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Research Article
Exploring Collembola Diversity in the Green Open Spaces of Baruga Forest, Kendari City, Indonesia

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Abstract
Background and Objective: The rapid development of Kendari City as the capital of Southeast Sulawesi Province has led to changes in land use patterns, particularly an increase in built-up areas, which threaten environmental stability. Rapid population growth contributes to rising carbon dioxide emissions, impacting air quality. Green spaces like Baruga Forest are ideal for environmental balance and bioservation. This study aims to identify the diversity of Collembola species in Baruga Forest, Kendari and understand the environmental factors influencing their presence. **Materials and Methods:** Collembola was collected in the Baruga Forest using a Berlese funnel, then identified and classified based on the family by counting the number of individuals in each taxonomic group. The diversity of Collembola was measured using the Shannon-Wiener index, while the evenness of individual distribution in each family was assessed using an evenness index. Additionally, environmental parameters such as air temperature, air humidity and soil pH were measured. The collected data were analyzed using descriptive statistical analysis. **Results:** The research results indicate that there are 75 individuals of Collembola belonging to the class Entognatha. The dominant order observed is Entomobryomorpha, consisting of three families: Oncopoduridae with 60 individuals, Isotomidae with 7 individuals and Orchesellidae with 5 individuals. Additionally, there is the order Symphypleona, represented by a single family, Bourletiellidae, with one individual. The biodiversity index (H') yielded a moderate value of 0.622, where the most significant contribution comes from the genus Isotomidae. Meanwhile, the evenness index (E) indicates a uniform distribution among the various genera of Collembola. **Conclusion:** Observed variations in temperature, humidity and soil pH changes underscore the need for ongoing management and conservation of Baruga Forest to maintain the diversity of Collembola species and the sustainability of the ecosystem in Baruga Forest.

Key words: Collembola, microarthropods, biodiversity, richness, soil fauna

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Kendari, the capital city of Southeast Sulawesi Province in Indonesia, has experienced significant growth. In 2022, projections indicated that Kendari's population reached 440,835, signifying a high population density[1]. This development often changes land use, transforming green areas into built-up zones. This increasingly common phenomenon has the potential to reduce environmental stability. Rapid population growth also significantly impacts the increasing needs and mobility of the community, leading to a decline in air quality, primarily due to rising CO_2 emissions from motor vehicles, industries and other sources[2,3]. In this context, green open spaces, such as Baruga Forest, are deemed crucial[2].

Green open spaces are open areas covered with grass, plants and trees, often designed for recreation or health purposes and to beautify urban environments. Their primary purposes are providing space for physical activities, wildlife protection, reducing air pollution and environmental beautification[4,5]. Green Open Spaces also play a critical role in providing oxygen and maintaining the urban microclimate[6].

Baruga Forest, measuring 150×100 m, is a vital example of green open space in Kendari, essential in maintaining urban biodiversity. Besides functioning as the city's lungs and providing fresh air, Baruga Forest also offers habitat to various flora and fauna species, including Collembola, small animals from the hexapoda class found in soil and organic substrates. The presence of Collembola in Baruga Forest contributes significantly to the urban ecosystem. To ensure the sustainability and diversity of Collembola in Baruga Forest, it is crucial to maintain and manage this habitat carefully. Protecting and preserving Baruga Forest through conservation and sustainable management will help maintain urban biodiversity[7]. However, ongoing urban development and human activities can pressure the diversity and abundance of Collembola in Baruga Forest.

Collembola, part of the arthropod group that has existed for over 400 million years, is highly adaptive and found in various habitats worldwide[8]. They play an essential role in soil ecology dynamics as primary consumers of soil organic matter, significantly contributing to the nutrient cycle and organic matter recycling in soil ecosystems[9]. In Indonesia, as many as 250 species from 124 genera have been identified, serving as indicators of soil quality and ecosystem integrity[10]. Their diversity and abundance provide insights into soil fertility conditions, organic matter content and pollutant exposure. Studies on the diversity of Collembola are vital to understanding the biodiversity and soil microorganism ecology in Baruga Forest.

The main objective of this study was to investigate the diversity of Collembola in Baruga Forest, Kendari City, particularly in terms of species composition, abundance and distribution in green open spaces. This research focuses on the influence of environmental factors such as temperature, humidity and soil pH on Collembola diversity. Through this study, an in-depth understanding of how environmental conditions affect Collembola communities in urban forest areas is expected.

MATERIALS AND METHODS

Study area: This research was conducted in the green open space of Baruga City Forest in Kendari, Indonesia. The study took place from January to April 2023.

Materials and tools: The equipment used included Berlese funnels, sample plastics, a measuring tape, label paper, ropes, a shovel, a microscope (ori relife RL-M3B1, China), a camera (6000D, Tokyo, Japan), writing tools, a thermometer (TPH01803, China), Petri dishes, a pH meter ((TPH01803, China) and notebooks. The materials used were 70% alcohol and distilled water.

Sampling of Collembola: Collembola samples were collected using a random soil sampling method with a plot size of 50×50 m. Fifty soil sampling points were chosen, spaced 5 m apart. The selection of sampling points was based on different characteristics, namely areas with varying amounts of litter. Soil samples at each point were collected using a pralon (soil borer) with a diameter of 15 cm. The depth of soil layers collected was adjusted to the shallowest soil layer along the sampling points in Baruga Forest. Extraction was done using a Tullgren funnel (Berlese funnel) for 2×24 hrs with a 5-watt lamp. The number of samples extracted was adjusted to the funnel's volume. The used funnel had a diameter of 20 cm, a height of 7 cm and a mesh for filtering of approximately 5 mm. Environmental parameters were also sure, including air temperature, soil moisture and soil pH. The collected Collembola in containers with 70% alcohol was then taken to the Biology Laboratory of the Islamic State Institute of Kendari for separation from other animals using a stereo microscope (ori relief RL-M3B1, China). This book provides detailed guidelines on the characteristics required to classify Collembola into their respective families[11,12].

Data analysis: This research analysis was conducted through various steps, including describing the characteristics of Collembola, identifying Collembola and determining the diversity index (H') and evenness (E). The identified Collembola were then grouped based on their family and a count of the number of individuals in each taxonomic group was calculated. The diversity of Collembola and arthropods was measured using the Shannon-Wiener diversity index[13,14]:

$$H' = -\sum pi \times \ln pi \quad H' = -\sum pi \times \ln pi$$

where, H represents the diversity index and pi is the proportion or relative number of the ith family. The evenness, indicating the uniformity of individual distribution across each family, was calculated using the evenness index[15]:

$$E = H' / \ln S$$

where, E represents the evenness index, H is the diversity index and S is the total number of types (in this case, families). The value of E ranges between 0 and 1, where a value of 1 indicates a condition where all species are equally abundant. If the value approaches 1, it suggests an even distribution of individuals among species. A value of E approaching 0 indicates an uneven distribution of individuals among species or dominance of one species.

RESULTS AND DISCUSSION

Environmental factors affecting the diversity of Collembola: Baruga Forest in Kendari City, Indonesia, represents a significant green open space spanning 150×100 m. The forest is home to various plant life, including trees, grasses and bushes. Additionally, it hosts diverse fauna such as birds, ants, snakes, caterpillars and Collembola. Environmental factor measurements in Baruga Forest, Kendari City, Southeast Sulawesi, were performed to determine the environmental parameter conditions in this area. The environmental factors measured include temperature, humidity and pH. The results of these environmental parameter measurements were mentioned in Table 1.

Environmental factors play a crucial role in shaping the diversity and abundance of Collembola. The measurement results (Table 1) indicate that air temperature during the observation period ranged from 30-32°C. In the first and third weeks, the temperature remained stable at 30°C but increased to 32°C in the second week. Although this temperature variation is not very significant, a 2°C increase within a week could suggest fluctuations in weather conditions or other environmental factors impacting the living organisms in the area, including Collembola[16]. Zhang *et al.*[17] found that temperature is a significant factor that positively affects the abundance of Collembola. The air humidity parameter experienced a slight increase from 60-65%. Although this change is not drastic, an increase in humidity could indicate an increase in water availability or changes in rainfall patterns, which can impact the local flora and fauna, including Collembola. Krediet *et al.*[18] assert that soil moisture greatly influences the presence of Collembola, both large and small.

Soil pH also underwent significant changes during the observation period. The soil was slightly acidic in the first week, with a pH of 6. However, in the second and third weeks, the soil pH increased to 7.5, indicating more neutral conditions. These pH changes can affect soil microorganisms, soil nutrients and the availability of certain metals that can impact the growth of plants and soil animals. Qiao *et al.*[19] explained that the diversity of Collembola depends on factors such as food availability, the presence of predators, air temperature, rainfall levels, irrigation, soil moisture, soil texture, pH and soil carbon and nitrogen content. Furthermore, Gruss *et al.*[20] demonstrated that a decrease in soil pH slightly increases toxicity effects on Collembola, which can be detrimental to their survival. Similarly, Rahardjo *et al.*[21] found that the microclimate is an essential factor in determining the diversity and vertical distribution of Collembola.

Collembola diversity in Baruga Forest: The presence of Collembola in Baruga Forest encompasses various microscopic species that inhabit this region. This group consists of small insects that play a significant role in the nutrient cycle and the decomposition of organic residues. They also act as decomposers and contribute to the formation of microsoil structures in forests. Collembola can also serve as indicators of forest ecosystem disturbances because the environmental conditions of the forest influence their presence and diversity. The results of identifying Collembola families in Baruga Forest were presented in Table 2.

Based on the Berlese funnel sampling results, all identified Collembola specimens belong to the class Entognatha, which reflects a characteristic group of soil arthropods. This class encompasses distinct groups of arthropods found in soil habitats. Observations indicate two orders of Collembola identified: Entomobryomorpha and Symphypleona. Both orders show different evolutionary adaptations to meet their needs in soil habitats. This aligned with the findings of Malcicka *et al.*[22] that their habitat environment influences the adaptation of Collembola. These findings are also consistent with research conducted by Milano *et al.*[23], which noted that

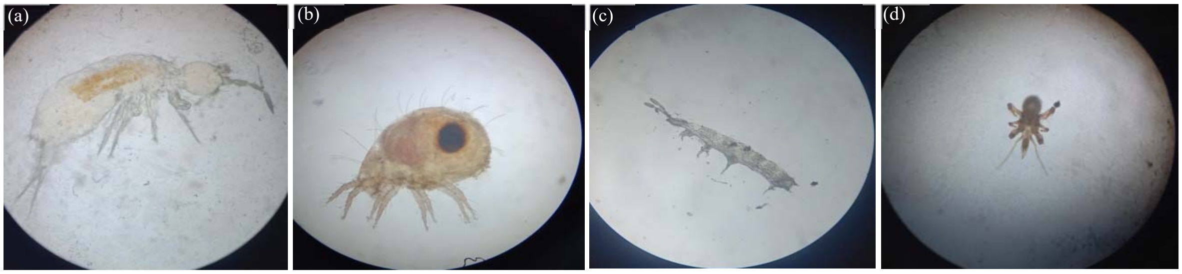

Fig. 1(a-d): Diversity of Collembola families found in the green open spaces of Baruga Forest, Kendari City (a) Family Oncopoduridae, (b) Family Bourletiellidae, (c) Family Isotomidae and (d) Family Orchesellidae

Table 1: Environmental parameter measurements in Baruga Forest, Kendari City

	Measurement of environmental parameters in Baruga Forest		
Time period	Air temperature (°C)	Humidity (%)	pH
Week-1	30	60	6
Week-2	32	65	7.5
Week-3	30	65	7.5

Table 2: Collembola families in Baruga Forest

Class	Order	Family	Number of individuals
Entognatha	Entomobryomorpha	Oncopoduridae	60
	Symphypleona	Bourletiellidae	1
	Entomobryomorpha	Isotomidae	7
	Entomobryomorpha	Orchesellidae	5

40 species of Collembola occupy habitats based on their environmental preferences. Similarly, research by Joimel *et al.*[24] stated that the adaptive capabilities of Collembola in their habitats allow them to thrive in suitable environments, such as moist forests, leaf litter and other damp surroundings, by acting as decomposers, which play a vital role in maintaining ecosystem balance and the cycle of organic matter.

Based on observations, diversity at the family level is relatively high, as evidenced by the presence of four different families: Oncopoduridae, Bourletiellidae, Isotomidae and Orchesellidae. However, their abundance distribution presents an interesting pattern. The Oncopoduridae family (Fig. 1a) emerged as the dominant group with 60 individuals, indicating that the environmental conditions in Baruga Forest greatly support the existence of this family. A characteristic of this family is the variability in body size. Their bodies have scales and setae. The head features distinctive antennal organs and they generally lack eyes and pigmentation, which supports their adaptiveness in subterranean habitats. The Oncopoduridae family's habitats include leaf litter, soil and caves[25]. The Oncopoduridae were found in more significant numbers than other families, as they can inhabit various types of habitats, such as in soil, leaf litter and caves[26]. Moreover, there is a suspected correlation between plant roots and the population density of soil fauna, including Collembola in Baruga Forest. Abd El-Karim *et al.*[27] reported a positive correlation between soil fauna diversity and plant diversity, indicating that plant diversity modulates spatial ecological conditions and affects soil fauna diversity.

Furthermore, Lakshmi *et al.*[28] stated that forest ecosystems provide a suitable habitat for Collembola that feeds on fungal hyphae, bacteria, dead or decaying plants and insects. The most common and abundant Collembola species tend to live in the upper soil layers where habitat productivity is maximum due to high levels of organic material, thereby providing a high rate of decomposition and a more stable environment for Collembola populations. The high adaptability of this family results in their numbers being more dominant compared to other families.

Meanwhile, the Bourletiellidae (Fig. 1b) were represented by only one individual, indicating that this family may be less adaptive to the habitat in Baruga Forest. This is consistent with research reported by Furgol *et al.*[29], which noted that the Bourletiellidae family is one of the less commonly encountered families, presumably related to habitat preference, as some Collembola species are highly influenced by microhabitat conditions affecting their adaptive capabilities. According to Jacobs *et al.*[30], the Collembola found in each habitat varies greatly depending on their sensitivity

Table 3: Collembola diversity index in Baruga Forest

Family name	Σ	Pi2= Ni/N	In	H'
Oncopoduridae	60	0.822	-0.197	0.161
Bourletiellidae	1	0.014	-4.342	0.056
Isotomidae	7	0.096	-2.353	0.223
Orchesellidae	5	0.068	-2.688	0.182
Total	73	1	-9.58	0.622

level to environmental stress. The characteristics of the Bourletiellidae family include having antennae with distinct segments. The thoracic segments are indistinct. Each limb has 2 or 3 hair (setae). Members of this family are generally found in grassy habitats, among vegetable plants and in shrubbery.

The Isotomidae family (Fig. 1c) has various body sizes and colors, ranging from white to dark blue to dark gray, with about 1-4 mm body lengths. The body shape of this family's members is elongated, the prothorax is reduced, the fourth abdominal segment is the same length or longer than the third, they have four antenna segments, simple hairs and the mucro does not resemble a hook and they have legs that are longer than the head. The habitat of the Isotomidae family is in leaf litter and soil. In contrast, the Orchesellidae family (Fig. 1d) members have body sizes of 1-4 mm, six antenna segments, abdominal segments and a furcula that is folded underneath. This family lives in the soil and among leaf litter. Both families have moderate abundance, with 7 and 5 individuals, respectively. The abundance and diversity of Collembola are related to the individuals' ability to adapt to environmental changes and food availability. Additionally, ecological factors such as the presence of predators and competition with other species can also influence the abundance of Collembola. The various Collembola family groups found in Baruga Forest were presented in the following Fig. 1.

The role of soil fauna, including Collembola, in driving key ecosystem processes in green open spaces is significant. Research by Tresch *et al.*[31] has revealed soil fauna's crucial role in supporting primary ecosystem processes in green spaces, including Collembola. This is reinforced by the study of Semerora *et al.*[32], highlighting the importance of neglected lands as urban green spaces. These areas serve not only ecological roles but also provide habitats for a variety of fauna and flora, as exemplified by the Baruga Forest in Kendari City, which supported the existence of Collembola. Further, research by Jacobs *et al.*[30] has contributed to a deeper understanding of Collembola diversity in specific regions. These studies assist in comprehending the distribution and abundance of Collembola in green open spaces. According to Lakshmi *et al.*[28] Collembola can live in various habitats, particularly leaf litter and soil, where they play a critical role in the decomposition of organic material. However, studies also indicated that the distribution and abundance of Collembola in Baruga Forest vary, signifying that each family has different ecological needs and adaptations to environmental conditions. This aligns with findings by Jureková *et al.*[33], stating that various factors, including vertical stratification, humus characteristics, habitat cover and air temperature, influence the presence of Collembola species. Therefore, the maintenance and conservation of Baruga Forest require a holistic approach that focuses not only on the dominant Collembola groups but also on the less abundant ones to ensure the sustainability of its ecosystem for the future.

Biological diversity is a crucial parameter in assessing ecosystem health. This is evident in the study of Collembola diversity in Baruga Forest, which shows relevant conservation and environmental management results. As an integral part of the ecosystem, Collembola maintains soil quality by consuming fungal hyphae and organic matter. They also influence the growth of mycorrhizae and control fungal diseases in plants, as described by Escribano-Álvarez *et al.*[34]. From the data presented in Table 3, four Collembola families were identified in Baruga Forest, namely Oncopoduridae, Bourletiellidae, Isotomidae and Orchesellidae. With a total of 73 individuals found, the Oncopoduridae family dominates with 60 individuals, while the Bourletiellidae family has only one individual. The proportional value (Pi2) of each family illustrates their relative contribution to the overall population, with Oncopoduridae having the highest proportion (0.822) and Bourletiellidae the lowest (0.014). Additionally, the in value or information value, ranging from -0.197 to -4.342, indicates each family's contribution to the diversity index (H') interestingly. However, these negative values suggest that families with lower abundance, such as Bourletiellidae, contribute more information to the diversity index, in line with research by Jacobs *et al.*[30].

The diversity index value (H') indicates that although the Oncopoduridae family has the highest abundance, it contributes only 0.161 to the diversity index. In contrast, the Isotomidae family, with a lower abundance, provides the highest contribution of 0.223. The overall diversity index (H') for all Collembola families in Baruga Forest is 0.622, indicating a moderate level of diversity. Despite the Oncopoduridae

Table 4: Collembola diversity index in Baruga Forest

Family name	Σ	Biodiversity index (H’)	Evenness index (E)
Oncopoduridae	60	0.161	0.116
Bourletiellidae	1	0.056	0.04
Isotomidae	7	0.223	0.16
Orchesellidae	5	0.182	0.131
Total	73	0.622	0.447

family’s dominance in the population, the presence of other families indicates that Baruga Forest maintains a healthy level of Collembola diversity. This group plays a crucial role in decomposing organic matter, improving soil quality, transferring nutrients and serving as food for predators in the forest. With an overall diversity index value of 0.622, diverse Collembola families in Baruga Forest suggest that the forest ecosystem has a balanced and stable species composition, vital in maintaining ecosystem balance and the sustainability of nutrient cycles in the forest.

The evenness index plays a crucial role in ecology to measure the even distribution of individuals within a community among various species or groups. According to Gregorius and Gillet[35], a high level of evenness indicates a more even distribution of individuals among species, while a low value suggests dominance by a few species. Table 4, detailing the evenness index of Collembola, shows that among the four identified Collembola families, the Oncopoduridae family has the highest number of individuals, with 60 individuals. In contrast, the Bourletiellidae family has the least, with only one individual. However, when analyzing the diversity index (H’), the Isotomidae family appears to make the most significant contribution to diversity, with a value of 0.223, despite having fewer individuals than the Oncopoduridae family. This illustrates that although the Oncopoduridae family dominates in number, species diversity in Baruga Forest remains significant. The evenness index measures the even distribution of individuals among groups. Its value ranges from 0, indicating total dominance by one family, to 1, indicating an even distribution among all families. The Isotomidae family records the highest evenness with a value of 0.16, while the Bourletiellidae family has the lowest evenness with a value of 0.04. The overall evenness index for Baruga Forest is 0.447, indicating a relatively even distribution among the families despite the dominance of some.

This research reveals that although the Oncopoduridae family is the dominant species, the level of evenness among Collembola species in Baruga Forest is well maintained. This indicates a more equitable distribution among other Collembola species, suggesting that the ecological conditions of Baruga Forest support this species’ diversity. Such a condition underscores the importance of ongoing conservation efforts to preserve the existence and diversity of Collembola species in Baruga Forest, which is crucial for maintaining the ecosystem balance.

CONCLUSION

Research results on Collembola diversity in Baruga Forest, Kendari City, Southeast Sulawesi, confirm that Collembola plays a vital role in forest ecosystems. As primary organic matter consumers, Collembola converts dead plant and animal remains into nutrients available for other organisms. The identification of four Collembola families, with the dominance of family Oncopoduridae, showed moderate diversity, characterized by a diversity index (H’) of 0.622 and a significant contribution from family Isotomidae. The evenness index (E) reflected a relatively even distribution among Collembola families. Environmental parameters such as temperature and humidity fluctuations and significant changes in soil pH emphasize the need for conservation and sustainable management. Maintaining the balance of soil ecosystems in Baruga Forest requires practical conservation approaches and continuous environmental monitoring to ensure the sustainability of Baruga Forest and Collembola diversity in Kendari City.

SIGNIFICANCE STATEMENT

Research in green open spaces, Kendari City on Collembola species diversity is very important to do because urbanisation has resulted in significant changes in the environment that potentially threaten biodiversity. The main objectives of this study were to determine the species diversity and understand the environmental variables that influence the distribution of Collembola in green open spaces in Baruga Forest, Kendari City. Four Collembola families: Oncopoduridae, Bourletiellidae, Isotomidae and Orchesellidae were identified in Baruga Forest, with Oncopoduridae being the most abundant family. The results of this study provide a deeper understanding of Collembola population dynamics in the context of environmental change in Kendari City's Baruga Forest, as well as their role in nutrient cycling and organic matter decomposition.

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