



Insect collecting bias in Arizona with a preliminary checklist of the beetles from the Sand Tank Mountains

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Abstract

Background

The State of Arizona in the south-western United States supports a high diversity of insects. Digitised occurrence records, especially from preserved specimens in natural history collections, are an important and growing resource to understand biodiversity and biogeography. Underlying bias in how insects are collected and what that means for interpreting patterns of insect diversity is largely untested. To explore the effects of insect collecting bias in Arizona, the State was regionalised into specific areas. First, the entire State was divided into broad biogeographic areas by ecoregion. Second, the 81 tallest mountain ranges were mapped on to the State. The distribution of digitised records across these areas were then examined.

A case study of surveying the beetles (Insecta, Coleoptera) of the Sand Tank Mountains is presented. The Sand Tanks are a low-elevation range in the Lower Colorado River Basin

subregion of the Sonoran Desert from which a single beetle record was published before this study.

New information

The number of occurrence records and collecting events are very unevenly distributed throughout Arizona and do not strongly correlate with the geographic size of areas. Species richness is estimated for regions in Arizona using rarefaction and extrapolation. Digitised records from the disproportionately highly collected areas in Arizona represent at best 70% the total insect diversity within them. We report a total of 141 species of Coleoptera from the Sand Tank Mountains, based on 914 digitised voucher specimens. These specimens add important new records for taxa that were previously unavailable in digitised data and highlight important biogeographic ranges.

Possible underlying mechanisms causing bias are discussed and recommendations are made for future targeted collecting of under-sampled regions. Insect species diversity is apparently at best 70% documented for the State of Arizona with many thousands of species not yet recorded. The Chiricahua Mountains are the most densely sampled region of Arizona and likely contain at least 2,000 species not yet vouchered in online data. Preliminary estimates for species richness of Arizona are at least 21,000 and likely much higher. Limitations to analyses are discussed which highlight the strong need for more insect occurrence data.

Keywords

Madrean Sky Islands, beetles, natural history museums, biogeography, Sonoran Desert

Introduction

Insects represent over half of all described species (Mayhew 2007) and perhaps not more than 20% of those that exist have thus far been described (Gaston 1991). The State of Arizona, located in south-western United States along the Mexico border, has high insect diversity and ranks as the State with the most species actively monitored for conservation (Bossart and Carlton 2002). Entomologists from around the country and around the world travel to southern Arizona every year during the monsoon season (late summer and early fall) where popular canyons may have five to ten campsites and road pull-offs occupied by blacklights and collectors scrambling around them until early morning. Despite its insect diversity and popularity as a collecting destination, we are unaware of any empirical studies that assessed total insect species richness within the State or its subregions or explored biases in insect collecting therein.

Biodiversity occurrence records represent an enormously important, invaluable and irreplaceable data source for understanding biodiversity, evolution and ecology (Cook et al.

2014, Page et al. 2015, Guralnick et al. 2016, Johnston et al. 2018, Kharouba et al. 2018, Meineke et al. 2018, Lendemer et al. 2019, Hedrick et al. 2020). The vast majority of these records, at least for insects, presently come from digitised preserved specimens from natural history collections. However, we know that the specimens stored within collections are not evenly distributed throughout space and time and have many implicit biases intertwined with the history and methods used to accumulate them (Hortal et al. 2015, Johnston et al. 2018, Kharouba et al. 2018, Cooper et al. 2019, Whitaker and Kimmig 2020, Laney et al. 2021, Davis et al. 2022). Human observations have been rapidly increasing thanks to popular platforms such as [iNaturalist](#) which have their own slightly different biases, limitations and strengths. We broadly consider fine-scale documentation of individual insects to be "collecting" for the purposes of this paper, though most of our recommendations are focused on traditional preserved-specimen-based collections.

The goals of this study are twofold. First, we present an analysis of digitised insect occurrence data from the State of Arizona and compare the relative levels of sampling for different mountain ranges and ecoregions. Second, we address one example of an underexplored region and provide the first checklist of beetle species from the Sand Tank Mountains of central Arizona. We hope that these data and analyses can inform and bolster future insect collecting to improve our understanding of Arizona's biodiversity.

Arizona regionalisation

Arizona encompasses a wide array of habitat types ranging from extreme deserts to mesic conifer forests. To efficiently classify these regions, different levels of the hierarchical ecoregions defined by Omernik and Griffith (2014) can be used. Level 3 of those ecoregions gives a broad look at the State and is helpful to consider distributions and collecting efforts in broad strokes (Fig. 1a). However, this level of classification does not account for the fine scale habitat and plant community shifts that are seen, especially in the mountainous parts of the State (see Brown (1978), Brown et al. (2007)).

Arizona can also be regionalised by its many mountain ranges. The Madrean Sky Islands are a series of discrete mountain ranges that arise from surrounding grasslands and are variously forested at their higher elevations (Fig. 1a area 12.1.1). These mountains are situated in the only gap of the North American Cordillera between the Rocky Mountain range to the north and the Sierra Madre Occidental range to the south and are a priority in insect conservation and phylogeographic research (Stock and Gress 2006, Ober et al. 2011, Moore et al. 2013, Halbritter et al. 2019, Yanahan and Moore 2019). Beyond the Madrean Sky Islands, the western and southern parts of Arizona are part of the Basin and Range Province of western North America which is characterised by a large number of mountain ranges that have formed as the Earth's crust stretched in this region (Morrison 1991) and which covers the Sonoran and Mojave Deserts (Fig. 1a areas 10.2.1 and 10.2.2). A final series of mountains occur in Arizona along the Mogollon Highlands region (Fleischner et al. 2017) which is a slightly oblique area of plateaus and associated mountains that generally separates north-eastern Colorado Plateau from the southern Basin and Range Province (Fig. 1a area 13.1.1 in centre of the State).

Outlines of the 81 mountain ranges in Arizona with the highest peaks were geographically mapped for use in this study and are shown in Fig. 1b. The shapefiles of Arizona ecoregions and mountain ranges now allow for exploration of digitised insect occurrence records (Fig. 1c, d) to understand underlying patterns in bias and diversity of these areas.

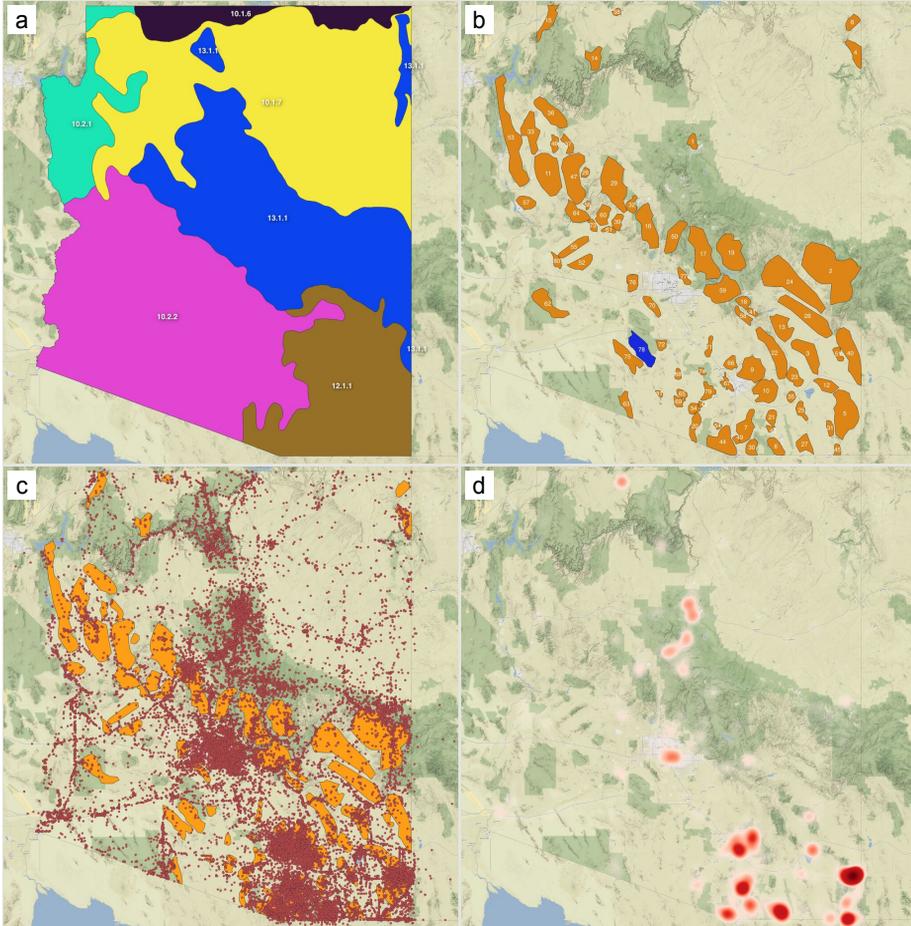


Figure 1.

Maps of the State of Arizona showing geographic regions and occurrence records.

a: Ecoregions of Arizona. Labels correspond to ecoregion codes with matching names as follows: 10.1.6 = Colorado Plateaus; 10.1.7 Arizona/New Mexico Plateau; 10.2.1 = Mojave Basin and Range; 10.2.2 = Sonoran Desert; 12.1.1 = Madrean Archipelago; 13.1.1 = Arizona/New Mexico Mountains. [doi](#)

b: Arizona mountain ranges. Labels refer to mountain range details in Suppl. material 3. The Sand Tank Mountains, number 78, are shaded in blue. [doi](#)

c: Georeferenced insect records from Arizona. Shapes underneath are outlines of mountain ranges shown in B. [doi](#)

d: Heatmap of georeferenced insect records from Arizona. [doi](#)

Sand Tank Mountains

The Sand Tank Mountains, located in south central Arizona (Fig. 1b label 78, Fig. 2), cover a moderately large area in the Lower Colorado River Basin region of the Sonoran Desert (Brown 1978). The mountain range is situated with roughly its northern half on the Sonoran Desert National Monument bounded by US Interstate 8 to the north and its southern half on the Barry M. Goldwater Air Force Range. The mountains are, therefore, nearly entirely on public land, though access and collecting largely requires permits from the latter two entities. The highest point in the range, Maricopa Peak, only reaches 1234 m in elevation. The mountains are named for a series of tanks or tinajas (natural stone water catchments) that were often largely filled with sand and typically available to wildlife and humans for most of the year (Bryan 1925: 224-228).

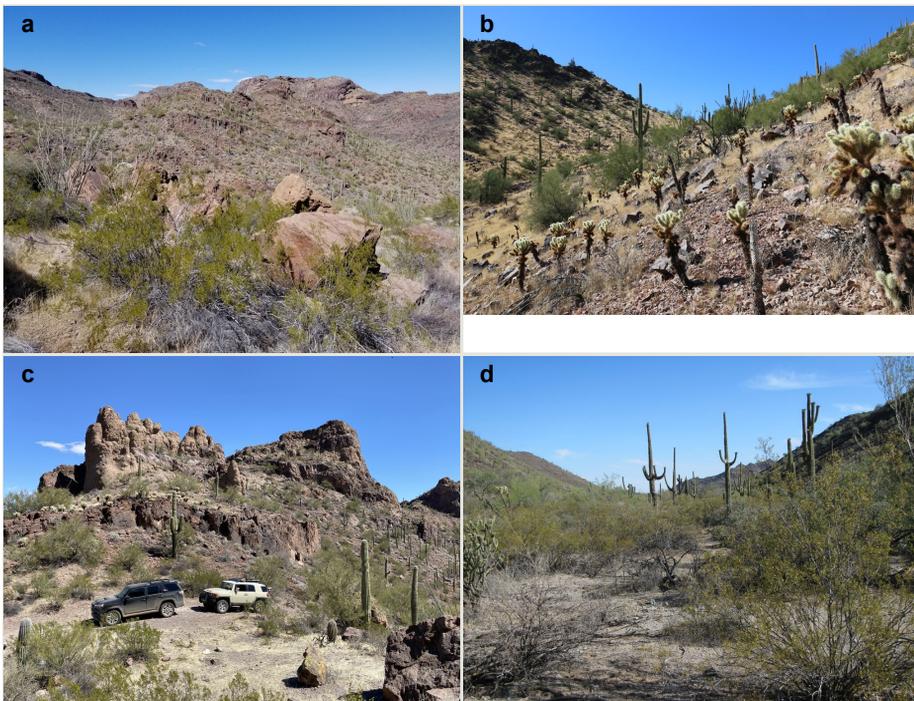


Figure 2.

Sand Tank Mountains with views of terrain and habitat.

- a: Typical habitat and vegetation of north-facing slopes in the Sand Tank Mountains. [doi](#)
- b: Typical habitat and vegetation of south-facing slopes in the Sand Tank Mountains. [doi](#)
- c: Mountain pass with 4-wheel-drive trail leading into the valley containing Bender Spring, one of the main sampling sites we visited in the Sand Tank Mountains. [doi](#)
- d: Sandy valley habitat which was one of the sampling sites we visited in the Sand Tank Mountains. [doi](#)

Very little is known about the fauna of the Sand Tank Mountains and the adjoining Saucedo Mountains to the southwest (Fig. 1b, label 75) which are almost never mentioned in the

scientific literature. Brown (1978) included the Sand Tank mountains in a list of lower-elevation Sonoran Desert ranges which had relictual patches of grassland and chaparral species on them. The Sand Tanks also are the location of a notable Jaguar (*Panthera onca* (Linnaeus, 1758), family Felidae) record from 1930 which represents the south-western known limit of the species in the State and likely the furthest documented excursion of the species into the Sonoran Desert (Babb et al. 2022).

Prior to the study presented here, a total of 27 occurrence records representing 16 insect taxa were available online (GBIF 2022a). This includes only a single record for the order Coleoptera which represents nearly 25% of all described species on Earth, from a photo voucher on [iNaturalist](#). We were unable to find any other beetle records from the mountains in the published scientific literature or in our own work in Arizona natural history collections.

Materials and methods

Data sources and region delimitation

Occurrence records for insects (Fig. 1) were downloaded from the online aggregator Global Biodiversity Information Facility (GBIF). Records were downloaded from GBIF (GBIF 2022a) by searching for every record that had geographic coordinates, contained 'Arizona' in the stateProvince data field and that belonged to Class Insecta, resulting in a dataset of 712,309 occurrence records. GBIF was chosen as the only data source for this analysis in part because of its versioned DOI for downloads and also because it provided the most records of any other portal. The Integrated Digitised Biocollections ([iDigBio](#)) portal contains 612,142 records using the same search parameters and the Symbiota Collections of Arthropods ([SCAN](#)) portal contains 683,645 records, nearly all of which are overlapping between the portals. The GBIF mediated data are further enhanced by their backbone taxonomy which is a synthetic management classification for the portal (GBIF Secretariat 2022). All records are harmonised to the GBIF taxonomy which helps to clean misspellings and differently formatted data from the various data contributors making diversity and species richness estimates more plausible. However, the influence of the GBIF taxonomy is influential in another way since there are so many taxonomic names that are not yet known to GBIF. This may affect as many as 75% of records and names for major insect orders (Waller 2022).

The occurrence records were imported into qGIS 3.24 (qGIS Development Team 2022) and checked against shape files with polygons representing ecoregions from the United States EPA (Omernik and Griffith 2014) and mountain ranges within Arizona. The list of mountain ranges was generated primarily by consulting online resources for mountain climbers. A curated list of mountain ranges and their highpoints (Anonymous 2022) was used as the starting point and each range was verified through a combination of United States Geological Survey (USGS) topographic maps, Google Maps searches and consulting regional gazetteers and atlases. Our working definition of a mountain range for the purposes of biological regionalisation is as follows: a geographically contiguous string

of mountains which seem to have a shared geological origin and are separated from other such groups by a lower elevational region which appears to have different geology and/or vegetative cover as assessed via satellite imagery. These mountain ranges typically matched very closely those labelled on topographic maps and gazetteers. Polygons for each mountain range were drawn by hand around geological formations as viewed in satellite imagery; topographic maps from the USGS, personal experience in the field and mountain range and place names in google maps were used to ascertain a polygon that represented the footprint around the mountain range. Shifts in geology and vegetative cover were especially helpful to define the periphery of mountain ranges. Our definitions attempted to delimit potentially biologically meaningful entities more than they were an attempt to perfectly outline the underlying geology. Any occurrence found within the footprint of one of the included shapes was annotated as such. A custom script (Suppl. material 5) was written in R 4.0.2 (R Core Team 2020) to summarise the number of records by area metrics. Figures were produced in the same R script and utilised the packages `dplyr` (Wickham et al. 2022), `ggplot2` (Wickham 2016) and `cowplot` (Wilke 2020).

Evaluating digitised records for collecting bias

For entomological field work, differences in occurrence records likely reveal a compilation of biological differences (e.g. increased insect biomass and population densities would increase the number of occurrence records), differences in survey effort (e.g. one area may have been visited by 100 researchers a year and another area by 10 researchers per year) and differences in social practices and research interests (e.g. one person may collect 100 of 200 observed individual insects at a particular event, while another person may collect 5 of 200 observed individual insects at a different event). Insect occurrence records were, therefore, analysed according to three different metrics, namely records, collecting events and species. First, the total number of occurrence records for a given ecoregion or mountain range were tallied as a sum. Second, collecting effort was approximated by pooling records into putative collecting events. All insect records from a particular ecoregion or mountain range that had an identical date (using `dwc:day`, `month` and `year` fields) and collector (`dwc:recordedBy` field) were considered to belong to a single collecting event. Third, putatively unique insect taxa were totalled for each ecoregion and mountain range by counting unique scientific names (`dwc:scientificName` field). These names correspond to the taxonomic interpretation according to the GBIF backbone taxonomy. This count may be considered an overestimate because different individuals of the same taxon may have been identified to different ranks (e.g. subspecies, species, genus and family) and be counted multiple times. However, because so many taxa at the species level are not known to the GBIF taxonomy, many differently identified taxa are prone to being 'lumped' into a higher classification level (Waller 2022). For studies where the goal is to create a verified checklist of names, the original verbatim data from individual providers are included on GBIF, but we deemed the taxon names as filtered by GBIF to be more standardised and at least easily comparable across ecoregions and mountain ranges. All data are made available as supplemental materials for annotated occurrence records (Suppl. material 1), summarised data for ecoregions (Suppl. material 2) and mountain ranges (Suppl. material 3).

Sampling effort to geographic area relationships were explored using linear regressions of both total occurrence records and tabulated collecting events to geographic area of regions (both for ecoregions and mountain ranges). A linear fit with high correlation would indicate that insect collecting was evenly distributed throughout space, while stronger departures from such a relationship would indicate confounding factors affecting the distribution of insect sampling across the State. There is some debate about what the most appropriate models are for species-area relationships and growing evidence suggests that very small, intermediate and very large areas operate under very different scaling parameters (Lomolino 2000, Lomolino and Weiser 2001, Stiles and Scheiner 2007, Dengler 2009, Storch et al. 2012, Storch 2016, Dengler et al. 2019). Different scaling parameters could warrant analysing data under different transformations. Our study is primarily focused on understanding the scale and bias of insect records as they relate to geographic areas in Arizona and, therefore, presents somewhat simplistic explorations of the data as a first step towards future studies which may employ more complex models to explore specific biological questions. However, we did assess our dataset for normality since different analytical techniques might apply to these data depending on the underlying biological power laws at play (García Martín and Goldenfeld 2006, Packard 2014). The untransformed data were not normal, but the log-transformed data were. Normality assessments and analyses on log-transformed data and plots of species by geographic area of EcoRegions and mountain ranges are available in (Suppl. material 6).

Possible factors responsible for underlying bias within the occurrence records were assessed using the R package *sampbias* (Zizka et al. 2020) to examine how spatial distribution of roads, cities, airports and rivers might affect where insects are collected. The analyses were run using all georeferenced insect records for the State using default settings within *sampbias* which performs a Bayesian analysis to determine the range of posterior probabilities for how each factor biases the underlying dataset. The bias each factor introduces is then compiled into a spatial model for an expected sampling effort given the calculated biases. The resulting bias model was calculated for Arizona and was then visualised along with a heatmap of insect occurrence records for the State.

Species richness within areas was estimated using the R package *iNEXT* (Chao et al. 2014, Hsieh et al. 2020) to perform species rarefaction and extrapolation analyses. Counts were tabulated for the total number of records for each unique taxon within a region and these abundance data were given to *iNEXT* and analysed using $q = 0$ for the appropriate Hill number estimation for abundance data (Chao et al. 2014). Our analyses were primarily focused on exploring relative completeness of species richness sampling found within occurrence data, but future studies primarily interested in modelling precise species richness would likely need to explore records in more detail to discern where there is and is not overlap at different taxonomic scales (e.g. how should records to the genus level be counted if a single species from that genus is already counted from the area?). We analysed taxa as unique name strings as described above for all analyses. We further re-analysed several areas with a more conservative approach where we only used the subset of records that were identified to species (i.e. `dwc:taxonRank = SPECIES`) to explore how that changed extrapolation of total species richness. None of the rarefaction and

extrapolation analyses presented here approaches an asymptote within an estimated doubling of sampling effort and, therefore, has limitations in truly accounting for unobserved taxa in species richness estimates (Willis 2019); nevertheless, the rarefaction curves and estimates are still useful tools to understand uses and limitations of the underlying data.

Checklist of Sand Tank Mountains Coleoptera

Three collecting trips were made to the Sand Tank Mountains to survey for beetles. The first was on 29 April 2022 where blacklighting and night searches with headlamps were performed in a rocky basin near a paved wildlife water catchment basin (32.7868, -112.5177). Uncovered pitfall traps were set here and in a wide sandy wash (32.7982, -112.5112, Fig. 2d). The second trip was a single overnight visit from 3-4 June 2022 where the previously deployed pitfall traps were collected and night collecting was performed in the sandy wash site involving beating vegetation, blacklighting and night searching. The third and final trip was on 15 July 2022 to a rocky canyon in which lies Bender Spring (32.6786, -112.3657, Fig. 2c) where blacklighting and night searches were performed. All beetle specimens were mounted and labelled and then identified to the lowest level possible. Full data for every voucher used in this study are fully digitised in the [Ecdysis portal](#) built on the Symbiota software (Gries et al. 2014), published to GBIF (GBIF 2022b) and in Suppl. material 4. Most specimens were deposited in the Arizona State University Hasbrouck Insect Collection (ASUHIC) with duplicates and focal research taxa deposited in the M. Andrew Johnston Research Collection (MAJC), Evan Waite Invertebrate Collection (EWIC) and Ethan Richard Wright Collection (ERWC), all of which are located in Tempe, Arizona, USA. Identifications were typically made using Arnett et al. (2002) to the level of family and genera. Species-level identifications were then performed by using appropriate primary literature or by consulting local taxonomic experts. The final identification resource for each species in the checklist is provided. For taxa identified by experts where a specific source is unknown, we attribute the identification to that person as unpublished data.

The checklist of species was built using the Ecdysis portal checklist tool from all of the digitised specimen records created as part of this project. The curated checklist was then exported for publication and inserted into the ARPHA writing platform for this journal. Families are presented in alphabetical order and all species are presented alphabetically under their family. A total of 140 new species level records were identified, anchored by 914 fully digitised pinned and labelled voucher specimens. When combined with the previously available record, the following checklist enumerates 141 species of Coleoptera from the mountain range.

Sand Tank Mountains Coleoptera

Family Anthicidae

***Duboisius arizonensis* (Champion, 1916)**

Notes: Identification reference: Abdullah (1964)

***Duboisius barri* Abdullah, 1964**

Notes: Identification reference: Abdullah (1964)

***Notoxus calcaratus* Horn, 1884**

Notes: Identification reference: Chandler (1982)

***Vacusus confinis* (LeConte, 1851)**

Notes: Identification reference: Werner (1961)

Family Bostrichidae

***Amphicerus cornutus* (Pallas, 1772)**

Notes: Identification reference: Fisher (1950)

***Amphicerus teres* Horn, 1878**

Notes: Identification reference: Fisher (1950)

***Apatides fortis* (LeConte, 1866)**

Notes: Identification reference: Arnett et al. (2002)

***Dendrobiella aspera* (LeConte, 1858)**

Notes: Identification reference: Fisher (1950)

***Xyloblaptus quadrispinosus* (LeConte, 1866)**

Notes: Identification reference: Fisher (1950)

Family Brachypsectridae

Brachypsectra fulva LeConte, 1874

Notes: Identification reference: Costa et al. (2006)

Family Buprestidae

Chrysobothris micromorpha Fall, 1907

Notes: Identification reference: Arnett et al. (2002), N. Woodley personal communication to MAJ 2022.

Gyascutus caelatus (LeConte, 1858)

Notes: Identification reference: iNaturalist

Melanophila atropurpurea (Say, 1823)

Notes: Identification reference: Sloop (1937)

Family Carabidae

Apristus sp.

Notes: This genus is in need of revision and we were unable to identify our specimens beyond genus.

Bembidion impotens Casey, 1918

Notes: Identification reference: Lindroth (1963)

Calosoma prominens LeConte, 1853

Notes: Identification reference: Gidaspow (1959)

Chlaenius orbis Horn, 1871

Notes: Identification reference: Bell (1960)

Cymindis punctigera LeConte, 1851

Notes: Identification reference: Horn (1882)

***Discoderus obsidianus* Casey, 1914**

Notes: Identification reference: Casey (1914)

***Elaphropus conjugens* (Notmann, 1919)**

Notes: Identification reference: Erwin (1974)

***Lebia tuckeri* (Casey, 1920)**

Notes: Identification reference: Madge (1967)

***Notiobia terminata* (Say, 1823)**

Notes: Identification reference: Noonan (1973)

***Schizogenius pygmaeus* Van Dyke, 1925**

Notes: Identification reference: Whitehead (1972)

***Selenophorus aeneopiceus* Casey, 1884**

Notes: Identification reference: Messer and Raber (2021)

***Selenophorus concinnus* Schaeffer, 1910**

Notes: Identification reference: Messer and Raber (2021)

***Tetragonoderus pallidus* Horn, 1868**

Notes: Identification reference: Horn (1881)

Family Cerambycidae***Anelaphus albofasciatus* (Linell, 1897)**

Notes: Identification reference: F.W. Skillman unpublished data.

***Anelaphus brevidens* (Schaeffer, 1908)**

Notes: Identification reference: F.W. Skillman unpublished data.

***Anelaphus piceus* (Chemsak, 1962)**

Notes: Identification reference: F.W. Skillman unpublished data.

***Anelaphus submoestus* Linsley, 1942**

Notes: Identification reference: F.W. Skillman unpublished data.

***Anoplocurius canotiae* Fisher, 1920**

Notes: Identification reference: F.W. Skillman unpublished data.

***Eustromula validum* (LeConte, 1858)**

Notes: Identification reference: F.W. Skillman unpublished data.

***Methia brevis* Fall, 1929**

Notes: Identification reference: F.W. Skillman unpublished data.

***Moneilema gigas* (LeConte, 1873)**

Notes: Identification reference: F.W. Skillman unpublished data.

***Sternidius centralis* (LeConte, 1884)**

Notes: Identification reference: F.W. Skillman unpublished data.

Family Chrysomelidae

***Colaspis viridiceps* Schaeffer, 1933**

Notes: Identification reference: Blake (1976)

***Coleorozena* sp.**

Notes: This genus needs revision and we were unable to identify our specimens beyond genus.

***Coleothorpa axillaris* (LeConte, 1868)**

Notes: Identification reference: Moldenke (1970)

***Diorhabda carinulata* (Desbrochers, 1870)**

Notes: Identification reference: TRACY and ROBBINS (2009)

***Glyptina* sp.**

Notes: This genus needs revision and we were unable to identify our specimens beyond genus.

***Pachybrachis connexus* Fall, 1915**

Notes: Identification reference: Barney (2019)

***Pachybrachis mellitus* Bowditch, 1909**

Notes: Identification reference: Fall (1915)

***Pachybrachis vigilans* Fall, 1915**

Notes: Identification reference: Barney (2019)

***Pachybrachis wickhami* Bowditch, 1909**

Notes: Identification reference: Barney (2019)

***Pachybrachis xanti* Crotch, 1873**

Notes: Identification reference: Barney (2019)

***Saxinis saucia* LeConte, 1857**

Notes: Identification reference: Moldenke (1970)

Family Cleridae***Araeodontia peninsularis* (Schaeffer, 1904)**

Notes: Identification reference: B.H. Reily unpublished data.

***Cymatodera latefascia* Schaeffer, 1904**

Notes: Identification reference: B.H. Reily unpublished data.

***Cymatodera oblita* Horn, 1876**

Notes: Identification reference: B.H. Reily unpublished data.

***Cymatodera punctata* Leconte, 1852**

Notes: Identification reference: B.H. Reily unpublished data.

***Enoclerus quadrisignatus* (Say, 1835)**

Notes: Identification reference: B.H. Reily unpublished data.

***Lecontella gnara* Wolcott, 1927**

Notes: Identification reference: B.H. Reily unpublished data.

***Phyllobaenus discoideus* (LeConte, 1852)**

Notes: Identification reference: B.H. Reily unpublished data.

Family Coccinellidae***Hyperaspis pleuralis* Casey, 1899**

Notes: Identification reference: Gordon (1985)

***Scymnus* sp.**

Notes: Identification of this genus requires examination of male terminalia. Our single putatively female specimen was only identified to the subgenus *Scymnus* (*Pullus*), of which there are a number of species known from this region.

Family Curculionidae***Eucyllus unicolor* Van Dyke, 1936**

Notes: Identification reference: Pelsue and Sleeper (1972)

***Ophryastes* sp.**

Notes: This diverse genus is difficult to identify without genitalic dissections and we were unable to identify our specimen to species.

***Rhinostomus frontalis* (LeConte, 1874)**

Notes: Identification reference: Morrone and Cuevas (2002)

***Sibinia simplex* (Casey, 1892: 421)**

Notes: Identification reference: Clark (1978)

***Sibinia transversa* (Casey, 1897: 665)**

Notes: Identification reference: Clark (1978)

***Smicronyx* sp.**

Notes: This speciose genus is difficult to identify and we were unable to identify our single specimen beyond genus.

Family Dascillidae***Anorus parvicollis* Horn, 1894**

Notes: Identification reference: Johnston and Gimmel (2020)

Family Dermestidae***Anthrenus lepidus* LeConte, 1854**

Notes: Identification reference: Beal (1998)

Family Dytiscidae***Eretes sticticus* (Linnaeus, 1767)**

Notes: Identification reference: Miller (2002)

Family Elateridae***Agrypnus illimis* (Horn, 1894)**

Notes: Identification reference: Arnett (1952)

***Anchastus bicolor* LeConte, 1866**

Notes: Identification reference: Van Dyke (1932)

***Esthesopus parvus* Horn, 1884**

Notes: Identification reference: Horn (1884)

***Horistonotus lutzi* Van Dyke, 1933**

Notes: Identification reference: Wells (2000)

***Horistonotus simplex* LeConte, 1863**

Notes: Identification reference: Wells (2000)

***Mulsanteus arizonensis* (Schaeffer, 1916)**

Notes: Identification reference: B. Mathison unpublished data.

Family Histeridae***Xerosaprinus coerulescens* (LeConte, 1851)**

Notes: Identification reference: W.B. Warner unpublished data.

***Xerosaprinus martini* (Fall, 1917)**

Notes: Identification reference: W.B. Warner unpublished data.

Family Meloidae***Epicauta lauta* (Horn, 1885)**

Notes: Identification reference: Werner et al. (1966)

***Epicauta tenebrosa* Werner, 1949**

Notes: Identification reference: Werner et al. (1966)

***Epicauta tenuilineata* (Horn, 1894)**

Notes: Identification reference: Werner et al. (1966)

***Epicauta virgulata* (LeConte, 1866)**

Notes: Identification reference: Werner et al. (1966)

***Pyrota trochanterica* Horn, 1894**

Notes: Identification reference: Werner et al. (1966)

Family Melyridae***Attalus serraticornis* Fall, 1917**

Notes: Identification reference: Marshall (1951)

***Trichochrous ferrugineus* (Gorham, 1886)**

Notes: Identification reference: M.L. Gimmel unpublished data.

***Trichochrous varius* Casey, 1895**

Notes: Identification reference: M.L. Gimmel unpublished data.

Family Mordellidae***Mordellina* sp.**

Notes: This genus has limited identification resources available. Our two specimens resemble *Mordellina testacea* (Blatchley, 1910) - a species only reported from the eastern United States.

Family Mycetophagidae***Typhaea stercorea* (Linnaeus, 1758)**

Notes: Identification reference: Arnett et al. (2002)

Family Oedemeridae***Oxacis cana* (LeConte, 1866)**

Notes: Identification reference: Arnett (1951)

***Oxacis laevicollis* Horn, 1896**

Notes: Identification reference: Arnett (1951)

***Oxycopis mariae* (Arnett, 1951)**

Notes: Identification reference: Arnett (1951)

***Oxycopis* sp.**

Notes: A moderate series of this *Oxycopis* species likely represent an undescribed species which we were unable to associate with any currently known from the western United States.

Family Phengodidae***Distremocephalus opaculus* (Horn, 1895)**

Notes: Identification reference: Zaragoza Caballero (1986)

Family Ptinidae***Niptus ventriculus* LeConte, 1859**

Notes: Identification reference: Aalbu and Andrews (1992)

***Ptinus paulonotatus* Pic, 1904**

Notes: Identification reference: Papp (1962)

***Tricorynus* sp.**

Notes: This speciose genus is in need of a modern revision. Our single specimen has elytra that lack discernible striae and may be near *Tricorynus lentus* (Fall, 1905).

Family Pyrochroidae***Cononotus bryanti* Van Dyke, 1939**

Notes: Identification reference: Van Dyke (1939)

Family Salpingidae***Dacoderus striaticeps* LeConte, 1858**

Notes: Identification reference: Aalbu et al. (2005)

Family Scarabaeidae

***Acoma arizonica* Brown, 1929**

Notes: Identification reference: W.B. Warner unpublished data.

***Ataenius desertus* Horn, 1871**

Notes: Identification reference: W.B. Warner unpublished data.

***Ataenius hirsutus* Horn, 1871**

Notes: Identification reference: W.B. Warner unpublished data.

***Ataenius lobatus* Horn, 1871**

Notes: Identification reference: W.B. Warner unpublished data.

***Diplotaxis fissilabris* Fall, 1909**

Notes: Identification reference: W.B. Warner unpublished data.

***Diplotaxis moerens* LeConte, 1856**

Notes: Identification reference: W.B. Warner unpublished data.

***Diplotaxis planidens* Fall, 1909**

Notes: Identification reference: W.B. Warner unpublished data.

***Diplotaxis rufiola* Fall, 1909**

Notes: Identification reference: W.B. Warner unpublished data.

***Haroldiataenius lucanus* (Horn, 1871)**

Notes: Identification reference: W.B. Warner unpublished data.

***Oxygrylius ruginasus* (LeConte, 1856)**

Notes: Identification reference: W.B. Warner unpublished data.

***Phyllophaga scoparia* (LeConte, 1856)**

Notes: Identification reference: W.B. Warner unpublished data.

Family Scaptiidae

Allopoda sp.

Notes: This genus lacks a comprehensive key to species, but genitalic dissections indicate that our series of specimens likely represent an undescribed species.

Diclidia greeni Liljeblad, 1918

Notes: Identification reference: Liljeblad (1945)

Naucles pusio (LeConte, 1858)

Notes: Identification reference: Liljeblad (1945)

Family Silvanidae

Ahasverus sp.

Notes: Our specimens somewhat resemble *Ahasverus rectus* (LeConte, 1854), but differ in several characters from the holotype of that species. We have seen conspecific specimens to ours labelled as "*Ahasverus n.sp.*" in collections and think it is likely that it is, indeed, an undescribed species.

Family Staphylinidae

Philonthus sp.

Notes: We were unable to identify our single specimen of this species beyond the level of genus in this speciose group.

Family Tenebrionidae

Alaephus macilentus Casey, 1891

Notes: Identification reference: M.A. Johnston unpublished data.

Anepsius delicatulus LeConte, 1851

Notes: Identification reference: Doyen (1987)

***Araeoschizus decipiens* Horn, 1890**

Notes: Identification reference: Papp (1981)

***Araeoschizus regularis* Horn, 1870**

Notes: Identification reference: Papp (1981)

***Argoporis bicolor* (LeConte, 1851)**

Notes: Identification reference: Berry (1980)

***Asbolus mexicanus* subsp. *angularis* (Horn, 1894)**

Notes: Identification reference: Aalbu (2005)

***Batuliodes rotundicollis* (LeConte, 1851)**

Notes: Identification reference: Doyen (1987)

***Chilometopon helopioides* (Horn, 1870)**

Notes: Identification reference: MacLachlan and Olson (1990)

***Conibius opacus* LeConte, 1866**

Notes: Identification reference: M.A. Johnston unpublished data.

***Craniotus pubescens* LeConte, 1851**

Notes: Identification reference: Arnett et al. (2002)

***Cryptoglossa muricata* (LeConte, 1851)**

Notes: Identification reference: Aalbu (2005)

***Cryptoglossa variolosa* (Horn, 1870)**

Notes: Identification reference: Aalbu (2005)

***Edrotes ventricosus* LeConte, 1851**

Notes: Identification reference: Doyen (1968)

***Eleodes armata* LeConte, 1851**

Notes: Identification reference: Johnston et al. (2015)

***Eleodes tribula* Thomas, 2005**

Notes: Identification reference: Johnston (2016)

***Eupsophulus castaneus* (Horn, 1870)**

Notes: Identification reference: Spilman (1959)

***Eurymetopon rufipes* Eschscholtz, 1831**

Notes: Identification reference: M.A. Johnston unpublished data.

***Eusattus dubius* LeConte, 1851**

Notes: Identification reference: Doyen (1984)

***Hymenorus papagonis* Fall, 1931**

Notes: Identification reference: Fall (1931)

***Hymenorus punctatissimus* LeConte, 1866**

Notes: Identification reference: Fall (1931)

***Hymenorus spinifer* Horn, 1894**

Notes: Identification reference: Fall (1931)

***Latheticus oryzae* Waterhouse, 1880**

Notes: Identification reference: Arnett et al. (2002)

***Nocibiotes caudatus* Casey, 1895**

Notes: Identification reference: M.A. Johnston unpublished data.

***Nocibiotes granulatus* (LeConte, 1851)**

Notes: Identification reference: M.A. Johnston unpublished data.

***Statira defecta* Schaeffer, 1905**

Notes: Identification reference: Parsons (1975)

***Statira pluripunctata* Horn, 1888**

Notes: Identification reference: Parsons (1975)

***Steriphanus subopacus* (Horn, 1870)**

Notes: Identification reference: M.A. Johnston unpublished data.

***Telabis longipennis* (Casey, 1890)**

Notes: Identification reference: M.A. Johnston unpublished data.

***Triorophus laevis* LeConte, 1851**

Notes: Identification reference: M.A. Johnston unpublished data.

***Zophobas subnitens* (Horn, 1874)**

Notes: Identification reference: M.A. Johnston unpublished data.

Family Trogidae***Omorgus carinatus* Loomis, 1922**

Notes: Identification reference: W.B. Warner unpublished data.

Family Trogossitidae***Temnoscheila chlorodia* (Mannerheim, 1843)**

Notes: Identification reference: Barron (1971)

Family Zopheridae***Hyporhagus gilensis* Horn, 1872**

Notes: Identification reference: Freude (1955)

***Rhagoderma costata* Horn, 1867**

Notes: Identification reference: Stephan (1989)

Analysis

Notes on the Sand Tank Mountains Coleoptera

The checklist provided herein significantly raises the entomological knowledge of this mountain range. Our collecting efforts unfortunately were comprehensively limited as they did not include sampling during the peak flowering season that typically occurs between late February and April or in the winter which has a distinct insect fauna that often does not overlap with the taxa found during the warmer times of year. We also were unable to access a number of distinct habitats, including the relictual chaparral plant communities, that likely would have greatly increased our taxon count.

Many of the species reported from this study occur throughout the Lower Colorado River Basin subregion of the Sonoran Desert, but are often poorly represented in natural history collections or in digitised occurrence records. Six species recorded by us had no prior digitised records from the State of Arizona even though they are known in literature (*Diclidia greeni*, *Horistonotus lutzi*, *Mulsanteus arizonensis*, *Niptus ventriculus*, *Oxycopsis mariae* and *Ptinus paulonotatus*). Many more represent the second digitised record or the first preserved specimen, as opposed to a human observation, from the State. These are notable in that they demonstrate specific examples of how digitised records both fall short of representing the full knowledge of the State's fauna, as well as the limited distributional information available for many species. It is also notable that three collecting events produced likely three undescribed species (*Ahasverus* sp., *Allopoda* sp. and *Oxycopsis* sp.). Our specimens of *Asbolus mexicanus angularis* are the first reported from Maricopa County in Arizona and represent a roughly 50 mile (ca. 75 km) north-east range extension of that species. Many other species we report may represent additional notable range extensions, though the limited knowledge and digitised specimens from the region hinder more in-depth analyses.

The actual number of Coleoptera species that inhabit the Sand Tank Mountains is surely much higher than what is recorded here. Based on our experience in the region, we presume this list is no more than 30% of the actual diversity and recommend future studies should focus on flower-feeding taxa and employ other trapping techniques, such as flight-intercept traps and Lindgren funnels. Estimating species richness using rarefaction and extrapolation (Fig. 3) estimates a total richness of 193 species which would mean we have sampled roughly 72% of the diversity so far. The lower estimate found in this analysis may be due to our employing similar collecting methods on all our trips. The estimate is perhaps a better reflection of the total number of species we could collect given the same techniques, while not accounting for taxa that diversifying techniques would add.

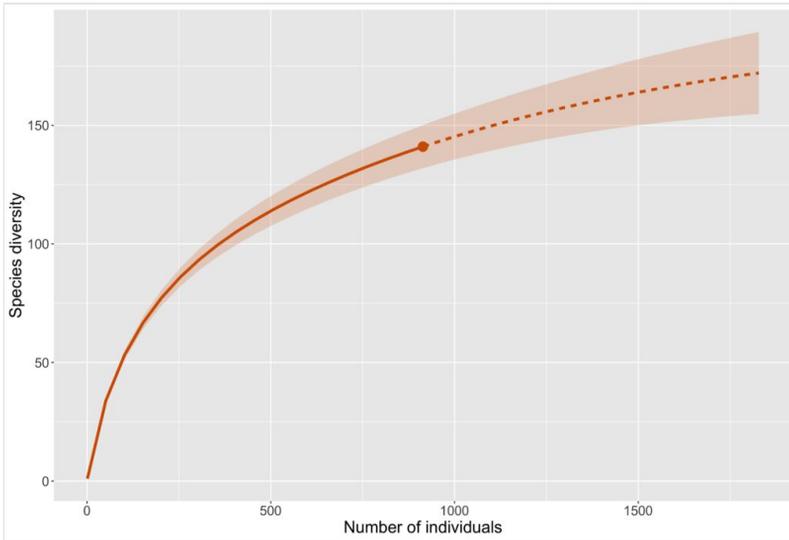


Figure 3. [doi](#)

Species richness estimated by rarefaction and extrapolation for the Sand Tank Mountain Coleoptera fauna.

We would define the Coleoptera fauna of the Sand Tank Mountains as typical of the Lower Colorado River Basin of the Sonoran Desert. Many species we collected are typically found in arid low elevation regions of the State which is exemplified by the 30 species of Tenebrionidae collected which are highly diverse in such habitats. We postulate that the beetle fauna of the Sand Tank Mountains is likely similar to the fauna found throughout most of the low mountain ranges in the south-western portion of Arizona - but direct comparison is stifled by the lack of knowledge of those other mountain ranges.

Collecting bias across ecoregions

Insect records and diversity for the ecoregions of Arizona are summarised in Fig. 4. The number of occurrence records are not very well correlated with the geographic area of the regions (Fig. 4a). When distinct collecting events are compared to geographic area (Fig. 4b), a trend of slightly more even distribution of sampling effort per area is observed. It seems clear that, relative to all the ecoregion in the State, the Madrean Archipelago (label 12.1.1 in figures) is disproportionately highly sampled, while the Arizona/New Mexico Plateau (label 10.1.7 in figures) is comparatively weakly sampled. This lack of correlation means that collecting efforts are not evenly distributed throughout space or between the different ecoregions.

Collecting bias across mountain ranges

Insect records and collecting events for Arizona mountain ranges by geographic area are summarised in Fig. 5. In contrast to the data for ecoregions presented above, mountain

ranges show a much less even distribution of collecting records. Both individual occurrence records by area (Fig. 5a) and collecting events by area (Fig. 5b) are highly skewed by a few very disproportionately well-collected mountain ranges and a large number of ranges with almost no sampling.

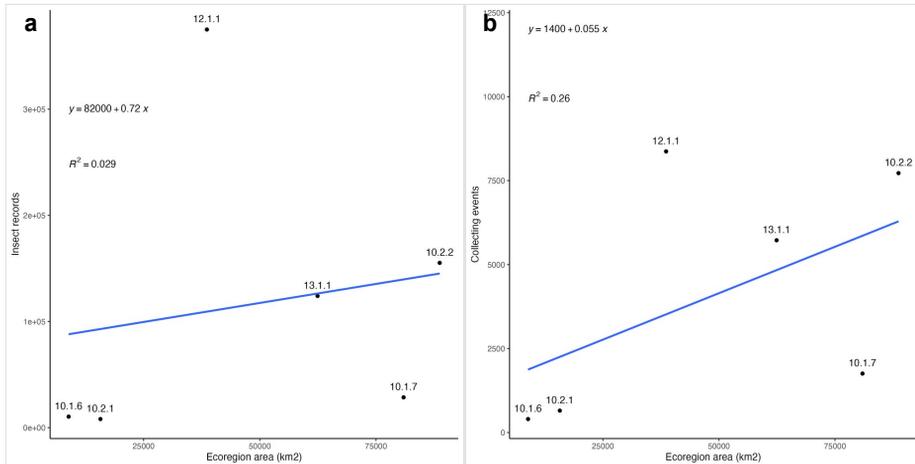


Figure 4.

Occurrence records by ecoregion from the State of Arizona. Ecoregion labels match Fig. 1a and Suppl. material 2.

a: Digitised insect records by geographic area (km²) of ecoregions in Arizona. [doi](#)

b: Collecting events by geographic area (km²) of ecoregions in Arizona. A single collecting event corresponds to all specimens with the same collector (DWC:recordedBy) and date (DWC:day, month, year). [doi](#)

The most distant outlier by far is the Chiricahua Mountains (label 5 in Fig. 5) which are located in the extreme south-eastern corner of the State and represent 117,396 (40%) out of 296,421 total occurrence records which were mapped to all 81 mountain ranges examined here. This high sampling rate is, in large part, due to an active research station located within the range. The following four mountain ranges were also incredibly highly sampled, though nowhere near the sampling effort seen in the Chiricahuas. The Huachuca Mountains (label 6 in Fig. 5) are located along the Mexican border of Arizona and are home to many classical collecting localities and popular canyons, such as Ramsey Canyon, Miller Canyon and Carr Canyon. The Santa Rita Mountains (label 7 in Fig. 5) are just south of Tucson and have good access by roads, a university experimental station and are home to the very popular Madera Canyon. The Santa Catalina Mountains (label 9 in Fig. 5) are located just north of Tucson and are very easily accessed by paved roads from that city with classic collecting localities, such as Sabino Canyon and Mount Lemmon. The Atascosa/Pajarito Mountains (label 44 in Fig. 5) are also located along the middle of the Mexican border with Arizona and are home to the very well visited Pena Blanca Canyon and lake. Together, these five ranges represent 221,815 (75%) of the 296,421 total occurrence records from mountains reported here.

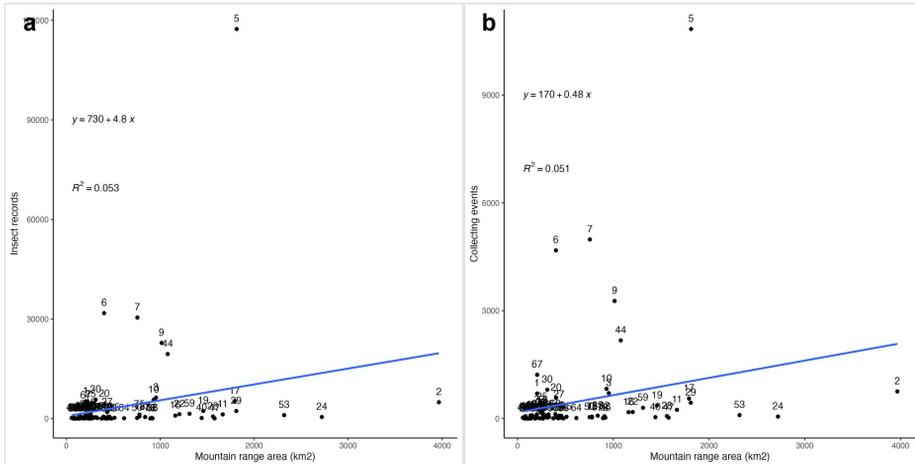


Figure 5.

Occurrence records by mountain range from the State of Arizona. Point labels match mountain ranges in Fig. 1b and Suppl. material 3.

- a:** Digitised insect records by geographic area (km^2) of mountain ranges in Arizona. [doi](#)
- b:** Collecting events by geographic area (km^2) of mountain ranges in Arizona. A single collecting event corresponds to all specimens with the same collector (DWC:recordedBy) and date (DWC:day, month, year). [doi](#)

Factors driving collecting bias

Analysis of the influence of proximity to roads, cities, airports and rivers is shown in Fig. 6. Proximity to roads was found to be the strongest factor of bias within our dataset, followed by proximity to cities and then airports. Proximity to rivers apparently has almost no effect on sampling bias. The underlying layer of roads was largely made up of paved, government-maintained roads and does not contain all smaller roadways that are often unpaved which provide access to most mountain ranges in Arizona. The analysis estimated both the weight of each biasing factor (Fig. 6a) and how that bias behaved by distance (Fig. 6b).

These biasing factors together generate a model of expected sampling frequency across Arizona. Fig. 7a shows this model rasterised across the State and Fig. 7b shows a heatmap of insect records overlaid on top. These visualisations demonstrate that, while proximity to population centres and roads are important, they clearly do not, alone, explain the distribution of insect collecting records across the State. In fact, the most heavily sampled Sky Islands in the south-western portion of the State are in areas of low expected collecting effort, while regions lying along major highways between population centres, such as the Interstate 10 corridor in central Arizona, are disproportionately less well collected.

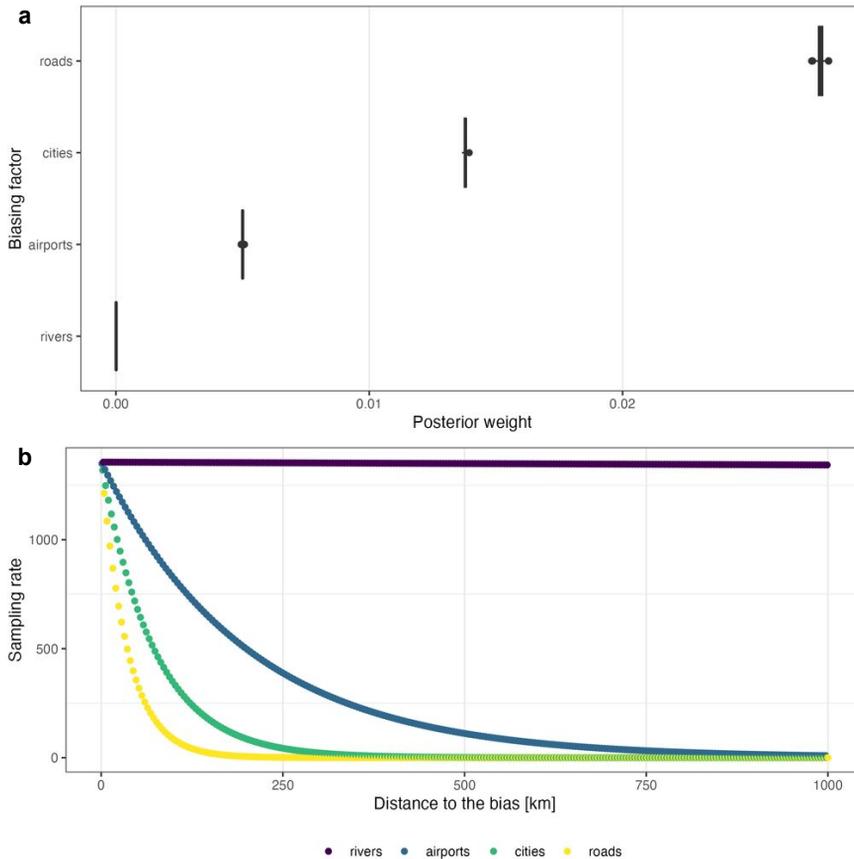


Figure 6.

Biasing factors in relation to digitised insect records for Arizona. Proximity to roads, cities, airports and rivers are shown as inferred via *sampbias* (Zizka et al. 2020).

a: Inferred posterior weight of each biasing factor. Each is represented by a narrow range, likely due to the size of our occurrence dataset. [doi](#)

b: Estimated sampling rate as a function of distance in kilometres from the biasing factor.

[doi](#)

Species richness estimates

The disproportionate levels of data amongst mountain ranges discussed above demonstrate that it is too soon to accurately model insect diversity from occurrence records for most ranges. However, the Chiricahua Mountains are so disproportionately highly collected that they offer an important case study into what we can infer about insect diversity from occurrence records. Analysis of species richness for the Chiricahuas (Fig. 8) indicate that we are fairly far from reaching a plateau or accurate assessment of the actual taxonomic diversity. The preliminary estimate for all taxa (Fig. 8a) suggests 9,600 unique taxa are present, while more conservative estimate of species (Fig. 8b) suggests 6,500

species are present. Perhaps more important than the total numbers, both estimates suggest that current digitised data at best account for 70% of the actual diversity from those mountains.

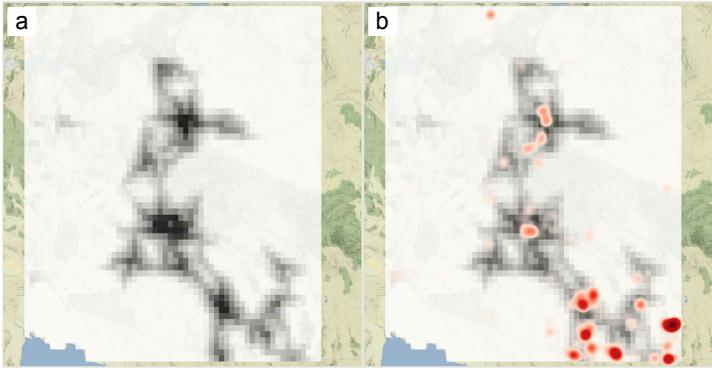


Figure 7.

Map plotting the model of expected sampling density given calculated bias of roads, cities, airports and rivers within Arizona.

a: Expected sampling effort given model of collecting bias. Darker hues represent higher expected sampling, while lighter hues represent lower expected sampling. [doi](#)

b: Expected sampling effort overlaid with heatmap of insect occurrence records showing actual sampling effort compared to the model. [doi](#)

Scaling up to ecoregions, species richness is similarly incompletely sampled by current collecting efforts (Fig. 9). The Madrean Archipelago, the proportionately highest sampled region by area (Fig. 4), boasts the largest recorded taxonomic diversity of the six ecoregions with just over 15,300 taxa which falls well short of a preliminary estimate of over 21,700. All ecoregions apparently require more than double the current sampling effort to begin to find a plateau and accurate species richness estimate.

Species richness estimates for the entire State of Arizona again fail to plateau with the available data (Fig. 10). Preliminary species richness estimates are much higher than those observed with all taxa (Fig. 10a) predicting roughly 36,000 total taxa and species-only data (Fig. 10b) predicting just over 21,600 species. As with the Chiricahua Mountains and ecoregions discussed above, both Arizona richness estimates imply that the current data only represent around 70% of predicted diversity and similarly demonstrate that online data will need to be greatly expanded before accurate estimates can be made.

Discussion

Species richness estimates

All rarefaction and extrapolation estimates of species (or taxonomic) richness failed to plateau and provided very similar results that only 70% of the full estimated species richness were observed. As all the analyses across the three scales explored here gave

these similar proportional results, it seems clear that the estimates are strongly affected by incomplete sampling. We again urge readers to be cautious with the absolute numbers presented here. However, given our knowledge of the Sand Tank Mountains Coleoptera study and its limitations along with the slopes of all rarefaction curves, the species richness estimates presented here seem to be extremely conservative counts and might be useful as a lowest-end predictor of what the true diversity is. We did not assess the diversity of collecting techniques represented in our dataset. This may mean that we are underestimating total insect taxa, even at larger scales, due to inadequate sampling techniques.

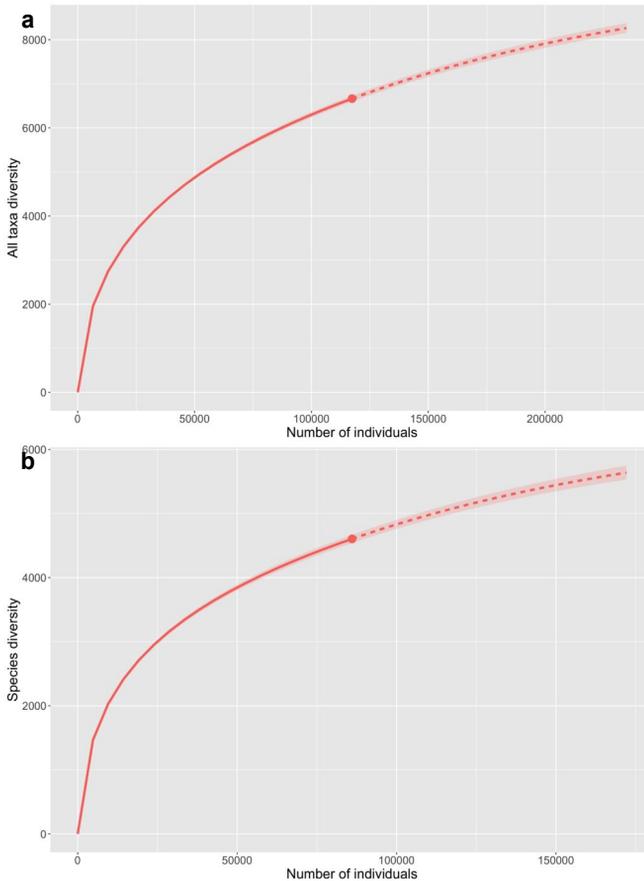


Figure 8.

Species richness estimation curve for the Chiricahua Mountains in Arizona by rarefaction and extrapolation.

a: Rarefaction and estimation curve for all taxa from all ranks for the Chiricahua Mountains (6,663 distinct taxon names observed). [doi](#)

b: Rarefaction and estimation curve for species level taxa for the Chiricahua Mountains (4,604 distinct taxon names observed). [doi](#)

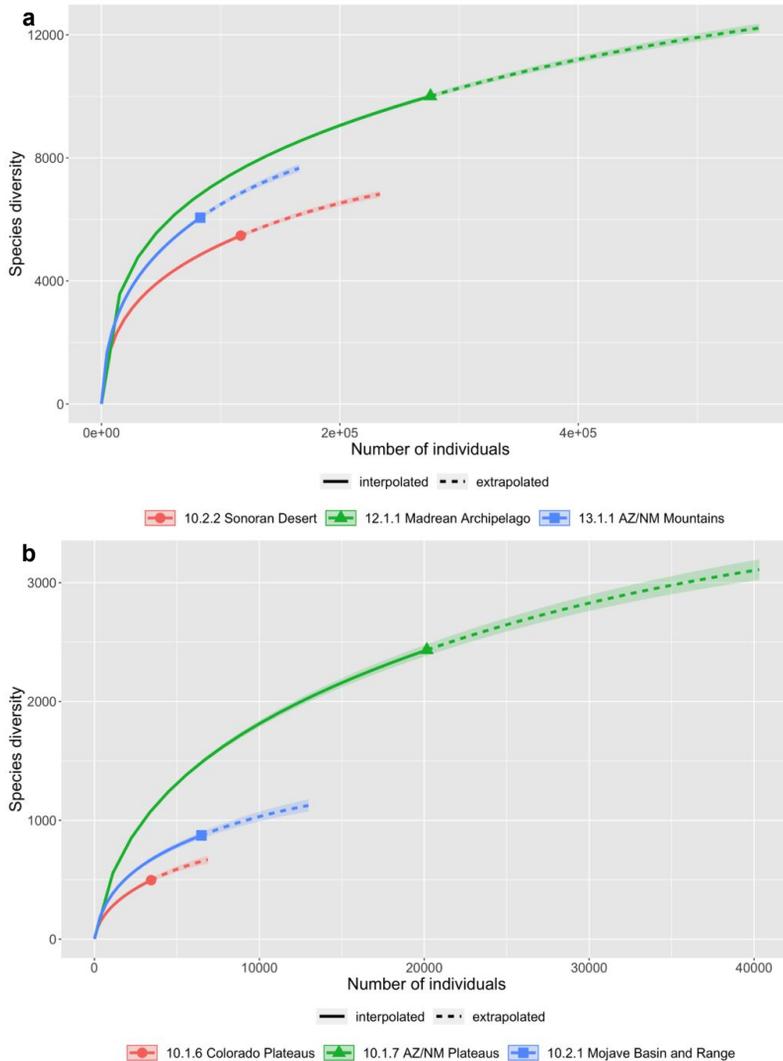


Figure 9.

Species richness estimation curve for the ecoregions of Arizona by rarefaction and extrapolation.

a: Sonoran Desert, Madrean Archipelago and Arizona/New Mexico Mountains ecoregions.

[doi](#)

b: Colorado Plateaus, Arizona/New Mexico Plateaus and Mojave Basin and Range ecoregions. [doi](#)

Additional factors driving collecting bias

The analyses presented here clearly demonstrate that, according to available data, insect collecting has not been done evenly throughout the State. The underlying factors that drive

the biases seen in the data are likely numerous and difficult to fully ascertain. We hypothesise that two of the primary drivers are habitat accessibility and social interactions.

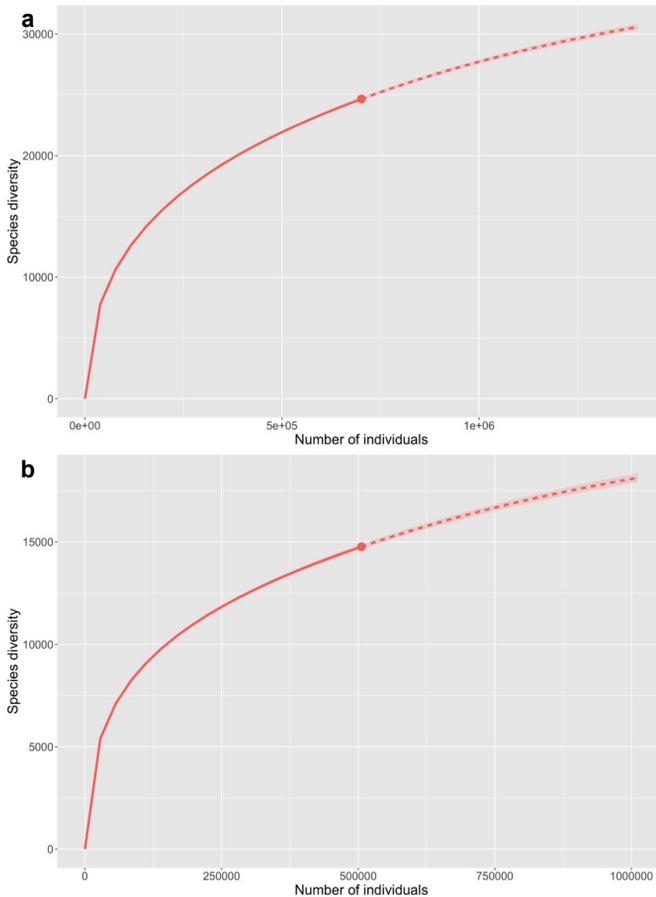


Figure 10.

Species richness estimation curves for the entire State of Arizona by rarefaction and extrapolation.

a: Rarefaction and estimation curve for all taxa from all ranks for Arizona (24,651 distinct taxon names observed). [doi](#)

b: Rarefaction and estimation curve for all species level taxa for Arizona (14,769 distinct species names observed). [doi](#)

Habitat access for insect collectors is very important and has many facets. Proximity to roads and populations centres is clearly important, but not the only limiting factor and not all cities and roads are the same. For example, the Chiricahua Mountains have roads accessible to passenger cars that go to the highest elevations. The Mountains are almost entirely on public lands and there are nearby towns with accommodation and stores, as well as a popular research station. In contrast, all sites visited in the Sand Tank Mountains involved rugged back-country roads requiring high clearance and four-wheel drive vehicles

in areas where it is unlikely to encounter other people in the event of an emergency. Habitat access is not equal at the large scale of ecoregions either. The majority of the Madrean Archipelago is covered by public lands (U.S. Forest Service and Bureau of Land Management) while large swathes of the Sonoran Desert and especially the Arizona/New Mexico Plateaus regions are Native American Reservations. Different sovereign tribal lands, private property and various public land management agencies all have unique regulations and permitting processes which affect collecting insects. The Mohave Basin and Range ecoregion is an interesting example of how these factors interact where most of the lands are public, but the terrain is very rugged and roads and population centres are limited which is likely why there are so few insect records from the region even though there are no major permitting restrictions.

The Patagonia Picnic Table Effect (Laney et al. 2021), named after the town of Patagonia, Arizona, is a term from the birdwatching community to describe how one sighting of a rare species leads to increased birdwatching effort in the immediate region. The equivalent in the insect world would be one collector finding a very rare or charismatic species which prompts future collectors to either go to the same locality to collect either that same species for themselves or in hopes that it might also produce a rare species of their own group of interest. Laney et al. (2021) analysed 10 years of birdwatching data and demonstrated that there is an increase of activity following the initial discovery, but there was no increased likelihood to find additional rare species in that area compared to any other. It seems clear that, despite its potential lack of utility in rare species documentation, it is a social phenomenon in naturalist communities which may also contribute to uneven insect collecting throughout the state.

Recommendations for future collecting

The full scale of insect diversity has been under-documented for the State of Arizona, its constituent ecoregions or even its most popular mountain ranges, at least in available online data. It is important that the entomological community continues to survey for and collect insects everywhere in the State. Continuing and increasing efforts to mobilise specimen data from natural history collections also remains a high priority and will likely help to account for many species which are not currently represented in online data. It is estimated that not more than 5% of specimens in insect collections of the United States have been fully digitised (Cobb et al. 2019). It is possible that some of the biases found in our dataset will be corrected as this proportion increases and it will be very interesting to see what will happen to species accumulation curves as the data increase. We would recommend that gap analyses be done on digitised insect data when the number of records approximately doubles from its current state since none of the species richness estimation curves reported here approached an asymptote.

We urge collectors to make a concerted effort to go to new places and consider targeting specifically undercollected regions and mountain ranges. Small and targeted studies can exponentially improve our understanding of Arizona insect fauna and are likely the best way to increase knowledge of species distributions and may be crucial to understanding

the entire State fauna. Our example of the Sand Tank Mountains beetles highlights how a modest collecting effort can still provide new occurrence records for species from the State and report on new localities for taxa that are otherwise considered rare in collections. We do not recommend that collectors avoid the classic and popular sites; indeed, we still need to sample those, but we would advocate that entomologists consider dividing their time in the field and only spend part of their efforts in the well-known habitats and spend the next day somewhere new.

The paucity of insect data from so many mountain ranges in the State strongly limit our ability to adequately protect and conserve insect biodiversity. Entomologists and insect collections should partner with local, State and federal land management agencies to increase insect sampling throughout the State. Increasing partnerships and professional connections with tribal nations within the State are also strongly recommended. Opportunities for occurrence-data driven estimates for species diversity are in their infancy, even for a biodiversity hotspot that is accessible and popular. Nevertheless, the growing availability of occurrence data is an important resource to continue to develop to understand the diversity and distributions of insects.

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References

- Aalbu R, Andrews F (1992) Revision of the spider beetle genus *Niptus* in North America, including new cave and phoeophile species (Coleoptera: Ptinidae). *The Pan-Pacific Entomologist* 68 (2): 73-96.

- Aalbu R (2005) The pimeliine tribe Cryptoglossini: classification, biology and inferred phylogeny (Coleoptera: Tenebrionidae). *Annales Zoologici* 55 (4): 677-756.
- Aalbu R, Andrews F, Pollock D (2005) Revision of western hemisphere Dacoderinae with a phylogenetic analysis of world taxa (Coleoptera: Salpingidae). *The Coleopterists Bulletin* 59 (mo4): 1-40.
- Abdullah M (1964) New Nearctic Eurygeniini (Coleoptera, Anthicidae, Pedilinae). *Annals and Magazine of Natural History* 7 (74): 81-94. <https://doi.org/10.1080/00222936408651443>
- Anonymous (2022) Arizona Mountain Ranges Highpoints List, 204 peaks, Revised May 14, 2020. <http://www.peakbagging.com/Peak%20Lists/AZRange1.htm>. Accessed on: 2022-1-04.
- Arnett R (1951) A revision of the Nearctic Oedemeridae (Coleoptera). *American Midland Naturalist* 45: 257-391.
- Arnett R (1952) A review of the Nearctic Adelocerina (Coleoptera: Elateridae, Pyrophorinae, Pyrophorini). *Wassmann Journal of Biology* 10 (1): 103-126.
- Arnett R, Thomas M, Skelley P, Frank J (2002) *American Beetles, Volume II: Polyphaga: Scarabaeoidea through Curculionoidea*. CRC Press, Boca Raton. [ISBN 0849309549]
- Babb R, Brown D, Culver M, Childs J, Thompson R, Kohls R, Taylor T (2022) Updates of historic and contemporary records of jaguars (*Panthera onca*) from Arizona. *Journal of the Arizona-Nevada Academy of Science* 49 (2). <https://doi.org/10.2181/036.049.0205>
- Barney R (2019) Definition and revision of the *pubescens* species-group of North American *Pachybrachis* Chevrolat (Coleoptera: Chrysomelidae: Cryptocephalinae), including descriptions of three new species. *The Coleopterists Bulletin* 73 (4). <https://doi.org/10.1649/0010-065x-73.4.1017>
- Barron J (1971) A revision of the Trogositidae of America north of Mexico (Coleoptera: Cleroidea). *Memoirs of the Entomological Society of Canada* 75: 1-143.
- Beal R (1998) Taxonomy and biology of Nearctic species of *Anthrenus* (Coleoptera: Dermestidae). *Transaction of the American Entomological Society* 124 (3+4): 271-332.
- Bell R (1960) A revision of the genus *Chlaenius* Bonelli (Coleoptera: Carabidae) in North America. *Miscellaneous Publications of the Entomological Society of America* 1: 97-166.
- Berry R (1980) A revision of the North American genus *Argoporis* (Coleoptera: Tenebrionidae: Cerenopini). *Ohio Biological Survey Bulletin New Series* 6 (1): 1-106.
- Blake D (1976) The brown semicostate and costate species of *Colaspis* in Mexico and Central America (Coleoptera: Chrysomelidae). *United States Department of Agriculture, Technical Bulletin* (1534)1-40.
- Bossart J, Carlton C (2002) Insect conservation in America: Status and perspectives. *American Entomologist* 48 (2): 82-92. <https://doi.org/10.1093/ae/48.2.82>
- Brown D (1978) The vegetation and occurrence of chaparral and woodland flora on isolated mountains within the Sonoran and Mojave Deserts in Arizona. *Journal of the Arizona-Nevada Academy of Science* 13 (1): 7-12. URL: <https://www.jstor.org/stable/40021812>
- Brown D, Unmack P, Brennan T (2007) Digitized map of biotic communities for plotting and comparing distributions of North American animals. *The Southwestern Naturalist* 52 (4): 610-616. [https://doi.org/10.1894/0038-4909\(2007\)52\[610:dmbocf\]2.0.co;2](https://doi.org/10.1894/0038-4909(2007)52[610:dmbocf]2.0.co;2)

- Bryan K (1925) The Papago country, Arizona, a geographic, geologic, and hydrologic reconnaissance, with a guide to desert watering places. Water-Supply Paper 499 <https://doi.org/10.3133/wsp499>
- Casey T (1914) Memoirs on the Coleoptera. Vol. 5. The New Era Printing Company, Lancaster, PA, 378 pp.
- Chandler D (1982) A revision of North American *Notoxus* with a cladistic analysis of the New World species (Coleoptera: Anthicidae). Entomography 1: 333-438.
- Chao A, Gotelli N, Hsieh TC, Sander E, Ma KH, Colwell R, Ellison A (2014) Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. Ecological Monographs 84 (1): 45-67. <https://doi.org/10.1890/13-0133.1>
- Clark W (1978) The weevil genus *Sibinia* Germar: natural history, taxonomy, phylogeny, and zoogeography, with revision of the New World species (Coleoptera: Curculionidae). Quaestiones Entomologicae 14 (2): 91-387.
- Cobb N, Gall L, Zaspel J, Dowdy N, McCabe L, Kawahara A (2019) Assessment of North American arthropod collections: prospects and challenges for addressing biodiversity research. PeerJ 7 <https://doi.org/10.7717/peerj.8086>
- Cook J, Edwards S, Lacey E, Guralnick R, Soltis P, Soltis D, Welch C, Bell K, Galbreath K, Himes C, Allen J, Heath T, Carnaval A, Cooper K, Liu M, Hanken J, Ickert-Bond S (2014) Natural history collections as emerging resources for innovative education. BioScience 64 (8): 725-734. <https://doi.org/10.1093/biosci/biu096>
- Cooper N, Bond A, Davis J, Portela Miguez R, Tomsett L, Helgen K (2019) Sex biases in bird and mammal natural history collections. Proceedings of the Royal Society B: Biological Sciences 286 (1913). <https://doi.org/10.1098/rspb.2019.2025>
- Costa C, Vanin S, Lawrence J, Ide S, Branham M (2006) Review of the family Brachypsectridae (Coleoptera: Elateroidea). Annals of the Entomological Society of America 99 (3): 409-432. [https://doi.org/10.1603/0013-8746\(2006\)99\[409:rotfbc\]2.0.co;2](https://doi.org/10.1603/0013-8746(2006)99[409:rotfbc]2.0.co;2)
- Davis C, Guralnick R, Zipkin E (2022) Challenges and opportunities for using natural history collections to estimate insect population trends. Journal of Animal Ecology <https://doi.org/10.1111/1365-2656.13763>
- Dengler J (2009) Which function describes the species-area relationship best? A review and empirical evaluation. Journal of Biogeography 36 (4): 728-744. <https://doi.org/10.1111/j.1365-2699.2008.02038.x>
- Dengler J, Matthews T, Steinbauer M, Wolfrum S, Boch S, Chiarucci A, Conradi T, Dembicz I, Marcenò C, García-Mijangos I, Nowak A, Storch D, Ulrich W, Campos JA, Cancellieri L, Carboni M, Ciaschetti G, De Frenne P, Dolezal J, Dolnik C, Essl F, Fantinato E, Filibeck G, Grytnes J, Guarino R, Güler B, Janišová M, Klichowska E, Kozub Ł, Kuzemko A, Manthey M, Mimet A, Naqinezhad A, Pedersen C, Peet R, Pellissier V, Pielech R, Potenza G, Rosati L, Terzi M, Valkó O, Vynokurov D, White H, Winkler M, Biurrun I (2019) Species–area relationships in continuous vegetation: Evidence from Palaeartic grasslands. Journal of Biogeography 47 (1): 72-86. <https://doi.org/10.1111/jbi.13697>
- Doyen J (1968) The phylogenetic position of *Edrotes* and a new species of the genus (Coleoptera: Tenebrionidae). The Pan-Pacific Entomologist 44 (3): 218-227.
- Doyen J (1984) Systematics of *Eusattus* and *Conisattus* (Coleoptera; Tenebrionidae; Coniontini; Eusatti). Occasional Papers of the California Academy of Sciences 141: 1-104.

- Doyen J (1987) Review of the tenebrionid tribe Anepsiini (Coleoptera). Proceedings of the California Academy of Sciences 44 (15): 343-371.
- Erwin T (1974) Studies of the subtribe Tachyina (Coleoptera: Carabidae: Bembidiini) supplement A: lectotype designations for New World species, two new genera, and notes on generic concepts. Proceedings of the Entomological Society of Washington 76: 123-155.
- Fall F (1915) A revision of the North American species of *Pachybrachis*. Transactions of the American Entomological Society 41: 291-486.
- Fall H (1931) The North American species of *Hymenorus* (Coleoptera: Alleculidae). Transactions of the American Entomological Society 57 (2): 161-247.
- Fisher W (1950) A revision of the North American species of beetles belonging to the family Bostrichidae. United States Department of Agriculture Miscellaneous Publications (698)1-157.
- Fleischner T, Hanna D, Floyd-Hanna L (2017) A preliminary description of the Mogollon Highlands ecoregion. Plant Press 40 (2): 3-6.
- Freude H (1955) Die Monommiden der Welt. II. Teil: Die Monommiden der amerikanischen Region. Entomologische Arbeiten aus dem Museum G. Frey 6: 684-763.
- García Martín H, Goldenfeld N (2006) On the origin and robustness of power-law species–area relationships in ecology. Proceedings of the National Academy of Sciences 103 (27): 10310-10315. <https://doi.org/10.1073/pnas.0510605103>
- Gaston K (1991) The magnitude of global insect species richness. Conservation Biology 5 (3): 283-296. <https://doi.org/10.1111/j.1523-1739.1991.tb00140.x>
- GBIF (2022a) GBIF Occurrence Download. Global Biodiversity Information Facility. Release date: 2022-3-24. URL: <https://doi.org/10.15468/dl.z4crnr>
- GBIF (2022b) GBIF Occurrence Download. Global Biodiversity Information Facility. Release date: 2022-12-02. URL: <https://doi.org/10.15468/dl.5dthvr>
- GBIF Secretariat (2022) GBIF Backbone Taxonomy. URL: <https://doi.org/10.15468/39omei>
- Gidaspow T (1959) North American caterpillar hunters of the genera *Calosoma* and *Callisthenes* (Coleoptera, Carabidae). Bulletin of the American Museum of Natural History 116 (3): 225-344.
- Gordon R (1985) The Coccinellidae (Coleoptera) of America North of Mexico. Journal of the New York Entomological Society 93 (1): 1-912.
- Gries C, Gilbert E, Franz N (2014) Symbiota – A virtual platform for creating voucher-based biodiversity information communities. Biodiversity Data Journal 2 <https://doi.org/10.3897/bdj.2.e1114>
- Guralnick R, Zermoglio P, Wieczorek J, LaFrance R, Bloom D, Russell L (2016) The importance of digitized biocollections as a source of trait data and a new VertNet resource. Database 2016 <https://doi.org/10.1093/database/baw158>
- Halbritter D, Storer C, Kawahara A, Daniels J (2019) Phylogeography and population genetics of pine butterflies: Sky islands increase genetic divergence. Ecology and Evolution 9 (23): 13389-13401. <https://doi.org/10.1002/ece3.5793>
- Hedrick BP, Heberling JM, Meineke EK, Turner KG, Grassa CJ, Park DS, Kennedy J, Clarke JA, Cook JA, Blackburn DC, Edwards SV, Davis CC (2020) Digitization and the future of natural history collections. BioScience 70 (3): 243-251. <https://doi.org/10.1093/biosci/biz163>

- Horn G (1881) Synoptic tables of Coleoptera. Bulletin of the Brooklyn Entomological Society 4 (7+8): 39-40.
- Horn G (1882) Synopsis of the species of the tribe Lebiini. Transactions of the American Entomological Society 10: 126-163.
- Horn G (1884) A study of some genera of Elateridae. Transactions of the American Entomological Society 12: 33-52.
- Hortal J, de Bello F, Diniz-Filho J, Lewinsohn T, Lobo J, Ladle R (2015) Seven shortfalls that beset large-scale knowledge of biodiversity. Annual Review of Ecology, Evolution, and Systematics 46 (1): 523-549. <https://doi.org/10.1146/annurev-ecolsys-112414-054400>
- Hsieh TC, Ma KH, Chao A (2020) iNEXT: iNterpolation and EXTrapolation for species diversity. URL: <http://chao.stat.nthu.edu.tw/wordpress/software-download/>
- Johnston MA, Fleming D, Franz N, Smith A (2015) Amphidorini Leconte (Coleoptera: Tenebrionidae) of Arizona: Keys and species accounts. The Coleopterists Bulletin 69: 27-54. <https://doi.org/10.1649/0010-065x-69.mo4.27>
- Johnston MA (2016) Redefinition of the *Eleodes* Eschscholtz subgenera *Tricheleodes* Blaisdell and *Pseudeleodes* Blaisdell, with the description of a new species (Coleoptera: Tenebrionidae). Annales Zoologici 66 (4): 665-679. <https://doi.org/10.3161/00034541anz2016.66.4.018>
- Johnston MA, Aalbu R, Franz N (2018) An updated checklist of the Tenebrionidae sec. Bousquet et al. 2018 of the Algodones Dunes of California, with comments on checklist data practices. Biodiversity Data Journal 6 <https://doi.org/10.3897/bdj.6.e24927>
- Johnston MA, Gimmel M (2020) Review of North American Dascillidae (Coleoptera: Dascilloidea), with descriptions of dramatic female wing reduction. The Coleopterists Bulletin 74 (4). <https://doi.org/10.1649/0010-065x-74.4.731>
- Kharouba HM, Lewthwaite JMM, Guralnick R, Kerr JT, Vellend M (2018) Using insect natural history collections to study global change impacts: challenges and opportunities. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 374 (1763). <https://doi.org/10.1098/rstb.2017.0405>
- Laney J, Hallman T, Curtis J, Robinson WD (2021) The influence of rare birds on observer effort and subsequent rarity discovery in the American birdwatching community. PeerJ 9 <https://doi.org/10.7717/peerj.10713>
- Lendemer J, Thiers B, Monfils AK, Zaspel J, Ellwood ER, Bentley A, LeVan K, Bates J, Jennings D, Contreras D, Lagomarsino L, Mabee P, Ford LS, Guralnick R, Gropp RE, Revelez M, Cobb N, Seltmann K, Aime MC (2019) The Extended Specimen Network: A strategy to enhance US biodiversity collections, promote research and education. BioScience 70 (1): 23-30. <https://doi.org/10.1093/biosci/biz140>
- Liljeblad E (1945) Monograph of the family Mordellidae (Coleoptera) of North America, north of Mexico. Miscellaneous Publications Museum of Zoology, University of Michigan 62: 1-229.
- Lindroth C (1963) The ground-beetles (Carabidae, excl. Cicindelinae) of Canada and Alaska. Part 4. Opuscula Entomologica Supplementum 34: 945-1192.
- Lomolino M (2000) Ecology's most general, yet protean pattern: the species-area relationship. Journal of Biogeography 27 (1): 17-26. <https://doi.org/10.1046/j.1365-2699.2000.00377.x>

- Lomolino MV, Weiser MD (2001) Towards a more general species-area relationship: diversity on all islands, great and small. *Journal of Biogeography* 28 (4): 431-445. <https://doi.org/10.1046/j.1365-2699.2001.00550.x>
- MacLachlan W, Olson C (1990) A revision of the Trimyini of America north of Mexico (Coleoptera: Tenebrionidae). *The Coleopterists Bulletin* 44 (1): 69-82.
- Madge R (1967) A revision of the genus *Lebia* Latreille in America north of Mexico. *Quaestiones Entomologicae* 3: 139-242.
- Marshall M (1951) Studies in the Malachiidae. III. *Proceedings of the California Academy of Sciences*, 4th series 27: 77-132.
- Mayhew P (2007) Why are there so many insect species? Perspectives from fossils and phylogenies. *Biological Reviews* 82 (3): 425-454. <https://doi.org/10.1111/j.1469-185x.2007.00018.x>
- Meineke E, Davies TJ, Daru B, Davis C (2018) Biological collections for understanding biodiversity in the Anthropocene. *Philosophical Transactions of the Royal Society B: Biological Sciences* 374 (1763). <https://doi.org/10.1098/rstb.2017.0386>
- Messer P, Raber B (2021) A Review of Nearctic Selenophorus Dejean (Coleoptera: Carabidae: Harpalini) North of Mexico with New Species, New Synonyms, Range Extensions, and a Key. *The Coleopterists Bulletin* 75 (1). <https://doi.org/10.1649/0010-065x-75.1.9>
- Miller K (2002) Revision of the genus *Eretes* Laporte, 1833 (Coleoptera: Dytiscidae). *Aquatic Insects* 24 (4): 247-272.
- Moldenke A (1970) A revision of the Clytrinae of North America north of the Isthmus of Panama. Stanford University, Stanford, 310 pp.
- Moore W, Meyer WM, Eble JA, Franklin K, Wiens JF, Brusca RC (2013) Introduction to the Arizona Sky Island Arthropod Project (ASAP): Systematics, biogeography, ecology, and population genetics of arthropods of the Madrean Sky Islands. *Proceedings RMRS* 2013: 144-168.
- Morrison R (1991) Quaternary geology of the southern Basin and Range Province. *Quaternary Nonglacial Geology: Coterminus US353-371*. <https://doi.org/10.1130/dnag-gna-k2.353>
- Morrone J, Cuevas P (2002) Cladistics of the pantropical genus *Rhinostomus* (Coleoptera: Curculionoidea: Dryophthoridae), with nomenclatural notes. *Journal of the New York Entomological Society* 110: 376-388. [https://doi.org/10.1664/0028-7199\(2002\)110\[376:cotpgr\]2.0.co;2](https://doi.org/10.1664/0028-7199(2002)110[376:cotpgr]2.0.co;2)
- Noonan G (1973) The anisodacylines (Insecta: Coleoptera: Carabidae: Harpalini): classification, evolution and zoogeography. *Quaestiones Entomologicae* 9 (4): 266-480.
- Ober K, Matthews B, Ferrieri A, Kuhn S (2011) The evolution and age of populations of *Scaphinotus petersi* Roeschke on Arizona Sky Islands (Coleoptera, Carabidae, Cychrini). *ZooKeys* 147: 183-97. <https://doi.org/10.3897/zookeys.147.2024>
- Omernik J, Griffith G (2014) Ecoregions of the Conterminous United States: Evolution of a hierarchical spatial framework. *Environmental Management* 54 (6): 1249-1266. <https://doi.org/10.1007/s00267-014-0364-1>
- Packard G (2014) On the use of log-transformation versus nonlinear regression for analyzing biological power laws. *Biological Journal of the Linnean Society* 113 (4): 1167-1178. <https://doi.org/10.1111/bj.12396>

- Page L, MacFadden B, Fortes J, Soltis P, Riccardi G (2015) Digitization of biodiversity collections reveals biggest data on biodiversity. *BioScience* 65 (9): 841-842. <https://doi.org/10.1093/biosci/biv104>
- Papp C (1962) An illustrated and descriptive catalogue of the Ptinidae of North America. *Deutsche Entomologische Zeitschrift* 5: 367-423.
- Papp C (1981) Revision of the genus *Araeoschizus* LeConte (Coleoptera: Tenebrionidae). *Entomologische Arbeiten aus dem Museum G. Frey* 29: 273-420.
- Parsons C (1975) A key to nearctic *Statira* and *Arthromacra* (Lagriidae). *The Coleopterists Bulletin* 29 (4): 211-226.
- Pelsue F, Sleeper E (1972) A review of *Eucyllus* Horn (Coleoptera: Curculionidae, Brachyrhininae, Peritelini). *Bulletin of the Southern California Academy of Sciences* 71: 80-91.
- qGIS Development Team (2022) QGIS Geographic Information System. 3.24. Open Source Geospatial Foundation Project. URL: <http://qgis.osgeo.org>
- R Core Team (2020) R: A language and environment for statistical computing. 4.0.2. R Foundation for Statistical Computing, Vienna, Austria. URL: <https://www.R-project.org/>
- Sloop K (1937) A revision of the North American buprestid beetles belonging to the genus *Melanophila* (Coleoptera, Buprestidae). *University of California Publications in Entomology* 7: 1-20.
- Spilman T (1959) Notes on *Edrotes*, *Leichenium*, *Palorus*, *Eupsophulus*, *Adelium*, and *Strongylium* (Tenebrionidae). *The Coleopterists Bulletin* 13 (2): 58-64.
- Stephan K (1989) The Bothrideridae and Colydiidae of America north of Mexico (Coleoptera: Clavicornia and Heteromera). *Occasional Papers of the Florida State Collection of Arthropods* 6: 1-65.
- Stiles A, Scheiner S (2007) Evaluation of species-area functions using Sonoran Desert plant data: not all species-area curves are power functions. *Oikos* 116 (11): 1930-1940. <https://doi.org/10.1111/j.0030-1299.2007.15703.x>
- Stock SP, Gress J (2006) Diversity and phylogenetic relationships of entomopathogenic nematodes (Steinernematidae and Heterorhabditidae) from the Sky Islands of southern Arizona. *Journal of Invertebrate Pathology* 92 (2): 66-72. <https://doi.org/10.1016/j.jip.2006.02.001>
- Storch D, Keil P, Jetz W (2012) Universal species–area and endemics–area relationships at continental scales. *Nature* 488 (7409): 78-81. <https://doi.org/10.1038/nature11226>
- Storch D (2016) The theory of the nested species-area relationship: geometric foundations of biodiversity scaling. *Journal of Vegetation Science* 27 (5): 880-891. <https://doi.org/10.1111/jvs.12428>
- TRACY J, ROBBINS T (2009) Taxonomic revision and biogeography of the *Tamarix*-feeding *Diorhabda elongata* (Brullé, 1832) species group (Coleoptera: Chrysomelidae: Galerucinae: Galerucini) and analysis of their potential in biological control of Tamarisk. *Zootaxa* 2101 (1): 1-152. <https://doi.org/10.11646/zootaxa.2101.1.1>
- Van Dyke E (1932) Miscellaneous studies in the Elateridae and related families of Coleoptera. *Proceedings of the California Academy of Sciences* 20 (9): 291-465.
- Van Dyke E (1939) New species and subspecies of west American Coleoptera. *The Pan-Pacific Entomologist* 15: 15-20.
- Waller J (2022) Finding data gaps in the GBIF backbone taxonomy. *Biodiversity Information Science and Standards* 6 <https://doi.org/10.3897/biss.6.91312>

- Wells S (2000) Two new species of *Horistonotus* Candeze (Coleoptera: Elateridae), new synonymies, and a key to the species of the United States and Canada. *Proceedings of the Entomological Society of Washington* 102 (2): 412-420.
- Werner F, Enns W, Parker F (1966) The Meloidae of Arizona. Technical Bulletin - Agricultural Experimental Station, the University of Arizona (175)1-96.
- Werner FG (1961) A Revision of the Genus *Vacusus* Casey (Coleoptera: Anthicidae). *Annals of the Entomological Society of America* 54 (6): 798-809. <https://doi.org/10.1093/aesa/54.6.798>
- Whitaker A, Kimmig J (2020) Anthropologically introduced biases in natural history collections, with a case study on the invertebrate paleontology collections from the middle Cambrian Spence Shale Lagerstätte. *Palaeontologia Electronica* <https://doi.org/10.26879/1106>
- Whitehead D (1972) Classification, phylogeny, and zoogeography of *Schizogenius* Putzeys (Coleoptera: Carabidae: Scaritinae). *Quaestiones Entomologicae* 8: 131-348.
- Wickham H (2016) ggplot2: Elegant graphics for data analysis. Springer-Verlag New York. URL: <https://ggplot2.tidyverse.org>
- Wickham H, François R, Henry L, Müller K (2022) dplyr: A grammar of data manipulation. URL: <https://CRAN.R-project.org/package=dplyr>
- Wilke C (2020) cowplot: Streamlined plot theme and plot annotations for 'ggplot2'. URL: <https://CRAN.R-project.org/package=cowplot>
- Willis A (2019) Rarefaction, alpha diversity, and statistics. *Frontiers in Microbiology* 10 <https://doi.org/10.3389/fmicb.2019.02407>
- Yanahan A, Moore W (2019) Impacts of 21st-century climate change on montane habitat in the Madrean Sky Island Archipelago. *Diversity and Distributions* 25 (10): 1625-1638. <https://doi.org/10.1111/ddi.12965>
- Zaragoza Caballero S (1986) El genero *Distremocephalus* Wittmer en Mexico (Coleoptera: Phengodidae; Mastinocerini). *Annales del Instituto de Biologia Universidad Nacional Autonoma de Mexico* 56: 933-938.
- Zizka A, Antonelli A, Silvestro D (2020) *sampbias*, a method for quantifying geographic sampling biases in species distribution data. *Ecography* 44 (1): 25-32. <https://doi.org/10.1111/ecog.05102>

Supplementary materials

Suppl. material 1: Arizona insect occurrence data annotated by which ecoregion or mountain range they occur within [doi](#)

Authors: M.A. Johnston

Data type: occurrences

Brief description: Zip archive of two occurrence recordsets for Arizona insects. The first file contains occurrence records annotated by which ecoregion they fall within and the second file contains annotated records by which mountain range they fall within.

[Download file](#) (53.24 MB)

Suppl. material 2: Arizona ecoregion data [doi](#)

Authors: M.A. Johnston

Data type: Geographical and biodiversity metrics of ecoregions

Brief description: This table includes data for all Arizona ecoregions including their geographic size and the number of insect records, collecting events and taxa found within them.

[Download file](#) (1.20 kb)

Suppl. material 3: Arizona mountain range data [doi](#)

Authors: M.A. Johnston

Data type: Geographic and biodiversity metrics for mountain ranges

Brief description: This table includes information about the tallest mountain ranges in Arizona. A polygon in WKT format, the geographic area, prominence and height of each mountain range is given. Totals for insect occurrence records, collection events and taxa are also given.

[Download file](#) (46.53 kb)

Suppl. material 4: Sand Tank Coleoptera specimen records [doi](#)

Authors: M.A. Johnston

Data type: occurrences

Brief description: Darwin Core Archive of new records

[Download file](#) (31.68 kb)

Suppl. material 5: Data analysis and figure generation script [doi](#)

Authors: M. Andrew Johnston

Data type: R script used for data analysis and for generating all the statistical figures used in this paper.

[Download file](#) (24.19 kb)

Suppl. material 6: Additional analyses for normality and log-transformed data

[doi](#)

Authors: M. Andrew Johnston

Data type: statistical graphs

Brief description: This file contains graphical analyses to test the Arizona insect occurrence dataset for normality across mountain ranges and Ecoregions. Additional graphs of log-transformed data are included for untransformed analyses presented in the main text.

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