2021

A Review and Comparison of U.S. State Wildlife Action Plans for Stonefly (Insecta, Plecoptera) Species of Greatest Conservation Need

Kathryn Greene
Western Kentucky University, kathryn.greene562@topper.wku.edu

A REVIEW AND COMPARISON OF U.S. STATE WILDLIFE ACTION PLANS FOR STONEFLY (INSECTA, PLECOPTERA) SPECIES OF GREATEST CONSERVATION NEED

A Capstone Experience/Thesis Project Presented in Partial Fulfillment

of the Requirements for the Degree Bachelor of Science

with Mahurin Honors College Graduate Distinction

at Western Kentucky University

By

Kathryn Greene

May 2021

*****

CE/T Committee:

Dr. Scott Grubbs, Chair

Dr. Keith Philips

Dr. Carl Dick

ABSTRACT

State Wildlife Action Plans (SWAPs) were created in order to identify Species of Greatest Conservation Need (SGCN) and develop plans to prevent their populations from further decline and the possibility of being listed as threatened or endangered. Which SGCNs are included are decided based on characteristics that determine their vulnerability. As of early 2021, approximately 720 stoneflies (Insecta, Plecoptera) species are found in the U.S., but only 143 are listed as SGCN. Only 29 states have stoneflies included on their SGCN lists, but 37 states use EPT (Ephemeroptera + Plecoptera + Trichoptera) metrics when assessing water quality issues in running water habitats. In future revisions of SWAPs, Plecoptera systematists and specialists should be consulted for more accurate information regarding at risk species. Existing conservation lists, such as those provided by the Natural Heritage Network (i.e., NatureServe), should also be consulted. Species that are endemic to specific areas should also be considered as they are not present anywhere else in the world. Overall, insects and other invertebrates tend to be left out of conservation efforts because of the lack of research and the lack of interest in protecting them. Their importance is often overlooked, and this continues to discourage additional research and conservation for these species.

Key Words: conservation, Plecoptera, stoneflies, rare species, United States

I dedicate this thesis to my parents, Michael and Laura Greene, who always push me to do my best and take chances on new and challenging experiences. Also, I dedicate this work to my friends and peers, who helped greatly in motivating me to do my best and allowing me to talk about my research with them.

ACKNOWLEDGEMENTS

I would like to thank Dr. Scott Grubbs for being so flexible during the trying times of a global pandemic. The lack of funding, reduced time, and shift in project focus brought on by the pandemic, though inconvenient, did not stop him from persevering and helping me complete this project. Without him, none of this would have been possible, so I just want to thank him for sticking with me the past three years.

I also want to thank Dr. Keith Philips and Dr. Carl Dick for being open to being my committee members and always willing to answer my questions or help me with any problems I may be having. I appreciate the conversations we had, both about my project and otherwise.

I want to thank the faculty of the geography department that taught me the GIS skills I needed to complete this project as well as one of Dr. Grubb's graduate students, Philip Hogan, for his help with creating jitter plots.

My project would not have been possible without the WKU Mahurin Honors College, specifically the advisors that always encouraged me to do a thesis project and were there to aid me and support me in any way through each step of the process.

VITA

EDUCATION

Western Kentucky University, Bowling Green, KY May 2021
B.S. in Biology – Mahurin Honors College Graduate
Honors Capstone: *A review and comparison of U.S. State Wildlife Action Plans for stonefly (Insecta, Plecoptera) Species of Greatest Conservation Need*

Randall K. Cooper High School, Union, KY May 2017

PROFESSIONAL EXPERIENCE

Global Learning and International Affairs, WKU Aug. 2019-Present
Student Worker

Guest Experience Specialist, Newport Aquarium May 2019-July 2019

AWARDS & HONORS

Magna Cum Laude, WKU, May 2021
President's List: Fall 2017; Spring 2020
Dean's List: Spring 2018, 2019; Fall 2018, 2019, 2020

PROFESSIONAL MEMBERSHIPS

The National Society for Leadership and Success (NSLS)
Beta Beta Beta Honors Biology Club (TriBeta)
Rho Chapter of Omega Phi Alpha National Service Sorority

INTERNATIONAL EXPERIENCE

University College Cork, Cork, Ireland Jan. 2019-May 2019
Academic Study

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Legislation was passed by the United States Congress in the early 2000s (University of Michigan 2008) in order to prevent national wildlife populations from declining, becoming endangered, or becoming extinct (Oberbillig 2008). This legislation required each state to create a State Wildlife Action Plan (SWAP) to protect wildlife and their habitats within state boundaries by October 2005 and then update them at least once every 10 years. A very important component of these plans includes the documentation of Species of Greatest Conservation Need (SGCN). SGCNs are wildlife that have small or declining populations or are vulnerable. SGCNs are identified based on criteria laid out by the Teaming with Wildlife Coalition (Bried & Mazzacano 2010). These criteria include a combination of: a) federal or state endangered, threatened, and candidate status, b) imperiled (globally rare) status, c) special conservation concern status, d) species with declining, endemic, disjunct, or vulnerable populations, e) dispersal-limited species, f) area-demanding and keystone species, g) species with unique life history or specialized habitat, h) indicator species, and i) species whose core range, migratory stopover, or key breeding area overlaps the state as well as species that have a lack of funding for conservation efforts or species that need more research on their distribution, habitats, and life history.

Insects have high extinction risk (Dunn 2005) and represent the taxon with the greatest expected biodiversity loss (Thomas et al. 2004). Stoneflies (Plecoptera) are a small order of aquatic insects that are common globally (ca. 3,700 species) and found on every continent except Antarctica (DeWalt & Ower 2019), with approximately 700 species present in the U.S. Stoneflies are present in all U.S. states except Hawaii (DeWalt et al.

2020). Because stonefly larvae are fully aquatic, inhabiting seeps, spring runs, streams, rivers, and large and high elevation lakes (Stewart & Stark 2002), they can play an important ecological role as indicators of water quality (Barbour et al. 1999; DeWalt & Ower 2019). Immature stoneflies are typically associated with healthy environmental conditions that can successfully sustain their populations with adequate food and habitat resources (Voshell 2002). Stoneflies are one of the key indicator groups for water quality assessments (Rosenberg & Resh 1993) because they have a high sensitivity to environmental contamination (Saltveit et al. 1987) and are among the first aquatic insects to vanish in the face of habitat change (Zwick 2000, DeWalt et al. 2005). One common metric for monitoring water quality is quantifying the number or proportion of stoneflies that are present within a body of water. One prominent example that incorporates stoneflies is the EPT (Ephemeroptera + Plecoptera + Trichoptera) metric (Lenat & Penrose 1996). Ephemeroptera are mayflies and Trichoptera are caddisflies, both of which are likewise typically sensitive to water quality.

Plecoptera are among the most sensitive and threatened invertebrates because of the specificity of habitats and low migratory rates (DeWalt et al. 2005; Fochetti & Tierno de Figueroa 2006; Tierno de Figueroa et al. 2010). Moreover, freshwater ecosystems are experiencing faster biodiversity decline than any other habitat (Ricciardi & Rasmussen 1999; Master et al. 2000; Bojková et al. 2012) due to several factors (Master et al. 2000). Climate change is another factor that puts stoneflies and their habitats at risk. As water temperatures increase, oxygen is depleted, and habitats are reduced for cold-water aquatic species such as stoneflies (Tierno de Figueroa et al. 2010). Other detrimental factors that also lead to increased variation in water temperature include channelization, field draintiling, building levees, and stream modifications that destroy riparian environments (DeWalt et al. 2005).

Master et al. (2000), using Natural Heritage data, found that stoneflies were the 3rd-most most imperiled aquatic group in the United States behind only freshwater mussels and crayfish. Only 29 states list Plecoptera species as SGCN, however, a majority of states use EPT metrics. The fact that the majority of states use EPT metrics demonstrates the importance of stoneflies for assessing water quality, yet there are still inconsistencies in showing their value through various conservation efforts, such as listing them as SGCN. The problem with improving conservation efforts for stoneflies is the lack of evidence and data that exist demonstrating species loss (Jackson & Füreder 2006; Bojková et al. 2012), which is why it is important to make note of imperiled species before it is too late. Of the nine criteria laid out by the Teaming with Wildlife Coalition (Bried & Mazzacano 2010), stoneflies fall into each of these categories leaving no reason to be excluded as SGCN from the 49 U.S. states currently supporting stonefly populations and their associated habitats.

The purpose of this study was three-fold: (1) to review 49 U.S. SWAPs in order to assess the number of SGCNs listed per state, (2) to determine which states use EPT metrics and compare this to SGCNs alongside Natural Heritage data, and (3) to draw conclusions from the data collected in order to make recommendations for future SWAPs.

METHODS

The most recent SWAPs were compiled for all 50 U.S. states from the individual state links available at https://www.fishwildlife.org/afwa-informs/state-wildlife-action-plans (Appendix 1). Some links were no longer active and the plans for those states were secondarily found by doing a search in Google and following the link to the individual state's plan. The total number of stonefly species and the scientific name of each stonefly species listed, if included in a SWAP, were recorded for each state.

The total number of species reported from each state were obtained by doing a faunal list search in Plecoptera Species File (DeWalt et al. 2020). MS Excel was used to calculate the proportion of species listed per state as SGCN out of the total reported. This same data was used to create a map that displayed the percent SGCN in each state using ArcMap 10.7. All stonefly species presently reported from the U.S. were organized first by family and secondarily by genus in order to assess the spread of SGCNs across to the two latter taxonomic ranks. The freeware program R 1.2.5001 (R Core Team 2013) was used to create box and whisker jitter plots to display propensity as SGCN data for all nine families and the eight most speciose genera reported from the U.S. Propensity was defined as the number of states that include a species as SGCN out of the total number of states where that species has been reported.

Stream biomonitoring protocols were compiled for each state (Appendix 2) in order to compile a list of the total number and which specific states use EPT metrics. Natural Heritage Network data via NatureServe was compiled for conservation status ranks for species listed as vulnerable, imperiled, critically imperiled, possibly extirpated, or presumed extirpated. States that included stonefly species on NatureServe were listed along with the species listed in that state and their conservation status rank. The data was used to compare states that have stoneflies ranked on NatureServe but no SGCNs.

RESULTS AND DISCUSSION

PATTERNS AND GAPS

In total, 719 species are presently known from the U.S. as of early 2021 (DeWalt et al. 2020) but only 143 were listed as an SGCN. The families Capniidae and Perlidae are both comprised by 28 SGCN species, making up 39% of the total number of SGCNs. Perlidae is the most proportionately species-rich of SGCNs because 30% of species were assigned as an SGCN at least once. The most species-rich genus in the U.S. is *Isoperla* with 83 species, of which 6 (0.07%) are listed as SGCN. The second most species-rich genus is *Allocapnia* with 47 species, of which 17 (36%) are listed as an SGCN. *Alloperla* and *Acroneuria* are other species-rich genera each with 33 and 18 species, 12 (36%) and 7 (39%) being SGCN, respectively. There are other genera in the U.S. that are not species-rich but have a high percentage of their species listed as SGCN, including *Sasquacapnia* (Capniidae), *Megaleuctra* (Leuctridae), *Lednia* and *Prostoia* (Nemouridae), *Strophopteryx* and *Taeniopteryx* (Taeniopterygidae), *Utaperla* (Chloroperlidae), *Attaneuria*, *Eccoptura*, *Hansonoperla* and *Perlinella* (Perlidae), and *Diploperla*, *Helopicus*, *Hydroperla*, *Isogenoides*, *Oconoperla*, *Pictetiella*, and *Remenus* (Perlodidae), all of which have at least 36% of their species listed as an SGCN.

The SGCN propensity patterns were inconsistent across the nine families (Fig. 1a). One family (Peltoperlidae) had a median propensity value of 100%, but this high value was due to a low number of species (3) recognized as an SGCN. Four families had a median propensity of 50% while the remaining four had median propensities below

35%. Excluding the high propensity of Peltoperlidae, the distribution within Capniidae (median propensity at 50% and large propensity at 100%) showed the greatest propensity to be designated as SGCN (Fig. 1a). When examining the most species-rich genera, *Capnia* and *Sweltsa* display the greatest propensity as SGCN, but because the data is only represented by four species and six species respectively, it is clear that *Allocapnia* is a better fit because the median falls at 50% with a large propensity at 100% (Fig. 1b) and it is more speciose for SGCNs.

In total, 139 (97%) stonefly SGCNs were recognized in only 1-3 states. Of these, 115 species (80%) were listed in only one state. Four SGCNs in particular, *Acroneuria abnormis* and *Perlinella drymo* (Perlidae) plus *Strophopteryx fasciata* and *Taeniopteryx burski* (Taeniopterygidae) are widespread North American species that do not fit the concept of taxa in peril and could potentially be removed from subsequent SWAPs. There is the possibility that these species have small or declining populations in the states that they are listed, but this should be assessed by Plecoptera experts so that truly imperiled species can be the focus of conservation efforts. In contrast, *Megaleuctra flinti*, *M. williamsae* (Leuctridae), *Ostrocerca complexa* (Nemouridae), and *Alloperla biserrata* (Chloroperlidae) were each listed as an SGCN in four states, the highest value for stoneflies. There were seven species that were listed in three states. All 11 species are found either in the northern Midwest or the Appalachian Mountains.

The majority of states listed 5 or less stonefly species as SGCNs (Fig. 2). Virginia listed the highest number of stoneflies as SGCNs (37) with Pennsylvania a distant second (21; Table 1). Only four other states, Tennessee and West Virginia (10 each) plus Florida and Idaho (12 each), had at least 10 species listed. In contrast, 21 states have zero species listed as an SGCN. The largest percentage of stonefly SGCNs relative to total number reported from an individual state was Rhode Island (67%; Fig. 3), yet this is mainly due to only three species reported to date. The lowest non-zero percentage of stonefly SGCNs relative to total number reported were California (0.5%) and Oregon (0.6%; Fig. 3). All other states that listed stonefly SGCNs range from 1-20% relative to the total number reported. The distribution of states that listed proportionately more Plecoptera SGCNs was mostly random, with states in the Northwest, Midwest, Northeast, and Southeast having higher percentages of SGCNs (Fig 3). Because species richness is highest in the U.S. states in montane regions (e.g., Appalachia, Cascade, Sierra Nevada), this also helps explain the random distribution of SGCNs throughout the U.S. Although it is logical that higher SGCN numbers would be in states with higher reported richness, this relationship is not apparent.

FILLING THE GAPS

Bried & Mazzacano (2010) noted that many states lacked data specifically with regard to dragonflies and damselflies (Insecta, Odonata) due to a lack of information to assess, lack of expertise, or because they were not legally designated as a species of concern. Some states also assumed that the protection of plants and vertebrates would indirectly protect insects (Bried & Mazzacano 2010), which is a somewhat fair assumption because much of the documented insect extinctions are due to the same factors as vertebrate extinction (Dunn 2005). However, there is still mixed evidence on whether or not this form of indirect conservation is effective for invertebrates (Martikainen et al. 1998; Oliver et al. 1998; Panzer & Schwartz 1998; Rubinoff 2001;

Vessby et al. 2002; Grand et al. 2004; Schulze et al. 2004; Betrus et al. 2005; Bried et al. 2007; Bried & Mazzacano 2010). Insects are narrow habitat specialists who often have populations that are restricted to a specific area, which would require more direct conservation efforts (Dunn 2005).

In order to improve conservation efforts for insects, there has to be more cooperation with experts and taxonomists (Bossart & Carlton 2002), as well as more of these experts. Presumably it would be favorable for stonefly specialists to form state and regional teams of experts in order to incorporate up-to-date information concerning SGCNs. These expert teams could use their own knowledge and data along with other important partners such as U.S. Natural Heritage programs. This would be especially beneficial in states that have reported no SGCNs to date or had a lack of data for Plecoptera species, because it would give the states the resources they need to create a better SGCN list. Compiling this information could be done through surveys or through collection projects in under-surveyed areas (Bried & Mazzacano 2010).

A good place to find current and relevant information on U.S. stonefly distributions is through Plecoptera Species File (DeWalt et al. 2020). This is a well maintained and frequently (i.e., continually during each year) updated website with easily searchable elements such as faunal lists, publications, and taxa. At one time the Tree of Life Web Project was developed in part to serve as a clearing house for references that pertain to specific information on life history and other biological characteristics (Nelson 1996), but this website is no longer updated.

When it comes to stonefly conservation, the spatial distribution of the order causes discrepancies among designating species as SGCNs. Arriving at a national standard for SGCN designations, instead of simply relying on the criteria laid out by the Teaming with Wildlife Coalition (Bried & Mazzacano 2010), would be advantageous because it would make ranking and prioritizing species easier and in a standardized manner. Although information regarding the "exact" distributions of all potential SGCN species will always be lacking to varying degrees, a standardized methodology would ensure that state lists are more accurate, more comparable, and easier to update potential future changes in status. Adopting the assessment process for the International Union for Conservation of Nature (IUCN) Red List of Threatened Species™ could standardize the process of designating SGCNs (Rodrigues et al. 2006; Mace et al 2008; Bried & Mazzacano 2010). The IUCN Red List of Threatened Species™ (2021) is determined based off of five criteria: 1) population reduction, 2) restricted geographic range, 3) small population size and decline, 4) very small or restricted population, and 5) extinction probability analysis. These criteria determine whether the species is considered vulnerable, endangered, or critically endangered.

As climate change continues to pose issues for stoneflies (DeWalt et al. 2005; Tierno de Figueroa et al. 2010) and other species, cooperation on planning SWAPs and designating SGCNs should continue to increase. Getting citizens involved with conservation efforts can also be an effective mechanism to assist with protecting vulnerable species. For example, organizations such as the Xerces Society for Invertebrate Conservation (http://www.xerces.org) promote the protection of at-risk invertebrates and their habitats. Xerces finds ways to get citizens involved through projects like the Endangered Species Conservation program, which educates the public on species that need help and how to help them. Continuing to educate and involve citizens through various community outreach programs as well as involving professional and amateur stonefly enthusiasts has the potential to increase knowledge and awareness for stoneflies in the U.S., ultimately leading to growth in conservation efforts for those species.

OTHER RECOMMENDATIONS

Implementation of species distribution models (SDMs) can help understand and predict a species' range, even when there are limits in space and observations (Guisan & Zimmermann 2000; Elith et al. 2006; Kearny & Porter 2009; Bried & Mazzacano 2010). For example, Young et al. (2019) effectively integrated SDMs with an iterative sampling approach to successfully locate several additional populations of rare *Arsapnia arapahoe* and thereby increased knowledge of the distribution of this species. Both states and regions within states should use SDMs in order to (a) refine potential sampling efforts to regions with higher predictive likelihood to locate previously undetected populations, and (b) fill in the gaps from data collection when not all areas are surveyable due to the key limitations: accessibility, resources, and time (Bried & Mazzacano 2010). Filling these gaps would allow for increasingly more refined and accurate SGCN designations and SWAP lists.

Rare or declining species within individual states are almost always more logical SGCN candidates than species with broader distributions. Of the 115 species that are only listed in one state, 30 have been reported from only that state. The rest of the single-state SGCN species were known from 7±2 states on average. The reason for this disjointedness may be because the species whose range overlaps several states may be much less prevalent in the outer parts of their range, making it seem as if their populations are unstable or declining. The reality is that these species may have stable populations in neighboring states in which they cover a greater area, so listing them as an SGCN may be in error. When referencing single-state SGCNs it is also important to remember endemics because these species are good contenders for SGCN designations. Endemism does not necessarily mean these species are limited to one state but perhaps isolated to one specific habitat type or a narrow range in elevation, thereby making them an important selection as an SGCN in multiple states within that range.

Alongside SWAPs and the IUCN Red List, NatureServe is another system for ranking at-risk species. NatureServe is the overarching organization for state-based Natural Heritage programs (Groves et al. 1995) and was taken heavily into consideration when the initial SWAPs were being created in 2005 (Bried & Mazzacano 2010). Several stonefly species were ranked as being vulnerable to presumed extirpated. These ranking would make a species a logical and good SGCN candidate, yet many states that had stonefly species ranked on NatureServe lacked SGCNs (Table 2). It is important to recognize that a species can be doing well globally but not at the state level and vice versa (Bried & Mazzacano 2010), which is why it is important to take all rankings into consideration.

Natural Heritage Network data is considered reliable and comprehensive in the U.S. (Groves et al. 1995), which is why it is so important to take the species listed on NatureServe into account when creating SGCN lists. Although Table 2 only includes the states that had no SGCNs, there were 36 other species from 14 states in total that were not listed on any of the 49 SWAPs that were reviewed. Because NatureServe data is reliable, those species need to be included on future SGCN lists.

CONCLUSION

The essential goal of U.S. SWAPs is to prevent further threat and decline of Species of Greatest Conservation Need. We reviewed 50 SWAPs and noticed the lack of representation for Plecoptera species as SGCN. In future revisions of SWAPs, the next one being in 4 years, it is important to focus on the states that previously excluded stoneflies as SGCNs. Several suggestions were made, including turning to Plecoptera specialists, using existing conservation lists (Table 2), referencing field guides and reviews, closer recognition of endemic species, and the use of distribution modelling. The efforts thus far should not be ignored, but it is important to continue to raise awareness for invertebrate conservation (Bossart & Carlton 2002; Bried & Mazzacano 2010).

The problem with the previous claim of information being deficient on invertebrate distribution and conservation is that it is assumed Plecoptera are the 3rd-most imperiled invertebrate group (Master et al. 2000), therefore they likely need better protection and recognition on important conservation efforts like SWAPs. Although stoneflies may not have the same intriguing looks as dragonflies and damselflies (DeWalt et al. 2005), they are vitally important ecological health indicators, as recognized by the use of Ephemoptera + Trichoptera + Plecoptera (EPT) metrics (Lenat & Penrose 1996), that need not be overlooked. Although lack of data is an issue, this is even more of a reason to include Plecoptera SGCNs because this will support the push for greater funding and research to go into conservation efforts for those species, leading to a better understanding of their distribution and life history.

Overall, future SWAPs need not focus on the specific data already available but consider the lack of data a better reason to include stoneflies and other lesser recognized species on SGCN lists. In order for SWAPs to be a success, they need to draw more attention to underrepresented species so that conservation efforts can be shifted to the truly at-risk species instead of just focusing on the species that may be more appealing to us. As Bried and Mazzacano (2010) stated, if well-studied invertebrates like dragonflies and damselflies are struggling to gain proper recognition, then less attractive insects such as stoneflies need even more attention when it comes to conservation efforts. Acknowledging these marginalized species on future SWAPs will help bridge the gap between active conservation efforts and the resources and funding available to maintain these efforts.

FIGURES

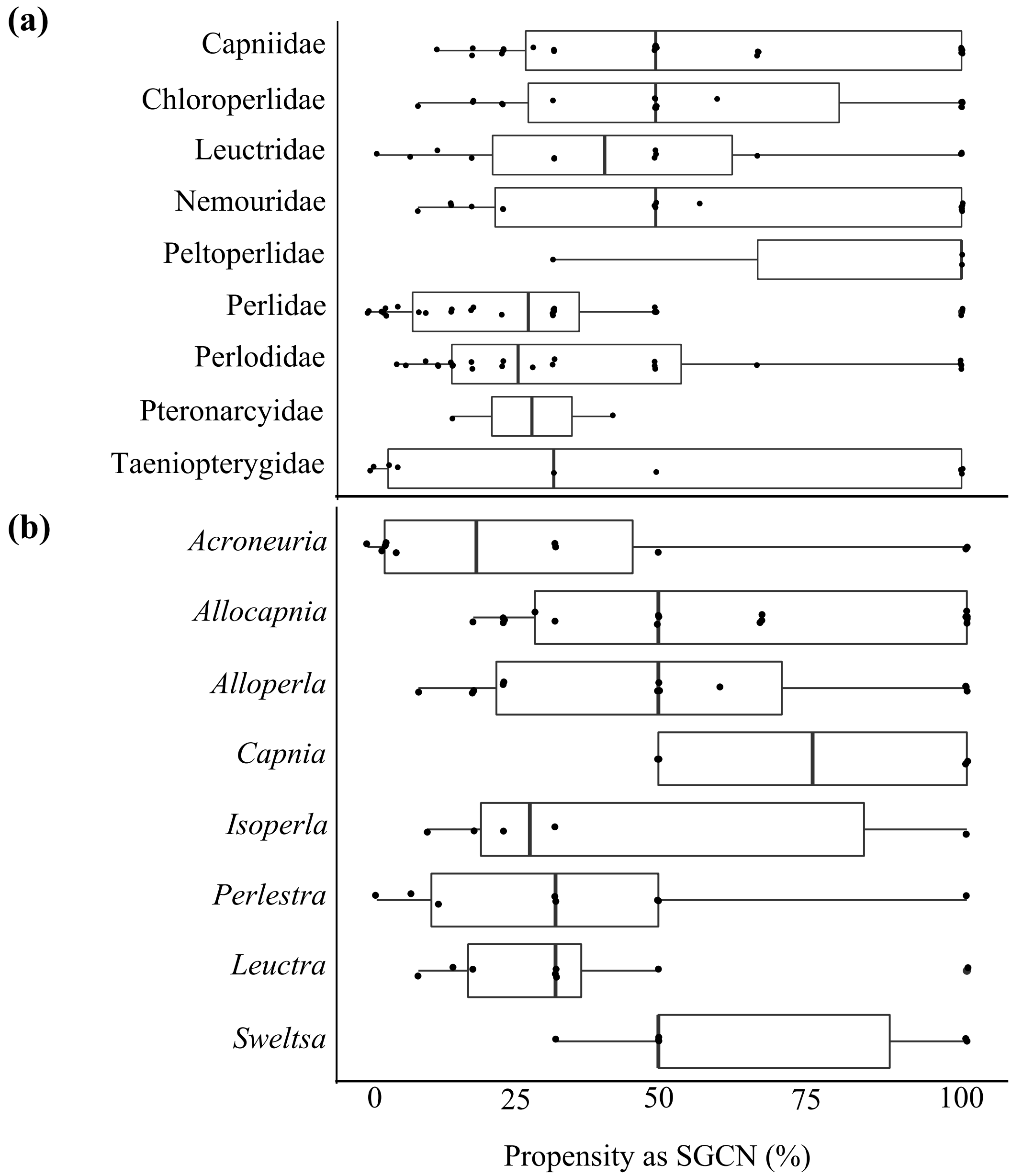

Figure 1. Distribution of Species of Greatest Conservation Need (SGCN) among (a) the nine Nearctic families and (b) the eight most species-rich genera of the U.S. Propensity as SGCN (represented by dots) is defined as the number of states that determine a species as SGCN out of the number of states it was known to occur according to Plecoptera Species File (DeWalt et al. 2020). The vertical bar, open rectangle, and whiskers represent the median value, interquartile range, and entre range of data, respectively.

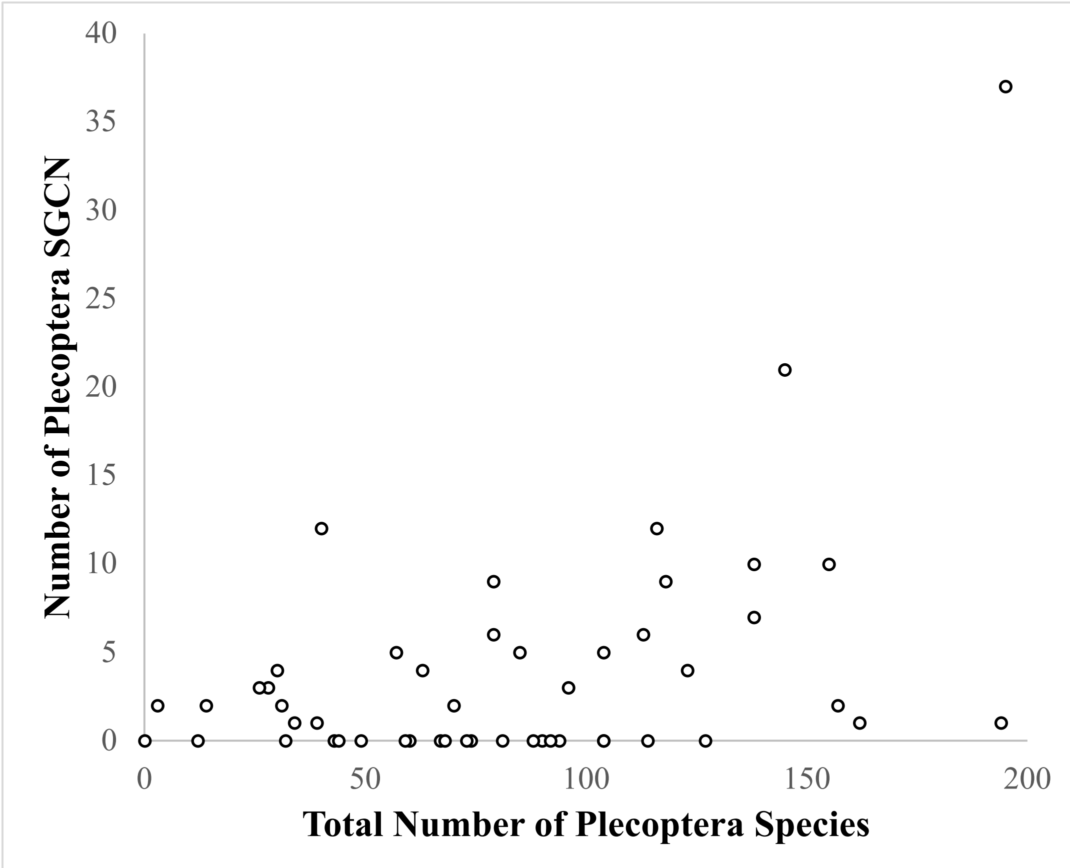

Figure 2. Number of Plecoptera designated as Species of Greatest Conservation Need (SGCN) versus the total number of Plecoptera species per state.

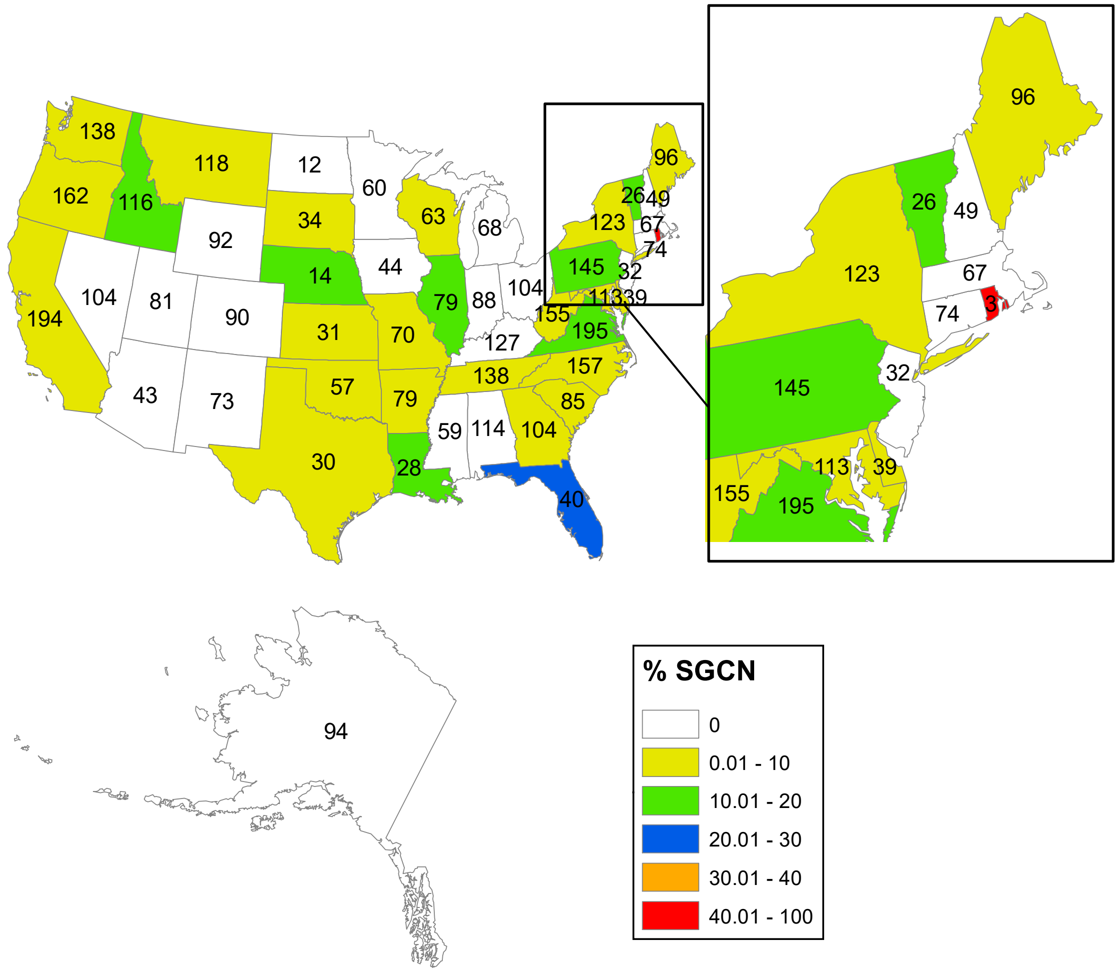

Figure 3. Total number of stonefly species per state (indicated by number) according to Plecoptera Species File (DeWalt et al. 2020) and the percentage that were recognized as Species of Greatest Conservation Need (SGCN).

TABLES

Table 1. Summary of the total Plecoptera species from Plecoptera Species File (DeWalt et al. 2020) and the number of Species of Greatest Conservation Need (SGCN) per state.

State	Total Plecoptera Species	Plecoptera SGCN
Alabama	114	0
Alaska	94	0
Arizona	43	0
Arkansas	79	6
California	194	1
Colorado	90	0
Connecticut	74	0
Delaware	39	1
Florida	40	12
Georgia	104	5
Hawaii	0	0
Idaho	116	12
Illinois	79	9
Indiana	88	0
Iowa	44	0
Kansas	31	2
Kentucky	127	0
Louisiana	28	3
Maine	96	3
Maryland	113	6
Massachusetts	67	0
Michigan	68	0
Minnesota	60	0
Mississippi	59	0
Missouri	70	2

Montana	118	9
Nebraska	14	2
Nevada	104	0
New Hampshire	49	0
New Jersey	32	0
New Mexico	73	0
New York	123	4
North Carolina	157	2
North Dakota	12	0
Ohio	104	0
Oklahoma	57	5
Oregon	162	1
Pennsylvania	145	21
Rhode Island	3	2
South Carolina	85	5
South Dakota	34	1
Tennessee	138	10
Texas	30	4
Utah	81	0
Vermont	26	3
Virginia	195	37
Washington	138	7
West Virginia	155	10
Wisconsin	63	4
Wyoming	92	0

Table 2. States with their total number of species listed as state-rare by the Natural Heritage Network but without listing stoneflies as Species of Greatest Conservation Need (SGCN)

State	Presumed Extirpated	Possibly Extirpated	Critically Imperiled	Imperiled	Vulnerable
Alabama	0	0	1	0	0
Arizona	0	0	0	1	0
Colorado	0	0	1	0	0
Indiana	3	2	10	10	8
Kentucky	0	0	2	1	0
Utah	0	0	0	2	1

REFERENCES

Barbour, M.T., J. Gerritsen, B.D. Snyder, & J.B. Stribling. (1999) Rapid bioassessment protocols for use in streams and wadable rivers: periphyton, benthic macroinvertebrates and fish, 2nd ed. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, DC.

Betrus, C.J., E. Fleishman & R.B. Blair. (2005) Cross-taxonomic potential and spatial transferability of an umbrella species index. *Journal of Environmental Management*, **74**, 79-87.

Bojková, J., K. Klára, T. Soldán, & S. Zahrádková. (2012) Species loss of stoneflies (Plecoptera) in the Czech Republic during the 20th century. *Freshwater Biology*, **57**: 2550-2567.

Bossart, J.L. & C.E. Carlton. (2002) Insect conservation in America: status and perspectives. *American Entomologist*, **48**: 82-89.

Bried, J.T. & 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.

Bried, J.T., B.D. Herman, & G.N. Ervin. (2007) Umbrella potential of plants and dragonflies for wetland conservation: a quantitative case study using the umbrella index. *Journal of Applied Ecology*, **44**: 833-842.

DeWalt, R.E., C. Favret, & D.W. Webb. (2005) Just How Imperiled Are Aquatic Insects? A Case Study of Stoneflies (Plecoptera) in Illinois. *Annals of the Entomology Society of America*, **98(6)**: 941-950.

DeWalt, R.E. & G.D. Ower. (2019) Ecosystem Services, Global Diversity, and Rate of Stonefly Species Descriptions (Insecta: Plecoptera). *Insects*, **10**: 99.

DeWalt, R.E., M.D. Maehr, U. Neu-Becker, & G. Stueber. (2020) Plecoptera species file. Available from: http://plecoptera.speciesfile.org/HomePage/Plecoptera/HomePage.aspx. Accessed on 10 December 2020.

Dunn, R.R. (2005) Modern Insect Extinctions, the Neglected Majority. *Conservation Biology*, **19**: 1030-1036.

Elith, J., C.H. Graham, R.P. Anderson, M. Dudik, S. Ferrier, A. Guisan, R.J. Hijmans, F. Huettmann, J.R. Leathwick, A. Lehmann, J. Li, L.G. Lohmann, B.A. Loiselle, G.

Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J.McC Overton, A.T. Peterson, S.J. Phillips, K. Richardson, R. Scachetti-Pereira, R.E. Schapire, J. Soberón, S. Williams, M.S. Wisz, & N.E. Zimmerman. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, **29**: 129-151.

Fochetti, R & J.M. Tierno de Figueroa. (2006) Notes on diversity and conservation of the European fauna of Plecoptera (Insecta). *Journal of Natural History*, **404**: 2361-2369.

Grand, J., J. Buonaccorsi, S.A. Cushman, C.R. Griffin, & M.C. Neel. (2004) A multiscale landscape approach to predicting bird and moth rarity hotspots in a threatened pitch pine-scrub oak community. *Conservation Biology*, **18**: 1063-1077.

Groves, C.R., M.L. Klein, & T.R. Breden. (1995) Natural Heritage Programs: public-private partnership for biodiversity conservation. *Wildlife Society Bulletin*, **23**: 784-790.

Guisan, A. & N.E. Zimmerman. (2000) Predictive habitat distribution models in ecology. *Ecological Modelling*, **135**: 147-186.

IUCN. (2021). The IUCN Red List of Threatened Species. Version 2021-1. https://www.iucnredlist.org. ISSN 2307-8235.

Jackson, J.K. & L. Füreder. (2006) Long-Term Studies of Freshwater Macroinvertebrates: A Review of the Frequency, Duration and Ecological Significance. *Freshwater Biology*, **51**: 591-603.

Kearny, M. & W. Porter. (2009) Mechanistic niche modelling: combining physiological and spatial data to predict species' ranges. *Ecology Letters*, **12**: 334-350.

Lenat, D.R. & D.L. Penrose. (1996) History of the EPT taxa richness metric. *Bulletin of the North American Benthological Society*, **13**: 305-306.

Mace, G.M., N.J. Collar, K.J. Gaston, C. Hilton-Taylor, H.R. Akcakaya, N. Leader-Williams, E.J. Milner-Gulland, & S.N. Stuart. (2008) Quantification of extinction risk: IUCN's system for classifying threatened species. *Conservation Biology*, **22**: 1424-1442.

Martikainen, P., L. Kaila, & Y. Haila. (1998) Threatened beetles in white-backed woodpecker habitats. *Conservation Biology*, **12**: 293-301.

Master, L.L., B.A. Stein, G.A. Kutner, & G.A. Hammerson. (2000) Vanishing assets, conservation status of U.S. species. In: *Precious Heritage, the Status of Biodiversity in the United States. The Nature Conservancy & Association for Biodiversity Information*. (Eds B.A. Stein, L.S. Kutner, & J.S. Adams), 93-118. Oxford University Press, Oxford.

Nelson, C.R. (1996) Plecoptera. Stoneflies. Version 01 January 1996.. http://tolweb.org/plecoptera *In* The Tree of Life Web Project, http://tolweb.org/

Oberbillig, D. (2008) *State wildlife action plans: working together to prevent wildlife from becoming endangered*. Available from: http://www.wildlifeactionplans.org/pdfs/wildlife_action_plans_summary_report.pdf. Accessed on 26 February 2021.

Oliver, I., A.J. Beatie, & A. York. (1998) Spatial fidelity of plant, vertebrate, and invertebrate assemblages in multiple-use forests in eastern Australia. *Conservation Biology*, **12**: 822-835.

Panzer, R. & M. Schwartz. (1998) Effectiveness of a vegetation-based approach to insect conservation. *Conservation Biology*, **12**: 693-702.

Ricciardi, A. & J.B. Rasmussen. (1999) Extinction rates of North American freshwater fauna. *Conservation Biology*, **13**: 1220-1222.

Rodrigues, A.S.L., J.D. Piligrim, J.F. Lamoreux, M. Hoffman, & T.M. Brooks (2006). The value of the IUCN Red List for conservation. *Trends in Ecology & Evolution*, **21**: 71-76.

Rosenberg, D.M. & V.H. Resh (1993) Introduction to freshwater biomonitoring and benthic macroinvertebrates. In: *Freshwater Biomonitoring and Benthic Macroinvertebrates*. (Eds D.M. Rosenberg & V.H. Resh), 1–9, Chapman and Hall, London.

Rubinoff, D. (2001) Evaluating the California gnatcatcher as an umbrella species for conservation of southern California coastal sage scrub. *Conservation Biology*, **15**: 1374-1383.

Saltveit, S.J., J.E, Brittain, & A. Lillehammer (1987) Stoneflies and river regulation – a review. In: *Regulated Streams*.(Eds J.F. Craig & J.B. Kemper), 117-129, Springer, Boston.

Schulze, C.H., M. Waltert, P.J.A. Kessler, R. Pitopang, D. Veddeler, M. Mühlenberg, S.R. Gradsetin, C. Leuschner, I. Steffan-Dewenter, & T. Tscharntke. (2004) Biodiversity indicator groups of tropical land-use systems: comparing plants, birds, and insects. *Ecological Applications*, **14**: 1321-1333.

Stewart, K.W. & B.P. Stark. (2002) Nymphs of North American stonefly genera (Plecoptera), 2nd ed. The Caddis Press, Columbus, OH. 1-510.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, & S.E. Williams. (2004) Extinction risk from climate change. *Nature* **427**: 145–148.

Tierno de Figueroa, J.M., M.J. López-Rodríguez, A. Lorenz, W. Graf, A. Schmidt-Kloiber, & D. Hering. (2010) Vulnerable taxa of European Plecoptera (Insecta) in the context of climate change. *Biodiversity and Conservation*, **19**: 1269-1277.

University of Michigan. (2008). About the State Wildlife Action Plans. http://seas.umich.edu/ecomgt/swap/About_SWAPs.html.

Vessby, K., B. Söderström, A. Glimskär, & B. Svensson. (2002) Species-richness correlations of six different taxa in Swedish seminatural grasslands. *Conservation Biology*, **16**: 430-439.

Voshell, Jr., J.R. (2002) *A Guide to Common Freshwater Invertebrates of North America*. The McDonald & Woodward Publishing Company, Blacksburg, Virginia.

Young, N.E,, M. Fairchild, T. Belcher, P. Evangelista, C.J. Verdone, & T.J. Stohlgren (2019) Finding the needle in the haystack: iterative sampling and modeling for rare taxa. Journal of Insect Conservation, **23**: 589-595.

Zwick, P. (2000) Phylogenetic system and zoogeography of the Plecoptera. *Annual Review of Entomology*, **45**: 709–746.

APPENDIX A: LIST OF STATE WILDLIFE ACTION PLANS

Appendix A. List of the State Wildlife Action Plans (SWAPs), containing the lists of Species of Greatest Conservation Need (SGCN), for each state (Last accessed in April 2021).

State	SWAP Link
Alabama	https://georgiaalabamalandtrust.org/wp-content/uploads/2017/08/AlabamaStateWildlifePlan2017.pdf
Alaska	https://www.adfg.alaska.gov/static/species/wildlife_action_plan/2015_alaska_wildlife_action_plan.pdf
Arizona	https://s3.amazonaws.com/azgfd-portal-wordpress/PortalImages/files/wildlife/2012-2022_Arizona_State_Wildlife_Action_Plan.pdf
Arkansas	https://www.wildlifearkansas.com/materials/2015/Insects.pdf
California	https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=109224&inline
Colorado	https://cpw.state.co.us/Documents/WildlifeSpecies/SWAP/CO_SWAP_Chapter2.pdf
Connecticut	https://www.ct.gov/deep/cwp/view.asp?a=2723&q=329520&depNav_GID=1719#Review
Delaware	http://www.dnrec.delaware.gov/fw/dwap/Documents/2015%20Submitted%20Documents/Appendix%201.A.pdf
Florida	https://myfwc.com/media/22767/2019-action-plan.pdf
Georgia	https://georgiawildlife.com/WildlifeActionPlan#explore
Hawaii	https://dlnr.hawaii.gov/wildlife/files/2020/07/HI-SWAP-2015-FINAL.pdf
Idaho	https://idfg.idaho.gov/sites/default/files/state-wildlife-action-plan.pdf

Illinois	https://www2.illinois.gov/dnr/conservation/IWAP/Documents/SGCN2015%20Appendix%201.pdf
Indiana	https://www.in.gov/dnr/fishwild/files/SWAP/fw-SWAP_2015_Appendix-E.pdf
Iowa	https://www.iowadnr.gov/Conservation/Iowas-Wildlife/Iowa-Wildlife-Action-Plan
Kansas	https://ksoutdoors.com/Services/Kansas-SWAP
Kentucky	https://fw.ky.gov/WAP/Pages/Wildlife-Action-Plan-Full.aspx
Louisiana	https://www.wlf.louisiana.gov/assets/Resources/Publications/Wildlife_Action_Plans/Wildlife_Action_Plan_2015.pdf
Maine	https://www.maine.gov/ifw/docs/2015%20ME%20WAP%20Element%201_DRAFT.pdf
Maryland	https://dnr.maryland.gov/wildlife/Documents/SWAP/SWAP_Chapter3.pdf
Massachusetts	https://www.mass.gov/files/documents/2016/12/wh/ma-swap-public-draft-26june2015-chapter3.pdf
Michigan	https://www.michigan.gov/dnr/0,4570,7-350-79136_79608_83053---,00.html
Minnesota	https://www.dnr.state.mn.us/mnwap/index.html
Mississippi	https://www.mdwfp.com/museum/seek-study/state-wildlife-action-plan/
Missouri	https://mdc.mo.gov/sites/default/files/downloads/SWAP.pdf
Montana	http://fwp.mt.gov/fishAndWildlife/conservationInAction/swap2015Plan.html
Nebraska	http://outdoornebraska.gov/naturallegacyproject/
Nevada	http://www.ndow.org/Nevada_Wildlife/Conservation/Nevada_Wildlife_Action_Plan/

New Hampshire	https://www.wildlife.state.nh.us/wildlife/documents/wap/chapter2-specieshabitatsatrisk.pdf
New Jersey	https://www.state.nj.us/dep/fgw/ensp/wap/pdf/wap_plan18.pdf
New Mexico	http://www.wildlife.state.nm.us/conservation/state-wildlife-action-plan/
New York	https://www.dec.ny.gov/docs/wildlife_pdf/sgnc2015list.pdf
North Carolina	https://www.ncwildlife.org/plan#6718619-2015-wildlife-action-plan-document-downloads
North Dakota	https://gf.nd.gov/sites/default/files/publications/swap-2015_0.pdf
Ohio	https://ohiodnr.gov/wps/portal/gov/odnr/discover-and-learn/safety-conservation/about-ODNR/wildlife/about-the-division/about-the-division
Oklahoma	https://www.wildlifedepartment.com/sites/default/files/Oklahoma%20Comprehensive%20Wildlife%20Conservation%20Strategy_0.pdf
Oregon	https://www.dfw.state.or.us/conservationstrategy/
Pennsylvania	https://www.fishandboat.com/Resource/Documents/SWAP-CHAPTER-1-apx13.pdf
Rhode Island	http://www.dem.ri.gov/programs/bnatres/fishwild/swap/sgcncomm.pdf
South Carolina	https://www.dnr.sc.gov/swap/index.html
South Dakota	https://gfp.sd.gov/UserDocs/WAPCh2_SGCN.pdf
Tennessee	http://www.tnswap.com/swap.cfm
Texas	https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/tcap/sgcn.phtml
Utah	https://wildlife.utah.gov/pdf/WAP/Utah_WAP.pdf
Vermont	https://vtfishandwildlife.com/sites/fishandwildlife/files/documents/About%20Us/Budget%20and%20Planning/WAP2015/5.-SGCN-Lists-Taxa-Summaries-%282015%29.pdf

Virginia	http://bewildvirginia.org/species/aquatic-insects.pdf
Washington	https://wdfw.wa.gov/sites/default/files/2019-03/sgcn_2015.pdf
West Virginia	https://www.wvdnr.gov/2015%20West%20Virginia%20State%20Wildlife%20Action%20Plan%20Submittal.pdf
Wisconsin	https://dnr.wisconsin.gov/topic/WildlifeHabitat/actionPlanSGCN.html
Wyoming	https://wgfd.wyo.gov/WGFD/media/content/PDF/Habitat/SWAP/Wyoming-SGCN.pdf

APPENDIX B: LIST OF STATE STREAM BIOMONITORING PLANS

Appendix B. List of stream biomonitoring assessments for each state (Last accessed in April 2021).

State	Assessment Link
Alabama	http://adem.alabama.gov/programs/water/wqsurvey/WQMonitoringStrategy.pdf
Alaska	https://www.adfg.alaska.gov/static/home/library/pdfs/habitat/07_02.pdf
Arizona	https://legacy.azdeq.gov/environ/water/assessment/riverandstream.html
Arkansas	https://www.adeq.state.ar.us/water/planning/integrated/303d/pdfs/2018/final-2018-assessment-methodology.pdf
California	https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/351.pdf
Colorado	https://pubs.usgs.gov/sir/2010/5148/pdf/SIR10-5148.pdf
Connecticut	https://portal.ct.gov/DEEP/Water/Inland-Water-Monitoring/Ambient-Benthic-Macroinvertebrate-Monitoring
Delaware	https://www.state.nj.us/drbc/library/documents/Bioassessment-draft-July2009rev.pdf
Florida	https://floridadep.gov/dear/bioassessment/content/bioassessment-methods#Streams
Georgia	https://epd.georgia.gov/watershed-protection-branch/monitoring#toc-macroinvertebrate-bioassessments
Hawaii	https://files.hawaii.gov/dlnr/cwrm/publishedreports/R84_HSA.pdf
Idaho	https://www2.deq.idaho.gov/admin/LEIA/api/document/download/14844

Illinois	https://www2.illinois.gov/dnr/education/Documents/StreamMonitoring.pdf
Indiana	https://www.in.gov/idem/riverwatch/files/volunteer_monitoring_manual_chap_5.pdf
Iowa	http://www.shl.uiowa.edu/env/limnology/biologicalmonitoring.xml
Kansas	https://www.kdheks.gov/befs/download/MonStrategy_2019.pdf
Kentucky	https://eec.ky.gov/Environmental-Protection/Water/QA/BioLabSOPs/KY%20Macroinvertebrate%20Bioassessment%20Index.pdf
Louisiana	https://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=1501&context=gradschool_theses
Maine	https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1205&context=aes_techbulletin
Maryland	https://www.baltimorecountymd.gov/departments/environment/monitoring/biological.html
Massachusetts	https://core.ac.uk/download/pdf/146521858.pdf
Michigan	https://www.michigan.gov/documents/deq/wrd-swas-strategy-2017_556101_7.pdf
Minnesota	https://www.pca.state.mn.us/sites/default/files/wq-bsm4-01.pdf
Mississippi	https://www.mdeq.ms.gov/wp-content/uploads/2017/05/MBISQ2015-with-appendixes-FINAL-20160203c.pdf
Missouri	http://www.mostreamteam.org/Documents/VWQM/Intro_Notebook/Chapter%2004%20Intro%20Biological%20Monitoring.pdf
Montana	https://semspub.epa.gov/work/08/100008036.pdf
Nebraska	http://deq.ne.gov/Publica.nsf/xsp/.ibmmodres/domino/OpenAttachment/Publica.nsf/42A94D537B17E30E8625784C0055E984/Attach/NebrStreamBiolMonitorReport20042008.pdf

Nevada	https://lands.nv.gov/uploads/documents/License_WildLife_A_Comparison_of_Stream_Physical_Habitat_Measurements_with_Benthic_Macroinvertebrate_Occurance_From_North_Canyon_Creek,_NV.PDF
New Hampshire	https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/2macro-class.pdf
New Jersey	https://www.nj.gov/dep/wms/bfbm/
New Mexico	https://aces.nmsu.edu/pubs/_circulars/CR677.pdf
New York	https://www.dec.ny.gov/docs/water_pdf/sop20819biomonitoring.pdf
North Carolina	https://www.townofchapelhill.org/home/showdocument?id=45238
North Dakota	https://deq.nd.gov/WQ/3_Watershed_Mgmt/5_WQMonit/WQMonit.aspx
Ohio	https://epa.ohio.gov/dsw/bioassess/ohstrat
Oklahoma	https://www.epa.gov/sites/production/files/2019-02/documents/rapid-bioassessment-streams-rivers-1999.pdf
Oregon	http://docs.streamnetlibrary.org/Protocols/021.pdf
Pennsylvania	https://files.dep.state.pa.us/Water/Drinking%20Water%20and%20Facility%20Regulation/WaterQualityPortalFiles/Technical%20Documentation/freestoneIBImarch2012.pdf
Rhode Island	http://www.dem.ri.gov/programs/water/quality/surface-water/bio-monitoring.php
South Carolina	https://www.epa.gov/wqc/bioassessment-and-biocriteria-program-status-south-carolina-streams-and-wadeable-rivers
South Dakota	https://www.epa.gov/wqc/bioassessment-and-biocriteria-program-status-south-dakota-streams-and-wadeable-rivers
Tennessee	https://trace.tennessee.edu/cgi/viewcontent.cgi?article=2825&context=utk_gradthes
Texas	https://www.tceq.texas.gov/assets/public/comm_exec/pubs/rg/rg416/chapter-5.pdf

Utah	https://extension.usu.edu/waterquality/files-ou/Publications/Utah-Stream-Team.pdf
Vermont	https://dec.vermont.gov/sites/dec/files/wsm/mapp/docs/bs_wadeablestream1a.pdf
Virginia	https://vasos.org/wp-content/uploads/easternmethodsops.pdf
Washington	https://ecology.wa.gov/Research-Data/Monitoring-assessment/River-stream-monitoring/Habitat-monitoring/Stream-biological-monitoring
West Virginia	http://dep.wv.gov/wwe/watershed/bio_fish/documents/wvsci.pdf
Wisconsin	https://dnr.wi.gov/topic/surfacewater/monitoring/strategy/Strategy_2015_2020.pdf
Wyoming	https://gis.deq.wyo.gov/MAPS/WQD_ACTIVE_PROJECTS/IR/AR/WYBR_CoantagCreek_1998.pdf