Minimum Information for Reusable Arthropod Abundance Data (MIReAAD)

Myriad: a countless or extremely great number

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Abstract

Introduction

Arthropods play a dominant role in the dynamics of practically all natural and human-modified terrestrial ecosystems[1–3], and have significant economic and health effects. For example, certain

77 insects provide significant economic benefits (*e.g.* pollination) exceeding $57 billion a year to
78 the United States alone[4]. Meanwhile, invasive insects cost an estimated $70 billion dollars per
79 year globally[5] and insect pests may reduce agricultural harvests by up to 16%, with an equal
80 amount of further losses of harvested goods[6]. Particularly noteworthy is a subset of arthropods
81 that are disease vectors, transmitting pathogens to and between animals as well as plants. Vector-
82 borne diseases cause billions of dollars in crop and livestock losses, every year[7–9]. In humans,
83 vector borne diseases account for more than 17% of all infectious diseases (*e.g.* malaria, Chagas,
84 dengue, and leishmaniasis, Zika, West Nile, Lyme disease, and sleeping sickness), with hundreds
85 of thousands of deaths, hundreds of millions of cases, and billions of people at risk, annually[10,11].
86
87 The current economic and health burden of arthropod pests, exacerbated by invasive species, and
88 uncertain effects of climate change[12,13], has driven significant research programs and data
89 collection efforts. These include crop pest, mosquito, and tick survey and reporting initiatives[14–
90 18], citizen science projects[19–21], and digitization of museum specimen data[22,23], all yielding a rich
91 and growing trove of field-based data spanning multiple spatial and temporal scales. Monitoring
92 arthropod abundance (*e.g.* Figure 1) in different disciplines (*e.g.*, biodiversity research, pest-
93 control assessment, vector-borne disease monitoring, or pollination research) uses similar
94 techniques, with similar objectives: to quantify abundance, phenology and geographical ranges
95 of target arthropod species. Despite a growing number of data collections, they are often not
96 reusable, or comparable to similar data, due to a lack of standardization and metadata. In
97 contrast, the advent of the deposition of data from high-throughput technologies (*e.g.* NCBI and
98 GenBank), data and code sharing, and other practices to improve transparency and reusability of
99 research results are increasing rapidly across the sciences[24–29]. Furthering these advances through

standardization and public archiving of arthropod abundance data can bring significant benefits, including (1) supporting empirical parameterization and validation of mathematical models (*e.g.* of pest or disease emergence and spread), (2) validation of model predictions, (3) reduction in the duplication of expensive empirical research, and (4) revealing new patterns and questions through meta-analyses[30–33]. This will also lead to substantial public benefit through improved human, animal, plant, and ecosystem health, and reduced economic costs.

A key impediment to the re-use of these data is the lack of adequate metadata or data descriptors (*i.e.* data about the data)[34–37]. In general, for data to be most valuable to the scientific community, they should meet the FAIR Principles – they should be Findable, Accessible, Interoperable and Reusable – and delineate the key components of good data management and stewardship practices[38,39]. Data are Findable and Accessible when they are archived and freely downloadable from an online public data repository that is indexed and easily searchable. Interoperability and reusability describe the ease with which humans or computer programs can understand the data (*e.g.* via metadata) and explore/re-use them across a variety of non-proprietary platforms. Even when data are available, metadata for arthropod abundance data are often absent or not readily interpretable, limiting their reusability at a fundamental level.

A minimum information standard for arthropod abundance data

Here, we present a Minimum Information for Reusable Arthropod Abundance Data (MIReAAD) standard for reporting primarily longitudinal (repeated, temporally explicit) field-based collections of arthropods. In the same manner as has been developed in other biological disciplines[40–45], this standard is “minimum” because it defines the necessary minimal information

123 required to understand and reuse a dataset without consulting any further text, materials, or
124 methods[46]. MIReAAD is designed to facilitate data archiving efforts of publishers and field
125 researchers. It is not a data model and therefore does not define controlled vocabularies, or
126 specific field titles, but should be easy to understand, and interpret by the wider scientific
127 community[46].
128
129 The minimal standards are separated into two components, metadata and data. For each
130 component, we provide a description of the information that should be included,
131 recommendations for how to make that information as useful as possible, and examples. The
132 metadata component (Table 1) includes information for the origin of the data set (*e.g.* study
133 information and licensing for usage). The second component (Table 2) lists and describes
134 specific data fields that should be included in data collection sheets. We also provide
135 recommendations and examples to demonstrate how these recommendations can be
136 implemented. MIReAAD was designed to match the data that are generally collected by
137 academic researchers and surveillance initiatives, and can serve as a checklist for important
138 information that needs to be recorded but is often unintentionally omitted (*e.g.* Figure 2A). By
139 adhering to MIReAAD standards, omissions and ambiguity can be avoided even if the data are
140 shared in different formats (Figure 2B and C). Finally, we identify common problems likely to
141 be encountered across all the MIReAAD metadata and data fields, and data quality standards that
142 can be employed to avoid confusion (Box 1).
143

Box 1. Data quality standards

Language. Once data are ready to be deposited/submitted, all fields and data need to be written in English. This will allow researchers and data curators worldwide to understand and reuse the data.

No abbreviations. Abbreviations (including in columns names) are ambiguous, with the exception of measurement units (*e.g.* centigrade and meters).

No external legend/key files. While repetitive, all data should be explicitly given within the data table. Separate files mapping ID numbers to GPS locations, full species names, etc., should be avoided.

Unambiguous dates. Because of country-level differences in date formats, data should be reported with 4 digit years, and months provided alphabetically and not numerically (*e.g.* 4-Jun-2017 or Nov 12, 2015).

Machine-readable file formats. Data should be provided in non-proprietary machine readable formats such as comma-separated text files. PDFs and multiple spreadsheets in the same document should be avoided.

No font styling or subsection headings. Formatting (color, bold, italics, subscripts, sheet tab names, *etc.*) should not be required for understanding the data. Subsection headings

should not be required to understand data; every line of data should be interpretable in isolation from any other line of data.

Highest precision possible. Data should be provided at the highest temporal, spatial, numerical, and taxonomic resolution available. If location (*e.g.*, geographical coordinate) data need to be presented at a lower resolution than available for privacy reasons, this should be made clear in the submission in Study Information (Resource Metadata; Table 1).

Examples

Below we provide three examples to illustrate MIReAAD compliant data (linked to Supplemental Data Files 1-4, respectively). Researchers can use these data sheets as a basis for formatting their own data. In these examples, note that all data meet the data quality standards of Box 1; are adequately described, have columns labeled, *etc*. to eliminate ambiguity (even if the data appear repetitive; for example, the sex and life stage are repeated in every row). Examples 1 and 2 should be sufficient for most data generators. Example 3 (Data Files 3-4) demonstrates a more complex data collection scenario.

1. *Long-format trapping data*. Each row captures count data for a single species' occurrence in a given sampling event. This illustrates an example of the most common mosquito collection

protocol. [Sup Datasheet 1]. Also see Figure 2B.

2. *Wide format trapping data.* Each row captures count data from a given sampling event. Each identified taxonomic group is identified in a separate column. An 'additional sample information' field, 'sub-location,' has been added to describe the various locations around the village where collections were made. [Sup Datasheet 2]. This illustrates an example of adult mosquito populations that have been tracked over time and in specific locations. Also see Figure 2C.

3. *Complex trapping data scenario.* Tick surveillance performed using tick drags and flags and collections of ectoparasites on trapped mice. The tick drags/flags report three life stages independently (adult, larvae, and nymph) [Sup Datasheet 3] . Larvae are only identified to the genus, while adults and nymphs are identified to the species. A Sample Name is used to help link these records (but would not be necessary.) The mouse survey uses an additional sample information field to record the sex of the trapped mouse from which the parasites were collected [Sup Datasheet 4].

Discussion

MIReAAD as the path to FAIR data principles

We designed MIReAAD to achieve a balance between standards that are too onerous for data generators and standards that are sufficient to ensure at least minimal reusability[31,40]. Like all minimum standards, MIReAAD only aims at ensuring data 'Reusability'. However, ultimately

this will promote the implementation of data models — the explicit definition of data field names, data formats (*e.g.*, for dates and GPS locations), and controlled vocabularies (*e.g.*, the Darwin Core[47]). Data models enable 'Interoperability', and in turn facilitate structured databases, public repositories, and development of data analysis tools[46,48]. Deposition in open databases make data 'Findable' and 'Accessible'[49–51]. MIReAAD compliant data contain sufficient information for established aggregators/databases such as VectorBase and SCAN (Symbiota Collections of Arthropods Network[52]) to process and store the data in a standardized data model (*e.g.*, Darwin Core[47]), and ultimately facilitate data transfer to even more comprehensive biodiversity databases (*e.g.* GBIF, which contains over one billion species occurrence records[51]). In this way, MIReAAD opens the door to FAIR data and more sophisticated methods to integrate data across many scales.

Benefits to field researchers

It is essential that the benefits of a minimal data standard extend not just to data re-users, but also to the researchers who collect and generate data in the first place. MIReAAD provides a framework for data preparation that can help scientists achieve recognized professional merit for sharing data such as increased citation rates, academic recognition, opportunities for co-authorship, and new collaborations [sensu Roche et al. 2014[31]]. Large, deposited data sets can now themselves be standalone, citable "data papers" (*e.g.* [53–55]) or even depositions without any traditional manuscript (but with persistent identifiers, such as a DOI number), if desired. Data sets are increasingly recognized as valuable research outputs that count towards academic recognition and professional advancement (*e.g.* grants, interviews, and tenure). For example, several funders (*e.g.* United States National Science Foundation and Swiss National Science

Foundation) have adopted or are in the process of adopting the Declaration on Research Assessments (DORA)[56], offering further opportunities for data generators to gain recognition and publication credit for their work[57]. Also, an increasing number of funders are mandating public data access, and detailed data management plans are often required even at the grant proposal stage. Therefore, reporting data according to MIReAAD will provide a foundational pipeline for stipulating archival formats.

Furthermore, many data generators are also data users. Developing analyses that rely on standardized fields can facilitate the development of generalized analytical tools that can be easily extended to datasets beyond those that were collected by a single individual or lab. In this way, they can enable extensions of work that would otherwise not happen, such as comparisons of population dynamics in different locations or assessments of interspecies interactions. Adopting MIReAAD therefore can both help data generators reap the benefits of sharing data they have collected and enable them to more readily leverage data collected by others.

Further MIReAAD applications and extensions

The creation of minimum information standards for these types of databases facilitates analyses of data at the scales that cannot be attained by a single individual or lab group. Linking records to additional information also extends the utility of these data to address population level questions. For example, a well-populated database presents opportunities to investigate interactions between populations of different species of arthropod that overlap in geography, but may be of interest individually to different realms of research. As a case in point, in the northeastern USA, *Agrilus plannipennis*, the Emerald Ash Borer (EAB), is a highly destructive

invasive insect, monitored closely by both state and federal agencies for management[58]. Interestingly, EAB are creating lots of new habitat for carpenter bees, a species interaction that can be tracked and anticipated using large scale arthropod data.

Another example of the utility of linked data is for disease vectors. Data on insecticide resistance linked with time and place would be valuable for coordinating control strategies within and between nations and communities. Presence/absence data on infection levels would be helpful for tracking and investigating disease outbreaks, and dynamics. Standardization of these data would be particularly useful for pathogens that infect multiple vectors and hosts and would facilitate a "One Health" approach. Other important vector phenotypes that contribute to control and transmission such as pathogen susceptibility, biting preferences, and breeding behaviours could be measured over time and space.

We note that MIRreAAD is applicable not only to abundance measurements, but could be easily extended to any other kind of routinely sampled time-series field data. For example, in addition to aphid abundance, plant pathogen (such as mosaic virus) infection and insecticide resistance statuses of the aphids could be reported in MIRreAAD format.

Conclusion

We present MIReAAD, a minimum information standard for representing arthropod abundance data. MIReAAD will facilitate collation and analyses of data at scales that cannot be attained by a single individual or lab, to address key questions across temporal and spatial scales,

244 such as within and across-year phenology of abundance of target arthropod taxa over large
245 geographical areas. This is particularly important given the pressing need to understand and
246 predict the population dynamics of harmful (e.g., disease vectors and pests) as well as beneficial
247 (e.g., pollinators, bio-control agents) arthropods in natural and human modified landscapes. This
248 is the first step for achieving the broad benefits of FAIR data for arthropod abundance. We call
249 on data generators, authors, reviewers, editors, journals, research infrastructures (*e.g.* data
250 repositories) and funders to embrace MIReAAD as a standard to facilitate FAIR data use and
251 compliance for arthropod abundance data.

252
253 **Table 1.** The MIReAAD Study Information (Resource metadata) fields. The information in this
254 table should be included with every data submission, for example by including data in the file
255 header as demonstrated in Data Files 1-4.
256

Field	Details	Recommendations	Examples
Contact details	A name, person, authority, etc. that may be contacted with enquiries about the data.	Include investigator ORCID(s), email address, website (if institutional) if possible.	Kurt Vandegrift orcid.org/0000-0002-5690-3300 kurtvandegrift@gmail.com State University Agricultural Extension John Smith (jsmith@StateU.edu) www.StateU.edu/AgriculturalExtension/
General description of the experiment/ collection set	A short description of the study objectives, sampling design, and hypotheses. Used to aid in browsing multiple studies. A short title and long form name might be helpful.	Useful things to indicate are: Random sampling or continuous monitoring in fixed locations General time frames and location. General description of where data is from.	"Long term, fixed trapped, municipal surveillance of west Nile vector population in Colorado from 2000-2010" ----- "Pennsylvania *Ixodes scapularis* weekly abundance" Continuous (weekly) monitoring of tick numbers attached to White-footed mice in fixed locations in Pennsylvania, USA (12 sites). 2003-present." ----- "Long term aphid emergence monitoring using continuous suction traps"

Citations	Reference to related publications, digital if possible (e.g. DOI(s) or PMID(s)).		"A web-based relational database for monitoring and analyzing mosquito population dynamics Sucaet Y, Van Hemert J, Tucker B, Bartholomay L." "PMID: 18714883" Horiuchi, Kaho, Kosei Hashimoto, and Fumio Hayashi. "Cantharidin world in air: Spatiotemporal distributions of flying canthariphilous insects in the forest interior." Entomological Science (2018).
Species Identification Method	A description of method of species identification. Particularly important for cryptic species complexes.		"Morphological" "Genotyped, using method of Smith et al 2014, PMID: 18714883"
Not present vs zero information	Indication of what gaps, zeros, NA, etc mean.	It is imperative, especially for population surveys, to understand the difference between a species was not found when the collection method would be expected to find the given species (confirmed absence) or a species was not looked for (*e.g.* a trap failure) Preferably, a zero indicates was looked for and not found, and a NA represents was not looked for/trap failure/ etc. Blank values are discouraged	"Zero indicates was looked for and not found. NA represents a trap failure etc"
GPS obfuscation information	If GPS data obfuscation (*e.g.* GPS points are intentionally offset from their actual locations) or de-resolution occurs (*e.g.* GPS precision is intentionally reduced) , a statement on the manner by which this occurred.	The highest resolution data (*e.g.* trap-level, specific GPS location) are the most useful. It is hoped that no data obfuscation / de-resolution occurs	"GPS locations have been truncated to 3 decimals" "GPS locations obfuscated using N-Dispersion" "No GPS deresolution was performed"

Data usage information	The data reuse policy for your data. Please provide a creative commons license identification. See https://creativecommons.org for more information.	For data to be F.A.I.R., it must be Reusable. We therefore recommend data be provided as "CC0" or "CC BY". "CC0", under which data are made available for any use without restriction or particular requirements on the part of users "CC BY", under which data are made available for any use provided that attribution is appropriately given for the sources of data used, in the manner specified by the owner (*e.g.* citation).	"CC0" or "CC BY"

Table 2. The MIReAAD data fields. Fig 1B provides an annotated example.

Field(s)	Details	Recommendations	Examples
Start Time (for collection)	Start time of the data sample collection. *e.g.* The trap was set...	Be as specific as *practically* possible. Month should be written out so that day and month are not confused. Provide timezone in field or in header if hourly data, a 24 hour clock is prefered, but should be made unambiguous as to which time format is being used.	"July 26, 2017" "2017-Jul-26" "2017-July-26 Morning " "2017-Jul-26 20:00 GMT "
End Time (for collection)	End time of the data sample	See above.	See above.

	collection. *e.g.* The trap was collected...	If instantaneous data collection (*e.g.* a tick drag), End Time may be the same as Start Time.	
Location	The geographical location of sample collection.	As detailed as possible. Latitude and longitude if possible with specified accuracy Providing *both* a GPS point (decimalized GPS points are prefered) field and a geographical name field is prefered. Note only providing location *names* is highly discouraged as they change over time and can be ambiguous. Place / Trap names and GPS fields can be provided. If obfuscation was used, it should be indicated in the Metadata (Table 1). Splitting latitude and longitude further into two columns further reduces ambiguity.	"Kukar Maikiya, Jigawa State, Nigeria" "40.697" and " -74.015"

Collection method	Sampling apparatus (*e.g.* trap type, observation method)		"CDC light trap" "Tick drag" "Quadrat count" "BG Sentinel Trap" "Pitfall trap" "Larval dip" "Johnson suction trap" "Lindgren Funnel Trap"
Collection attractants	The attractant/ lures used to attract insects to a trap or collection		"None" "Carbon dioxide" "UV light" "BG-Sweetscent Mosquito Lure" "Human/animal bait"
Collection area	The spatial extent (area or volume) of the sample.	If relevant (*e.g.*, when collection method is transect or quadrat), in units of area or volume, the spatial coverage of the sampling unit Note this field would not typically be used for mosquito collections.	"100 m^2" "1 liter" "1 ha" "10m^3"
Taxonomy	Classification of sample collected.	Scientific genus and species preferred. Avoid abbreviation.	*"Ixodes scapularis*" *"Aedes aegypti*" '*Anopheles gambiae sensu stricto*"

Unit(s) of measurement and observation	Description of exactly what was observed, the unit for "Value" below. For counts, should indicate life stage, sex, etc. Unit measures can be encoded into value field header. Consider multiple unit fields (*e.g.* separate fields for sex and stage.) See Figure 2.	Do not abbreviate. Coded data key should be provided in field name (*e.g.* "1 = species present 0= species absent")	"Number of individuals per m^2" "Female" and "Adult" "Male and Female" and "Nymphs"
Value	The numerical amount or result from the sample collection. Often this will be a quantity of observed individuals. Unit measures can be encoded into value field header. See Figure 2.	Units should be provided in a separate field.	"0" "23" "Yes" "Not present"
Additional sample information	This could be more than one field and should be used when more information is required to understand the experiment, for example experimental variables, sub-locations, etc. Some users may report wind speeds, temperatures, elevations etc.	Do not abbreviate.	"Forest" vs "Field" "Winter" vs "Summer" "Inside" vs "Outside" "200 meters above sea level"

Sample Name	A human readable sample name. May exist solely for the benefit of the depositor in organizing their data, use their own internal naming conventions etc. May also be used to tie related observations together.	Naming convention is not restricted, but any encoded metadata should be revealed in the other datafields. For example, you may name a sample named 'Aphid1_StickyTrap_Jan4,' but you will still have "Sticky Trap" listed in a Collection Method field, and "Jan 4, 2017" in the date field.	"Trap1_Night1" "KissingBug_2" "00004" "Jan08_animal_4,"

Field names in bold should be considered also required. Remaining fields are optional or depend on the complexity of the experimental design

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Figures

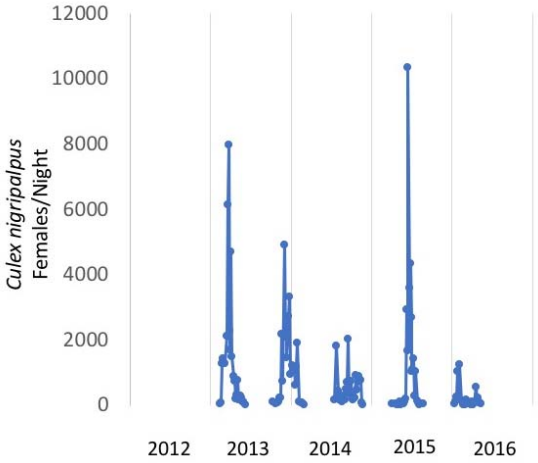

Figure 1. Example population abundance time-series.

A.

What is being counted? Adults? Females?

Is this date of collection? How long was trap set?

Date	Trap	Count	Species
12/11/18	LT-5	6	C. inornata
12/11/18	LT-6	4	C. inornata
12/11/18	LT-7	6	C. inornata
12/11/18	LT-5	8	A. francisc.
12/11/18	LT-6	3	A. francisc.
12/11/18	LT-7	11	A. francisc.

Ambiguous genus: *Culex inornata* or *Culiseta inornata* ?

Ambiguous species: *Anopheles franciscanus* or *Anopheles Franciscoi* ?

Ambiguous date format: Different countries use alternate day, month, and year orders

Where is this trap located? What kind of trap? "LT" could be "light trap," but there are multiple kinds. Was an attractant used?

B.

The time period of collection is unambiguous

What was counted or measured is clear

Taxonomic ambiguity avoided by not using abbreviations.

Trap Set	Trap Collected	Collection Method	Attractants	Count	Life stage	Sex	Trap ID	Trap Location	Latitude	Longitude	Species
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	6	Adult	Female	LT-5	High School	22.211	84.974	Culex inornata
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	4	Adult	Female	LT-6	High School	22.209	84.894	Culex inornata
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	6	Adult	Female	LT-7	High School	22.199	85.012	Culex inornata
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	8	Adult	Female	LT-5	High School	22.211	84.974	Anopheles franciscanus
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	3	Adult	Female	LT-6	High School	22.199	85.012	Anopheles franciscanus
11-Dec-2018	11-Dec-2018	CDC Light Trap	Light, CO2	11	Adult	Female	LT-7	High School	22.199	85.012	Anopheles franciscanus
11-Dec-2018	11-Dec-2018	CDC Light Trap	Light, CO2	1	Adult	Male	LT-7	High School	22.199	85.012	Anopheles franciscanus

Unambiguous date format

The type of trap and attractants used is clear

Human readable (but ambiguous) place names are made unambiguous with GPS coordinates

C.

Trap Set	Trap Collected	Collection Method	Attractants	Trap ID	Latitude	Longitude	Culex inornata (Adult Female Count)	Anopheles franciscanus (Adult Female Count)
11-Dec-2018	13-Dec-2018	CDC Light Trap	Light, CO2	LT-5	22.211	84.974	3	5
13-Dec-2018	15-Dec-2018	CDC Light Trap	Light, CO2	LT-5	22.211	84.974	4	4
15-Dec-2018	17-Dec-2018	CDC Light Trap	Light, CO2	LT-5	22.211	84.974	5	6
17-Dec-2018	19-Dec-2018	CDC Light Trap	Light, CO2	LT-5	22.211	84.974	3	8
19-Dec-2018	21-Dec-2018	CDC Light Trap	Light, CO2	LT-5	22.211	84.974	4	2

Data reported in wide format can still be unambiguous by including relevant metadata in column headings

Figure 2. MIReAAD reduces data ambiguity. A. Seemingly clean data can still lack key information or have ambiguous metadata, hindering data reuse. B. MIReAAD compliant data includes the metadata necessary for data reuse and removes ambiguity. C. Note data can be formatted differently, but still be MIReAAD complaint, such as by presenting data in a wide format

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