A Conservation Status Assessment of Odonata for the Northeastern United States

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Executive Summary

Odonates are valuable biological indicators of freshwater ecosystem integrity and climate change. Approximately 18% of odonates in the US are considered rare and vulnerable to extirpation or extinction. Northeastern North America hosts a rich and ancient odonate fauna, especially for a temperate region. Recognition of northeastern North America as both a hotspot of odonate diversity, and a region of historical and growing threats to freshwater ecosystems, highlights the urgency of developing a comprehensive conservation assessment of the Northeast's resident odonate species.

Here, we develop and apply a prioritization framework for 228 species of dragonflies and damselflies occurring in the northeastern US (Virginia to Maine). Specifically, we offer a modified version of NatureServe's methodology for assessing conservation status ranks by assigning a single, regional vulnerability metric (R-rank) reflecting each species' degree of relative extinction risk in the northeastern US. We combine this newly formulated vulnerability assessment with an updated analysis of the degree of endemicity (% of the species' US and Canada range within the Northeast) as a proxy for regional responsibility, thereby deriving a list of species of combined vulnerability and regional management responsibility. In so doing our goals are two-fold: a) to develop a credible list of odonate species of conservation concern in northeastern North America, and more generally, b) to invite scrutiny of a science-based species prioritization methodology that might be applied to assess other diverse taxa that have not yet received adequate conservation attention.

We compiled all confirmed, county-level odonate data from all years. This dataset contained 248,059 records, with data from all NEAFWA states. We calculated a single vulnerability rank (R-rank) based on five factors: three rarity factors (range extent, area of occupancy, and habitat specificity), one threat factor (vulnerability of occupied habitats), and one trend factor (relative change in range size). This yielded a regional vulnerability rank (R-rank) for each species, ranging from R1 (most vulnerable) to R5 (least vulnerable). We calculated regional responsibility as the proportion of the US & Canadian range occurring within the Northeast US. Odonate species fell into three categories based on their responsibility calculation: "Primary" responsibility species were those for which ≥50% of their range fell in the Northeast; "Significant" responsibility species were those for which 25-50% of their range fell in the Northeast; and "Shared" responsibility species were those for which <25% of their range fell in the Northeast. We created a matrix of species in three vulnerability categories (High: R1 and R2, Medium: R3, and Low: R4 and R5) and three responsibility categories (Primary, Significant, and Shared). We also present results on habitat associations for northeastern Odonata along with all metric components of our conservation assessment. Overall, 18% of our region's odonate fauna is imperiled (R1 and R2) and peatlands, low gradient streams and seeps, high gradient headwaters, and larger rivers that harbor a disproportionate number of these species should be considered as priority habitat types for conservation, monitoring, and management.

We recommend that our assessment be used to inform the strategic allocation of limited state and federal conservation resources and help foster collaborations across state lines to implement similar goals for conserving regionally at-risk Odonata. We also anticipate our products will help guide and standardize conservation assessments of Odonata, and potentially other invertebrate taxa, at the statewide level in the Northeast. Finally, we recommend that a regional Odonata conservation working group be formed to help guide protocols for surveys,

monitoring, research, habitat protection, and education, and thereby develop a framework for a coordinated comprehensive conservation plan for northeastern Odonata.

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Introduction

Relative to their geographic extent across the earth's surface (<1%), freshwater ecosystems host a disproportionate number (~10%) of described animal species, a fauna that is dominated by aquatic macroinvertebrates (Strayer and Dudgeon 2010). Due to their frequent proximity to human population centers and simultaneous exposure to aquatic, terrestrial, and atmospheric pollution, freshwater ecosystems in the United States are already impaired and demonstrate symptoms of stress due to a host of anthropogenic threats (Strayer 2006, Martinuzzi *et al.* 2013). In North America, this has translated into significantly greater rates of endangerment and extinction for freshwater taxa compared to terrestrial fauna (Ricciardi and Rasmussen 1999, Wilcove and Master 2005). While freshwater species and habitat declines are less formally documented in most areas of the world, endangerment in North America is especially disturbing in light of the high global richness and endemism of the freshwater fauna found here (Stein *et al.* 2000).

One relatively well-studied and diverse group of aquatic invertebrates in North America is the Odonata (Damselflies and Dragonflies), an order comprised of 462 species in the US and Canada (Paulson 2011). Approximately 18% of odonates in the US are considered rare and vulnerable to extirpation or extinction (Master *et al.* 2000). International threats to Odonata are also well documented, with the order represented on the Red List of Threatened Species (IUCN 2013), though at a relatively lower proportion (~10%) than for some other freshwater groups (e.g., ~30% of amphibians) (Clausnitzer *et al.* 2009). Among insects with life histories that traverse aquatic and terrestrial boundaries, odonate (larvae and adults) biomass and densities can be exceptional, underscoring the ecological importance of Odonata as predator and prey (Bried 2005). Odonates are also valued as biological indicators of freshwater ecosystem integrity (Corbet 1993, Clark and Samways 1996, Stewart and Samways 1998, Kutcher and Bried 2014) and climate change (Hassall and Thompson 2008, Bush *et al.* 2013) because they exhibit: a) complex life-histories requiring aquatic habitat as larvae and riparian and upland areas as adults, b) diverse species assemblages with varied tolerances for aquatic pollution, and c) large size and diurnal behavior, facilitating detection and observation by members of the scientific community, and increasingly, the general public. Thus, the loss of odonate species, or even the decline of locally robust odonate populations, is likely to have functional ripple effects in surrounding ecosystems.

Northeastern North America hosts a rich and ancient freshwater invertebrate and odonate fauna, especially for a temperate region (Master *et al.* 1998, Collen *et al.* 2014, Corser *et al.* 2014). Among Odonata, this is exemplified by larger species lists in most northeastern states than in all of Europe combined (Kalkman *et al.* 2008) and indeed even of many southeastern US states of lower latitude, an important anomaly of historical biogeography (Corser *et al.* 2014). Furthermore, coastal New England is recognized as one of four regions of exceptional conservation significance for odonate biodiversity in North America due mainly to the restricted distribution of several damselflies (Genus *Enallagma*) (Dunkle 1995) and the recent explosive endemic radiation of Gomphidae dragonflies (Corser *et al.* 2014). Significantly, northeastern North America also has an early history of European colonization, one of the highest per capita population densities on the continent, and continues to experience human population growth and habitat degradation (Foster *et al.* 2002, Sanderson *et al.* 2002) with potentially negative impacts on Odonata and freshwater ecosystems.

Recognition of northeastern North America as both a hotspot of odonate diversity, and a region of historical and growing threats to freshwater ecosystems, highlights the urgency of developing a comprehensive conservation assessment of the Northeast's 228 resident odonate species. A first attempt at this was effectively conducted in 2005 when all 50 US states and all inhabited US territories (6) met a congressional mandate to develop state wildlife action plans (SWAPs). The overarching goal of the SWAP program is to prevent wildlife from becoming listed as endangered or threatened, or declining to levels where recovery becomes unlikely. Toward this end, a required element of every SWAP is a list of state Species of Greatest Conservation Need (SGCN) – generally, those species with rare or declining populations, and other characteristics that make them particularly vulnerable to extirpation. While several existing international (e.g., IUCN; NatureServe) and taxa-specific (e.g., Partners for Amphibian and Reptile Conservation [PARC]; Partners in Flight [PIF]) models exist for guiding US species conservation priorities, the development of SWAPs, and associated SGCN lists offers a potentially comprehensive wildlife conservation prioritization scheme while leveraging access to natural resource professionals and funding for at-risk wildlife.

While laudable, the first iteration of assigning species to SGCN lists involved highly variable, often subjective, criteria. As a result, nearly 2/3 of all Odonata species in the US, and approximately 87% in the Northeast, were included on at least one state SGCN list. Determining regional conservation priorities from state-level SGCN lists within the region is therefore challenging. To illustrate the variability taken in listing SGCN odonates: Alaska listed 100% of its odonate fauna, while 15 states listed none at all (Bried and Mazzacano 2010).
These inconsistencies and lack of a quantifiable, repeatable prioritization approach - coupled in many cases with large species distributions in the eastern US - highlights the value of assessing diverse invertebrate taxa at a regional scale, helping to reduce edge-of-range effects and less parochial estimates of rarity. Additionally, transparent, science-based criteria for identifying regionally high priority species targets can better meet the spirit of the SWAP program by helping inform the strategic allocation of limited state and federal conservation resources while fostering inter-state collaboration. Meaningful conservation actions for freshwater taxa are coincidentally often best undertaken at the regional scale, where watersheds and catchment basins form natural boundaries, frequently crossing over political jurisdictions (Master *et al.* 1998, Samways 2007, Collen *et al.* 2014).

The critical importance of prioritizing the imperiled elements of freshwater habitats for conservation action was highlighted in Strayer & Dudgeon's (2010) insightful review, and the field of conservation biology has fostered many attempts at tackling large regional faunas in this way (Vane-Wright *et al.* 1991, Freitag and Van Jaarsveld 1997, Hansen *et al.* 1999, NEPARC 2010), including Odonata (Patten and Smith-Patten 2013, Simaika *et al.* 2013). Yet, to date there has not been an accepted standardized methodology that can be applied to a wide array of taxa regardless of location or scale of inquiry. Here, we develop and apply a prioritization framework for 228 species of resident (breeding) dragonflies and damselflies occurring in the northeastern US (Virginia to Maine). Specifically, we develop and apply a modified version of NatureServe's methodology for assessing conservation status ranks (NatureServe 2012) by assigning a single, regional vulnerability metric (R-rank) reflecting each species' degree of relative extinction risk in the northeastern United States.
We combine this new vulnerability assessment with an updated analysis of the degree of endemicity (% of the species' US and Canada range that falls within the Northeast) as a proxy for regional responsibility, thus deriving a list of species of combined vulnerability and regional

management responsibility. In so doing our goals are two-fold: a) to develop a credible list of odonate species of conservation concern in northeastern North America, and more generally, b) to invite scrutiny of a science-based species prioritization methodology that might be applied to assess other diverse taxa that have not yet received adequate conservation attention.

Methods

Study area

The study area for this northeastern US region-wide conservation assessment of Odonata comprises states and districts belonging to the Northeastern Association of Fish and Wildlife Agencies (NEAFWA) including CT, DE, DC, MA, ME, MD, NH, NJ, NY, PA, RI, VA, VT, and WV. See Anderson and Olivero Sheldon (2011) for a full treatment of broad ecological patterns in this region.

Project participants and their roles

Over 40 participants developed the data associated with this report. Participants were classified into one or more of the following roles: Steering Committee, Advisor, Collaborator, or Workshop Participant (see full list of participants at end of report). The steering committee, comprised of the authors of this manuscript, performed the data compilation, project coordination, conservation assessment, and reporting. Advisors provided feedback on the project schedule and timeline and technical feedback on the prioritization matrix, assessment methodology, and handling of various taxa in the analysis. Our collaborators were those representatives from the northeastern states who compiled records for use with this project. Workshop participants were those individuals who provided feedback on draft products at a project workshop in June 2013. In addition, there were countless contributors who completed Odonata surveys in the Northeast and submitted records that would later be confirmed and included in this study by collaborators.

Data compilation and taxonomy

We worked with at least one collaborator from each of the aforementioned states to compile all confirmed, county-level odonate data for their jurisdiction from all years (Table 1). Our assessment was conducted at the county level because this was the finest common scale available for all records from participating states. New York Natural Heritage Program (NYNHP) staff compiled these diverse datasets into a single Microsoft Access database containing species name, county, state, year, voucher type (e.g., specimen, photo), and source information. Most records were based on the adult life stage which most surveys targeted, but we also included larval and exuvial records. We relied on the collaborators to determine the validity of records, with the understanding that only confirmed records should be included. In addition to state representatives, we obtained distribution data for the US and Canada for northeastern species from Odonata Central (Abbott 2007-2014). When the exact year of a record was unknown, we assigned a broad category (e.g., “post-1970”, “pre-2005”) or “unknown.” We chose a cut-off of 1970 for historical vs. current records, as this was NatureServe’s standard cut-off used for Odonata.

We performed quality control on the dataset and removed records for species that our Advisors assessed as probable vagrants to the region (*Coryphaeschna ingens*, *Lestes vidua*, *Miathyria marcella*, *Orithemis ferruginea*, *Sympetrum corruptum*, *Tramea abdominalis*, *T. calverti*, *T. onusta*, *Triacanthagyna trifida*). We initially followed Paulson (2011) for taxonomy and then collapsed nearly all subspecies designations to species level (*Argia fumipennis*, *Cordulegaster obliqua*, *Enallagma traviatum*, *Macromia illinoiensis*, *Ophiogomphus incurvatus*, *O. mainensis*). *Gomphus septima* was separated to subspecies for conservation reasons explained later in the results section. We refer to all taxa in our assessment as "species" for simplicity.

Due to variation within the region in recognition of the species *Sympetrum janeae*, we recognized all *S. janeae* records as *S. internum,* as advised by our collaborators. As Connecticut records for *S. internum* and *S. rubicundulum* could not be separated by species, we included all "*Sympetrum internum* or *rubicundulum"* records for mapping distributions of both species. We removed all hybrids and records with uncertain or unconfirmed identifications from the dataset, including potential new records for the region for *Ophiogomphus edmundo* and *Gomphus dilatatus*.

Table 1. Databases used in the conservation assessment.

State	Data Source
CT	Thomas, M. C. and D. L. Wagner. 2014. The Odonata Fauna of Connecticut. County and Flight Records. http://ghostmoth.eeb.uconn.edu/dragons/records.pdf (accessed January 2014).
DE, MD, PA	White,H. 2012. Personal collection and field notes.
MA	Mass Audubon. 2012. Massachusetts Audubon Odonate Database. sanctuaryinventory@massaudubon.org. Lincoln, MA 01773.
MA	Massachusetts Natural Heritage & Endangered Species Program. 2010. Massachusetts element occurrence database. Massachusetts Division of Fisheries & Wildlife, West Boylston, MA.
MD	Maryland Natural Heritage Program. 2012. Database report for Select Rare, Threatened and Endangered Odonata of Maryland. Maryland Department of Natural Resources, Wildlife and Heritage Service, Annapolis, Maryland.
MD, DC	Orr, R. 2012. The Dragonflies and Damselflies of Maryland and the District of Columbia, Mid-Atlantic Invertebrate Field Studies (MAIFS) website. http://www.marylandinsects.com/MDDCOdonateRecords.html
ME	Maine Department of Inland Fisheries and Wildlife. 2012. Maine Damselfly and Dragonfly Survey (MDDS) Database. Bangor, Maine.
NH	New Hampshire Audubon. 2012. New Hampshire Dragonfly Survey database. New Hampshire Audubon and New Hampshire Fish and Game Department, Concord, NH.
NH	Hunt, P. 2012. Personal information.
NJ	New Jersey Odonata Survey. 2012. New Jersey dragonfly and damselfly survey database.
NY	Eib, D. 2013. Staten Island Dragonfly Atlas, 2009 - 2013. Staten Island Museum. Staten Island, NY.

State	Data Source
NY	New York Natural Heritage Program. 2010. New York dragonfly and damselfly survey database. New York State Department of Environmental Conservation. Albany, NY.
NY	New York Odonate Group. 2012. New county records database. Albany, NY
PA	Pennsylvania Natural Heritage Program. 2013. Element Occurrence Digital Data Set. Pennsylvania Natural Heritage Program, PA Department of Conservation and Natural Resources, Harrisburg, PA.
PA	Pennsylvania Natural Heritage Program. 2013. Pennsylvania Odonate Database. Pennsylvania Natural Heritage Program, PA Department of Conservation and Natural Resources, Harrisburg, PA.
RI	Brown, V. 2013. Rhode Island Odonata Atlas. Rhode Island Natural History Survey and The Nature Conservancy. Unpublished data.
VA	Roble, S. 2012. Unpublished database of Virginia Odonata county and city records. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, VA.
VT	Michael Blust and Bryan Pfeiffer. Personal information.
WV	Olcott, S. 2012. West Virginia dragonfly and damselfly atlas database. WV Division of Natural Resources, Wildlife Resources Section, Elkins, WV.
Multiple	Donnelly, T. W. 2004a. Distribution of North American Odonata. Part I: Aeshnidae, Petaluridae, Gomphidae, Cordulegastridae. Bulletin of American Odonatology 7:61–90; Donnelly, T. W. 2004b. Distribution of North American Odonata Part II: Macromiidae, Corduliidae, and Libellulidae. Bulletin of American Odonatology 8:1–32; Donnelly, T. W. 2004c. Distribution of North American Odonata Part III: Calopterygidae, Lestidae, Coenagrionidae, Protoneuridae, Platystictidae. Bulletin of American Odonatology 8:33–99.
Multiple	Paulson, D.R. 2012. Personal collection.
All	Abbott, J.C. 2007 - 2014. OdonataCentral: An online resource for the distribution and identification of Odonata. The University of Texas at Austin. Available at http://www.odonatacentral.org.

Regional vulnerability analysis

Regional vulnerability assessments for other US taxa have often focused on SGCN status (USFWS Wildlife & Sport Fish Restoration Program 2013) and NatureServe rarity ranks (Master *et al.* 2012) for each species in each northeastern state where it occurs (NEPARC 2010, Anderson and Olivero Sheldon 2011). However, since approximately 87% of northeastern US odonates are currently listed as SGCN in one or more states, we further refined our approach as suggested by Bried et al. (2010). We modeled our vulnerability assessment after the approach developed by NatureServe and the network of Natural Heritage programs (Master *et al.* 2012) for calculating global, national, and subnational (state and province) conservation status ranks. NatureServe's ranking methodology is a scientifically rigorous, transparent method for assessing vulnerability at a variety of spatial scales. Status ranks in the NatureServe methodology are derived from a suite of rarity, trends, and threats factors.

We calculated a single vulnerability rank (R-rank) based on five factors: three rarity factors (range extent, area of occupancy, and habitat specificity), one threat factor (vulnerability of occupied habitats), and one trend factor (relative change in range size) (Fig. 1). That 60% of our vulnerability assessment was composed of rarity factors mirrored the importance of rarity to the NatureServe rank calculation. Since species-specific information on threats was lacking, we evaluated threats for each species based on a professional assessment of vulnerability of habitat types in which a species typically breeds region-wide. Similarly, due to a lack of specific population trend information for each species, we used a surrogate metric for trend by calculating a relative change in range size for each species.

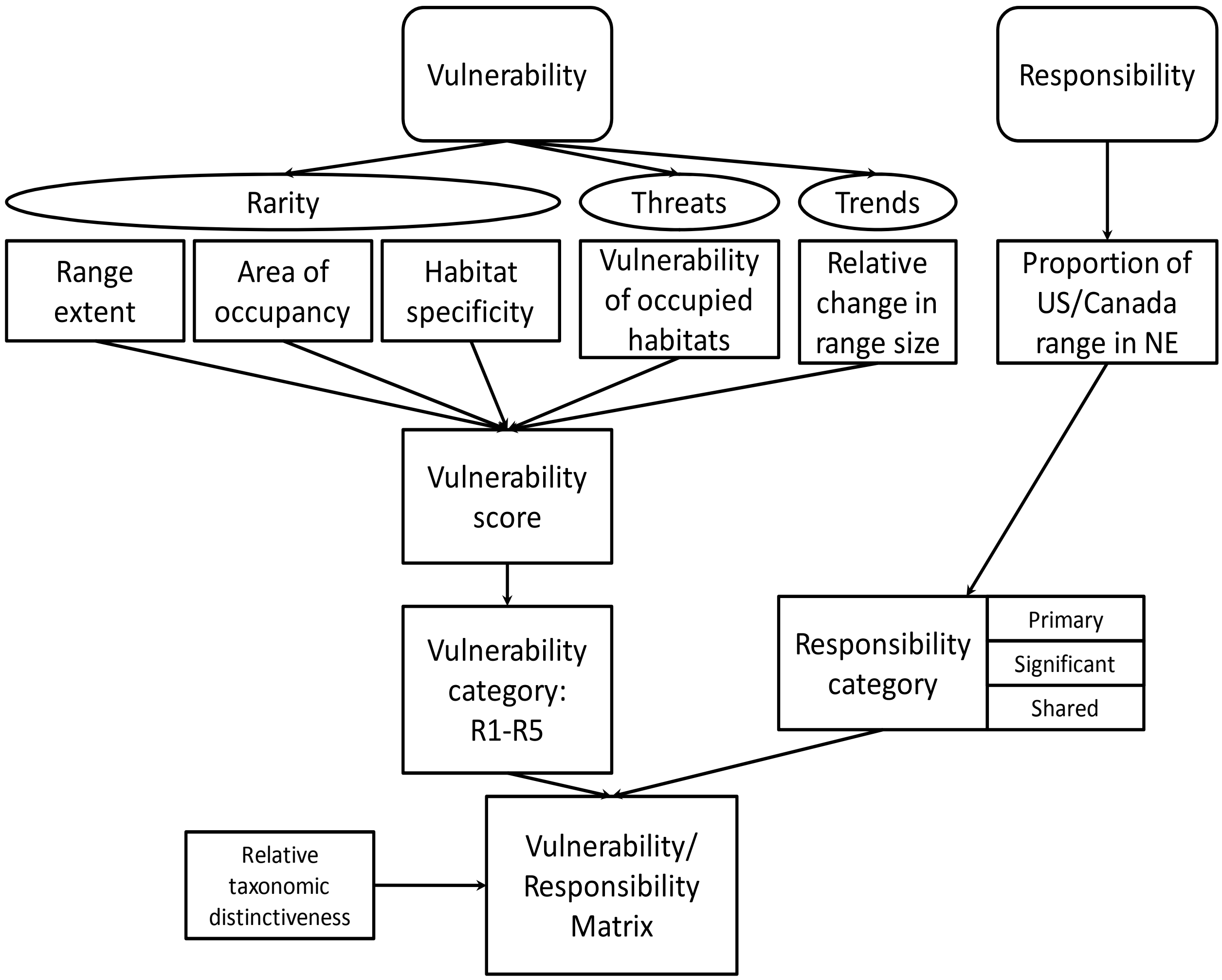

Figure 1. Schematic of conservation prioritization scheme for odonates of the northeastern US.

Rarity: Range extent

We calculated Northeastern range extent as the area in km^2 of a minimum convex polygon surrounding all occupied northeast US counties since 1970, using the gConvexHull command in the rgeos package (Bivand and Rundel 2013) in the R statistics software (R Development Core Team 2013). No records fell in the Atlantic Ocean or Great Lakes, but because of the shape and geography of the region, some species' polygons included large areas of those waterbodies, thereby inflating the size of their polygons, while other polygons had no such area. Therefore, we clipped out the ocean, Great Lakes, and study area boundaries from all minimum convex polygons (Fig. 2), using gIntersection, also in the rgeos package. We also calculated range extent based on all records for a species, including those that could not be assigned a date category, to accommodate the uncertainty surrounding records without dates. For this portion of the study, all GIS layers were projected to Albers Equal-Area (NAD 83) and area estimates were based on this projection.

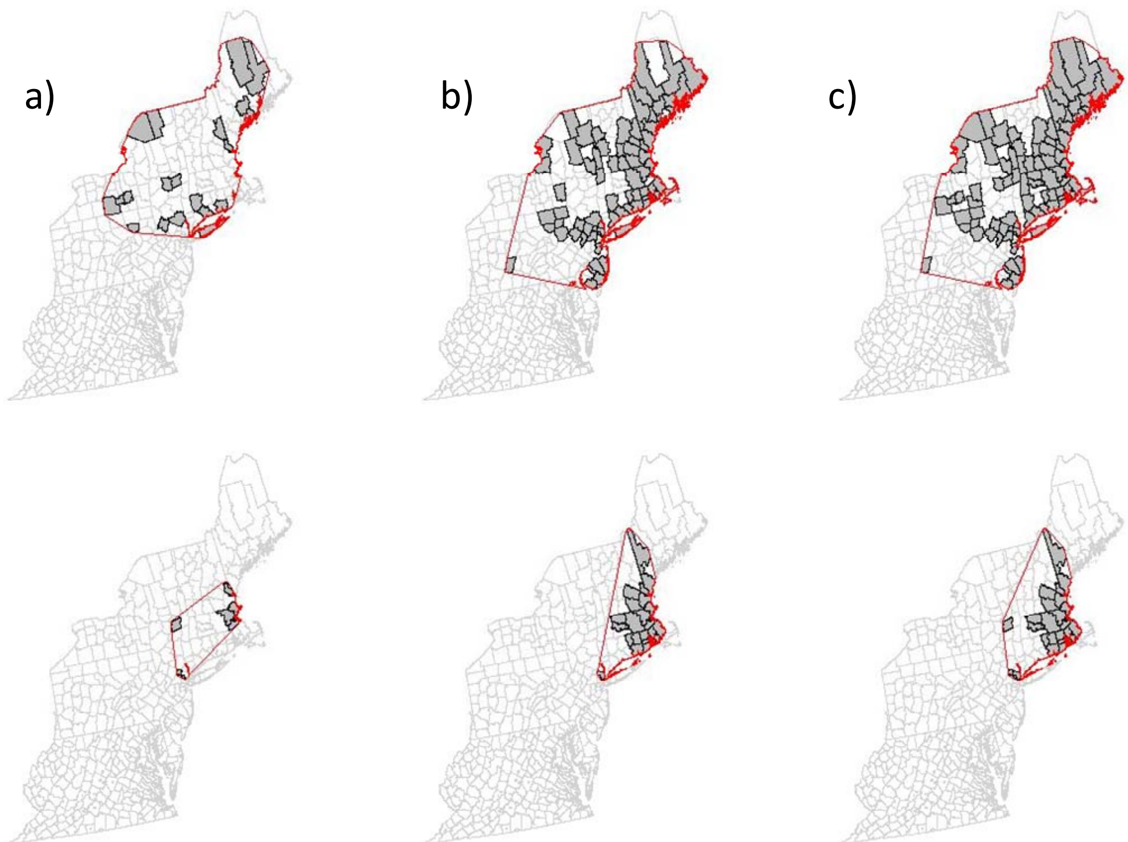

Figure 2. Example range maps of two species (top: *Aeshna clepsydra*; bottom: *Williamsonia lintneri*) with modified convex hull depicted in red. a) Counties with records prior to 1970; b) counties with records since 1970; c) all counties with records, including those that could not be assigned to either time period.

Rarity: Area of occupancy

NatureServe (Faber-Langendoen *et al.* 2012) recommends calculating another measure of rarity, area of occupancy, to help distinguish between species that are widely distributed throughout their range and those with disjunct or highly fragmented distributions. NatureServe uses the number of occupied cells in a standardized grid laid across each species' range to represent area of occupancy, but because our data were at the county level, and counties in the Northeast varied widely in size (generally with smaller counties in the south and larger counties in the north), we modified this approach. We calculated the area of occupied counties in km^2 and divided it by the range extent. The result was akin to the proportion of the range actually occupied by the species. We performed this calculation two ways to account for the uncertainty around records without dates, as for range extent (above): 1) based on records since 1970 and 2) for all records including those that could not be assigned a date category.

Rarity: Habitat specificity

We also assessed species rarity by determining habitat specificity for each odonate occurring in the region. NatureServe uses this factor (more broadly termed "environmental specificity") when the number of occurrences for a species is unknown, as it was in our data. We also include species-specific habitat associations to facilitate incorporation of this project's results into State Wildlife Action Plans (SWAPs).

Anderson et al. (2013) recently described 166 habitat types (143 terrestrial/wetland and 23 aquatic) within the northeastern US and modeled their spatial occurrence across the region. At its finest resolution, this classification system (hereafter "Northeast Classification") was too fine-grained for identifying odonate breeding habitats, so we generally used higher levels in this nested classification framework.

The 228 species of Odonata that occur regularly in the Northeast were assigned to one or more of the preceding habitats through a combination of expert knowledge and review of regional publications (Dunkle 2000, Beaton 2007, Nikula *et al.* 2007, Rosche *et al.* 2008, White *et al.* 2010, Olcott 2011, Paulson 2011). We initially populated a matrix of species by habitat type, which we sent out for review by other regional experts. Further refinement occurred at a workshop at the June 2013 Northeast Dragonfly Society of the America's (DSA) meeting in Griswold, Connecticut. The final list contains 11 habitat types (7 lentic and 4 lotic, Table 2). We counted the number of habitat types used by each species in the region as a measure of habitat specificity (Appendix I).

Five of the seven lentic habitat types (Table 2) correspond roughly to habitat groups ("formations") in the Northeast Classification. In some cases, formations have been combined and in others, individual habitat types ("macrogroups") are broken off into their own category. These changes were based largely on the degree to which odonate species were known to be specialized on a given set of habitat types. Pond habitats were not mapped by the Northeast Classification, necessitating the creation of two additional pond habitat types solely for this project– Coastal Plain Pond and Lake and Pond Shoreline.

In an earlier version of the Northeast Classification, "Coastal Plain Pond" was listed as a distinct habitat within a larger group, but the most recent edition (Anderson *et al.* 2013) contains no reference to this habitat type. We have retained Coastal Plain Pond in our classification as a separate type due to their unique biota and higher vulnerability compared to marshes as a whole. "Lake and Pond Shoreline" was created in an attempt to characterize habitat for a number of generalist species that often occur in places such as gravel pit ponds, sand plain ponds, or wooded lakes and ponds.

For the purposes of this assessment, the freshwater emergent/shrub marsh category is restricted to wetlands lacking significant open water. Fringing marshes and shrubs on lakes and ponds are better treated under the "Coastal Plain Pond" and/or "Lake and Pond Shoreline" categories. Small ponds that occur in rock basins at high elevations in the Northeast were originally separated into a category of “Cold Acidic Pond.” However, as only *Somatochlora albicincta* could be considered restricted to such ponds, the category was eliminated, and this species was moved to “Lake and Pond Shoreline.” A category of "Fishless Ponds" was created to recognize the importance of such habitats for those species that can complete their life cycles in short time frames (e.g., *Lestes*, *Pantala*, some *Ischnura* and *Sympetrum*). Many species in these habitats have evolved predator-avoidance behaviors that make them particularly susceptible to fish, while others (e.g., *Pantala*) are specialized on temporary late-season water bodies (albeit not entirely). The category includes vernal pools as well as small isolated water bodies with longer photoperiods, often near stream headwaters. As in the case of Coastal Plain Ponds, several generalist species will use “Fishless Ponds” in addition to the preceding habitat category, and so we assign odonates to this habitat only if they are considered restricted to fishless pond conditions in some portion of their northeastern range.

The Northeastern Stream Classification consists of 23 categories generally reflecting size, temperature, and gradient. For the purposes of this assessment, these 23 types were further combined into four lotic categories (Table 2). Because substrate can be an important determinant of odonate use, the dominant substrate is noted in our lotic habitat descriptions.

Table 2. Description of habitat types used in the vulnerability assessment.

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lentic	Coastal Plain Pond	Split off from the original Freshwater Marsh group because of unique botanical characteristics and regional vulnerability. Includes "Carolina Bays" from the southern coastal plain.	High	Occur primarily from MA south, where threatened by development. May also be affected by hydrologic changes associated with water withdrawals and drought. Species include a mix of lentic generalists and range-restricted "specialists," with some of the latter more specialized in the southern portions of their ranges (e.g., *Enallagma pictum*). Species listed in the habitat associations table are only those that are specialized on this habitat somewhere in their Northeastern range.
Lentic	Peatland	Coastal Plain and Northern Peatland	High-Moderate	Mostly protected by wetland regulations, and seem resilient in the north. Farther south they are less common, and limited to high elevations or coastal plains, where hydrologic impacts may be important. In southern New England and the Appalachians, they are at higher risk from development, mining, shale gas drilling, and likely climate change. Peatlands generally do not support a rich odonate fauna, but often host specialists and some regional endemics or near-endemics.

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lentic	Fishless Pond	Not in the Northeast Classification. Includes permanent and semi-permanent water bodies that do not normally support fish populations. For the purposes of this assessment, only species *restricted* to Fishless Ponds in some portion of their range are listed here.	High-Moderate	Many ponds in this category are small and not protected by regulation in most of the region, and some ephemeral vernal pools can be difficult to recognize. As a result, they are often threatened by development and may also decline under some drought scenarios predicted under climate change. In a portion of the region, shale gas drilling is a threat. No species are restricted to vernal pools, but several appear to prefer them and other "fishless" habitats, and some species may be affected by introduced fish.
Lentic	Forested Wetland	Northern Swamp, Central Hardwood Swamp, Coastal Plain Swamp, Large River Floodplain, and Southern Bottomland Forest. Some of these are only seasonally flooded, and may not always qualify as habitat for odonates.	Moderate	Generally less protected than other palustrine types, but also perceived as more resilient. Used by relatively few species of odonates, but many that do are specialized and occur at low densities (e.g., *Somatochlora*). In a portion of the region, shale gas drilling is a threat to this habitat type.
Lentic	Salt Marsh/Salt Pond	Equivalent to the Tidal Marsh macrogroup, including brackish marshes. Also includes "salt ponds" that are regularly inundated by seawater during storms or high tides.	Moderate	The limited amount of this habitat in the region is highly protected, although pre-existing impacts include channelization and tidal restriction. Sea level rise associated with climate

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lentic	Salt Marsh/Salt Pond (cont.)			change is the most important threat, exacerbated by development that may impede marsh migration. Only one species (*Erythrodiplax berenice*) is restricted to salt marshes, although a few others can tolerate brackish conditions.
Lentic	Lake and Pond Shoreline	Lakes and ponds were not included in the Northeast Classification, although an early version of the system attempted to classify them based on combinations of size, elevation, and temperature. Because most odonates only use the littoral zones of lakes and ponds, we created this category to define the sparsely-vegetated edges of lakes and ponds (otherwise see Freshwater Marsh, below).	Moderate	Protections vary considerably across the region, and threats include non-point-source pollution and shoreline development. However, most of the species that occur in these areas are generalists and the communities as a whole appear resilient. Water bodies in the "Cold Acidic Pond" subcategory are relatively well protected on public lands. The potential effect of climate change includes colonization and competition by less cold-tolerant species.
Lentic	Freshwater Emergent/Shrub Marsh	Emergent Marsh and Wet Meadow/Shrub Marsh. This broad category covers the majority of wetland habitats in the region, from cattail marshes to shrub swamps. These intergrade along hydrologic gradients.	Low	Generally well-protected by wetland regulations and appear relatively resilient to disturbance. Climate change impacts are expected to be low and primarily shift habitats within the marsh-shrub continuum. The majority of species living here are widespread habitat generalists.

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lotic	Low Gradient Small Stream and Seep	Includes small, low gradient warm and cool streams. Also includes seeps, a category not in the original classification. Substrate is typically silt or mud, sometimes with organic material. Many of these streams are embedded in other habitats such as peatlands, marshes, and forested wetlands.	High-Moderate	The smaller streams within this category are not usually covered by riparian area protections. Even if not directly impacted by development or shale gas drilling, they may be adversely affected by changes to hydrology or chemistry that result from proximate development. Drought or increased temperatures resulting from climate change may also be factors. Non-native hemlock woolly adelgid is killing hemlocks that shade cold-water streams in our region. Many species in this habitat could be considered specialists, although some generalists may occur in higher order and more vegetated stream reaches.
Lotic	Moderate-High Gradient Headwater Stream	Includes small to medium cool and cold streams. Substrate is typically sand or gravel, and even bedrock in higher gradient reaches.	High-Moderate	Like other small streams, these are not well-protected and thus are subjected to numerous direct and indirect impacts. Flows are often restricted or altered as a result of improperly-sized culverts or other crossings, which can also increase sedimentation. Shoreline development can increase erosion (and sedimentation) and light levels (and temperature), and reduce woody

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lotic	Moderate-High Gradient Headwater Stream (cont.)			in-stream microhabitat. In a portion of the region, shale gas drilling is a threat to this habitat type. Any of these threats may be exacerbated by increased temperatures and flashier precipitation patterns expected under climate change. Non-native hemlock wooly adelgid is killing hemlocks that shade cold-water streams in our region. Many species in this habitat are specialists, and burrowing gomphids in particular may be sensitive to changes in substrate.
Lotic	Moderate-High Gradient River and Large Stream	This category includes a wide variety of generally higher gradient streams, but they can range from small to large and cool to warm. Substrate is typically dominated by sand or gravel.	Moderate	Because these streams tend to be larger, they often benefit from shoreline protections, and are likely more resilient to perturbation where development occurs. They face threats associated with erosion, restricted flows, and increasing temperatures, which may reduce oxygen levels sufficiently to eliminate some species. In a portion of the region, shale gas drilling is a threat to this habitat type. Species composition is more diverse than headwater streams, and in higher-order streams some species of low gradient habitats can occur.

Habitat Grouping	Habitat Type	Macrogroups included from the Northeast Classification and notes on description (Anderson *et al.* 2013).	Habitat Vulnerability	Justification
Lotic	Low Gradient River and Large Stream	Includes medium to large low gradient cool to warm rivers, including tidal freshwater. Substrate is typically silt, mud, and some sand. Riffles can occur in some stretches of even the larger rivers in this category, and these are sometimes used by odonates typical of higher gradient streams.	Moderate-Low	This habitat generally benefits from relatively strong shoreline protections, but as higher-order rivers they tend to be embedded in watersheds with higher development. However, this habitat has improved dramatically in water quality in recent decades, and is considered relatively resilient to climate change. Odonate faunas include a mix of lotic species and lentic generalists that use backwaters and impounded sections.

Threats: Vulnerability of occupied habitats

As we lacked species-specific threat information for Odonata of the region, our threat factor was assigned based on expert opinion of vulnerability of specific habitat types associated with each species. Habitat loss and degradation threatens 80% of freshwater species (Collen *et al.* 2014) and most conservation actions for Odonata in the region will likely be carried out at the scale of habitats or local watersheds. To assess habitat vulnerability, we created a qualitative scale and assigned each habitat type to one of five categories: Low, Low-Moderate, Moderate, High-Moderate, and High. We assigned habitats to vulnerability categories based on professional experience, literature review, and regional regulatory protections generally afforded the habitat type (Table 2). This initial vulnerability assessment was presented at the Northeast Regional Meeting of the DSA in June 2013, where participants provided valuable input and state-specific perspectives, thereby modifying the initial vulnerabilities of some habitat types.

We calculated a simple index of the vulnerability of occupied habitats as follows:

$$(H \times 5 + HM \times 4 + M \times 3 + LM \times 2 + L) / T$$

where H was the number of high vulnerability habitat types occupied, HM was the number of high-moderate types, M was the number of moderate types, LM was the number of low-moderate types, L was the number of low types, and T was the total number of habitat types occupied. The measure was designed to be uncorrelated with habitat specificity and could in theory range from 1 to 5, with a species scoring 1 occupying habitat types of low vulnerability only, and a species scoring 5 occupying habitat types of high vulnerability only.

Trends: Relative change in range size

From the occurrence data, we calculated a relative range change index value (Telfer *et al.* 2002, Telfer 2003) for each species based on the percentage of counties (N = 434) occupied before and after 2000. We chose 2000 as the year when interest in Odonata skyrocketed in North America with the publication of the first field guides (e.g., Dunkle 2000) and many state-wide atlasing efforts. This method uses the standardized residuals from a logit regression as a relative measure to assess the change in range size of a species in a defined area over two different time periods. The standardized residual for each species resulting from this regression represents an index of that species' change in range size relative to the trend in the whole group. Thus the estimation of range change is a relative value rather than an absolute increase or decrease. Because all 434 counties had at least one pre-2000 record, we assumed that all received some sample effort in both time periods. Since we gleaned historical records from a variety of sources such as museum and published records across several decades, a bias may arise from undue concentration on certain species or groups in the historical records (Telfer *et al.* 2002, Telfer 2003).

The biases in biological atlas data are widely understood including an increase in survey effort over time. The Telfer method minimizes (but does not eliminate) such biases. Bias may be introduced with this method if the following assumptions are not met: 1) all species are equally recordable and there has been no change in recorder behavior over time, 2) recorders attempt to record as many species as they can; 3) there is a linear relationship in range size between the earlier and later period (i.e., widespread species remain common and narrowly-distributed species stay rare). We clearly have not fully met these assumptions, but we reduced bias by accepting only records verified by experts, and because our species sample size is very large (228).

Overall Vulnerability calculation

We calculated a single vulnerability score (R-rank) based on five factors that were equally weighted: three rarity factors (range extent, area of occupancy, and habitat specificity), one threat factor (vulnerability of occupied habitats), and one trend factor (relative change in range). First, we normalized all factors by converting them to a 0-1 scale with lower numbers representing greater vulnerability, and added them together. We calculated the final index two ways: 1) using range extent and area of occupancy based on records since 1970, and 2) using these factors based on all records regardless of date. When there were fewer than 10 occupied counties, we calculated the index without area of occupancy and relative change in range, as those factors can be misleading for very narrowly distributed species. We divided by the number of factors (five for most species, three for species occupying fewer than 10 counties) to arrive at the final index score, which ranged from 0-1. Lower index scores reflected greater vulnerability.

We converted the vulnerability index to an R-rank using cutoffs based on the distribution of index values (R1: 0-0.2; R2: 0.2-0.3, R3: 0.3-0.4, R4: 0.4-0.5, R5: 0.5-1.0). In cases where the two calculations (using post-1970 only and using all records) of the index resulted in different R-ranks, we assigned a "range rank" such as R1R2 (Faber-Langendoen *et al.* 2012).

The R-ranks were reviewed by 17 additional Odonata experts from the region at the June 2013 Northeast DSA meeting and by additional invited experts afterward. This feedback informed revisions to the vulnerability analysis. In the fall of 2013, we made changes to the species to habitat type assignments based on feedback and re-ran the analysis. At this time, there were no major methodological issues highlighted and many of the suggested R-rank changes to species at the June meeting were reconciled by the updated version.

Regional Responsibility Analysis

NatureServe staff created distributional range maps for the entire US and Canadian range of all northeastern Odonata. NatureServe produced an ArcGIS 10.0 geodatabase containing a spatial data layer for each species depicting shaded counties for US records. For Canadian records, our data source was OdonataCentral (Abbott 2007-2014). We recognize that additional sources for Canadian records exist; however, it was beyond the scope of this project to compile these in addition to our regional dataset. As a shapefile of Canadian counties was not available to us, Canadian georeferenced coordinates were mapped and intersected against a custom hexagon grid layer where each hexagon was of a comparable size to a typical US eastern county (approximately 2,590 km^2). On the final maps, if more than one record occurred in a given county or hexagon over time, the post-1970 (current) record was displayed. A designation of "Unknown" year was displayed instead of pre-1970 (historical record), and pre-1970 records were displayed if all records representing a species in a given county had that value.

We calculated regional responsibility (sensu Rosenberg and Wells 1995, NEPARC 2010) as the proportion of the US & Canadian range that falls in the northeastern US. We calculated this statistic using the area (km^2) of occupied US counties and Canadian hexagons across all years. We put odonate species into three categories based on their responsibility calculation:

“Primary” responsibility species for which ≥50% of their range fell in the Northeast; “Significant” responsibility species for which 25-50% of their range fell in the Northeast; and “Shared” responsibility species for which <25% of their range fell in the Northeast (Table 3).

Table 3. Number of species within each vulnerability rank in each responsibility category, separated by Anisoptera (Dragonflies) and Zygoptera (Damselflies).

	Anisoptera	Zygoptera	Total
Primary responsibility (≥50%)			
R1	0	0	0
R2	4	1	5
R3	7	3	10
R4	19	2	21
R5	3	1	4
Significant responsibility (25-50%)			
R1	1	0	1
R2	2	1	3
R3	9	0	9
R4	8	4	12
R5	19	10	29
Shared responsibility (<25%)			
R1	11	3	14
R2	14	5	19
R3	19	9	28
R4	24	12	36
R5	22	15	37
Grand Total	162	66	228

Relative taxonomic distinctiveness

We used a simple index formula to calculate the relative taxonomic distinctiveness (RTD) of each species in order to account for phylogenetic effects on species rarity (Freitag and Van Jaarsveld 1997):

$$RTD = 1/\sqrt{(\text{family x genus x species})}$$

Where: family = number of regionally represented families in the suborder, genus = number of regionally represented genera in the family, and species = number of regionally represented species in the genus. Thus, distinct taxa like *Tachyopteryx* received higher index scores than more speciose groups (e.g., *Enallagma*). In Table 4, we highlight those species that fell in the top 15% of the overall range of index scores, a rather conservative taxonomic threshold.

Results

Data summary and regional odonate fauna

The compiled dataset contained 248,059 records, with data from all NEAFWA states. As we also obtained data from Odonata Central, where many regional experts submit data, some of these records were duplicates, but since our analysis included only unique combinations of species, county, and year, duplicates were not an issue. After consulting with state and regional experts, we came up with a final list of 228 resident (breeding, not accidental) odonate species, including 162 dragonflies and 66 damselflies. The number of states occupied ranged from one to all 13 (mean = 9.13, s.d. = 3.91) and the number of counties occupied ranged from one to 367 (mean = 115.96, s.d. = 97.56).

Regional vulnerability

Rarity

Range extent (considering records from all time periods) of edge-of-range species totaled as little as 145 km^2 in the Northeast (e.g., *Macrodiplax balteata*), while species occupying much of the region covered nearly 630,000 km^2 (e.g., *Boyeria vinosa*, *Anax junius*) (mean = 379,867, s.d. = 205,280).

Area of occupancy, considering records from all time periods, ranged from 0.07 for species with widely scattered records to one for species with no “holes” in their distribution (mean = 0.53, s.d. = 0.22). There was no correlation between area of occupancy and range extent ($r = 0.17$).

Habitat associations for Northeastern Odonata are displayed in Appendix I along with all metric components of our conservation assessment. The number of associated habitat types ranged from one to seven (mean = 2.64, s.d. = 1.14) out of a possible 11.

Threats: Vulnerability of occupied habitats

The habitat vulnerability index ranged from 2.0 to 4.0 (mean = 3.16, s.d. = 0.56). Habitat specificity and the index of habitat vulnerability were uncorrelated.

Trends: Relative change in range

Based on the proportions of the 434 counties occupied by a species pre-post 2000 (controlled for survey effort), those species' with both the largest declines and increases relative to the fauna as a whole were generally species on their range margins in the Northeast. Thus, they had low numbers of counties occupied initially so that a small change in the occupancy in the latter time period caused a relatively large change in index value.

For example, *Telebasis byersi,* a southern damselfly that just enters our study area, had one of the largest increases in its relative index value, but this species has only been found in 11 counties in our region. Likewise, most of the species that demonstrated the largest relative range reductions since 2000, such as *Macromia margarita*, were initially found in just a very small portion of our study area. The only species whose range significantly shrank from a rather high level since 2000 was *Lestes unguiculatus.* Although this bias is inherent to the method we used, it does make biological sense because species with smaller ranges, or that are on their range margin, are generally subject to greater population fluctuations.

Final vulnerability calculation

Vulnerability scores ranged from 0.15 to 3.92 (mean = 2.17, s.d. = 0.78) and, once rescaled from zero to one, resulted in 15 species assigned R1, 27 species assigned R2, 47 species assigned R3, 69 species assigned R4, and 70 species assigned R5. Examples of R1s include a southern dragonfly of large rivers and streams, *Gomphus apomyius* (narrowly distributed, habitat specialist, but relatively increasing), a southern damselfly of forested wetlands, *Ischnura prognata* (widely distributed, apparently declining, highly specialized), and many species on the edge of their range (e.g., *Leucorrhinia patricia*). Examples of R5s included a mostly eastern damselfly occurring in a variety of lentic and lotic habitat types, *Ischnura posita* (widely distributed, relatively increasing, generalist), and many other species occurring in all the northeastern states.

Families with the most R1 species include Gomphidae and Corduliidae (Fig. 3). The top habitats where most R1 species occur are Moderate-High Gradient Headwater Streams, Moderate-High Gradient River and Large Stream, and Low-gradient Small Stream and Seep. Low-gradient Small Stream and Seep, Low-gradient River and Large Stream, Moderate-High Gradient River and Large Stream, and Lake and Pond Shoreline host more R2 species than other habitat types. Three out of seven of the R2 species found in Lake and Pond Shoreline also inhabit lotic habitat types. Peatlands also host a disproportionate number of at-risk Odonata and half of species known to use Coastal Plain Ponds are considered high or moderate vulnerability in the region (Fig. 4). When reviewing this figure, it is important to remember a species can be assigned to more than one habitat type.

Regional responsibility

The proportion of a species' US and Canadian range occurring in the Northeast ranged from miniscule (e.g., the edge-of-range *Macrodiplax balteata*, *Enallagma anna*, and *Aeshna juncea*) to 100% (the regional endemics *Enallagma laterale*, *E. pictum*, and *E. recurvatum*). Using our 0.50 cutoff, the Northeast has primary responsibility for the conservation of 40 (17.5%) of the 228 species, including 33 (20.4%) dragonflies and 7 (10.6%) damselflies (Table 3). Again Gomphidae and Corduliidae are among the families with the most species of primary responsibility in our region (Fig. 5). Final maps for all northeastern species will be displayed online through the NatureServe Explorer website showing both current and historical distributions in North America (New York Natural Heritage Program and NatureServe 2014).

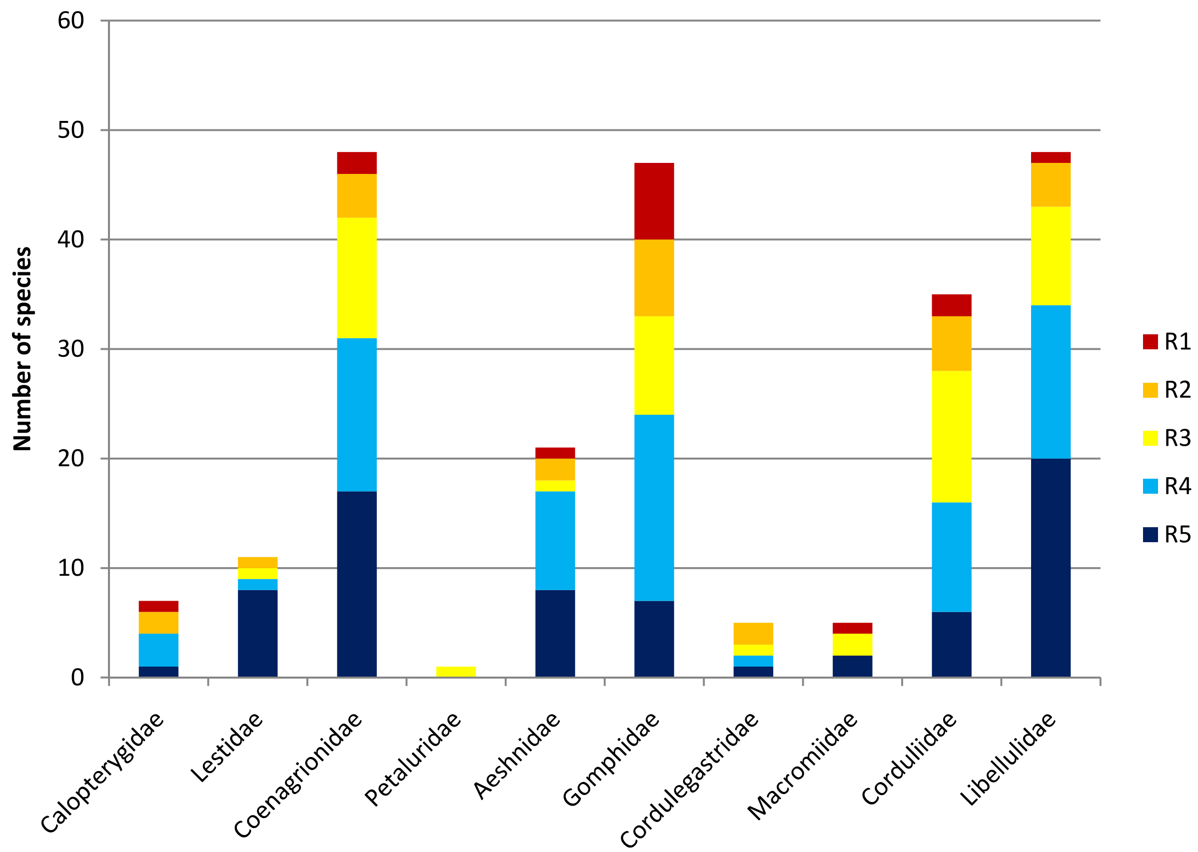

Figure 3. The number of odonate species in each vulnerability category displayed by family.

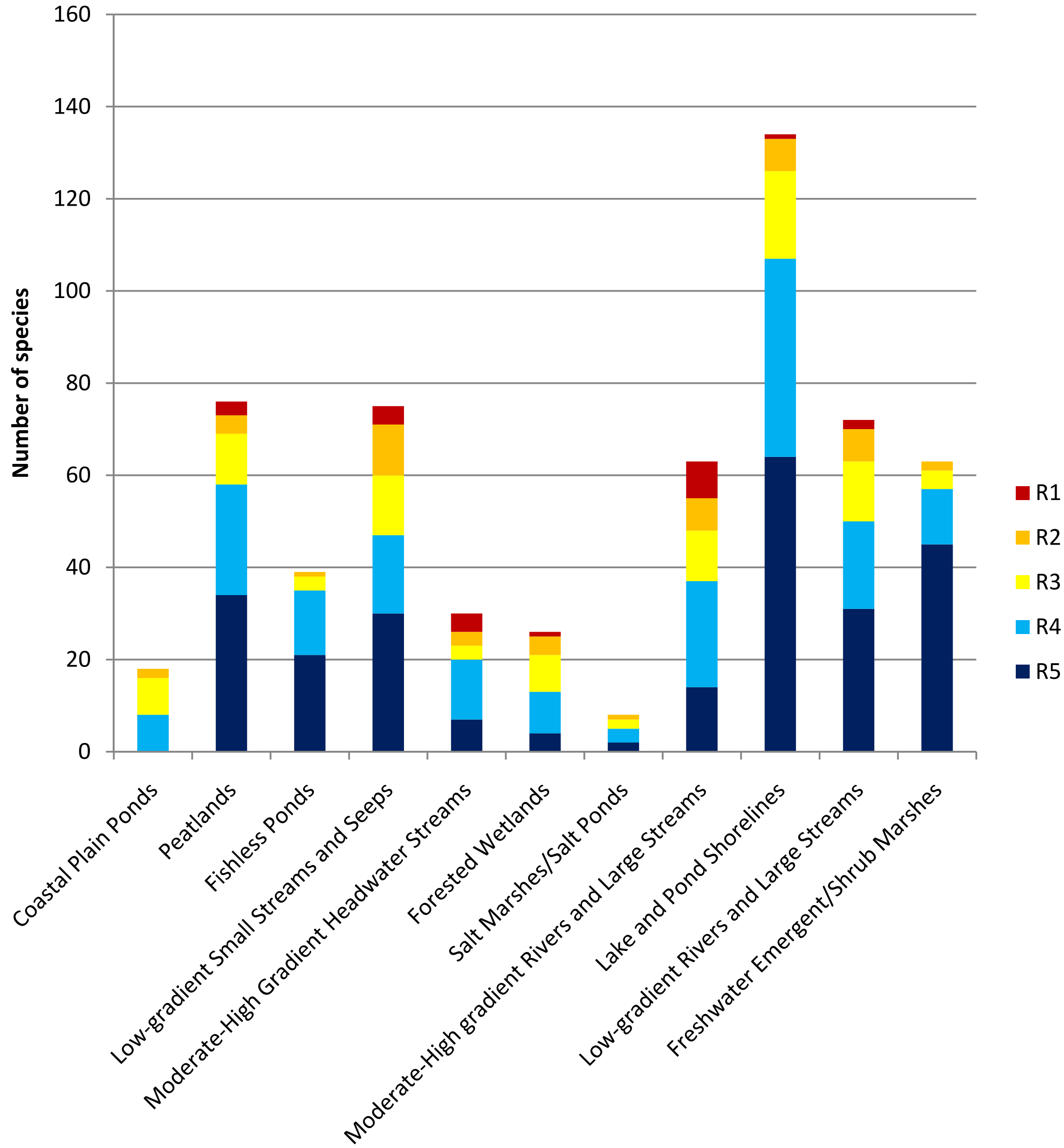

Figure 4. The number of odonate species in each vulnerability category displayed by habitat type. Habitat types are listed in decreasing order of vulnerability from left to right.

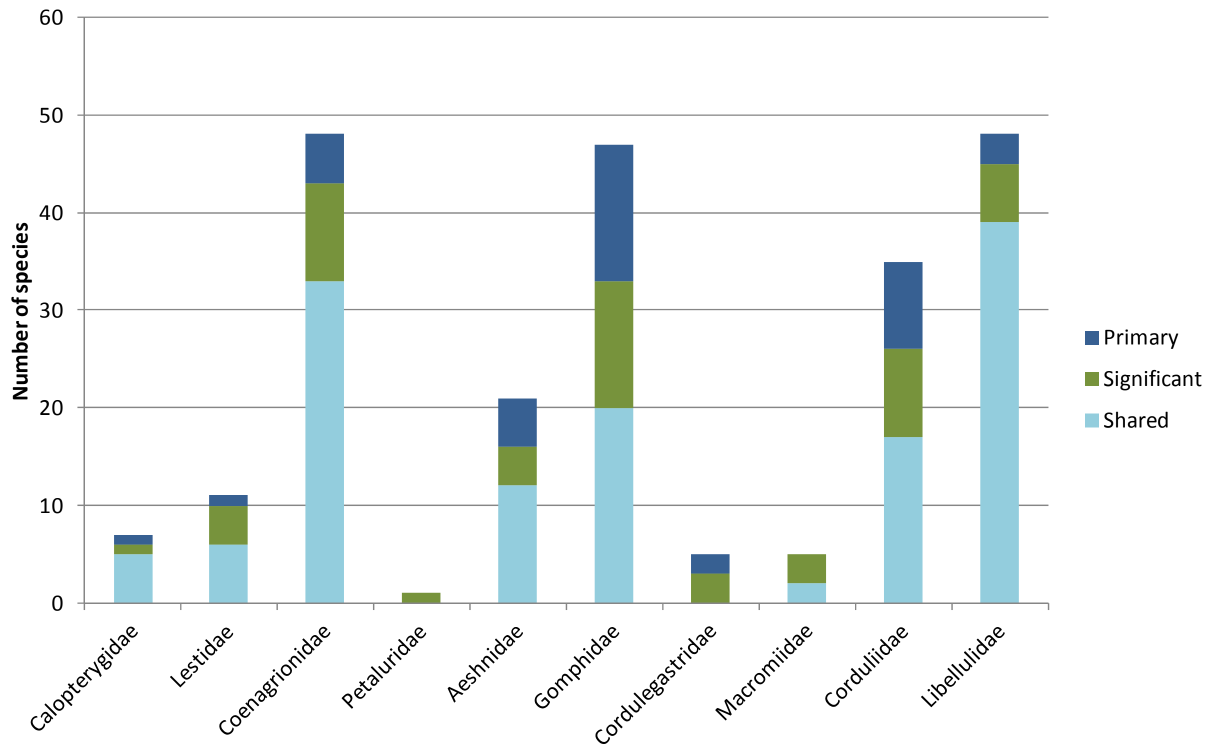

Figure 5. The number of species in each responsibility category displayed by family.

Prioritization matrix

We created a matrix of species vulnerability and regional responsibility to identify priorities for conservation of Odonata in the northeastern US (Table 4). This matrix has three vulnerability categories (High: R1 and R2, Medium: R3, and Low: R4 and R5) and three responsibility categories (Primary, Significant, and Shared). Range ranks were "rounded" to the more vulnerable category for this purpose. The five levels of vulnerability were collapsed into three for ease of interpretation and comparison to similar regional assessments for other taxa.

Here, we also highlight species occurring in just one or two states with an asterisk, as these may not justifiably be considered regional priorities. Those species with a dagger in the matrix are the top 15% taxonomically distinct species in the region. The matrix indicates that five dragonfly species are the highest priority for conservation in the Northeast due to the combination of high vulnerability and primary responsibility. The matrix permits users to identify many other high and intermediate conservation species priorities depending on the identification of user-defined thresholds for the complementary concepts of vulnerability and responsibility.

Table 4. Matrix of odonate species sorted into three vulnerability and responsibility groups.

Vulnerability	Primary responsibility (≥50%)	Significant responsibility (25-50%)	Shared responsibility (<25%)
High (R1-R2)	Cordulegaster erronea † Enallagma recurvatum Gomphus rogersi Gomphus septima delawarensis Williamsonia lintneri	Calopteryx angustipennis † Cordulegaster bilineata † Ophiogomphus incurvatus Somatochlora brevicincta *	Aeshna juncea * Aeshna sitchensis Aphylla williamsoni * Archilestes grandis † Argia bipunctulata Arigomphus cornutus * Calopteryx dimidiata † Celithemis ornata Dromogomphus spoliatus * Dythemis velox * Enallagma anna * Enallagma doubledayi Enallagma pallidum Gomphaeschna antilope Gomphus apomyius Gomphus consanguis * Gomphus parvidens * Gomphus septima septima * Helocordulia selysii Hetaerina titia † Ischnura prognata Leucorrhinia patricia * Libellula flavida Macrodiplax balteata * Macromia margarita * † Neurocordulia molesta * Neurocordulia virginiensis * Ophiogomphus colubrinus * Somatochlora georgiana Somatochlora minor Stylogomphus sigmastylus * Stylurus laurae Stylurus notatus
Moderate (R3)	Celithemis martha Enallagma laterale Enallagma minusculum Enallagma pictum Ladona exusta Nannothemis bella Neurocordulia michaeli * Ophiogomphus anomalus Somatochlora elongata Somatochlora incurvata	Cordulegaster obliqua † Epitheca spinosa Erythrodiplax berenice Gomphus viridifrons Macromia alleghaniensis † Ophiogomphus howei Ophiogomphus susbehcha * Somatochlora forcipata Tachopteryx thoreyi †	Aeshna subarctica Argia sedula Celithemis fasciata Enallagma antennatum Enallagma basidens Enallagma daeckii Enallagma dubium Enallagma weewa Epitheca costalis Erpetogomphus designatus * Erythrodiplax minuscula Gomphus lineatifrons Gomphus ventricosus Lestes unguiculatus Libellula needhami Macromia taeniolata † Nehalennia integricollis Somatochlora albicincta Somatochlora filosa

Vulnerability	Primary responsibility (≥50%)	Significant responsibility (25-50%)	Shared responsibility (<25%)
			Somatochlora franklini Somatochlora kennedyi Somatochlora linearis Somatochlora provocans Stylurus amnicola Stylurus plagiatus Sympetrum costiferum Sympetrum danae Telebasis byersi †
Low (R4-R5)	Aeshna clepsydra Aeshna verticalis Arigomphus furcifer Arigomphus villosipes Boyeria grafiana Calopteryx amata † Cordulegaster diastatops † Dorocordulia lepida Gomphaeschna furcillata Gomphus abbreviatus Gomphus borealis Gomphus descriptus Helocordulia uhleri Lanthus parvulus Lanthus vernalis Lestes eurinus Nehalennia gracilis Neurocordulia obsoleta Ophiogomphus aspersus Ophiogomphus carolus Ophiogomphus mainensis Rhionaeschna mutata† Somatochlora tenebrosa Stylogomphus albistylus Williamsonia fletcheri	Aeshna tuberculifera Amphiagrion saucium † Anax longipes Basiaeschna janata† Boyeria vinosa Celithemis elisa Chromagrion conditum † Cordulegaster maculata † Didymops transversa † Dorocordulia libera Dromogomphus spinosus Enallagma aspersum Enallagma divagans Enallagma durum Enallagma geminatum Enallagma traviatum Enallagma vernale Enallagma vesperum Epitheca canis Epitheca semiaquea Gomphus adelphus Gomphus exilis Gomphus lividus Gomphus quadricolor Gomphus spicatus Ischnura kellicotti Lestes forcipatus Lestes inaequalis Lestes rectangularis Lestes vigilax Leucorrhinia frigida Libellula cyanea Libellula semifasciata Macromia illinoiensis † Neurocordulia yamaskanensis Ophiogomphus rupinsulensis Somatochlora walshii Somatochlora williamsoni Stylurus scudderi Stylurus spiniceps Sympetrum rubicundulum	Aeshna canadensis Aeshna constricta Aeshna eremita Aeshna interrupta Aeshna umbrosa Anax junius Argia apicalis Argia fumipennis Argia moesta Argia tibialis Argia translata Brachymesia gravida Calopteryx aequabilis † Calopteryx maculata † Celithemis eponina Celithemis verna Coenagrion interrogatum † Coenagrion resolutum † Cordulia shurtleffii † Enallagma annexum Enallagma boreale Enallagma carunculatum Enallagma civile Enallagma ebrium Enallagma exsulans Enallagma hageni Enallagma signatum Epiaeschna heros† Epitheca cynosura Epitheca princeps Epitheca spinigera Erythemis simplicicollis Gomphus fraternus Gomphus vastus Hagenius brevistylus Hetaerina americana † Ischnura hastata Ischnura posita Ischnura ramburii Ischnura verticalis Ladona deplanata Ladona julia Lestes australis Lestes congener Lestes disjunctus

Vulnerability	Primary responsibility (≥50%)	Significant responsibility (25-50%)	Shared responsibility (<25%)
			Lestes dryas Leucorrhinia glacialis Leucorrhinia hudsonica Leucorrhinia intacta Leucorrhinia proxima Libellula auripennis Libellula axilena Libellula incesta Libellula luctuosa Libellula pulchella Libellula quadrimaculata Libellula vibrans Nasiaeschna pentacantha† Nehalennia irene Pachydiplax longipennis Pantala flavescens Pantala hymenaea Perithemis tenera Plathemis lydia Progomphus obscurus Somatochlora cingulata Sympetrum ambiguum Sympetrum internum Sympetrum obtrusum Sympetrum semicinctum Sympetrum vicinum Tramea carolina Tramea lacerata

* Occurs in one or two states only
† High relative taxonomic distinctiveness index (> 0.15)

G. rogersi and *W. lintneri* are both ranked as primary responsibility in the Northeast with a high vulnerability rank (R2). These were two of the species most frequently ranked as SGCNs in the eastern states (Bried and Mazzacano 2010). Other species with a moderate vulnerability rank that were ranked as SGCNs by five or more states in the region include *E. laterale*, *E. pictum*, *N. integricollis*, *T. thoreyi*, *G. ventricosus*, *G. viridifrons*, *S. elongata*, *S. forcipata*, and *S. linearis*. Some of the most frequently ranked SGCN species in the eastern states received a low vulnerability rank of R4 or R5 regionally, including *R. mutata*, *A. longipes*, *G. abbreviatus*, *G. fraternus*, *G. quadricolor*, and *G. vastus* (Bried and Mazzacano 2010). *R. mutata* and *A. longipes* are primarily pond Aeshnids and the Gomphids are all riverine species.

We recommend special attention for those species that currently hold subspecies status, but that may be designated as separate species in the future. We were unable to use subspecies designations for *O. mainensis* (*mainensis* vs. *fastigiatus*) because we could not parse out all records in the region. The southern portion of the range of *O. mainensis* holds populations of *O. mainensis fastigiatus*, which will likely be raised to full species status in the near future (T. Donnelly, J. McCann, pers.comm.). In addition, we were not able to discern subspecies for *C. obliqua* and there is disagreement on whether there are two subspecies in this taxon. *G. septima septima* and *G. s. delawarensis* both occur in our study region and we could assign species-level records to one or the other subspecies because their populations are widely geographically separated. Both rank as highly vulnerable in our assessment: *G. s. delawarensis* is endemic to the

Delaware River in NJ, NY, and PA, while *G. s septima* is known from VA (and is also disjunct in Alabama and North Carolina). There does remain some disagreement among taxonomists as to whether these are indeed two separate species. Regardless, each population should receive primary conservation attention and the Delaware River population is endemic to the region.

Discussion

Prioritizing species for conservation based on measures of rarity and threat is a critical tool for helping conservation biologists direct limited resources to individual species most in need of management attention. Many well-known species prioritization examples exist at larger global (e.g., IUCN, NatureServe) and national (e.g., USESA, COSEWIC) scales. Fewer such examples exist at local or regional scales (though see Partners In Flight [Panjabi *et al.* n.d.] and Partners for Amphibian and Reptile Conservation [NEPARC 2010]). Instead, many states and provinces resort to limited jurisdictional assessments of species status using lists of legally Endangered and Threatened species, the criteria for which are inconsistent, often narrow in taxonomic breadth, and frequently subject to political influence.

Beyond scale, a further complicating factor in the species prioritization process is that most rigorous methodologies include science-based criteria, thus requiring detailed knowledge of geographic distribution, population status, and life history. As such, few comprehensive assessments of species status have been conducted for invertebrate taxa, both because of the overwhelming diversity of species involved and the relatively poor level of scientific study. Among north temperate invertebrates, Odonata present a potential exception to both of these challenges in that their numbers are relatively manageable (e.g., North America: ~462 species; Northeast: ~228 species) and their distribution and biology is relatively well known, having attracted significant study by professional entomologists and citizen scientists alike.

To this end, we offer a species conservation prioritization approach for northeastern Odonata, modeled after a widely accepted methodology for determining vulnerability status by NatureServe (2012). As previously discussed, Odonata are important members of freshwater and terrestrial ecosystems, and indicators of ecosystem integrity and climate change. Our methodology is designed to assist conservation practitioners in identifying broader taxonomic patterns in vulnerability, as well as individual species of regional conservation concern. Additionally, habitat types for special management consideration in the Northeast can be identified as those hosting a disproportionate number of high and moderately vulnerable species; specifically including: a) Peatland, b) Low-gradient Small Stream and Seep, c) Moderate-High Gradient Headwater Stream, and d) River and Large Stream (Moderate-High Gradient and Low-gradient) in our analysis. We anticipate that this Odonata assessment will help inform the strategic allocation of limited state and federal conservation resources and help foster collaborations across state lines to conserve regionally at-risk species. Furthermore, because our methodology employs transparent, quantitative, and science-based criteria, we invite its replication in geographic regions beyond northeastern North America, and with other similarly well-studied invertebrate taxa -- e.g., Order Unionoida (Freshwater Mussels) and Order Lepidoptera (Butterflies and Moths).

In a comprehensive assessment of US biodiversity, Master *et al.* (2000) found disproportionate impacts to freshwater-dependent taxa and identified 18% of Odonata as rare and vulnerable. Consistent with their findings, our more detailed analysis of northeastern Odonata found exactly the same rate of imperilment (R1 or R2). However, nearly half of the 41 imperiled species in our assessment are likely listed because they are on their range margins in the Northeast (Table 4) and are not regionally vulnerable. Arguably, there is validity in investing local conservation effort in highly vulnerable edge of range species, those that occur for example in one or two states in the Northeast, to conserve genetic diversity of the species as a whole and to preserve ecosystem function values where the species occurs (Hunter and Hutchinson 1994). Nonetheless, when conservation resources are limited, as is especially the case for invertebrate conservation, these more parochial species conservation targets should be weighed against other critical conservation priorities at higher scales, regionally and globally.

Matrix Guidance

All 228 northeastern odonates are prioritized in our species conservation matrix (Table 4) by regional vulnerability and responsibility. In lieu of a full discussion of the ecological and conservation implications of our findings, we provide guidance below on matrix interpretation to assist users in determining conservation strategies for northeastern Odonata. We suggest that species whose vulnerability ranked as High (R1 or R2; n= 41) receive targeted species-specific attention by all jurisdictions where they occur in the Northeast. Among these highly vulnerable species, priority should be further triaged, if necessary, towards those eight species for which the Northeast hosts a primary (>50%) or significant (>25%) proportion of their North American geographic range. We further suggest that a regional Odonata conservation working group be formed to help guide protocols for surveys, monitoring, research, habitat protection, and education, and thereby develop a framework for a coordinated comprehensive conservation plan for northeastern Odonata.. A Conservation Action Plan approach similar to what has been done for many imperiled bird species such as the Bicknell's Thrush (*Catharus bicknelli*) should be the working group's primary focus for R1, R2 species of primary responsibility (five species). A worthy precedent is the status assessment reports that Canada has assembled for certain odonates deemed to be of conservation importance (e.g., COSEWIC 2008). Such a regional working group might consider the following uses of the matrix:

1) Implementing habitat-based (coarse-filter) approaches as suggested by Samways (2007) and Strayer (2006) for those breeding habitats hosting disproportionate numbers of vulnerable (R1-R3) and high responsibility (primary or significant) species. These habitats should include, but are not limited to peatlands, low-gradient streams and seeps, high-gradient headwaters, larger rivers for highly vulnerable species with the addition of coastal plain ponds for moderately vulnerable species (Fig. 4, Appendix I). Coarse-filter insect management strategies could include habitat protection, linking good-quality habitats with corridors to connect freshwater systems, and maintaining large, good quality, unisolated habitat patches (Samways 2007, Collen *et al.* 2014). Other strategies could include odonate conservation as part of the protection of freshwater resources and water quality for human use (Strayer 2006) and as part of watershed-wide planning (Wilkinson *et al.* 2013). Further, terrestrial forests surrounding aquatic breeding habitats are also important to Odonata because naturally vegetated riparian and wetland buffers increase the health of aquatic systems, and provide maturing, roosting, and foraging habitat for adults (Corbet 2006). An additional good resource for regional habitat-based conservation planning for the Northeast is Anderson *et al.* (2011).

2) Identifying species of a) High Regional Vulnerability (R1-R2) and b) Moderate Regional Vulnerability (R3) and Primary or Significant Responsibility for consideration as Species of

Greatest Conservation Need (SGCN) in State Wildlife Action Plans. Those jurisdictions with access to relatively more capacity for invertebrate conservation might also consider adding Low Regional Vulnerability species (R4-R5) of Primary Responsibility (only) in the Northeast.

3) Surveying region-wide to document and monitor all occurrences of highly vulnerable, primary responsibility species populations over time. After gathering existing information on occurrences and viability, additional survey effort could determine population size, habitat details, and threats to local sites. Alternatively, all species of high vulnerability across responsibility categories could be tracked in this way.

4) Monitoring populations of the three endemic damselfly species (*Enallagma laterale*, *E. pictum*, and *E. recurvatum*) in the Northeast and implementing pro-active conservation measures to ensure they do not become more vulnerable.

5) Identifying taxonomically distinct species for conservation attention regardless of their vulnerability or responsibility scores. The method we have employed to highlight these taxa is simplistic and somewhat arbitrary. For example, one could make the case that monotypics such as *Hagenius* or the two *Williamsonia's* are highly taxonomically distinct. On the other hand, some have argued that recently radiating (i.e., younger) lineages such as *Argia* hold the most promise for the continued future evolution of biodiversity (Erwin 1991). We believe that conserving both older relictual species as well as younger groups undergoing active speciation (i.e., *Enallagma*) is called for, and the inclusion of evolutionary approaches in conservation prioritization has gained much ground in recent years. In the absence of complete phylogenies for Odonata, one practical way to implement this idea would be to use the phylogenetic trees in Corser *et al*. (2014) to more systematically pinpoint the lineages that have disproportionally contributed to the diversity of damselflies and dragonflies in the Northeast and then to target those taxa, and the habitat types that they depend on for conservation, because these will preserve both ecological and evolutionary potentials.

6) Coordinating with other US regions and Canadian provinces for successful conservation of vulnerable species of shared responsibility.

7) Continuing to collect Odonata information region-wide via targeted professional surveys and citizen science atlasing efforts, thereby keeping the Northeast Regional Conservation Need odonate database comprehensive and dynamic. Re-assessing the regional conservation status of Odonata periodically (e.g., every 10 years), keeping abreast of taxonomic changes and new occurrence data.

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Literature Cited

Abbott, J. 2007, 2014. Odonata central: An online resource for the distribution and identification of Odonata. The University of Texas at Austin. [Online]. Available: http://www.odonatacentral.org/index.php/MapAction.windowed.

Anderson, M., M. Clark, and A. Olivero Sheldon. 2011. Resilient Sites for Species Conservation in the Northeast and Mid-Atlantic Region. The Nature Conservancy, Eastern Conservation Science. 122 pages.

Anderson, M. G., M. Clark, C. E. Ferree, A. Jospe, A. Olivero Sheldon, and K. J. Weaver. 2013. Northeast habitat guides: A companion to the terrestrial and aquatic habitat maps. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office, Boston, MA.

Anderson, M. G., and A. Olivero Sheldon. 2011. Conservation status of fish, wildlife, and natural habitats in the northeast landscape: Implementation of the Northeast Monitoring Framework. The Nature Conservancy, Eastern Conservation Science., Boston, MA. 289 pages.

Beaton, G. 2007. Dragonflies and Damselflies of Georgia and the Southeast. Wormsloe Foundation Publications, Athens, GA.

Bivand, R., and C. Rundel. 2013. rgeos: Interface to Geometry Engine - Open Source (GEOS).

Bried, J. T. 2005. Community and conservation ecology of dragonfly and damselfly adults in Mississippi wetlands. M.S. Thesis. Mississippi State University, Mississippi.

Bried, J. T., and C. A. Mazzacano. 2010. National review of state wildlife action plans for Odonata species of greatest conservation need. Insect Conservation and Diversity 3:61–71.

Bush, A., G. Theischinger, D. Nipperess, E. Turak, and L. Hughes. 2013. Dragonflies: climate canaries for river management. Diversity and Distributions 19:86–97.
Clark, T. E., and M. J. Samways. 1996. Dragonflies (Odonata) as indicators of biotype quality in the Kruger National Park, South Africa. Journal of Applied Ecology 33:1001–1012.
Clausnitzer, V., V. J. Kalkman, M. Ram, B. Collen, J. E. M. Baillie, M. Bedjanic, W. R. T. Darwall, K. B. Dijkstra, R. Dow, J. Hawking, H. Karube, E. Malikova, D. R. Paulson, K. Schutte, F. Suhling, R. J. Villanueva, N. von Ellenrieder, and K. Wilson. 2009. Odonata enter the biodiversity crisis debate: the first global assessment of an insect group. Biological Conservation 142:1864–1869.
Collen, B., F. Whitton, E. E. Dyer, J. E. Baillie, N. Cumberlidge, W. R. Darwall, C. Pollock, N. I. Richman, A. Soulsby, and M. Böhm. 2014. Global patterns of freshwater species diversity, threat and endemism. Global Ecology and Biogeography 23:40–51.
Corbet, P. 1993. Are Odonata useful as bioindicators. Libellula 12:91–102.
Corbet, P. S. 1999. Dragonflies: Behavior and ecology of Odonata. Cornell University Press, Ithaca, New York.
Corbet, P. S. 2006. Forests as habitats for dragonflies (Odonata). Pages 13–36 in *in* A. C. Rivera, editor. Forests and Dragonflies. Fourth WDA International Symposium of Odonatology, Pontevedra (Spain), July 2005.
Corser, J. D., E. L. White, and M. D. Schlesinger. 2014. Odonata origins, biogeography, and diversification in an Eastern North American hotspot: multiple pathways to high temperate forest insect diversity. Insect Conservation and Diversity.
COSEWIC. 2008. COSEWIC assessment and status report on the Rapids Clubtail Gomphus quadricolor in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. 35 pages.
Dunkle, S. W. 1995. Conservation of dragonflies (Odonata) and their habitats in North America. Proceedings of the International Symposium on the Conservation of Dragonflies and Their Habitats. Japanese Society for Preservation of Birds, Kushiro, Japan:23–27.
Dunkle, S. W. 2000. Dragonflies through binoculars. Oxford University Press, New York, NY.
Erwin, T. L. 1991. An evolutionary basis for conservation strategies. Science 253:750–752.
Faber-Langendoen, D., J. Nichols, L. Master, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young. 2012. NatureServe conservation status assessments: methodology for assigning ranks. NatureServe, Arlington, Virginia. 44 pages.
Foster, D. R., G. Motzkin, D. Bernardos, and J. Cardoza. 2002. Wildlife dynamics in the changing New England landscape. Journal of Biogeography 29:1337–1357.
Freitag, S., and A. Van Jaarsveld. 1997. Relative occupancy, endemism, taxonomic distinctiveness and vulnerability: prioritizing regional conservation actions. Biodiversity & Conservation 6:211–232.
Hansen, A., J. Rotella, M. Kraska, and D. Brown. 1999. Dynamic habitat and population analysis: an approach to resolve the biodiversity manager's dilemma. Ecological Applications 9:1459–1476.
Hassall, C., and D. J. Thompson. 2008. The effects of environmental warming on Odonata: A review. International Journal of Odonatology 11:131–153.
Hunter, M. L., and A. Hutchinson. 1994. The virtues and shortcomings of parochialism: Conserving species that are locally rare, but globally common. Conservation Biology 8:1163–1165.

IUCN. 2013. IUCN Red List of Threatened Species. Version 2013.1. [Online]. Available: www.iucnredlist.org. [Accessed: 24-Oct-2013].
Kalkman, V. J., V. Clausnitzer, K. B. Dijkstra, A. G. Orr, D. R. Paulson, and J. van Tol. 2008. Global diversity of dragonflies (Odonata) in freshwater. Hydrobiologia 595:351–363.
Kutcher, T. E., and J. T. Bried. 2014. Adult Odonata conservatism as an indicator of freshwater wetland condition. Ecological Indicators 38:31–39.
Martinuzzi, S., V. Radeloff, J. Higgins, D. Helmers, A. Plantinga, and D. Lewis. 2013. Key areas for conserving United States' biodiversity likely threatened by future land use change. Ecosphere 4:art58.
Master, L. L., D. Faber-Langendoen, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, VA.
Master, L. L., S. R. Flack, B. A. Stein, and N. Conservancy. 1998. Rivers of life: critical watersheds for protecting freshwater biodiversity. Nature Conservancy, Arlington, VA.
Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammerson. 2000. Vanishing assets: conservation status of US species. Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York.
NatureServe. 2012. NatureServe conservation status assessments: rank calculator version 3.1. Arlington, VA.
NEPARC. 2010. Northeast amphibian and reptile species of regional responsibility and conservation concern. Northeast Partners in Amphibian and Reptile Conservation (NEPARC). Publication 2010-1.
New York Natural Heritage Program and NatureServe. 2014. Digital Distribution Maps of the Odonates of Eastern North America. Version 1.0. Arlington, VA. U.S.A.
Nikula, B. J., J. L. Ryan, and M. R. Burne. 2007. A field guide to the dragonflies and damselflies of Massachusetts. 2nd ed. Massachusetts Division of Fisheries & Wildlife, Natural Heritage & Endangered Species Program, Westborough, MA.
Olcott, S. 2011. Final report for the West Virginia dragonfly and damselfly atlas. West Virginia Division of Natural Resources, Wildlife Resources Section, Elkins, WV.
Panjabi, A. O., P. J. Blancher, R. Dettmers, and K. V. Rosenberg. (n.d.). Partners in flight handbook on species assessment. Version 012. Partners in Flight Technical Series No. 3. Rocky Mountain Bird Observatory website:
Patten, M. A., and B. D. Smith-Patten. 2013. Odonata species of special concern for Oklahoma, USA. International Journal of Odonatology 16:327–350.
Paulson, D. R. 2011. Dragonflies and damselflies of the East. Princeton University Press, Princeton, NJ.
R Development Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13:1220–1222.
Rosche, L., J. M. Semroc, and L. K. Gilbert. 2008. Dragonflies and damselflies of Northeast Ohio. Cleveland Museum of Natural History, Cleveland, OH.
Rosenberg, K. V., and J. V. Wells. 1995. Importance of geographic areas to neotropical migrant birds in the Northeast. Report submitted to the US Fish and Wildlife Service, Region-5, Hadley, MA.

Samways, M. J. 2007. Insect conservation: a synthetic management approach. Annual Review of Entomology 52:465–487.
Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The Human Footprint and the Last of the Wild: The human footprint is a global map of human influence on the land surface, which suggests that human beings are stewards of nature, whether we like it or not. BioScience 52:891–904.
Simaika, J. P., M. J. Samways, J. Kipping, F. Suhling, K.-D. B. Dijkstra, V. Clausnitzer, J.-P. Boudot, and S. Domisch. 2013. Continental-scale conservation prioritization of African dragonflies. Biological Conservation 157:245–254.
Stein, B. A., L. S. Kutner, and J. S. Adams. 2000. Precious Heritage: The Status of Biodiversity in the United States. Oxford University Press, Oxford.
Stewart, D. A., and M. J. Samways. 1998. Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African savanna game reserve. Conservation Biology 12:683–692.
Strayer, D. L. 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society 25:271–287.
Strayer, D. L., and D. Dudgeon. 2010. Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society 29:344–358.
Telfer, M. G. 2003. Change index: a measure of change in range size that is independent of changes in survey effort. Proceedings of the 13th International Colloquium European Invertebrate Survey, September 2001 (ed. by G. DeKnijf, A. Anselin, & P. Goffart).107–110. Leiden, Belgium.
Telfer, M. G., C. Preston, and P. Rothery. 2002. A general method for measuring relative change in range size from biological atlas data. Biological Conservation 107:99–109.
USFWS Wildlife & Sport Fish Restoration Program. 2013. State wildlife grant program-overview. [Online]. Available: http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG.htm. [Accessed: 31-Mar-2014].
Vane-Wright, R. I., C. J. Humphries, and P. H. Williams. 1991. What to protect?—Systematics and the agony of choice. Biological conservation 55:235–254.
White, E., J. D. Corser, and M. D. Schlesinger. 2010. The New York dragonfly and damselfly survey: Distribution and status of the odonates of New York. New York Natural Heritage Program, Albany, NY.
Wilcove, D. S., and L. L. Master. 2005. How many endangered species are there in the United States? Frontiers in Ecology and the Environment 3:414–420.
Wilkinson, J., M. P. Smith, and N. Miller. 2013. The watershed approach: Lessons learned through a collaborative effort. National Wetlands Newsletter 35:9–13.

Appendix I. Data used in the vulnerability analysis for 228 odonate taxa in the northeastern US. For field definitions see text.

Taxon	Number of States (out of 13)	Number of counties (out of 434)	Range (1000s km^2) since 1970	Range (1000s km^2), all records	Area of occupancy since 1970 (approximate proportion of range)	Area of occupancy, all records	Coastal Plain Ponds	Peatlands	Fishless Ponds	Low-gradient Small Streams and Seeps	Mod-High Gradient Headwater Streams	Forested Wetland	Salt Marsh/Salt Pond	Mod-High-gradient Rivers & Large Streams	Lake and Pond Shorelines	Low-gradient Rivers and Large Streams	Freshwater Emergent/Shrub Marsh	Number of habitat types (out of 11)	Habitat vulnerability index	Relative change in range	Calculated rank (low)	Calculated rank (high)	**R-rank**	Proportion of range in NE	**Responsibility**
Zygoptera																									
Calopterygidae																									
Calopteryx aequabilis	11	111	351	465	0.65	0.59					x			x		x		3	3.00	-0.71	0.47	0.51	**R4R5**	0.15	**Shared**
Calopteryx amata	11	91	424	428	0.56	0.61					x			x		x		3	3.00	-0.47	0.49	0.50	**R4R5**	0.72	**Primary**
Calopteryx angustipennis	5	44	145	265	0.20	0.24								x				1	3.00	-0.97	0.26	0.30	**R2R3**	0.39	**Significant**
Calopteryx dimidiata	10	55	130	179	0.23	0.38								x				1	3.00	-0.27	0.28	0.32	**R2R3**	0.15	**Shared**
Calopteryx maculata	13	357	609	630	0.73	0.94				x	x			x		x		4	3.25	0.52	0.63	0.68	**R5**	0.19	**Shared**
Hetaerina americana	13	192	542	592	0.26	0.49					x			x		x		3	3.00	0.04	0.49	0.54	**R4R5**	0.08	**Shared**
Hetaerina titia	4	25	5	236	0.23	0.13								x		x		2	2.50	-3.05	0.19	0.29	**R1R2**	0.03	**Shared**
Lestidae																									
Archilestes grandis	9	70	300	396	0.18	0.22				x								1	4.00	-0.51	0.27	0.30	**R2R3**	0.06	**Shared**
Lestes australis	9	108	450	586	0.15	0.28			x						x		x	3	2.67	1.04	0.48	0.54	**R4R5**	0.12	**Shared**
Lestes congener	13	200	546	577	0.55	0.71			x						x		x	3	2.67	0.33	0.57	0.61	**R5**	0.11	**Shared**
Lestes disjunctus	12	150	475	535	0.53	0.64		x	x						x		x	4	3.00	-0.21	0.54	0.58	**R5**	0.08	**Shared**
Lestes dryas	11	119	417	457	0.54	0.64		x	x	x					x		x	5	3.20	-1.05	0.52	0.55	**R5**	0.08	**Shared**
Lestes eurinus	13	183	554	575	0.58	0.67		x	x						x			3	3.67	0.04	0.52	0.54	**R5**	0.51	**Primary**
Lestes forcipatus	13	178	544	589	0.53	0.61		x	x	x					x		x	5	3.20	0.03	0.59	0.61	**R5**	0.32	**Significant**
Lestes inaequalis	13	190	565	599	0.49	0.60									x		x	2	2.00	0.42	0.57	0.60	**R5**	0.40	**Significant**
Lestes rectangularis	13	299	568	628	0.68	0.83			x	x					x		x	4	3.00	0.32	0.62	0.66	**R5**	0.29	**Significant**
Lestes unguiculatus	11	102	364	453	0.30	0.51			x						x			2	3.50	-1.33	0.34	0.41	**R3R4**	0.08	**Shared**
Lestes vigilax	13	234	579	615	0.61	0.73		x	x	x					x		x	5	3.20	0.93	0.64	0.67	**R5**	0.37	**Significant**
Coenagrionidae																									

Taxon	Number of States (out of 13)	Number of counties (out of 434)	Range (1000s km^2) since 1970	Range (1000s km^2), all records	Area of occupancy since 1970 (approximate proportion of range)	Area of occupancy, all records	Coastal Plain Ponds	Peatlands	Fishless Ponds	Low-gradient Small Streams and Seeps	Mod-High Gradient Headwater Streams	Forested Wetland	Salt Marsh/Salt Pond	Mod-High-gradient Rivers & Large Streams	Lake and Pond Shorelines	Low-gradient Rivers and Large Streams	Freshwater Emergent/Shrub Marsh	Number of habitat types (out of 11)	Habitat vulnerability index	Relative change in range	Calculated rank (low)	Calculated rank (high)	**R-rank**	Proportion of range in NE	**Responsibility**
Amphiagrion saucium	13	233	558	620	0.45	0.70				x								1	4.00	0.00	0.42	0.49	**R4**	0.48	**Significant**
Argia apicalis	12	215	446	490	0.46	0.59									x	x		2	2.50	0.27	0.50	0.53	**R4R5**	0.10	**Shared**
Argia bipunctulata	5	31	141	224	0.12	0.16		x		x								2	4.00	0.23	0.26	0.29	**R2**	0.11	**Shared**
Argia fumipennis	13	328	605	629	0.68	0.89				x				x	x	x		4	3.00	0.06	0.62	0.67	**R5**	0.18	**Shared**
Argia moesta	13	286	589	624	0.62	0.83								x	x	x		3	2.67	0.24	0.60	0.64	**R5**	0.14	**Shared**
Argia sedula	5	66	244	294	0.14	0.29								x		x		2	2.50	-0.53	0.35	0.39	**R3**	0.04	**Shared**
Argia tibialis	7	133	358	376	0.29	0.43				x				x	x	x		4	3.00	0.69	0.48	0.51	**R4R5**	0.10	**Shared**
Argia translata	11	142	413	454	0.36	0.44								x	x	x		3	2.67	-0.34	0.47	0.50	**R4**	0.17	**Shared**
Chromagrion conditum	13	248	572	621	0.61	0.77		x		x					x		x	4	3.00	0.39	0.61	0.65	**R5**	0.47	**Significant**
Coenagrion interrogatum	4	13	126	131	0.67	0.65		x				x						2	3.50	0.89	0.40	0.40	**R4**	0.15	**Shared**
Coenagrion resolutum	7	59	297	330	0.51	0.56		x	x	x					x		x	5	3.20	-0.39	0.49	0.51	**R4R5**	0.08	**Shared**
Enallagma anna	1	1	3	3	0.75	0.75				x						x		2	3.00	0.88	0.18	0.18	**R1**	0.00	**Shared**
Enallagma annexum	12	124	483	487	0.51	0.62		x	x						x			3	3.67	-0.20	0.48	0.50	**R4**	0.07	**Shared**
Enallagma antennatum	6	67	283	283	0.27	0.49									x	x		2	2.50	-0.01	0.40	0.44	**R3R4**	0.12	**Shared**
Enallagma aspersum	13	263	582	625	0.67	0.77		x	x						x		x	4	3.00	-0.02	0.61	0.64	**R5**	0.40	**Significant**
Enallagma basidens	8	150	386	413	0.37	0.50				x					x			2	3.50	-0.26	0.40	0.43	**R3R4**	0.10	**Shared**
Enallagma boreale	10	83	393	400	0.49	0.58		x	x						x			3	3.67	-0.39	0.44	0.46	**R4**	0.06	**Shared**
Enallagma carunculatum	9	102	362	457	0.43	0.52									x	x		2	2.50	-0.73	0.44	0.48	**R4**	0.07	**Shared**
Enallagma civile	13	299	577	626	0.58	0.79							x		x	x		3	2.67	0.41	0.59	0.64	**R5**	0.10	**Shared**
Enallagma daeckii	9	44	71	160	0.42	0.34	x					x			x		x	4	3.00	0.64	0.39	0.44	**R3R4**	0.22	**Shared**
Enallagma divagans	13	162	556	599	0.33	0.42				x				x	x			3	3.33	-0.03	0.49	0.51	**R4R5**	0.31	**Significant**
Enallagma doubledayi	8	31	82	193	0.31	0.19	x								x			2	4.00	0.42	0.26	0.31	**R2R3**	0.13	**Shared**
Enallagma dubium	3	10	15	37	0.36	0.30	x			x		x			x			4	3.75	0.52	0.33	0.35	**R3**	0.06	**Shared**
Enallagma durum	12	85	211	243	0.30	0.42							x		x	x		3	2.67	0.12	0.41	0.44	**R4**	0.42	**Significant**
Enallagma ebrium	11	149	365	464	0.80	0.74		x							x		x	3	2.67	-0.34	0.53	0.57	**R5**	0.18	**Shared**

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Enallagma exsulans	13	306	586	624	0.62	0.87								x		x		2	2.50	0.03	0.57	0.63	**R5**	0.25	**Shared**
Enallagma geminatum	13	267	582	606	0.54	0.75									x	x		2	2.50	0.48	0.56	0.61	**R5**	0.30	**Significant**
Enallagma hageni	12	194	521	540	0.62	0.77		x							x		x	3	2.67	-0.12	0.56	0.60	**R5**	0.20	**Shared**
Enallagma laterale	9	51	202	202	0.44	0.44	x								x			2	4.00	-0.53	0.32	0.32	**R3**	1.00	**Primary**
Enallagma minusculum	7	41	174	174	0.68	0.73	x								x			2	4.00	-0.22	0.36	0.38	**R3**	0.78	**Primary**
Enallagma pallidum	3	7	21	21	0.39	0.44				x		x			x			3	3.33	-0.42	0.21	0.21	**R2**	0.09	**Shared**
Enallagma pictum	7	37	119	120	0.52	0.56	x								x			2	4.00	0.46	0.33	0.34	**R3**	1.00	**Primary**
Enallagma recurvatum	6	18	58	58	0.47	0.47	x								x			2	4.00	0.19	0.30	0.30	**R2**	1.00	**Primary**
Enallagma signatum	13	302	609	621	0.57	0.81									x	x		2	2.50	0.59	0.58	0.63	**R5**	0.22	**Shared**
Enallagma traviatum	12	177	491	508	0.37	0.50									x		x	2	2.00	1.69	0.56	0.59	**R5**	0.35	**Significant**
Enallagma vernale	6	46	335	356	0.38	0.37		x							x	x	x	4	2.50	0.70	0.51	0.52	**R5**	0.47	**Significant**
Enallagma vesperum	13	152	536	562	0.42	0.53									x	x		2	2.50	0.76	0.53	0.56	**R5**	0.33	**Significant**
Enallagma weewa	6	26	73	74	0.29	0.42								x		x		2	2.50	0.99	0.36	0.39	**R3**	0.14	**Shared**
Ischnura hastata	13	181	457	538	0.30	0.46			x	x			x		x		x	5	3.00	0.88	0.55	0.60	**R5**	0.12	**Shared**
Ischnura kellicotti	13	89	359	363	0.33	0.40									x			1	3.00	1.34	0.42	0.43	**R4**	0.35	**Significant**
Ischnura posita	13	348	596	629	0.73	0.91		x	x	x		x			x	x	x	7	3.00	1.06	0.74	0.78	**R5**	0.21	**Shared**
Ischnura prognata	7	22	2	181	0.74	0.11						x						1	3.00	-3.89	0.11	0.29	**R1R2**	0.12	**Shared**
Ischnura ramburii	10	72	153	208	0.30	0.36							x		x		x	3	2.33	0.27	0.41	0.44	**R4**	0.05	**Shared**
Ischnura verticalis	13	337	589	618	0.75	0.92			x	x					x	x	x	5	2.80	0.31	0.68	0.71	**R5**	0.17	**Shared**
Nehalennia gracilis	13	142	529	530	0.52	0.59		x										1	4.00	0.64	0.44	0.46	**R4**	0.53	**Primary**
Nehalennia integricollis	7	25	116	191	0.20	0.19		x							x		x	3	2.67	0.26	0.36	0.38	**R3**	0.13	**Shared**
Nehalennia irene	13	193	538	568	0.60	0.72		x							x		x	3	2.67	0.04	0.57	0.60	**R5**	0.22	**Shared**
Telebasis byersi	4	11	56	109	0.12	0.12			x			x						2	3.50	2.77	0.32	0.34	**R3**	0.08	**Shared**
Anisoptera																									

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Petaluridae																									
Tachopteryx thoreyi	7	103	417	420	0.20	0.34				x								1	4.00	-0.19	0.32	0.35	**R3**	0.29	**Significant**
Aeshnidae																									
Aeshna canadensis	12	156	486	488	0.62	0.75		x							x		x	3	2.67	0.10	0.56	0.59	**R5**	0.23	**Shared**
Aeshna clepsydra	9	90	351	355	0.47	0.58		x							x		x	3	2.67	-0.27	0.47	0.50	**R4**	0.57	**Primary**
Aeshna constricta	10	127	378	460	0.58	0.61			x						x		x	3	2.67	-0.40	0.50	0.53	**R5**	0.18	**Shared**
Aeshna eremita	5	48	208	229	0.78	0.76		x							x		x	3	2.67	-0.17	0.49	0.50	**R4**	0.07	**Shared**
Aeshna interrupta	9	76	335	427	0.60	0.54		x							x		x	3	2.67	-0.12	0.49	0.53	**R4R5**	0.05	**Shared**
Aeshna juncea	2	3	36	37	0.42	0.54		x										1	4.00	-0.71	0.07	0.07	**R1**	0.01	**Shared**
Aeshna sitchensis	4	10	120	120	0.55	0.59		x										1	4.00	-0.08	0.29	0.30	**R2R3**	0.06	**Shared**
Aeshna subarctica	6	19	227	227	0.39	0.41		x										1	4.00	0.75	0.32	0.33	**R3**	0.15	**Shared**
Aeshna tuberculifera	13	173	518	561	0.58	0.64		x							x		x	3	2.67	-0.02	0.56	0.58	**R5**	0.43	**Significant**
Aeshna umbrosa	13	269	560	622	0.64	0.81		x		x		x			x			4	3.50	0.08	0.57	0.62	**R5**	0.15	**Shared**
Aeshna verticalis	13	156	499	519	0.58	0.66		x							x		x	3	2.67	-0.22	0.55	0.56	**R5**	0.55	**Primary**
Anax junius	13	335	611	630	0.68	0.90			x						x		x	3	2.67	0.66	0.63	0.67	**R5**	0.09	**Shared**
Anax longipes	13	118	475	565	0.27	0.31	x		x						x		x	4	3.25	0.10	0.48	0.52	**R4R5**	0.29	**Significant**
Basiaeschna janata	13	256	603	626	0.54	0.73				x				x	x	x		4	3.00	-0.01	0.59	0.63	**R5**	0.26	**Significant**
Boyeria grafiana	10	135	502	571	0.50	0.54					x			x	x			3	3.33	-0.59	0.49	0.51	**R4R5**	0.56	**Primary**
Boyeria vinosa	13	294	612	629	0.60	0.84				x	x			x	x	x		5	3.20	0.12	0.63	0.67	**R5**	0.26	**Significant**
Epiaeschna heros	13	199	531	602	0.28	0.50			x	x		x						3	3.67	0.08	0.45	0.52	**R4R5**	0.25	**Shared**
Gomphaeschna antilope	8	39	137	323	0.19	0.14		x				x						2	3.50	-0.72	0.25	0.32	**R2R3**	0.21	**Shared**
Gomphaeschna furcillata	12	178	491	627	0.57	0.56		x				x						2	3.50	0.24	0.48	0.52	**R4R5**	0.52	**Primary**
Nasiaeschna pentacantha	13	104	472	562	0.26	0.31				x		x			x	x		4	3.00	0.18	0.50	0.53	**R4R5**	0.17	**Shared**
Rhionaeschna mutata	13	82	435	441	0.32	0.35		x	x						x		x	4	3.00	0.11	0.49	0.50	**R4**	0.66	**Primary**
Gomphidae																									

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Aphylla williamsoni	1	3	0	5	0.00	0.60									x	x		2	2.50	-0.70	0.22	0.22	**R2**	0.01	**Shared**
Arigomphus cornutus	1	1	7	7	0.99	0.99				x					x			2	3.50	0.88	0.14	0.14	**R1**	0.02	**Shared**
Arigomphus furcifer	10	108	453	469	0.50	0.54		x		x					x			3	3.67	0.11	0.47	0.48	**R4**	0.60	**Primary**
Arigomphus villosipes	13	228	537	554	0.48	0.66				x					x			2	3.50	0.87	0.50	0.54	**R5**	0.63	**Primary**
Dromogomphus spinosus	13	259	602	626	0.55	0.73								x	x	x		3	2.67	0.40	0.59	0.63	**R5**	0.26	**Significant**
Dromogomphus spoliatus	2	8	62	62	0.16	0.16									x	x		2	2.50	-3.05	0.25	0.25	**R2**	0.01	**Shared**
Erpetogomphus designatus	2	26	19	96	0.24	0.28								x		x		2	2.50	2.77	0.39	0.42	**R3R4**	0.03	**Shared**
Gomphus abbreviatus	12	98	484	501	0.36	0.42								x		x		2	2.50	-0.57	0.47	0.48	**R4**	0.92	**Primary**
Gomphus adelphus	12	103	504	514	0.46	0.54					x			x				2	3.50	-0.50	0.44	0.46	**R4**	0.44	**Significant**
Gomphus apomyius	3	9	13	35	0.69	0.37								x				1	3.00	1.63	0.14	0.15	**R1**	0.13	**Shared**
Gomphus borealis	9	90	396	396	0.60	0.64		x							x			2	3.50	-0.12	0.45	0.46	**R4**	0.77	**Primary**
Gomphus consanguis	1	3	5	5	0.89	0.89				x								1	4.00	-1.94	0.05	0.05	**R1**	0.22	**Shared**
Gomphus descriptus	11	103	465	475	0.53	0.57					x			x				2	3.50	-0.38	0.45	0.46	**R4**	0.73	**Primary**
Gomphus exilis	13	287	605	627	0.60	0.81		x		x					x	x		4	3.25	0.26	0.60	0.64	**R5**	0.32	**Significant**
Gomphus fraternus	11	50	392	534	0.15	0.18								x	x	x		3	2.67	-0.33	0.42	0.47	**R4**	0.14	**Shared**
Gomphus lineatifrons	4	33	65	121	0.26	0.35								x		x		2	2.50	-0.72	0.30	0.34	**R3**	0.17	**Shared**
Gomphus lividus	12	228	498	522	0.38	0.66				x					x	x		3	3.00	0.44	0.51	0.57	**R5**	0.26	**Significant**
Gomphus parvidens	2	6	23	47	0.22	0.14					x			x				2	3.50	-2.60	0.15	0.16	**R1**	0.11	**Shared**
Gomphus quadricolor	11	86	442	446	0.31	0.36								x		x		2	2.50	-0.34	0.45	0.46	**R4**	0.41	**Significant**
Gomphus rogersi	7	54	279	279	0.26	0.30					x							1	4.00	0.14	0.29	0.30	**R2R3**	0.65	**Primary**
Gomphus septima delawarensis	3	8	19	24	0.75	0.62								x		x		2	2.50	-0.06	0.23	0.23	**R2**	#N/A	**Primary**
Gomphus septima septima	1	3	6	6	0.43	0.43								x				1	3.00	-1.45	0.13	0.13	**R1**	#N/A	**Shared**
Gomphus spicatus	9	126	391	411	0.66	0.76		x		x					x			3	3.67	0.06	0.48	0.51	**R4R5**	0.33	**Significant**
Gomphus vastus	11	91	469	509	0.21	0.29								x		x		2	2.50	-0.04	0.45	0.47	**R4**	0.18	**Shared**
Gomphus ventricosus	9	25	348	361	0.11	0.14								x		x		2	2.50	-1.04	0.36	0.37	**R3**	0.22	**Shared**

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Gomphus viridifrons	6	43	260	288	0.17	0.23					x			x				2	3.50	-0.57	0.31	0.32	**R3**	0.26	**Significant**
Hagenius brevistylus	13	203	536	621	0.49	0.61								x	x	x		3	2.67	0.14	0.55	0.60	**R5**	0.24	**Shared**
Lanthus parvulus	9	100	439	495	0.45	0.52					x			x				2	3.50	-0.63	0.42	0.45	**R4**	0.77	**Primary**
Lanthus vernalis	12	118	516	564	0.32	0.42					x			x				2	3.50	-0.47	0.42	0.45	**R4**	0.89	**Primary**
Ophiogomphus anomalus	4	24	219	226	0.46	0.50					x			x		x		3	3.00	-1.86	0.37	0.37	**R3**	0.54	**Primary**
Ophiogomphus aspersus	9	65	254	448	0.72	0.43					x			x		x		3	3.00	-0.39	0.41	0.53	**R4R5**	0.73	**Primary**
Ophiogomphus carolus	9	81	410	449	0.44	0.50					x			x				2	3.50	-0.49	0.41	0.43	**R4**	0.51	**Primary**
Ophiogomphus colubrinus	2	6	99	101	0.50	0.51								x		x		2	2.50	-1.08	0.27	0.27	**R2**	0.11	**Shared**
Ophiogomphus howei	7	22	294	319	0.24	0.25								x		x		2	2.50	-0.72	0.38	0.38	**R3**	0.46	**Significant**
Ophiogomphus incurvatus	4	12	95	96	0.14	0.17				x	x			x				3	3.67	-2.66	0.20	0.21	**R2**	0.25	**Significant**
Ophiogomphus mainensis	12	95	489	536	0.45	0.48					x			x				2	3.50	-0.73	0.43	0.45	**R4**	0.78	**Primary**
Ophiogomphus rupinsulensis	11	101	497	548	0.39	0.46								x		x		2	2.50	0.15	0.50	0.52	**R4R5**	0.33	**Significant**
Ophiogomphus susbehcha	2	10	2	31	0.90	0.35					x					x		2	3.00	0.88	0.32	0.44	**R3R4**	0.45	**Significant**
Progomphus obscurus	12	96	463	486	0.17	0.26	x							x	x	x		4	3.25	-0.34	0.45	0.47	**R4**	0.09	**Shared**
Stylogomphus albistylus	13	212	601	613	0.54	0.70					x			x				2	3.50	0.59	0.52	0.56	**R5**	0.51	**Primary**
Stylogomphus sigmastylus	1	1	1	1	0.96	0.96					x			x				2	3.50	-2.29	0.14	0.14	**R1**	0.01	**Shared**
Stylurus amnicola	9	21	245	256	0.13	0.17								x		x		2	2.50	-0.37	0.35	0.36	**R3**	0.12	**Shared**
Stylurus laurae	3	19	72	88	0.18	0.26				x				x				2	3.50	-2.58	0.19	0.21	**R1R2**	0.14	**Shared**
Stylurus notatus	5	7	13	189	0.16	0.07										x		1	2.00	-2.31	0.22	0.31	**R2R3**	0.06	**Shared**
Stylurus plagiatus	7	57	221	334	0.20	0.21				x						x		2	3.00	0.70	0.36	0.40	**R3**	0.07	**Shared**
Stylurus scudderi	12	76	508	508	0.37	0.40				x	x			x		x		4	3.25	-0.03	0.51	0.52	**R5**	0.43	**Significant**
Stylurus spiniceps	13	112	421	559	0.35	0.36								x		x		2	2.50	0.57	0.48	0.52	**R4R5**	0.43	**Significant**
Cordulegastridae																									
Cordulegaster bilineata	5	48	154	171	0.22	0.36				x								1	4.00	1.08	0.27	0.31	**R2R3**	0.29	**Significant**
Cordulegaster diastatops	13	160	551	552	0.50	0.65				x	x							2	4.00	0.21	0.46	0.49	**R4**	0.61	**Primary**

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Cordulegaster erronea	8	74	341	432	0.18	0.23				x								1	4.00	-0.10	0.29	0.33	**R2R3**	0.57	**Primary**
Cordulegaster maculata	13	208	590	610	0.50	0.66				x	x			x		x		4	3.25	-0.16	0.56	0.59	**R5**	0.33	**Significant**
Cordulegaster obliqua	12	118	573	590	0.27	0.34				x								1	4.00	-0.44	0.38	0.39	**R3**	0.31	**Significant**
Macromiidae																									
Didymops transversa	13	229	573	625	0.53	0.69				x				x	x	x		4	3.00	0.41	0.59	0.63	**R5**	0.27	**Significant**
Macromia alleghaniensis	5	36	157	213	0.19	0.23								x		x		2	2.50	-0.60	0.32	0.35	**R3**	0.26	**Significant**
Macromia illinoiensis	13	236	612	622	0.48	0.72					x			x	x	x		4	3.00	0.23	0.59	0.64	**R5**	0.26	**Significant**
Macromia margarita	1	1	1	1	0.87	0.87					x			x				2	3.50	-2.29	0.14	0.14	**R1**	0.04	**Shared**
Macromia taeniolata	5	37	172	238	0.13	0.18									x	x		2	2.50	-0.46	0.32	0.35	**R3**	0.07	**Shared**
Corduliidae																									
Cordulia shurtleffii	12	150	518	519	0.62	0.69		x							x			2	3.50	-0.38	0.48	0.50	**R4**	0.13	**Shared**
Dorocordulia lepida	11	94	327	419	0.60	0.53		x				x			x			3	3.33	-0.19	0.45	0.49	**R4**	0.82	**Primary**
Dorocordulia libera	9	134	356	383	0.78	0.84		x							x		x	3	2.67	0.07	0.55	0.56	**R5**	0.39	**Significant**
Epitheca canis	12	138	459	461	0.57	0.72		x		x					x		x	4	3.00	-0.04	0.55	0.58	**R5**	0.29	**Significant**
Epitheca costalis	6	25	119	147	0.22	0.20				x					x			2	3.50	0.83	0.31	0.32	**R3**	0.06	**Shared**
Epitheca cynosura	13	332	598	630	0.68	0.90		x		x					x	x	x	5	2.80	0.71	0.67	0.72	**R5**	0.25	**Shared**
Epitheca princeps	13	281	588	627	0.62	0.80									x	x		2	2.50	0.47	0.58	0.63	**R5**	0.21	**Shared**
Epitheca semiaquea	8	36	274	338	0.40	0.35	x			x					x			3	4.00	2.50	0.44	0.47	**R4**	0.36	**Significant**
Epitheca spinigera	9	82	284	320	0.68	0.74		x		x					x			3	3.67	-0.48	0.44	0.46	**R4**	0.19	**Shared**
Epitheca spinosa	4	27	73	109	0.24	0.29				x		x			x			3	3.33	0.37	0.32	0.34	**R3**	0.32	**Significant**
Helocordulia selysii	3	21	58	60	0.31	0.42				x	x			x				3	3.67	-2.25	0.24	0.26	**R2**	0.13	**Shared**
Helocordulia uhleri	12	139	457	558	0.36	0.56				x	x			x				3	3.67	-0.52	0.43	0.50	**R4**	0.52	**Primary**
Neurocordulia michaeli	2	13	166	166	0.45	0.49								x				1	3.00	-0.88	0.32	0.33	**R3**	0.84	**Primary**
Neurocordulia molesta	1	6	9	9	0.55	0.55					x			x				2	3.50	-2.60	0.14	0.14	**R1**	0.02	**Shared**
Neurocordulia obsoleta	11	80	498	530	0.25	0.31								x	x	x		3	2.67	-0.31	0.48	0.50	**R4**	0.61	**Primary**

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Neurocordulia virginiensis	1	9	6	18	0.40	0.48								x		x		2	2.50	0.52	0.22	0.23	**R2**	0.08	**Shared**
Neurocordulia yamaskanensis	11	83	462	507	0.39	0.42								x	x	x		3	2.67	0.57	0.52	0.53	**R5**	0.48	**Significant**
Somatochlora albicincta	4	10	82	98	0.72	0.65									x			1	3.00	-0.72	0.34	0.35	**R3**	0.05	**Shared**
Somatochlora brevicincta	1	4	51	51	0.95	0.95		x										1	4.00	0.52	0.07	0.08	**R1**	0.45	**Significant**
Somatochlora cingulata	5	20	155	197	0.65	0.57									x	x		2	2.50	-0.09	0.41	0.44	**R4**	0.23	**Shared**
Somatochlora elongata	11	84	439	463	0.49	0.51		x		x		x						3	3.67	-0.37	0.34	0.35	**R3**	0.50	**Primary**
Somatochlora filosa	5	32	40	64	0.57	0.53				x		x						2	3.50	0.45	0.34	0.35	**R3**	0.16	**Shared**
Somatochlora forcipata	8	43	353	353	0.43	0.47		x		x								2	4.00	-0.47	0.36	0.37	**R3**	0.43	**Significant**
Somatochlora franklini	4	14	126	126	0.70	0.70		x										1	4.00	-0.48	0.32	0.32	**R3**	0.14	**Shared**
Somatochlora georgiana	7	14	82	94	0.19	0.19				x		x						2	3.50	-0.08	0.27	0.27	**R2**	0.20	**Shared**
Somatochlora incurvata	5	29	285	311	0.42	0.39		x										1	4.00	-0.09	0.32	0.33	**R3**	0.57	**Primary**
Somatochlora kennedyi	6	28	206	239	0.46	0.51		x		x								2	4.00	-1.09	0.31	0.33	**R3**	0.25	**Shared**
Somatochlora linearis	11	95	379	472	0.21	0.26				x		x						2	3.50	0.22	0.38	0.41	**R3R4**	0.19	**Shared**
Somatochlora minor	5	18	166	188	0.58	0.58				x								1	4.00	-1.04	0.29	0.30	**R2**	0.14	**Shared**
Somatochlora provocans	4	17	48	51	0.33	0.42				x		x						2	3.50	1.38	0.32	0.34	**R3**	0.21	**Shared**
Somatochlora tenebrosa	13	207	577	601	0.46	0.64		x		x								2	4.00	0.70	0.48	0.52	**R4R5**	0.51	**Primary**
Somatochlora walshii	10	92	398	400	0.57	0.63		x		x							x	3	3.00	0.28	0.51	0.52	**R5**	0.30	**Significant**
Somatochlora williamsoni	11	70	417	457	0.40	0.44				x					x			2	3.50	-0.34	0.41	0.43	**R4**	0.34	**Significant**
Williamsonia fletcheri	5	32	222	222	0.55	0.58		x	x			x						3	3.67	0.25	0.41	0.42	**R4**	0.53	**Primary**
Williamsonia lintneri	7	25	77	101	0.51	0.40		x	x			x						3	3.67	-1.22	0.29	0.32	**R2R3**	0.67	**Primary**
Libellulidae																									
Brachymesia gravida	5	28	28	60	0.31	0.40							x		x		x	3	2.33	1.81	0.41	0.44	**R4**	0.04	**Shared**
Celithemis elisa	13	309	611	629	0.65	0.84		x							x		x	3	2.67	0.72	0.62	0.66	**R5**	0.26	**Significant**
Celithemis eponina	13	247	578	586	0.53	0.65									x		x	2	2.00	0.78	0.59	0.62	**R5**	0.15	**Shared**
Celithemis fasciata	11	107	341	458	0.25	0.29	x								x			2	4.00	1.18	0.37	0.41	**R3R4**	0.14	**Shared**

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Celithemis martha	11	56	297	300	0.34	0.39	x	x							x			3	4.00	-0.29	0.36	0.37	**R3**	0.92	**Primary**
Celithemis ornata	4	6	1	38	0.83	0.20									x		x	2	2.00	-4.18	0.26	0.28	**R2**	0.03	**Shared**
Celithemis verna	7	29	169	185	0.13	0.22	x	x							x		x	4	3.25	1.96	0.41	0.43	**R4**	0.19	**Shared**
Dythemis velox	1	9	42	42	0.24	0.24				x					x	x		3	3.00	0.19	0.25	0.25	**R2**	0.01	**Shared**
Erythemis simplicicollis	13	337	599	606	0.62	0.84				x					x		x	3	2.67	1.06	0.62	0.67	**R5**	0.13	**Shared**
Erythrodiplax berenice	11	87	115	184	0.54	0.49							x					1	3.00	0.11	0.34	0.37	**R3**	0.28	**Significant**
Erythrodiplax minuscula	7	34	182	221	0.09	0.19									x		x	2	2.00	-0.53	0.34	0.37	**R3**	0.06	**Shared**
Ladona deplanata	11	99	269	298	0.30	0.42	x	x							x			3	4.00	2.68	0.43	0.46	**R4**	0.15	**Shared**
Ladona exusta	11	72	261	261	0.46	0.58	x	x							x			3	4.00	0.00	0.38	0.41	**R3R4**	0.85	**Primary**
Ladona julia	12	168	497	515	0.63	0.74		x							x			2	3.50	0.13	0.50	0.52	**R4R5**	0.25	**Shared**
Leucorrhinia frigida	11	139	424	470	0.68	0.71		x							x		x	3	2.67	0.26	0.55	0.57	**R5**	0.42	**Significant**
Leucorrhinia glacialis	11	90	402	402	0.56	0.63		x							x			2	3.50	-0.11	0.44	0.46	**R4**	0.21	**Shared**
Leucorrhinia hudsonica	12	111	446	449	0.57	0.64		x							x			2	3.50	0.09	0.46	0.48	**R4**	0.11	**Shared**
Leucorrhinia intacta	13	216	528	528	0.65	0.81		x	x						x		x	4	3.00	0.04	0.58	0.62	**R5**	0.15	**Shared**
Leucorrhinia patricia	1	5	69	69	0.64	0.64		x										1	4.00	2.77	0.08	0.09	**R1**	0.18	**Shared**
Leucorrhinia proxima	11	99	332	442	0.72	0.59		x							x		x	3	2.67	0.15	0.50	0.56	**R5**	0.16	**Shared**
Libellula auripennis	10	63	246	347	0.21	0.25	x			x					x		x	4	3.25	0.88	0.42	0.46	**R4**	0.15	**Shared**
Libellula axilena	10	81	213	300	0.28	0.33			x	x		x			x			4	3.50	1.28	0.42	0.46	**R4**	0.22	**Shared**
Libellula cyanea	13	254	570	605	0.48	0.61									x	x	x	3	2.00	0.70	0.61	0.64	**R5**	0.29	**Significant**
Libellula flavida	7	54	124	222	0.22	0.27				x								1	4.00	-0.72	0.21	0.25	**R2**	0.13	**Shared**
Libellula incesta	13	250	606	628	0.60	0.70		x							x	x	x	4	2.50	0.70	0.65	0.67	**R5**	0.22	**Shared**
Libellula luctuosa	13	341	589	606	0.67	0.88			x						x	x	x	4	2.50	0.75	0.66	0.70	**R5**	0.13	**Shared**
Libellula needhami	11	82	138	157	0.36	0.51							x		x			2	3.00	0.59	0.36	0.40	**R3**	0.23	**Shared**
Libellula pulchella	13	325	602	620	0.68	0.89		x	x						x	x	x	5	2.80	0.45	0.67	0.71	**R5**	0.11	**Shared**
Libellula quadrimaculata	10	149	363	467	0.78	0.72		x							x			2	3.50	-0.09	0.46	0.51	**R4R5**	0.09	**Shared**

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Libellula semifasciata	13	208	529	601	0.37	0.54		x	x						x		x	4	3.00	0.98	0.56	0.61	**R5**	0.34	**Significant**
Libellula vibrans	11	127	310	328	0.29	0.44			x	x		x			x			4	3.50	1.05	0.45	0.48	**R4**	0.11	**Shared**
Macrodiplax balteata	1	1	0	0	0.94	0.94							x				x	2	2.00	0.88	0.26	0.26	**R2**	0.01	**Shared**
Nannothemis bella	12	98	389	407	0.51	0.59		x										1	4.00	-0.22	0.37	0.39	**R3**	0.50	**Primary**
Pachydiplax longipennis	13	333	596	614	0.63	0.84		x		x		x			x	x	x	6	2.83	0.91	0.70	0.74	**R5**	0.10	**Shared**
Pantala flavescens	13	208	577	608	0.38	0.58			x									1	4.00	0.39	0.43	0.47	**R4**	0.11	**Shared**
Pantala hymenaea	13	175	582	615	0.33	0.46			x									1	4.00	1.13	0.44	0.47	**R4**	0.10	**Shared**
Perithemis tenera	13	314	598	611	0.59	0.79									x	x	x	3	2.00	0.67	0.64	0.68	**R5**	0.14	**Shared**
Plathemis lydia	13	367	611	630	0.71	0.95		x	x	x		x			x	x	x	7	3.00	0.48	0.73	0.77	**R5**	0.11	**Shared**
Sympetrum ambiguum	6	57	194	232	0.12	0.26	x		x			x			x		x	5	3.20	1.16	0.42	0.46	**R4**	0.08	**Shared**
Sympetrum costiferum	9	69	302	324	0.54	0.62			x						x			2	3.50	-0.95	0.38	0.40	**R3R4**	0.08	**Shared**
Sympetrum danae	5	17	182	257	0.46	0.35		x									x	2	2.50	-0.50	0.37	0.41	**R3R4**	0.04	**Shared**
Sympetrum internum	13	183	513	567	0.63	0.66		x		x					x		x	4	3.00	-0.20	0.57	0.59	**R5**	0.10	**Shared**
Sympetrum obtrusum	11	146	527	531	0.52	0.61		x	x	x					x			4	3.75	-0.34	0.51	0.53	**R5**	0.10	**Shared**
Sympetrum rubicundulum	10	193	469	511	0.29	0.55		x		x					x		x	4	3.00	0.53	0.51	0.57	**R5**	0.27	**Significant**
Sympetrum semicinctum	13	209	528	598	0.63	0.70			x	x					x		x	4	3.00	-0.19	0.58	0.61	**R5**	0.12	**Shared**
Sympetrum vicinum	13	312	597	626	0.66	0.85		x		x					x		x	4	3.00	0.15	0.62	0.66	**R5**	0.20	**Shared**
Tramea carolina	13	130	458	527	0.20	0.32	x		x						x			3	4.00	1.39	0.44	0.48	**R4**	0.16	**Shared**
Tramea lacerata	13	252	539	566	0.45	0.65			x						x		x	3	2.67	0.42	0.57	0.62	**R5**	0.09	**Shared**

Habitat color coding: Red=High Vulnerability, Orange=High-Moderate, Yellow=Moderate, Light Blue=Low-Moderate, Dark Blue=Low. Cell shading: Species formerly associated with freshwater marsh, but removed because their association was more with shorelines are indicated by green shading in the marsh column. Only species specialized on coastal plain ponds in some portion of their range are listed for that habitat by an ‘x’. Other, more generalized species that use such ponds are shaded dark gray. The single species restricted to cold acidic ponds is indicated by pale blue shading. This habitat was deleted and merged with lake and pond shorelines. Cut-offs for R-rank are as follows: (0-0.20 for R1, 0.20-0.30 for R2, 0.30-0.40 for R3, 0.40-0.50 for R4, and 0.50-1 for R5).