Prioritizing Odonata for conservation action in the northeastern USA

Erin L. White[1,4], Pamela D. Hunt[2,5], Matthew D. Schlesinger[1,6], Jeffrey D. Corser[1,7], and Phillip G. deMaynadier[3,8]

[1]New York Natural Heritage Program, State University of New York College of Environmental Science and Forestry, 625 Broadway 5th Floor, Albany, New York 12233-4757 USA
[2]Audubon Society of New Hampshire, 84 Silk Farm Road, Concord, New Hampshire 03301 USA
[3]Maine Department of Inland Fisheries and Wildlife, 650 State Street, Bangor, Maine 04401 USA

Abstract: Odonata are valuable biological indicators of freshwater ecosystem integrity and climate change, and the northeastern USA (Virginia to Maine) is a hotspot of odonate diversity and a region of historical and growing threats to freshwater ecosystems. This duality highlights the urgency of developing a comprehensive conservation assessment of the region's 228 resident odonate species. We offer a prioritization framework modified from NatureServe's method 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 USA. We calculated the R-rank based on 3 rarity factors (range extent, area of occupancy, and habitat specificity), 1 threat factor (vulnerability of occupied habitats), and 1 trend factor (relative change in range size). We combine this R-rank with the degree of endemicity (% of the species' USA and Canadian range that falls within the region) as a proxy for regional responsibility, thereby deriving a list of species of combined vulnerability and regional management responsibility. Overall, 18% of the 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. We anticipate that our analysis might serve as a model for guiding and standardizing conservation assessments at multiple scales for Odonata and other diverse taxa that have not yet received attention to prioritization.
Key words: Odonata, conservation, vulnerability, dragonfly, damselfly, Northeast, prioritization, status, rare, at-risk

Freshwater ecosystems host a disproportionate number (∼10%) of described animal species, dominated by aquatic macroinvertebrates, relative to their geographic extent across the earth's surface (<1%) (Strayer and Dudgeon 2010). Because of their frequent proximity to human population centers and simultaneous exposure to aquatic, terrestrial, and atmospheric pollution, freshwater ecosystems in the USA already are impaired and demonstrate symptoms of stress caused by anthropogenic stressors (Strayer 2006, Martinuzzi et al. 2013). In North America, this stress has led to significantly greater rates of endangerment and extinction for freshwater than for terrestrial fauna (Ricciardi and Rasmussen 1999, Wilcove and Master 2005). Freshwater species and habitat declines are less formally documented in many areas of the world than in North America, but endangerment in North America is especially disturbing because of the continent's high global richness and endemism of freshwater fauna (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 comprising 462 species in the USA and Canada (Paulson 2011). Approximately 18% of Odonata in the USA are considered rare and vulnerable to extirpation or extinction (Master et al. 2000). International threats to Odonata also are well documented, and the order is represented on the Red List of Threatened Species (IUCN 2013), but at a relatively lower proportion (∼10%) than for most other freshwater groups (e.g., ∼30% of amphibians) (Clausnitzer et al. 2009). Odonata are valued as biological indicators of freshwater ecosystem integrity (Corbet 1993, Clark and Samways 1996, Stewart and Samways 1998, Kutcher and Bried 2014) and climate

E-mail addresses: [4]white@nynhp.org; [5]phunt@nhaudubon.org; [6]mdschles@esf.edu; [7]jdcorser@esf.edu; [8]phillip.demaynadier@maine.gov

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change (Hassall and Thompson 2008, Bush et al. 2013) because they have: 1) complex life histories requiring aquatic habitat as nymphs and riparian and upland areas as adults, 2) diverse species assemblages with varied tolerances for aquatic pollution, 3) significant predatory influence on the faunal community of many aquatic systems, and 4) large size and conspicuous diurnal behavior, which facilitates 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.

The northeastern USA (Virginia to Maine; hereafter, the Northeast; Fig. 1) hosts an unusually rich and ancient odonate fauna, especially for a temperate region (Master et al. 1998, Collen et al. 2014, Corser et al. 2014), as is exemplified by larger species lists in most northeastern states than in all of Europe combined (Kalkman et al. 2008). Furthermore, coastal New England is recognized as 1 of 4 regions of exceptional conservation significance for odonate biodiversity in North America (Dunkle 1995, Corser et al. 2014). The Northeast also has an early history of European colonization and 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 effects on freshwater ecosystems and resident Odonata.

Recognition of the Northeast as both a hotspot of odonate diversity and a region of increasing threats to freshwater ecosystems highlights the urgency of developing a comprehensive conservation assessment of the region's 228 resident odonate species. A first attempt at such an assessment was made a decade ago when all 50 USA states and all inhabited USA 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 endangered or threatened or declining to levels where recovery becomes unlikely. 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. Several international (e.g., International Union for the Conservation of Nature [IUCN]; NatureServe) and taxon-specific (e.g., Partners in Amphibian and Reptile Conservation [PARC]; Partners in Flight [PIF]) models exist for identifying species' conservation priorities, but the development of SWAPs and associated SGCN lists offers a potentially comprehensive scheme for prioritizing wildlife conservation needs while leveraging access to natural resource professionals and funding for at-risk wildlife.

Figure 1. The location of the states within our study area in the northeastern USA.

The first iteration of assigning species to SGCN lists involved highly variable, often subjective, criteria. As a result, nearly 65% of all Odonata species in the USA, and ~87% in the Northeast, were included on at least 1 state SGCN list, and SGCN listings were highly variable. For example, Alaska listed 100% of its odonate fauna, whereas 15 states listed none (Bried and Mazzacano 2010). Such inconsistencies and lack of a quantifiable, repeatable prioritization approach (coupled in many cases with wide species distributions in the eastern USA) highlight the value of regional-scale assessments, which would reduce edge-of-range effects and provide estimates of rarity less limited in scope. Moreover, transparent scientific criteria for identifying high-priority targets can better meet the intent of SWAPs by helping to inform strategic allocation of limited resources while fostering interstate collaboration. Meaningful conservation actions for freshwater taxa also are often best undertaken at the regional scale, where watersheds and catchment basins form natural boundaries that frequently cross political boundaries (Master et al. 1998, Samways 2007, Collen et al. 2014).

The critical importance of prioritizing the imperiled biota of freshwater habitats for conservation action was highlighted in an insightful review by Strayer and Dudgeon (2010), and conservation biologists have fostered many attempts to assess large regional faunas (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). However, to date no standardized method has been developed 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 Northeast. We used a modified version of NatureServe's method for assessing conservation status ranks (NatureServe 2012) to assign a single, regional vulnerability metric (R-rank) reflecting each species' relative extinction risk in the Northeast. We combine this new vulnerability rubric with an updated analysis of the degree of endemicity (% of the species' USA and Canada range that falls within the Northeast) as a proxy for regional management responsibility. Our goals were 2-fold: 1) to develop a credible list of odonate species of conservation concern in northeastern North America, and more generally, 2) to invite scrutiny of a science-based species-prioritization method that might be applied to assess other taxa that have not yet received adequate conservation attention.

METHODS

Study area

Our study area includes Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Virginia, Washington DC, and West Virginia. These states make up the jurisdictions of 2 regional entities that facilitate collaborative conservation projects across state boundaries: Northeastern Association of Fish and Wildlife Agencies and the Northeast Region of the US Fish and Wildlife Service. Our work originated in a need recognized at the regional level for conservation assessments for nonvertebrate taxa and was supported by all of the state wildlife agencies in the region.

This 630,000-km^2 region consists of 13 different ecoregions. Twenty-eight percent of the land has been converted to development or agriculture and 16% has land conservation status (Anderson and Olivero Sheldon 2011). Freshwater habitats including wetlands are hotspots of wildlife diversity in the Northeast, and the region has 322,000 km of river and stream networks that are highly fragmented with dams and have heavily converted riparian ecosystems (Anderson and Olivero Sheldon 2011).

Data compilation and taxonomy

We worked with at least 1 collaborator from each state in the region to compile all confirmed, county-level odonate data for their jurisdiction from all years (Table 1). The collaborators agreed that the county level was the finest scale at which data were commonly available. We compiled these diverse data sets into a single database containing species name, county, state, year, and source. Most records were based on the adult life stage, but we also included nymphal and exuvial (cast-off larval skin) records. We asked collaborators to include confirmed records only, but criteria for record confirmation varied. Some collaborators confirmed only vouchered records, and others confirmed sight records for selected species. We also obtained distribution data from Odonata Central (Abbott 2007–2014), an online odonate data repository, for the USA and Canada for northeastern species. When the exact year of a record was unknown, we assigned a broad category (e.g., "post-1970", "pre-2005") or "unknown". We chose 1970 as the cutoff for historical vs current records because this year is NatureServe's standard cutoff for Odonata.

Table 1. Databases used in the conservation assessment.

State	Data source
Connecticut	Thomas and Wagner (2014)
Delaware, Maryland, Pennsylvania	H. White, University of Delaware. Personal collection and field notes.
Massachusetts	Massachusetts Audubon (2012)
Massachusetts	Massachusetts Natural Heritage and Endangered Species Program (2010)
Maryland	Maryland Natural Heritage Program (2012)
Maryland, Washington DC	Orr (2012)
Maine	Maine Department of Inland Fisheries and Wildlife (2012)
New Hampshire	New Hampshire Audubon (2012)
New Hampshire	P. Hunt, New Hampshire Audubon. Personal communication.
New Jersey	New Jersey Odonata Survey (2012)
New York	Eib (2013)
New York	New York Natural Heritage Program (2010)
New York	New York Odonate Group (2012)
Pennsylvania	Pennsylvania Natural Heritage Program (2013a)
Pennsylvania	Pennsylvania Natural Heritage Program (2013b)
Rhode Island	V. Brown. Rhode Island Odonata atlas. Rhode Island Natural History Survey and The Nature Conservancy, Providence, Rhode Island. Unpublished data.
Virginia	S. Roble. Virginia Odonata county and city records. Virginia Department of Conservation and Recreation, Division of Natural Heritage, Richmond, Virginia. Unpublished database.
Vermont	M. Blust, Green Mountain College, professor emeritus and B. Pfeiffer, Dragonfly Society of the Americas. Personal communication.
West Virginia	Olcott (2012)
Multiple	Donnelly (2004a, b, c)
Multiple	D. R. Paulson. 2012. Personal collection.
All	Abbott (2007–2014)

We performed quality control on the data set, and removed all hybrids and records for species that our collaborators determined were probable vagrants in the region. Species considered vagrants were those known to be highly migratory and usually were represented by single records at the southern edge of the region or were widely scattered in space and time with no evidence of local breeding. We followed Paulson (2011) for taxonomy and then collapsed nearly all subspecies designations to species level. *Gomphus septima* was separated to subspecies for conservation reasons explained later (see Results). We refer to all taxa in our assessment as "species" for simplicity.

Because of variation within the region in recognition of *Sympetrum janeae*, we recognized all *S. janeae* records as *Sympetrum internum* (Paulson 2011). Connecticut records for *S. internum* and *Sympetrum rubicundulum* were all designated as "*Sympetrum internum* or *rubicundulum*", so these records could not be separated by species. Therefore, we included all "*Sympetrum internum* or *rubicundulum*" records for mapping distributions of both species.

Regional vulnerability analysis

Regional vulnerability assessments for other USA taxa (NEPARC 2010, Anderson and Olivero Sheldon 2011) have often focused on SGCN status (USFWS 2013) and state-level NatureServe conservation status ranks (S-ranks) (Master et al. 2012). However, ~87% of northeastern Odonata are currently listed as SGCN in ≥1 state, and states assign S-ranks using a variety of methods and data. Therefore, we refined our approach as suggested by Bried and Mazzacano (2010). Rather than using existing assessments of state-level status, we modeled our regional vulnerability assessment after NatureServe's approach (Master et al. 2012) to yield a scientific, transparent, and repeatable method.

We calculated a single vulnerability rank for the region (R-rank) based on 5 factors: 3 rarity factors (range extent, area of occupancy, and habitat specificity), 1 threat factor (vulnerability of occupied habitats), and 1 trend factor (relative change in range size) (Fig. 2). That 60% of our vulnerability assessment was composed of rarity factors mirrored the importance of rarity to the NatureServe calculation of rank.

Rarity: range extent We calculated range extent as the area (km^2) of a minimum convex polygon surrounding all occupied Northeast counties since 1970, using the *gConvexHull* command in the *rgeos* package (Bivand and Rundel 2013) in the R statistics software (version 0.3-2; R Project for Statistical Computing, Vienna, Austria). No records fell in the Atlantic Ocean or Laurentian Great

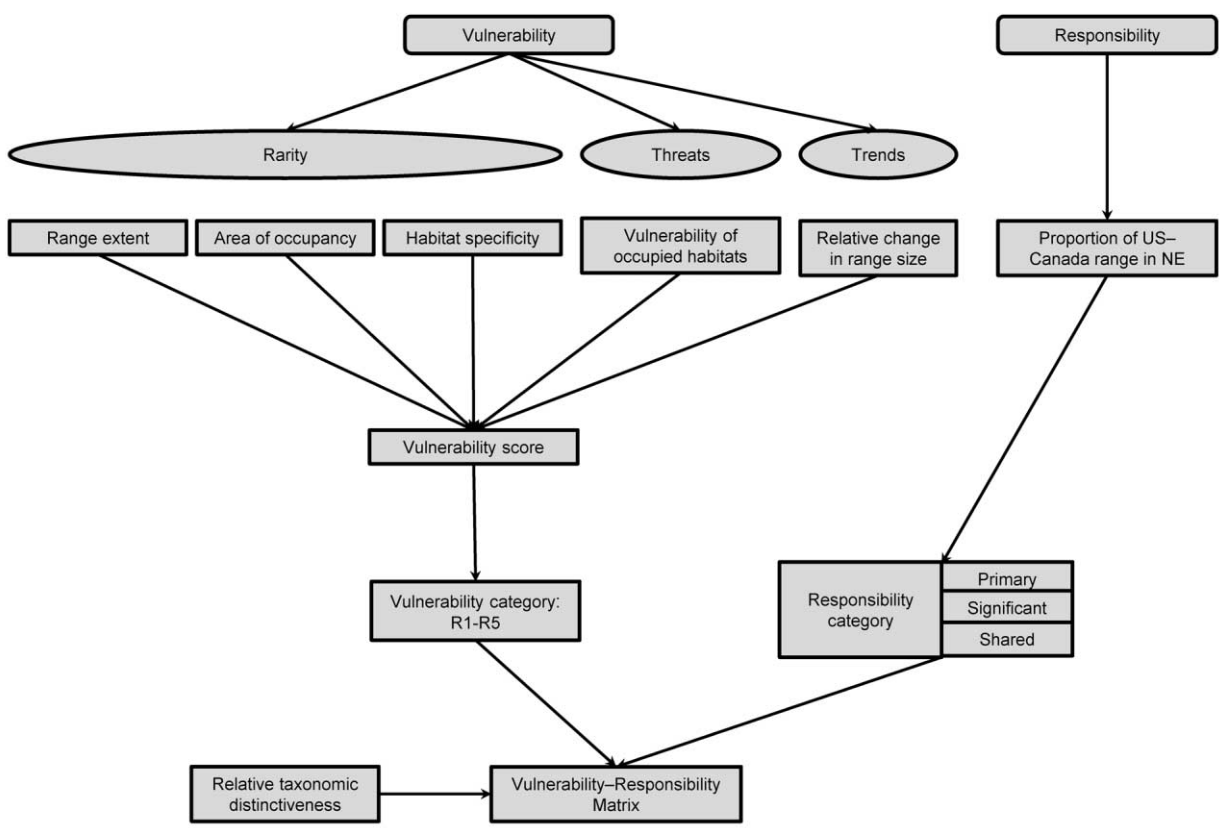

Figure 2. Schematic of conservation prioritization method for Odonata of the northeastern USA.

Lakes, but because of the shape and geography of the region, some species' polygons included large areas of those water bodies, thereby inflating the size of their polygons, whereas other polygons had no such area. Therefore, we clipped out the Atlantic Ocean, Laurentian Great Lakes, and study-area boundaries from all minimum convex polygons (Fig. 3A–F), 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, to accommodate the uncertainty surrounding records without dates. For this portion of the study, all geographic information system (GIS) layers were projected to Albers Equal-Area (NAD 83), and we based area estimates on this projection.

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 southern states), we calculated the area of occupied counties (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 did this calculation 2 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.

Rarity: habitat specificity Habitat specificity is akin to NatureServe's environmental specificity, used when the number of occurrences of a species is unknown, as it was in our data. Anderson et al. (2013) recently described 166 habitat types (143 terrestrial/wetland and 23 aquatic) in the Northeast and modeled 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 classification framework. We identified 11 habitat types (7 lentic and 4 lotic; Appendix S1) for this analysis.

Five of the 7 lentic habitat types corresponded roughly to habitat groups (formations) in the Northeast Classification. In some cases, formations were combined and in others, individual habitat types (macrogroups) were broken off into their own category. These changes were based largely on the degree to which odonate species were known to specialize on a given set of habitat types. Pond habitats

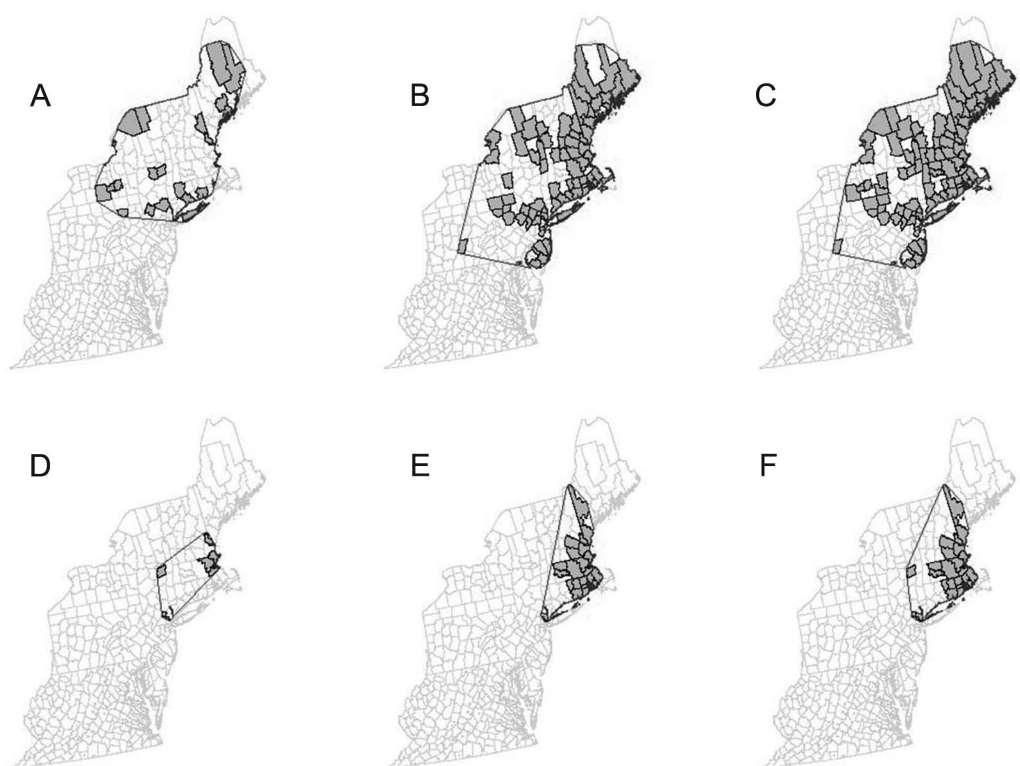

Figure 3. Example range maps of *Aeshna clepsydra* (A–C) and *Williamsonia lintneri* (D–F) with modified convex hull for counties with records prior to 1970 (A, D) counties with records since 1970 (B, E), and all counties with records, including those that could not be assigned to either time period (C, F).

were not mapped by the Northeast Classification, so we created Coastal Plain Pond, Fishless Pond, and Lake and Pond Shoreline habitat types. We assigned Odonata to Coastal Plain Pond and Fishless Pond only if they were considered restricted to these habitat types in some portion of their northeastern range.

The stream portion of the Northeast Classification consists of 23 categories generally reflecting size, temperature, and gradient. For the purposes of this assessment, these 23 types were combined into 4 lotic categories (Appendix S1). Because substrate can be an important determinant of Odonata use, we noted the dominant substrate in our lotic habitat descriptions.

We assigned each species to ≥1 types using 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), and these assignments were reviewed by regional experts. We counted the habitat types used by each species in the region as a measure of habitat specificity (Appendix S2).

Threats: vulnerability of occupied habitats We lacked species-specific vulnerability information for Odonata of the region, so we assigned our threat factor based on expert opinion of vulnerability of the specific habitat types associated with each species. To assess habitat vulnerability, we created a qualitative scale and assigned each habitat type to 1 of 5 categories: Low (L), Low–Moderate (LM), Moderate (M), High–Moderate (HM), and High (H) (Appendix S1). We assigned habitats to vulnerability categories based on expert opinion, literature review, and regional regulatory protections generally afforded the habitat type (Appendix S1). This initial vulnerability assessment was presented at a workshop, at which participants provided valuable input and state-specific perspectives that led to modification of the vulnerabilities of some habitat types.

We calculated a simple index of the vulnerability of occupied habitats as $(5H + 4HM + 3M + 2LM + L)/T$, where T was the total number of habitat types occupied. The multipliers were chosen arbitrarily based on the number of vulnerability categories we selected. 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 a habitat type of low vulnerability only, and a species scoring 5 occupying a habitat type of high vulnerability only.

Trends: relative change in range size We lacked information on species-specific population trends, so we created a surrogate metric for trend by calculating an index of the relative change in range size (Telfer et al. 2002, Telfer 2003) for each species based on the proportion of counties (n = 434) occupied before and after 2000. We chose 2000 as the year of publication of the first field guides (e.g., Dunkle 2000) and the start of many statewide efforts to create atlases. 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 2 periods. The standardized residual is an index of that species' change in range size relative to the trend in the entire species group rather than an absolute increase or decrease. All 434 counties had at least 1 pre2000 record, so we assumed that all had received some sampling effort in both periods.

Bias can 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, including an increase in survey effort over time, are widely understood. Our method minimizes (but does not eliminate) such biases. Our potential bias also was low because we accepted only records verified by experts and because our species pool was very large (228 species).

Overall vulnerability calculation We weighted the 5 factors equally to calculate a single vulnerability score. We normalized all factors to a scale of 0 to 1 by dividing each factor score by the maximum value for that factor, after converting to positive numbers or reordering when needed, so that lower index scores represented greater vulnerability. We added normalized scores and calculated the final index in 2 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 the number of occupied counties was <10, we calculated the index without area of occupancy and relative change in range because those factors can be misleading for very narrowly distributed species. We divided the total by the number of factors (5 for most species, 3 for species occupying <10 counties) to arrive at the final index score that ranged from 0 to 1. We converted the vulnerability index to an R-rank with 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 2 calculations (using post-1970 only and using all records) resulted in different R-ranks, we assigned a range rank, such as R1R2 (Faber-Langendoen et al. 2012).

Regional responsibility analysis

NatureServe created distributional range maps (depicted as shaded counties) for USA records in an ArcGIS (version 10.0; Environmental Systems Research Institute, Redlands, California) geodatabase for all northeastern Odonata. Canadian records with georeferenced coordinates were mapped and intersected against a custom hexagon grid layer in which each hexagon was of a size comparable to a typical eastern USA county (~2590 km^2).

We calculated regional responsibility (sensu Rosenberg and Wells 1995, NEPARC 2010) as the proportion of the USA and Canadian range that fell within the Northeast. We used the area (km^2) of occupied US counties and Canadian hexagons across all years to calculate this statistic. We assigned species to 1 of 3 categories based on the responsibility calculation: primary responsibility species for which ≥50% of their range fell in the Northeast, significant responsibility species for which 25 to 50% of their range fell in the Northeast, and shared responsibility species for which <25% of their range fell in the Northeast (Table 2).

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

$$\mathrm{RTD} = 1/\sqrt{\text{family} \times \text{genus} \times \text{species}}$$

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, more distinct taxa like *Tachopteryx* received higher index scores than more speciose groups like *Enallagma*. In Table 3, we highlight those species that fell in the top 15% of the overall range of index scores, a conservative taxonomic threshold.

Table 2. Number of species within each vulnerability rank (R1 = highest, R5 = lowest) in each responsibility category.

Responsibility category	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

RESULTS

Data summary and regional odonate fauna

The compiled data set contained 248,059 records, with location data across the 13 states. Some of these records were duplicates, but our analysis included only unique combinations of species, county, and year, so duplicates could be ignored. After consulting with state and regional experts, we arrived at a final list of 228 breeding odonate species, including 162 Anisoptera and 66 Zygoptera. The number of states occupied/species ranged from 1 to 13 (mean ± SD: 9.13 ± 3.91) and the number of counties occupied ranged from 1 to 367 (115.96 ± 97.56).

Regional vulnerability

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*), whereas species occupying much of the region covered nearly 630,000 km^2 (e.g., *Boyeria vinosa*, *Anax junius*) (mean: 379,867 ± 205,280). Area of occupancy, considering records from all time periods, ranged from 0.07 for species with widely scattered records to 1.00 for species with no gaps in their distribution (mean: 0.53 ± 0.22). Area of occupancy and range extent were positively correlated ($r_s = 0.47$, $p < 0.001$), but the relationship was somewhat u-shaped, with higher areas of occupancy at the extreme values of range extent and no obvious relationship at intermediate values of range extent. Habitat associations (and all metrics of our assessment) are given in Appendix S2. The number of associated habitat types ranged from 1 to 7 of a possible 11 (mean: 2.64 ± 1.14). The habitat vulnerability index ranged from 2.0 to 4.0 (mean: 3.16 ± 0.56). Habitat specificity and the index of habitat vulnerability were uncorrelated. Based on the proportions of the 434 counties occupied by a species before and after 2000 (controlled for survey effort), those species with the largest declines or increases relative to the fauna as a whole generally were species at the margin of their range in the Northeast. Thus, they had initially low occupancy so that a small change after 2000 caused a relatively large change in index value.

Final vulnerability scores ranged from 0.15 to 3.92 (mean: 2.17 ± 0.78) and, once rescaled from 0 to 1, resulted in 15 species assigned to R1, 27 species assigned to R2, 47 species assigned to R3, 69 species assigned to R4, and 70 species assigned to R5. Families with the most R1 species were Gomphidae and Corduliidae (Fig. 4). The habitat types occupied by the most R1 species were

Table 3. Matrix of odonate species sorted into 3 regional vulnerability and responsibility groups.

Vulnerability	Primary responsibility (≥50%)	Significant responsibility (25–50%)	Shared responsibility (<25%)	
High (R1–R2)	*Cordulegaster erronea*[b]	*Calopteryx angustipennis*[b]	*Aeshna juncea*[a]	*Gomphus septima septima*[a]
	Enallagma recurvatum	*Cordulegaster bilineata*[b]	*Aeshna sitchensis*	*Helocordulia selysii*
	Gomphus rogersi	*Ophiogomphus incurvatus*	*Aphylla williamsoni*[a]	*Hetaerina titia*[b]
	Gomphus septima delawarensis	*Somatochlora brevicincta*[a]	*Archilestes grandis*[b]	*Ischnura prognata*
	Williamsonia lintneri		*Argia bipunctulata*	*Leucorrhinia patricia*[a]
			Arigomphus cornutus[a]	*Libellula flavida*
			Calopteryx dimidiata[b]	*Macrodiplax balteata*[a]
			Celithemis ornata	*Macromia margarita*[ab]
			Dromogomphus spoliatus[a]	*Neurocordulia molesta*[a]
			Dythemis velox[a]	*Neurocordulia virginiensis*[a]
			Enallagma anna[a]	*Ophiogomphus colubrinus*[a]
			Enallagma doubledayi	*Somatochlora georgiana*
			Enallagma pallidum	*Somatochlora minor*
			Gomphaeschna antilope	*Stylogomphus sigmastylus*[a]
			Gomphus apomyius	*Stylurus laurae*
			Gomphus consanguis[a]	*Stylurus notatus*
			Gomphus parvidens[a]	
Moderate (R3)	*Celithemis martha*	*Cordulegaster obliqua*[b]	*Aeshna subarctica*	*Libellula needhami*
	Enallagma laterale	*Epitheca spinosa*	*Argia sedula*	*Macromia taeniolata*[b]
	Enallagma minusculum	*Erythrodiplax berenice*	*Celithemis fasciata*	*Nehalennia integricollis*
	Enallagma pictum	*Gomphus viridifrons*	*Enallagma antennatum*	*Somatochlora albicincta*
	Ladona exusta	*Macromia alleghaniensis*[b]	*Enallagma basidens*	*Somatochlora filosa*
	Nannothemis bella	*Ophiogomphus howei*	*Enallagma daeckii*	*Somatochlora franklini*
	Neurocordulia michaeli[a]	*Ophiogomphus susbehcha*[a]	*Enallagma dubium*	*Somatochlora kennedyi*
	Ophiogomphus anomalus	*Somatochlora forcipata*	*Enallagma weewa*	*Somatochlora linearis*
	Somatochlora elongata	*Tachopteryx thoreyi*[b]	*Epitheca costalis*	*Somatochlora provocans*
	Somatochlora incurvata		*Erpetogomphus designatus*[a]	*Stylurus amnicola*
			Erythrodiplax minuscula	*Stylurus plagiatus*
			Gomphus lineatifrons	*Sympetrum costiferum*
			Gomphus ventricosus	*Sympetrum danae*
			Lestes unguiculatus	*Telebasis byersi*[b]
Low R4–R5)	*Aeshna clepsydra*	*Aeshna tuberculifera*	*Aeshna canadensis*	*Lestes congener*
	Aeshna verticalis	*Amphiagrion saucium*[b]	*Aeshna constricta*	*Lestes disjunctus*
	Arigomphus furcifer	*Anax longipes*	*Aeshna eremita*	*Lestes dryas*
	Arigomphus villosipes	*Basiaeschna janata*[b]	*Aeshna interrupta*	*Leucorrhinia glacialis*
	Boyeria grafiana	*Boyeria vinosa*	*Aeshna umbrosa*	*Leucorrhinia hudsonica*
	Calopteryx amata[b]	*Celithemis elisa*	*Anax junius*	*Leucorrhinia intacta*
	Cordulegaster diastatops[b]	*Chromagrion conditum*[b]	*Argia apicalis*	*Leucorrhinia proxima*
	Dorocordulia lepida	*Cordulegaster maculata*[b]	*Argia fumipennis*	*Libellula auripennis*
	Gomphaeschna furcillata	*Didymops transversa*[b]	*Argia moesta*	*Libellula axilena*
	Gomphus abbreviatus	*Dorocordulia libera*	*Argia tibialis*	*Libellula incesta*
	Gomphus borealis	*Dromogomphus spinosus*	*Argia translata*	*Libellula luctuosa*
	Gomphus descriptus	*Enallagma aspersum*	*Brachymesia gravida*	*Libellula pulchella*
	Helocordulia uhleri	*Enallagma divagans*	*Calopteryx aequabilis*[b]	*Libellula quadrimaculata*
	Lanthus parvulus	*Enallagma durum*	*Calopteryx maculata*[b]	*Libellula vibrans*
	Lanthus vernalis	*Enallagma geminatum*	*Celithemis eponina*	*Nasiaeschna pentacantha*[b]
	Lestes eurinus	*Enallagma traviatum*	*Celithemis verna*	*Nehalennia irene*

Table 3 (*Continued*)

Vulnerability	Primary responsibility (≥50%)	Significant responsibility (25–50%)	Shared responsibility (<25%)	
	Nehalennia gracilis	*Enallagma vernale*	*Coenagrion interrogatum*[b]	*Pachydiplax longipennis*
	Neurocordulia obsoleta	*Enallagma vesperum*	*Coenagrion resolutum*[b]	*Pantala flavescens*
	Ophiogomphus aspersus	*Epitheca canis*	*Cordulia shurtleffii*[b]	*Pantala hymenaea*
	Ophiogomphus carolus	*Epitheca semiaquea*	*Enallagma annexum*	*Perithemis tenera*
	Ophiogomphus mainensis	*Gomphus adelphus*	*Enallagma boreale*	*Plathemis lydia*
	Rhionaeschna mutata[b]	*Gomphus exilis*	*Enallagma carunculatum*	*Progomphus obscurus*
	Somatochlora tenebrosa	*Gomphus lividus*	*Enallagma civile*	*Somatochlora cingulata*
	Stylogomphus albistylus	*Gomphus quadricolor*	*Enallagma ebrium*	*Sympetrum ambiguum*
	Williamsonia fletcheri	*Gomphus spicatus*	*Enallagma exsulans*	*Sympetrum internum*
		Ischnura kellicotti	*Enallagma hageni*	*Sympetrum obtrusum*
		Lestes forcipatus	*Enallagma signatum*	*Sympetrum semicinctum*
		Lestes inaequalis	*Epiaeschna heros*[b]	*Sympetrum vicinum*
		Lestes rectangularis	*Epitheca cynosura*	*Tramea carolina*
		Lestes vigilax	*Epitheca princeps*	*Tramea lacerata*
		Leucorrhinia frigida	*Epitheca spinigera*	
		Libellula cyanea	*Erythemis simplicicollis*	
		Libellula semifasciata	*Gomphus fraternus*	
		Macromia illinoiensis[b]	*Gomphus vastus*	
		Neurocordulia yamaskanensis	*Hagenius brevistylus*	
		Ophiogomphus rupinsulensis	*Hetaerina americana*[b]	
		Somatochlora walshii	*Ischnura hastata*	
		Somatochlora williamsoni	*Ischnura posita*	
		Stylurus scudderi	*Ischnura ramburii*	
		Stylurus spiniceps	*Ischnura verticalis*	
		Sympetrum rubicundulum	*Ladona deplanata*	
			Ladona julia	
			Lestes australis	

[a] Occurs in only 1 or 2 states.
[b] High relative taxonomic distinctiveness index (>0.15).

Moderate–High Gradient Headwater Stream, 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 hosted more R2 species than other habitat types. Three of the 7 R2 species found in Lake and Pond Shoreline also inhabited lotic habitat types. Peatlands hosted a disproportionate number of at-risk Odonata and ½ of species known to use Coastal Plain Ponds are considered highly or moderately vulnerable in the region (Fig. 5).

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% (regional endemics *Enallagma laterale*, *E. pictum*, and *E. recurvatum*). Based on 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 2). Gomphidae and Corduliidae are among the families with the most species of primary responsibility in the region (Fig. 6). Final maps can be found online through the NatureServe Explorer website (http://explorer.natureserve.org/) showing both current and historical distributions in North America (New York Natural Heritage Program and NatureServe 2014).

Prioritization matrix

We created a matrix of species vulnerability and regional responsibility to identify priorities for conservation of Odonata in the Northeast (Table 3). The matrix has 3 vulnerability categories (high: R1–R2, medium: R3, and low: R4–R5) and 3 responsibility categories (primary, significant, and shared). Range ranks were rounded to the more vul-

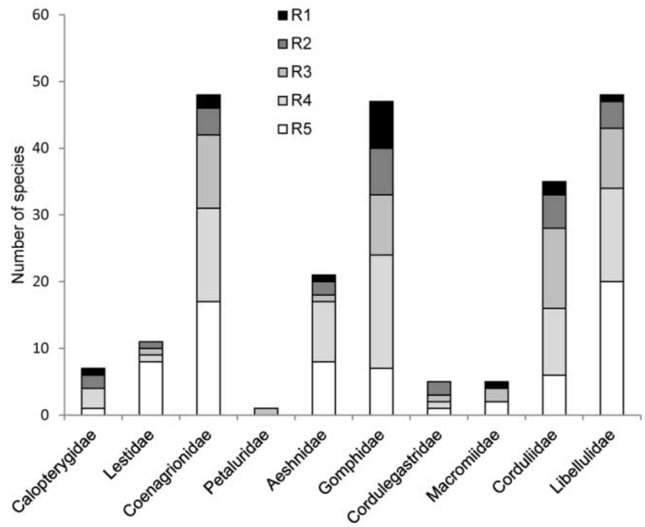

Figure 4. The number of northeastern USA odonate species in each vulnerability category (R1 = highest vulnerability, R5 = lowest vulnerability) by family.

nerable category for this purpose. The 5 levels of vulnerability were collapsed into 3 for ease of interpretation and comparison to similar regional assessments for other taxa. We highlighted species occurring in just 1 or 2 states because these species may not justifiably be considered regional priorities. We also highlighted species that are in the top 15% of taxonomically distinct species in the region. Five dragonfly species are the highest priority for conservation in the Northeast because of a combination of high vulnerability and primary responsibility. The matrix permits users to identify many other high and intermediate conservation priorities depending on user-defined thresholds for the complementary concepts of vulnerability and responsibility.

We recommend special attention for particular species that currently hold subspecies status, but that may be designated as separate species in the near future. We were unable to use subspecies designations for *Ophiogomphus mainensis* (*mainensis* vs. *fastigiatus*) because we could not assign all regional records to subspecies. The southern portion of the range of *O. mainensis* holds populations of *O. mainensis fastigiatus*, which probably will be raised to full species status in the near future (T. Donnelly, SUNY-Binghamton, professor emeritus and J. McCann, Maryland Department of Natural Resources, personal communication). In addition, we were not able to discern subspecies for *Cordulegaster obliqua*, and disagreement exists regarding whether this taxon has 2 subspecies. *Gomphus septima septima* and *G. s. delawarensis* both occur in the study region, and we assigned species-level records to 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 New Jersey, New York, and Pennsylvania, whereas *G. s. septima* is known from Virginia and farther south.

DISCUSSION

Prioritizing species for conservation actions based on measures of rarity and threat is a useful way to help conservation biologists direct limited resources to species most in need of management attention. Many well known examples exist at larger global (e.g., IUCN, NatureServe) and national (e.g., US Endangered Species Act, Committee on the Status of Endangered Wildlife in Canada) scales. Fewer such examples exist at local or regional scales (but see PIF, Panjabi et al. 2012; PARC, NEPARC 2010).

Most rigorous prioritization methods require detailed knowledge of geographic distribution, population status, and life history. As such, few comprehensive status assessments have been conducted for invertebrates because of the lack of detailed knowledge for most of these taxa. Among north-temperate invertebrates, Odonata present an exception to both challenges in that the number of species is manageable and their distribution and biology are relatively well known. To this end, we offer a species conservation prioritization approach for northeastern Odonata, modeled after a widely accepted method for determining vulnerability status (NatureServe 2012). This method has been designed

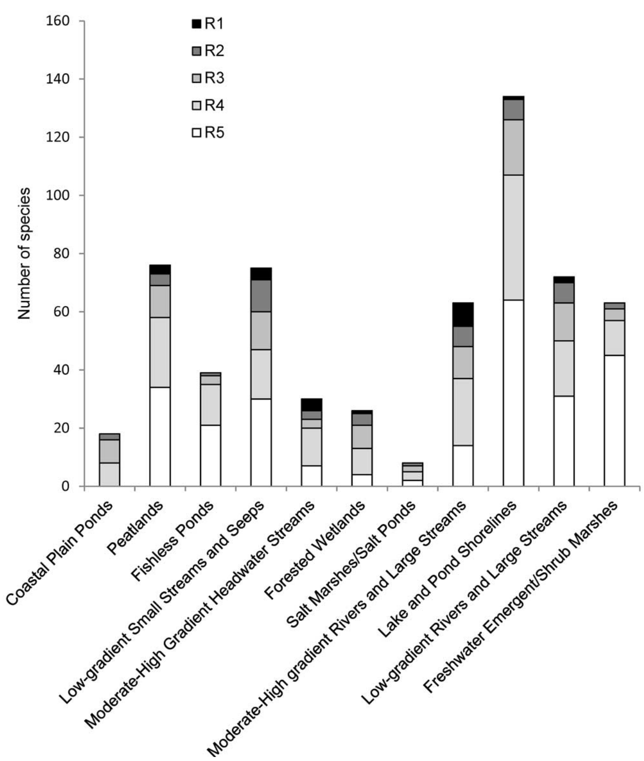

Figure 5. The number of northeastern USA odonate species in each vulnerability category (R1 = highest vulnerability, R5 = lowest vulnerability) displayed by habitat type. Habitats are listed in decreasing order of vulnerability from left to right.

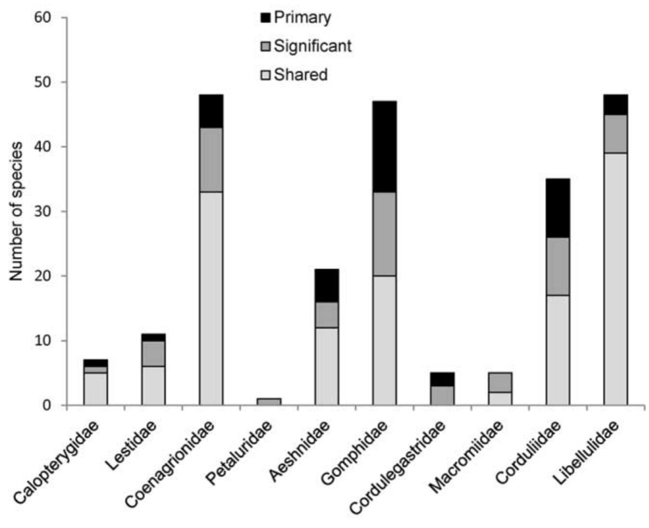

Figure 6. The number of northeastern USA odonate species in each responsibility category (primary responsibility: ≥50% of species' range fell in the northeastern USA, significant: 25–50% of species' range fell in the northeastern USA, shared: <25% of species' range fell in the northeastern USA) displayed by family.

to assist conservation practitioners in identifying broader (taxonomic and habitat) patterns in vulnerability and individual species of regional conservation concern.

Our vulnerability assessment is largely species based, but we related species to regional freshwater ecosystems, in part to highlight the importance of habitat-based conservation approaches (Strayer 2006). A coarse-filter (habitat focus) and fine-filter (species focus) strategy for landscape-scale conservation planning is frequently recommended for applied insect conservation (e.g., Samways 2007). A habitat-based approach is efficient at protecting multiple species within a system, but it also can be important for single species when populations are difficult to quantify (as is often the case for insects) and the species is management-reliant (Bried et al. 2014). Coarse-filter approaches are often coupled with a fine-filter approach to help focus conservation effort on the rarest species that need additional management attention (Nature Conservancy 2004). Coarse-filter insect-management strategies should include habitat protection and maintaining large, high-quality, connected patches of freshwater habitat (Samways 2007, Collen et al. 2014). Furthermore, forest and other natural and seminatural land uses surrounding aquatic breeding habitats are very important to Odonata because intact riparian and wetland buffers increase the health of aquatic systems and provide adult habitat for maturing, roosting, and foraging (Corbet 2006). Odonate conservation also is compatible with protection of freshwater resources and water quality for human use (Strayer 2006) and with watershed-wide planning (Wilkinson et al. 2013).

Last, species prioritization is only as valuable as the applied conservation strategies that make use of the information. We recommend that a regional working group build upon our assessment results by developing a comprehensive conservation plan for northeastern Odonata that includes protocols for surveys, monitoring, research, habitat protection, and education. We present considerations for such a working group and highlights from our analysis below.

Prioritization highlights and guidance

Our prioritization revealed that species living in seep, peatland, and riverine habitats dominate the categories of highly vulnerable species of primary and significant responsibility (Appendix S2, Fig. 5). Many seep obligates (e.g., *Cordulegaster erronea*, *C. obliqua*, *Argia bipunctulata*, and *Tachopteryx thoreyi*) have vulnerability ranks of R2 and R3. The most vulnerable habitat type was Coastal Plain Pond, but this type hosted fewer total regional priority species. Most damselflies that breed in this habitat are highly or moderately vulnerable (R1–R3), highlighting the importance of Coastal Plain Ponds to Odonata conservation in the Northeast.

Taxonomic patterns in vulnerability are highlighted in Fig. 4. Seventy-two percent of peatland dwelling corduliids (species in the genera *Somatochlora* and *Williamsonia*) have a regional vulnerability rank of high or moderate (R1–R3). In general, riverine habitats were not ranked as vulnerable in the Northeast, but a large proportion of riverine species are in the highly vulnerable categories (67% of R1 and 63% of R2 species are primarily lotic; Appendix S2). This pattern also occurs in the US at the state level (White et al. 2010, Patten and Smith-Patten 2013). Similarly, 49% of species in the family Gomphidae and 43% of species in the family Calopterygidae, all mainly riverine taxa, fall in R1 to R3 categories, supporting Bried and Mazzacano's (2010) findings. Clausnitzer et al. (2012) also noted that lotic species generally have smaller ranges than lentic species and, thus, are less tolerant of environmental changes and more likely to be threatened. Northeastern lotic habitats also could be experiencing degradation or other pressures (Bried and Mazzacano 2010) and, thus, could be more vulnerable than our assessment suggests. The families Gomphidae and Corduliidae also have the largest proportions (30 and 26%, respectively) of species in the primary responsibility category (Fig. 6), highlighting the importance of peatland and riverine habitats for Odonata conservation.

Therefore, we suggest implementing habitat-based 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: 1) Peatlands, 2) Low-Gradient Small Streams and Seeps, 3) Moderate–High Gradient Headwaters, and 4) rivers and large streams (Moderate–High Gradient and Low-Gradient) for highly vulnerable species, with the addition of 5) Coastal Plain Ponds for moderately vulnerable species.

From a species perspective, we recommend that each northeastern state consider species of high regional vulnerability (R1–R2), moderate regional vulnerability (R3), and primary or significant responsibility for SGCN for State Wildlife Action Plans. Species falling in these categories should be evaluated by jurisdictions where they occur in the Northeast as to whether species-specific conservation actions are needed. Species should be further prioritized, if necessary, based on whether the Northeast hosts a primary (>50%) or significant (>25%) proportion of their North American range. Those jurisdictions with access to relatively more capacity for invertebrate conservation might also consider monitoring low regional vulnerability species (R4–R5) of primary responsibility in the Northeast.

The 3 endemic damselfly species in the Northeast (*Enallagma laterale* [R3], *Enallagma pictum* [R3], and *Enallagma recurvatum* [R2]) and near-endemic *Enallagma minisculum* (R3) should be monitored and conservation measures implemented to ensure they do not become increasingly vulnerable. These geographically restricted damselflies are ecologically similar in life history and specialized to relatively undisturbed lacustrine habitats and are relatively extinction prone (Butler and deMaynadier 2008).

Vulnerability or regional responsibility aside, we also have highlighted taxonomically distinct species as a simple evolutionary approach to fine-filter conservation attention. We think that conserving older relictual species (e.g., *Tachopteryx*) and younger groups undergoing active speciation (e.g., *Enallagma*) is warranted. In light of our cursory taxonomic analysis here, the phylogenetic trees in Corser et al. (2014) could be consulted to more systematically pinpoint lineages that have disproportionally contributed to diversity of Odonata in the Northeast. Conservation of such taxa and their associated habitats will help to preserve both ecological and evolutionary potentials into the future.

Limitations and assumptions

We strove to conduct an assessment that was objective and repeatable, but later iterations of our method could benefit from some improvements. For example, we did not have information on population trends, and relied instead on relative change in range size as a surrogate measure. The statistical method we used accounts for overall differences in effort between the 2 periods, but it assumes that relative survey effort toward different taxa, habitats, and geographies did not vary between periods, an assumption we could not test. For example, if a certain species was detected less frequently before 2000 because interest in that species was lower, then it might have been erroneously identified as having increased. Given that interest in individual species (or habitats) as conservation targets is likely to wax and wane, additional data collected in the future should enable a more robust analysis of change over time.

In addition, we recognize the limitations of Canadian data and nonnortheastern USA state data used in our analysis because many current odonate records for North America (post2004) are not available in the Odonata Central database. We decided to focus our limited data-gathering efforts on mining databases in our study area, the Northeast (Table 1). We referred to Odonata Central, an online odonate data repository, to obtain records from outside our study area. If complete and current information could be obtained for all of North America, our regional responsibility calculations might decrease the Northeast responsibility rank for some species (e.g., from primary to significant), if species were found to have greater ranges outside our region. Therefore, the potential bias of our analysis is likely to be one of species inclusion in higher responsibility lists, which we consider preferable to a bias of species exclusion when identifying potential species of conservation concern.

A further limitation of our analysis was its spatial scale. Whereas states that had conducted recent atlas-style inventories had point data (species records tied to a set of x–y coordinates), many states had species records by county only, so the county became our smallest unit of analysis. However, northeastern US counties are not of equal size, and counties tend to be larger to the north, thereby making estimates of area occupied challenging and potentially inflating range extent estimates for northerly species. Precise locality data would have enabled us to avoid these potential biases. Comparisons to vague historical records will always be challenged by imprecise locality data from the past, but with use of global positioning system technology now standard in field inventories and citizen-science efforts, future analyses will have the benefit of precise location data that can be rolled up to any number of coarser grid sizes, watersheds, ecoregions, and political units. Point data also will assist with identification of species-habitat associations driven more by data than by expert opinion.

Conclusions

In a comprehensive assessment of USA biodiversity, Master et al. (2000) 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 ½ of the 41 imperiled species in our assessment are listed because they are near their range margins in the Northeast (Table 3). Arguably, investing local conservation effort in highly vulnerable edge-of-range species (e.g., species occurring in 1 or 2 states in the Northeast) has value for conserving genetic diversity of the species as a whole and for preserving ecosystem function where the species occurs (Hunter and Hutchinson 1994). Nonetheless, when conservation resources are limited, these more localized conservation targets should be weighed against other critical conservation priorities at regional and global scales.

Our analysis has demonstrated the ongoing need for atlasing efforts directed at all northeastern Odonata to keep the regional database comprehensive and dynamic. Furthermore, spatially explicit tracking of highly vulnerable and primary responsibility species populations is important for monitoring population status of the region's highest priority species and for guiding targeted conservation practices on the ground.

We anticipate that our conservation 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. Our method uses transparent, quantitative, and scientific criteria, and we invite its replication in geographic regions beyond the Northeast and with other invertebrate taxa lacking comprehensive conservation assessments.

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LITERATURE CITED

Abbott, J. 2007–2014. Odonata Central: an online resource for the distribution and identification of Odonata. University of Texas at Austin, Austin, Texas. (Available from: http://www.odonatacentral.org/index.php)

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. Eastern Conservation Science, The Nature Conservancy, Boston, Massachusetts.

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. Eastern Conservation Science, The Nature Conservancy, Boston, Massachusetts.

Beaton, G. 2007. Dragonflies and damselflies of Georgia and the southeast. Wormsloe Foundation Publications, Athens, Georgia.

Bivand, R., and C. Rundel. 2013. rgeos: interface to geometry engine—open source (GEOS). R Project for Statistical Computing, Vienna, Austria. (Available from: http://cran.r-project.org)

Bried, J., T. Tear, R. Shirer, C. Zimmerman, N. Gifford, and S. Campbell. 2014. A framework to integrate habitat monitoring and restoration with endangered insect recovery. Environmental Management 54(6):1–14.

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.

Butler, R. G., and P. G. deMaynadier. 2008. The significance of aquatic and shoreline habitat integrity to the conservation of lacustrine damselflies (Odonata). Journal of Insect Conservation 12:23–36.

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., K.-D. B. Dijkstra, R. Koch, J.-P. Boudot, W. R. Darwall, J. Kipping, B. Samraoui, M. J. Samways, J. P. Simaika, and F. Suhling. 2012. Focus on African freshwaters: hotspots of dragonfly diversity and conservation concern. Frontiers in Ecology and the Environment 10:129–134.

Clausnitzer, V., V. J. Kalkman, M. Ram, B. Collen, J. E. M. Baillie, M. Bedjanic, W. R. T. Darwall, K.-D. 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. 2006. Forests as habitats for dragonflies (Odonata). Pages 13–36 *in* A. C. Rivera (editor). Forests and Dragonflies. Fourth WDA International Symposium of Odonatology, Pensoft Publishers, Sofia, 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 7:393–404.

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.

Dunkle, S. W. 1995. Conservation of dragonflies (Odonata) and their habitats in North America. Pages 23–27 *in* P. S. Corbet, S. W. Dunkle and H. Ubukata (editors). Proceedings of the International Symposium on the Conservation of Dragonflies and their Habitats. Japanese Society for Preservation of Birds, Kushiro, Japan.

Dunkle, S. W. 2000. Dragonflies through binoculars. Oxford University Press, New York.

Eib, D. 2013. Staten Island dragonfly atlas, 2009–2013. Staten Island Museum, Staten Island, New York. (Available from: http://sidragonflyatlas.blogspot.com/)

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.

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 and 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 (International Union for the Conservation of Nature). 2013. IUCN Red List of Threatened Species. Version 2013.1. International Union for the Conservation of Nature, Gland, Switzerland. (Available from: www.iucnredlist.org)

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.

Maine Department of Inland Fisheries and Wildlife. 2012. Maine damselfly and dragonfly survey (MDDS) database. Maine Department of Inland Fisheries and Wildlife, Bangor, Maine. (Available from: http://mdds.umf.maine.edu/)

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.

Maryland Natural Heritage Program. 2012. Database report for select rare, threatened and endangered Odonata of Maryland. Wildlife and Heritage Service, Maryland Department of Natural Resources, Annapolis, Maryland.

Massachusetts Audubon. 2012. Massachusetts Audubon odonate database. Massachusetts Audubon, Lincoln, Massachusetts. (Available from: sanctuaryinventory@massaudubon.org)

Massachusetts Natural Heritage and Endangered Species Program. 2010. Massachusetts element occurrence database. Massachusetts Division of Fisheries and Wildlife, West Boylston, Massachusetts.

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, Virginia.

Master, L. L., S. R. Flack, and B. A. Stein. 1998. Rivers of life: critical watersheds for protecting freshwater biodiversity. Nature Conservancy, Arlington, Virginia.

Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammerson. 2000. Vanishing assets: conservation status of US species. Pages 93–118 *in* B. A. Stein, and L. S. Kutner (editors). Precious heritage: the status of biodiversity in the United States. Oxford University Press, New York.

Nature Conservancy. 2004. High Allegheny Plateau ecoregional plan: first iteration. Eastern Regional Office, Nature Conservancy, Boston, Massachusetts. (Available from: https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/Documents/ED_terrestrial_ERAs_HALfinalreport.pdf)

NatureServe. 2012. NatureServe conservation status assessments: rank calculator. Version 3.1. NatureServe, Arlington, Virginia. (Available from: https://connect.natureserve.org/index.php?q=publications/statusassess_download)

NEPARC (Northeast Partners in Amphibian and Reptile Conservation). 2010. Northeast amphibian and reptile species of regional responsibility and conservation concern. Publication 2010-1. Northeast Partners in Amphibian and Reptile Conservation. (Available from: http://www.northeastparc.org/products/pdfs/NEPARC_NEspeciesofresponsibility.pdf)

New Hampshire Audubon. 2012. New Hampshire dragonfly survey database. New Hampshire Audubon and New Hampshire Fish and Game Department, Concord, New Hampshire.

New Jersey Odonata Survey. 2012. New Jersey dragonfly and damselfly survey database. (Available from: http://www.njodes.com/data.htm)

New York Natural Heritage Program. 2010. New York dragonfly and damselfly survey database. New York State Department of Environmental Conservation, Albany, New York.

New York Natural Heritage Program and NatureServe. 2014. Digital distribution maps of the odonates of eastern North

America. Version 1.0. NatureServe, Arlington, Virginia. (Available from: http://explorer.natureserve.org/)

New York Odonate Group. 2012. New county records database. New York Natural Heritage Program, Albany, New York.

Nikula, B. J., J. L. Loose, and M. R. Burne. 2007. A field guide to the dragonflies and damselflies of Massachusetts. 2nd edition. Natural Heritage and Endangered Species Program, Massachusetts Division of Fisheries and Wildlife, Westborough, Massachusetts.

Olcott, S. 2011. Final report for the West Virginia dragonfly and damselfly atlas. Wildlife Resources Section, West Virginia Division of Natural Resources, Elkins, West Virginia. (Available from: http://www.wvdnr.gov/publications/PDFFiles/OdenateAtlasReportweb.pdf)

Olcott, S. 2012. West Virginia dragonfly and damselfly atlas database. Wildlife Resources Section, West Virginia Division of Natural Resources, Elkins, West Virginia.

Orr, R. 2012. The dragonflies and damselflies of Maryland and the District of Columbia. Mid-Atlantic Invertebrate Field Studies (MAIFS), Columbia, Maryland. (Available from: http://www.marylandinsects.com/MDDCOdonateRecords.html)

Panjabi, A. O., P. J. Blancher, R. Dettmers, and K. V. Rosenberg. 2012. Partners in flight handbook on species assessment. Version 012. Technical Series No. 3. Partners in Flight, Rocky Mountain Bird Observatory, Brighton, Colorado. (Available from: http://rmbo.org/pubs/downloads/PIFHandbook2012.pdf)

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, New Jersey.

Pennsylvania Natural Heritage Program. 2013a. Element occurrence digital data set. Pennsylvania Natural Heritage Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg, Pennsylvania.

Pennsylvania Natural Heritage Program. 2013b. Pennsylvania odonate database. Pennsylvania Natural Heritage Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg, Pennsylvania.

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, Ohio.

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, Massachusetts.

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, UK.

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. Pages 107–110 *in* G. De Knijf, A. Anselin, and P. Goffart (editors). Proceedings of the 13th International Colloquium European Invertebrate Survey, September 2001. European Invertebrate Survey – the Netherlands, 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.

Thomas, M. C., and D. L. Wagner. 2014. The Odonata fauna of Connecticut. County and flight records. University of Connecticut, Storrs, Connecticut. (Available from: http://ghostmoth.eeb.uconn.edu/dragons/records.pdf).

USFWS (US Fish and Wildlife Service). 2013. State wildlife grant program-overview. Wildlife and Sport Fish Restoration Program, US Fish and Wildlife Service, Washington, DC. (Available from: http://wsfrprograms.fws.gov/Subpages/GrantPrograms/SWG/SWG.htm)

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, New York. (Available from: http://www.dec.ny.gov/animals/31061.html)

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.