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Forum

Towards global volunteer monitoring of odonate abundance

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Insects are reportedly experiencing widespread declines, yet we generally have sparse data on their abundance. Correcting this shortfall will take more effort than professional entomologists alone can manage. Volunteer nature enthusiasts can greatly help to monitor the abundance of dragonflies and damselflies (Odonata), iconic freshwater sentinels and one of the few non-pollinator insect groups appreciated by the public and amenable to citizen science. Although counting individual odonates is common in some locations, present data will not enable a global perspective on odonate abundance patterns and trends. Borrowing insight from butterfly monitoring efforts, we outline basic plans for a global volunteer network to count odonates, including organizational structure, advertising and recruiting, and data collection, submission, and synthesis. We hope our proposal serves as a catalyst for richer coordinated efforts to understand population trends of odonates and other insects in the Anthropocene.

Keywords: citizen science, community science, Odonata, insect declines, Prestonian shortfall

Provocative headlines such as *Insectaggedon, Insect Apocalypse* and *The Great Insect Dying* have directed the world's attention to a purported widespread decline of insects and elicited calls for immediate action (Basset and Lamarre 2019, Forister et al. 2019, Sánchez-Bayo and Wyckhuys 2019, Cardoso et al. 2020, Harvey et al. 2020). While deeply concerning, the flashpoint study (Sánchez-Bayo and Wyckhuys 2019) has come under academic criticism and doubt lingers over how well existing data and analyses can predict trends and support the notion of a general demise (Cardoso and Leather 2019, Komonen et al. 2019, Thomas et al. 2019, Didham et al. 2020, Montgomery et al. 2020, Saunders et al. 2020, Wagner 2020).

One of the key problems is not having the requisite baseline and monitoring data, beyond anecdotes like less bug splatter on the windshield and fewer fireflies at night (Lewis et al. 2020). Recent interviews with 24 entomologists from 12 nations on six continents pointed to how people typically record species richness of insects, but not the abundance of each species (Hance 2019). Except for high-interest pests and pollinators (e.g. Ries and Oberhauser 2015) there is an overall dearth of abundance knowledge ("Prestonian shortfall"; Cardoso et al. 2011) for insects (Samways 2015). For certain taxa, citizen or community science may be the only solution to addressing the Prestonian shortfall and rapidly assessing global trends, as volunteer nature enthusiasts far outnumber professional biologists and can provide significantly more geographic coverage and data points over time (McKinley et al. 2017, Callaghan et al. 2019). Despite challenges in working with citizen-science data (Dickinson et al. 2010), the complex path to assessing insect declines will have to include broad-scale, long-term abundance monitoring driven largely by volunteers (Cardoso et al. 2020, Didham et al. 2020, Harvey et al. 2020, Montgomery et al. 2020, Samways 2020, Wagner 2020).

As showy pollinators, butterflies (Lepidoptera) are gateway insects and perennial favorites of entomological citizen science (Acorn 2017), with abundance-based monitoring backed by national funding initiatives in Europe and institutional coalitions in the United States (Taron and Ries 2015, Cardoso and Leather 2019). The similarly charismatic dragonflies and damselflies (Odonata) have not received this level of attention, despite their interesting behavioral repertoire (Cordero-Rivera 2017) and importance as targets, tools, and models in conservation (Clausnitzer et al. 2009, Bried and Samways 2015, Vorster et al. 2020). Their trophic position as top or mid-level consumers has great influence on freshwater interaction webs and land-water energy transfers (Córdoba-Aguilar 2008). Odonates are also a leading indicator of large-scale environmental change (Hassall 2015) and potential proxies for broader segments of freshwater biodiversity (Kietzka et al. 2019). Combined with butterflies, they colorfully symbolize the terrestrial and freshwater realms supporting nearly the entire insect tree of life. And like butterflies, odonates attract public interest and can be easy to identify and enumerate, creating prime opportunities for citizen science and improving the biocultural, socioecological, and psychological dimensions of insect conservation (Lemelin 2007, Ngiam et al. 2017, Simaika and Samways 2018).

Here we (i) explain why abundance matters; (ii) review the global data and challenges for estimating odonate species abundances; and (iii) propose an approach to global volunteer monitoring, outlining basic plans for organizational structure, advertising and recruiting, and data collection, submission, and synthesis. Public participation will be essential to overcoming the Prestonian shortfall for a flagship insect group capable of connecting people and nature.

Why abundance matters

Estimating the abundance of insect species is paramount to safeguarding their populations (Samways 2015, 2020). Unfortunately for insect conservation, species abundance data are generally very limited in space and time, and occurrence-based surrogates are commonly used to evaluate odonate population trends and extinction risk (Goertzen and Suhling 2019, Termaat et al. 2019, Rocha-Ortega et al. 2020). Occurrence patterns across space and time may correlate with changes in population abundance (Gaston et al. 2000, Thorne et al. 2006), especially in cases of small or low-density populations or when species are structured into metapopulations (MacKenzie et al. 2006). However, occurrences inherently mask underlying abundance variation and can have less statistical power than abundance to signal population declines (Pollock 2006), potentially delaying critical actions. There is growing evidence that even some common insect species are declining (Wepprich et al. 2019, Wagner 2020), which we cannot detect with occurrence data. Furthermore, many datasets lack information on absence (e.g. museum specimens, most biodiversity databases) and using presence-only data to make inferences about abundance is still premature (Ries et al. 2019).

Abundance is central in manifestations of evolutionary ecology such as behavioral diversity (Cordero-Rivera 2017) and species coexistence (Siepielski et al. 2018), and to applied areas such as bioindication of stressors (e.g. pollution, riparian deforestation; Silva et al. 2010, Córdoba-Aguilar and Rocha-Ortega 2019) and provisioning of ecological and cultural services (Dee et al. 2019). Characterization of services is especially critical to improving people's awareness and psychological connection with insects (Simaika and Samways 2018). Dragonflies and damselflies offer abundance-related services such as regulation of energy flows and biological pests (e.g. mosquitos) but may cause disservices by hosting parasites and consuming pollinators (Simaika and Samways 2008, Sang and Teder 2011, May 2019). Additionally, counts of individual odonates can help to identify autochthonous (resident, non-immigrant) species occurrences, which may in turn strengthen inferences on abundance patterns and their relationship to environmental gradients (Patten et al. 2015, Bried et al. 2016).

Insects generally exhibit substantial population fluctuations that call for direct measures of abundance. Of course, larger fluctuations require longer time series and larger sample sizes to detect, assess, and predict changes through time (Pollock 2006, Magurran et al. 2010, White 2019). Realistically, given the large geographic ranges of many taxa, only citizen-science monitoring can attain the necessary statistical power for spatially robust trends analysis of odonates, as it has for butterflies (Weiser et al. 2019, Wepprich et al. 2019).

Who's counting?

Odonata citizen science has surged with the proliferation of field guides, digital photography, and online data portals. Odonata enthusiasts around the world are engaged in record collecting and have greatly contributed to species inventories and distribution knowledge. Abundance knowledge, however, has lagged significantly (Fig. 1). Here we give an overview of major abundance efforts for odonates (summarized in Table 1) and the strong contribution of volunteers ranging from amateur naturalists to career biologists. Nearly all the records information in Table 1 and summarized below comes from the adult stages.

Europe

The Netherlands is home to the world's largest odonate abundance campaign. Since the early 19th century, tens of thousands of Dutch citizens have opportunistically contributed over three million odonate records totaling over 25 million individuals. Data are validated by experienced volunteers and conservation professionals through online data-sharing platforms (https://www.waarneming.nl, https://www.ndff.nl/overdendff/). In 1999, the government-funded Dutch Dragonfly Monitoring Scheme began an initiative collecting standardized abundance data across 500 transects to estimate national population trends, with a focus on species listed by the European Union's Habitats Directive. As of September 2019, the Scheme had documented about 281,000 records (unique species-transect-count combinations), counted more than 2.8 million individuals, and over recent decades indicated a strong abundance recovery nationwide (Termaat et al. 2015).

Odonata citizen scientists have been active in the United Kingdom, with nearly 13,000 people contributing over time, especially during 1996–2014 (includes Ireland as well; Cham et al. 2014). The British Dragonfly Society coordinates and curates the data collection, including the nearly 1.3 million records (as of September 2019) in the National Biodiversity Network Atlas (http://www.nbnatlas.org). Yet only about 2% of these contain counts of individuals, despite the Society using abundance to help identify priority sites and viable breeding populations. During 2009–2012, the Society piloted the British Dragonfly Monitoring Scheme, a transect approach to derive population indices following the Dutch scheme. However, difficulties with volunteer recruitment and retention, combined with disagreements over the accuracy of count data, led to the scheme being discontinued in favor of species lists and occupancy modelling approaches.

Odonata abundance is also being recorded in the Czech Republic, France, Germany, Spain, and Sweden (Table 1). In the Czech Republic, volunteers usually count individual odonates (https://www.biolib.cz), and recent monitoring (2016–2018) by the national Nature Conservation Agency (https://www.portal.nature.cz) added a significant boost to the abundance records. In France, a complex network of organizations, programs, and naturalist groups has built a large opportunistic records database (http://www.insectes.org) and launched a project aimed specifically at assessing national population trends (http://steli.mnhn.fr). Germany maintains a large odonate distribution atlas (Brockhaus et al. 2015) compiled by the GdO (dragonfly society of German-speaking Odonatologists) across 89 organizations and 2,900 contributors; however, fewer than half of the ~1.2 million records include counts of individuals. Several regions of Spain have published distribution atlases driven mainly by volunteers, with count data available for Catalonia (https://www.oxygastra.org) and ongoing projects in Andalusia, Galicia, Valencia, and the Balearic Islands. Most observations in the Swedish database (https://www.artportalen.se/) come from volunteers (5,635 people) and contain counts of individuals, with over 45,000 standardized abundance records found in select jurisdictions (Östergötland county and Scania province).

North America

Odonata abundance counting in North America is limited overall, but strong in selected provinces and states (Table 1). The Migratory Dragonfly Partnership (http://www.MigratoryDragonflyPartnership.org) and Pond Watch (http://www.PondWatch.org) initiative provide an ongoing multinational citizen program focused on North America's major migratory species. However, this amounts to barely 1% of the continent's 400 dragonfly (Odonata: Anisoptera) species, and efforts to record abundance have been sparse (Table 1). The United States accounts for most (92%) of the more than 300,000 records stored in Odonata Central (Abbott 2006-2019), but numeric count data have largely been confined to a few state-based programs (Table 1). Some datasets are extensive but not yet digitized, such as a long time series of structured (transect-based) abundance surveys led by the Northern Virginia Audubon Society.

Some of the most active citizen science for North American odonates has occurred in eastern Canada (Cannings 2019). The Ontario Odonata Atlas includes abundance observations in over 60% of nearly 100,000 total records (Table 1). The Atlantic Dragonfly Inventory Program contains over 21,000 records, approximately 62% of which contain abundance information (Table 1). Interest in odonates is seen elsewhere in Canada (British Columbia's *Living Landscapes* project, Entomofaune du Québec, Manitoba Dragonfly Survey) but lags compared to butterflies, and knowledge of abundance could be improved for virtually all odonate species nationwide (Acorn 2017, Cannings 2019).

Africa

Africa has two major databases for odonates: OdonataMAP (Loftie-Eaton et al. 2018) and the Odonata Database of Africa (Kipping et al. 2009). OdonataMAP has logged over 90,000 photographic citizen-science records from 32 countries, mostly (>90%) from South Africa (Loftie-Eaton et al. 2018), but no abundance information. The Odonata Database of Africa currently stores close to 135,000 records, of which about 84,000 (62%) contain abundance information (Table 1). Most of the records come from the southern African region, led by South Africa (20%), Namibia (7%), Botswana (5%), and Zambia (5%); from the Democratic Republic of the Congo (5%) and Uganda (4%) in Central and East Africa; and from Gabon in West Africa (9%).

Caveats and grey areas

Table 1 ignores locations with extensive occurrence records but scarce abundance data (e.g. Mexico, Japan, Singapore, Taiwan), and so the overall proportion of abundance records is much smaller than shown. Furthermore, many of the "abundances" are not standardized (i.e., number of individuals per unit effort) and therefore may not help in estimating relative population sizes and abundance trends or would need sophisticated computational methods (e.g. Zipkin and Saunders 2018) to leverage the information. There also is variability in data access, with some sources open and freely available and others publicly inaccessible or requiring fees. For these reasons, and due to large information gaps (Fig. 1), far more geographic coverage, data points, standardization, and integration will be needed for a global perspective on odonate abundance.

The world map shows large grey areas (Fig. 1), much of it short on taxonomic descriptions and keys (so-called "Linnaean shortfall" Cardoso et al. 2011). South America, for example, supports high Odonata richness and mostly lacks identification tools required for citizen science. Yet manuals have been appearing (e.g. Lencioni 2017, Bota-Sierra et al. 2019) and valiant efforts are underway by researchers and a growing volunteer base to document distributions and abundance in the vast and rugged Brazilian Amazon and Cerrado regions (Fig. 2a-b). Many well-illustrated field guides have appeared over the past decade in Odonata-rich tropical Asia and Australasia, although with exceptions like Australia, Hong Kong, Japan, New Zealand, Singapore, and Taiwan, an acute lack of distribution knowledge ("Wallacean shortfall"; Cardoso et al. 2011) remains. Engaging bases of strong Odonata enthusiasm in Asia and South America is a priority moving forward.

Moving forward

A successful global abundance initiative obviously requires coordination and many dedicated volunteers to motivate, shape, and implement the project. Borrowing from the butterfly experience, this section outlines basic plans and infrastructure towards global volunteer monitoring of odonate abundance (Fig. 3). Our aim here is to spark interest and discourse on the approach and issues while leaving many details open for future discussions among Odonata enthusiasts, students, and researchers; general entomologists and naturalists; and interested conservation biologists, social scientists, data scientists, and others.

Organizational structure

Many large-scale monitoring schemes have worked well without being highly centralized or fueled by major funding (Cardoso and Leather 2019). A good example and strong model for odonates is the North American Butterfly Monitoring Network (https://www.thebutterflynetwork.org/) launched in 2012. The network is a conglomeration of many butterfly projects, programs, committees, and organizations along with individual lepidopterists, informatics experts, and downstream data users. Its goals are to track and consolidate North American butterfly recording efforts, standardize protocols and data sharing, recruit and train volunteers, and develop computational tools. The network has improved knowledge of not only butterfly geographical distributions but also their relative population sizes across years and the effects of large-scale environmental change.

The proposed initiative could benefit from having a central base of operations, an institution stepping forward with international reach and experience building extensive citizen networks (e.g. Cornell Lab of Ornithology, The Xerces Society for Invertebrate Conservation). With or without a dedicated institution, the implementation (outlined below) will require: (1) a core group of leaders/organizers, (2) coalitions and coordination across regional or national levels. Arguably the hardest work and greatest achievement of the North American Butterfly Monitoring Network has been in uniting many regional and national entities that historically operated independently of each other (Taron and Ries 2015). International collaboration seems critical for standardization to minimize sampling effects (Dickinson et al. 2010) and enable global inference. The initiative should further aim to maximize the quality of participation, allowing members of the public to serve as collaborators and co-creators and not just data contributors (Shirk et al. 2012, Ries and Oberhauser 2015).

Advertising and recruiting

Once the data collection and submission protocol (discussed below) are in place, a massive outreach campaign (Fig. 3) will be needed to promote awareness and engage volunteers across continents, regions, nations, or even smaller jurisdictions. We should advertise through social media platforms and the many Odonata societies and reach out to entomological and ornithological (many odonate enthusiasts are also birders) organizations that maintain vast citizen networks, such as Birds Canada and Britain's Buglife. A dedicated project website should help along with social opportunities to stimulate elements of fun, pride, inclusion, and (healthy) competition. For example, holding an annual event in desirable locations (e.g. the Algonquin Odonata Count held annually since 1996 in Algonquin Provincial Park, Ontario, Canada) or during a culturally and biologically significant time, such as the July 4th U.S. Independence Day celebration when flight activity is at or near peak for many species and people are gathered at lakes and other prime odonate sites. Such events could be modelled after the North American Butterfly Association's counts program (https://www.naba.org) and the Audubon Society's Christmas Bird Count, which supplied data crucial to documenting a nearly 30% decline since

1970 in the total North American avifauna (Rosenberg et al. 2019). For added capacity, the abundance campaign should coordinate with active citizen-science Odonata projects (e.g. Pond Watch) and professional biodiversity surveys and monitoring networks, such as the U.S. Long Term Ecological Research Network, National Ecological Observatory Network, and Natural Heritage Network (Groves et al. 1995, Huang et al. 2020).

Data collection

In the pursuit of a universal or broadly applicable methodology for standardized volunteer-friendly odonate counting, we must look to the successes, challenges, and failures of past and present odonate abundance efforts. Equally important will be consultation of other broad-based initiatives and protocols, especially for butterflies (Taron and Ries 2015, van Swaay et al. 2015). There are many challenges to volunteer-based standardized insect surveys (Weiser et al. 2020). Here we cover a few key design elements as a starting point to more robust and detailed planning of data collection (Fig. 3).

The field protocol needs to be simple and flexible, designed to generate a large sample size and monitor trends, as in Pollard-style butterfly surveys (Pollard 1977, Taron and Ries 2015). Robust trends monitoring requires multi-year, effort-standardized data (Montgomery et al. 2020, Wagner 2020) and so volunteers would, at minimum, count odonates on a single within-year visit to a fixed locality and repeat the survey, preferably in consecutive years. Repeat annual surveys ideally should occur during peak times of diel and seasonal activity and abundance, at approximately the same time of year while being mindful of progressively shifting seasonal phenology due to climate change (Didham et al. 2020). At least 10 years, preferably 15 or more, may be needed to overcome false baseline and snapshot effects and detect non-random trends in abundance (Fournier et al. 2019, White 2019, Didham et al. 2020).

Ideally counting will occur along fixed transect routes using a small detection window to improve detections (i.e., Pollard walk), at or immediately adjacent to water, controlling for habitat differences either by stratifying the counts or staying in a single habitat type. Although true random sampling is rarely possible for citizen science surveys, stratification will help account for site-selection bias and nonrandom placement of transects (Fournier et al. 2019, Weiser et al. 2020). The next best approach to transects or fully structured Pollard walks is keeping track of survey durations and other pertinent features that vary among data-collection events (e.g. start time, ambient temperature). Counting should aim at whole numbers and secondarily at numeric categories or ranges (e.g. 1–5, 6–20, 21–100, >100 individuals; Bried et al. 2015). Enumerating species by sex (male/female), age (teneral/post-teneral), pairs (tandem or mating), and oviposition attempts can be done and would help distinguish resident from immigrant abundance records (Patten et al. 2019). Ultimately, standardized counts do not give a true population estimate but generally suffice for indexing changes and patterns in relative abundance to ascertain where populations are declining and to what degree (Schmucki et al. 2016).

In general, adults will have to be targeted because Odonata citizen science typically avoids non-adult stages (larvae, exuviae) that require more work to sample and identify. Adult surveys can greatly improve species-level inventories compared to larval samples (Bried and Hinchliffe 2019), and in many cases adults are counted with ease (Moore 1991, Suh and Samways 2005). Although frequently on the move, their local abundance provides a means of correcting for their vagrancy (Bried et al. 2015, Patten et al. 2019), and rather than track specific localities we would analyze numerous records aggregated over the biosphere or very large areas (continents, biomes).

Adults of some species cannot be identified without capture, others exhibit elusive behavior (flying too swiftly or at dusk, spending too much time over open water or up in tree canopies, etc.), and many regions still have undescribed species or lack user-friendly identification tools. Even readily observed and easily identified species may become difficult to track and enumerate during peak activity in locally diverse assemblages, or when they congregate in large numbers (Fig. c-d) due to mass emergence, swarm feeding, and migration events. There is heightened risk of overlooking or miscounting rarer species and those of conservation significance belonging to mixed populations of similar looking species, although sometimes hand-net samples of confusing species mixes can be prorated to the relative numbers of each species in the total visual count. Volunteers will have to try their best to count everything they reliably can, with as rough numbers as necessary in overwhelming situations. Unidentified individuals should still be separated and counted to the extent possible (such as “8 Sp. A and 37 Sp. B”, “8 *Aeshna* and 37 *Enallagma*”, or “45 unidentified”), avoiding spurious zeros and facilitating total abundance and higher taxonomic level analyses.

Data submission

We should adhere to the FAIR (findable, accessible, interoperable, reusable; Wilkinson et al. 2016) principles for data submission and reporting (Fig. 3). Funding to build custom systems and technical support is difficult to find and even harder to maintain, so using an established biodiversity monitoring data portal (e.g. BioTIME; Dornelas et al. 2018) is the most realistic option for any new citizen science initiative. However, mature biodiversity platforms for managing observation data generally are designed for opportunistic records and not structured or semi-structured survey programs (Kelling et al. 2019). The few portals that do support more organized data collections tend to either be very program-specific (e.g. Breeding Bird Surveys, the many European butterfly monitoring schemes) or entirely generic but able to adapt to individual protocols (e.g. http://www.CitSci.org).

Reporting abundances even as corollary information to an occurrence record is not straightforward or allowable in most portals (Ball-Damerow et al. 2019). In fact, the most useful reporting feature will allow users not only to enter abundances but also indicate whether they have included every species they observed on their trip, as this allows distinguishing presence-only vs. presence-absence data which has substantial implications for the types of analyses possible (Zipkin and Saunders 2018). With exceptions like eBird (Sullivan et al. 2009), eButterfly (http://www.e-butterfly.org), and Observation.org (https://www.observation.org), most biodiversity platforms, including major Odonata databases, do not allow users to indicate whether everything observed was reported.

The data management system will need to align with the semi-structured protocol (Kelling et al. 2019) and support detailed information on effort including the exact route surveyed, detection window, and time spent on the survey (see ‘Data collection’). To this end, PollardBase (https://www.pollardbase.org) offers a useful platform that can be adapted for odonates (Doug Taron, The Chicago Academy of Sciences, Illinois, USA, personal communication, March 2020). PollardBase is built specifically around Pollard surveys and therefore accommodates information about the route and survey event (habitat, effort, conditions, etc.) and not just the butterfly observations. It was designed for flexibility across a network of various monitoring schemes (https://www.thebutterflynetwork.org) and to unify them into a maintainable structure (Taron and Ries 2015). Having a unified flexible platform should help to coordinate standardized odonate abundance monitoring across regions and projects (Table 1). Perhaps the greatest barrier, based on the butterfly experience, will be finding a home institution and sustained funding for long-term stability (Cardoso and Leather 2019, Kelling et al. 2019).

Data synthesis

The eventual challenge will be to integrate the accrued data towards a large-scale synthesis of odonate species abundances (Fig. 3). Data scientists from outside the Odonata sphere will be needed to help analyze and visualize the abundance patterns and trends. This could start by using available standardized abundances (Fig. 1, Table 1) and first-year monitoring data to explore and potentially optimize sampling schemes for trends estimation (Callaghan et al. 2019, Weiser et al. 2019). Statistical methods and computational tools have advanced rapidly (Freckleton et al. 2020) and we will need to be on the cutting edge of approaches for large and complex datasets. We hope the proposed initiative opens new ideas, collaborations, and funding bids to support technical and synthetic activities like data integration and meta-analyses.

Conclusion

Insect population abundances are often poorly known yet must be prioritized for assessing global insect trends moving forward (Cardoso and Leather 2019, Sánchez-Bayo and Wyckhuys 2019, Didham et al. 2020, Harvey et al. 2020, Montgomery et al. 2020). Given the dearth of abundance data, especially *standardized* abundance data, it is no surprise that open-access biodiversity databases are mined predominantly for taxonomic purposes and distribution records (Ball-Damerow et al. 2019). To be clear, we are not advocating for an overhaul of

Odonata citizen science, but rather are encouraging an expanded focus on abundance and a more coordinated response at a critical time for insect conservation (Samways 2020). We see abundance as bonus information that flows from an already strong recording effort, and something to further stimulate the volunteer's sense of purpose and accomplishment.

An army of amateur naturalists may contribute far more data than a small cadre of professional observers (Ries and Oberhauser 2015). Citizen science promotes biophilia while contributing enormously to understanding large-scale biodiversity loss and environmental change, especially in developing or transitioning regions (Braschler 2009, Loos et al. 2015). Even if a globally small percentage of enthusiasts becomes committed to standardized abundance counting, or if those counts comprise a similarly small percentage of the global submitted records, it will be far more information than we have now. Moreover, when counting becomes difficult (e.g. Fig. 2c-d) or where abundance data reach insufficient quantity or quality, the background occurrence data will still be available and potentially useful.

The authors collectively have centuries of experience watching dragonflies and damselflies, and many of us have observed local declines (e.g. Córdoba-Aguilar and Rocha-Ortega 2019) at least anecdotally. Aquatic insects may not actually be facing widespread decline (van Klink et al. 2020), but with variation geographically and by species this is difficult to infer at large scales (Saunders et al. 2020), which is exactly where citizen science is needed. Through a global network of volunteers, and by exploiting novel computational approaches and emerging technologies like entomological radar (Didham et al. 2020, Montgomery et al. 2020), we can acquire a better understanding of odonate abundance, thereby curtailing the Prestonian shortfall for insects in general and helping us safeguard insect diversity into the future.

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Table 1. A global representation of dragonfly and damselfly (Odonata) abundance counts as of Fall 2019. Abundance records consist of whole number counts or, when indicated by an asterisk (*), numeric categories/ranges. Most records (95–99%) are from observing adult stages.

Location	Project or Database	Survey type	No. total records	No. abundance records
Europe				
Czech Republic	BioLib	opportunistic	7,855	6,283*
	Nature Conservancy Agency	standardized	21,661	10,455
France	French National Inventory of Odonata	opportunistic	631,469	21,149
	Temporal Monitoring of Dragonflies	standardized	21,426	20,149
Germany	GdO (compilation of all data in Germany)	opportunistic	1,167,782	~79,200 ~512,300*
Netherlands	National Database for Flora and Fauna	opportunistic	3,234,062	3,220,187
	Dutch Dragonfly Monitoring Scheme	standardized	280,940	~280,940
Spain	Seguiment de les libèllules de Catalunya	standardized	29,276	~12,700
	Atlas of Odonata of Galicia	opportunistic	15,533	7,396
Sweden	Artportalen, Species Observation System	opportunistic	169,860	93,039
	Provincial and county surveys	standardized	45,898	45,898
United Kingdom	British Dragonfly Society Recording Scheme	opportunistic	1,279,682	<25,600
	British Dragonfly Monitoring Scheme	standardized	84,265	~84,265
North America	Migratory Dragonfly Partnership / Pond Watch	standardized	55,000	574
Canada	Atlantic Dragonfly Inventory Program	opportunistic	21,591	≥13,294*
	Ontario Odonata Atlas Database	opportunistic	96,080	61,386

United States	Maine Dragonfly & Damselfly Survey	opportunistic	15,803	≥8,755*
	New York Dragonfly & Damselfly Survey	opportunistic	19,434	9,126*
	Oklahoma Odonata Project	opportunistic	55,288	33,729
Africa	Odonata Database of Africa	opportunistic	134,756	84,313

LIST OF FIGURES

Figure 1. Amalgamation of current distribution and trend (standardized abundance) data for dragonflies and damselflies (Odonata). *Grey* – no large publicly available distribution database, identification tools lacking, and minimal citizen participation; *Light green* – publicly available distribution database(s) but generally limited citizen participation and/or identification tools; *Green* – extensive distribution data and citizen participation but generally lacking trends data (see Table 1); *Dark green* – extensive distribution and trends data and citizen participation.

Figure 2. a-b) Training citizen scientists in the Brazilian Amazon to assess stream quality using dragonflies and damselflies (Odonata) and other bioindicators (photos by CEPAM/icmbio). For more information visit: http://www.icmbio.gov.br/portal/monitoramento-2016/programas-de-monitoramento-da-biodiversidade-em-ucs. c-d) *Aeshna mixta* resting and swarming in extremely high numbers in southwestern Ukraine on August 8, 2006 (photos by E. Dyatlova and V. Kalkman).

Figure 3. Proposed infrastructure for moving forward on global volunteer monitoring of dragonfly and damselfly (Odonata) abundance.

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