

Research Article

The Effect of Decreasing Temperature on Arthropod Diversity and Abundance in Horse Dung Decomposition Communities of Southeastern Massachusetts

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Dung from large mammalian herbivores provides a concentrated food resource, rich in bacteria, nitrogen, and many forms of carbon that support a diverse community of arthropods. Detrital communities, while essential to nutrient cycling, are poorly studied. From July 2010 to October 2010, we sampled these arthropod assemblages using pitfall traps baited with horse dung at five sites southeast of Boston, MA. A total of 396 samples were collected, resulting in 10,299 arthropod specimens. We found a highly diverse group of arthropods dominated by Coleoptera ($n = 3696$) and Diptera ($n = 3791$) and noted the absence of hymenopterans, a group that was dominant in previous studies on these communities. The community had a high level of evenness (0.93 Shannon evenness) and lacked a dominant species, with no one species obtaining more than 7% relative abundance. Species accumulation curves indicate near maximum diversity was reached for each site and the study as a whole (93% maximum calculated Shannon Diversity). A strong effect of seasonality was also observed on the community, as shown by a strong shift in community at the end of August. The community sampled displayed a high similarity to previous studies, indicating a cosmopolitan distribution as well as an opportunistic community.

1. Introduction

Detrital matter, including plant material, feces, and carrion, provides an important resource for a wide variety of organisms ranging from microbes to invertebrates [1]. Dung is an important resource and many organisms have evolved to use this nutrient source [2, 3]. Several taxa of terrestrial arthropods are known to inhabit dung and are important in its recycling. Large quantities of dung can be eaten and dispersed by arthropods in a matter of days, returning valuable nutrients back into the environment [4]. Arthropods that congregate at dung are vitally important to the earth as a whole and represent a dynamic community.

Research on fecal decomposition has historically focused on cattle and their dung as they are a highly important economic entity and are known to harbor pest species of flies such as the face (*Haematobia irritans*) and horn flies (*Musca autumnalis*) [5]. Dung processing impacts both

pasture health [6] and livestock susceptibility to parasites [7]. Dung removal has become such a big concern to ranchers that species of dung beetles have been introduced in Texas [8], Australia [9], and other areas [10]. Introduction of dung beetle species appear to have a positive effect on the ecosystem via added dung removal and suppression of pest species [7]; any ancillary effects still remain unclear.

While studies conducted in the United States addressing dung beetle ecology are prevalent in the literature [11], there are few studies on the community structure of dung inhabiting arthropods. Those that are available have demonstrated that a diverse and abundant assemblage of arthropods regularly inhabit feces. Researchers have investigated dung communities west of the Mississippi [3, 12, 13], central New York [14], Canada [15], and New Zealand [16]. Each study used similar techniques (retrieving placed cow pats) and observed a highly similar community of arthropods. The high level of similarity across these studies demonstrated

that many of the arthropods inhabiting dung are common throughout the United States and often have ranges outside of North America.

Fecal decomposition communities in North America have displayed a high degree of similarity (Table 1) because they utilized similar techniques and sampled highly similar areas (pasture land). Equine and bovine fecal decomposition communities in the Chihuahuan Desert had a community dominated by ants (Hymenoptera: Formicidae) and documented a strong presence of spiders (Aranea), moths (Lepidoptera), crickets (Orthoptera), and Tenebrionid beetles (Coleoptera: Tenebrionidae), taxa lacking from other studies. While there were no observed community differences between cattle and horse dung in the Chihuahuan Desert, Coffey [17] and Finn and Giller [18] observed distinctive dung preferences for flies and beetles, respectively.

Prior studies which collected arthropods associated with fecal decomposition reported communities typically dominated by flies (Diptera), beetles (Coleoptera), and wasps (Hymenoptera). Other arthropods like springtails (Collembola) and mites (Acari) were also collected as a part of this community. Many of these groups have demonstrated a strong specificity for certain dung types and environmental parameters, for example, a squirrel den or grassland [19].

Despite the high levels of diversity within these assemblages, competition for nutrients is scarce. Valiela [20] demonstrated that dung communities are rarely saturated and can support higher number of individuals than studies have reported within pasture ecosystems. However, competition for space is vitally important as dung varies in quality even within a single cow patty [21]. Though there is competition for space, generally the earliest to arrive dictates what organisms are able to colonize the habitat [18, 22]. Studies have demonstrated that there is a sequence of succession of arthropods within dung communities as the dung ages. Flies are generally the first to arrive, often landing within minutes of excrement deposition [23, 24]. They are followed by several beetle families, both carnivorous (Staphylinidae, Hydrophilidae, Carabidae, and Histeridae) and coprophagous or dung inhabiting organisms (Scarabaeidae and Geotrupidae) [25]. The final stages of decomposition are characterized by the presence of generalist taxa such as fungi and earthworms [23, 26].

Succession in communities is often controlled by the presence of organisms within the system, but can be strongly influenced by environmental factors [27]. Valiela [20] quantified changes in community structure in bovine dung and found that environmental parameters were the limiting factors, not dung or prey availability. Merritt [6] further showed that climate was the primary determinant of diversity and abundance except in cases where overabundance of one organism or group can strongly dictate the structure of the community. Human perturbations, through habitat fragmentation and destruction, have also been shown to strongly influence dung-inhabiting communities [28].

In the present study, we focused on horse dung as its communities are rarely investigated and it is readily available in Massachusetts. We aimed to survey the biodiversity of arthropods associated with equine feces, to characterize the

arthropods present, and to examine the impacts of environmental parameters.

2. Methods

2.1. Site Descriptions. We collected arthropods at five sites less than 25 km apart, located 9–40 km south of Boston (Figure 1) in Norwell, Plymouth County and Milton, Norfolk County, Massachusetts, USA. The arthropods were intensively sampled from July 01, 2010 to October 15, 2010. This choice of time period was based upon the peak and subsequent end of arthropod activity on horse dung observed during a pilot study conducted in 2009. Each collection site is located on privately owned land, consisting of a family-run horse stable which houses four to six adult horses. The sites are approximately 1.2 hectares in size, consisting of two or three fenced in dirt corrals, a family residence, and a medium-sized barn surrounded by a similar area of mixed hardwood conifer forest. The stables reside at about 0.04 km above sea level with an average annual temperature of 10°C and average annual precipitation of 1.3 m. Horses at each site were fed similar standard diets (hay, grain, vegetables, and water) and were given minimal antiparasitics; strong antiparasitics were absent from their diets (personal communication from owners).

2.2. Arthropod Sampling Methods. We constructed pitfall traps to capture arthropods. At each site, eight $16.5 \times 16.5 \times 15.25$ cm white plastic buckets were dug into the earth and baited with approximately 100 grams of fresh horse dung (balled and flattened into patties) obtained from the resident horse population. We set traps approximately 10 m apart outside of the corrals, bordering wooded areas, in order to avoid interference from horses and humans. Traps were shielded with a board to protect the traps from rain and animal disturbance. To prevent desiccation of the dung, samples were collected within two days and traps were immediately rebaited with fresh dung. After each sampling, adult arthropods were sorted in the laboratory via hand picking and stored in 90% ethanol until identification. Larval insects were reared to adulthood in the laboratory, allowing for proper identification. Identification was based upon group specific keys indicated in Table 1.

2.3. Weather Data. Air temperature, humidity, and precipitation data were gathered from NOAA (<http://www.ncdc.noaa.gov/>) for sites four and five from the geographically closest weather station (42.1895° , -70.8665°), approximately 3 km from site four and 3.5 km from site five. Weather data for sites 1–3 was obtained from the Blue Hill Observatory (<http://www.bluehill.org/>), a long-term observatory located within the Blue Hill Reservation (42.213072 , -71.094375) and, within 1 km of site one, two and three. The weather between each site was highly similar over the course of the experiment, allowing us to examine how abiotic factors affected the community.

TABLE 1: A table containing the 76 species of insects ($n = 61$), arachnids ($n = 8$), myriapods ($n = 2$), spring tails ($n = 3$), and crustaceans ($n = 2$) collected from the five sites over the course of the 4-month experiment. Individuals were identified from the key indicated next to each family. Average lengths were determined from the average of 25 measurements (when possible) taken after storage in 90% ethanol. The standard deviation (in mm) of the 25 measurements is indicated next to each average. Our captured species were compared to similar studies; bracketed numbers indicate the references compared to.

Taxa	Number	Physical length (mm)	Sites occurred at	Occurrences in literature
Coleoptera [29–34]				
Scarabaeidae				
<i>Onthophagus pennsylvanicus</i> (Harold)	152	4.79 (0.12)	2, 3, 4, 5	[3, 12, 13]
<i>O. orpheus</i> (Panzer)	79	5.55 (0.09)	1, 2, 3, 5	
<i>O. striatulus</i> (Blatchley)	46	6.29 (0.20)	All	
<i>Aphodius rubripennis</i> (Horn)	132	8.21 (0.01)	All	
<i>A. distinctus</i> (Müller)	81	5.55 (0.41)	All	[12, 15]
<i>A. bicolor</i> (Say)	132	7.12 (0.24)	All	[12, 13]
<i>A. rubeolus</i> (Beauvois)	40	4.12 (0.09)	All	
<i>A. lutulentus</i> (Haldeman)	56	5.16 (0.10)	All	
<i>A. fossor</i> (Linnaeus)	142	9.00 (0.11)	All	[12, 14, 15]
<i>A. stercorosus</i> (Melsheimer)	91	3.55 (0.02)	1, 3, 4, 5	[12, 14]
<i>Dialytes truncates</i> (Melsheimer)	43	4.11 (0.17)	All	
<i>D. striatus</i> (Melsheimer)	118	5.91 (0.22)	All	
<i>Ataenius spretulus</i> (Haldeman)	46	5.21 (0.19)	1, 3, 4, 5	[3, 12]
<i>Canthon</i> sp. 1	92	10.10 (0.08)	All	[3]
<i>C.</i> sp. 2	37	11.01 (0.13)	1, 4, 5	[3]
Geotrupidae				
<i>Geotrupes hornii</i> (Blanchard)	83	14.91 (0.55)	All	
<i>G. egeriei</i> (Germar)	118	13.99 (0.20)	All	
<i>G. blackburnii</i> (Fabricius)	39	14.51 (0.06)	All	
<i>G. splendidus</i> (Fabricius)	25	16.12 (0.66)	All	
<i>G. balyi</i> (Windham)	69	14.33 (0.11)	All	
Carabidae				
<i>Carabus</i> sp.	116	19.15 (0.42)	All	
<i>Agonum</i> sp.	85	9.12 (0.29)	All	
Staphylinidae				
<i>Platydracus maculosus</i> (Gravenhorst)	43	24.95 (0.41)	All	
<i>P. fossator</i> (Gravenhorst)	40	19.45 (0.09)	All	
<i>Ocyptus</i> sp.	38	17.55 (0.22)	2, 3, 4	
<i>Tachinus basalis</i> (Erichson)	114	7.45 (0.31)	2, 3, 4, 5	
<i>T. frigidus</i> (Erichson)	129	6.99 (0.08)	1, 3, 4, 5	
<i>T. luridus</i> (Erichson)	135	8.11 (0.41)	All	
<i>Platystethus</i> sp.	85	2.22 (0.10)	All	
<i>Aleochara littoralis</i> (Mä, klin)	106	5.21 (0.92)	1, 3, 4, 5	
<i>A. bimaculata</i> (Gravenhorst)	179	5.11 (0.40)	All	[3, 12, 15]
<i>Falagria</i> sp.	138	4.99 (0.11)	All	
Hydrophilidae				
<i>Cercyon</i> sp. 1	165	6.11 (1.01)	All	[12–15, 35]
<i>Cercyon</i> sp. 2	46	3.33 (0.50)	All	[12–15]
<i>Sphaeridium</i> sp.	42	9.91 (0.31)	1, 3, 4, 5	[3, 12–15, 35]
Histeridae				
<i>Saprinus</i> sp.	101	7.41 (0.02)	All	[3]
<i>Hister abbreviatus</i> (Fabricius)	73	5.91 (0.10)	All	[3, 12–15]
Ptiliidae				
<i>Acrotrichis</i> sp.	243	1.00 (0.05)	All	
<i>Nephanes</i> sp.	197	1.20 (0.20)	All	

TABLE 1: Continued.

Taxa	Number	Physical length (mm)	Sites occurred at	Occurrences in literature
Diptera [34, 36–40]				
Sphaeroceridae				
<i>Scathophaga</i> sp. 1	219	7.42 (0.41)	All	[3]
<i>Scathophaga</i> sp. 2	94	6.89 (0.91)	1, 3, 4, 5	
<i>Leptocera</i> sp.	111	7.21 (0.83)	All	[3, 13–15]
Calliphoridae				
<i>Lucilla</i> sp. 1	585	9.46 (0.09)	All	
<i>Lucilla</i> sp. 2	218	5.21 (0.20)	All	
<i>Lucilla</i> sp. 3	27	8.32 (0.39)	All	
<i>Phorima</i> sp.	248	12.39 (0.08)	2, 3, 4, 5	[3]
<i>Chrysomya</i> sp.	245	8.11 (0.21)	All	
Muscidae				
<i>Musca</i> sp. 1	215	10.13 (0.40)	2, 3, 4, 5	[12–15]
<i>Musca</i> sp. 2	162	8.12 (0.50)	1, 2, 3, 5	[14, 15, 35]
<i>Hydrotaea</i> sp. 1	90	9.90 (0.08)	All	[3, 12, 14]
<i>Hydrotaea</i> sp. 2	156	11.21 (0.09)	All	[12, 14]
Sepsidae				
<i>Sepsis</i> sp. 1	212	6.12 (0.07)	All	[3, 12–14, 35]
<i>Sepsis</i> sp. 2	224	6.95 (0.10)	All	[3, 12, 14, 15, 35]
Syrphidae				
<i>Eristalis</i> sp.	288	7.48 (0.11)	All	[14]
Sarcophagidae				
<i>Sarcophaga</i> sp. 1	279	16.51 (0.20)	All	[3, 13, 14]
<i>Sarcophaga</i> sp. 2	67	15.80 (0.33)	1, 3, 5	[13, 14]
<i>Sarcophaga</i> sp. 3	76	17.12 (0.08)	All	[13]
<i>Ravina</i> sp.	275	15.63 (0.11)	All	[3, 12–15, 35]
Orthoptera [41]				
Gryllinae				
<i>Gryllus</i> sp.	66	16.51 (0.74)	All	[3]
<i>Neomemboius</i> sp.	67	10.01 (0.45)	All	
<i>Anurogryllus</i> sp.	72	11.09 (0.90)	All	
Opiliones [42]				
Phalangidae				
<i>Phalangium</i> sp.	56	7.15 (0.09)	All	
Sclerosomatidae				
<i>Leiobunum</i> sp.	62	5.97 (0.40)	All	
Aranea [43, 44]				[16]
Lycosidae sp.	71	3.31 (0.08)	All	
Salticidae				
Sp. 1	63	5.12 (0.10)	All	
Sp. 2	61	8.83 (0.19)	2, 3, 4	
Sp. 3	84	4.99 (0.14)	1, 3, 5	
Mesostigmata (Acari) [45]				
Dinychidae	618	0.56 (0.01)	All	[14, 15]
Parasitidae	320	0.91 (0.02)	All	[12, 14–16]
Poduromorpha (Collembola) [46]				
Poduridae	538	1.12 (0.10)	All	[14, 16]
Entomobryomorpha (Collembola)				
Paronellidae	224	1.24 (0.02)	All	
Entomobryidae	353	1.52 (0.02)	All	[14, 16]

TABLE 1: Continued.

Taxa	Number	Physical length (mm)	Sites occurred at	Occurrences in literature
Isopoda [47]				
Armadillidiidae				
<i>Armadillidium</i> sp.	53	11.15 (0.09)	All	
Cylisticidae				
<i>Cylisticus</i> sp.	20	7.95 (0.05)	All	
Julida (Diplopoda) [48]				
Julidae				
<i>Cylindroiulus caeruleocinctus</i> (Wood)	29	14.12 (0.29)	All	
Spirobolida (Diplopoda)				
Rhinocricidae				
<i>Eurhinocricus</i> sp.	55	17.65 (0.71)	All	
Total	10,299			



FIGURE 1: Map of the study area. The GPS coordinates for the 5 sites are as follows: (1) 42.240909, -71.067724, (2) 42.212054, -71.096306, (3) 42.226801, -71.098194, (4) 42.15351, -70.798774, and (5) 42.146049, -70.831583.

2.4. Data and Statistical Analysis. The 10,299 biodiversity observations were organized and maintained in spreadsheet files. All graphs were created using the R statistical package (R Core Development Team). Species accumulation curves were plotted for each of the five sites based upon the collection data. To examine how temperature affected the diversity and abundance, we plotted the number of species collected and the number of arthropods collected as a function of temperature. Data among sites showed a high degree of similarity. Data was combined into two-day intervals (53 data points).

We quantified the diversity and evenness of the community by calculating the Shannon Diversity Index for the study using the Primer 5 (Primer LTE) statistical package. The maximum diversity (H') was determined by using

$$H' = \ln(S), \quad (1)$$

where, S is the total number of species. Community evenness (E_{Shannon}) was calculated based upon the Shannon Diversity Index and the equation

$$E_{\text{Shannon}} = \frac{H'}{\ln(S)}. \quad (2)$$

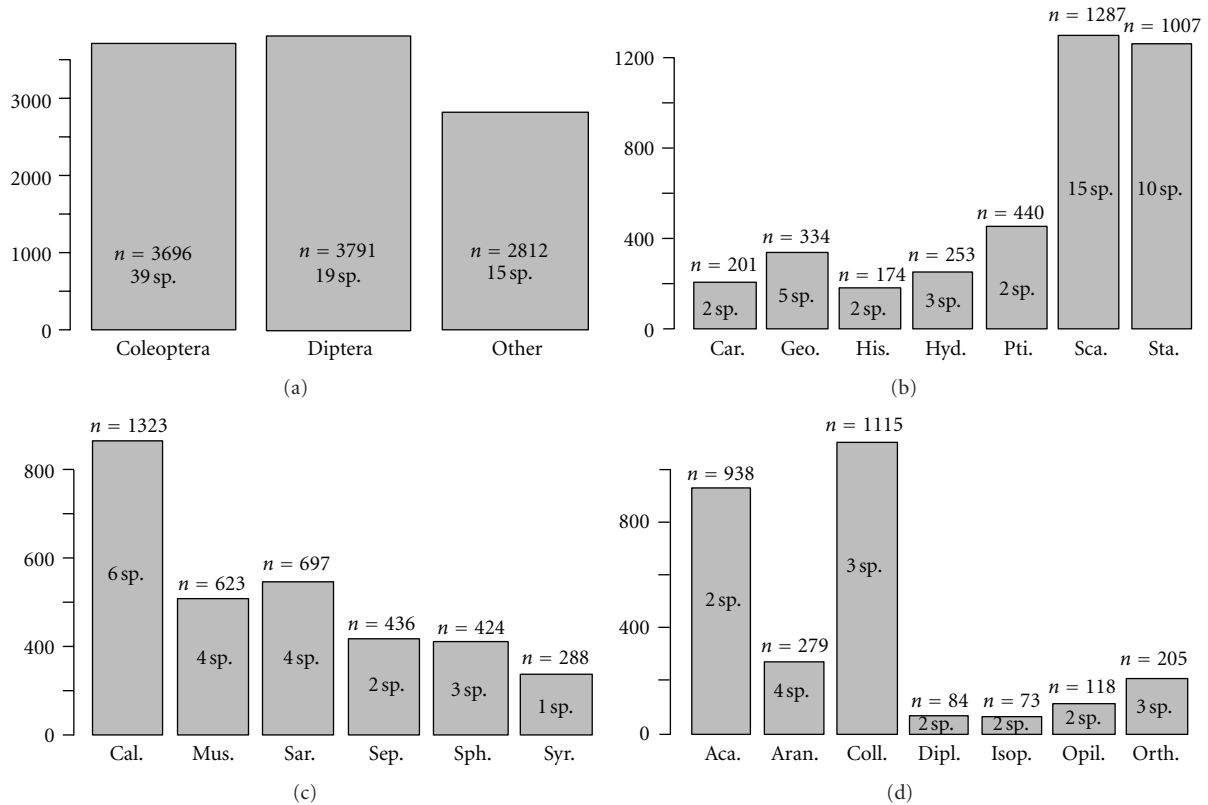


FIGURE 2: A graphical breakdown of the arthropods collected during the study. (a) represents the totals for the whole study, (b) the totals for the 7 beetle families, (c) the totals for the 6 fly families, and (d) the remaining individuals collected. Values above each bar represent the number of individuals collected while the values within the bars represent the number of species observed. Abbreviations represent the following: Car.: Carabidae, Geo.: Geotrupinae, His.: Histeridae, Hyd.: Hydrophilidae, Pti.: Ptiliidae, Sca.: Scarabaeidae, Sta.: Staphylinidae, Cal.: Calliphoridae, Mus.: Muscidae, Sar.: Sarcophagidae, Sep.: Sepsidae, Sph.: Sphaeroceridae, Syr.: Syrphidae, Aca.: Acari, Aran.: Aranea, Coll.: Collembola, Dipl.: Diplopoda, Isop.: Isopoda, Opil.: Opiliones, and Ortho.: Orthoptera.

Species richness (d) was calculated based upon the Margalef species richness index:

$$d = \frac{S - 1}{\ln(n)}, \quad (3)$$

where S is the number of taxa, and n is the number of individuals. To determine how the community composition changed over the course of the sampling period, Primer 5 was used to construct a multidimensional scaling plot (MDS) based upon presence/absence data (Bray-Curtis Similarity) for the observed species over one-week periods. No standardization was applied and no transformations were performed on the data.

To compare the five sites, a similarity matrix was constructed and analyzed in Primer (Primer LTE) based upon Bray-Curtis Similarity [49]. To tease out the driver behind the change in the community composition, we performed a similarity percentage analysis (SIMPER) based upon the Bray-Curtis similarity index.

3. Results

3.1. Community Composition. Over the four month study period, 10,299 arthropods were collected from 398 samples across the five sites. Arthropods collected represented 11 orders, 27 families, 49 genera, and approximately 76 species (Table 1). Coleoptera was the most species rich taxa (Figure 2), equaling 48% ($n = 39$) of the species, while comprising 36% ($n = 3696$) of the arthropods collected. The majority of coleopteran species came from the families Scarabaeidae ($n = 15$) and Staphylinidae ($n = 10$). The remaining 35% of the beetles came from 6 families: Geotrupidae ($n = 5$), Ptiliidae ($n = 2$), Carabidae ($n = 2$), Histeridae ($n = 2$), and Hydrophilidae ($n = 3$). In terms of abundance, small dung beetles (Scarabaeidae) were the most abundant ($n = 1007$). Staphylinid beetles were a close second with $n = 1260$ and they were followed by Ptiliidae ($n = 440$), Geotrupidae ($n = 334$), Hydrophilidae ($n = 253$), Carabidae ($n = 201$), and Histeridae ($n = 174$).

The order Diptera marked the next largest and diverse group of arthropods collected, comprised of 6 families representing 3791 individuals. Fly species were more evenly spread among the six families than beetle species with Calliphoridae

TABLE 2: Calculated diversity and evenness values. Maximum Shannon Diversity was calculated using the formula: $H'(\text{Max}) = \ln(S)$, where S is the maximum number of species observed.

	Number of individuals (N)	Number of species (S)	Shannon Diversity, H'	Shannon evenness, E (H')	Maximum Shannon diversity	Species richness (d)
Site 1	2,176	70	3.78	0.88	4.24	8.97
Site 2	2,011	66	3.83	0.90	4.18	8.54
Site 3	3,028	76	3.88	0.92	4.33	9.35
Site 4	968	71	3.89	0.91	4.26	10.1
Site 5	2,116	72	3.82	0.89	4.27	9.27
Total	10,299	76	4.03	0.93	4.33	8.11

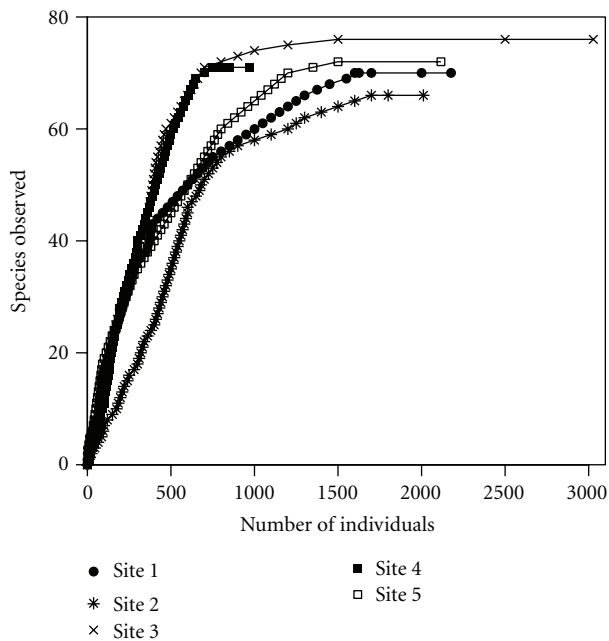


FIGURE 3: Species accumulation curves for each of the five sites. From the 10,299 arthropods collected, the total number of species gathered was 76 and included a wide range of arthropods including beetles, flies, arachnids, and springtails. Further, the curves all displayed a similar steep slope before leveling out at their respective maximum number of species and arthropods collected site 1: 70 and 2176, site 2: 66 and 2011, site 3: 76 and 3028, site 4: 71 and 968, and site 5: 72 and 2116.

($n = 5$), Muscidae ($n = 4$ species), Sarcophagidae ($n = 4$), Sepsidae ($n = 2$), Sphaeroceridae ($n = 3$), and Syrphidae ($n = 1$) accounting for the observed 19 species. The family Calliphoridae was the most abundant of the fly families with $n = 1323$. This was followed by Sarcophagidae ($n = 697$), Muscidae ($n = 623$), Sepsidae ($n = 436$), Sphaeroceridae ($n = 424$), and Syrphidae ($n = 288$). Flies represented 37% of the arthropods collected in the study.

The remaining 2812 individuals collected were represented by about 18 species. Of these, springtails ($n = 1115$) and mites ($n = 938$) dominated numerically. A group of predators, omnivores, and decomposers including crickets (Orthoptera, $n = 205$), harvestmen (Opilliones, $n = 118$),

isopods (Isopoda, $n = 73$), spiders (Aranea, $n = 279$) and millipedes (Diplopoda, $n = 84$) rounded out the remaining 759 individuals captured.

3.2. Comparisons Among Sites. Minor differences in species composition were observed among the five sites (Table 1). All genera occurred at each site, but specific species were often absent from a given site. Site three was the most diverse (species total $n = 76$), capturing all the species in the study as well as possessing the most arthropods collected ($n = 3028$). Site one and five had similar species totals ($n = 70$ and $n = 72$ resp.) as well as possessing nearly identical abundances ($n = 2176$ and $n = 2116$ resp.). Site 2 was the least diverse of all the sites ($n = 66$) despite capturing 2011 arthropods at the location. Half the number of arthropods of the other sites ($n = 968$) were collected at site 4, while nearly the same species total ($n = 71$) was reached. In light of the differences between the sites in species number and abundance, no one site had an organism unique to it. The five sites demonstrated a high degree of similarity, with greater than 90% similarity between the five sites.

To determine how complete our sampling of each site was, we plotted species accumulation curves (Figure 3). Each site plateaued at their respective maximum, well before the end of the experiment. Sites one, two, and five displayed highly similar curves. While the curves are relatively steep, they do not exhibit as strong of a plateau as seen in site three. The curves for sites three and four closely mimic one another as individuals were collected. Site four had far fewer individuals collected than site three ($n = 968$ to $n = 3028$) yet showed a similar curve. The defining characteristic of site three is its extreme plateauing for the last 1500 individuals collected. The steep slopes of all five sites indicate that the diversity was at a maximum when the experiment began and the weather was warmer. The diversity slowly decreased over the course of the experiment, in line with the temperature, as seen in Figure 4(b).

3.3. Diversity, Community Evenness, and Relative Abundance. The Shannon Diversity Index was calculated to determine the maximum diversity possible for each site as well as our total captured diversity (Table 2). The total maximum diversity was 4.33 while our calculated diversity was 4.03 (93.08% of the maximum diversity), indicating that near maximum

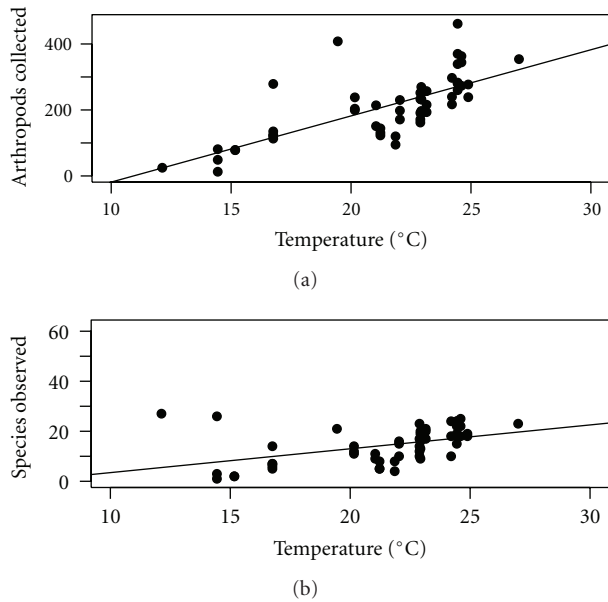


FIGURE 4: Plots of arthropod abundance (a) and diversity (b) as functions of temperature. Each of the graphs demonstrated an increasing linear trend with increasing temperature ($y = 2.84x - 17.63$, $r^2 = 0.715$ (a) and $y = 20.05x - 219.67$, $r^2 = 0.521$ (b)).

diversity was reached in the study. Shannon Diversity for each site ranged from 3.78 to 3.89 (Table 2). With between 89 and 92% of maximum Shannon Diversity, each site possessed near maximum diversity, supporting our species accumulation curves.

The community displayed a high degree of species evenness as demonstrated by the lack of a dominant species or small group of species (Table 1). Calculated relative abundance values (data not shown) showed that the three most numerically dominant species represented less than 17% of the total community and no one species was more abundant than 7%. To examine the evenness of the community, the Shannon Diversity Index was used. Shannon evenness values (Table 2) indicated that each site was extremely even with evenness close to or above 0.90 for each site and the study as a whole.

3.4. The Effect of Temperature and Seasonality

3.4.1. Activity, Diversity, and Temperature. Air temperature is positively correlated with arthropod abundance (Figure 4(a)) and arthropod diversity (Figure 4(b), $y = 2.84x - 17.63$, $r^2 = 0.72$, $y = 20.05x - 219.67$, $r^2 = 0.52$). We observed that the abundance of arthropods changed over the course of the experiment. While we did not observe seasonal pulses for a majority of the organisms collected, a majority of arthropods demonstrated an appreciable decline near the end of August (data not shown), as seen in the abundance of large flies and hydrophillid beetles (Figures 5(a) and 5(b)). Hister beetles and small flies (Figures 5(a) and 5(b)) experienced increases in their numbers as all other arthropods began to drop off.

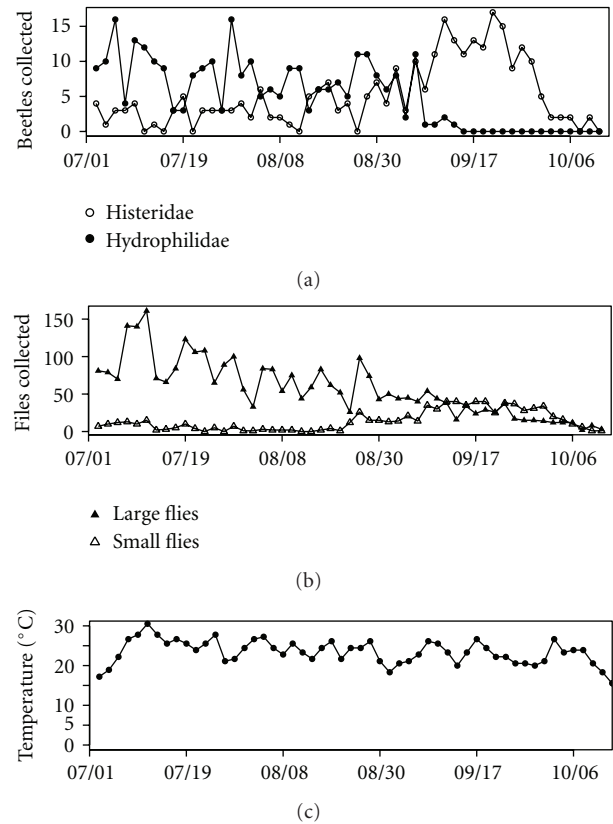


FIGURE 5: Stacked plots of temperature over the length of the experiment, as well as the fluctuations of select groups of arthropods (large flies, small flies, hister beetles, and hydrophillid beetles) as their abundance varied over time. Small flies are represented by the genera: *Sepsis* and *Eristalis*. Large flies are represented by the genera: *Scathophaga*, *Leptocera*, *Lucilla*, *Phorima*, *Chrysomya*, *Musca*, *Hydrotaea*, *Sarcophaga*, and *Ravina*.

3.4.2. Seasonal Changes in the Community. The multidimensional scaling plot (MDS) showed five distinct clusters of data that were strongly grouped by time and were independent of site (Figure 6). Group one represented samples from the first eight weeks of the experiment (July 1–August 26). Despite spanning two months of the experiment, the community experienced only minor changes in community structure across all sites. The final six weeks of the experiment, groups 2–5 (Aug. 27–Oct. 15), demonstrated a great deal of variability in community structure between weeks. The plot showed a distinct change in the community in the middle to end of August. Further, the community changed more radically in the last third of the experiment than in the first third. When one compares the temperature data (Figure 5(c)) to this change in community, we see that they are correlated to one another as the weather appreciably changes around the middle to end of August. The abrupt change in temperature near the end of August ushered in a change in diversity across all five sites, and to determine the main cause of this shift, further analysis was performed.

SIMPER analysis indicated that the absence of large fly larvae (−30.74% contribution) was the main driver behind

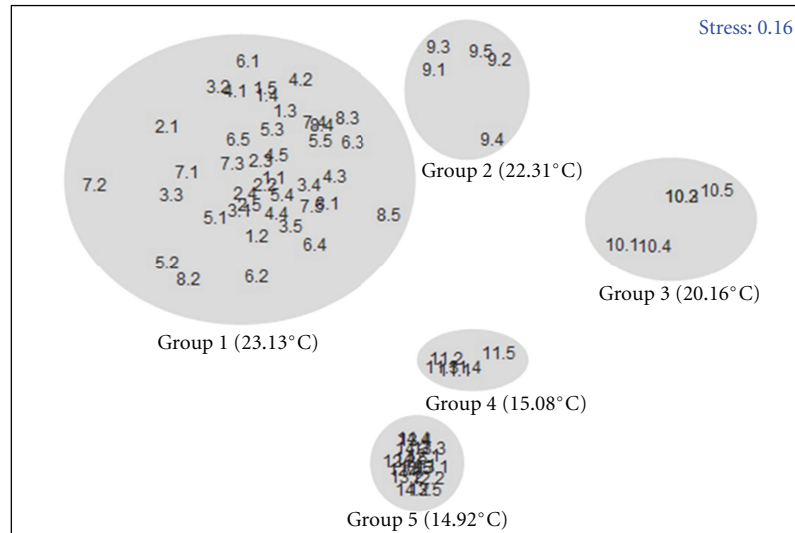


FIGURE 6: Multidimensional scaling plot (MDS) of the community composition as it varied over time. The data clustered into 5 distinct groups based upon the time and was independent of site. Group 1: July 1–August 26, Group 2: August 27–September 2, Group 3: September 3–September 9, Group 4: September 10–September 16, and Group 5: September 17–October 15. Numbers (x.x) in the plot indicate week number, followed by site number and the average temperature for each time period.

the drastic change in community. Mites (−10.26%) and springtails (−10.6%) also experienced appreciable drops in their numbers at this junction as well. Other groups such as large predatory beetles (−2.57%), hydrophilid beetles (−4.09%), small fly larvae (+6.44%), small Staphylinid beetles (−9.18%), and Hister beetles (+3.41%) also experienced noticeable changes to their populations. Taken together with Figure 4, the SIMPER analysis indicates that all groups of organisms are affected by the change in temperature.

4. Discussion

Mohr [24] was one of the first to recognize bovine droppings as a distinct ecological habitat and, since then, many studies have shed light on the communities inhabiting fecal matter. Most studies have focused on cattle excrement as they are motivated by hefty economic interests [25]. Our study marks one of the few to examine the communities associated with horse dung as well as the second examination of fecal decomposition communities in the northeastern United States [14, 20].

Compared to similar studies on fecal decomposition communities, our data show similar species composition (Table 1) and relative abundance of arthropods (see [12] and references within). With approximately 76 species of arthropods, our work is on par with similar studies which have species totals ranging from 30 to 125 individuals. While we only sampled one dung type, our study was less diverse than Valiela [14], the closest geographic study (~400 km); our findings were consistent with Coffey [17], who showed that cow dung has the most diverse communities. Horse dung is a much different resource than cow dung, possessing

more undigested material [11] allowing for a slightly different community to thrive. The differences in the communities reflect the differences in dung type and that even dung from the same animals can have remarkably different qualities [22].

Despite the great deal of similarities between the studies, our study contained several unique groups of arthropods, in particular a strong presence of crickets, spiders, and harvestmen. Outside of Moeed et al. [16] and Schoenly [50], these organisms were unique to our study. A defining characteristic from our study is the lack of hymenopterans, in particular, wasps, which were a major contributor in all other studies up to this point, generally representing ~20% of the observed abundance and diversity. While the cause of their absence is unknown, it may be as simple as the sample technique (pitfall traps versus retrieving placed cow pats) employed.

Despite being highly similar (>90% similarity) in terms of species composition and number of species present (66–76 species for all sites), the sites demonstrated distinct species accumulation curves and yielded different amounts of arthropods. Site three demonstrated the most diversity ($n = 76$), while site two ($n = 66$) was the least diverse. The small differences in the sites could be a reflection of local differences in weather or habitat, but the underlying cause is currently unknown.

Species accumulation curves (Figure 3) indicate that near maximum diversity was reached for each of the five sites and the study as a whole; this is further supported by the calculated Shannon Diversity Index (Table 2). With the high level of sampling (398 samples in 3.5 months) over the course of the experiment, it is probable that the maximum species diversity was reached for this study. Given the poor taxonomic information on mites [51], we may possess a

greater diversity than reported here. Several parameters could influence our observed diversity including habitat disturbance and the sampling technique employed. Longino et al. [4] document that at least three different sampling techniques are needed to properly sample a community, while human perturbations have been shown to have a large impact on dung beetle communities [52]. With a greater diversity of sampling techniques as well as sampling a more natural area, we could possibly capture more diversity within the community.

Several studies have reported a strong seasonal effect on dung beetles [53, 54] and arthropod communities alike [40]. Temperature, soil conditions, sun exposure, and precipitation have all been shown to influence the degradation and quality of dung [19, 55–57] which in turn influences the arthropods that congregate there [22]. Wright [58], Maelzer [59], and Tyndale-Biscoe [60] reported that activity of dung inhabiting arthropods was strongly influenced by rainfall while Doube et al. [9] and Vernes et al. [54] both indicate that temperature was the main driver behind dung arthropod activity. In observational studies, evaluating the effects of a specific environmental variable on communities is complicated by the simultaneous variation in other environmental parameters [57]. While humidity and precipitation demonstrated no appreciable effect on the community (data not shown), temperature appears to be the strongest correlate of arthropod abundance and diversity within our study (Figures 4(a) and 4(b)). As ectotherms, arthropods are more subject to environmental temperature than are endotherms. Within a wide range of temperatures, high temperatures being the exception, growth, development, and metabolism increase with increasing temperatures [61, 62]. Thus from the perspective of the individual organism, our results are not surprising, but linking physiological process to population and community levels remains a challenge [51].

Certain groups of arthropods also demonstrated a differential effect to temperature within our experiment (Figures 5(a) and 5(b)). Though we did not observe species specific seasonality as seen in Vernes et al. [54] and similar studies, we did observe seasonality in select groups of our arthropods. Outside of hister beetles and small fly larvae, which experienced an increase in numbers, all collected arthropods demonstrated a noticeable decline in abundance during the middle to end of August. Large fly larvae may illicit an inhibitory effect upon the populations of small fly larvae. Figure 5(b) shows that small flies only become abundant once large flies are in substantial decline. This could also be due to a preferred temperature preference by the small flies, but the limited literature does not indicate such a life history for the three species of small flies. Because large flies are the most numerically abundant in our and other studies, it may be that they are the main biological drivers behind the community structure. A similar idea is seen in Merritt [6], where the presence of an aphodiine dung beetle, *Aphodius fimetarius*, was the strongest driver of community structure and abundance. The regulatory effects of large flies within our community are still unclear and future work could be done to illuminate these and other interactions.

All of the arthropods collected in the study are able to occupy several niches (personal observations). Though dung beetles are commonly thought to use only dung, they are able to utilize other nutrient sources such as carrion and mushrooms. A better assessment of the community would be that it is an opportunistic one, utilizing dung when it becomes available but switching to other nutrient sources when dung is unavailable. Dung is generally a rapidly decomposed ecological unit [63] and could not support a permanent community.

The idea of an opportunistic community is further supported by the lack of a truly dominant species or small group of species. One generally observes a few dominant species representing >60% of the individuals collected [35], but we do not see that in this community. Without a single species achieving more than seven percent dominance, our system represents a community with a high level of species evenness (0.9307 Shannon evenness) as well as high species richness (8.12 Margalef species richness) [64], further supporting an opportunistic community. Valiela [20] and Merritt [6] also arrive at the same conclusion in their studies based upon the cosmopolitan distribution of the collected arthropods. Despite the lack of obligate dung going organisms, the organisms found in our study as well as others have developed an elaborate community that can effectively dispose of dung. The inner workings of the community, with respect to trophic interactions, remain largely unknown [35].

In conclusion, our investigations into the communities associated with horse dung have demonstrated a high level of diversity as well as high degree of evenness. Our datum suggests that air temperature may be a driver of the diversity and abundance of arthropods, as indicated by sharp drop offs in abundance and diversity at the end of August. Future work could be done to characterize the spring communities of dung beetles as well as the arthropods associated with other dung types.

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