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Evaluation of speculated reproductive habitat for *Somatochlora calverti* (Corduliidae), a rare and range-restricted dragonfly

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Abstract. Globally, freshwater ecosystems and the organisms that depend on them are at risk. Dragonflies and damselflies (collectively, "odonates") have a history of being used as bioindicators of freshwater habitat quality due to their wide range in environmental sensitivities across species and because they are relatively accessible. However, the nymphal stage is severely understudied compared to the adult stage, which inhibits conservation efforts. *Somatochlora calverti* is a rare species of dragonfly in the family Corduliidae; members of the genus *Somatochlora* are notoriously difficult to find and collect in the field as nymphs and adults. *Somatochlora calverti* is known primarily from the Florida panhandle but has been documented in Alabama, Georgia, and South Carolina. The nymph of this species is speculated to use seepage streams analogous to sympatric congeners; however, the nymph has never been collected in the field and, therefore, its specific microhabitat is unknown. We conducted a review from a suite of informational sources to generate a holistic consensus on what is defined to be suitable reproductive habitat for *S. calverti*. Sources identified eight major environmental characteristics that are likely to harbor *S. calverti*: shallow seepage streams, including steephead ravines, with undercut banks and mats of *Sphagnum* moss adjacent to intact sandhill forest. These ecosystems are being lost and degraded by anthropogenic activity, which has considerable impacts on the persistence of habitat specialists, including *S. calverti*, and managers' ability to conserve them.

Key words. Conservation, Florida panhandle, freshwater streams, nymphal habitat, rare species

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Data Availability Statement:
All relevant data are within the paper and its Supporting information files.

Introduction

The southeastern US is home to particularly high levels of endemic and rare odonates yet is and has been for a long time now highly modified by anthropogenic activities (United States Fish and Wildlife Service [USFWS], 2011). For example, agricultural and urban practices, such as the use of fertilizers and biocides, pollute groundwater (Florida Natural Areas Inventory [FNAI], 2010). Erosion from timber harvest, development, and even excessive foot traffic can accelerate the rate of sedimentation and loss of sensitive organisms (FNAI, 2010). In addition to these direct anthropogenic stressors, indirect impacts from intensifying precipitation events (e.g., from climate change) may further damage the erosional integrity of streams and the biota they support. These actions have resulted in a drastic decline in available habitat for many sensitive endemics (USFWS, 2011). For instance, it is thought that all six species of the genus *Somatochlora* (Corduliidae) that occur in Florida inhabit small streams, particularly seepage streams (Tennessen, 2021). The nymphs are known to utilize the undercuts of banks in these small streams, where they hide in aquatic plants, mosses, and detritus (Tennessen, 2021). Seepage streams have relatively stable hydrological conditions (van der Kamp, 1995) if left undisturbed, but these specialized areas are at particular risk. For example,

waste dumping is a frequent occurrence in the ravines in which these wetlands occur, which smothers vegetation and degrades water quality (FNAI, 2010). Steephead ravines have also suffered from impoundment, which decimates the unique microhabitats and the lotic systems that these ravines feed (FNAI, 2010). Finally, rooting damage by invasive feral swine is detrimental for erosional integrity in steephead ravines, particularly during drought conditions, which concentrate the swine at steepheads for the perpetual water supply they yield (Engeman et al., 2019). These anthropogenic activities may negatively affect odonate diversity (Vilenica et al., 2020) and may be exacerbating and contributing to rarity in *Somatochlora* and other species that use seepage streams.

Of the six *Somatochlora* in the southeastern US, *S. calverti* Williamson & Gloyd, 1933 (Calvert's Emerald) has the most restricted geographic range. It has only been found in the Pensacola, Apalachicola, St. Marks, and St. Marys watersheds in northern Florida as well as two records in the Blackwater watershed for Alabama and two specimens in the Savannah River watershed of South Carolina. No documentations for the species have occurred in Alabama or South Carolina since 1995 and 1977, respectively (Figure 1). Though the adult was taxonomically described in 1933, it was not until 2019 that the nymph was morphologically described; even so, the description remains incomplete, being solely based on the reared neotype, the biological specimen used for the description of the nymphal stage of this species (Tennessen, 2021; Williamson & Gloyd, 1933). Therefore, all field observations of this species have been of adults; nymphs have never been collected in the field. *Somatochlora calverti* nymphs are speculated to use seepage streams similar in structure to other sympatric *Somatochlora* (Paulson, 2011; Worthen, 2005). However, there is no consensus on the microhabitat required that might elucidate why it is the most range-restricted species of southeastern *Somatochlora*. Thus, its ecology is especially poorly understood, hindering management efforts (Paulson, 2011). As a result, *S. calverti* was considered for the federal Endangered Species List in 2010; listing was deemed warranted but never granted because the species is too data-deficient to assign a definitive status (USFWS, 2011; Worthen, 2005). It has additionally been assigned an IUCN status of data deficient (Paulson, 2018), and NatureServe ranks this species G3 globally (i.e., vulnerable: at moderate risk of extinction or collapse due to a fairly restricted range and relatively few populations/occurrences), imperiled (S2) in Florida, critically imperiled (S1) in Alabama, and unranked (SNR) in South Carolina due to lack of data in all states with verified occurrences (NatureServe, 2023). The southeastern US does not currently recognize any odonate as a regional species of greatest conservation need (Rice et al., 2019). Only Florida has assigned *S. calverti* as a state-recognized species of greatest conservation need (Florida Fish and Wildlife Commission [FWC], 2019). There is thus an imperative need for information about this species for its conservation, particularly in the nymphal stage, which may be particularly sensitive to pollutants (Ferreras-Romero et al., 2009). Here, we attempt to provide consensus on speculated reproductive habitat for *S. calverti* to allow researchers and managers a concrete starting point for conducting *S. calverti* nymph surveys.

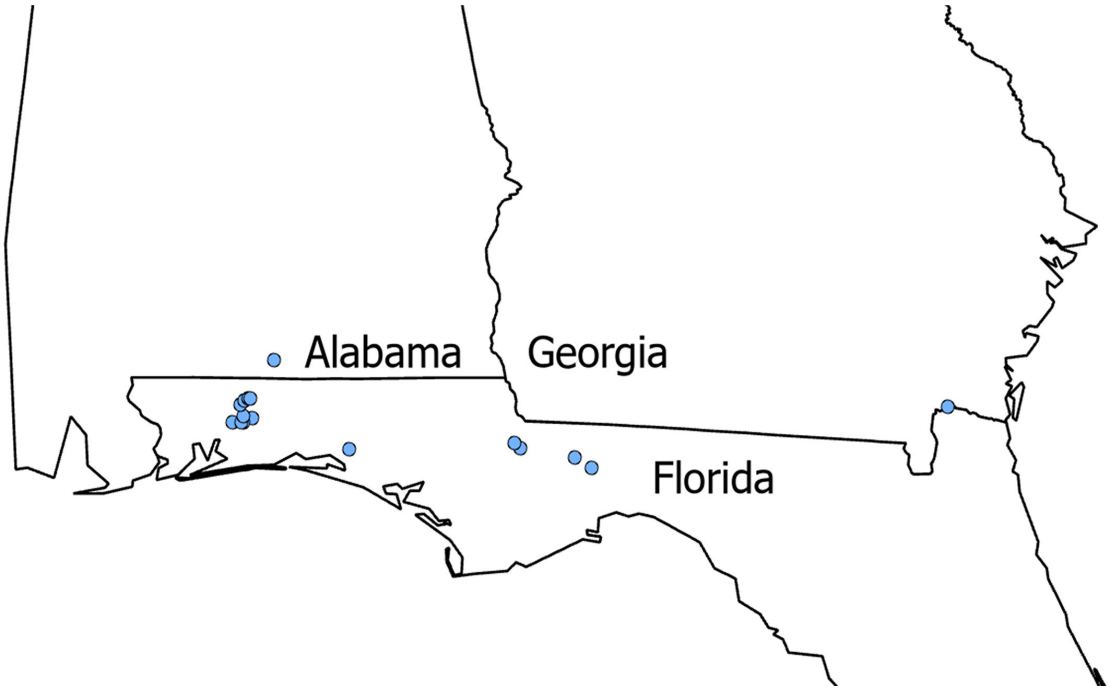

Figure 1. Adult records (shown as blue points) for *S. calverti* across northern Florida and southern Alabama. Occurrences from South Carolina have not been included due to the absence of records for *S. calverti* in > 50 years and geographic isolation from the core range.

Methods

Lack of published data for *S. calverti* necessitated a broad review of data sources. Indeed, much of the knowledge regarding *S. calverti* is anecdotal (unpublished) from experienced odonate hobbyists and scientists who have dedicated their lives to observing and documenting odonate natural history. Therefore, a large part of our review relied on the expertise of these individuals. We compiled data from (a) literature (published and unpublished, print and digital); (b) survey responses; and (c) observation notes in citizen science databases. Thirty-five sources referencing *S. calverti* were obtained; sources that did not meet the criteria highlighted below were removed, yielding 25 total sources for analysis.

Literature sources

We input the search terms "*Somatochlora calverti*", "*S. calverti*", and "Calvert's Emerald" into Google Scholar to locate literature, both "gray" (e.g., agency technical reports) and published, that referenced this species. However, many sources that refer to the species have not been digitized in a manner that allows the document text to be searched, so many documents that mention the species did not come up in initial search results. To address this, the literature cited of each document found was searched and appropriate documents cited that were published after 1933 (the year *S. calverti* was described) were checked for mention of *S. calverti*. The search yielded 24 documents that referenced *S. calverti*, but not all discussed habitat associations; only documents that made comments regarding possible *S. calverti* reproductive habitat (N = 15) were used. These 15 literature sources were then filtered by whether the habitat listed for the species was an original description of speculated habitat or if the description was cited from elsewhere. Only sources that were primary descriptors of probable *S. calverti* habitat were used to avoid biasing results toward one person's opinion. Lastly, to further reduce potential author bias, multiple sources by the same author were removed and only the author's most recent work was kept to ensure that all documents used in the review were original descriptions of habitat by unique authors. After removal of secondary habitat descriptions and identical authors, six literature sources were used in data analysis. We reviewed these sources for environmental features that attempted to describe where *S. calverti* nymphs likely develop and/or features of the broader landscape (i.e., landcover types) that these microhabitat characteristics are embedded in so as not to miss any potentially important descriptor that may prove necessary for finding nymphs.

Survey responses

A Google survey was designed to query as many people as possible who have field and/or academic experience with *Somatochlora* or *S. calverti* and would, therefore, be qualified to speculate on the habitat it occupies. The survey consisted of 25 questions across six sections (see Supplemental data). The number of questions and sections a survey responder answered was dependent on their answers to previous questions. The sections were designed to understand the level of personal experience a respondent had with the species, whether they had ever witnessed mating behavior or female oviposition of eggs as well as their experience with co-occurring species of *Somatochlora* and personal thoughts on what the habitat for *S. calverti* might be. The survey was emailed directly to several odonate enthusiasts and experts in the field known by the authors. Additionally, the survey was posted on the social media platforms Facebook, Instagram, and X (formerly known as Twitter) to reach a broader audience. The survey was left up indefinitely, but responses stopped being received after about a month. At the conclusion of the survey, 14 survey responses were recorded and downloaded into Microsoft Excel. Responses that both failed to speculate on probable breeding habitat and lacked any field experience with either the species or genus that could be useful were removed. After removal, there were 11 survey responses eligible for the review.

Citizen science observations

The final source we searched for mention of habitat relevant to *S. calverti* were citizen science databases, specifically iNaturalist and OdonataCentral. There were 24 unique verified observations of *S. calverti* on iNaturalist and OdonataCentral; nine were unique to iNaturalist, 13 were unique to OdonataCentral, and two occurred on both platforms. Nine of these observations included comments that mentioned the habitat in which the individual was documented. However, multiple observations made by the same observer in the same place within a narrow window of time were combined to reduce biasing the frequency of reported characteristics. This left only eight records eligible for our review. We included these eight occurrences of adults, not as specific indicators of nymphal habitat, but to characterize the broader landscape in which *S. calverti* is found.

Data analyses

Collected data from literature, survey responses, and citizen science data bases were compiled into a data table in Microsoft Excel with sources listed by type (journal, book, agency report, survey response, etc.) and its associated environmental descriptors listed exactly as stated within the source, which resulted in a total of 27 terms across 35 sources (Appendix 1a). However, some sources used different terms to describe the same environmental feature; to simplify the summary of results, we condensed words used to describe the same fea-

Table 1. Descriptions for the environmental characteristics cited in over 10% of all 25 sources used in the review.

Environmental characteristic	Definition
Sandhill	A xeric forest community that is maintained by frequent wildfire regimes and is comprised mainly of longleaf pine (*Pinus palustris*), American Turkey Oak (*Quercus cerris*) and Wiregrass (*Aristida stricta*). This ecological community is largely concentrated within the southeastern region of the United States.
Forested	Communities other than sandhill such as mixed pines, second growth deciduous, or hardwood forests that often for the riparian areas of seepage streams in the southeast.
Small stream	Streams that are characterized by being both shallow (≤ 20-30 cm deep, on average) and narrow (≤ 3 m wide, on average).
Seepage	Seepage streams are formed by the slow percolation of groundwater into the stream channel which, in this region dominated by sandy soils, causes the water to be quite cool (~17–20°C) and clear and often means that even during times of heavy rain, the volume and velocity of flow remains low in these channels. In addition to the seeping of groundwater into the channel, most of these seepage streams also receive inputs from surface water erosion down the landscape, which scours a "V-shaped" ravine down into the stream.
Sphagnum moss	A genus of moss (phylum Bryophyta), whose distribution is largely concentrated in the northern hemisphere. This genus of moss tends to grow in large patches called "hummocks" that many species of *Somatochlora* nymphs (particularly in northern latitudes) are known to use as a source of refugia.
Steephead	A unique type of seepage stream that is mostly restricted to the north Florida/panhandle type region of the southeastern United States. What makes steepheads unique among seepage streams is that when ground water percolates through these sandy soils, it becomes blocked at an impervious layer, typically clays, and the water begins to move laterally in a process known as groundwater sapping. This lateral movement erodes the sediment at the head of the stream and sediment from above falls to fill it. This continuous process creates a steep, U-shaped or amphitheater-like shape to the ravine and the head of the stream will migrate with this continual process. The result of these differences is that while seepage streams can be either perennial or intermittent in flow, steepheads are most often a perpetual water source and their steep-sloped ravines are like canyons on Florida's otherwise flat landscape which provide a microclimate of cooler, more humid conditions with a denser/thicker canopy of more unique, typically northern-distributed flora (such as large *Sphagnum* hummocks) and fauna.
Sand bottom	Stream beds that are predominantly composed of sand as opposed to other common substrates.
Undercut banks	A stream bank that vertically rises and overhangs the stream channel, which creates cover for odonates, particularly clingers like *Somatochlora* nymphs, to hide in. These can also be formed by the root balls of trees that are growing directly on the stream margin.

ture into one term for a total of 17 descriptors (Appendix 1b). For example, sources that cited "pinelands" or "longleaf forest" were lumped into the term "sandhill" because longleaf forest is unique to the sandhill ecosystem and sandhill is the dominating pineland throughout the range of *S. calverti*. Characteristics that were mentioned in fewer than 10% of sources were removed from the review, which resulted in a final count of eight descriptors reported here (see Appendix 1a for the full list, and Table 1 for a description of each environmental feature). After ineligible sources were removed using the aforementioned criteria and cited environmental characteristics were combined, the number of times each characteristic was cited across the 25 eligible sources was calculated and converted into a percentage of occurrence. Characteristics were labeled by scale as "landscape" or "local" and the frequency of occurrence for each term was graphed using the package *ggplot2* in RStudio (Wickham, 2016).

Results

Of the 25 sources reviewed, landscape-scale descriptors were the dominant terms (Figure 2). Specifically, sandhill ecosystems and the presence of forest were cited by over half of the reviewed sources (76% and 52%, respectively). Among source types, these landscape-scale descriptors were most often mentioned in citizen science observations but also came up frequently in survey responses and less so in literature sources. Certain environmental descriptors were never discussed by citizen science observations and were only mentioned within literature or surveyed sources. The only local term to be mentioned in a citizen science observation was the term "small stream." This descriptor, along with the term "seepage," were the most cited local habitat characteristics, being cited in 36% of the reviewed sources. Survey responses cited these terms the most (56%), but they were common among literature

sources as well, with "small stream" appearing 33% of the time and "seepage" being mentioned 44% of the time. *Sphagnum* moss was expressed by 24% of sources as being an important microhabitat for the survival and development of *S. calverti* nymphs. Among these sources, survey responses were the most common, accounting for 67% of the six sources to cite *Sphagnum* moss (Figure 2). The terms "steephead", "sand bottom", and "undercut banks" were all mentioned equally among the 25 sources used. Furthermore, 67% of the sources that cited "sand bottom" and "undercut banks" came from literature whereas the other 33% of sources were cited in survey responses. The pattern was reversed for the term "steephead", with 67% of its citations coming from survey respondents and only 33% being cited in literature (Figure 2).

Discussion

The results of this review suggest that *S. calverti* is like all its sympatric congeners in that the nymphs are speculated to use small, slow flowing streams. Indeed, it is thought that all species of *Somatochlora* nymphs that have mid-dorsal hooks (such as *S. calverti* and all its sympatric congeners), inhabit these slow flowing, seepage-spring type habitats (Tennessen, 2021). Adults are thought to only use these streams for breeding, retreating to open forest clearings for foraging and high into the canopy for roosting (Walker, 1925). Sand, gravel, or rocky substrate are most cited for many of the stream inhabiting *Somatochlora* nymphs, and these substrates would match the primary substrate present in seepage streams across the range of *S. calverti*. Likewise, these species overlap heavily in the duration of their flight seasons, flying mostly between June and August (Paulson, 2011). These similarities are likely influencing speculation about the habitat associations of *S. calverti*, yet *S. calverti* remains the only species of this co-occurring group with such a restricted geographic range. Interestingly, *S. calverti* is also a species where the adult habitat is thought to be associated with a specific forest community. Most southeastern *Somatochlora* adults are reported to be in clearings and roads near forested areas (Dunkle, 2000; Paulson, 2011). In contrast, *S. calverti* has been reported to be associated primarily with dirt roads, specifically in sandhill forest (FNAI, 2020). This could indicate that contiguous sandhill forest is restricting *S. calverti* from a more expansive range like its congeners. The sandhill ecosystem historically occupied a much larger region of the eastern US If sandhill were the only limiting factor it would be expected that there would be historical records for *S. calverti* adults throughout a much broader area of the southeast. It is possible, therefore, that the factors influencing the rarity of this species are far more numerous and potentially complex. Long-term, intensive field surveys for this species to document specifics of microhabitat to compare to its sympatric congeners are the only way to elucidate these hidden factors that isolate this species to such a

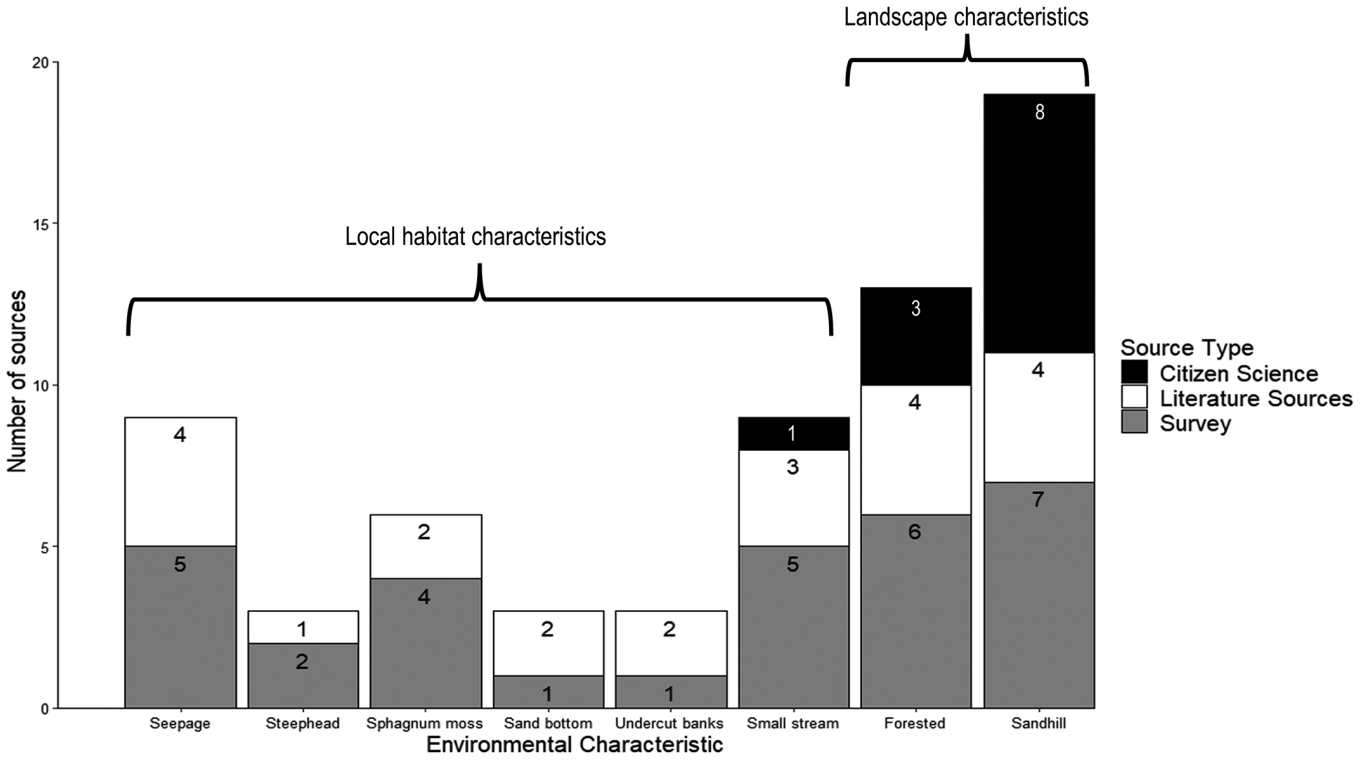

Figure 2. The eight most mentioned environmental characteristics, separated by scale (local habitat and landscape-level descriptors) and the frequency at which each term was mentioned among 25 sources from three source types (citizen science databases [in black], published resources [in white], and survey responses [in gray]). Numbers in each color indicate the number of each source type that mentioned a habitat characteristic.

small region. Field work is imperative to ground-truth the putative habitat requirements of *S. calverti*. We hope that the information provided herein can guide such efforts.

The description of microhabitat in tandem with landscape context is needed to holistically delineate the narrow distribution of *S. calverti* compared to its more widely distributed congeners. Indeed, there is evidence that even within water-rich regions, odonates such as *S. calverti* with highly specialized habitat requirements will occupy only a few of these water bodies (Hassall & Thompson, 2008; Korkeamäki & Suhonen, 2002; Schilling et al., 2019; Suhonen et al., 2014). Our review affirms that terrestrial adults, though vagile, are thought to be sandhill specialists, restricting their extent of occurrence to northern Florida and southern Alabama/Georgia where sandhill ecosystems are largely contiguous. However, the second most highly mentioned landscape descriptor was "forested", which can refer to the presence of more deciduous or mixed forest rather than sandhill forest, which is predominantly composed of Longleaf Pine (*Pinus palustris*), Turkey Oak (*Quercus cerris*), and Wiregrass (*Aristida stricta*) (FNAI, 2010).

The frequent mention of deciduous patches may point to more localized areas within the sandhill landscape where *S. calverti* reproduction and oviposition occur. Specifically, these localized patches of deciduous forest embedded within the broader sandhill landscape could be in reference to the presence of steephead ravines, one of the speculated local habitat requirements cited by the reviewed sources for the development of *S. calverti*. Steephead ravines are a classification of seepage stream that occur primarily throughout the northwestern panhandle of Florida east to southwest Georgia (Engeman et al., 2019; Means, 2011). These geologically unique ravines are the result of rainwater percolating through sandy, upland soils and becoming blocked by an impermeable layer of clays (Engeman et al., 2019; FNAI, 2010). Once blocked, lateral groundwater sapping causes the emergence of seeps and springs to erode the area into a steep, amphitheater-shaped ravine that erodes headward, lengthening the stream channel in the opposite direction of flow (Engeman et al., 2019; FNAI, 2010; Higgins, 1984; Means, 1991). The consequence is a microclimate of generally greater humidity and cooler/constant conditions that support a diversity of organisms, including the unique slope forest community (mixed forest with deciduous and evergreen species more typical of the Appalachians) that may otherwise be incapable of persisting on the landscape (Blaustein, 2008; Kwit et al., 1998; Means, 2011). Though steepheads are rarely mentioned in literature directly related to *S. calverti*, many survey respondents, especially those who are familiar with the steephead ecosystem, indicated that steepheads are the most likely habitat for nymphal development. "Steepheads" may not have been highly cited from being used interchangeably with "seepage stream." Therefore, it is likely that sources may have steepheads in mind when using the term seepage stream. In fact, all local terms used to describe the microhabitat in this review are also characteristics used to describe seepage and steephead streams.

Most survey respondents that specifically identified steepheads also emphasized the presence of *Sphagnum* moss as an important predictor, which grows ubiquitously in steephead streams. The presence of other *Somatochlora* species, particularly in northern latitudes, is tightly linked to the presence of *Sphagnum* (Tennessen, 2021; Walker, 1925). Some survey respondents expressed that in lotic *Somatochlora*, the nymphs may reside in *Sphagnum*-lined undercut banks of the stream and hardly ever venture into the stream channel itself. Overall, the consensus among most in the odonate community is that the most likely areas to host the nymphal stages of the elusive *S. calverti* are narrow and shallow seepage streams, including steephead ravines, with undercut banks and mats of *Sphagnum* moss adjacent to intact sandhill forest. Without field-collected specimens to corroborate, this is the most cohesive idea of what is required for *S. calverti* nymphal development and, therefore, conservation efforts for *S. calverti* should be focused on these areas until nymphs are detected in the field.

Conservation barriers

Odonata that are restricted in their habitat requirements and have narrow regional distributions are known to be more susceptible to shifts in environmental conditions and, therefore, more vulnerable to local extirpation and extinction (Korkeamäki & Suhonen, 2002). Therefore, the persistence of localized habitats on the landscape will dictate the persistence of rare habitat specialists, like *S. calverti*, that utilize them. Specifically, the habitats highlighted in this review (narrow, shallow seepage/steephead streams with undercut banks and mats of *Sphagnum* moss adjacent to intact sandhill forest) should be protected and further surveyed for *S. calverti*, yet these areas are under threat from an array of anthropogenic stressors. Among these stressors, deforestation and fragmentation of surrounding sandhill and slope forests for development and timber harvest are particularly harmful. Deforestation increases surface erosion and leads to excessive sedimentation within stream channels (FNAI, 2010); additionally, the loss of slope forests via erosion and timber harvest increases solar radiation and facilitates overgrowth of emergent herbaceous species along stream banks that displace the historically depauperate community of mosses, ferns, and liverworts (FNAI, 2010). However, the repercussions of deforestation impact all stages of *S. calverti*'s life cycle. Adults rely on intact sandhill forests to feed, mate, roost, and evade threats (NatureServe, 2023). Fragmentation of forest patches has been shown to restrict adult movement between suitable habitat patches (Jonsen & Taylor, 2000). In a species already limited in distribution, this has substantial

implications for reproduction and population connectivity. Furthermore, it is thought that adult odonates use visual cues to determine nymphal habitat quality (Gyssels & Stocks, 2005; Harabiš & Dolný, 2012; McCauley, 2007; Schilling et al., 2009). Indeed, it is not uncommon for adults to select heavily altered freshwater sites for oviposition despite in-stream conditions contradicting the elevated requirements necessary for development and emergence of their offspring (Harabiš & Dolný, 2012).

The Florida panhandle is a biodiversity hotspot of which seepage steams, particularly steephead ravines, are a major component (Blaustein, 2008; Means, 2011; Stein et al., 2000; Wolfe et al., 1988); therefore, mitigation of these stressors is imperative for the persistence of these habitats and sensitive species that depend on them. However, managing the protection of key habitats for *S. calverti* is a challenge without definitive evidence of occurrence. Perhaps one of the largest barriers to conserving *S. calverti*, and many species of Odonata, is data deficiency. Data on reproductive habitat preferences and microhabitat use is limited in odonates, which impedes our ability to conserve them for the longest period of their life cycle (Patten et al., 2015). There are currently no odonates listed as RSGCN and *S. calverti* is only listed as an SGCN in one of the four states it has potential to occur in, which pose major barriers to filling some of the most fundamental knowledge gaps for this species and further prolong hope for its protection. Long-term, intensive surveys of the habitat characteristics delineated here to aid in the assignment of this species as a RSGN and a SGCN are sorely needed. Until nymphs can be discovered in the field and their exact habitat (on landscape and local scales) be affirmed, the best course of action to protect *S. calverti* is to impart protections for sandhill ecosystems and the seepage streams that occur within them.

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Appendix 1

Appendix 1a: https://github.com/hannahgwojo/S.calverti_Habitat-Review-Ch1-/blob/main/HEG_SCRH-appendix1a.xlsx

Appendix 1b: https://github.com/hannahgwojo/S.calverti_Habitat-Review-Ch1-/blob/main/HEG_SCRH-appendix1b.xlsx

Supplementary Material

https://github.com/hannahgwojo/S.calverti_Habitat-Review-Ch1-/tree/main