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# Estimation of Sorting Time for Arthropod Samples Collected with Tullgren Funnels

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**Abstract**

Arthropods were sorted from samples obtained with Tullgren funnels. Each sorter maintained a log of time per session and arthropods removed per session. Five individuals removed all arthropods from 12 separate samples and sorted them into previously designated class or ordinal taxa. Each sample was sorted by a single student. Students were allowed to develop their own approaches to sorting and do it as time permitted. Mean sorting rate per sample was 2.43 arthropods per minute, with a range of 1.42-5.64, while mean sorting rate for a sorting session was 3.41 specimens per minute. Specimen density was only weakly correlated with sort time. Fatigue did not appear to be a major factor in sorting rate, as indicated by the similarity of the linear and quadratic coefficients of determination for each sample.

The problems involved with sorting bulk samples of collected invertebrates for further study are widely recognized, but few studies address the quantification of sorting parameters for mass collections. Time and cost investments have been determined empirically for insects caught in Malaise traps (Danks and Winchester 2000) and for soil microfauna (Berthold et al. 1999). With the increasing emphasis on broad-based biodiversity surveys (White and Langdon 2006, Nichols and Langdon 2007), realistic estimates of time and cost expenditures are necessary for developing realistic survey budgets, especially if purpose-trained parataxonomists are used. This need is particularly pressing for soil arthropods. In most soil environments, soil arthropods are diverse and abundant, sometimes reaching densities of close to 250,000/m$^2$ (Price 1973; Lagerlöf and Andrén, 1988, 1991; Kopeszki and Meyer 1994). A well-recognized impediment to soil arthropod diversity studies is the great effort and expenditure of resources necessary to separate thousands of specimens from soil and organic debris and sort them to the desired taxonomic level. This work requires carefully thought-out plans and protocols (Danks 1996). Often this work is the responsibility of students hired and trained for the purpose; funds for their hiring typically are derived from grants in which the principal investigator has provided an estimate of the number of hours necessary to complete the work. However, there appears to be no published estimate of the rate of sorting, without which there cannot be an accurate estimate of the time necessary to sort the organisms collected in a project. The purpose of this paper is to report time estimates for the removal and sorting of arthropods to class and (or) order collected by means of Tullgren funnels (Tullgren 1918, Murphy 1962). Given a realistic estimate of arthropod densities, sorting rates can be used to develop an accurate cost figure for removal and sorting of arthropods from bulk samples.

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## Materials and Methods

Four M.S.-level students enrolled in a Concentrated Study in Entomology - Apterygotes course at the University of Tennessee and one research associate participated in this exercise. While all of the students were entomology graduate students, none had significant experience in sorting bulk samples from litter and soil. The research associate had considerable experience in sorting these kinds of samples. All of the samples provided were collected from Great Smoky Mountains National Park and placed in Tullgren funnels for arthropod extraction. Litter volumes varied greatly, thus providing a range of specimen numbers. All students were briefed on the appearance of the various arthropod groups and provided with typical illustrations to aid differentiation.

Each student received at least one sample with an estimated lower number of arthropods (<6,000), and another sample with a higher number (>7,000). Most spiders had previously been removed for other research purposes. Each person was allowed to sort more than two samples if desired. Each sorter was instructed to sort specimens at his/her individual pace as time permitted; that accuracy was more important than speed; and that every effort should be made to get even the smallest specimens, including juvenile mites. Each student maintained a log provided for recording dates, start and finish times for each sorting session, and the numbers of individuals in the taxa Acari, Araneae, Chilopoda, Collembola, Diplopoda, Diplura, Pauropoda, Protura, Pseudoscorpiones, Symphyla, and Insecta. All sorted samples, including debris at the end of each sort, were checked by one of the authors to insure that the sorters were being accurate in their identifications, and as accuracy was stressed as a component of the course grade, very few specimens were miscategorized.

Linear regression analysis was performed on total time spent sorting a sample vs. total specimens sorted to obtain an average estimate of sorting efficiency on a per sample basis. The same data were analyzed by comparing specimens sorted during single sessions to specimens sorted per session. For each sample done by an individual sorter, linear regression was performed on time per session vs. specimens sorted in that session to obtain an estimate of variability in individual efficiency. First and second-order solutions for each regression were compared to estimate possible sorting fatigue. Sorting sessions were arbitrarily grouped by numbers of specimens (<100, 100–300, 301-600, 601-1,000, >1,000) and plotted vs. sort time to determine whether specimen abundance was closely related to sorting time. Coefficients of determination ($r^2$) were calculated for all regression lines. Calculations and graphs were produced with SigmaPlot and SigmaStat (Systat Software, San Jose, CA). Significance of the coefficient of correlation $r$ was determined by reference to Rohlf and Sokal (1969).

## Results and Discussion

Five participants in this study sorted and counted 12 samples to completion, in 202 separate sessions. Analysis of the 12 samples with first-order linear regression yielded a straight line with $r^2 = 0.59$ (Fig. 1A). The relationship of sorting time to sorted specimens was 2.43 specimens per minute and explained 59% of the variation. The same data analyzed for second-order regression improved fit only to an $r^2$ of 0.60. Similar analysis of the 202 individual sessions yielded 3.41 specimens per minute (Fig. 1B), accounting for 32% of the variation. The two figures are approximately equivalent to 144-205 specimens per hour. A quadratic solution explained only an additional 2% of the session analysis. If fatigue were a factor in long sorting sessions, a quadratic solution (slope declining with time) would be expected to provide a much better fit to the data than a straight line. However, sorting efficiency among the sorters did not decline even for long sessions of several hours. In general, performance of each sorter was individualistic and efficiency was variable from sample to sample (Fig. 2; Table 1). Rate of sorting as

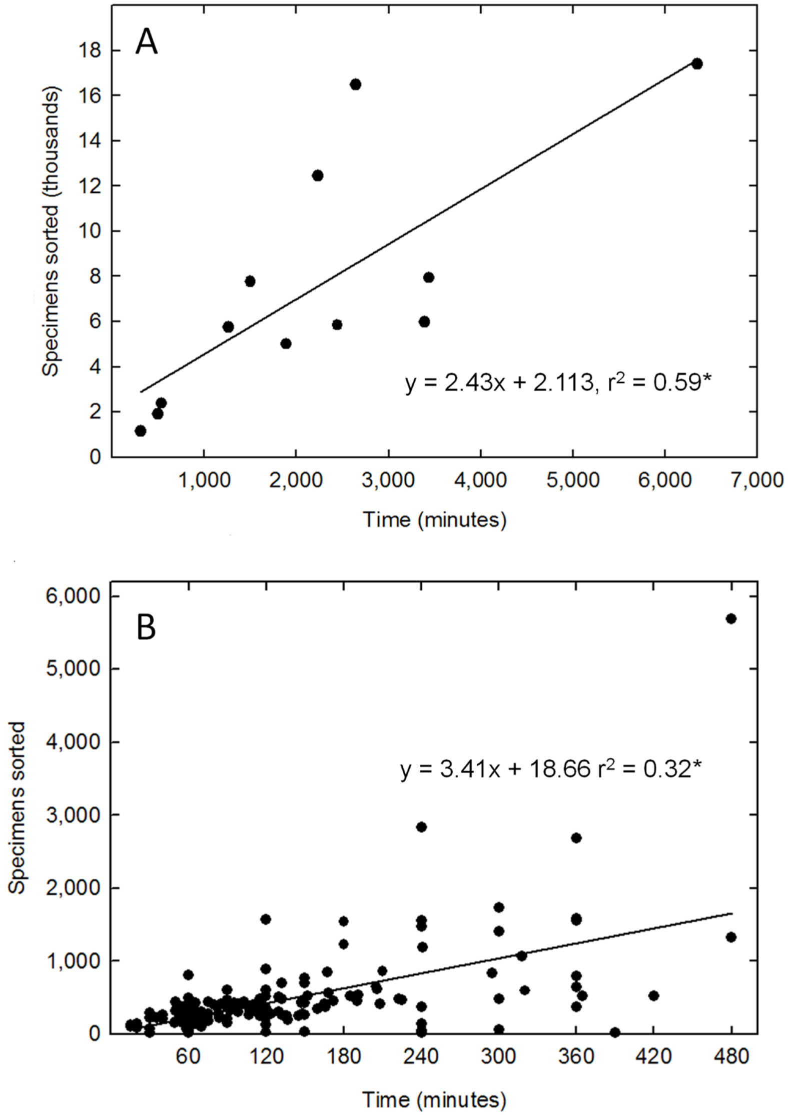


Fig. 1A-B. Relationship of sorting time to numbers of specimens in samples. A) Relation of total sample sorting time to total arthropods in sample. B) Relation of sorting session length to specimens. Each point represents a complete sample (A) or a session (B). An asterisk following the $r^2$ value indicates a significant coefficient of correlation $r$ ($P < 0.05$).

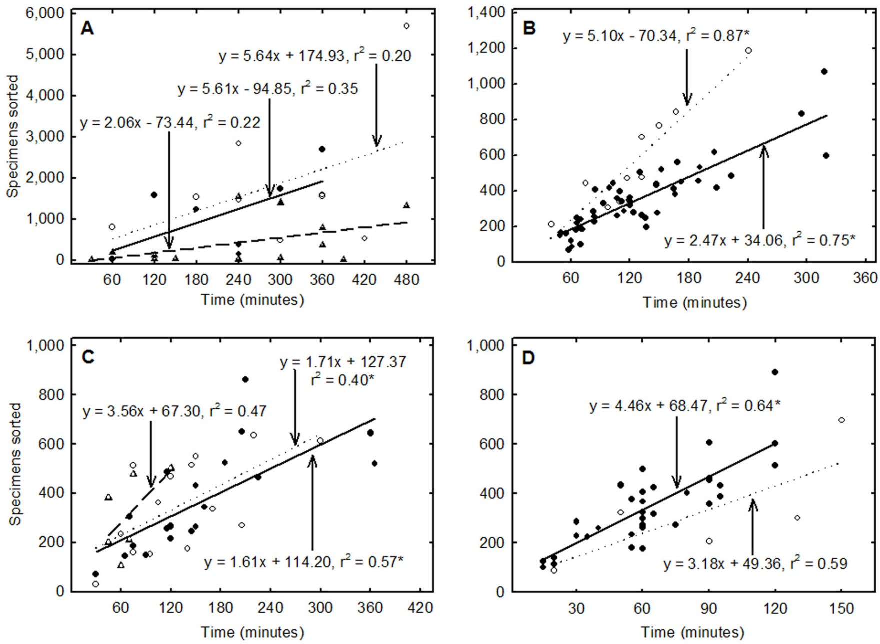


Fig. 2A-D. Relationship of time spent sorting arthropods to number of sorted arthropods by sorter (A-D) and sample. Each line represents a sample; each point represents a separate sorting session for the sample. An asterisk following the $r^2$ value indicates a significant coefficient of correlation $r$ ($P < 0.05$). Sorter A was the most experienced sorter.

Table 1. Sorting sessions, total specimens sorted, and linear first- and second-order coefficients of determination ($r^2$) of arthropod specimens sorted vs. time to sort each sample.

| Sorter, sample | Sessions | Total Specimens | First Order $r^2$ [b] | Second Order $r^2$ [b] |
|---|---|---|---|---|
| A1 | 9 | 16,471 | 0.22 | 0.23 |
| A2 | 14 | 5,972 | 0.20 | 0.20 |
| A3 | 7 | 7,752 | 0.35 | 0.35 |
| B1 | 50 | 17,388 | 0.75* | 0.75* |
| B2 | 10 | 5,734 | 0.87* | 0.89* |
| C1 | 21 | 7,936 | 0.57* | 0.67* |
| C2 | 14 | 5,011 | 0.40* | 0.42* |
| C3 | 7 | 2,377 | 0.47 | 0.50 |
| C4 | 3 | 1,127 | ---[c] | ---[c] |
| D1 | 36 | 12,439 | 0.64* | 0.65* |
| D2 | 6 | 1,887 | 0.59 | 0.65 |
| E1 | 25 | 5,843 | 0.34* | 0.35* |

[a]Designations A-D correspond to graphs in Fig. 2.
[b]Asterisks indicate a significant coefficient of correlation $r$ ($P < 0.05$).
[c]Sample C4 not analyzed due to small number of sessions.

measured by line slope was 1.61-5.64 specimens per minute. The experienced research associate had the two highest rates of sorting, but also one rate lower than the mean (Fig. 2A). Students (Figs. 2B-D) had a more constant rate of sorting, as measured by $r^2$, than the research associate. Some factors that may have produced variability in efficiencies and rates included amount of debris in a sample, methodology for separating specimens from debris, sorting fatigue, and interruptions. No attempt was made to select samples with equal volumes or similar components of soil and organic debris. More time likely is necessary for separation of specimens from debris with much fine matter than separation in a sample with coarse litter. Also, the approach to separation of specimens from debris varied among the sorters. Two sorters (A, E) removed most of the sample debris before beginning the sorting process, while the others sorted in a grid pattern, removing specimens from the litter in a particular area of the sorting dish, then moving on. Sorting fatigue was initially assumed to have occurred if the second-order regression coefficient was much larger than the first-order coefficient, as observed in samples C1 and D2 (Table 1). In sample C1, slope of the second-order line decreased with increasing sorting time, suggesting a fatigue factor; however, the slope for the second-order line in D2 increased with time, suggesting an accelerating sorting rate. Therefore, fatigue over time was not a significant factor for most of the samples. Finally, interruptions in the sorting process may have had a significant effect on sorting rate during individual sessions. The research associate, who was generally the fastest sorter, also had the most variability in sorting rates among sessions, as measured by the low $r^2$ values (Fig. 2A). This sorter frequently had short, unpredictable interruptions due to telephone calls, questions from students, and attendance to other minor duties not long enough in duration to terminate a session, but long enough to add time to the session. Thus, this sorter probably would have had even higher sorting rates given an environment where sorting was the only activity.

This project was not planned to analyze every variable that could be present. For instance, fine debris varied markedly among the samples and may have skewed the natural sorting aptitude of some sorters. Also, students were not asked about interruptions to their sorting activity, such as looking at vial contents or taking closer looks at particularly interesting specimens (comments volunteered by participants). Students did not perform the sorting in a uniform setting, since the teaching laboratory also accommodated other courses; instead, they worked in their own labs or borrowed a microscope to work at home. In a funded project, workers likely would have dedicated work spaces, have fewer distractions, and be paid for the number of hours worked. Therefore, it can be suggested that in a long-term setting the potential number of specimens sorted would be closer to the 5 per minute realized by the research associate.

The data also were examined to determine if specimen abundance in a sample was closely related to sorting time per session. More sessions yielded 100-300 or 301-600 specimens (83 and 71, respectively) than any other grouping; this result suggests that the sorters fixed on this range as a suitable target for a session. However, number of specimens sorted per session was not closely related to the time per session except for the 301-600 specimen range (Fig. 3); even then, the $r^2$ values are low and explain little of the variability among these points. A paucity of specimens in a sample presumably with much debris may prolong the search; in one session, 390 minutes were needed to locate 17 specimens. Conversely, some specimen-rich samples could be sorted rapidly due to the lack of debris (Fig. 3). Given a sorting rate of 3.41 specimens per minute and a common focus on 100-600 specimens per session, it can be hypothesized that sorters will be efficient in sessions lasting up to about 3 hours.

The results of this study demonstrate a sorting rate that can be used by grant writers to estimate the financial costs of the laborious process of separating and enumerating specimens from bulk samples, if the number of samples and the approximate density of specimens are known. Although sort rate was calculated at 2.43-3.41 organisms per minute for these mostly inexperienced sorters, a more realistic figure for experienced parataxonomists, such as sorter A, could be more than 5 specimens per minute. The utility and limitations of trained parataxonomists have been well documented (Basset et al. 2000, Janzen 2004, Krell 2004, Ward and Larivière 2004, Abadie et al. 2008). In the current study, bulked arthropods were separated into classes or orders to facilitate identification by experts, who often are amenable to providing identifications of already sorted material. The nature of the exercise did not allow for a study of sorting to families, genera, or morphospecies, but previous attempts (Majka and Bondrup-Nielsen 2006) suggest that this would not be a fruitful exercise for microarthropods.

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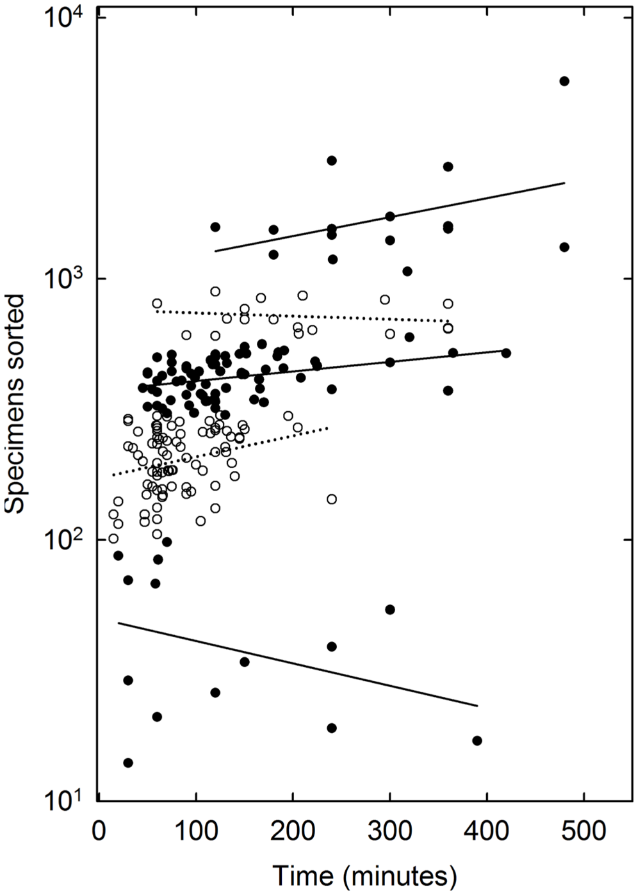


Fig. 3. Relationship of time per sorting session on number of specimens sorted, grouped in five arbitrary categories. An asterisk following the $r^2$ value indicates a significant coefficient of correlation $r$ ($P < 0.05$).

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