COLLEMBOLA FAUNA IN THE CORONATION GARDEN OF TRIBHUVAN UNIVERSITY, KIRTIPUR, NEPAL

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Submitted to

Central Department of Zoology

Institute of Science and Technology

Tribhuvan University

Kirtipur, Kathmandu

Nepal

August, 2022

DECLARATION

I hereby declare that the work presented in this thesis has been done by myself, and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

Date ..26/08/2022..

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Renuka Karki

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RECOMMENDATION

This is to recommend that the thesis entitled **"Collembola fauna in the Coronation Garden of Tribhuvan University, Kirtipur, Nepal"** has been carried out by Miss Renuka Karki for the partial fulfilment Master's Degree of Science in Zoology with special paper Entomology. This is her original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

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LETTER OF APPROVAL

On the recommendation of supervisor Associate Professor Dr. Daya Ram Bhusal, Central Department of Zoology, Tribhuvan University, this thesis submitted by Miss Renuka Karki entitled **"Collembola fauna in the Coronation Garden of Tribhuvan University, Kirtipur, Nepal"** is approved for the examination and submitted to the Tribhuvan University in partial fulfilment of the requirements for Master's Degree of Science in Zoology with special paper Entomology.

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CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Miss Renuka Karki entitled **"Collembola fauna in the Coronation Garden of Tribhuvan University, Kirtipur, Nepal"** has been accepted as a partial fulfilment for the requirement of Master's Degree of Science in Zoology with special paper Entomology.

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Renuka Karki

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LIST OF ABBREVIATIONS

Abbreviated form	Detail of abbreviations
ANOVA	Analysis of Variances
CDZMTU	Central Department of Zoology Museum Tribhuvan University
M asl	metre above sea level
mm	millimetre
PAST	Paleontological Statistics
pH	Hydrogen ion concentration
TU	Tribhuvan University

ABSTRACT

Collembola (springtails) are small, apterygote, hexapodous arthropod possessing an important ecological role as decomposer. The study was carried out to explore the Collembola fauna in the Coronation Garden of Tribhuvan University, Kirtipur. The Coronation Garden was divided on the basis of heterogenous feature into four vegetation categories (near to road, near to water source, invasive plant dominated and non–invasive plant dominated). From each category six sampling plot of 1 m^2 quadrat size was randomly selected. Two soil samples were collected from the quadrat and pitfall trap was installed at each sampling point. The study aimed to determine the seasonal diversity of fauna, relation of faunal abundance with respect to soil parameters (pH, moisture and temperature) and to assess species composition across categorized heterogenous environment. The species diversity of Collembola fauna in Coronation Garden was high (H= 2.63, E=0.77). The fauna is represented by 30 species (unidentified) belonging to three order, eight families and 17 genera (*Callyntrura*, *Cyphoderus*, *Dicranocentroides*, *Entomobrya*, *Homidia*, *Hypogastrura*, *Isotomiella*, *Isotomurus*, *Lepidocyrtus*, *Procerura*, *Ptenothrix*, *Salina*, *Seira*, *Sinella*, *Sminthurus*, *Stenognathellus*, *Tomocerina*). The genera *Homidia*, *Seira*, *Salina*, *Isotomurus* and *Procerura* are new record for Nepal. The dominant family group are Entomobryidae followed by Paronellidae and Isotomidae whereas *Hypogastrura*, *Ptenothrix*, *Sminthurus* and *Cyphoderus* are the dominant genera. The species richness, abundance and diversity were higher in spring (S= 26, H=2.51, J=0.77) than winter season (S= 19, H= 2.45, J=0.83). The faunal abundance showed highly significant positive relation with respect to the soil pH, temperature and moisture. Across the heterogenous environment within coronation garden, the species diversity and evenness were higher in roadside vegetation though the species abundance was lowest in it whereas the species richness and abundance were highest in vegetation near water suggesting it as more suitable habitat for the fauna. Among 30 species recorded 18 species was observed across all the heterogenous environment category suggesting wide range of habitat preference in most of the species. *Hypogastrura* species was dominant in all sites except near water vegetation whereas *Sminthurus* sp.1 (8.03%), *Homidia* sp.1 (6.64%), *Ptenothrix* sp.1 (42.05%) and *Procerura* sp. (17.18%) are the species dominant in invasive, non–invasive, near water and roadside vegetation respectively.

1. INTRODUCTION

1.1 Background

Collembola commonly known as springtails are small wingless hexapodous arthropods subsisting as an important soil mesofauna (Deharveng & Bedos 2004, Cipola et al. 2018). Their body size ranges from 0.12 to 17 mm. They are characterized by the presence of ventral forked structure furcula on the fourth abdominal segments which serve as jumping apparatus, entognathous mouthparts and four segment antennae (Cipola et al. 2018). The body of Collembola is globular or tubular and comprises three tagma head capsules, thorax with three segments and with six segment abdomen (Yadav et al. 2018). The abdomen bears three pregenital appendages ventral tube or collophore, tenaculum and furcula on the first, third and fourth abdominal segment respectively that differs it from all hexapods whereas the presence of antennae and absence of cerci differs it from entognathous apterygotes (Cipola et al. 2018, Yadav et al. 2018).

Collembola have internal fertilization with indirect sperm transfer and copulation does not occur due to the absence of copulatory organ (Deharveng & Bedos 2004, Cipola et al. 2018). The male generates small packets of spermatophores that are deposited to the substrate which is taken by female into its reproductive tract after accidental contact with the packet of sperms whereas some species of Poduridae and Symphpleona exhibits courtship behavior for successful uptake of spermatophore (Thibaud 1997, Deharveng & Bedos 2004, Christiansen et al. 2009, Glime 2016). Parthenogenesis is frequent in several genera of Collembola (Deharveng & Bedos 2004). They encompass egg, juvenile and adult stage. They are ametabolous, young differ from adult in size, pigment and absence of reproductive organ. The successive molt results sexual maturity but the molting continues throughout in its life and depending on the species they can molt 20 to 50 times during adult stage (Thibaud 1997, Christiansen et al. 2009) and the lifespan varies from three months to three years (Thibaud 1997).

Collembola represent one of the most abundant group in soil as an important constituent of soil mesofauna in terrestrial ecosystem (Rusek 1998, Castaño-Meneses et al. 2004). They generally inhabit ground litter, humus and few centimeter of soil and have epi–edaphic, hemi–edaphic and euedaphic life forms (Thibaud 1997). Epi–edaphic species are surface dwellers living on plant litter, mosses, trunk, rock whereas hemi–edaphic species dwells on soil surface and in litters and euedaphic are deep soil dwellers (Thibaud 1997, Malcicka et al. 2017). Most soil and litter dwelling Collembola feed on decaying vegetation and soil microbiota (fungi, bacteria, algae), few occasionally or primarily feed on nematodes, tardigrades, enchytraeids, rotifers to other collembolans; some are coprophagic feeding on arthropod excreta whereas vegetation inhabiting species feed on algae, pollen, fungal spores (Thibaud 1997, Christiansen et al. 2009).

Soil serves as nutrient reservoir and habitat for multivarious soil fauna which have profound roles. Likewise soil mesofauna Collembola contribute in disintegration of litter, detritus and excrement of macro and megafauna, thereby play major role in formation of soil microstructure (Rusek 1998). They equalize carbon and nitrogen fluxes in soil by regulating the trajectories of soil microbial community (Theenhaus et al. 1999, Coulibaly et al. 2019). They play vital role in material and energy cycles, organic matter decomposition and soil formation; since they are represented as abundant soil fauna are important in study of soil and microhabitat ecology (Scott 1957, Vu & Nguyen 2000). Collembola are sensitive to environmental change and disturbances and responds to it by change in the faunal abundance, diversity and species composition and are potential candidate of bioindicator (Greenslade 2007, Zeppelini et al. 2008, Fiera 2009). The knowledge about the fauna might be useful in development of conservation approaches and monitoring of natural and human impacted area (Culik 2003).

Environmental factors have pronounced effect on soil invertebrates' population densities and fluctuation (Badejo & Van Straalen 1993). Similarly soil pH, temperature and moisture have limiting role in controlling population densities and diversity of Collembola (Bhagawati et al. 2018, Islam et al. 2018). Collembola have ubiquitous occurrence across wide range of ecosystem and around 9,300 species of Collembola fauna are recorded worldwide (Bellinger et al. 1996-2022).

Coronation garden in Tribhuvan University, Kirtipur is a botanical garden inside T.U. premises constituting diverse vegetation and serving as habitat for various lifeforms. The diverse vegetation cover and heterogenous land feature within the garden ignites the enormous possibilities of presence of Collembola fauna in the garden. The information about the Collembola fauna study from Nepal is minimal the study might further enhance the faunal information in the country.

1.2 Objectives of the study

The general objective of the study was to explore the diversity of collembola fauna in the Coronation Garden of Tribhuvan University.

The specific objectives of the study are;

i. To determine the seasonal diversity (winter and spring) of Collembola fauna.

ii. To analyze the relation of Collembola fauna abundance with respect to soil parameters: soil pH, moisture and temperature.

iii. To assess the Collembola fauna composition across the heterogenous environment (vegetation near to- road and water flow, invasive vegetation dominated sites, non–invasive vegetation dominated sites) within the Coronation Garden.

1.3 Significance of the study

Collembola plays an important role in plant litter decomposition processes, nutrient cycling and in forming soil microstructure and the ecological role of Collembola as reducer in an ecosystem is inevitable (Scott 1961, Vu & Nguyen 2000). The study aims to acknowledge about the prevailing Collembola fauna at the coronation garden at different heterogenous environment. The knowledge about the fauna and its distribution range can be beneficial in understanding the tolerant species in wide range habitat and can be utilized in restoring soil of poor quality. The taxonomic study is essential and serves as prior step to know the ecology of fauna, the study helps to enlighten about the Collembola fauna present in the Coronation Garden.

1.4 Limitations of the study

- Collembola fauna were identified only up to genus level due to unavailability of higher magnification microscope to observe the distinguishing feature of species.

2. LITERATURE REVIEW

2.1 Diversity of Collembola fauna

The global estimation of Collembola fauna recorded is around 9,300 species (Bellinger et al. 1996-2022). Thapa (2015) listed 122 species of Collembola fauna belonging to 43 genera with seven endemic species amongst it whereas 167 species of fauna represented by 78 genera belonging to 17 families with 45 endemic species was listed from Nepal by (Shrestha & Budha 2021). Most of the Collembola species are reported from Nepal by taxonomist Yoshii (Shrestha & Budha 2021). Potapov and Cassagnau (2000) described two new species of *Folsomia* from Nepal. *Superodontella gladiator* new species of order Poduromorpha was recorded from Nepal (Agolin et al. 2009) and new species of *Willowsia* was reported by (Zhang 2015). In India, 342 species of Collembola fauna under 113 genera belonging to 20 families are recorded (Mandal 2018).

Collembola and Oribatid mites form primary constituent of soil arthropods (Petersen & Luxton 1982, Vu & Nguyen 2000). Collembola fauna are versatile in their feeding habit and on the basis of availability of the diet and favorable condition they switch their diet accordingly as fungivore, herbivore, omnivore, detritivore, coprophage using wide resources as diet and low degree of food specialty as well as shows seasonal variation on the feeding diet (Anderson & Healey 1972, Saur & Ponge 1988, Castaño-Meneses et al. 2004). Salmon and Ponge (2012) in their study depicted the trait of the species are significantly related to their habitat so as the surface–dwelling species are characterized by having large body size, eyes well develop along with jumping organ furcula and body covered with cuticular clothing to prevent from desiccation whereas the soil dwelling are small in size, reduced or absent of eyes and furcula with poor protection from desiccation and parthenogenesis. According to the diet utilized the mouthparts differ in structure, scavenger/carnivore species group have scratching/piercing mandibulae without a molar plate whereas the herbivore and microbivore species have chewing mandibulae with molar plate (Malcicka et al. 2017). The collembolan fauna group shows preference to the litter, humus and mineral layers of the soil showing vertical distribution and coexistence of various species of the fauna within the soil sustaining high diversity within the soil (Takeda 2018). The generalist feeding habit along with the morphological feature developed to sustain in the diverse habitat and division of the soil microhabitat might have account for the existence of diverse form of Collembola in the soil.

2.2 Relation of faunal abundance with environmental factors

The natality, mortality, development and duration of life of Collembola fauna is dependent on soil moisture and temperature (Takeda 2018). Hazra (1978) in his study found soil moisture and Collembola fauna population have strong positive correlation throughout the study in the deciduous forest floor and considered moisture to be one of the important factors for governing its population. The diversity and density of fauna showed significant positive correlation with soil moisture and organic carbon whereas soil pH showed positive non–significant relationship in Majuli river island, India (Bhagawati et al. 2018). The abundance of Collembola fauna was positively correlated with the temperature, organic materials, nitrogen, potassium, sulfur content of the soil whereas negatively correlated with humidity, zinc and pH of soil (Islam et al. 2018) whereas soil pH and temperature both were negatively correlated to population of collembola (Abbas 2012). Badejo and Van Straalen (1993) in their study found that the number of springtails varied with the moisture and temperature, the availability of high moisture content result high number of springtails and vice versa whereas high temperature results low number of springtails and low temperature favor high number of springtails (Badejo & Van Straalen 1993).

The effect of soil pH, moisture on springtails diversity varied in forest and agroecosystem in the study carried out in hills of Shillong, India though soil temperature and diversity of fauna showed positive significant correlation in both the land use. Soil pH and fauna diversity correlation was weakly positive in forest whereas it was positively correlated in agroecosystem. Likewise, the soil moisture and diversity have negative significant relation in forest whereas was non–significant in agroecosystem (Paul et al. 2011). During all four seasons and in all the studied ecosystem (forest, vegetable, tea) the soil carbon and moisture have significant positive correlation with density and diversity of the fauna (Bhagawati et al. 2021). Mandal and Hazra (2009) in their study of Collembola diversity from east and northeast India found that fauna was affected by the soil moisture, temperature, pH, organic carbon, nitrogen and phosphate have effect in the distribution of fauna in soil though the effect varied in various study sites.

The Collembola fauna sampled from Aligarh in various season showed that the fauna have high population in winter and spring months whereas the faunal number was low in summer and rainy season (Abbas 2012) whereas in another study fauna number was least in winter (December) (Hossain et al. 2017). Collembola fauna population changes with season and the increase in number occurs in spring while the number declines in winter as well as the birth and death of fauna is associated with seasonal change (Takeda 2018). The prevalence of Collembola fauna varied among months in the maize fields at Rajshahi district of Bangladesh based on species type, species was mostly found in April and was least in abundance in December, *Entomobrya nivalis* was recorded in all month whereas *Hypogastrura armata* and *Tomocera minor* absent in November and December whereas the irrespective of the place the fauna number was found to be highest in May and least in October (Hossain et al. 2017). Collembolan diversity and density in Majuli river island, India varied with season and the highest diversity of fauna was observed in summer season followed by spring, autumn and winter whereas the density was highest in summer followed by autumn, spring and winter (Bhagawati et al. 2018). In the study of Collembola fauna in the forest floor, fauna population reach maximum in July, minimum in May and less constant in December and January (Hazra 1978).

2.3 Species composition in different habitat

Takeda (2018) through litter bag experiment showed the habitat heterogeneity as an important factor for determining the species composition of communities developed in each habitat. In the study habitat categorized as open grassland, shady grassland, crop field margin, roadside vegetation and pondside vegetation, the species composition varied across the habitat; species *Seira indica*, *Lepidocyrtus lignorum*, *Tomocerus* sp., and *Salina* sp. were highest in roadside vegetation whereas *Dicranocentroides indica* in pondside vegetation and *Entomobrya albocincta* in crop field margin (Islam et al. 2018). The Collembola fauna was recorded having higher density and abundance in disturbed (agricultural land) than native forest ecosystem (Abbas 2012).

The study of soil arthropods diversity on forest floor and ex–road in natural reserve of Indonesia, soil arthropod diversity was higher in forest floor than ex–road and the Collembola fauna that was present in forest floor were of family Paronellidae and Entomobryidae whereas in ex–road only Paronellidae fauna was recorded (Suheriyanto et al. 2016). The soil dwelling Collembola in forest, vegetable and tea ecosystem in Assam, India was observed and the highest diversity of fauna was found in forest followed by vegetable growing land and tea ecosystem. Regarding the species composition, five genera *Cyphoderus, Entomobrya, Isotoma, Folsomia and Hypogastrura* was observed in forest whereas among these *Folsomia* was not observed from vegetable growing land similarly *Folsomia* and *Hypogastrura* was absent in tea ecosystem (Bhagawati et al. 2021).

The microarthropod community structures study carried out in Tam Dao National Park, Vietnam across the various habitat– natural forest, human impacted forest, shrubland, grassland, cultivated land, tea field showed the species number increased from human impacted forest to tea field, shrubland and cultivated land respectively and the association of faunal composition was high in human impacted forest and shrubland as well as among the tea field, cultivated land and shrubland (Vu & Nguyen 2000). Collembola fauna composition didn't varied much in forest and agroecosystem only one species was absent from the agroecosystem while other species being present in both habitat although the density of fauna was higher in forest than in agroecosystem (Paul et al. 2011). The effect of land use on Collembola diversity pattern was studied on Mediterranean landscape where the diversity and species richness were highest in closed oak forest followed by pasture land, managed woodland and monoculture woodland respectively and the significant difference in species composition was encountered among them (Sousa et al. 2004).

Rusterholz et al. (2014) studied the effects of invasive plant *Impatiens glandulifera* on Collembola and Acari in a deciduous forest, the species richness and abundance of soil and litter fauna was unaffected but the species composition differed in the invaded and uninvaded plots of forest. Similarly, there was no difference in diversity and abundance of Collembola fauna and was unaffected in the uninvaded and invaded meadow by *Solidago gigantea* only species composition differed (Sterzyńska et al. 2017).

3. MATERIALS AND METHODS

3.1 The study area

The Coronation Garden lies in Kirtipur located at the south–west of Kathmandu valley. It is botanical garden that extends over an area of around 2.7 hectare within T.U. premises. The study was carried out at different sites of Coronation Garden in T.U. within geographical coordinates 27°67´911´´-27°68´106´´N, 85°28´49´´-85°29´176´´E and elevation at 1,280–1,321 m asl. The climate in Kirtipur is mild and generally warm and temperate with average annual temperature 16.1°C and average rainfall of 2,812 mm. The common vegetation during study period were *Eucalyptus* sp., *Ficus* sp., *Shorea* sp., *Juniperus* sp., *Callistemon* sp., *Cinnamomum camphora*, *Zigyphus* sp., *Psidium guajava*, *Salix* sp., *Jacaranda mimosifolia*, *Cotonoeaster bacillaris*, *Quercus lanata*, *Alnus nepalensis*, *Lagerstroemia indica* and *Lantana camara* and *Ageratina adenophora* as invasive shrub vegetation in the study site.

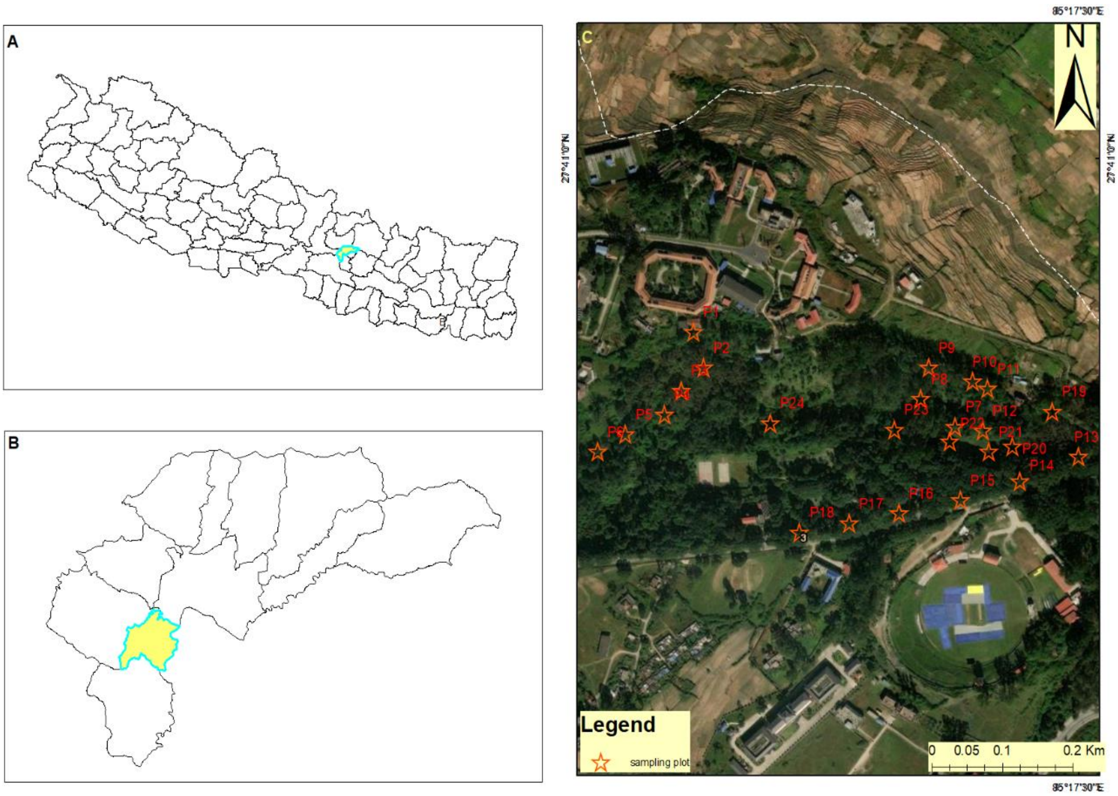

Figure 1. Map of study area- A. Map of Nepal showing Kathmandu district **B.** Kathmandu district showing Kirtipur municipality **C.** Coronation Garden with sampling points

3.2 Materials

In Field – Soil thermometer (Omsons), GPS (Garmin etrex ® 10), soil corer, zip–lock bags, alcohol, plastic cups.

In Lab – Sieve, aspirator, white sheet, vials, alcohol, glycerol, lactic acid, distilled water, pH meter (pHep HI96107), slides and coverslips, weighing machine, oven, stereomicroscope (Best scope BS-3020B) and phase contrast microscope (Swift).

3.3 Methods

3.3.1 Sampling method

The Coronation Garden was divided on the basis of heterogenous feature into four vegetation categories (near to road, near to water source, invasive plant dominated and non–invasive plant dominated). From each category six sampling plot of 1m^2 quadrat size was randomly selected and two soil sample was collected from the quadrat. Hence 12 soil samples were collected from each category whereas in total 48 soil samples were collected. Pitfall trap was used along for collection of Collembola fauna and in each sampling point two traps was setup for the collection of fauna (Badejo & Van Straalen 1993). Samples collection was done in two seasons– winter (December– January 2022) and spring (February– March 2022).

For collection of Collembola fauna, soil sample of around 635 gm was collected with the metallic cylindrical soil corer of diameter 9 cm and height 10 cm and soil sample was then transferred to zip–lock bag along with the litter above the soil. Pitfall trap was placed using same size plastic cups of volume around 0.25 liter, containing 70% alcohol, ethylene glycol and detergent till the half of the cup. The traps were emptied once after three days for three times. For the determination of soil parameters around 200 gm of soil was collected in separate zip–lock bag from each sampling plot.

The fauna from soil sample was extracted by sieving with sieves of size 850 µm and 550 µm on white sheet cloth for dry soil sample whereas damp soil was carefully spread on large white sheet and in both the cases fauna was collected through aspirator into vials containing 70% alcohol with drop of glycerol. The vials were then labelled with sample plot number and date of collection. The labelled vials were then subjected for the further identification of species for which the collected species from vials were poured into petri–dishes and under stereomicroscope the number of individuals of each species observed from the plot was counted and noted.

3.3.2 Soil parameters measurement

a. Soil moisture

The moisture content of soil was measured through gravimetric method. In aluminium foil 100 gram of soil was taken and kept in an oven at 105°C to dry for 24 hours and then the dried soil sample was weighed (Reynolds 1970). The moisture content of the soil was calculated using formula;

$$\text{Soil moisture (\%)} = \frac{\text{Weight of moist soil} - \text{Weight of oven dried soil}}{\text{Weight of oven dried soil}}$$

b. Soil pH

For soil pH determination, 20 gm of soil sample was taken in a beaker of size 100 ml or larger volume into which 50 ml of distilled water was added. Then soil water suspension was gently stirred with the glass rod and was allowed to stand for around twenty minutes. Then the calibrated pH meter was immersed in the suspension and the stable reading in the meter was noted after.

c. Soil temperature

Soil temperature was measured in the field with the soil thermometer.

3.3.3 Preservation and identification

The collected species was preserved in 70% ethyl alcohol. The collected specimen was sorted under stereomicroscope whereas the identification of species was done under phase contrast microscope considering morphological traits like antennae, body shape along with its color patterns, furcula structure. For the identification of species to genus level specimen slide was prepared in glycerol and for some pigmented specimen mounting medium used was lactic acid and glycerol in ratio of 3:1, then a cover glass was gently placed on the top and the slide was sealed with transparent nail polish. The fauna was identified with the help of relevant published taxonomic keys (Scott 1961, Chen & Christiansen 1993, Bellinger et al. 1996-2022, Wang et al. 2003, Deharveng & Bedos 2004, Tripplehorn & Johnson 2005, Hazra & Mandal 2007, Soto-Adames et al. 2008, Mandal & Hazra 2009, Pan et al. 2012, Greenslade et al. 2014, Fjellberg 2015, Hazra & Mandal 2015, Yu et al. 2016, Cipola et al. 2018, Ma 2018, Cipola et al. 2019, Mandal & Arbea 2019, Tripathy 2019, Zhang et al. 2019).

The identified species were well labelled with the taxonomic description, collection locality and date. The slides were kept in the slide box whereas other specimen was preserved in vials containing 70% alcohol and are deposited in CDZM–TU, Kirtipur, Nepal.

3.4 Data analysis

The data were managed in MS excel. Data were analysed by using Shannon–Weiner Diversity Index (H'), Pielou Evenness (J), Richness (S) in MS–excel 2016 for determination of diversity of fauna.

The diversity of species was calculated by using Shannon-Weiner diversity index (Shannon & Weiner 1948) designated as H´ and calculated as:

$H' = -\Sigma (Pi)*\ln (Pi)$

where,

Pi = the proportion of individuals in the ith species, Pi= ni/N

Ni = Number of individuals of ith species.

N = Total number of all individuals in the sample.

ln = Logarithm of base e.

The evenness index was determined by the following equation (Pielou 1969).

$E = H' / \log S$

where,

H´ = Shannon- Weiner's diversity index.

S = Total numbers of species in the sample.

Generalized Linear Model with Poisson distribution and log link function employed in the R-studio (R version 4.2.1) with lme4, MuMin, AICcmodavg packages was used to analyze the relation of Collembola fauna abundance with soil parameters. The relationship between fauna abundance and soil parameters were established by polynomial regression in PAST version 4.08. The best fit model for polynomial regression was selected on the basis of lowest AIC value significant at $P<0.05$. The species composition difference across the heterogenous environment within the garden was analysed by one–way ANOVA test in excel.

4. RESULTS

4.1 Diversity of Collembola fauna

The Collembola fauna in Coronation Garden is represented by 30 species belonging to three order, eight families and 17 genera (Table 1, Annex I). The species diversity of Coronation Garden, T.U. was found to be 2.63 whereas the evenness was 0.77. Among the 5,289 individuals of Collembola collected, *Hypogastrura* sp. 2 has the highest abundance and the species *Tomocerina* sp.3 and *Isotomiella* sp. have the lowest abundance in the Coronation Garden (Table 3).

Table 1: Genera of Collembola fauna recorded in Coronation Garden

Order	**Family**	**Genus**
Entomobryomorpha	Entomobryidae	*Entomobrya* sp.
		Sinella spp.
		Homidia spp.*
		Seira sp.*
		Lepidocyrtus spp.
	Paronellidae	*Cyphoderus* spp.
		Callyntrura sp.
		Dicranocentroides sp.
		Salina sp.*
	Isotomidae	*Isotomiella* sp.
		Isotomurus spp.*
		Procerura sp.*
	Tomoceridae	*Tomocerina* spp.
Poduromorpha	Hypogastruridae	*Hypogastrura* spp.
Symphypleona	Sminthuridae	*Sminthurus* spp.
	Dicyrtomidae	*Ptenothrix* spp.
	Katiannidae	*Stenognathellus* spp.

*- The genera *Homidia*, *Seira*, *Salina*, *Isotomurus* and *Procerura* are new genera record for Nepal and the diagnostic features (Bellinger et al. 1996-2022) of these genus are described in (Table 2).

Table 2: Diagnostic feature of newly recorded genera of Collembola for Nepal (Bellinger et al. 1996-2022)

S.No.	Genus	Diagnostic features
1.	*Homidia* spp.	- Body scale absent. - Dental crenulation present. - Mucro bidentate. - Presence of dental spines.
2.	*Seira* sp.	- Body scale present. - Presence of dental crenulation. - Falcate mucro.
3.	*Salina* sp.	- Smooth cylindrical dens. - Short tridentate mucro. - Bladder like appendage at the end of mucro.
4.	*Isotomurus* spp.	-Abdominal segments fourth, fifth and sixth distinct. - Anal spine absent. - Mucro 4 toothed. - Manubrium with more than 14 ventral setae. - Bothriotricha present in fourth abdominal segment.
5.	*Procerura* sp.	-Tridentate mucro. - No anal spine. - Fifth and sixth abdominal segment separate.

Entomobryidae, Paronellidae, Isotomidae, Tomoceridae, Hypogastruridae, Sminthuridae, Dicyrtomidae and Katiannidae are the recorded families of Collembola and the family Entomobryidae represents the highest number of genera followed by Paronellidae and Isotomidae (Figure 2). *Hypogastrura*, *Ptenothrix*, *Sminthurus* and *Cyphoderus* were the dominant genera in the Coronation Garden (Figure 3).

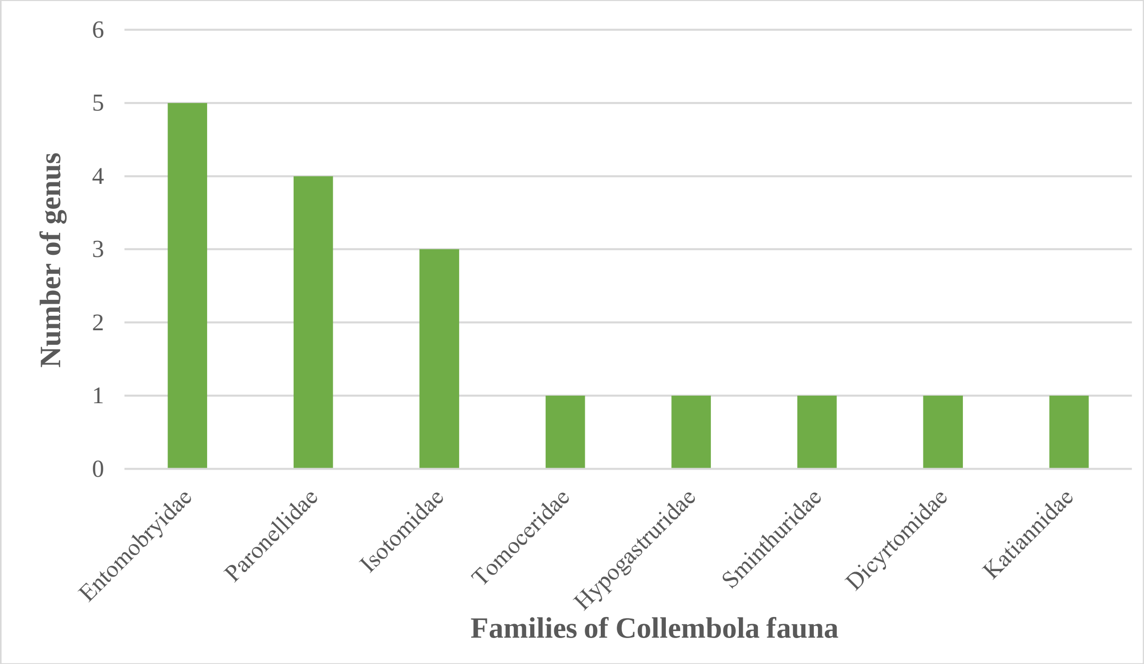

Figure 2. Number of observed genera within families of Collembola.

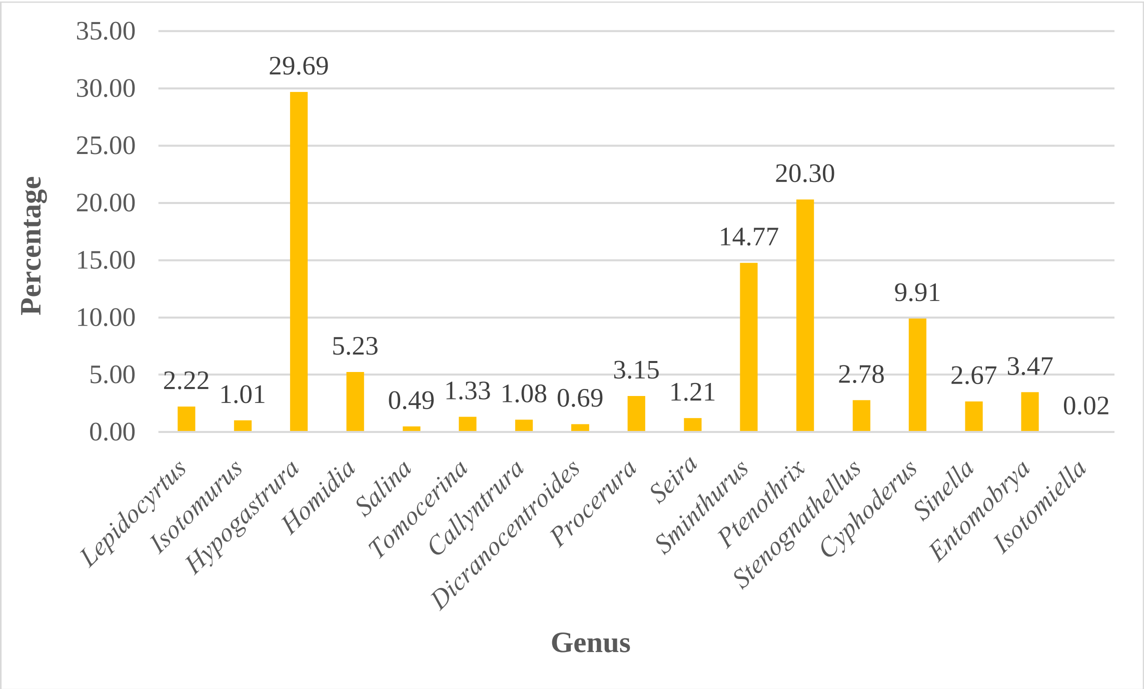

Figure 3. Generic composition of observed Collembola fauna**.**

Amongst the Collembola fauna collected, *Hypogastrura* sp.2 (24.45%) has the highest abundance followed by *Ptenothrix* sp.1 (16.37%) whereas *Tomocerina* sp.3 (0.02%) and *Isotomiella* sp. (0.02%) have the lowest abundance (Table 3) in the Coronation Garden during study period.

Table 3: Abundance of the recorded Collembola fauna in Coronation Garden

Species	**Number of individuals**	**Relative abundance (%)**
Lepidocyrtus sp.1	78	1.47
Lepidocyrtus sp.2	54	1.02
Isotomurus sp.1	11	0.21
Isotomurus sp.2	49	0.93
Hypogastrura sp.1	472	8.92
Hypogastrura sp.2	1293	24.45
Homidia sp.1	183	3.46
Homidia sp.2	128	2.42
Salina sp.	29	0.55
Tomocerina sp.1	13	0.25
Tomocerina sp.2	65	1.23
Tomocerina sp.3	1	0.02
Callyntrura sp.	64	1.21
Dicranocentroides sp.	41	0.78
Procerura sp.	187	3.54
15eir asp.	72	1.36
Sminthurus sp.1	111	2.10
Sminthurus sp.2	12	0.23
Ptenothrix sp.1	866	16.37
Ptenothrix sp.2	341	6.45
Stenognathellus sp.1	60	1.13
Stenognathellus sp.2	105	1.99
Cyphoderus sp.1	337	6.37
Cyphoderus sp.2	252	4.76
Sinella sp.1	157	2.97
Sinella sp.2	2	0.04

Entomobrya sp.	206	3.89
Isotomiella sp.	1	0.02
Isotomidae sp.	7	0.13
Entomobryinae sp.	92	1.74
Total	**5289**	

4.1.1 Seasonal diversity of Collembola fauna

The species richness, abundance and diversity of Collembola fauna was higher in spring season (S= 26, abundance= 4,286 and H´= 2.51) than the winter season (S= 19, abundance= 1003 and H´= 2.45) whereas the species were distributed more evenly in winter season than the spring season (Table 4).

Table 4: Diversity of Collembola in different seasons

	Winter	Spring
Species richness (S)	19	26
Abundance	1,003	4,286
Shannon-Weiner Diversity Index (H´)	2.45	2.51
Evenness (J)	0.83	0.77

4.1.2 Collembolan diversity across heterogenous environment within Coronation Garden

Table 5: Diversity of Collembola across heterogenous environment

	Species richness (S)	Abundance	Shannon-Weiner Diversity Index (H´)	Evenness (J)
Invasive vegetation	24	1,220	2.22	0.70
Non–invasive vegetation	21	1,311	2.15	0.71
Roadside vegetation	20	716	2.47	0.83
Near water source vegetation	26	1,988	2.21	0.68

Amongst the categorized heterogenous environment, the Collembola fauna was more diverse and evenly distributed in the roadside vegetation site (H= 2.47, J= 0.83) whereas the species richness and abundance were lowest in it (Table 5). The species richness and abundance were highest in sites with vegetation near to water flow (S= 26, abundance= 1988) but species evenness was lowest in it (Table 5). The diversity was lowest in the sites with non–invasive vegetation (H= 2.15).

4.2 Relation of Collembola fauna abundance with soil parameters

The relation of Collembola fauna abundance with soil parameters– pH, temperature and moisture were determined using Generalized Linear Model (GLM) in both winter and spring season. In both the season the soil pH, temperature and moisture have highly significant positive relation with the Collembola fauna abundance (Table 6 and Table 7).

Table 6: Generalized linear model (GLM) with Poisson distribution and log link function test showing the relations between Collembola fauna abundance with soil parameters in winter

Parameters	Estimate	Standard Error	Z–value	Pr(>|z|)
Intercept	–8.035634	0.675438	–11.897	<2e–16***
pH	0.965288	0.085017	11.354	<2e–16***
Temperature	0.217977	0.025815	8.444	<2e–16***
Moisture	0.051574	0.003047	16.929	<2e–16***

Table 7: Generalized linear model (GLM) with Poisson distribution and log link function test showing the relations between Collembola fauna abundance with soil parameters in spring

Parameters	Estimate	Standard Error	Z–value	Pr(>|z|)
Intercept	1.302952	0.213332	6.108	0.001***
pH	0.314258	0.035166	8.936	0.0002***
Temperature	0.058869	0.007399	7.956	0.001***
Moisture	0.018692	0.001838	10.172	0.0001***

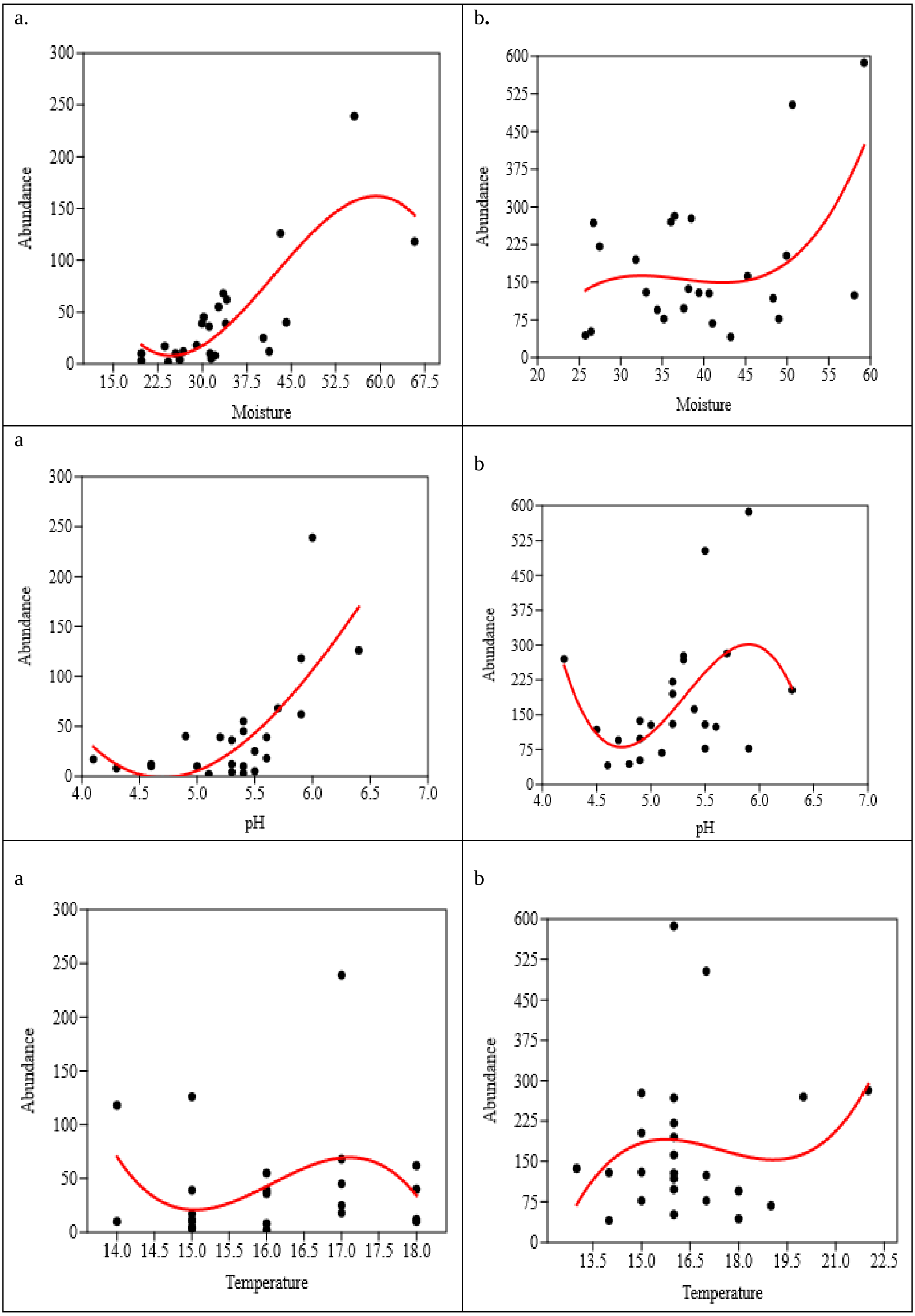

Figure 4. Relationship between Collembola abundance and soil parameters (moisture, pH, temperature) in a: winter season and b: spring season.

Table 8: Polynomial regression of species abundance with soil parameters (pH, temperature, moisture) in winter

Regression	pH	Temperature	Moisture
First order r^2	0.36	0.007	0.511
AIC	42155	65957	29136
Second order r^2	0.55	0.007	0.563
AIC	29827	65397	28984
Third order r^2	0.55	0.137	0.634
AIC	29648	57309	24231

Table 9: Polynomial regression of species abundance with soil parameters (pH, temperature, moisture) in spring

Regression	pH	Temperature	Moisture
First order r^2	0.1353	0.022	0.189
AIC	3.6914E05	4.176E05	3.6748E05
Second order r^2	0.149	0.022	0.225
AIC	3.6294E05	4.1757E05	3.307E05
Third order r^2	0.307	0.069	0.263
AIC	2.9598E05	3.9738E05	3.1476E05

The relationship between Collembola fauna abundance and soil parameters were established by polynomial regression in the PAST (Figure 4). The model selection based on lowest corrected Akaike Information Criterion values significant at $P< 0.05$. The polynomial regression analysis of third order was the best fit model for depicting relation of collembolan species abundance with moisture, pH and temperature (Figure.4, Table. 8 and Table. 9). In winter and spring, the abundance of species increased with high moisture content of soil. The pH range of 4.5–5.5 is favorable in both seasons and increase in abundance of species within this range. In both seasons with the increase in soil pH abundance of Collembola species increased. High abundance of species is favored by increase in soil temperature in winter as well as in spring season.

4.3 Species composition across heterogenous environment

Out of 30 species 18 species occurred across all the four categorised heterogenous environment (Figure 5). The species composition of invasive vegetation dominated site is mainly represented by *Hypogastrura* sp.2(39.92%), *Hypogastrura* sp.1(13.2%), *Sminthurus* sp.1(8.03%), *Homidia* sp.1(6.15%), *Ptenothrix* sp.2(5.90%) whereas the species dominantly present in non–invasive vegetation site are *Hypogastrura* sp.2(39.82%), *Hypogastrura* sp.1(13.04%), *Cyphoderus* sp.1(8.31%), *Homidia* sp.1(6.64%). Likewise, the dominant group of species of roadside vegetation are *Hypogastrura* sp.2(22.91%), *Hypogastrura* sp.1(6.42%), *Procerura* sp.(17.18%), *Cyphoderus* sp.1(10.61%), *Ptenothrix* sp.2(7.82%) and the main representative species of near water vegetation are *Ptenothrix* sp.1(42.05%), *Ptenothrix* sp.2(10.31%), *Cyphoderus* sp.1(6.34%), *Hypogastrura* sp.2(6.04%), *Stenognathellus* sp.2(5.28%).

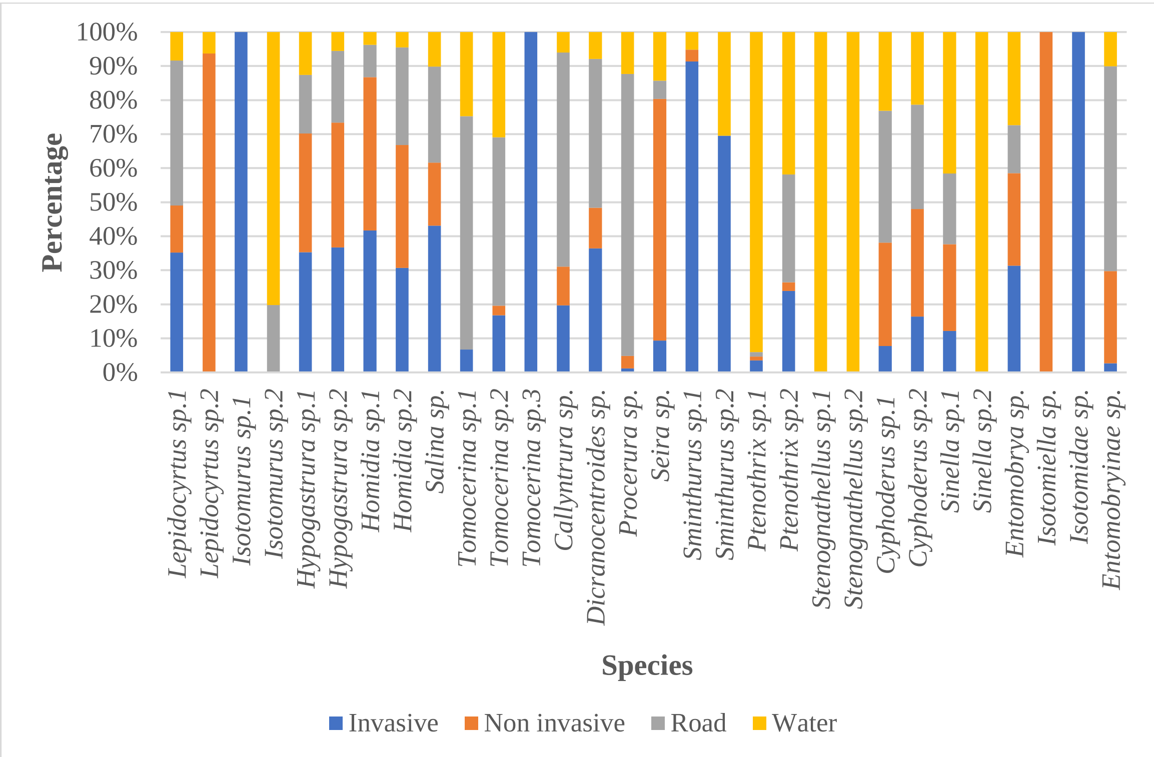

Figure 5. Percentage composition of Collembola fauna in heterogenous environment.

Table 10: One–way ANOVA difference in species composition across heterogenous environment

Source of Variation	SS	DF	MS	F	P–value	F crit
Between Groups	27353.82	3	9117.942	0.840	0.474	2.683
Within Groups	1258460	116	10848.8			
Total	1285814	119				

Note: SS = Sum of square, DF = Degree of freedom, MS = mean square

The result of one–way ANOVA (Table 10) revealed that there was no significant difference in species composition across the heterogenous feature within the coronation garden ($P=0.474>0.05$).

5. DISCUSSION

5.1 Diversity of Collembola fauna

The Collembola fauna in the Coronation Garden was represented by 30 species identified under 17 genera belonging to three order, eight families during study period. The order Entomobryomorpha is represented by four families Entomobryidae, Paronellidae, Isotomidae and Tomoceridae whereas Poduromorpha order is represented by family Hypogastruridae and order Symphpleona is represented by families Sminthuridae, Dicyrtomidae and Katiannidae. *Hypogastrura*, *Ptenothrix*, *Sminthurus*, *Cyphoderus* and *Homidia* are amongst the dominant genera of the Coronation Garden amongst 17 genera recorded. The family Entomobryidae represents the highest number of genera followed by Paronellidae and Isotomidae in the garden which is similar to the results obtained by (Yadav 2017, Yadav et al. 2017, Kerketta et al. 2018). The diversity of the Collembola fauna of the Coronation Garden, T.U. is high with diversity index 2.63 and the evenness 0.77 which might be due to the environmental heterogeneity within the garden (Takeda 2018). *Hypogastrura* sp. has the highest abundance in the Coronation Garden similarly *Hypogastrura* sp. was found having high abundance in forest and agroecosystem soil (Paul et al. 2011). *Hypogastrura* species is amongst the collembolan species showing mass emergence (Christiansen 1964) that might account for the highest abundance in the Coronation Garden. The species of genera *Willowsia* and *Dicranocentrus* were recorded from Ranibari Community Forest, Kathmandu (Shrestha 2021) whereas three species of genera *Willowsia*, *Dicranocentrus* and *Sminthurus* were recorded from T.U. Kirtipur area (Bhattarai 2021) but *Willowsia*, *Dicranocentrus* were not recorded in the Coronation Garden during study period only *Sminthurus* species was recorded amongst them.

The seasonal variation was observed in the species richness during winter and spring season. The species *Stenognathellus* sp.1, *Tomocerina* sp.1, *Tomocerina* sp.3 and Entomobryinae species was recorded in winter only whereas the species *Lepidocyrtus* sp.1, *Lepidocyrtus* sp.2, *Isotomurus* sp.1, *Isotomurus* sp.2, *Dicranocentrides* sp., *Procerura* sp., *Seira* sp., *Stenognathellus* sp.2, *Isotomiella* sp., *Sinella* sp.2 was recorded only in the spring season. The species diversity and number of springtails in spring was higher in comparison to winter season. Similar result was obtained with diversity high in spring than in winter (Bhagawati et al. 2018). The population of springtails was found high in winter and spring in comparison to the other season (Abbas 2012, Takeda 2018). The variation in fauna abundance with season might be due to the influence of increase in soil temperature and moisture from winter to spring season.

Across the four categorized sites in Coronation Garden, the species richness and abundance were highest in near water vegetation site. The carbon and nitrogen ratio was found to be high in the wetland soil (Vincent et al. 2018) since the site is characterized by marshy land feature that might have account for high abundance and richness species in the site. The species abundance and richness was lowest in the roadside vegetation in my study in comparison to other site contrastingly the fauna abundance was recorded highest in the roadside vegetation with respect to crop field margin, shady, open grassland (Islam et al. 2018). In comparison amongst the invasive plant dominated vegetation and non–invasive plant dominated vegetation site the species richness was high in invasive dominated vegetation whereas abundance was high in non–invasive dominated vegetation contrastingly there was no difference in Collembola richness and abundance amongst invaded and uninvaded plot (Rusterholz et al. 2014, Sterzyńska et al. 2017).

5.2 Relation of Collembola fauna abundance with soil parameters

In the study the temperature has significant positive effect on the abundance of the Collembola fauna in both the seasons (winter and spring). The soil temperature of the Coronation Garden ranged from 14°C–18° C in winter and 13°C–22°C in spring. Likewise, temperature has been found as an important factor for soil fauna distribution and has shown to have positive association with Collembola fauna abundance in the study in the university of Bangladesh (Islam et al. 2018) and findings are similar to (Paul et al. 2011) whereas temperature has negative correlation with springtail number in forest floor and cassava plots (Badejo & Van Straalen 1993) . Soil warming for longer time period has been found to cause decline in abundances of Collembola (Lindberg 2003).

The moisture content of soil of Coronation Garden varied from 19.73%–65.78% and 25.74–59.24% in winter and spring respectively and it was found to be significantly and positively related to Collembola fauna abundance. Likewise, moisture have significant positive effects in Collembola population in all seasons in (Hazra 1978, Badejo & Van Straalen 1993, Bhagawati et al. 2018, Bhagawati et al. 2021).

Soil pH was in acidic range in Coronation Garden ranging from 4.1–6.4 and 4.2–6.4 in winter and spring season respectively. The Collembola fauna abundance was found to be significantly positive with the pH range in both season in the study site. The number of species was directly proportional to the increasing soil pH (Hagvar 1982). The Collembola faunal density was negatively correlated with the soil pH (Mandal & Hazra 2009) while soil pH has no relation to the fauna population (Bhagawati et al. 2018). Soil pH showed insignificant relation in forest floor whereas significant positive relation in agroecosystem with Collembola diversity (Paul et al. 2011), the effect of soil pH on fauna population is varied in the study.

Collembola having cuticular respiration, the soil properties are crucial for their survival. The effect of soil temperature, moisture and pH with respect to Collembola fauna abundance, diversity have shown varied response in different studies, amongst soil parameters they are the important determining factor but along with it in environment there are numerous other biotic and abiotic factors which might have account for these variation in the results.

5.3 Species composition across heterogenous environment

Amongst the 30 species recorded in the study area 18 species were recorded in all the habitat. The species that were recorded from all the sites are *Lepidocyrtus* sp. 1, *Hypogastrura* sp.1, *Hypogastrura* sp.2, *Homidia* sp.1, *Homidia* sp.2, *Salina* sp., *Tomocerina* sp.2, *Callyntrura* sp., *Dicranocentroides* sp., *Procerura* sp., *Seira* sp., *Ptenothrix* sp. 1, *Ptenothrix* sp.2, *Cyphoderus* sp.1, *Cyphoderus* sp. 2, *Sinella* sp.1, *Entomobrya* sp., and Entomobryinae. The percentage composition of these 18 species does differ but due to their distribution across the heterogenous environment these can be considered as species with wide range of habitat preference in the study site. While *Isotomiella* sp. was recorded only from non-invasive vegetation site; *Isotomurus* sp.1, *Tomocerina* sp.3 and Isotomidae sp. found only in invasive plant dominated site whereas *Sinella* sp.2, *Stenognathellus* sp.1 and *Stenognathellus* sp.2 were encountered only in near water vegetation site. *Lepidocyrtus* sp.2 was found in non-invasive and near water vegetation plot; *Isotomurus* sp.2 in roadside and near water vegetation; *Tomocerina* sp.1 in invasive, near roadside and near water vegetation whereas *Sminthurus* sp.1 was recorded from all except roadside vegetation and *Sminthurus* sp.2 in invasive and near water vegetation. *Hypogastrura* species was dominant in all sites except near water vegetation. Besides Sminthurus sp.1, *Homidia* sp.1, *Ptenothrix* sp.1 and *Procerura* sp. was dominant in invasive, non-invasive, near water and roadside vegetation respectively. The species composition across the heterogenous feature of coronation garden showed no significant difference similar to (Paul et al. 2011) but the species composition differ across habitat in (Islam et al. 2018).

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The Coronation Garden in T.U. have high diversity of Collembola fauna represented by 30 species belonging to eight families and 17 genera. The genera *Homidia*, *Seira*, *Salina*, *Isotomurus* and *Procerura* are new record for Nepal collected from Coronation Garden. The species richness, diversity and abundance of the fauna are affected by the change in season, soil parameters and habitat heterogeneity. The species richness, diversity and abundance of fauna in spring is higher than the winter season. The faunal abundance has significant positive relation with the soil pH, moisture and temperature. The vegetation near to water flow sustain many species in high number in comparison to other habitats whereas the species diversity is higher and the distribution is more evenly along the roadside vegetation in the Coronation Garden. Since, Collembola fauna population are affected by soil parameters, seasonal variation and are abundant in soil, these attributes of them might contribute as useful indicator of change in soil conditions.

6.2 Recommendations

Taxonomically there are enormous possibilities to explore the new Collembola species in Nepal so the study should be carried covering all the season and diverse habitat coverage for the better exploration of the Collembola fauna.

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ANNEX

ANNEX I: The diagnostic character of the collected species (Bellinger et al. 1996-2022);

S.No.	Species	Diagnostic feature
1.	*Salina* sp. (New genus for Nepal)	Light yellow in color without scale and purple pigment longitudinal stripe dispersed from the side of thorax to abdomen as well in the joint of antennal segment and legs. Body size of 1.5 mm. Smooth cylindrical dens short tridentate mucro with bladder like appendage at the end of mucro. (Photo 19)
2.	*Callyntrura* sp.	Brown yellow colored with long antennae, body and head covered with scale with body size 4 mm. Smooth cylindrical dens, mucro lobed into 5 teeth. (Photo 21)
3.	*Dicranocentroides* sp.	Brown yellow colored with purple color pigmentation in the abdomen and joints of antenna and legs with body size 3 mm. Body covered with scales. Smooth cylindrical dens, dens and manubrium long and are equal sized; first and second antennal segments with thick outstanding brush setae. (Photo 20)
4.	*Procerura* sp. (New genus for Nepal)	Black colored, body size of 1mm with equal sized abdominal segments. Tridentate mucro, no anal spine, fifth and sixth abdominal segment separate. (Photo 29)
5.	*Seira* sp. (New genus for Nepal)	Yellow colored with dark purple color band on third thoracic and first three abdominal segment and on the tip of abdomen. Body size of 2.5 mm and covered with scales and hair. Presence of dental crenulation with falcate mucro. (Photo 15)
6.	*Entomobrya* sp.	White colored of size 1 mm with no body scales. Dental crenulation present; fourth abdominal segment at midline more than three times as long as third segment. (Photo 30)

7.	*Isotomiella* sp.	White color body; fourth abdominal segment longer than third; fourth and fifth abdominal segment separated and absence of eye and post antennal organ. (Photo 27)
8.	*Hypogastrura* sp. 1	First thoracic segment well developed on dorsal part, head is distinct; eye and post antennal organ present. Body pigmented black color of size 1mm. Mucro tapering with pointed tip, short anal spine and no extrusible sac in between third and fourth antennal segments. (Photo 1)
9.	*Hypogastrura* sp. 2	First thoracic segment well developed on dorsal part, head is distinct; eye and post antennal organ present. Body pigmented, brown color of size less 1mm. Mucro tapering with pointed tip, short anal spine and no extrusible sac in between third and fourth antennal segments. (Photo 2)
10.	*Homidia* sp. 1 (New genus for Nepal)	Light yellow colored with complete dark purple band on second and third abdominal segments and on the lower end of fourth abdominal segment. Body size 2.5 mm, scale absent, dental crenulation present, mucro bidentate and presence of dental spines. (Photo 13)
11.	*Homidia* sp.2 (New genus for Nepal)	Light yellow in color with purple color pigment disperse over thorax and abdomen. Body size 3 mm, scale absent, mucro bidentate, dental crenulation and dental spines present. (Photo 14)
12.	*Cyphoderus* sp.1	Milky white in color and absence of any pigment. Body size of 1.25 mm. Eyes and post antennal organ absent. Dental crenulation absent, dens with fringed setae and long mucro. (Photo 3)
13.	*Cyphoderus* sp.2	Transparent shiny water color and absence of any pigment. Body size 1 mm. Eyes and post antennal organ absent. Dental crenulation absent, dens with fringed setae and long mucro. (Photo 4)

14.	*Sinella* sp. 1	White in color, without scale, eyes 2+2, dental crenulation present. (Photo 5)
15.	*Sinella* sp.2	Light yellow in color, body without scale, eyes 2+2, dental crenulation present. (Photo 6)
16.	*Tomocerina* sp.1	Brown in color of length 2 mm and body covered with scales. Presence of four segmented long antennae, third antennal segment longer than fourth; third and fourth antennal segments annulated. Elongate mucro basally with two teeth; toothlet on basal dental tooth of mucro absent. (Photo 22)
17.	*Tomocerina* sp.2	Black colored with tinge of yellow among the joints, body covered with scales and 5 mm length body size. Antennae four segmented, third and fourth antennal segments annulated; third antennal segment longer than fourth. Elongate mucro basally with two teeth; toothlet on basal dental tooth of mucro absent. (Photo 23)
18.	*Tomocerina* sp.3	Black colored, body covered with scales and 6 mm length body size. Antennae four segmented, third and fourth antennal segments annulated; third antennal segment longer than fourth. Elongate mucro basally with two teeth; toothlet on basal dental tooth of mucro absent. (Photo 24)
19.	*Lepidocyrtus* sp. 1	Shining yellow colored, with purple pigment dispersed on third thoracic segment and on abdomen; purple color pigment on the tip of each antennal segment. Dental crenulation presents with bidentate mucro. Body scale truncate and finely striated. Mesothorax projects over head. (Photo 17)
20.	*Lepidocyrtus* sp. 2	Light brown colored body and light purple color antennae and eye. Dental crenulation with bidentate mucro. Mesothorax projects over head. (Photo 18)
21.	*Isotomurus* sp. 1	Yellow colored body with long black stripes at the both sides of throughout the body and transverse black band

	(New genus for Nepal)	at the tip of each segment of the body. The abdominal segments fourth, fifth and sixth are distinct. Anal spine absent, furcula present, mucro 4 toothed, manubrium with more than 14 ventral setae, bothriotricha present in fourth abdominal segment. (Photo 25)
22.	*Isotomurus* sp. 2 (New genus for Nepal)	Light grey colored with median longitudinal stripe from thorax to abdominal tip. The abdominal segments fourth, fifth and sixth are distinct. Anal spine absent, furcula present, mucro 4 toothed, manubrium with more than 14 ventral setae, bothriotricha present in fourth abdominal segment. (Photo 26)
23.	*Sminthurus* sp.1	Faint yellow colored with black patch on abdomen, body of size 1.5 mm. Subanal appendage present directed toward anus; fourth antennal segment longer than third; fourth antennal segment divided into subsegments and third antennal segment with strong setae and trunk dorsally with many macrosetae. (Photo 7)
24.	*Sminthurus* sp.2	Yellow colored with dispersed brown pigments over the abdomen and body length of 1.5 mm. Subanal appendage present directed toward anus; fourth antennal segment longer than third; fourth antennal segment divided into subsegments and third antennal segment with strong setae and trunk dorsally with many macrosetae. (Photo 8)
25.	*Ptenothrix* sp.1	Yellow colored with reddish brown stripe at the both sides from head to abdomen and body size 1.2 mm. Subanal appendage present; third antennal segment longer than fourth. Bothriotrichium D present; abdomen posteriorly with short spines. (Photo 9)
26.	*Ptenothrix* sp.2	Yellow colored with the black pigment pattern over the abdomen and body size of 1 mm. Subanal appendage present; third antennal segment longer than fourth.

		Bothriotrichium D present; abdomen posteriorly with short spines and two median clypeal setae. (Photo 10)
27.	*Stenognathellus* sp.1	Body black colored and of size 0.6 mm. Subanal appendage present directed toward genital opening; with capitate tenant hairs. Head and mouthparts elongated. (Photo 11)
28.	*Stenognathellus* sp.2	Whole body black colored except the anterior head region yellow colored and of size 1 mm. Subanal appendage present directed toward genital opening; with capitate tenant hairs. Head and mouthparts elongated. (Photo 12)
29.	Entomobryidae sp.	Body clothed with setae with dispersed purple pigment. Dental crenulation and spines present, mucro short and bidentate. (Photo 16)
30.	Isotomidae sp.	Light brown color. Fourth, fifth and sixth segment distinct; tridentate mucro. (Photo 28)

ANNEX II: Number of species recorded in winter and spring;

S.No.	Species	Winter	Spring
1	*Lepidocyrtus* sp.1	0	78
2	*Lepidocyrtus* sp.2	0	54
3	*Isotomurus* sp.1	0	11
4	*Isotomurus* sp.2	0	49
5	*Hypogastrura* sp.1	38	434
6	*Hypogastrura* sp.2	72	1221
7	*Homidia* sp.1	51	132
8	*Homidia* sp.2	18	110
9	*Salina* sp.	14	15
10	*Tomocerina* sp.1	13	0
11	*Tomocerina* sp.2	4	61
12	*Tomocerina* sp.3	1	0
13	*Callyntrura* sp.	24	40
14	*Dicranocentroides* sp.	0	41
15	*Procerura* sp.	0	187
16	*Seira* sp.	0	72
17	*Sminthurus* sp.1	16	95
18	*Sminthurus* sp.2	5	7
19	*Ptenothrix* sp.1	240	626
20	*Ptenothrix* sp.2	5	336
21	*Stenognathellus* sp.1	60	0
22	*Stenognathellus* sp.2	0	105
23	*Cyphoderus* sp.1	127	210
24	*Cyphoderus* sp.2	96	156
25	*Sinella* sp.1	54	103
26	*Sinella* sp.2	0	2
27	*Entomobrya* sp.	73	133

28	*Isotomiella* sp.	0	1
29	Isotomidae sp.	0	7
30	Entomobryinae sp.	92	0

ANNEX III: Habitat and season of collection of Collembola species

S.No.	Species	Collection habitat site	Season
1	*Lepidocyrtus* sp.1	Invasive, non-invasive, near to water and road vegetation.	Spring
2	*Lepidocyrtus* sp.2	Non-invasive, near to water vegetation.	Spring
3	*Isotomurus* sp.1	Invasive vegetation.	Spring
4	*Isotomurus* sp.2	Near water and road side vegetation.	Spring
5	*Hypogastrura* sp.1	Invasive, non-invasive, near to water and road side vegetation	Winter, Spring
6	*Hypogastrura* sp.2	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
7	*Homidia* sp.1	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
8	*Homidia* sp.2	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
9	*Salina* sp.	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
10	*Tomocerina* sp.1	Invasive, near water and road side vegetation.	Winter
11	*Tomocerina* sp.2	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
12	*Tomocerina* sp.3	Invasive vegetation.	Winter
13	*Callyntrura* sp.	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
14	*Dicranocentroides* sp.	Invasive, non-invasive, near to water and road side vegetation.	Spring

15	*Procerura* sp.	Invasive, non-invasive, near to water and road side vegetation.	Spring
16	*Seira* sp.	Invasive, non-invasive, near to water and road side vegetation.	Spring
17	*Sminthurus* sp.1	Invasive, non-invasive and near to water vegetation.	Winter, Spring
18	*Sminthurus* sp.2	Invasive and near water vegetation.	Winter, Spring
19	*Ptenothrix* sp.1	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
20	*Ptenothrix* sp.2	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
21	*Stenognathellus* sp.1	Vegetation near water.	Winter
22	*Stenognathellus* sp.2	Vegetation near water.	Spring
23	*Cyphoderus* sp.1	Invasive, non-invasive, near to water and road side vegetation.	Winter, Spring
24	*Cyphoderus* sp.2	Invasive, non-invasive, near to water and road vegetation.	Winter, Spring
25	*Sinella* sp.1	Invasive, non-invasive, near to water and road vegetation.	Winter, Spring
26	*Sinella* sp.2	Vegetation near water.	Spring
27	*Entomobrya* sp.	Invasive, non-invasive, near to water and road vegetation.	Winter, Spring
28	*Isotomiella* sp.	Non-invasive vegetation.	Spring
29	Isotomidae sp.	Invasive vegetation.	Spring
30	Entomobryinae sp.	Invasive, non-invasive, near to water and road vegetation.	Winter

ANNEX IV: Location of collection sites of Collembola in Coronation Garden

Habitat	Sampling plot	Latitude N	Longitude E	Elevation m
Invasive	P1	27.6813°	85.2867°	1313
Invasive	P2	27.68085°	85.28687°	1293
Invasive	P3	27.6806°	85.2866°	1295
Invasive	P4	27.6803°	85.2864°	1305
Invasive	P5	27.6801°	85.2859°	1304
Invasive	P6	27.6799°	85.2855°	1312
Non-invasive	P7	27.6802°	85.2901°	1295
Non-invasive	P8	27.6805°	85.2897°	1310
Non-invasive	P9	27.6809°	85.2898°	1291
Non-invasive	P10	27.6807°	85.2903°	1292
Non-invasive	P11	27.6806°	85.2905°	1289
Non-invasive	P12	27.6801°	85.2904°	1289
Roadside	P13	27.6798°	85.2917°	1298
Roadside	P14	27.6795°	85.2909°	1313
Roadside	P15	27.6793°	85.2902°	1307
Roadside	P16	27.6791°	85.2894°	1313
Roadside	P17	27.679°	85.2887°	1317
Roadside	P18	27.6789°	85.2881°	1321
Near Water	P19	27.6803°	85.2913°	1283
Near Water	P20	27.6799°	85.2908°	1303
Near Water	P21	27.6799°	85.2905°	1295
Near Water	P22	27.68°	85.29°	1302
Near Water	P23	27.6801°	85.2893°	1309
Near Water	P24	27.6802°	85.2877°	1307

PHOTO PLATES

Photo 1. *Hypogastrura* sp.1

Photo 2. *Hypogastrura* sp.2

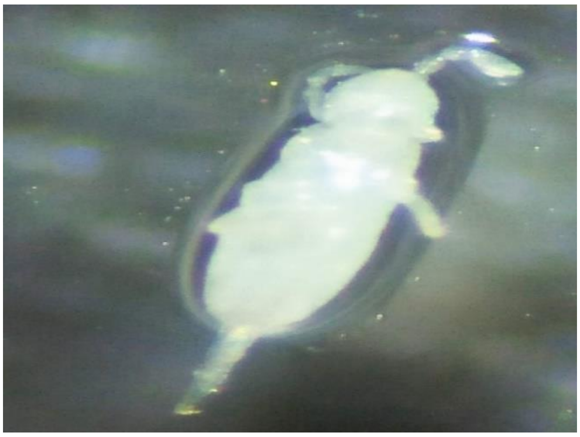

Photo 3. *Cyphoderus* sp.1

Photo 4. *Cyphoderus* sp.2

Photo 5. *Sinella* sp.1

Photo 6. *Sinella* sp.2

Photo 7. ***Sminthurus*** **sp.1**

Photo 8. ***Sminthurus*** **sp.2**

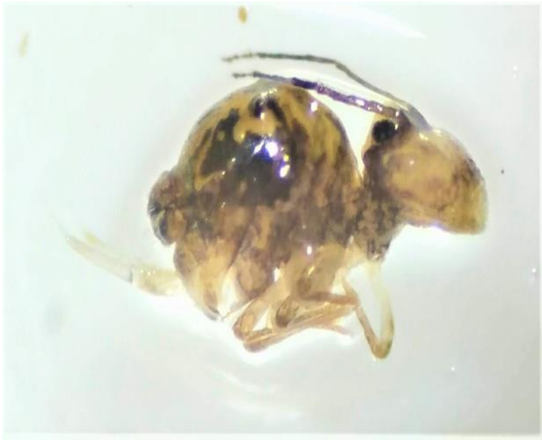

Photo 9. ***Ptenothrix*** **sp. 1**

Photo 10. ***Ptenothrix*** **sp. 2**

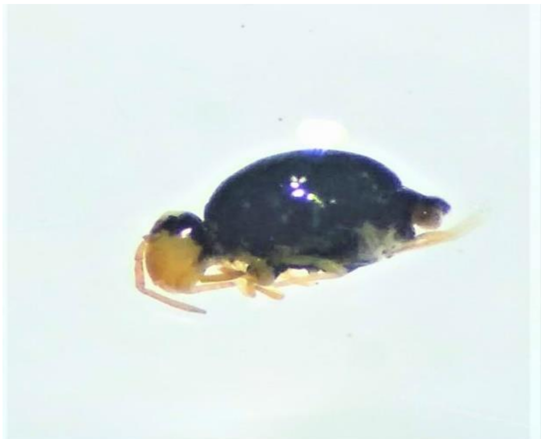

Photo 11. ***Stegnognathellus*** **sp.1**

Photo 12. ***Stenognathellus*** **sp.2**

Photo 13. ***Homidia*** **sp.1 (New genus)**

Photo 14. ***Homidia*** **sp.2 (New genus)**

Photo 15. ***Seira*** **sp. (New genus)**

Photo 16. Entomobryinae sp.

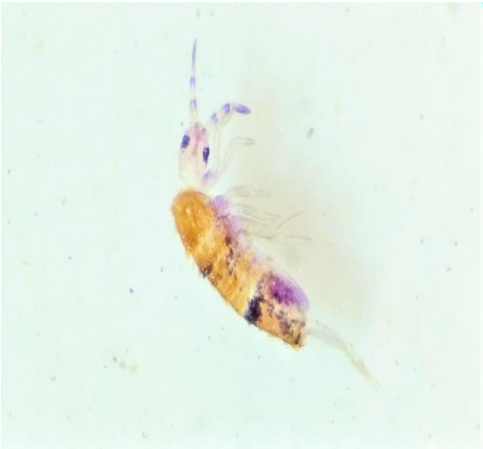

Photo 17. ***Lepidocyrtus*** **sp.1**

Photo 18. ***Lepidocyrtus*** **sp.2**

Photo 19. ***Salina*** **sp. (New genus)**

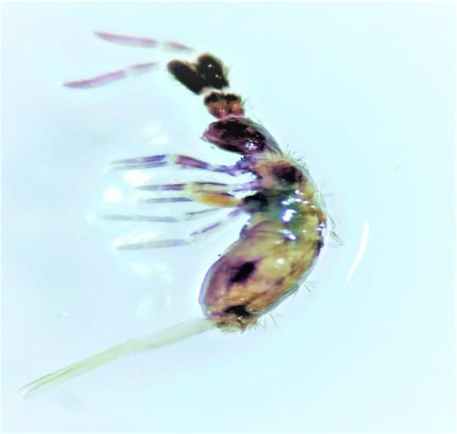

Photo 20. ***Dicranocentroides*** **sp.**

Photo 21. ***Callyntrura*** **sp.**

Photo 22. ***Tomocerina*** **sp.1**

Photo 23. ***Tomocerina*** **sp. 2**

Photo 24. ***Tomocerina*** **sp.3**

Photo 25. ***Isotomurus*** **sp.1 (New genus)**

Photo 26. ***Isotomurus*** **sp.2 (New genus)**

Photo 27. ***Isotomiella*** **sp.**

Photo 28. Isotomidae sp.

Photo 29. ***Procerura*** **sp. (New genus)**

Photo 30. ***Entomobrya*** **sp.**