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A STUDY ON THE DIVERSITY OF MILLIPEDES (DIPLOPODA) IN VARIOUS HABITATS OF SATARA TAHSIL, WESTERN GHAT, MAHARASHTRA

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ABSTRACT

Diplopods are common in temperate, tropical, and subtropical plantation environments, as well as further atmospheres. Millipedes (Diplopoda) form a diverse group of invertebrates, playing an important role in distributing soil ecosystem facilities, though often poorly known. They act as decomposers, conserving soil erosion and nutrient cycling, and are among the greatest vital foliage litter creatures. Sympathetic soil invertebrate groups, together with the habitually essential millipedes, are vital (David 2015). The present study aims to know the diversity of millipedes in the exact habitations of Satara tahsil and to study how seasonal and edaphic structures affect their diversity. The present paper emphasizes the influence of these structures on millipede-type diversity, which originates from field studies conducted at three selected sites. These work efforts are focused on recording various millipede species found in the different habitats of Satara's study area. The study took place over a year, starting from 2023-24 and continuing to the present, focusing on the study area region in Satara. Our results showed that there are four genera present in the region, namely Anoplodesmus, Gyrodrepanum, Trigoniulus, and Xenobolus. The importance of millipedes in soil plays a direct role in its fertility. We distinguish various millipedes as indicators of ecological situations. The presence of millipedes is correlated with the content of organic matter and nutrient elements in the soil. The present assessment is attentive to their diversity, communication with fauna, food and feeding habits, and protection.

INTRODUCTION

Biodiversity monitoring in protected areas is an integral part of the assessment of their performance and provides necessary information for an effective management (M. C. Geoch et. al. 2011). Invertebrates are useful and informative indicators of other elements of biodiversity, ecosystem function, and restoration (M. C. Geoch 2007, M. C. Geoch et al. 2011, Hamer & Slotow 2017). While invertebrates inhabit a wide range of environmental places and exhibit various significant environmental functions, they obtain comparatively little attention, mainly due to taxonomic problems encountered in identifying many taxa (Minelli 2015). It is important to determine the level and patterns of diversity in an area, including the identities and number of taxa, their distributions, and community diversity. One of the main reasons for conserving and monitoring invertebrates, particularly in protected areas, is to ensure adequate protection of rare and threatened species and communities (Samways 1993). India is a mega-diverse nation with a high quantity of endemicity in its floral plant diversity and animal diversity. The Diplopods are generally known as millipede. More than 80000 species, approximately highly diverse, include the described ones, numbering 12000. They have been found to confine the moderate and tropical parts of the world (Sierwald et al., 2007). As per the scientific classification, millipedes are classified under Diplopoda, coming under Myriapoda and Arthropoda, which are the subphylum and phylum, respectively. Despite the importance of millipedes in ecosystem functioning and their high diversity in tropical regions, the current version of the IUCN Red List comprises only ca. 200 millipede species assessments (IUCN 2023), which represents only 1% of the described taxa (Karam-Gemael et al. 2018). Millipede communities in old-growth forests are often species-rich, perhaps related to the high diversity of tree leaf litter (David 2009). Taxonomists have found a lot of prominence in documenting the diversity of many other invertebrate groups, but the diversity of millipedes has received less consideration and is only lightly represented in available works.

Macro invertebrates play an important role to provide fertility to soil by stimulating the stability and productivity of forest. Moreover, elevation is purely alternate for a suit of biotic and abiotic factors that influence the level of biodiversity. Among the most significant leaf litter animals in forest environments are millipedes, which are important detritivores invertebrates that increase the breakdown of decaying plant matter and promote microbial activity (Seeber et al 2008). Hence, it appears to be influencing the cycle of nutrients by redistributing organic matter, which in turn releases chemicals like nitrogen into the soil

(Golovatch et.al, 2009). Furthermore, numerous millipedes can assist as indicators of ecological situations, improving the structure and organic content of soil nutrient elements.

The determination of the level and outlines of variety in a zone, which contains the identities and numbers of taxa, their distributions, and community diversity, is considered important. A main reason for the conservation and observation of invertebrates, particularly in threatened areas, has been identified as confirming suitable defense for rare and endangered species and communities (Samways, 1993). The millipedes are generally affected by ecological fluctuations, mainly high temperatures. They are also measured biological indicators, as they determine differences in environmental and climatic situations (Brunner H., 2001). Periodic arthropods, millipedes are naturally originated through the rainy season and are infrequently seen in the summer, as temperature variations affect those (Ashwini et al., 2006). Most of their lives are expended in the soil, where they also overwinter. Millipedes are not recognized for their rapidity and can simply be caught by predators.

Alagesan and Ramanathan (2013) reported five species of millipedes from Alagar hills of Tamil Nadu; Chezhian et al. (2016) documented 10 species from Yelagiri hills, Eastern Ghats, Vellor, and Tamil Nadu. Millipedes (Diplopoda) in India have been essentially considered in facts by Golovatch and Wesener (2016), who noted the existence of species in their thorough survey. Despite this, a wider spread examination that covers all kinds of habitats and ecosystems is essential to accumulate an extensive list of millipedes found in India. Modern research focused on how biodiversity influences ecosystems and ecological processes, which created a positive relationship between biodiversity and ecosystems. The occurrence and abundance of millipede species depend on their habitat, which alters with increasing altitude; documentation and identification of millipedes are poor in India, and young researchers come forward to make proper taxonomy keys for Indian millipede species. We investigated changes in millipede diversity, distribution, and community structure within various habitat types in the Satara Forest area. We also discuss the implications for millipede conservation in this protected area located in the evergreen forest zone of Satara. So the main objective of this study is to provide information about the diversity and distribution of millipede species in the forest area of Satara tehsil, Maharashtra, India.

Material and Method Study Area

The present study material selected was Millipedes from Satara tehsil. Satara district area is one of the main districts in Maharashtra. The Satara district is divided into the hilly range, tableland, plateau, and plain area. The biodiversity of Satara tehsil is rich. So many new records and new species of plants and animals have been described from the Satara region. Satara is located at 17.68^0N and 73.98^0E in Satara district. It is a biodiversity hotspot. The combination of the Deccan Plate forest area its evergreen, semi-evergreen and deciduous types of forest. A diversity of soils is found in Satara, fluctuating from deep black soils of the plain & lack zone to shallow, red or reddish- brown soils of sub mountain & western Ghat zone. The area is characterized by a humid atmosphere, has a hot summer, a short winter period and heavy rainfall. The average temperature here is approximately 27.8^0C and the average yearly rainfall is about 762 mm.

A survey of three sampling sites of the Western Ghats, foothills of Thoseghar (Site A as shown in Fig. 6) (17.5981^0 N 73.8482^0 E), Sajjangad (Site B as shown in Fig. 7) (17.6485^0 N 73.9158^0 E) and Yavteshwar (Site C as shown in Fig. 8) (17.6835^0 N, 73.9507^0 E) during pre- and post-monsoon seasons revealed were selected for examination and collection of millipede species in the related atmosphere. The three sites differed commonly in terms of soil pattern, geography, category of vegetation, wetness pleased etc. The soil is found in the heavy rainfall zone of the Sahyadri high range. The observation and occurrence of a variety of Millipedes spp. In the Western Ghats and foothill's locations done a survey of the Western Ghats and the occurrence of different species of millipedes. An extensive study was conducted from January 2023 to December 2024 and observed the presence of diverse species of Millipedes.

The flora here is rich in dry deciduous and evergreen plant life. The main plants in the inhabited area include *Shorea robusta* (Sal), *Bauhinia variegata* (Kachnar), *Tectona grandis* (Teak), *Mangifera indica* (Mango), *Bombax* (Semal), *Artocarpus heterophyllus* (Jackfruit), *Azadirachta indica* (Neem), *Tamarindus indica* (Tamarind), *Butea monosperma* (Palash), *Syzygium cumini* (Jambhul), *Ficus carica* (Fig), *Dendrocalamus strictus* (Bamboo), *Phyllanthus emblica* (Amla), and *Acacia catechu* (Khair) and some other trees, shrubs, herbs, and grasses. Founded on the obtainability and availability of millipedes, specimen facts were decided diagonally in the study area.

Collection Methods

Collections were systematically made in the early hours of the morning, specifically between 6 am and 9 am, on a fortnightly basis spanning from the beginning of January 2023 through to the end of December 2024. This meticulous schedule was observed without fail, ensuring a consistent collection process over the two-year period. The hand-picking technique was used to survey randomly particular sites in the particular areas. These areas the upper soil stratum, leaf litter, rock crevices, garbage, grass cover, rotten wood, and moist soil were the main sources for the collection of millipedes. These samples were occupied from decayed litter, deadwood, all fragments, soil limit stratum, and below stones, etc. Afterward, collecting these millipedes was kept in plastic sample bottles. The certain individuals were photographed, and millipede representatives were brought to the laboratory. Then the sample was rinsed with water for removing the soil; after rinsing, these samples were kept in 70% ethanol for permanent preservation, and morphological investigations were carried out in the laboratory. For careful study of size, coloration, and other morphological features, accurate structures like mandibles, labium, labrum, head, antennae, eyes, genitalia, legs, and gonopods were observed for identification. Identification was done using standard literature and taxonomic keys (Shear 2011, Blower 1985, Nguyen & Sierwald 2013) and available records (Hoffman 1999; Golovatch and Wesener 2016).

Table 1: Diversity and systematic position of the millipedes identified

Sr. No.	Family	Order	Genus	Species
1	Paradoxosomatidae (Daday, 1889)	Polydesmida (Pocock, 1887)	*Anoplodesmus* (Carl, 1932)	*Anoplodesmus saussurii* (Humbert, 1865)
2	Paradoxosomatidae (Daday, 1889)	Polydesmida (Pocock, 1887)	*Gyrodrepanum* (Carl, 1932)	*Gyrodrepanum lamprum* (Chamberlin, 1920)
3	Trigoniulidae (Attems, 1909)	Spirobolida (Cook, 1895)	*Trigoniulus* (Pocock, 1894)	*Trigoniulus corallines* (Gervais, 1841)
4	Pachybolidae (Cook, 1897)	Spirobolida (Cook, 1895)	*Xenobolus* (Carl, 1919)	*Xenobolus carnifex* (Fabricius, 1775)

Fig. 1 Anoplodesmus saussurii

Fig. 2 Xenobolus carn

Fig. 3 *Trigoniulus corallines*

Fig. 4 *Gyrodrepanum lamprum*

Species Collected from the study area during field investigation

Table 2: Comparison of abundance of millipedes at Site A, Site B and Site C

Species Name / Year	Site A	Site B	Site C	Site A	Site B	Site C
		2023			2024	
Anoplodesmus Saussurii (Humbert, 1865)	5	9	6	4	7	6
Xenobolus Carnifex (Fabricius, 1775)	7	6	8	8	9	10
Trigoniulus Corallinus (Gervais, 1847)	10	9	9	11	10	13
Gyrodrepanum lamprum (Chamberlin, 1920)	5	3	4	2	6	5

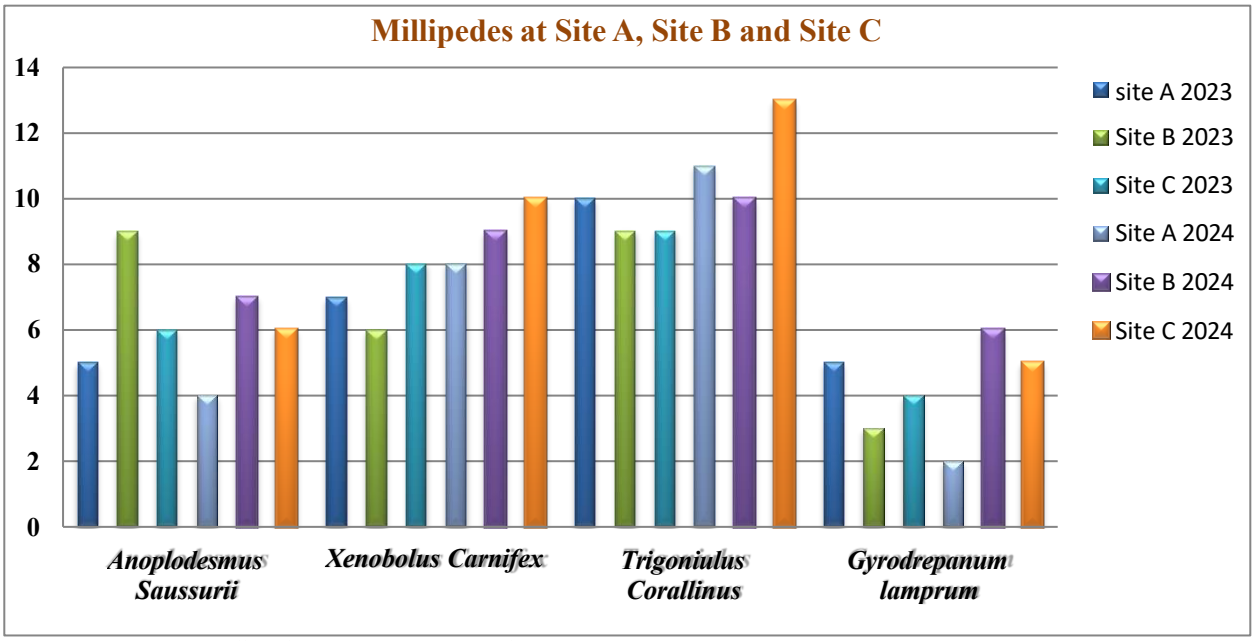

Fig. 5 Comparison of Millipedes at Site A, Site B and Site C

Observations

The data collected from the field study was analyzed and interpreted as presented in **Table 2**. A comparative study was conducted to assess the abundance of millipedes across three different sites: Site A (Thoseghar), Site B (Sajjangad), and Site C (Yavteshwar). This study covers the period from January 2023 to December 2024 (up to the present date). The findings have been documented and visually represented in the form of a graph, which is illustrated in Figure 5. This graphical representation provides a clear comparative analysis of millipede distribution and population trends across the selected sites over the specified time frame.

As shown in Fig. 1. ***A. saussurii*** is primarily nocturnal and tends to seek shelter during the daytime to prevent desiccation. While generally harmless to humans, it may release defensive secretions when threatened. ***A. saussurii*** also plays a crucial role in nutrient cycling by decomposing organic matter and returning essential nutrients to the soil.

Xenobolus carnifex (Fig. 2), commonly referred to as the "carnifex millipede," is recognized for its elongated and robust body. Its coloration is typically dark, ranging from black to deep brown, allowing it to blend seamlessly into its surroundings. This species plays a vital role in its ecosystem by contributing to soil fertility and structure through the decomposition of organic matter. Notably, its ability to secrete defensive chemicals highlights the diverse survival strategies millipedes employ in their natural habitats.

Trigoniulus corallinus, commonly called the "pink dragon millipede," is easily identified by its distinctive bright pink coloration (Fig. 3). This vivid hue is believed to serve as a warning signal to potential predators, indicating its toxicity. The species is typicallyfound in warm and subtropical regions, primarily in Southeast Asia. Its natural habitat includes leaf litter, decomposing logs, and forest soil. Though rare, it can release toxic secretions from glands along its body, which may be harmful or irritating to predators.

Gyrodrepanum lamprum (Fig. 4) is characterized by its cylindrical body, a defining feature of millipedes in the order Spirobolida. Its body consists of numerous segments, each equipped with two pairs of legs. While specific details regarding the colour and size of ***G. lamprum*** are limited, members of the Pachybolidae family typically display subdued shades ranging from brown to black. This species is likely to possess glands that secrete defensive chemicals, which can deter predators through toxicity or irritation. Its coloration and behaviour help it blend into its surroundings, providing effective camouflage against potential threats.

Results and Discussion

The study conducted across the selected sites (**Site A, Site B, and Site C**) led to the identification of four distinct millipede species (Diplopoda), as illustrated in **Figures 1-4**. These species were classified into two taxonomic orders, three families, and four distinct genera, as detailed in **Table 1**. Among the observed millipedes, it was found that the order Polydesmida (Pocock, 1887) exhibited the highest dominance within the study area. Additionally, within this order, the family Paradoxosomatidae (Daday, 1889) emerged as the most prevalent among the collected specimens. Notably, Trigoniulus corallinus (Gervais, 1847) was identified as the most abundant species across the study sites. Its significant presence suggests its adaptability and ecological prominence in these regions. The population distribution of this species indicates that it thrives in the environmental conditions provided by both locations, further emphasizing its role in the ecosystem.

A comparative analysis of millipede diversity and abundance across the three study sites - Thoseghar **(Site A),** Sajjangad **(Site B),** and Yavteshwar **(Site C)** revealed that **Site C** (Yavteshwar Forest Floor) exhibited the highest species diversity and abundance. This indicates that the environmental conditions at Site A are more favorable for millipede populations compared to the other two locations. The greater species richness and abundance observed at Site A can be attributed to several ecological factors. This site contains a significantly higher number of organic debris, including decaying wood, decomposing leaf litter, and other organic matter, which serve as primary food sources for millipedes. Additionally, the presence of more shaded and moist areas in Yavteshwar creates an ideal habitat for millipede survival and reproduction, as these organisms thrive in humid environments that help prevent desiccation. To provide a comprehensive comparison, **Table2** presents a detailed overview of the abundance of different millipede species recorded at each site. This comparative table highlights the variations in species distribution and population density, offering insights into the ecological conditions influencing millipede diversity in the studied forest regions.

CONCLUSION

It is important to highlight that comparing and distinguishing the abundance and diversity patterns of these invertebrates presents a significant challenge. Despite their crucial role in decomposition and nutrient cycling, millipedes remain an understudied and overlooked group in terms of their taxonomy and ecological significance within the country. Given this knowledge gap, it is imperative to conduct extensive surveys, thorough documentation, and long-term monitoring of millipede

populations, especially across diverse and ecologically sensitive habitats. Such efforts are essential not only for a better understanding of their taxonomic classification and ecological contributions but also for the development of effective conservation strategies aimed at preserving both millipede species and the broader ecosystem they inhabit.

Observations from this study indicate that millipede populations tend to be more abundant during the rainy season compared to summer and winter. This seasonal variation in species richness is largely attributed to the increased availability of organic matter, such as decomposing plant material, which serves as a primary food source for millipedes. The impact of seasonal fluctuations on millipede diversity has been closely examined, revealing that environmental factors such as moisture levels, temperature, and resource availability play a crucial role in shaping population dynamics. To ensure the conservation of millipedes and support their ecological functions, it is essential to designate and protect biodiversity hotspots where these species are naturally abundant. Establishing such protected areas can contribute significantly to enhancing millipede species richness, promoting their survival, and maintaining the balance of forest ecosystems.

No prior research has been conducted on millipede diversity in Satara, and no published studies exist on this subject to date. As a result, the present study serves as a pioneering effort in documenting the millipede species found in this region. This research has been instrumental in generating a detailed and accurate classification of millipedes belonging to the families Paradoxosomatidae, Trigoniulidae, and Pachybolidae. Through systematic identification and classification, a valuable foundation has been laid for further taxonomic and ecological studies on millipedes in Satara.

The present investigation has significantly contributed to understanding the species diversity, richness, and seasonal variations in millipede populations across different regions of Satara. A particular focus has been placed on millipedes belonging to the subphylum Myriapoda, highlighting their ecological roles and distribution patterns. By analyzing their abundance across seasons, this study has provided insights into the environmental factors that influence millipede populations, shedding light on their adaptability to varying climatic conditions.

The study area comprises soil types typically found in tropical and subtropical regions, each possessing a distinct composition and set of characteristics. These soils are primarily formed through the prolonged weathering of rocks, particularly those rich in iron and aluminum, under conditions of high temperature and humidity. Due to the unique properties of these soils, specific management practices are often required to enhance their fertility and suitability for agricultural and ecological purposes. Understanding these soil characteristics is essential for devising effective conservation and land management strategies, ensuring the sustainability of both soil health and the biodiversity it supports.

Although Satara is located within the richly bio diverse region of the Western Ghats, there remains a significant lack of recorded data on millipede species from this particular study area. Despite the ecological importance of these organisms, no prior research has documented their presence or diversity within this zone. The current study addresses this knowledge gap by systematically identifying and listing millipede species found in the Western Ghats of Satara District, Maharashtra. Within plantation ecosystems, millipedes play a crucial role, functioning in a manner similar to earthworms by contributing to soil aeration, decomposition, and nutrient recycling. However, very few studies have classified or thoroughly investigated the ecological significance of millipedes. Generally, if high species diversity is observed in a particular region, it serves as an indicator of the area's ecological health. When compared to other forested regions, the study area exhibits a rich diversity of millipede species, highlighting the necessity of enhancing existing documentation to support conservation efforts.

Millipedes are considered bio indicators of conservation health, as they thrive in moist and well-balanced ecosystems. Their occurrence frequently shows a constant and nutrient-rich habitat that supports the decomposition of organic material and soil fertility. Comprehensive documentation and study on millipedes are important for addressing present knowledge gaps and evolving conservation creativities. The findings of this study provide a systematic record of millipede species in the Western Ghats of Satara District, contributing to a better understanding of their ecological roles. Given their importance in soil ecosystems and nutrient cycling, millipedes must be prioritized for protection efforts, mostly inside selected biodiversity hotspots. Caring these species and their natural habitats will help maintain species richness and confirm their constant contribution to ecosystem stability.

Conflict of Interest

There is no any conflict of interest including any financial, personal or other relationships with other people or organizations that can influence their work.

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Fig.6 Site A Location Map of Study Area Thoseghar Forest (7.5981^0 N 73.8482^0 E.)

Fig. 7 Site B Location Map of Study Area Sajjangad region (17.6485^0 N 73.9158^0 E)

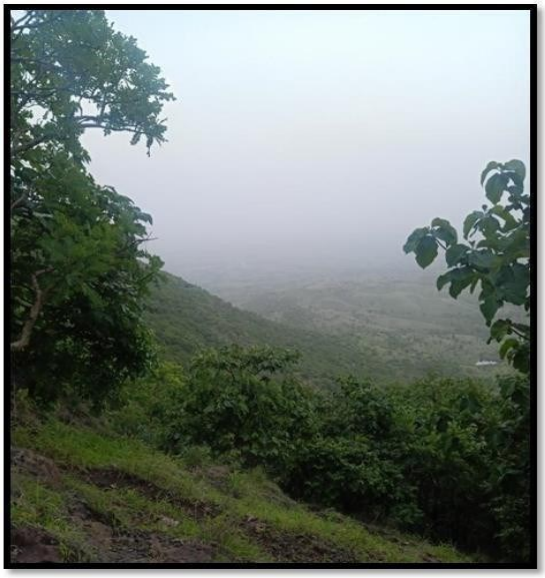
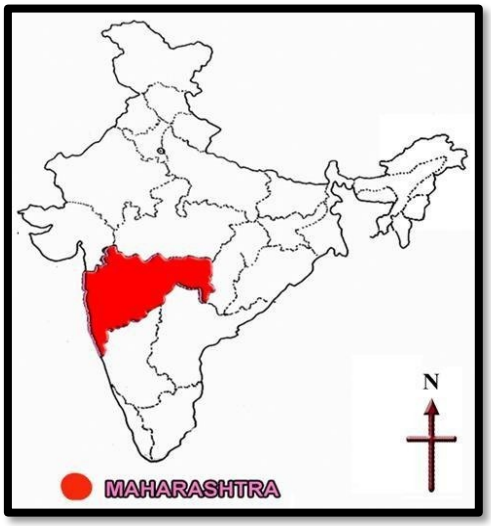
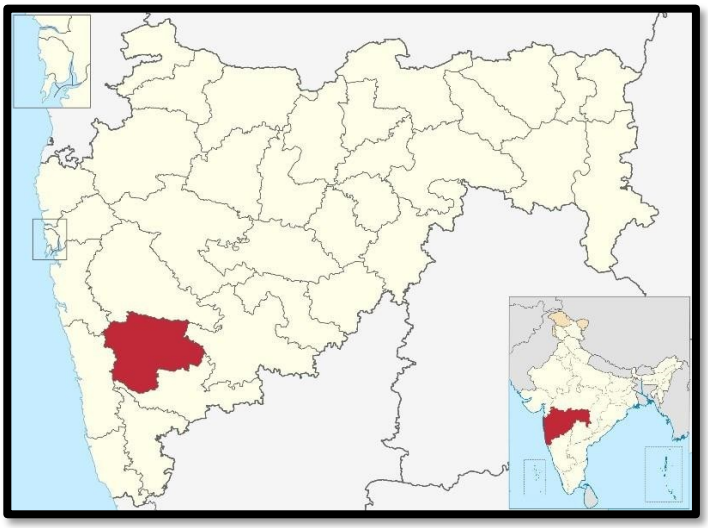


Figure. 8 Site C Location Map of Study Area Yavteshwar Forest (17.6835^0 N, 73.9507^0 E) Collection of Species from Study area

Fig. 1 - Map of India showing

Fig. 2 - Map of Maharashtra showing Maharashtra Satara district





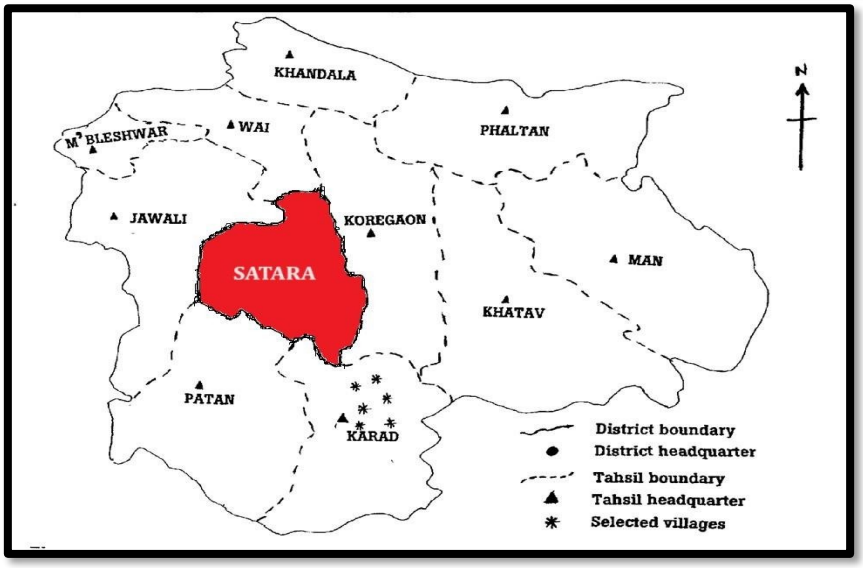


Fig. 3 Map of Satara district showing Satara Tahsil