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Investigations on soil nematode diversity in three contrasting habitat types in Bolu, Turkey

Bolu İli'nde üç farklı habitat tipinde karasal nematod topluluklarındaki çeşitliliğinin incelenmesi

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Abstract

The study investigated nematode diversity in three contrasting habitat types around the Yeniçağa Lake, Bolu Province, Turkey, in 2019 and 2020. The Shannon-Wiener index was used to evaluate nematode diversity in different taxonomic categories (order, family and genus level), trophic group and colonizer-persister (c-p) group in grassland, cropland and peatland in two locations, Hamzabey and Adaköy, in the Yeniçağa Lake Reserve. The results revealed that there was statistically significant variation in the composition of nematode fauna between the study sites by the assessments of the higher taxa whereas genus level and family level lower taxa did not differentiate such variation in Hamzabey and Adaköy. In addition, the variation in nematode diversity in relation to soil types were better reflected by assessing the trophic group structures rather than the c-p groups. The findings indicated that the diversity at higher taxa might serve as a better indicator than the diversity of lower taxa (family and genera) variation among the habitat types of the study areas.

Keywords: C-p groups, diversity, indicator, terrestrial nematodes

Öz

Çalışma, 2019 ve 2020 yıllarında Bolu İli'ndeki Yeniçağa Gölü çevresinde üç farklı habitat tipi altında nematod çeşitliliğini incelemiştir. Shannon-Wiener indeksi, Yeniçağa Gölü rezerv alanındaki Hamzabey ve Adaköy lokasyonlarında otlak, tarım arazisi ve turbalık alanlardan üç arazi tipinde farklı taksonomik kategorileri (takım, familya ve cins seviyesi), trofik grup ve kolonizör-persister (c-p) grupları ve nematod çeşitliliğini değerlendirmek için kullanılmıştır. Sonuçlara göre, çalışma sahaları arasında nematod fauna kompozisyonunda, takım seviyesindeki taksonlarda istatistiksel olarak önemli farklılıklar olduğunu, cins seviyesi ve familya seviyesindeki düşük taksonlarda ise Hamzabey ve Adaköy'deki varyasyonları ayırt etmede daha zayıf kaldığı görülmüştür. Ayrıca, toprak tiplerine göre nematod çeşitliliğindeki varyasyonlar, c-p grupları yerine trofik grup yapıları değerlendirildiğinde daha iyi sonuçlar alınmıştır. Bulgular, yüksek taksonlardaki çeşitliliğin daha düşük taksonlara (familya ve cins) göre, çalışma alanındaki habitatlar arası farkın ayırımında daha iyi bir gösterge olabileceğini ortaya koymuştur.

Anahtar sözcükler: C-p grupları, çeşitlilik, indikatör, karasal nematodlar

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Introduction

Nematodes are one of the most important organisms in terrestrial habitats from which to draw information about the state of the ecosystem in which they live by analyzing their diversity. Due to their commonality and prevalence, which can exceed 10^6 individuals/m^2, they are a useful tool for studying soil biodiversity (Bongers & Bongers, 1998). Nematode diversity can vary widely depending on the type of ecosystem (Boag & Yeates, 1998; Nielsen et al., 2014; Song et al., 2017; Melakeberhan et al., 2021), and assessing nematode diversity in terrestrial habitats has been widely adopted as a research method.

Community structure of nematodes can reflect the state of soil biodiversity, soil conditions, including a source of information as the indicator of nutrient availability in ecosystems, and the current state of soil biota (Neher & Barbercheck, 1998; Ferris et al., 2001, 2012; Ferris & Tuomisto, 2015). Thus, due to their diversity and adaptability, they become the most functional secondary consumers of the soil fauna (Ferris et al., 2001; Mulder et al., 2005). As a reliable soil ecological indicator, they are expected to possess the potential reliable ecological soil indicator that can accurately determine the effects of soil variables on the soil biota. Any relationship with ecosystem services and fauna composition of nematodes still has some uncertainty, and there are no set of rules and protocols to follow, therefore; most assemblages of nematodes have shortcomings to rely on a single evaluation tool (Neher & Darby, 2009).

Nematodes have a number of biological characteristics that give them priority as the indicator organisms over other organisms in environmental monitoring programs since nematodes are easy to isolate from soil, they are relatively easier to examine under a light microscope and no deep expertise is needed to count and allocate to trophic groups (Freckman, 1988). These communities in various terrestrial habitats and in almost all parts of the world have been extensively studied. Taxon diversity is one of the most common methods of assessing nematode diversity whereas some researchers prefer to use indices of nematode fauna (Bhusal et al., 2014). Like all other organisms, nematodes are classified into taxonomic categories and assigned to certain groups depending on their ecological role in the soil environment, and it is also possible to assign nematodes to functional groups, e.g., trophic adaptations and c-p groups (colonizer-persister), or combining both groups (Bongers & Bongers, 1998; Ferris et al., 2001; Yeates, 2003). Nematodes at the genera level can react differently to environmental change (Fiscus & Neher, 2002; Zhao & Neher, 2013). The Shannon-Wiener index (H') has been a widely used tool to define the diversity of the terrestrial nematode fauna (Yeates & Bongers, 1999; Neher & Darby, 2009). H' gives the best results for rare specimens (Neher & Darby, 2009; Zhao et al., 2014). A c-p scaling has been formulated including determining the ordination of nematode life-history strategy based on the ability of taxa to colonize and persist in habitats (Bongers, 1990).

A nematode community is usually arranged into feeding groups, i.e., bacterivores, fungivores, herbivores, omnivores and predators. Also, each nematode family can be allocated into a c-p scale (1-5) based on the idea that closely related species have similarities in terms of life-history traits based on an affinity in phylogenetic origin, morphology, anatomy, physiology and genetics (Bongers, 1990).

Although, there are numerous studies around the world on the influence of habitat and environmental variables on nematode community assemblages, large scale studies on the diversity of the nematode communities are not always applicable to every geographical region due to the existing variation from region to region, habitat to habitat. Therefore, local studies on nematode assemblages and some taxa associated with certain disturbances are considered more reliable and informative for land use in local areas. As such, this study collected data for the study area based on the local nematode communities affected by the Yeniçağa Lake surrounding habitat types which mainly differ in soil composition and land use regimes.

In the present study, H' was used to assess the taxonomic diversity of nematodes and c-p groups in grassland, cropland and peatland in the Lake Yeniçağa Reserve (Adaköy and Hamzabey) in Bolu Province of Turkey. The aim of this study was to determine (1) if the analysis of nematode diversity requires fine-level arrangements to monitor environmental differences between habitats, and (2) how the taxonomic diversity, trophic groups and c-p groups reflect environmental differences.

Materials and Methods

Study site

Lake Yeniçağa is located in Bolu, in the northwestern Black Sea Region, Turkey. The climate of the area is influenced by a warm temperate climate regime in the summer season and a cool and rainy in the winter season. Lake Yeniçağa lies between the 40º46'12"-40º47'24" N and 32º00'36"-32º02'24" E and extends over an area of about 2.78 km^2 with surroundings. The lake is located at an altitude of 990 m above sea level with the following characteristics: shallow, non-stratified, with a surface area of about 1.8 km^2, and an average depth of 4 m. The water level usually fluctuates depending on the season and extends to the surrounding reedy and peat zones.

Soil samples were collected from the Lake Yeniçağa study areas (Adaköy and Hamzabey) by selecting three types of habitat in each site: peatland, grassland and cropland. The peatland was the closest to the lake with minor disturbance; grassland was second after peatland with a typical transition zone with a high organic matter than arable land used as pasture for domestic animals and arable land with a slightly sloppy mineral soil structure that was cultivated for wheat and barley and/or maize.

Sampling

Soil samples were collected in May, July, and September 2018 and 2019 from three types of habitat in two locations. Thirty-two sampling sites were marked from each land cluster and a total of 96 samples were collected. The sampling points were in an S-shape for analyzing soil nematode communities across the entire area of each site. Each soil sample was taken from five sub-sampling points, which were then mixed thoroughly to produce a composite sample. All soil samples were placed in sterile plastic bags, in a box to keep cool and protect from sunlight before being transported to the laboratory.

Soil properties of the study site were as follows. Peat soils were dark in color due to the high content of the organic matter (≥50%). Arable land was loamy with 1-2% organic matter content, neutral to alkaline mineral soils. The grassland soil was between the peat and arable land soil having both types of properties especially high content of organic matter (≥15-20%).

Extraction and identification of nematodes

To extract nematodes from the samples, 100 g of soil was processed by using the Cobb sieving method (van Bezooijen, 2006). Each soil sample was immersed in 1 L of water for 60 min to allow soil clumps to dissolve and allow nematodes to move into the water. The suspension was then gently poured onto a 1-mm sieve to remove the debris and allowed to settle for 2 min in a 10 L bucket. The sample suspension was then poured onto a fine sieve (50 µm) to remove fine particles from the suspension containing nematodes. The resultant suspension was then poured onto cotton filter discs placed on Baermann funnels, and the nematodes were left to migrate to the bottom of the funnels over 24 h. Finally, the accumulated nematodes were collected from the tips of the funnels.

The nematodes were immediately counted to determine the total number using a stereomicroscope at 40× magnification and preserved in 4% hot formaldehyde. Temporary mounts of the nematode suspension were made, and nematodes were identified using a compound microscope at 400× magnification to the genus level, with the exception of individuals belonging to the Rhabditidae according to Bongers (1994).

Nematode trophy groups were defined as described in Yeates et al. (1993) and Okada et al. (2005); and the c-p g scale (1-5) were classified according to descriptions of Bongers & Bongers (1998).

Data analysis

In order to study the diversity of the nematodes, they were allocated to genera, families and orders to test the impact of the taxonomic composition. Although the division of nematodes into trophic groups and c-p groups in which nematodes are grouped into a 1-5 scale based on their sensitivities to the environmental differences besides their r-K life strategist features, is usually also based on the properties of the genera and family features (Yeates et al., 1993; Bongers & Bongers, 1998), and the feeding types (trophic groups) were identified based on the food preference of nematodes based on the structure of mouthparts described by Yeates et al. (1993) and Okada et al. (2005).

H' enables the weighting of rare specimens with the formula: $H' = -\Sigma P_i (\ln P_i)$, where P is the proportion of in the i-th taxon for the entire community (McSorley & Frederick, 1996; Pen-Mouratov et al., 2003; Pen-Mouratov & Steinberger, 2005). H' is frequently used to obtain information from various classification levels and varying mixed groups. However, the data require logarithmic transformation (x + 1) to adjust variance for normality and uniformity. The occurrence of nematodes was calculated as sites with nematodes/total sites × 100. To assess variation in the nematode compositions, a one-way ANOVA was calculated for habitat types. In case, the ANOVA result was significantly different ($P < 0.05$), the LSD test was run to evaluate the variation between the habitat types. In addition, Tamhane's (T2) was employed when the transformed data variances were not at the desired level to assess the effect of habitat type variation on nematode composition. One-way ANOVA calculations were performed using the SPSS24 (IBM, Armonk, NY, USA).

Results

Forty taxa of nematodes were recovered from the soil samples: Fifteen taxa of plant parasites, thirteen bacterivores, four fungivores, two predators and six omnivores. The abundance of nematodes ranged from 2 to 420 nematodes/100 g of soil and total numbers of 482 to 2,485 nematodes/100 g of soil in the samples. The abundance and frequencies of recovered nematodes are given in Table 1.

Diversity of nematode community

Diversity patterns of the order, family and genus of nematode generated by H' had significant differences ($p < 0.05$) among the three types of habitat (grassland, cropland, and peatland) in the two locations: Adaköy and Hamzabey in the Lake Yeniçağa lake reserve areas (Figure 1).

In Hamzabey, H' of cropland was significantly higher at the order level when compared to grassland and peatland. Significant differences ($p < 0.05$) were also found between the grassland and peatland at the order level (Figure 1a). In the family, H' of grassland and cropland differed significantly ($p < 0.05$) from peatland but not significantly between grassland and cropland (Figure 1c). At the genus level, H' of cropland was significantly ($p < 0.05$) higher than that of grassland and peatland, but significantly different between grassland and cropland (Figure 1c).

In Adaköy, H' for the grassland and cropland was significantly ($p < 0.05$) higher than that of peatland at the order level whereas there was no significant difference between the cropland and grassland at the order level (Figure 1d). H' of grassland was significantly ($p < 0.05$) different from that of cropland and peatland in the family level, but significantly different between cropland and peatland (Figure 1e). At the genus level, H' of grassland had a significantly ($p < 0.05$) higher value than that of cropland and peatland but was significantly different between cropland and peatland (Figure 1f).

Table 1. The incidence values of nematode communities in grassland, cropland, and peatland areas (mean±SEM)

Nematode	Cropland		Grassland		Peatland	
	Abundance	Occurrence (%)	Abundance	Occurrence (%)	Abundance	Occurrence (%)
Plant Parasitic						
Helicotylenchus Steiner, 1945	7.6±2.2	38.6	6.4±1.8	22.5	4.5±1.6	13.5
Rotylenchus Linford & Oliveira, 1940	1.4±0.2	8.2	2.2±0.6	12.8	0.5±0.2	3.8
Heterodera Schmidt, 1871	1.2±0.1	8.3	0±0.0	0.0	0±0.0	0.0
Meloidogyne Göldi, 1889	1.4 ±0.1	4.3	0±0.0	0.0	0±0.0	0.0
Merlinius Siddiqi, 1970	42.4 ±4.2	72.5	48.6 ±5.1	76.4	31.5 ±5.1	36.7
Tylenchorhynchus Cobb, 1913	51.4 ±4.9	75.8	46.8 ±5.1	69.7	36.4 ±5.1	43.8
Paratylenchus Micoletzky, 1922	12.8 ±2.1	36.8	20.4 ±3.2	43.4	10.2 ±2.1	23.1
Pratylenchoides Winslow, 1958	21.2±2.2	43.7	28.6±2.2	51.8	16.2±2.8	26.5
Pratylenchus Filipjev, 1936	22.4 ±3.9	56.4	34.5 ±3.2	73.8	6.6 ±2.8	36.6
Trophurus Loof, 1956	0.6±0.2	4.7	0.4±0.2	3.2	0±0.0	0.0
Paratrophurus Arias, 1970	0.8±0.3	6.8	0±0.0	0.0	0.6±0.4	4.1
Filenchus Andrassy, 1954	70.6±7.4	64.4	0±0.0	0.0	0±0.0	0.0
Tylenchus Bastian, 1865	26.8 ±4.2	28.6	36.8 ±5.3	64.4	18.4 ±3.4	22.4
Psilenchus De Man, 1921	0.8 ±0.2	4.2	1.5 ±0.4	8.9	0.6 ±0.8	2.1
Criconema Hofmanner & Menzel, 1914	46.5±8.6	35.4	58.4±9.2	52.8	32.4±3.5	26.3
Bacterivores						
Rhabditis Dujardin, 1845	26.4±5.7	65.8	38.2±9.2	70.4	15.3±1.4	34.1
Monhysteridae De Man, 1876	74.4±5.4	88.7	80.6±6.5	92.4	55.4±1.6	62.4
Cephalobus Bastian, 1865	123.2±11.6	100.0	132.8±6.5	100	84.6±1.6	92.5
Eucephalobus Steiner, 1936	102.6±8.8	100.0	118±5.5	100	84.6±1.6	92.5
Acrobeloides Cobb, 1924	108.6±9.8	100.0	55.4±4.8	84.5	38.4±3.4	45.4
Acrobeles Von Linstow, 1877	88.6±5.5	96.4	64.8±6.3	76.3	42.4±4.6	49.8
Achramodora	5.9±0.8	18.8	8.7±0.6	24.4	0±0.0	0.0
Cervidellus Thorne, 1937	4.4±0.6	21.4	0.±0.0	0.0	6.7±0.7	24.4
Alaimidae Thorne 1934	2.2±0.2	11.2	0±0.0	0.0	0±0.0	0.0
Alaimus De Man, 1880	6.2±5.5	14.3	8.3±0.6	26.4	2.9±0.6	6.4
Wilsonema Cobb, 1913	4.8±0.6	11.4	6.3±0.8	17.6	3.2±0.2	4.2
Plectus Bastian, 1865	88.4±4.6	92.8	103.4±5.5	100	52.4±4.8	70.4
Panagrolaimus	1.1±0.1	4.5	0±0.0	0.0	0±0.0	0.0
Fungivores						
Aphelenchoides Fischer, 1894	82.8±5.4	100.0	114.8±8.4	100	66.8±5.9	86.8
Aphelenchus Bastian, 1865	66.6±7.9	98.8	94.6±4.5	96.5	64.6±6.5	72.8
Ditylenchus Filipjev, 1936	48.8±5.4	79.6	86.6±6.4	88.4	58.6±4.9	68.8
Tylencholaimus De Man, 1876	0±0.0	0.0	0±0.0	0.0	4.6±0.4	8.2
Predators						
Mononchus Bastian, 1865	1.9±0.4	22.2	1.4±0.5	65.6	0.6±6.5	12.4
Seinura Fuchs, 1931	0.6±0.1	18.2	1.1±0.2	36.4	0±0.0	0.0
Omnivores						
Dorylaimidae De Man, 1876	2.9±0.5	6.6	3.4±0.8	8.8	1.6±0.9	8.8
Dorylaimus Dujardin, 1845	0±0.0	0.0	1.4±0.6-2	5.4	0±0.0	0.0
Mesodorylaimus Andrassy 1959	0.9±0.2	5.4	0.8±0.8	4.2	0.4±0.1	1.2
Prodorylaimus	10.2±0.7	11.4	12.4±0.6	14.6	6.8±0.8	7.2
Aporcelaimus Thorne & Swanger, 1936	5.9±1.1	8.4	0±0.0	0.0	5.5±0.7	6.9
Aporcelaimellus Heyns, 1965	44.2±3.4	74.6	48.6±1.4	85.4	78.4±4.6	54.4

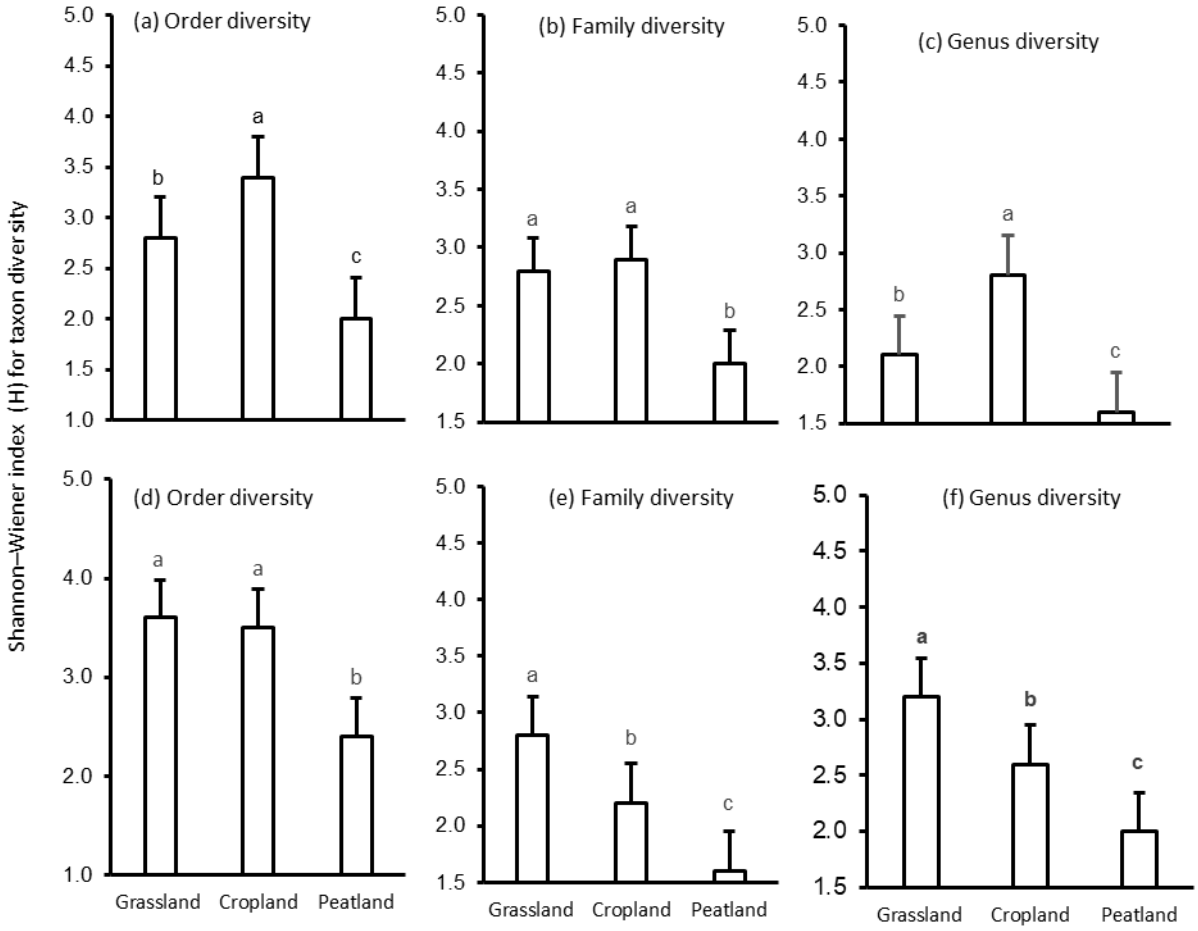

Figure 1. Distribution of Shannon-Wiener indices indicating the taxonomic structure of study sites (Hamzabey (a-c) and Adaköy (d-f) and significance levels ($P < 0.05$) and SEM for each study plot.

Diversity indices for trophic structure

The trophic structure of the nematode community and H' had significant differences ($p < 0.05$) among the three types of habitat in the two reserve areas (Figure 2). In Hamzabey, H' of bacterivores, and fungivores for the peatland was significantly lower ($p < 0.05$) than that of grassland and cropland. It was also significantly lower for the grassland than for the cropland (Figure 2a, b). There were no significant differences in the value of H' of herbivores nematodes among the three habitats (Figure 2c). H' of defining the omnivores was significantly higher in the grassland when compared to the cropland and peatland. Also, it had a significantly lower value in the cropland than in the peatland (Figure 2d). H' of the predator nematodes had no significant difference between grassland, cropland and peatland (Figure 2e).

In Adaköy, the cropland and grassland had higher index values that might be associated with H' of cropland and peatland for bacterivores, and fungivores. There were also significant differences ($p < 0.05$) between cropland and grassland (Figure 2g, f). For the herbivores and omnivores, H' was significantly higher value for the grassland than for peatland and cropland. There was a significant difference ($p < 0.05$) between the cropland and peatland (Figure 2h, i). Also, the H' was significantly higher for the grassland than the cropland and peatland for predators (Figure 2j).

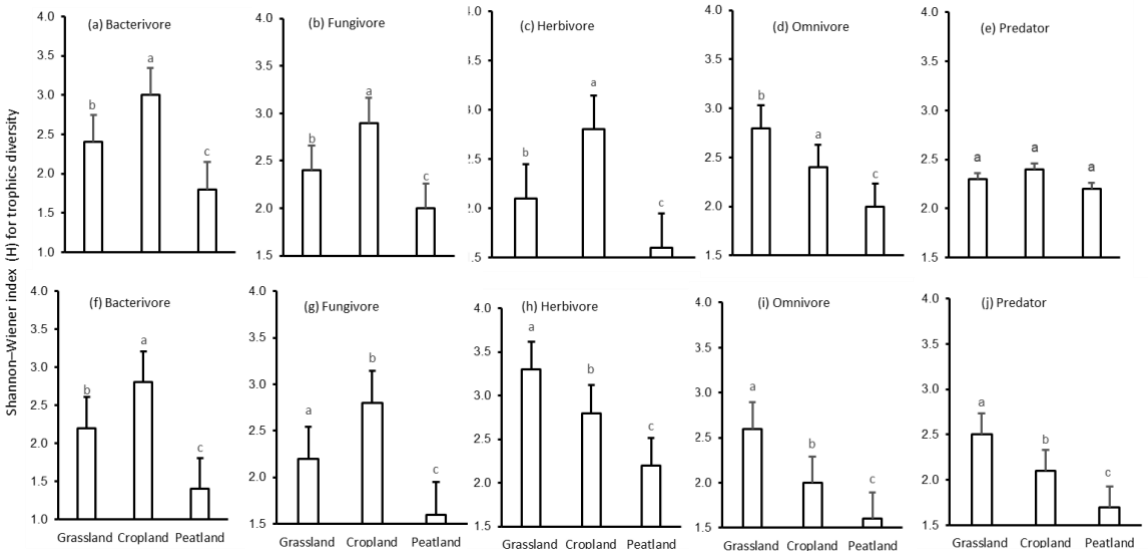

Figure 2. Distribution of Shannon-Wiener indices indicating the trophic structure of study sites (Hamzabey (a-e) and Adaköy (f-j) and significance levels ($P < 0.05$) and SEM for each study plot.

Diversity indices for c-p groups

For the diversity of groups cp1, c-p2, c-p3, c-p4, and c-p5, H' had significant differences ($p < 0.05$) among the three habitats in the two study sites (Figure 3). In Hamzabey, H' of cp1 group, c-p4 group, and c-p5 group for cropland and peatland were significantly higher for the grassland than (Figure 3a, d, e). There was also a significant difference between the cropland and peatland. However, the c-p2 and the c-p3 groups had high index values in cropland when compared to that of grassland and peatland. There was also a slight difference between grassland and peatland in Hamzabey (Figure 3b, c).

In Adaköy, H' of the cp2 group and the cp3 group for the cropland and grassland were significantly higher than for peatland, with no significant differences between cropland and grassland (Figure 3g, h). The cp1 group, the cp4 group, and the cp5 group also had a low H' and did not show significant differences among the three habitats (Figure 3f-j).

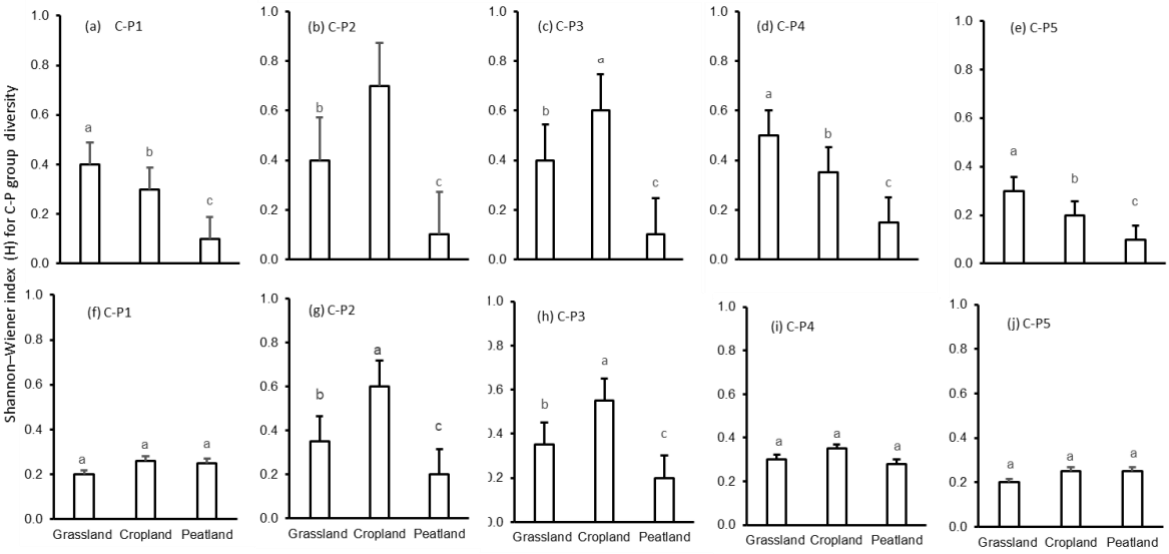

Figure 3. Distribution of Shannon-Wiener indices indicating the colonizer-persister groups of study sites (Hamzabey (a-e) and Adaköy (f-j) and significance levels ($P < 0.05$) and SEM for each study plot.

Discussion

The study revealed that the diversity of nematode fauna in the upper taxa, particularly at the order level, provides more reliable information on habitat type than the lower taxa (at family or genus level), so assessments based on the lower taxonomic categories are not always more sensitive than higher taxa that have a larger number of members to reflect habitat conditions. However, large scale studies on the diversity of the entire terrestrial nematode communities is practically impossible due to the variation from region to region, instead, local studies on nematode assemblages and some taxa associated with certain disturbances are considered more reliable.

The study findings revealed that difference in the nematode genera and family structures had similar patterns as in previous studies (Bhusal et al., 2014; Li et al., 2020). The inconsistency in the differences of the orders, families and genera compositions associated with the habitat types may be attributed to variation in the number of taxa recovered. It is well-documented that soil nematodes are strongly influenced by their microenvironment, which can also reflect the health and function of soil (Mulder et al., 2005). Agricultural management measures (e.g., tillage, irrigation and fertilization) cause disturbances in the soil ecosystem (Bongers et al., 1997) and influence communities of the soil nematode (Yardirn & Edwards, 1998). The abundance of nematodes reflects the ability of the soil to perform basic ecological functions (e.g., nutrient cycling) (Overstreet et al., 2010). Differences in the numbers of nematodes, trophic groups and c-p groups were observed among the three habitats: in grassland, cropland and peatland, indicating that reclamation had a significant impact on the nematode communities. The abundance and diversity of nematodes are closely related to the organic matter in the soil (Wall et al., 2002). The increase in organic matter provides an abundant source of food, especially for the free-living nematodes. In the process of reclamation, the application of organic or mineral fertilizers, and long-term agricultural cultivation resulted in the residue of plant roots into the soil, which increased the organic matter content in the grassland and cropland soil. However, due to their compact structure and low oxygen content, peatlands were not conducive to the survival of nematodes, which limited their abundance to relatively low levels.

The diversity pattern, as well as the structures of trophic groups and the compositions of c-p groups of the nematode communities in the study area, had some differences. In particular, the trophic groups differed more strongly between habitat type than the c-p groups. The findings of the study were consistent with those of Bushal et al. (2014), who suggested that trophic groups might be a better tool as an indicator of ecological aspects of the nematode fauna. In addition, the structure of trophic groups, described through H', were significantly different between the habitats in the current study. As a final statement, the results indicated that there were similar patterns but higher taxonomic grades might be preferable to the diversity of trophic groups to reflect different characteristics of the heterogeneous ecosystems or habitat types. Nematodes occupy several different trophic levels of soil biota and have adapted to take several different food sources (Bongers, 1990; Yeates et al., 1993; Zhao & Neher, 2013). Thus, environmental conditions especially food sources have different availabilities among the ecosystems; therefore, trophic groups of nematodes may better reflect differences in the variation of resource types and as well as environmental change (Ferris & Tuomisto, 2015).

In this study, the dominant trophic groups were bacterivores and fungivores. They contained many individuals that constitute the bulk of nematode communities in the cropland and grassland. This result differs from the study of Ou et al. (2005), who found herbivores to be the dominant trophic group in maize fields with yellow brown soil. This may be due to differences in climate and soil type (Yeates & Bongers, 1999). Bacterivores are usually abundant in planting soils (Wardle et al., 1995). Our result contradicted his view. The high abundance of bacterivores and fungivores in the cropland and grassland means that they are important in the nutrient cycling (Mikola & Sulkava, 2001). After bacterivores and fungivores, herbivores dominated nematode communities in cropland and grassland. The reason why the high abundance of

bacterivores indicates that they feed on bacteria and the intake of organic matter nourishes many of the bacteria in the farmland (Bulluck III et al., 2002). Van der Putten & van der Stoel (1998) noted that the feeding of herbivores accelerated the transportation of nutrients from plants to the soil ecosystem and promoted the accumulation of soil organic matter. The next trophic level organism (i.e., omnivores-predators) is slow to respond to prey, and soil pores can be effective in reducing the efficiency of predator access to prey (Mikola & Setälä, 1998). These results indicate that the flow of matter and energy in the soil food web run in the bottom-up direction. The frequency of nematodes feeding on bacteria and fungi is much higher than that of herbivores, omnivores and predators. A study by Sánchez-Moreno et al. (2006) indicated that agricultural management measures had a significant impact on growth than that of the reproduction of K-strategist nematodes. In grassland and cropland, the mineralization of nitrogen is accelerated when the microbivores (bacterivore and fungivore) nematodes dominate, increasing the availability of nitrogen to plants (Ferris et al., 2004).

The patterns of the c-p groups were different depending on the type of habitat, only the nematodes of the c-p2 group and the c-p3 group were significantly different between habitat types. The nematodes of the c-p2 and c-p3 groups were found to be relatively sensitive to environmental change (Bongers & Bongers, 1998). Thus, the variables of soil environment are the driving forces of these influences affecting differences in nematode fauna in ecosystems. As an example, mineral fertilization can reduce the incidence of nematodes in the omnivorous group (Neher & Barbercheck, 1998). Studies have shown that grassland with minor human intervention has had the potential to produce a substantial range of plant diversity over the last 25 years, which could ultimately become a rich resource of food for the soil fauna (Zhao et al., 2015). It can be concluded that abundant food resources, in addition to an undisturbed environment, may be more favorable for omnivore nematodes as well as the c-p3 nematode group. As a result, the taxonomic diversity of nematodes can also indicate a rich soil biota, the availability of nutritional resources, as well as disturbances in the ecosystem.

As mentioned above, when assessing diversity of taxonomic categories, the nematodes of trophic groups and c-p groups revealed significant effects of habitat types based on nematode community structures and can serve as acceptable indicators. In conclusion, analysis of nematode diversity at the higher level of classification (Ordo level) was more reliable for tracking variation in habitat types compared to the lower level of classification. In addition, the nematodes in trophic groups and c-p groups had significantly different patterns among habitat types. In the light of the study, the main order of the nematode diversity to express the responses of nematode fauna in these three types of habitat was peatland < cropland ≤ grassland, which is consistent with that from by Zhao et al. (2015) and Li et al. (2020). Conversely, environmental disturbance had a suppressive effect on the diversity of nematode fauna. The findings revealed that the diversity of nematodes in environmental monitoring might give beneficial information on soil biota via (1) the taxonomic structure or richness of the nematode fauna, (2) the structure of trophic groups and c-p groups of the given nematode community, and (3) taxon richness of each nematode trophic group.

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