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Ants of the Palouse Prairie: diversity and species composition in an endangered grassland

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Abstract

Grasslands are globally imperiled ecosystems due to widespread conversion to agriculture, and there is a concerted effort to catalogue arthropod diversity in grasslands to guide conservation decisions. The Palouse Prairie is one such endangered grassland; a mid-elevation habitat found in Washington and Idaho, United States. Ants (Formicidae) are useful indicators of biodiversity and historical ecological disturbance, but there has been no structured sampling of ants in the Palouse Prairie. To fill this gap, we employed a rapid inventory sampling approach using pitfall traps to capture peak ant activity in five habitat fragments. We complemented our survey with a systemic review of field studies for the ant species found in Palouse Prairie. Our field inventory yielded 17 ant species across 10 genera, and our models estimate the total ant species pool to be 27. The highest ant diversity was found in an actively managed ecological trust in Latah County, Idaho, suggesting that restoration efforts may increase biodiversity. We also report two rarely collected ants in the Pacific Northwest, and a microgyne that may represent an undescribed species related to *Brachymyrmex depilis*. Our score-counting review revealed that grassland ants in Palouse prairie have rarely been studied previously, and that more ant surveys in temperate grasslands have lagged behind sampling efforts of other global biomes.

Keywords

Palouse Prairie, ant biodiversity, rapid species inventory, agroecosystems, insect conservation, prairies

Introduction

Temperate grasslands and savannah are among the most endangered biomes in the world, having the highest rate of conversion to agriculture and the lowest rate of government protection (Hoekstra et al. 2005). In the United States, grasslands, savanna, and barrens communities are critically endangered, experiencing > 98% decline in areas since European settlement (Noss et al. 1995). Since organisms found in prairies are threatened by habitat loss, biodiversity surveys that describe the native and non-native fauna are necessary to help inform future conservation efforts and guide restoration to impactful areas. Ants are useful biodiversity indicators in grasslands and characterizing ant community composition through rapid assessment is pertinent for monitoring and evaluating global grassland restoration efforts (Peters et al. 2016).

Biodiversity surveys play a strategic role in grassland conservation, aiding arguments that habitats contain rare or endemic species (Van Schalkwyk et al. 2019). Temperate grasslands are host to a wide range of endemic plant and animal communities, including many insects of conservation concern (Sampson and Knopf 1994). A comprehensive list of globally threatened species, the Red List, counts over 2,000 grassland species that are critically engendered, endangered, or vulnerable worldwide, 108 of which are in North America (I.U.C.N. 2020). Grasslands are frequently fragmented by agricultural production, and they are therefore prone to increased rates of local extinctions through a variety of modes such as reduced population sizes, increased invaders, and elimination of keystone predators (Leach and Givnish 1996).

The Palouse Prairie is an endangered grassland ecosystem that originally encompassed southeastern Washington state and neighboring northern Idaho (Looney and Eigenbrode 2012, Noss et al. 1995). The Palouse landscape is characterized by rolling hills formed from wind-blown fertile loess soils, which form the foundation for plant communities of caespitose grass, co-dominant shrub, and flowering forbs (Looney et al. 2009, Daubenmire 1970). The Palouse Prairie has experienced an estimated 99.9% decline in habitat across its former range due to agricultural land use, making it one of the most imperiled ecosystems in the United States (Donovan et al. 2009, Black et al. 2000). What habitat remains is fragmented into small, thin areas, and a majority of fragments are smaller than two hectares with high perimeter-area ratios (Yates et al. 2004). Encouragingly, these fragments are capable of supporting several endangered species (Looney and Eigenbrode 2012).

Published biodiversity surveys are limited for the Palouse Prairie, encompassing a survey of bumblebees (Hatten et al. 2013), macromoths (Thompson et al. 2014), and flowering forbs (Donovan et al. 2009). In this study we chose ants (Formicidae) as a candidate for biodiversity survey efforts in Palouse prairie. Ants are used prominently for monitoring because they are ubiquitous in terrestrial ecosystems, sampling is relatively inexpensive, and many ant species respond quickly to disturbances (Tiede et al. 2017, Hoffmann 2010, Underwood and Fisher 2006, Folgarait 1998, Andersen 1990). However, in poorly surveyed regions using ants as biodiversity indicators can be challenging if taxonomic resources are not well developed (Hevia et al. 2016). The Pacific Northwest region is generally under-sampled for ants, and thus up-to-date taxonomic resources are limited (Hoey-Chamberlain et al. 2010). Consequently, we included a systematic review of all ant species found and referred directly with taxonomic experts to verify all species-level identifications.

Material and methods

Rapid inventory survey

Ant surveys were completed at five prairie fragments: Hudson Biological Reserve, Kamiak Butte County Park, Skinner Ecological Preserve, Idler's Rest Nature Preserve, and Philip's Farm County Park (Figs 1, 2, Suppl. material 1). We used a rapid inventory sampling method with pitfall trap transects among the five sites (Agosti et al. 2000, Ellison et al. 2007). We used 4 cm diameter, 14 cm depth, pitfall traps filled 2/3 with propylene glycol (Higgins and Lindgren 2012). Our time selected for this survey intended to capture peak ant activity in August on days above 24°C and no precipitation. We worked in four teams to ensure all traps were placed and collected simultaneously. Pitfall traps were run for 48 h, after which ants were transferred to 95% ethanol. Afterwards, ants were pinned for later identification and storage. In all, we ran 131 pitfall traps and collected 424 individual ants (Suppl. material 2).

Species-level identification of ants can be time consuming and difficult in regions with poorly described ant fauna (reviewed in Ellison 2012). The Inland Northwestern US has few recent records of ants to aid in identification, and we thus employed a four-step identification approach. First, all ants were identified to genus using Ant Genera of North America (Fisher and Cover 2007). Second, we used records and pinned specimen photographs posted to online ant taxonomy databases (i.e. Guénard 2017) to identify ants to species. Third, we compared specimens to collections at the Washington State University MT James Museum and the University of Idaho WF Barr Entomological Museum. We also consulted published checklists of ants known from Idaho, Washington, and the western United States (Cole 1936, Smith 1941, Yensen et al. 1977, Cook 1953, Wheeler and Wheeler 1986), although these studies reflect the lack of recent comprehensive reports published.

Systematic review methods

We searched for studies in Web of Science that quantified abundance or richness of the ant species within prairie or grassland from 2016 to the present. Our search was conducted in June 2020 using the term "ant AND divers* AND prairie OR ant AND divers* AND grassland". Our search yielded 106 studies that were reviewed for inclusion based on three criteria: (i) the study assessed more than one species; (ii) the study was performed in non-managed grassland or prairie; and (iii) the biome of the study could be determined; 21 studies met these criteria (Suppl. material 3). We classified the biome of each study using either the site coordinates or other geographic descriptors to locate study areas, then cross-referenced with the EcoRegions web app (Dinerstein et al. 2017).

We examined the frequency of recent publications on each individual species collected in our pitfall survey using the same approach as the biome survey, but instead used the genus and species names as search terms. We tabulated the number of studies from 2010-2020 that reported ant species we found. We read abstracts to ensure that all studies included in this survey involved field observations of the insect species in question, and we included multiple species names recently revised species (Schar et al. 2018). We did not include purely lab-based studies on behavior (i.e. Bordoni et al. 2019 report on *Temnothorax rugatulus*).

Statistical methods

Analyses and figure generation was completed in R ver 4.0.2 (CRAN 2020). Visualization of sites was mapped using ggpmap package (Kahle and Wickham 2013). Species accumulation curves were run using the 'vegan' package in R (Dixon 2003). We estimated species richness using the Chao1 estimate, an abundance-based estimate of species richness, following decision-tree recommendations (Hortal et al. 2006).

Results

Among all sites, we collected 17 ant species (Table 1), with *Aphaenogaster occidentialis* the most common. Ants in the genus *Formica* were the most diverse, with six species (Fig. 3). The non-native species *Tetramorium immigrans* was found in three locations but was not abundant. We found a single microgyne (miniature queen) similar to *Brachymyrmex depilis.* Scattered records of similar *Brachymyrmex* spp. microgynes exist and they have been interpreted as undescribed, socially parasitic species (Moreau et al. 2014, Deyrup 2016). Finally, we collected *Temnothorax nevadensis* and *Formica puberula,* two ant species that are rarely collected in Pacific Northwest temperate ecosystems (Guénard 2017).

Ant species richness varied among sites, with the highest diversity at Skinner Ecological Preserve (Fig. 4), and a total predicted species pool of 27 (*Chao1* index = 27.9, SE = 10.2). Skinner Preserve, the largest intact prairie fragment, had the highest species richness (16) and estimated species pool (*Chao1* index = 25.8, SE = 10.0). Smoot Hill had the lowest species richness (4) and smallest species pool (*Chao1* index = 5.9, SE = 3.6). Two restored habitats adjacent to Ponderosa Pine – Doug-Fir forests near Moscow, Idaho had intermediate species pools (Philip's Farm [9 species] – *Chao1* index = 18.0, SE = 9.2; Idler's Rest [13.6 species] – *Chao1* index = 13.6; SE = 4.8). Kamiak Butte had 11 species (*Chao1* index = 13.9; SE = 4.4).

We found 95 publications detailing a study containing at least one species observed in our survey (Table 1). No field studies have been published for *Formica neoclara*, *F. puberula* and *F. subaenescens,* and only one study included *Temnothorax nevadensis* (Table 1). These limited numbers show our pitfall sampling found several rarely studied ant species. In fact, there were five or fewer publications for all the ant species collected besides the common "tramp species", or urban pests like *Tapinoma sessile* and *Tetramorium immigrans* (Kamura et al. 2007, Uno et al. 2010). Our systematic review of ant biodiveristy surveys in different biomes over the last five years revealed a bias towards for Tropical &

Subtropical Grasslands, Savanas & Shurblands (eight studies, Cross et al. 2016, Van Schalkwyk et al. 2019, Arcoverde et al. 2016, Lasmar et al. 2020, Drose et al. 2019, Hlongwane et al. 2019, Queiroz et al. 2020, Santoandre et al. 2019). We found two studies on Tropical & Subtropical Moist Broadleaf Forests (Laws et al. 2017, Klunk et al. 2018), one study on Tropical & Subtropical Coniferous Forests (Cuautle et al. 2016), three studies on Temperate Broadleaf & Mixed Forests (Braschler and Baur 2016, Helms et al. 2020, Heuss et al. 2019), one study on Montaine Grasslands & Shrublands (Jamison et al. 2016), three studies on Mediterranean Forests, Woodlands & Scrub (Adams et al. 2018, Catarinue et al. 2018, Flores et al. 2018), and one study on Deserts & Xeric Shrublands (Alvarez and Ojeda 2019). In the last five years, only two citations have included information on ants in Temperate Grasslands, Savannas and Grassland biomes (Ramos et al. 2018, Kim et al. 2018), the biome that encompasses Palouse Prairie (Fig. 5).

Discussion

Our field survey results show there are likely many more ant species to be discovered with more intensive sampling in Palouse Prairie, and that there is likely appreciable diversity of other insect species beyond those of the limited taxonomic focus of this study. Furthermore, one of our collected specimens may be a currently undescribed species of ant, but taxonomic revision of *Brachymyrmex* is required to demonstrate if this is the case and this putative ant species is rarely collected. In many ecosystems insect's faunas are poorly described (Berenbaum 2008, Dunn 2005) and lack of recent publications on temperate grassland ant faunas, and dearth of work on several species collected in Palouse Prairie, underscore the importance of survey work in endangered ecosystems. As habitat destruction and fragmentation continue, we may never be able to sample or study the more rarely collected species (Dunn 2005, Noss et al. 1995).

Ant communities are under-sampled in cool-temperate ecosystems compared to the tropics and sub-tropics, including temperate grasslands in the northwestern United States (Ellison 2012, Radtke et al. 2014). Since ants are excellent biological indicators of ecosystem health, sampling efforts may use our data as a comparison point to see if restoration efforts have been successful (Folgarait 1998, Williams 1994). Luckily, once taxonomic resources are available, assessment of an ecosystem's ant communities can be completed quickly with greater accuracy of species-level identification (Ellison et al. 2007). The intermediate levels of ant diversity at sites adjacent to forest validate predictions that Palouse Prairie-forest ecotones may support high biodiversity (Morgan et al. 2020) Finally, our estimates of a species pool of 27 reflect similar scale of ant species richness found in large ant surveys in grassland systems such as Wisconsin, USA tallgrass prairie (29 species in control sites, Kim et al. 2018) and Argentinian grasslands (46 species in grassland sites, Santoandre et al. 2019). However given our absolute species richness was 17, there is more sampling to be completed to comprehensively describe this fauna.

Research in conservation biological control has shown the value of ants as predators in agroecosystems (Way and Khoo 1992). In our study we found multiple species of ants in genera often implicated as predators of chewing herbivores, such as *Formica* and

Camponotus (Choate and Drummond 2011). More recent work demonstrates that social insects, including ground-nesting ants, have positive effects on dryland crop yield by increasing water and micronutrient availability to cereals (Evans et al. 2011). However, the value of these ecosystem services likely pales in comparison to the benefit ants could provide as predators of weed seeds (e.g., Evans and Gleeson 2016). Weeds and herbicide resistance are among the most economically challenging pest problems in dryland agriculture (Powell and Shaner 2001), and ants have been implicated in regulating seed banks in other grasslands (Motze et al. 2013). Recovery of more Palouse Prairie could promote higher ant diversity and abundance (Laws et al. 2017), thus increasing the likelihood that ants are available to provide these critical ecosystem services, including weed seed predation.

Conclusions

The remaining habitat in the Palouse is highly fragmented and only protected by a range of public and private trusts (Looney and Eigenbrode 2012). This is problematic since we found several species of ants that are uncommonly collected. While these species are not endemic to Palouse prairie, our observations suggest that opportunities to study these insects in grassland habitats are limited. Furthermore, in addition to fragmentation and disturbance from agriculture, several of our sites are invaded by the Pavement ant (*Tetramorium immigrans*), which is associated with disturbed, agricultural habitats (Cerda et al. 2009). The extremely reduced range of the Palouse Prairie and the presence of invasive species means many other taxonomic groups of animals are in urgent need of sampling before opportunities to describe this fauna are irreversibly lost.

Author contributions

KAD, ALC, ECO, and REC completed field surveys. REC analyzed data. KAD, ALC, GSM, and ECO performed systematic review. KDA, REC and MLB curated and identified ants. All authors contributed to writing and editing the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

References

- Abbate A, Campbell J (2013) Parasitic beechdrops (*Epifagus virginiana*): a possible ant-pollinated plant. Southeastern Naturalist 12: 661-665. https://doi.org/10.1656/058.012.0318

- Adams TA, Straubus WJ, Meyer M (2018) Fire impacts on ant assemblages in California sage scrub. Southwestern Entomologist 42: 323-334. https://doi.org/10.3958/059.043.0204
- Agosti JD, Alonso LE, Donat TR (2000) Ants: standard methods for measuring and monitoring biodiversity. Smithsonian Instittion Scholarly Press, Washington, DC.
- Akyurek B, Zeybekoglu U, Gorur G, Karavin M (2016) Reported aphid (Hemiptera: Aphidoidea) and ant (Hymenoptera: Formicidae) species associations from Samsun Province. Journal of the Entomological Research Society 18: 97-106.
- Alvarez F, Ojeda M (2019) Animal diversity and biogeography of the Cuatro Cienegas Basin. Springer International Publishing, Switzerland. https://doi.org/10.1007/978-3-030-11262-2
- Andersen AN (1990) The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. Proceedings of the Ecological Society of Australia 16: 347-357.
- Arcoverde GB, Anderson AN, Setterfield SA (2016) Is livestock grazing compatible with biodiversity conservation? Impacts on ant communities in the Autstrailian seasonal tropics. Biodiversity and Conservation 26: 883-897. https://doi.org/10.1007/s10531-016-1277-5
- Barton BT, Ives AR (2014) Direct and indirect effects of warming on aphids, their predators, and ant mutualists. Ecology 95: 1479-1484. https://doi.org/10.1890/13-1977.1
- Berenbaum M (2008) Insect conservation and the Entomological Society of America. American Entomologist 54: 117-120. https://doi.org/10.1093/ae/54.2.117
- Black AE, Strand E, Morgan P, Scott JM, Wright RG, Watson C (2000) Biodiversity and land-use history of the Palouse bioregion: pre-European to present, Chapter 10. In: Sisk T (Ed.) Land use history of North America. U.S. Geological Survey.
- Blonder B, Dornhaus A (2011) Time-ordered networks reveal limitations to information flow in ant colonies. PLOS One 6.
- Bordoni A, Matejkova Z, Chimenti L (2019) Home economics in an oak gall: behavioural and chemical immune strategies against a fungal pathogen in *Temnothorax* ant nests. The Science of Nature 106: 11-1.
- Bowens S, Glatt D, Pratt S (2013) Visual navigation during colony emigration by the ant *Temnothorax rugatulus*. PLOS One 8.
- Brant M, Gedan K, Garcia E (2010) Disturbance type affects the distribution of mobile invertebrates in a high salt marsh community. Northeastern Naturalist 17: 103-114. https://doi.org/10.1656/045.017.0108
- Braschler B, Baur B (2016) Diverse effects of a seven-year grassland fragmentation on major invertebrate groups. PLOS One 11.
- Buczkowski G, Bennett G (2009) The influence of forager number and colony size on food distribution in the odorous house ant, *Tapinoma sessile*. Insectes Sociaux 56: 185-192. https://doi.org/10.1007/s00040-009-0011-7
- Buczkowski G (2010) Extreme life history plasticity and the evolution of invasive characteristics in a native ant. Biological Invasions 12: 3343-3349.
- Buczkowski G, Krushelnycky P (2012) The odorous house ant, *Tapinoma sessile* (Hymenoptera: Formicidae), as a new temperate-origin invader. Myrmecological News 16: 61-66.

- Buczkowski G, Richmond D (2012) The effect of urbanization on ant abundance and diversity: a temporal examination of factors affecting biodiversity. PLOS One 7.
- Burford B, Lee G, Friedman D, Brachmann E, Khan R, MacArthur Waltz D, McCarty A, Gordon D (2018) Foraging behavior and locomotion of the invasive Argentine ant from winter aggregations. PLOS One 13.
- Campbell J, Grodsky S, Halbritter D, Vigueira P, Vigueira C, Keller O, Greenberg C (2019) Asian needle ant (*Brachyponera chinensis*) and woodland ant responses to repeated applications of fuel reduction methods. Ecosphere 10.
- Cao T (2013) High social density increases foraging and scouting rates and induces polydomy in *Temnothorax* ants. Behavioral Ecology and Sociobiology 67: 1799-1807. https://doi.org/10.1007/s00265-013-1587-5
- Catarinue C, Reyes-Lopez J, Herriaz JA, Barbera GG (2018) Effect of pine reforestation associated with soil disturbance on ant assemblages (Hymenoptera: Formicidae) in a semiarid steppe. European Journal of Entomology 115: 562-574. https://doi.org/10.14411/eje.2018.054
- Cerda X, Palacios R, Retana J (2009) Ant community structure in citrus orchards in the Mediterranean Basin: impoverishment as a consequence of habitat homogeneity. Environmental Entomology 38: 317-324. https://doi.org/10.1603/022.038.0203
- Charbonneau D, Hills N, Dornhaus A (2015) 'Lazy' in nature: ant colony time budgets show high 'inactivity' in the field as well as in the lab. Insectes Sociaux 62: 31-35. https://doi.org/10.1007/s00040-014-0370-6
- Charbonneau D, Sasaki T, Dornhaus A (2017) Who needs 'lazy' workers? Inactive workers act as a 'reserve' labor force replacing active workers, but inactive workers are not replaced when they are removed. PLOS One 12.
- Chin DB, G. (2018) Dominance of pavement ants (Hymenoptera: Formicidae) in residential areas of West Lafayette, IN, USA. Journal of Entomological Science 53: 379-385. https://doi.org/10.18474/JES17-120.1
- Choate B, Drummond F (2011) Ants as biological control agents in agricultural cropping systems. Terrestrial Arthropod Reviews 4: 157-180. https://doi.org/10.1163/187498311X571979
- Clark R, Singer M (2018) Differences in aggressive behaviors between two ant species determine the ecological consequences of a facultative food-for-protection mutualism. Journal of Insect Behavior 31: 510-522. https://doi.org/10.1007/s10905-018-9695-8
- Cole ACJ (1936) An annotated list of the ants of Idaho (Hymenoptera: Formicidae). The Canadian Entomologist 68: 34-39. https://doi.org/10.4039/Ent6834-2
- Collignon B, Detrail C (2010) Distributed leadership and adaptive decision-making in the ant *Tetramorium caespitum*. Proceedings of the Royal Society B: Biological Sciences 277: 1267-1273. https://doi.org/10.1098/rspb.2009.1976
- Cook TW (1953) The Ants of California. Pacific Books, IL.
- Cordonnier M, Bellec A, Dumet A, Escarguel G, Kaufmann B (2019a) Range limits in sympatric cryptic species: a case study in *Tetramorium* pavement ants (Hymenoptera: Formicidae) across a biogeographical boundary. Insect Conservation and Diversity 12: 109-120. https://doi.org/10.1111/icad.12316
- Cordonnier M, Gibert C, Bellec A, Kaufmann B, Escarguel G (2019b) Multi-scale impacts of urbanization on species distribution within the genus *Tetramorium*. Landscape Ecology 34: 1937-1948.

- Cordonnier M, Bellec A, Escarguel G, Kaufmann B (2020a) Effects of urbanization-climate interactions on range expansion in the invasive European pavement ant. Basic and Applied Ecology 44: 46-54. https://doi.org/10.1016/j.baae.2020.02.003
- Cordonnier M, Escarguel G, Dumet A, Kaufmann B (2020b) Multiple mating in the context of interspecific hybridization between two *Tetramorium* ant species. Heredity 124: 675-684. https://doi.org/10.1038/s41437-020-0310-3
- CRAN (2020) R version 4.0.2 R: A language and environment for statistical computing. R Foundation for Statistical Computing. URL: https://www.R-project.org/
- Cross AT, Myers C, Mitchell CN (2016) Ant biodiversity and its environmental predictors in the North Kimberley region of Australia's seasonal tropics. Biodiversity and Conservation 25: 1727-1759. https://doi.org/10.1007/s10531-016-1154-2
- Cuautle M, Vergara C, Badano E (2016) Comparison of ant community diversity and functional group composition associated to land use change in a seasonally dry oak forests. Neotropical Entomology 45: 170-179. https://doi.org/10.1007/s13744-015-0353-y
- Cuesta-Segura D, Garcia F, Espadaler X (2012) The westernmost locations of *Lasius jensi* Seifert, 1982 (Hymenoptera: Formicidae): first records in the Iberian Peninsula. Myrmecological News 16: 35-38.
- Dash S, Sanchez L (2009) New distribution record for the social parasitic *Antanergates atratulus* (Hymonptera: Formicidae): an IUCN red-listed species. Western North American Naturalist 69: 140-141. https://doi.org/10.3398/064.069.0109
- Daubenmire R (1970) Steppe vegetation of Washington. Washington Agricultural Experiment Station
- Davenport S, Mull J, Hoagstorm C (2013) Consumption of a dangerous ant (*Camponotus vicinus*) by a threatened minnow (*Notropis simus pecosensis*). Southwestern Naturalist 58: 126-128.
- Deyrup M (2016) Ants of Florida: Identification and Natural History. CRC Press https://doi.org/10.1201/9781315368023
- Dinerstein E, Olson D, Joshi A, Vynne C, Burgess ND, Wikramanayake E, Hahn N, Palminteri S, Hedao P, Noss R (2017) An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. Bioscience 67: 534-545. https://doi.org/10.1093/biosci/bix014
- DiRienzo N, Dornhaus A (2017) Temnothorax rugatulus ant colonies consistently vary in nest structure across time and context. PLOS One 12.
- Dixon P (2003) VEGAN, a package of R functions for community ecology. Journal of Vegetation Science 14: 927-930. https://doi.org/10.1111/j.1654-1103.2003.tb02228.x
- Doering G, Pratt S (2016) Queen location and nest site preference influence colony reunification by the ant *Temnothorax rugatulus*. Insectes Sociaux 63: 585-591. https://doi.org/10.1007/s00040-016-0503-1
- Doering G, Pratt S (2019) Symmetry breaking and pivotal individuals during the reunification of ant colonies. Journal of Experimental Biology 222: jeb194019. https://doi.org/10.1242/jeb.194019
- Doering G, Sheehy K, Lichtenstein J, Drawert B, Petzold L, Pruitt J (2019) Sources of intraspecific variation in the collective tempo and synchrony of ant societies. Behavioral Ecology 30: 1682-1690. https://doi.org/10.1093/beheco/arz135
- Doering G, Sheehy K, Barnett J, Pruitt J (2020) Colony size and initial conditions combine to shape colony reunification dynamics. Behavioural Processes 170: 103994.

- Donovan SM, Looney C, Hanson T (2009) Reconciling social and biological needs in an endangered ecosystem: The Palouse as a model for bioregional planning. Ecology and Society 14: 9. https://doi.org/10.5751/ES-02736-140109
- Drose W, Podgaiski LR, Dias CR, Souza Mendonca M (2019) Local and regional drivers of ant communities in forest-grassland ecotones in South Brazil: A taxonomic and phylogenetic approach. PLOS One 14.
- Dunn RR (2005) Modern Insect Extinctions, the Neglected Majority. Conservation Biology 19: 1030-1036. https://doi.org/10.1111/j.1523-1739.2005.00078.x
- Ellison AM, Record S, Arguello A, Gotelli NJ (2007) Rapid inventory of the ant assemblage in a temperate hardwood forest: species composition and assessment of sampling methods. Environmental Entomology 36: 766-775. https://doi.org/10.1093/ee/36.4.766
- Ellison AM (2012) Out of Oz: opportunities and challenges for using ants (Hymenoptera: Formicidae) as biological indicators in north-temperate cold biomes. Myrmecological News 17: 105-119.
- Evans TA, Dawes TZ, Ward PR, Lo N (2011) Ants and termites increase crop yield in a dry climate. Nature Communications 2.
- Evans TA, Gleeson PV (2016) Direct measurement of ant predation of weed seeds in wheat cropping. Journal of Applied Ecology 53: 1177-1185. https://doi.org/10.1111/1365-2664.12640
- Fisher BL, Cover SP (2007) Ants genera of North America. University of California Press https://doi.org/10.1525/9780520934559
- Fitzgerald K, Gordon D (2012) Effects of vegetation cover, presence of a native ant species, and human disturbance on colonization by Argentine ants. Conservation Biology 26: 525-538. https://doi.org/10.1111/j.1523-1739.2012.01836.x
- Flores O, Seoane J, Hevia V, Azcarate FM (2018) Spatial patterns of species richness and nestedness in ant assemblages along an elevational gradient in a Mediterranean mountain range. PLOS One 3.
- Folgarait PJ (1998) Ant biodiversity and its relationship to ecosystem functioning: a review. Biodiversity & Conservation 7: 1221-1244. https://doi.org/10.1023/A:1008891901953
- Gibson J, Suarez A, Qazi D, Benson T, Chiavacci S, Merrill L (2019) Prevalence and consequences of ants and other arthropods in active nests of Midwestern birds. Canadian Journal of Zoology 97: 696-704. https://doi.org/10.1139/cjz-2018-0182
- Gordon D, Heller N (2014) The invasive Argentine ant *Linepithema humile* (Hymenoptera: Formicidae) in Northern California reserves: from foraging behavior to local spread. Myrmecological News 19: 103-110.
- Gow E, Wiebe K, Higgins R (2013) Lack of diet segregation during breeding by male and female northern flickers foraging on ants. Journal of Field Ornithology 84: 262-269. https://doi.org/10.1111/jofo.12025
- Guénard B (2017) The Global Ant Biodiversity Informatics (GABI) database: synthesizing data on the geographic distribution of ant species (Hymenoptera: Formicidae). Myrmecological News 24: 83-89.
- Guyer A, Hibbard BE, Holzkamper A, Erb M, Robert CA (2018) Influence of drought on plant performance through changes in belowground tritrophic interactions. Ecology and Evolution 8: 6756-6765. https://doi.org/10.1002/ece3.4183

- Hamm C (2010) Multivariate discrimination and description of a new species of *Tapinoma* from the western United States. Annals of the Entomological Society of America 103: 20-29. https://doi.org/10.1603/008.103.0104
- Hatten TD, Looney C, Strange JP, Bosque-Pérez NA (2013) Bumble bee fauna of Palouse prairie: survey of native bee pollinators in a fragmented ecosystem. Journal of Insect Science 13: 1-19.
- Heinze J, Rueppell O (2014) The frequency of multi-queen colonies increases with altitude in a Nearctic ant. Ecological Entomology 39: 527-529. https://doi.org/10.1111/een.12119
- Helms JA, Ijelu SE, Wills BD, Landis DA, Haddad NM (2020) Ant biodiversity and ecosystem services in bioenergy landscapes. Agriculture, Ecosystems & Environment 290.
- Heuss L, Greve ME, Scafter D, Bush V, Felhaar H (2019) Direct and indirect effects of land-use intensification on ant communities in temperate grasslands. Ecology and Evolution 9: 4013-4024.
- Hevia V, Carmona CP, Azcarate FM, Torralba M, Alcorlo P, Arino R, Lozano J, Castro-Cobo R, Gonzalez JA (2016) Effects of land use on taxonomic and functional diversity: a cross-taxon analysis in a Mediterranean landscape. Oecologia 181: 959-970. https://doi.org/10.1007/s00442-015-3512-2
- Higgins R, Lindgren B (2012) An evaluation of methods for sampling ants (Hymenoptera: Formicidae) in British Columbia, Canada. Can. Entomol 144: 491-507. https://doi.org/10.4039/tce.2012.50
- Hlongwane ZT, Mwabyu T, Munyai TC, Tsvuura Z (2019) Epigaeic ant diversity and distribution in the Sandstone Sourveld in KwaZulu-Natal, South Africa. African Journal of Ecology 57: 382-393. https://doi.org/10.1111/aje.12615
- Hoekstra JM, Boucher TM, Ricketts TH, Roberts C (2005) Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters 8: 23-29. https://doi.org/10.1111/j.1461-0248.2004.00686.x
- Hoey-Chamberlain R, Hansen L, Klotz J, McNeeley C (2010) A survey of the ants of Washington and surrounding areas in Idaho and Oregon focusing on disturbed sites (Hymenoptera: Formicidae). Sociobiology 56: 195-207.
- Hoffmann BD (2010) Using ants for rangeland monitoring: global patterns in the responses of ant communities to grazing. Ecological Indicators 10: 105-111. https://doi.org/10.1016/j.ecolind.2009.04.016
- Hortal JP, Borges AV, Gaspar C (2006) Evaluating the performance of species richness estimators: sensitivity to sample grain size. Journal of Animal Ecology 75: 274-287. https://doi.org/10.1111/j.1365-2656.2006.01048.x
- I.U.C.N. (2020) The IUCN Red List of Threatened Species, Version 2020-1. Downloaded on.
- Jamison SL, Robertson M, Engelbrecht I, Hawkes P (2016) An assessment of rehabilitation success in an African grassland using ants as bioindicators. Koedoe 58: 1-16.
- Joharchi O, Halliday B, Saboori A (2012a) Three new species of *Laelaspis berlese* from Iran (Acari: Laelapidae), with a review of the species occurring in the Western Palaearctic Region. Journal of Natural History 46: 1999-2018. https://doi.org/10.1080/00222933.2012.707240

- Joharchi O, Jalaeian M, Paktinat-Saeej S, Ghafarian A (2012b) A new species and new records of Laelaspis berlese (Acari. Laelapidae) from Iran. Zookeys 208: 17-25.
- Joharchi O, Halliday B (2013) A new species and new records of *Gymnolaelaps* Berlese from Iran (Acari: Laelapidae), with a review of the species occurring in the Western Palaearctic Region. Zootaxa 3646: 39-50. https://doi.org/10.11646/zootaxa.3646.1.3
- Kahle D, Wickham H (2013) Ggmap: Spatial Visualization with ggplot2. The R Journal 5: 144-161. https://doi.org/10.32614/RJ-2013-014
- Kamura CM, Morini MS, Figueiredo CJ, Bueno OC, Campost-Farinha AE (2007) Ant communities (Hymenoptera: Formicidae) in an urban ecosystem near the Atlantic Rainforest. Brazilian Journal of Biolog 67: 635-641. https://doi.org/10.1590/S1519-69842007000400007
- Karban R, Grof-Tisza P, Mcmunn M, Kharouba H, Huntzinger M (2015) Caterpillars escape predation in habitat and thermal refuges. Ecological Entomology 40: 725-731. https://doi.org/10.1111/een.12243
- Kaspari M, Chang C, Weaver J (2010) Salted roads and sodium limitation in a northern forest ant community. Ecological Entomology 35: 543-548. https://doi.org/10.1111/j.1365-2311.2010.01209.x
- Kautz S, Williams T, Ballhorn D (2017) Ecological importance of cyanogenesis and extrafloral nectar in invasive English laurel, *Prunus laurocerasus*. Northwest Science 91: 214-221. https://doi.org/10.3955/046.091.0210
- Kimball C (2016a) Colony structure in *Tapinoma sessile* ants of northcentral Colorado: a research note. Entomological News 126: 357-362. https://doi.org/10.3157/021.125.0507
- Kimball C (2016b) Independent colong foundation in *Tapinoma sessile* of northcentral Colorado. Entomological News 126: 83-86. https://doi.org/10.3157/021.126.0203
- Kim TN, Bartel S, Wills BD, Landis DA, Gratton C (2018) Disturbance differentially affects alpha and beta diversity of ants in tallgrass prairies. Ecosphere 9.
- King J, Tschinkel W (2016) Experimental evidence that dispersal drives ant community assembly in human-altered ecosystems. Ecology 97: 236-249. https://doi.org/10.1890/15-1105.1
- Kjar D, Park Z (2016) Increased ant (Hymenoptera: Formicidae) incidence and richness are associated with alien plant cover in a small mid-Atlantic riparian forest. Myrmecological News 22: 109-117.
- Klunk CL, Giehl EL, Lopes BC, Marcineiro FR, Rosumek FB (2018) Simple does not mean poor: grasslands and forests harbor similar ant species richness and distinct composition in highlands of southern Brazil. Biota Neotropica 18: e20170507.
- Lasmar CJ, Ribas CR, Louzada J, Queiroz AC, Feitosa RM, Imata MM, Alves P, Nascimento GB, Neves NS, Domingos DQ (2020) Disentangling elevational and vegetational effects on ant diversity patterns. Acta Oecologica 102.
- Laws MJ, Moore AM, Anderson AN, Preece ND, Franklin DC (2017) Ants as ecological indicators of rainforest restoration: Community convergence and the development of an Ant Forest Indicator Index in the Australian wet tropics. Ecology and Evolution 7: 8442-8455. https://doi.org/10.1002/ece3.2992
- Leach MK, Givnish TJ (1996) Ecological determinants of species loss in remnant prairies. Science 273: 1555-1558. https://doi.org/10.1126/science.273.5281.1555
- Lenz E, Krasnec M, Breed M (2013) Identification of undecane as an alarm pheromone of the ant Formica argentea. Journal of Insect Behavior 26: 101-108. https://doi.org/10.1007/s10905-012-9337-5

- Li T, Shao M, Jia Y, Jia X, Huang L, Gan M (2019) Small-scale observation on the effects of burrowing activities of ants on soil hydraulic processes. European Journal of Soil Science 70: 236-244. https://doi.org/10.1111/ejss.12748
- Looney C, Caldwell BT, Eigenbrode SD (2009) When the prairie varies: the importance of site characteristics for strategising insect conservation. Insect Conservation and Diversity 2: 243-250. https://doi.org/10.1111/j.1752-4598.2009.00061.x
- Looney C, Eigenbrode SD (2012) Characteristics and distribution of Palouse prairie remnants: implications for conservation planning. Natural Areas Journal 32: 75-85. https://doi.org/10.3375/043.032.0109
- Lundgren J, Toepfer S, Haye T, Kuhlmann U (2010) Haemolymph defence of an invasive herbivore: its breadth of effectiveness against predators. Journal of Applied Entomology 134: 439-448. https://doi.org/10.1111/j.1439-0418.2009.01478.x
- Molnar AV, Meszaros A, Csatho AI, Balogh G, Csosz S (2018) Ant species dispersing the seeds of the myrmecochorous *Sternbergia colchiciflora* (Amaryllidaceae). North-Western Journal of Zoology 14: 2565-267.
- Moreau CS, Deyrup MA, Davis Jr. LR (2014) Ants of the Florida Keys: species accounts, biogeography, and conservation (Hymenoptera: Formicidae). Journal of Insect Science 14: 295.
- Morgan P, Heyerdahl EK, Strand EK, Bunting SC, Riser II JP, Abatzoglou JT, Nielsen-Pincus M, Johnson M (2020) Fire and land cover change in the Palouse Prairie–forest ecotone, Washington and Idaho. USA. Fire Ecology 16: 1-17.
- Motze I, Tscharntke T, Sodhi NS, Klein AM, Wagner TC (2013) Ant seed predation, pesticide applications and farmers' income from tropical multi-cropping gardens. Agricultural and Forest Entomology 15: 245-254. https://doi.org/10.1111/afe.12011
- Nelson A, Zapata G, Sentner K, Mooney K (2019) Are ants botanists? Ant associative learning of plant chemicals mediates foraging for carbohydrates. Ecological Entomology 45: 251-258. https://doi.org/10.1111/een.12794
- Neumann K, Pinter-Wollman N (2019) Collective responses to heterospecifics emerge from individual differences in aggression. Behavioral Ecology 30: 801-808. https://doi.org/10.1093/beheco/arz017
- Noss RF, Laroe III FT, Scott JM (1995) Endangered ecosystems of the United States: a preliminary assessment of loss and degradation: volume 28 of biological report. U.S. Department of the Interior, National Biological Service, Washington, DC.
- Ouellette G, Drummond F, Choate B, Groden E (2010) Ant diversity and distribution in Acadia National Park, Maine. Environmental Entomology 39: 1447-1456. https://doi.org/10.1603/EN09306
- Pacarevic M, Danoff-Burg J, Dunn RR (2010) Biodiversity on Broadway- enigmatic diversity of the societies of ants (Formicidae) on the streets of New York City. PLOS ONE 5.
- Paluh DJ, Eddy C, Ivanov K, Hickerson CA, Anthony CD (2015) Selective foraging on ants by a terrestrial polymorphic salamander. American Midland Naturalist 174: 265-277. https://doi.org/10.1674/0003-0031-174.2.265
- Park SH, Moon TY (2020) Structure of ant assemblages on street trees in urban Busan, Korea. Entomological Research 50: 131-137. https://doi.org/10.1111/1748-5967.12415
- Pech P (2012) Hyenism in ants: Non-target ants profit from *Polyergus rufescens* Raids (Hymenoptera: Formicidae. Sociobiology 59: 67-69. https://doi.org/10.13102/sociobiology.v59i1.667

- Peters V, Campbell K, Dienno G (2016) Ants and plants as indicators of biodiversity, ecosystem services, and conservation value in constructed grasslands. Biodiversity and Conservation 25: 1481-1501. https://doi.org/10.1007/s10531-016-1120-z
- Powell B, Brightwell R, Silverman J (2009) Effect of an invasive and native ant on a field population of the black citrus aphid (Hemiptera: Aphididae). Environmental Entomology 38: 1618-1625. https://doi.org/10.1603/022.038.0614
- Powell SB, Shaner DL (2001) Herbicide Resistance and World Grains. CRC Press
- Queiroz A, Rabello AM, Braga DL, Santiago GS, Zurlo LF, Philpott SM, Ribas CR (2020) Cerrado vegetation types determine how land use impacts on ant biodiversity. Biodiversity and Conservation 29: 2017-2034. https://doi.org/10.1007/s10531-017-1379-8
- Radtke T, Glasier J, Wilson S (2014) Species composition and abundance of ants and other invertebrates in stands of crested wheatgrass (*Agropyron cristatum*) and native grasslands in the northern Great Plains. Canadian Journal of Zoology 92: 49-55. https://doi.org/10.1139/cjz-2013-0103
- Ramos CS, Isabel Bellocq M, Paris CI, Filloy J (2018) Environmental drivers of ant species richness and composition across the Argentine Pampas grassland. Austral Ecology 43: 424-434. https://doi.org/10.1111/aec.12579
- Resasco J, Pelini SL, Stuble KL, Sanders NJ, Dunn RR, Diamond SE, Ellison AM, Gotelli NJ, Levey DJ (2014) Using historical and experimental data to reveal warming effects on ant assemblages. PLOS One 9.
- Rojas P, Fragoso C, Mackay WP (2014) Ant communities along a gradient of plant succession in Mexican tropical coastal dunes. Sociobiology 61: 119-132.
- Rosas-Mejia M, Vasquez-Bolanos M, Gaona-Garcia G, Vanoye-Eligio V (2019) New records of ant species for Sinaloa, Mexico. Southwestern Entomologist 44: 551-554.
- Rowles A, Silverman J (2009) Carbohydrate supply limits invasion of natural communities by Argentine ants. Oecologia 161: 161-171. https://doi.org/10.1007/s00442-009-1368-z
- Salyer A, Bennett G, Buckiwski G (2014) Odorous house ants (*Tapinoma sessile*) as back-seat drivers of localized ant decline in urban habitats. PLOS One 9.
- Sampson F, Knopf F (1994) Prairie Conservation in North America. BioScience 44: 418-421. https://doi.org/10.2307/1312365
- Sanchez-Pena S, MacGown J (2013) House infestation and outdoor winter foraging by the winter ant, *Prenolepis imparis* Say (Hymenoptera: Formicidae) in Saltillo, Mexico. Southwestern Entomologist 38: 357-360. https://doi.org/10.3958/059.038.0219
- Santoandre S, Filloy J, Zurita GA, Bellocq MI (2019) Taxonomic and functional β-diversity of ants along tree plantation chronosequences differ between contrasting biomes. Basic and Apply Ecology 41: 1-12. https://doi.org/10.1016/j.baae.2019.08.004
- Schar S, Talavera G, Espadeler X, Rana JD, Anderson AA, Cover SP, Vila R (2018) Do Holarctic ant species exist? Trans-Beringian dispersal and homoplasy in the Formicidae. Journal of Biogeography 45: 1917-1928. https://doi.org/10.1111/jbi.13380
- Schmidt A, Fraser L, Carlyle C, Bassett E (2012) Does cattle grazing affect ant abundance and diversity in temperate grasslands? Rangeland Ecology & Management 65: 292-298. https://doi.org/10.2111/REM-D-11-00100.1
- Scholes D, Suarez A (2009) Speed-versus-accuracy trade-offs during nest relocation in Argentine ants (*Linepithema humile*) and odorous house ants (*Tapinoma sessile*). Insectes Sociaux 56: 413-418. https://doi.org/10.1007/s00040-009-0039-8

- Sheard J, Sanders N, Gundlach C, Schar S, Larsen R (2020) Monitoring the influx of new species through citizen science: the first introduced ant in Denmark. PeerJ 8.
- Slipinski P, Zmihorski M, Czechowski W (2012) Species diversity and nestedness of ant assemblages in an urban environment. European Journal of Entomolog 109: 197-206. https://doi.org/10.14411/eje.2012.026
- Smith F (1941) A list of the ants of Washington state. Pan Pacific Entomologist 17: 23-28.
- Sorrells T, Kuritzky L, Kauhanen P, Fitzgerald K, Sturgis S, Chen J, Dijamco C, Basurto K, Gordon D (2011) Chemical defense by the native winter ant (*Prenolepis imparis*) against the invasive Argentine ant (*Linepithema humile*). PLOS One 6.
- Steiner F, Seifert B, Moder K, Schlick-Steiner B (2010) A multisource solution for a complex problem in biodiversity research: Description of the cryptic ant species *Tetramorium alpestre* (Hymenoptera: Formicidae). Zoologischer Anzeiger 249: 223-254. https://doi.org/10.1016/j.jcz.2010.09.003
- Taylor K, Visvader A, Nowbahari E, Hollis K (2013) Precision rescue behavior in North American ants. Evolutionary Psychology 11: 665-677.
- Thomas C, Tillberg C, Schultz C (2020) Facultative mutualism increases survival of an endangered ant-tended butterfly. Journal of Insect Conservation 24: 385-395. https://doi.org/10.1007/s10841-020-00218-2
- Thompson JL, Zack RS, Crabo L, Landolt PJ (2014) Survey of macromoths (Insecta: Lepidoptera) of a Palouse prairie remnant site in eastern Washington State. Pan-Pacific Entomologist 90: 191-204.
- Tiede Y, Schlautmann J, Donoson DA (2017) Ants as indicators of environmental change and ecosystem processes. Ecological Indicators 83: 527-537. https://doi.org/10.1016/j.ecolind.2017.01.029
- Toennisson T, Sanders N, Klingeman W, Vail K (2011) Influences on the structure of suburban ant (Hymenoptera: Formicidae) communities and the abundance of *Tapinoma sessile*. Environmental Entomology 40: 1397-1404. https://doi.org/10.1603/EN11110
- Underwood E, Christian C (2009) Consequences of prescribed fire and grazing on grassland ant communities. Environ. Entomol 38: 325-332. https://doi.org/10.1603/022.038.0204
- Underwood EC, Fisher BL (2006) The role of ants in conservation monitoring: If, when, and how. Biological Conservation 132: 166-182. https://doi.org/10.1016/j.biocon.2006.03.022
- Uno S, Cotton J, Philpott SM (2010) Diversity, abundance, and species composition of ants in urban green spaces. Urban Ecosystems 13: 425-441. https://doi.org/10.1007/s11252-010-0136-5
- Van Schalkwyk J, Pryke JS, Samways MJ (2019) Contribution of common vs. rare species to species diversity patterns in conservation corridors. Ecological Indicators 104: 279-288. https://doi.org/10.1016/j.ecolind.2019.05.014
- VanWeelden M, Bennett G, Buckiwski G (2015) The effects of colony structure and resource abundance on food dispersal in *Tapinoma sessile* (Hymenoptera: Formicidae. Journal of Insect Science 15.
- Vonshak M, Gordon D (2015) Intermediate disturbance promotes invasive ant abundance. Biological Conservation 186: 359-367. https://doi.org/10.1016/j.biocon.2015.03.024

- Wagner H, Arthofer W, Seifert B, Muster C, Steiner F, Schlick-Steiner B (2017) Light at the end of the tunnel: Integrative taxonomy delimits cryptic species in the *Tetramorium caespitum* complex (Hymenoptera: Formicidae). Myrmecological News 25: 95-129.
- Wagner H, Karaman C, Aksoy V, Kiran K (2018a) A mixed colony of *Tetramorium immigrans* SANTSCHI, 1927 and the putative social parasite *Tetramorium aspina* sp.n (Hymenoptera: Formicidae). Myrmecological News 28: 25-33.
- Wagner H, Gamisch A, Arthofer W, Moder K, Steiner F, Schlick-Steiner B (2018b) Evolution of morphological crypsis in the *Tetramorium caespitum* ant species complex (Hymenoptera: Formicidae). Scientific Reports 8.
- Wang C, Strazanac J, Butler L (2001) Association between ants (Hymenoptera: Formicidae) and habitat characteristics in oak-dominated mixed forests. Environmental Entomology 30: 842-848. https://doi.org/10.1603/0046-225X-30.5.842
- Warren RJ, Giladi I, Bradford MA (2012) Environmental heterogeneity and interspecific interactions influence nest occupancy by key seed-dispersing ants. Environmental Entomology 41: 463-468. https://doi.org/10.1603/EN12027
- Way M, Khoo KC (1992) Role of ants in pest management. Annual Review of Entomology 37: 479-503. https://doi.org/10.1146/annurev.en.37.010192.002403
- Weseloh R (2000) Paths of *Formica neogagates* (Hymenoptera: Formicidae) on tree and shrub leaves: Implications for foraging. Environmental Entomology 29: 525-534. https://doi.org/10.1603/0046-225X-29.3.525
- Weseloh R (2001) Patterns of foraging of the forest ant *Formica neogagates* Emery (Hymenoptera: Formicidae) on tree branches. Biological Control 20: 16-22. https://doi.org/10.1006/bcon.2000.0880
- Wheeler GC, Wheeler J (1986) The ants of Nevada. Natural History Museum of Los Angeles County, CA.
- Williams DF (1994) Exotic ant biology, impact, and control of introduced species. Westview Press, San Francisco, CA.
- Yates ED, Levia Jr. DF, Williams CL (2004) Recruitment of three non-native invasive plants into a fragmented forest in southern Illinois. Forest Ecology and Managment 190: 119-130. https://doi.org/10.1016/j.foreco.2003.11.008
- Yensen NP, Clark WH, Francoeur A (1977) A checklist of Idaho ants. The Pan-Pacific Entomologist 53: 181-187.
- Yitbarek S, Vandermeer JH, Allen D (2011) The combined effects of exogenous and endogenous variability on the spatial distribution of ant communities in a forested ecosystem (Hymenoptera: Formicidae). Environmental Entomology 40: 1067-1073. https://doi.org/10.1603/EN11058
- Zhu Y, Wang D (2018) Response of ants to human-altered habitats with reference to seed dispersal of the myrmecochore *Corydalis giraldii* Fedde (Papaveraceae). Nordic Journal of Botany 36.

Figure 1.

Example of an intact Palouse Prairie habitat fragment located at the Hudson Biological Preserve ("Smoot Hill") in Albion, Washington.

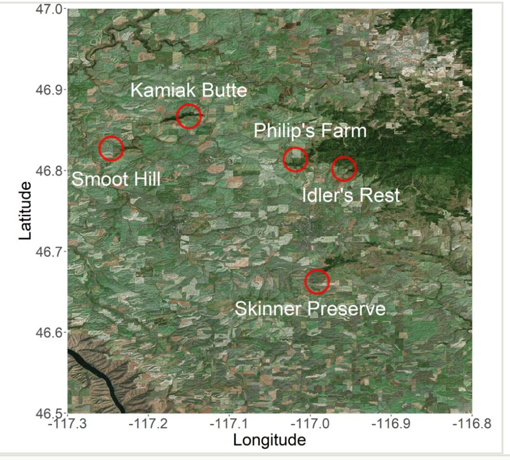

Figure 2.

Map of survey locations for the five Palouse prairie sites. Red circles encompass the prairie fragment sampled. Inset shows map extent in the Pacific Northwest.

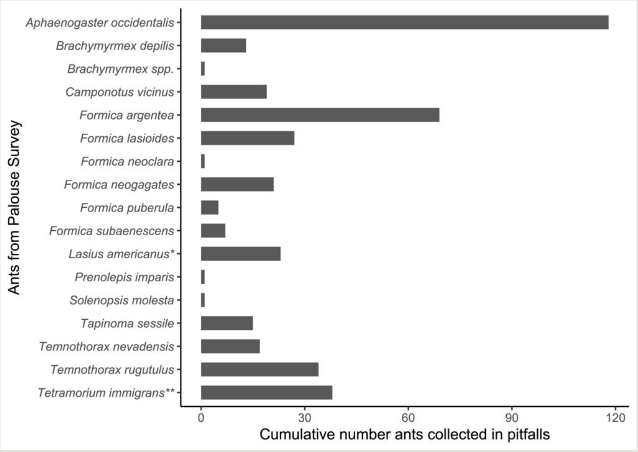

Figure 3.

Numbers of ants collected in all pitfalls for each species. Asterisks indicates a species that has recently been revised, thus the literature search includes **Lasius neoniger* and ***Tetramorium caespitum*. *Brachymyrmex* spp. indicates abundance of *Brachyrmex* “microgyne” queens collected.

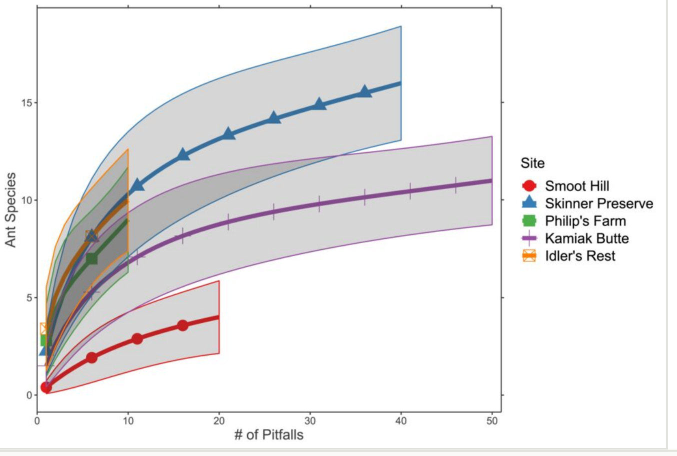

Figure 4.

Species accumulation curve with expected mean species richness plotted for each survey location. Dots and lines show estimated species richness at a given sampling interval, while shaded area shows 95% CI.

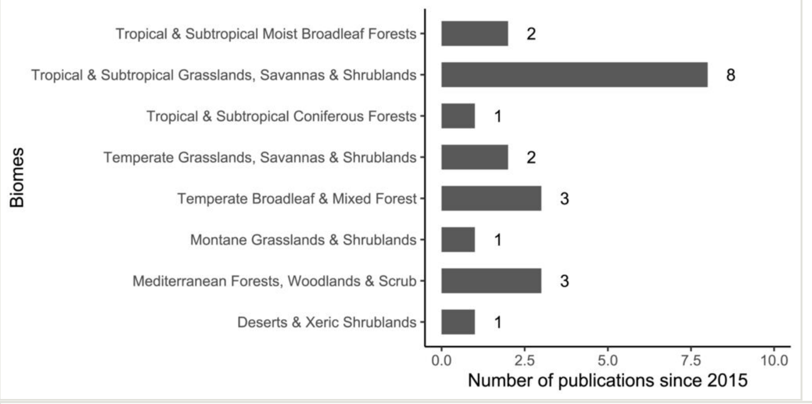

Figure 5.

Number of ant biodiversity surveys published over a 5-year period from 2016-2020 where locations were reported. Biome classifications inferred from a global terrestrial ecoregion map (Dinerstein et al. 2017).

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Table 1.

Studies reporting species found in this survey between, published 2010 and 2020.

Ant species	Studies	Paper References
Aphaenogaster occidentalis	1	Thomas et al. 2020
Brachymyrmex depilis	3	King and Tschinkel 2016, Rosas-Mejia et al. 2019, Underwood and Christian 2009
Brachymyrmex spp. 'microgyna'	2	Moreau et al. 2014, Deyrup 2016
Camponotus vicinus	1	Davenport et al. 2013
Formica argentea	2	Lenz et al. 2013, Ouellette et al. 2010
Formica lasioides	1	Karban et al. 2015
Formica neoclara	0	
Formica neogagates	5	Clark and Singer 2018, Ellison et al. 2007, Wang et al. 2001, Weseloh 2000, Weseloh 2001
Formica puberula	0	
Formica subaenescens	0	
Lasius americanus and *Lasius alienus*	11	Akyurek et al. 2016, Barton and Ives 2014, Cuesta-Segura et al. 2012, Molnar et al. 2018, Paluh et al. 2015, Park and Moon 2020, Pech 2012, Warren et al. 2012, Yitbarek et al. 2011, Zhu and Wang 2018
Prenolepis imparis	13	Abbate and Campbell 2013, Burford et al. 2018, Campbell et al. 2019, Cuautle et al. 2016, Fitzgerald and Gordon 2012, Gordon and Heller 2014, Kjar and Park 2016, Rowles and Silverman 2009, Sanchez-Pena and MacGown 2013, Sorrells et al. 2011, Taylor et al. 2013, Thomas et al. 2020, Vonshak and Gordon 2015
Solenopsis molesta	4	Guyer et al. 2018, Pacarevic et al. 2010, Resasco et al. 2014, Rojas et al. 2014
Tapinoma sessile	20	Buczkowski and Bennett 2009, Buczkowski 2010, Buczkowski and Krushelnycky 2012, Buczkowski and Richmond 2012, Gibson et al. 2019, Gow et al. 2013, Hamm 2010, Kaspari et al. 2010, Kautz et al. 2017, Kimball 2016a, Kimball 2016b, Nelson et al. 2019, Neumann and Pinter-Wollman 2019, Ouellette et al. 2010, Powell et al. 2009, Salyer et al. 2014, Schmidt et al. 2012, Scholes and Suarez 2009, Toennisson et al. 2011, VanWeelden et al. 2015
Temnothorax nevadensis	1	Adams et al. 2018

Temnothorax rugatulus	11	Bowens et al. 2013, Blonder and Dornhaus 2011, Cao 2013, Charbonneau et al. 2015, Charbonneau et al. 2017, DiRienzo and Dornhaus 2017, Doering and Pratt 2016, Doering and Pratt 2019, Doering et al. 2020, Doering et al. 2019, Heinze and Rueppell 2014
Tetramorium immigrans and *Tetramorium caespitum*	23	Brant et al. 2010, Cerda et al. 2009, Chin and G. 2018, Collignon and Detrail 2010, Cordonnier et al. 2019a, Cordonnier et al. 2020a, Cordonnier et al. 2020b, Cordonnier et al. 2019b, Dash and Sanchez 2009, Helms et al. 2020, Hoey-Chamberlain et al. 2010, Joharchi et al. 2012a, Joharchi et al. 2012b, Li et al. 2019, Lundgren et al. 2010, Pacarevic et al. 2010, Sheard et al. 2020, Slipinski et al. 2012, Steiner et al. 2010, Wagner et al. 2017, Wagner et al. 2018a, Wagner et al. 2018b, Joharchi and Halliday 2013

Supplementary materials

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