological value of these habitat patches.

7.4 Threats recorded in sacred groves

The study also focused on the threats affecting the conservation of these ecosystems. The main threats found in this study are the following

7.4.1 Encroachment

One of the major threats affecting these sacred groves is the expansion of adjacent agricultural land, which reduces the effective area of the groves and disrupts ecosystem balance. Such encroachment is evident in the Kammadam sacred grove of northern Kerala, where surrounding rubber plantations have progressively extended into the grove. The absence of a protective boundary, such as a compound wall, has facilitated this intrusion, resulting in significant disturbance to the vegetation. Although Kammadam is considered one of the largest sacred groves in Kerala, a substantial portion of its area has been altered due to the spread of rubber plantations.

A similar trend is observed in Iringole Kavu, where, despite the presence of relatively high canopy cover within the core area, the peripheral regions are increasingly degraded and dominated by plantation activities. The lack of continuous boundary protection in certain sections has further contributed to this disturbance. Comparable patterns of encroachment are also recorded in Raloor Kavu in southern Kerala and Kayyath Nagam sacred grove in northern

Kerala, both of which are experiencing similar pressures from adjacent land-use expansion (Table 18).

Table 18
Area of Encroachment in Selected Sacred Groves

Sacred grove	District	Area encroached(ha)	Adjacent habitat
Kammadam sacred grove	Kasaragod	4.04	Rubber plantations
Mannampurath sacred grove	Kasaragod	0.016	Homesteads
Neliar kottam	Kannur	0.016	Homesteads and plantations
Vallikkatu Kavu	Kozhikode	0.80	Hill
Iringole Kavu	Ernakulam	1.21	Wetlands
Kizhakomb Kavu	Ernakulam	0.0081	Wetlands
Raloor kavu	Thiruvananthapuram	0.81	Homesteads and plantations

7.4.2 Change in the landscape

A major and increasingly significant threat to sacred groves is the conversion of natural land into built structures by the landowners, resulting in substantial loss of vegetation. This trend is frequently observed in Pambumekkatu Mana sacred grove, Pathirikunnath Mana, Raloor Kavu sacred grove, and Mamanikunnu sacred grove in Kannur, where vegetation is intentionally cleared to facilitate the construction of artificial structures for worship. Traditionally, sacred groves represent sites of nature worship, often centered around deities associated with natural elements such as trees. However, the transformation of idols from beneath natural vegetation into man-made temple structures reflects a shift away from this ecological and cultural tradition.

Such practices contribute to a redefinition of the concept of sacred groves, reducing their ecological functionality and habitat value. One notable practice observed during the study is the relocation of idols from sacred patches by temple authorities, as documented in Pambumekkatu Mana and Pathirikunnath Mana. These idols are relocated within temple premises, allowing landowners to modify the original grove landscape according to their preferences.

Within the temple complex of Pambumekkatu Mana, more than 500 idols were observed, many of which have been relocated from different parts of Kerala. Each of these idols is believed to represent a sacred grove that once existed in its natural form. This process indicates a large-scale transformation, where numerous sacred groves have lost their ecological identity and have been converted into built environments for religious purposes.

Many of the remaining groves, particularly in southern Kerala, have undergone significant alteration, losing their pristine ecological character and being transformed into temple-dominated landscapes with reduced vegetation cover.

7.4.3 Anthropogenic disturbances

Although sacred groves are traditionally protected through religious beliefs and community-based conservation practices, several patches in Kerala are increasingly subjected to anthropogenic disturbances. Activities such as frequent human intrusion, disposal of waste within the groves, and the construction of buildings following vegetation clearance represent some of the major threats affecting these ecosystems. These disturbances not only alter the structural integrity of the groves but also negatively impact their ecological functions and biodiversity. The following sacred groves were identified as highly disturbed in the present study:

- Poil Kavu, Kozhikode

The studied patch, with an area of approximately 4.4 hectares, comprises vegetation that is generally suitable for supporting vertebrate species. However, field observations indicate significant anthropogenic pressures, including human encroachment and the disposal of waste within the grove. Unregulated and frequent human entry into the sacred patch has likely contributed to disturbances in vertebrate distribution. Despite possessing adequate vegetation cover that could potentially support higher biodiversity, the grove exhibited a relatively low Shannon diversity index in the present study. This suggests that habitat quality may be compromised by ongoing disturbances. Furthermore, the partially damaged compound wall appears insufficient to restrict human access, thereby exacerbating the level of disturbance within the grove.

- Mannampuram temple sacred grove

Human encroachment and frequent entry of local residents into this grove are notably high. The presence of a public pathway passing through the grove facilitates regular human movement, as the sacred patch is situated within an urban setting. Such continuous disturbance is likely to influence habitat conditions and species distribution. Nevertheless, the grove retains relatively well-developed cover and a diversity of microhabitats, indicating its potential to support a considerable number of vertebrate species despite ongoing anthropogenic pressures.

- Pathirikunath temple sacred grove

  Vegetation clearing is a major problem in this grove. The temple authorities remove floral species for the expansion of temple activities, thereby reducing available habitat for vertebrates. Frequent human entry into the patches further alters habitat conditions, potentially affecting the habitat requirements of vertebrate species.

7.5 Strategies to promote conservation of sacred groves

7.5.1 Construction and maintenance of a compound wall

A considerable number of the sacred groves examined in this study lack well-defined boundary structures, such as compound walls, which poses a challenge for effective conservation. The absence of such protective barriers facilitates encroachment from adjacent land uses, leading to a gradual reduction in vegetation cover and habitat area across several study sites. This encroachment ultimately contributes to habitat degradation and loss of biodiversity. The establishment and maintenance of properly constructed boundary walls could play a significant role in preserving these patches in their natural state by limiting external disturbances. However, inadequate financial resources among managing authorities remain a major constraint in implementing such measures. Therefore, the formulation and promotion of supportive government policies and conservation initiatives are essential to ensure the long-term protection and ecological integrity of sacred groves.

7.5.2 Prevention of Construction within Sacred Groves

The present study identified the replacement of natural vegetation with built structures for temple-related activities as a significant threat to sacred grove ecosystems. Such transformations lead to habitat loss and a decline in biodiversity, particularly affecting vertebrate species dependent on vegetation cover and microhabitats. Preventing construction activities within sacred groves and prioritizing the conservation of existing vegetation are essential to maintain ecological balance. Conservation strategies should emphasize the preservation of natural landscape features over infrastructural development to sustain the ecological integrity of these patches.

7.5.3 Regulation of Anthropogenic Activities

Anthropogenic disturbances, including waste disposal, collection of fallen wood, and frequent human entry, were observed in several sacred groves. These activities disrupt habitat structure and negatively influence faunal distribution. Limiting unnecessary human access and regulating resource extraction within the groves are crucial steps toward maintaining biodiversity. Implementing controlled access measures and raising awareness among local communities can help ensure that these ecosystems remain relatively undisturbed.

7.5.4 Establishment of Designated Pathways

In several sacred groves, the absence of clearly defined pathways has resulted in unregulated human movement across the vegetation, leading to habitat disturbance. The construction of designated pathways along the boundaries of the groves can effectively minimize direct human interference within core vegetated areas. Such measures would help protect sensitive microhabitats while still allowing regulated access for cultural and religious purposes, thereby supporting both conservation and traditional practices.

7.5.5 Prevention of Exotic Species Establishment

The study recorded the presence of invasive plant species such as *Lantana camara* and *Chromolaena odorata* in several sacred groves, including Raloor Kavu, Kulathoopuzha, and Poil Kavu. These species, although often unintentionally introduced, can significantly alter biodiversity by outcompeting endemic flora. Sacred groves are known to function as reservoirs of endemic and medicinal plant species, and the establishment of invasive species poses a serious threat to this ecological role. Preventing the introduction and spread of exotic species, along with promoting awareness among grove custodians regarding native vegetation, is essential for maintaining ecosystem health and biodiversity conservation.

7.5.6 Defining Minimum Ecological Criteria for Sacred Groves

The study highlights the absence of clear ecological criteria for defining sacred groves, particularly with respect to minimum area and vegetation structure. In several instances, patches with minimal vegetation or even a single tree associated with an idol are designated as sacred groves, despite lacking the ecological characteristics necessary to support biodiversity. Observations from sites such as Kulathoopuzha, Raloor Kavu, Kizhakomb Kavu, Mannarasala, and Pambumekkatu Mana indicate that not all officially recognized groves provide suitable habitat for vertebrate species. In contrast, smaller groves like Athipatta Mana (0.6 ha) demonstrate high ecological value due to favorable vegetation structure, landscape configuration, and proximity to larger forested areas such as Silent Valley National Park. These findings suggest that criteria for classifying sacred groves should be revised to include factors such as continuous vegetation cover, habitat quality, and ecological functionality, rather than solely cultural designation.

7.5.7 Comprehensive Documentation of Sacred Groves

A systematic and region-wise documentation of sacred groves, including their spatial extent, vegetation characteristics, and disturbance levels, is currently lacking. The absence of such data limits effective conservation planning and management. Developing a comprehensive inventory of sacred groves at the district or state level would facilitate better monitoring, policy formulation, and prioritization of conservation efforts. Incorporating ecological parameters into documentation frameworks would further enhance the protection and sustainable management of these culturally and ecologically significant landscapes.

Sacred groves are comparable to fragmented forest patches with respect to their limited area and isolated distribution. Recent studies have emphasized the conservation importance of small forest fragments (Svensson et al., 2025; Hurtado et al., 2025). The findings of the present study further support this view, demonstrating that small sacred groves contribute significantly to biodiversity conservation despite their restricted size. Landscape ecology recognizes small habitat patches as integral components of heterogeneous landscapes, contributing to biodiversity conservation through their interactions with the surrounding matrix and their role in maintaining landscape connectivity. Recent studies have demonstrated that small forest patches collectively enhance landscape-scale biodiversity and should be incorporated into conservation planning rather than being overlooked because of their limited size (Perrin et al., 2025).

This two-year study documented the presence of vertebrates in the selected sacred groves and analyzed the factors influencing their diversity. Based on the findings, the study puts forward a set of recommendations, which are discussed in the following chapter.

8. Conclusion and recommendations

The study was conceptualized and completed over five years, with two years of systematic field sampling, covering twenty sacred groves distributed across three geographical zones. While the study provides valuable insights into vertebrate diversity, certain methodological and logistical constraints must be acknowledged.

The selection of study sites was initially based on grove area and geographical representation. However, access to some ecologically significant sites was restricted due to cultural and religious considerations. For instance, Theyyotu Kavu sacred grove and Aravanchal Kavu sacred grove could not be included in the study as permission was denied by the respective authorities. Such exclusions may have limited the representation of larger and potentially more diverse sacred groves in the dataset.

In addition, restrictions imposed by temple authorities in several sites prevented the conduct of nocturnal surveys. This limitation may have resulted in the underrepresentation of nocturnal vertebrate species, particularly certain mammals, reptiles, and amphibians. Despite these constraints, efforts were made to ensure comprehensive data collection through both direct and indirect observation methods.

Vertebrate species were documented using direct visual encounters as well as indirect evidence such as faecal matter, feathers, and pugmarks. While these methods are widely accepted in ecological studies, they may not fully capture elusive or cryptic species, thereby influencing the overall assessment of species diversity.

The present study was subject to certain limitations inherent to field-based ecological research. Complete detection of arboreal microhabitats was not always possible, as observations were primarily conducted from ground level. Although binoculars were used to enhance visibility, some microhabitats located at greater heights or obscured by dense canopy cover may have been overlooked. Sampling intensity varied among study sites, ranging from lower to higher proportions of area coverage, primarily due to differences in site area and accessibility. However, a sufficiently large number of randomly distributed plots were sampled in each site, and a standardized methodology was consistently applied, ensuring reliable representation and valid comparisons across study sites.

Furthermore, the study was conducted within the framework of site-specific rules and time constraints, which may have affected the uniformity of sampling effort across all locations. Nevertheless, the documentation of a considerable number of endemic and native vertebrate species across the selected sites highlights the ecological importance of sacred groves and supports their role as significant biodiversity reservoirs.

Overall, while acknowledging these limitations, the study provides a reliable baseline for understanding vertebrate diversity in sacred groves and underscores the need for more comprehensive and long-term investigations incorporating broader access and advanced survey techniques.

8.1 Major outcomes

One of the major observations of the present study was the occurrence of the Wayanad Bush Frog, an endangered amphibian according to the IUCN Red List, in the Kammadam Sacred Grove. In addition, a raptor species, the White-bellied Sea Eagle, which is relatively uncommon in Kerala, has been consistently roosting in the Edayilekad Sacred Grove since 2003. These observations highlight the ecological significance of sacred groves as refugia for both rare and regionally uncommon species.

Furthermore, representatives from all major vertebrate groups were recorded, indicating that even small sacred groves function as important conservation units for both flora and fauna. Diversity indices, including the Shannon index, Simpson index, and dominance index, along with cluster analysis, revealed that sacred groves across different geographical zones of Kerala support vertebrate diversity with relatively high Shannon index values, irrespective of their size.

The dominance index indicated a relatively even distribution of species, suggesting the absence of strong dominance by any particular species. This pattern implies that available resources and microhabitats are utilized in a balanced manner. However, it is more appropriate to interpret this as reduced competitive exclusion rather than a complete absence of competition, as competition is an inherent ecological process.

Cluster analysis further demonstrated more than 50% similarity in species composition among the studied groves, emphasizing their collective importance in sustaining native fauna within human-dominated landscapes. Overall, the study documented a total of 105 bird species, underscoring the role of sacred groves as significant reservoirs of avian diversity.

Several factors influence the distribution and diversity of vertebrates, including patch area, seasonal variation, and climatic parameters such as temperature, humidity, and rainfall. These factors are common drivers of species distribution across ecosystems. However, in the context of sacred groves, a distinctive factor influencing species richness and diversity is the presence of human-mediated, unwritten religious practices that regulate resource use and disturbance. As observed in the present study, these traditional belief systems contribute positively to biodiversity conservation by limiting exploitation and maintaining habitat integrity.

Another important determinant is the proximity of sacred groves to larger forested landscapes. For instance, Athipatta Mana sacred grove, despite its small size (0.6 hectares), exhibited a relatively high Shannon diversity index and emerged as a potential key biodiversity area. Its location in close proximity to Silent Valley National Park likely facilitates species movement and enhances diversity through spillover effects. Similar patterns were observed in other sacred groves, where distance from continuous forest cover influenced species composition and richness. These findings support the relevance of sacred groves as model systems for understanding the Single Large Or Several Small (SLOSS**)** debate, as variations in patch size and isolation resulted in differing levels of biodiversity.

Habitat structure also played a crucial role in shaping vertebrate distribution. The availability of eighteen distinct microhabitats positively influenced species occurrence, with reptiles emerging as the most diverse users of microhabitats. Among these, cracks and scars were the most frequently utilized, highlighting their ecological importance. Additionally, vegetation cover and the availability of water sources were key factors enhancing habitat suitability and supporting higher species diversity.

The surrounding landscape matrix further influenced biodiversity patterns within sacred groves. In most cases, adjacent land uses included paddy fields, rubber plantations and coconut groves. Notably, sacred groves located near coastal regions provided important roosting habitats for raptors such as the Brahminy Kite, White-bellied Sea Eagle, and Black Kite. The Iringole Sacred Grove, despite being situated within an urban landscape, supported diverse vertebrate communities due to its high canopy cover, availability of microhabitats, presence of water sources, and proximity to paddy fields. The occurrence of the White-bellied Treepie, a species typically associated with semi-evergreen forests, further emphasizes its ecological significance.

Multiple factors contribute to the degradation of sacred groves, including the absence of protective boundary structures, landscape modification, relocation of idols, encroachment, and shifts in socio-cultural practices. These pressures collectively threaten the ecological integrity of these landscapes. In several groves, natural vegetation has been reduced and replaced by built structures, leading to habitat loss and a decline in biodiversity.

In addition, inadequate or inappropriate management practices by grove custodians have further altered ecosystem balance in certain sites, such as Poil Kavu and Pathirikunnath Mana. Although many sacred groves possess favourable conditions for vertebrate distribution, unsustainable management decisions—particularly vegetation clearance and landscape alteration—have negatively impacted biodiversity. This trend is especially pronounced in the sacred groves of southern Kerala, where frequent landscape modifications have resulted in significant loss of vegetation and associated habitats.

Despite the existence of numerous studies on sacred groves, there remains a lack of clear criteria defining the minimum ecological requirements for designating a patch as a sacred grove. Furthermore, comprehensive documentation of existing groves—incorporating parameters such as ecosystem health, disturbance levels, socio-cultural practices, and floral and faunal diversity—is currently insufficient. Establishing such a database would be essential for informed conservation planning and effective management of these ecologically and culturally significant ecosystems.

8.2 Recommendations

- Future studies should emphasize the conservation significance of small habitat fragments, as certain patches, may support a relatively high diversity of vertebrate species. Detailed and extended surveys in these areas could facilitate the documentation of additional species.
- Future studies should further investigate the role of small habitat patches in biodiversity conservation, as their importance is increasingly recognized. Expanding vertebrate distribution studies to other fragmented landscapes, such as urban forests and isolated forest patches, may provide deeper insights into the ecological significance of small habitat fragments.
- Future conservation efforts should recognize the role of multiple small habitat patches within urbanized landscapes in maintaining ecosystem balance. Ensuring the preservation of a minimum extent of undisturbed vegetation within such landscapes may promote a sustainable human–nature relationship while minimizing management challenges.
- Future efforts should prioritize the comprehensive documentation of sacred groves, including their spatial location, vegetation cover, faunal diversity, and levels of disturbance, to accurately assess their current ecological status. Such documentation would provide a scientific basis for developing effective management and conservation policies. The present study also identified key issues such as the absence of compound walls and lack of designated pathways in several ecologically significant groves, which contribute to biodiversity degradation. Therefore, improved documentation combined

with the implementation of appropriate management strategies would enhance the conservation and sustainable management of sacred groves in Kerala.

- Future research and conservation efforts should extend beyond sacred groves to include other culturally protected natural features such as mountains, lakes, rivers, and individual trees. Systematic biodiversity monitoring of these landscapes may strengthen human-mediated conservation practices and contribute to broader ecological conservation at regional and global scales.
- Sacred groves may serve as potential model systems for examining the Single Large Or Several Small (SLOSS) debate. Future studies should focus on evaluating how factors such as proximity to larger forested areas, in addition to patch size, influence species diversity. Expanding research across a wider range of sacred groves could further strengthen their applicability in understanding this ecological concept.

In conclusion, the present study underscores the ecological and cultural significance of sacred groves as vital repositories of biodiversity within human-dominated landscapes. Despite increasing anthropogenic pressures, these ecosystems continue to support diverse vertebrate communities, highlighting their conservation value. The findings emphasize the need for integrated conservation approaches that combine traditional knowledge systems with scientific management strategies. Strengthening protection measures, improving documentation, and promoting sustainable practices will be essential to ensure the long-term preservation of these unique ecological landscapes.

References

Anbarashan, M., Parthasarthy, N., & Padmavathy, A. (2011). Ethno-floristic survey in sacred groves, Pudukottai district, Tamil Nadu- India. *Journal of Medicinal Plant Research*, *5*(3), 439–443.

Asbeck, T., Großmann, J., Paillet, Y., Winiger, N., & Bauhus, J. (2021). The Use of Tree-Related Microhabitats as Forest Biodiversity Indicators and to Guide Integrated Forest Management. *Current Forestry Reports*, *7*(1), 59–68. https://doi.org/10.1007/s40725-020-00132-5

Aswathy, M. D., & Sudhikumar, A. V. (2022). Review of the millipede genus Propyrgodesmus Silvestri, 1920, with the description of a new species from a sacred grove in Kerala, India (Diplopoda: Polydesmida: Pyrgodesmidae). *Zootaxa*, *5116*(4), 591–599. https://doi.org/10.11646/zootaxa.5116.4.7

Athira, J, M., & K, T. (2023). An overview of some pharmacologically relevant therapeutic plants from Kerala's sacred groves. *Kongunadu Research Journal*, *10*(2), 21–30. https://doi.org/10.26524/krj.2023.12

Baidya, S., Thakur, B., & Devi, A. (2022). The influence of tree population structure on regeneration potential in the sacred forests of Assam, India. *Tropical Ecology*, *63*(2), 239–251. https://doi.org/10.1007/s42965-021-00208-8

Bars-Closel, M., Kohlsdorf, T., Moen, D. S., & Wiens, J. J. (2017). Diversification rates are more strongly related to microhabitat than climate in squamate reptiles (lizards and snakes). *Evolution*, *71*(9), 2243–2261. https://doi.org/10.1111/evo.13305

Batame, M., Sarfo, I., Yeboah, E., Njomaba, E., & Puplampu, D. A. (2023). Mapping of sacred groves in Ghana: the case of Talensi district in the guinea ecological zone. *SN Social Sciences*, *3*(9). https://doi.org/10.1007/s43545-023-00737-0

Bhagwat, S. A. (2009). Ecosystem services and sacred natural sites: Reconciling material and non-material values in nature conservation. *Environmental Values*, *18*(4), 417–427. https://doi.org/10.3197/096327109X12532653285731

Bhagwat, S. A., Kushalappa, C. G., Williams, P. H., & Brown, N. D. (2005). The role of informal protected areas in maintaining biodiversity in the Western Ghats of India. *Ecology and Society*, *10*(1). https://doi.org/10.1111/j.1523-1739.2005.00248.x

Bhagwat, S. A., Nogué, S., & Willis, K. J. (2014). Cultural drivers of reforestation in tropical forest groves of the Western Ghats of India. *Forest Ecology and Management*, *329*, 393–400. https://doi.org/10.1016/j.foreco.2013.11.017

Bhagwat, S. A., & Rutte, C. (2006). Sacred groves: Potential for biodiversity management. In *Frontiers in Ecology and the Environment*. https://doi.org/10.1890/1540-9295(2006)4[519:SGPFBM]2.0.CO;2

Blicharska, M., Mikusiński, G., Godbole, A., & Sarnaik, J. (2013). Safeguarding biodiversity and ecosystem services of sacred groves – experiences from northern Western Ghats. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *9*(4), 339–346. https://doi.org/10.1080/21513732.2013.835350

Boraiah, K. T., Vasudeva, R., Bhagwat, S. A., & Kushalappa, C. G. (2003). Do informally managed sacred groves have higher richness and regeneration of medicinal plants than state-managed reserve forests? *Current Science*, *84*(6), 804–808.

Campbell, M. O. N. (2005). Sacred groves for forest conservation in Ghana's coastal savannas: Assessing ecological and social dimensions. *Singapore Journal of Tropical Geography*, *26*(2), 151–169. https://doi.org/10.1111/j.0129-7619.2005.00211.x

Chanda, S., & Ramachandra, T. V. (2019). *Sacred Groves-Repository of Medicinal Plant Resources: A Review*. *January*, 12–20. www.stmjournals.com

Chandran, M. D. S., & Hughes, J. D. (1997). The Sacred Groves of South India: Ecology, Traditional Communities and Religious Change. *Social Compass*, *44*(3), 413–427. https://doi.org/10.1177/003776897044003008

Chandran, M. D. S., & Hughes, J. D. (2000). Sacred groves and conservation: The comparative history of traditional reserves in the Mediterranean area and in South India. *Environment and History*, *6*(2), 169–186. https://doi.org/10.3197/096734000129342262

Chandrashekara, U. M., & Sankar, S. (1998). Ecology and management of sacred groves in Kerala, India. *Forest Ecology and Management*, *112*(1–2), 165–177. https://doi.org/10.1016/S0378-1127(98)00326-0

Chaudhry, P., & Murtem, G. (2015). Role of sacred groves, value education and spirituality in conserving biodiversity with special reference to Arunachal Pradesh state of India. *International Journal of Society Systems Science*, *7*(2), 151. https://doi.org/10.1504/IJSSS.2015.069736

Choudhary, V., & Gupta, V. (2016). Study the Causes of Biodiversity Degradation and their impacts on Wildlife in a Sacred Grove Nai-Ka-Nath, Bassi, Jaipur Rajasthan. *International Journal of Scientific & Engineering Research*, *7*(4), 1094–1105.

Das, I. (2010). Zootaxa, A new species of Leptolalax (Anura: Megophryidae) from the sacred groves... *Zootaxa*, *56*(January), 44–56.

Decena, S. C. P., Macasait, D. R., & Arguelles, M. S. (2023). Species Accounts, Assemblage, and Microhabitats of Amphibians and Reptiles of Northeastern Leyte, Philippines. *Philippine Journal of Science*, *152*(1), 1–34. https://doi.org/10.56899/152.01.01

Deepa, M. R., Udayan, P. S., & Anilkumar, K. A. (2017). Taxonomical and phytosociological studies on Chithalikavu- A sacred grove, Thrissur district, Kerala. *Tropical Plant Research*, *4*(1), 20–30. https://doi.org/10.22271/tpr.2017.v4.i1.004

Dharmapal, S., Deepa, C., Mr, D., & Ps, U. (2016). Medicinal plants in the selected sacred groves of Kodungallur, Thrissur district, Kerala. *Journal of Medicinal Plants Studies JMPS*, *149*(43), 149–155.

Dudani, S. N., Nayaka, S., & Mk, M. (2015). *Journal of Biodiversity Management & Forestry Lichen Diversity in the Sacred Forest Fragments of Central Western Ghats*. *May*, 2–7. https://doi.org/10.4172/2327-4417.1000139

Dudley, N. (Ed.). (2008). *Guidelines for applying protected area management categories*. IUCN. https://doi.org/10.2305/iucn.ch.2008.paps.2.en

Duggal, R. R., Sk, M., & Rp, M. (2017). Medicinally Valuable Plants from Sacred Groves of Jabalpur

Forest Division (Madhya Pradesh). *Asian Journal of Plant Science and Research*, *7*(2), 37–44. http://www.imedpub.com/articles/medicinally-valuable-plants-from-sacred-groves-of-jabalpur-forest-division-madhya-pradesh.pdf

Fahrig, L. (2020). Why do several small patches hold more species than few large patches? *Global Ecology and Biogeography*, *29*(4), 615–628. https://doi.org/10.1111/geb.13059

Fournier, A. (2011). Consequences of wooded shrine rituals on vegetation conservation in West Africa: A case study from the Bwaba cultural area (West Burkina Faso). *Biodiversity and Conservation*, *20*(9), 1895–1910. https://doi.org/10.1007/s10531-011-0065-5

Frascaroli, F., Bhagwat, S., Guarino, R., Chiarucci, A., & Schmid, B. (2016). Shrines in Central Italy conserve plant diversity and large trees. *Ambio*, *45*(4), 468–479. https://doi.org/10.1007/s13280-015-0738-5

Gadgil, M., & Vartak, V. D. (1975). Sacred groves of India-A plea for continued conservation. In *Bombay Natural History Society* (Vol. 72, pp. 313–320).

Gaude, K., & Janarthanam, M. K. (2015). The butterfly (Insecta: Lepidoptera) diversity of four sacred groves of Goa, India. *Journal of Threatened Taxa*, *7*(12), 7927-7932.

Garda, A. A., Wiederhecker, H. C., Gainsbury, A. M., Costa, G. C., Pyron, R. A., Calazans Vieira, G. H., Werneck, F. P., & Colli, G. R. (2013). Microhabitat Variation Explains Local-scale Distribution of Terrestrial Amazonian Lizards in Rondônia, Western Brazil. *Biotropica*, *45*(2), 245–252. https://doi.org/10.1111/j.1744-7429.2012.00906.x

Gokhale, Y., Malhotra, K. C., Chatterjee, S., & Srivastava, S. (2001). *Cultural and ecological dimensions of sacred groves in India*. *February*, 1–30.

Hangarge, L. M., Kulkarni, D. K., Gaikwad, V. B., & Mahajan, D. M. (2015). Soil organic carbon (SOC) in selected sacred groves from Bhor region of western ghats, Maharashtra . *Asian Journal of Environmental Science*, *10*(2), 166–171. https://doi.org/10.15740/HAS/AJES/10.2/166-171

Hangarge, L. M., Kulkarni, D. K., Gaikwad, V. B., Mahajan, D. M., & Gunale, V. R. (2016). Plant diversity of sacred groves and its comparative account with surrounding denuded hills from Bhor region of Western Ghats. *Bioscience Discovery*, *7*(2), 121–127.

Hurtado, C. M., Curveira-Santos, G., Garcia-Olaechea, A., Appleton, R., Barros-Diaz, C., Hermosilla, T., ... & Burton, A. C. (2025). Importance of connectivity for carnivore richness and occupancy in fragmented biodiversity hotspots. *Conservation Biology*, *39*(6), e70096.

Imam, I., Mazumder, A., Mallick, K., & Mitra, S. (2016). *Diversity of ground dwelling insect fauna in the sacred groves of Purulia district , West Bengal*. *4*(1), 474–478.

Institution of Foresters Kerala. (2022). *Comprehensive study on the status of sacred groves in Kerala*. Kerala Forest Department.

IUCN. (2017). *Protected area categories*. https://www.iucn.org/theme/protected-areas/about/protected-area-categories

Jins, V. J., Mukherjee, A., Arun, P. R., Michael, D. R., & Bhupathy, S. (2022). Microhabitat preferences and guild structure of a tropical reptile community from the Western Ghats of India: implications for conservation. *Journal of Tropical Ecology*, *38*(5), 295–303. https://doi.org/10.1017/s0266467422000190

Juhé-Beaulaton, D., & Salpeteur, M. (2017). Sacred groves in African contexts (Benin, Cameroon): Insights from history and anthropology. *A History of Groves*, *Mab 1971*, 119–134. https://doi.org/10.4324/9781315561066-8

Jyothi, M., Nameer, O., & Access, O. (2015). Birds of sacred groves of northern Kerala, India. *Journal of Threatened Taxa*, *7*(15), 8226–8236. https://doi.org/10.11609/jott.2463.7.15.8226-8236

Kandari, L. S., Bisht, V. K., Bhardwaj, M., & Thakur, A. K. (2014). Conservation and management of sacred groves, myths and beliefs of tribal communities: a case study from north-India. *Environmental Systems Research*, *3*(1), 16. https://doi.org/10.1186/s40068-014-0016-8

Kekuda, P., Sciences, A., & View, P. (2016). *Vegetation analysis of Ammanaghatta sacred forest of Central Western Ghats , Karnataka*. *April*.

Kerala Forest Department. (2023). *Forest statistics 2022–23*. State Forest Headquarters, Government of Kerala. **https://kerala.gov.in**

Koda, S., Shyamal, T., Ch, M. K., & SB, P. (2021). Tree diversity in the Borra Sacred Groves of Anathagiri in Visakhapatnam District, Andhra Pradesh, India. *Scholars Academic Journal of Biosciences*, *9*(8), 205–208. https://doi.org/10.36347/sajb.2021.v09i08.004

Kofi Sarfo-Adu, G., Kwabena Kokofu, H., Aferdi Dadebo, M., Nkrumah, G., & Kwaku Galley, D. (2022). Management of Sacred Groves and Customary Practices in Pursuit of Sustainable Forest Management. *Journal of Environment and Ecology*, *13*(1), 31. https://doi.org/10.5296/jee.v13i1.19836

Kulkarni, Aboli; Datar, Mandar; Awasarkar, Umesh and Upadhye, A. (2014). Northernmost distribution of five tree species to the Western Ghats from the sacred groves of Pune district, Maharashtra, India. *Journal of Threatened Taxa*, *6*(8), 6093–6100. https://doi.org/10.11609/JoTT.o3644.6093-100

Kumar, R., & Koli, V. K. (2025). Elevation and distance to human habitation regulate high bird diversity and abundance across sacred groves in Aravalli range, Udaipur, Rajasthan, India. *Biodiversity and Conservation*, *34*(9), 3175–3191. https://doi.org/10.1007/s10531-023-02711-x

Kushalappa, C. G., & Raghavendra, S. (2012). Community-linked conservation using devakad (sacred groves) in the kodagu model forest, India. *Forestry Chronicle*, *88*(3), 266–273. https://doi.org/10.5558/tfc2012-053

Landry Yuan, F., Ballullaya, U. P., Roshnath, R., Bonebrake, T. C., & Sinu, P. A. (2020). Sacred groves and serpent-gods moderate human–snake relations. *People and Nature*, *2*(1), 111–122. https://doi.org/10.1002/pan3.10059

Larrieu, L., Paillet, Y., Winter, S., Bütler, R., Kraus, D., Krumm, F., Lachat, T., Michel, A. K., Regnery, B., & Vandekerkhove, K. (2018). Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. *Ecological Indicators*, *84*(August 2017), 194–207. https://doi.org/10.1016/j.ecolind.2017.08.051

Mace, G. M., & Baillie, J. E. M. (2007). The 2010 biodiversity indicators: Challenges for science and policy. *Conservation Biology*, *21*(6), 1406–1413. https://doi.org/10.1111/j.1523-1739.2007.00830.x

Mahabaleshwarkar, M., Ghayal, N., & ... (2023). Phytosociological and ethnobotanical aspects of selected sacred groves in different agroclimatic zones of Pune district, India. *Res. Jr. Agril …*, *March*.

https://www.researchgate.net/profile/Mukul-Mahabaleshwarkar/publication/369625684_Phytosociological_and_Ethnobotanical_Aspects_of_Selected_Sacred_Groves_in_Different_Agroclimatic_Zones_of_Pune_District_India/links/64252df3a1b72772e437d620/Phytosociologica

Mahabaleshwarkar, M., Ghayal, N., & Mahabaleshwarkar, S. (2023). *Records of Faunal Diversity from Selected Sacred Groves in Pune District , Records of Faunal Diversity from Selected Sacred Groves in Pune District , India*. *14*(September), 1244–1250.

Manju, C. N., Nishida, P. P., Vineesha, P. M., Mufeed, B., & Rajesh, K. P. (2023). Cylindrocolea devendrae Manju & P.P.Nishida (Cephaloziellaceae), a new leafy liverwort species from virgin low-elevation sacred groves in Kerala, India. *Journal of Bryology*, *45*(3), 243–248. https://doi.org/10.1080/03736687.2023.2274663

Maru, R. N., & Patel, R. S. (2013). Ethno-Botanical Survey of Sacred Groves and Sacred Plants of Jhalod and Surrounding Areas in Dahod District , Gujarat , India. *Research Journal of Recent Sciences*, *2*, 130–135.

Mumbrekar, K. D., & Madhyastha, N. A. (2006). Land molluscs of Pillarkan sacred grove. *Zoos' Print Journal*, *21*(6), 2295–2295. https://doi.org/10.11609/JoTT.ZPJ.1485b.2295

Nair, H. R., & Mathew, L. (2024). Floristics and indigenous knowledge of agro-climatically diverse Sacred groves of central Kerala. *Plant Science Today*, *11*(x), 147–159. https://doi.org/10.14719/pst.3512

Narasimha, N. (2015). A Community Initiative in Conserving Natural Resources through Sacred Groves in Western Ghats of Karnataka, Peninsular India. *Procedia Earth and Planetary Science*, *15*, 762–766. https://doi.org/10.1016/j.proeps.2015.08.123

Nganso, T. B., Kyerematen, R., & Obeng-Ofori, D. (2012). Review of biodiversity in sacred groves in Ghana and implications on conservation. *Current Trends in Ecology, Volume 3*, *3*(May 2014), 1–10.

Notermans, C., Nugteren, A., & Sunny, S. (2016). The Changing Landscape of Sacred Groves in Kerala (India): A Critical View on the Role of Religion in Nature Conservation. *Religions*, *7*(4), 38. https://doi.org/10.3390/rel7040038

Olsen, D. H., & Timothy, D. J. (2021). The Routledge Handbook of Religious and Spiritual Tourism. *The Routledge Handbook of Religious and Spiritual Tourism*, *August 2021*, 1–505. https://doi.org/10.4324/9780429201011

Onyekwelu, J. C. (2021). Can the fear of the gods sustain biodiversity conservation in sacred groves? *Academia Letters*, *July*. https://doi.org/10.20935/al635

Onyekwelu, J. C., & Olusola, J. A. (2014). Role of sacred grove in in-situ biodiversity conservation in rainforest zone of south-western Nigeria. *Journal of Tropical Forest Science*, *26*(1), 5–15.

Ormsby, A. A., & Bhagwat, S. A. (2010). Sacred forests of India: a strong tradition of community-based natural resource management. *Environmental Conservation*, *37*(03), 320–326. https://doi.org/10.1017/S0376892910000561

Osuri, A. M., Chakravarthy, D., Mudappa, D., Raman, T. R. S., Ayyappan, N., Muthuramkumar, S., & Parthasarathy, N. (2017). Successional status, seed dispersal mode and overstorey species influence tree regeneration in tropical rain-forest fragments in Western Ghats, India. *Journal of Tropical*

Ecology, *33*(4), 270–284. https://doi.org/10.1017/S0266467417000219

Padmanabhan, P. (2007). Documentation and conservation of small mammals in the sacred groves of Kerala, Peninsular India (2005-2008). *BAT NET - CCINSA Newsletter*, *8*(1–2), 4.

Page, N. V., Qureshi, Q., Rawat, G. S., & Kushalappa, C. G. (2009). Plant diversity in sacred forest fragments of Western Ghats: A comparative study of four life forms. *Plant Ecology*, *206*(2), 237–250. https://doi.org/10.1007/s11258-009-9638-8

Parthasarathy, N., & Naveen Babu, K. (2021). *Sacred Groves: Potential for Biodiversity and Bioresource Management*. *June 2020*, 865–880. https://doi.org/10.1007/978-3-319-95981-8_10

Prasad, K. S., & Raveendran, K. (2012). Sacred Groves Of North Malabar: Refugia of Endemic and Rare Medicinal Plants. *Plant Sciences Feed*, *2*(10), 154–158.

Perrin, A., Rein, F., Christe, P., & Pellet, J. (2025). Habitat fragmentation impact on insect diversity: opposing forces at patch and landscape levels. *Landscape Ecology*, *40*(6), 113.

Pruthi, I., & Burch, W. J. (2009). A Socio-Ecological Study of Sacred Groves and Memorial Parks: Cases from USA and India. *Journal Of Environmental Science And Engineering*, *1*(1), 7–14.

Rajasri, R., Sreevidya, E. A., & Ramachandra, T. V. (2017). Functional importance of sacred forest patches in the altered landscape of Palakkad region, Kerala, India. *Journal of Tropical Ecology*, *33*(6), 379–394. https://doi.org/10.1017/S0266467417000360

Rajendraprasad, M., Krishnan, P. N., & Pushpangadan, P. (2000). Vegetational characterisation and litter dynamics of the sacred groves of Kerala, southwest India. *Journal of Tropical Forest Science*, *12*(2), 320–335.

Rajesh, M., Gangadharan, A., Kishore, R., & Ganapathi, S. (2021). Avian Diversity in Manjamalai Sacred Grove, Madurai District, Tamil Nadu, India. *Avian Diversity in Manjamalai Sacred Grove*, *06*(04), 110–122. https://doi.org/10.46243/jst.2021.v6.i04.pp110-122

Raman, T. R. S., Joshi, N. V, & Sukumar, R. (2005). Tropical rainforest bird community structure in relation to altitude, tree species composition, and null models in the Western Ghats, India. *Most*, *102*(2), 36. http://arxiv.org/abs/q-bio/0510033

Ray, R., Chandran, M. D. S., & Ramachandra, T. V. (2014). Biodiversity and ecological assessments of Indian sacred groves. *Journal of Forestry Research*, *25*(1), 21–28. https://doi.org/10.1007/s11676-014-0429-2

Ray, R., & Ramachandra, T. V. (2010). Small sacred groves in local landscape: are they really worthy for conservation? *Current Science*, *98*(9), 1178–1180.

Ray, R., S Chandran, M. D., & Ramachandra, T. V. (2015). Hydrological importance of sacred forest fragments in Central Western Ghats of India. *Tropical Ecology*, *56*(1), 87–99. www.tropecol.com

Ray, R., Subash Chandran, M. D., & Ramachandra, T. V. (2014). Socio-cultural protection of endemic trees in humanised landscape. *Biodiversity and Conservation*, *23*(8), 1977–1994. https://doi.org/10.1007/s10531-014-0699-1

Rebancos, C. M., & Buot, I. E. (2007). Sacred groves and plant biodiversity conservation. *Nature Studies*, *6*(December 2013), 31–36.

Regnery, B., Couvet, D., Kubarek, L., Julien, J. F., & Kerbiriou, C. (2013). Tree microhabitats as indicators of bird and bat communities in Mediterranean forests. *Ecological Indicators*, *34*, 221–230. https://doi.org/10.1016/j.ecolind.2013.05.003

Rim-Rukeh, A.; Irerhievwie, G.; Agbozu, I. E. (2013). Traditional beliefs and conservation of natural resources : Evidences from selected communities in Delta State , Nigeria. *International Journal of Biodiversity and Conservation*, *5*(7), 426–432. https://doi.org/10.5897/IJBC2013.0576

Sanil, M. S., Sreekumar, V. B., Sreejith, K. A., Dev, S. A., Sasi, R., & Balakrishnan, S. (2022). Population status and habitat suitability of Vatica chinensis L., an endangered Dipterocarp from the Western Ghats, India . *Biodiversity Research and Conservation*, *67*(1), 21–32. https://doi.org/10.2478/biorc-2022-0009

Savithramma, N., Yugandhar, P., & Rao, M. L. (2014). Ethnobotanical studies on Japali hanuman theertham- a sacred grove of Tirumala hills, Andhra Pradesh, India. *Journal of Pharmaceutical Sciences and Research*, *6*(2), 83–88.

Scheffers, B. R., Edwards, D. P., Diesmos, A., Williams, S. E., & Evans, T. A. (2014). Microhabitats reduce animal's exposure to climate extremes. *Global Change Biology*, *20*(2), 495–503. https://doi.org/10.1111/gcb.12439

Sen, U. K. (2018). *Assessment of Human Impact on a Sacred Grove in Jhargram District, West Bengal, India*. *84*(November), 420–426.

Sharma, S., & Devi, R. (2014). *Sacred Groves : Traditional Way of Conserving Plant Diversity in Block Bhalwal of Jammu District (J & K)*. *3*(2), 239–242.

Singh, S., Youssouf, M., Malik, Z. A., & Bussmann, R. W. (2017). Sacred Groves: Myths, Beliefs, and Biodiversity Conservation-A Case Study from Western Himalaya, India. *International Journal of Ecology*, *2017*. https://doi.org/10.1155/2017/3828609

Sinthumule, N. I. (2024). Sacred forests as repositories of local biodiversity in Africa: A systematic review. *Forest Science and Technology*, *20*(4), 337–348. https://doi.org/10.1080/21580103.2024.2397522

Sukumaran, S., & Jeeva, S. (2008). A floristic study on miniature sacred forests at Agastheeshwaram, southern peninsular India. *EurAsian Journal of BioSciences*, *2*(December), 66–72.

Sukumaran, S., Pepsi, A., SivaPradesh, D. S., & Jeeva, S. (2018). Phytosociological studies of the sacred grove of Kanyakumari district, Tamilnadu, India. *Tropical Plant Research*, *5*(1), 29–40. https://doi.org/10.22271/tpr.2018.v5.i1.006

Svensson, J., Lopez-Peinado, A., Jonsson, B. G., & Singh, N. J. (2025). The contribution to forest conservation and restoration in Sweden of small, protected patches on private forest land. *Restoration Ecology*, *33*(3), e14390.

Tambat, B., Rajanikanth, G., Ravikanth, G., Uma Shaanker, R., Ganeshaiah, K. N., & Kushalappa, C. G. (2005). Seedling mortality in two vulnerable tree species in the sacred groves of Western Ghats, South India. *Current Science*, *88*(3), 350–352.

Uday, U. K. Sen, & Bhakat, R. K. (2021). Assessment of pteridophytes' composition and conservation status in sacred groves of Jhargram District, South West Bengal, India. *Biodiversitas*, *22*(6), 3171–3178. https://doi.org/10.13057/biodiv/d220620

Upadhaya, K., Barik, S. K., Pandey, H. N., & Tripathi, O. P. (2008). Response of woody species to anthropogenic disturbances in sacred forests of Northeast India. *International Journal of Ecology and Environmental Sciences*, *34*(3), 245–257.

Upadhyay, K. K., Japang, B., Singh, N. S., & Tripathi, S. K. (2019). Status and socio-ecological dimensions of sacred groves in Northeast India. *Journal of Applied and Natural Science*, *11*(3), 590–595. https://doi.org/10.31018/jans.v11i3.2121

Ward, B. S., & Conner, P. E. (1891). *Memoir of the Survey of Travancore and Cochin, 1816-1820*. Superintendent Government Press.

Warrier, K., Warrier, R. R., & Thangavel, V. (2023). Status of sacred groves in India: a review. *International Journal of Environment and Climate Change*, *13*(8), 170-181.

Westaway, D. M., Jolly, C. J., Michael, D. R., & Nimmo, D. G. (2024). Factors affecting microhabitat use in two agamid species from south-eastern Australia. *Austral Ecology*, *49*(7), 1–10. https://doi.org/10.1111/aec.13567

Plates

Pseudophilautus wynaadensis

Monilesaurus rouxii

Dicrurus aeneus

Minervarya keralensis

Cnemaspis gracilis

Geokichla citrina cyanota

Duttaphrynus melanostictus[*1]

Ahaetulla malabarica[2]

Terpsiphone paradisi

Plate 1: Amphibians **Plate 2: Reptiles** **Plate 3: Birds**

*Photo credit : [1] Nithin Divakar, [2] Sreejith Sivaraman- Kerala Forest Research Institute, Peechi, Kerala

Bark micro soil

Hollow branch

Root buttress cavity

Tree cavity (Natural)

Pteropus giganteus

Burrow

Termite mound

Plate 4: Mammal

Plates 4: Microhabitats

Appendix 1: List of recorded vertebrates from the sacred groves

Birds	MAN	KAR	NEL	EDA	KAY	POI	VAL	CHA	MOO	ATH	PAT	MRS	VET	KAM	PAM	IRI	KIZ	SAR	KUL	RAL
Corvus splendens	5	4	4	6	4	5	5	7	5	4	4	6	3	4	4	7	2	2	4	4
Dendrocitta vagabunda	3	5	5	5	3	1	4	4	2	2	2	4	2	2	3	5	2	4	0	2
Psilopogon viridis	2	4	4	2	4	1	3	1	1	0	1	1	1	2	2	4	1	2	2	2
Eudynamys scolopaceus	0	3	3	1	2	0	0	1	0	1	1	1	0	1	0	2	0	0	0	0
Halcyon smyrnensis	1	2	1	2	1	0	2	1	0	0	2	0	0	1	1	1	0	1	1	0
Hemiprocne coronata	0	1	3	2	2	0	1	0	2	0	0	0	0	1	0	0	0	1	0	0
Turdoides affinis	4	3	5	4	7	0	6	3	1	0	0	0	0	2	2	4	4	3	0	1
Cinnyris asiaticus	1	1	2	1	2	0	6	0	0	1	2	2	0	1	1	2	0	1	0	2
Sturnia malabarica	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnonotus cafer	2	1	2	1	4	0	5	2	1	3	2	3	2	4	1	3	0	1	0	2
Oriolus kundoo	1	2	2	1	3	0	4	0	0	0	0	0	0	1	0	1	0	0	0	0

Glaucidium radiatum	1	1	1	0	1	0	2	0	0	1	2	1	2	1	0	1	0	1	0	0
Dicrurus paradiseus	6	7	7	4	6	10	8	4	3	2	4	6	4	6	4	5	1	3	0	4
Leptocoma zeylonica	2	1	3	2	2	0	4	2	0	1	2	2	3	2	0	1	0	1	1	2
Dicaeum concolor	2	1	2	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinopium benghalense	2	3	2	2	2	1	3	2	4	3	2	1	1	4	3	4	2	1	0	2
Oriolus chinensis	0	1	2	2	1	0	1	0	0	0	2	0	0	2	0	1	0	0	0	0
Dicaeum erythrorhynchos	2	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Dicrurus macrocercus	1	2	1	1	0	1	2	0	1	1	1	1	1	2	2	4	0	1	0	2
Pycnonotus jocosus	2	2	4	3	6	0	12	3	5	2	4	2	2	6	2	6	0	2	0	3
Copsychus saularis	4	2	1	1	3	0	5	1	1	0	0	2	0	1	0	2	0	0	0	1
Centropus sinensis	1	2	2	1	3	1	4	0	0	1	3	1	1	1	1	1	1	0	0	2
Milvus migrans	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geokichla citrina cyanota	1	2	1	0	0	0	2	0	1	0	1	1	1	1	0	4	0	1	0	2
Monticola cinclorhynchus	1	2	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Rhopocichla atriceps	3	2	0	2	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Merops	1	2	2	0	0	0	0	1	0	2	1	0	0	0	0	1	0	0	0	0

philippinus																				
Merops orientalis	0	2	1	0	0	0	0	1	1	2	3	1	0	3	0	3	0	0	0	2
Oriolus xanthornus	0	2	2	1	0	0	2	0	0	0	0	1	0	1	2	2	0	2	0	1
Terpsiphone paradisi	0	2	4	2	2	0	0	0	0	2	0	0	0	3	0	4	0	0	0	0
Acridotheres tristis	0	2	4	0	3	0	5	4	4	5	3	2	3	6	2	4	2	1	0	2
Acritillas indica	0	2	0	0	0	0	0	1	2	1	0	1	0	1	1	0	0	0	0	0
Dicrurus leucophaeus	0	2	0	0	0	0	3	0	0	0	0	1	0	1	0	3	0	1	0	0
Spilornis cheela	0	2	1	0	1	0	1	1	0	1	1	0	0	0	0	1	0	0	0	0
Cyornis tickelliae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Chloropsis aurifrons	0	2	0	0	0	0	0	1	0	0	0	1	0	1	1	1	0	0	0	0
Rhipidura aureola	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Phylloscopus nitidus	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acrocephalus dumetorum	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthotomus sutorius	0	2	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Prinia socialis	0	2	0	0	0	0	0	0	0	0	2	0	0	1	0	2	0	0	0	0
Parus cinereus	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Lanius cristatus	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Tephrodornis sylvicola	0	2	0	2	2	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
Psilopogon malabaricus	0	2	0	2	0	0	0	0	1	1	0	1	0	1	0	0	0	1	0	0
Alcedo atthis	0	2	0	0	2	0	0	1	0	2	1	0	0	2	0	1	0	1	0	0
Alcippe	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

poioicephala																				
Pellorneum ruficeps	0	2	3	2	3	0	0	0	0	1	0	0	0	0	0	2	0	1	0	0
Zosterops palpebrosus	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Geokichla citrina	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Saxicoloides fulicatus	0	2	2	1	0	0	0	2	1	2	0	0	1	1	1	1	0	1	0	0
Saxicola caprata	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dicrurus aeneus	0	2	2	2	0	0	0	1	0	1	0	0	1	1	1	0	0	0	0	0
Pericrocotus flammeus	0	2	0	0	2	0	2	1	0	1	0	0	0	2	0	0	0	0	0	0
Leptocoma minima	0	2	2	2	0	0	0	2	0	0	2	1	0	1	1	0	0	1	0	0
Aegithina tiphia	0	2	1	0	0	0	1	0	0	1	1	1	0	1	1	1	0	0	0	1
Chloropsis jerdoni	0	2	2	0	0	0	0	0	1	0	0	1	0	1	0	1	0	1	0	0
Eumyias thalassinus	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Muscicapa dauurica	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilopogon haemacephalus	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Phylloscopus trochiloides	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cinnyris lotenius	0	2	2	0	0	0	4	2	1	0	0	0	1	2	1	0	0	0	0	0
Arachnothera longirostra	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rubigula gularis	0	2	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Spilopelia senegalensis	0	2	2	0	0	0	0	0	2	0	2	2	0	1	0	1	0	0	0	0
Corvus	0	2	2	0	0	0	0	1	0	2	0	0	0	3	0	2	0	1	0	0

culminates																				
Hypothymis azurea	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phylloscopus magnirostris	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Hierococcyx varius	0	2	1	1	0	0	1	1	1	1	2	1	1	1	0	1	0	1	0	0
Parus xanthogenys	0	2	0	2	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Pericrocotus cinnamomeus	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ninox scutulata	0	2	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0
Apus affinis	0	2	0	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Sitta castanea	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acridotheres fuscus	0	2	0	2	3	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Spilopelia chinensis	0	2	0	0	1	1	4	2	0	2	1	2	4	4	0	1	0	0	0	0
Tephrodornis pondicerianus	0	2	0	1	0	0	0	0	2	1	1	1	1	3	0	0	0	0	0	0
Strix ocellata	0	2	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Haliaeetus leucogaster	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chalcophaps indica	0	2	0	0	0	3	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Bubo zeylonensis	0	2	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0
Ardeola grayii	0	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Psittacula krameria	0	2	0	0	0	0	5	0	0	1	3	0	0	2	0	4	0	1	0	0
Prinia hodgsonii	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Gallus sonneratii	0	2	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0

Bubulcus ibis	0	2	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Accipiter badius	0	2	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
Amaurornis phoenicurus	0	2	0	0	0	0	4	1	0	0	0	0	0	2	0	0	0	0	0	0
Motacilla cinerea	0	2	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0
Motacilla maderaspatensis	0	2	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
Harpactes fasciatus	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Ocyceros griseus	0	2	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Psittacula cyanocephala	0	2	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0
Coracias benghalensis	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Turdoides striata	4	2	4	4	2	5	4	3	4	4	6	6	5	4	0	6	0	0	2	0
Haliastur indus	2	2	0	4	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Myophonus horsfieldii	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Yungipicus nanus	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Dumetia hyperythra	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Dendrocitta leucogastra	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Ducula badia	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	7	0
Columba livia	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Otus bakkamoena	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coracina macei	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Sitta frontalis	0	2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0

Reptiles	MAN	KAR	NEL	EDA	KAY	POI	VAL	CHA	MOO	ATH	PAT	MRS	VET	KAM	PAM	IRI	KIZ	SAR	KUL	RAL
Monilesaurus rouxii	1	0	1	0	2	0	1	0	0	0	0	0	0	3	0	1	0	0	0	0
Cnemaspis gracilis	0	0	2	1	0	1	1	0	1	0	0	0	0	2	0	1	0	0	0	0
Sphenomorphus dussumieri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Calotes versicolor	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	1
Draco dussumieri	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Varanus bengalensis	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eutropis macularia	2	2	2	1	1	2	1	1	1	1	1	1	0	3	0	2	0	0	0	1
Hemidactylus frenatus	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Ahaetulla malabarica	1	1	0	1	1	1	1	0	0	0	0	1	0	2	1	0	0	0	0	0
Naja naja	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Daboia russelii	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligodon arnensis	0	0	0	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bungarus caeruleus	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Ptyas mucosa	1	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0	0	0	0	0
Indotyphlops braminus	1	2	1	1	0	1	1	1	1	1	1	3	1	2	1	1	0	1	0	1
Gerrhopilus tindalli	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Amphibians	MAN	KAR	NEL	EDA	KAY	POI	VAL	CHA	MOO	ATH	PAT	MRS	VET	KAM	PAM	IRI	KIZ	SAR	KUL	RAL
Duttaphrynus melanostictus	0	1	0	0	0	0	3	1	1	1	1	2	0	2	1	1	1	1	1	2
Indirana beddomii	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
Pseudophilautus wynadensis	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Minervarya keralensis	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Rhacophorus malabaricus	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Micrixalus Saxicola	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0

Mammals	MAN	KAR	NEL	EDA	KAY	POI	VAL	CHA	MOO	ATH	PAT	MRS	VET	KAM	PAM	IRI	KIZ	SAR	KUL	RAL
Funambulus palmarum	2	2	5	3	3	3	6	5	2	4	5	4	3	7	3	5	2	3	2	4
Herpestes edwardsii	2	1	1	1	1	1	2	0	0	0	1	0	0	1	0	1	0	0	0	0
Rattus norvegicus	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sus scrofa domesticus	0	0	0	0	4	0	7	0	0	0	0	0	0	6	0	0	0	0	0	0
Hystrix indica	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Canis aureus indicus	0	4	2	2	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
Paradoxurus hermaphroditus	1	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Macaca radiata	0	0	0	6	0	0	9	0	0	0	0	0	0	7	0	0	0	7	0	0
Pteropus medius	14	0	0	5	0	12	0	12	0	3	4	0	3	0	4	0	0	0	0	0

Abbreviations: MAN – Mannampurath Temple; KAR – Karakkayil Kavu; NEL – Neliar Kottam; EDA – Edayilekkad Kavu; KAY – Kayyath Nagam; POI – Poil Kavu; VAL – Vallikkatu Kavu; CHA – Chandana Kavu; MOO – Mookuthala Kavu; ATH – Athipatta Mana; PAT – Pathirikkunnath Mana; MRS – Mannarasala; VET – Vettikode Temple; KAM – Kammadam Kavu; PAM – Pambumekkatu Mana; IRI – Iringole Kavu; KIZ – Kizhakkomb Kavu ; SAR – Saranga Kavu; KUL – Kulathoopuzha Kavu;.RAL – Raloor Kavu.

Appendix 2: Questionnaire Survey on Sacred Grove Use and Awareness

No.	Question	1 (Never)	2 (Rarely)	3 (Sometimes)	4 (Often)	5 (Always)
1	How often do you enter sacred groves?	☐	☐	☐	☐	☐
2	How often do you collect fallen wood from sacred groves for personal use?	☐	☐	☐	☐	☐
3	How often do you intentionally disturb or harm animals within sacred groves?	☐	☐	☐	☐	☐
4	How often do you use sacred groves as a public pathway?	☐	☐	☐	☐	☐
5	How often do you dispose of household waste in sacred groves?	☐	☐	☐	☐	☐
6	How often do you follow the rules and instructions associated with sacred groves?	☐	☐	☐	☐	☐
7	How often do you offer rituals or offerings in sacred groves?	☐	☐	☐	☐	☐
8	How often do you visit sacred groves for worship purposes?	☐	☐	☐	☐	☐
9	I am interested in observing the species inhabiting sacred groves.	☐	☐	☐	☐	☐
10	I encourage others to follow the rules and practices of sacred groves.	☐	☐	☐	☐	☐
11	I am aware of the myths and traditional beliefs associated with sacred groves.	☐	☐	☐	☐	☐
12	I am aware of the plant species conserved within sacred groves.	☐	☐	☐	☐	☐