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Combining Citizen Science with Traditional Biotic Surveys to Enhance Knowledge Regarding the Natural History of Secretive Species: Notes on the Geographic Distribution and Status of the Green Salamander (*Aneides aeneus*) in the Cumberland Mountains of Virginia, USA

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Abstract.—The Green Salamander (*Aneides aeneus*) is a secretive, arboreal cliff specialist distributed discontinuously across the southern and central Appalachian Mountains, USA. While intensively studied in some parts of its range in the Appalachian Plateau and Blue Ridge Provinces, the distribution of *A. aeneus* is still poorly understood, particularly in the Cumberland Mountains physiographic province of the Appalachian region. This data deficiency is partly the result of a lack of formal historic surveys across this region, coupled with a high amount of privately owned land that is inaccessible to traditional biotic surveys. We used a combination of citizen science efforts and traditional field surveys to investigate the distribution and status of *A. aeneus* across the Cumberland Mountains of southwestern Virginia, USA. Local landowners and outdoor recreation enthusiasts reported a relatively high rate of encounters with *A. aeneus*, verifying the species' persistence at four historic localities and leading to the discovery of 36 previously unknown populations. Although we are cautious about making inferences about the true conservation status of *A. aeneus* across this region given the scarcity of current data, these findings suggest that the distribution of *A. aeneus* in Virginia has been vastly underestimated and that expanded monitoring programs are needed to further ascertain this species' status. More broadly, our results illustrate the utility of coupling public initiatives with more traditional field surveys to expand the biogeographic knowledge of secretive, difficult-to-study amphibian species.

Keywords: *Aneides aeneus*; Green Salamander; conservation; biogeography; Virginia; Appalachian Mountains; distribution; citizen science; amphibian; Cumberland Mountains

Data deficiency, or a lack of basic biological knowledge regarding a species' taxonomic placement, biogeographic distribution, life history, habitat requirements, or reproductive behavior, is considered a major impediment to biodiversity conservation (Whittaker et al. 2005; Kozlowski 2008; Brito 2010). While not considered a conservation threat *per se*, this lack of knowledge often is considered alongside other conservation threats due to the inability for managers to accurately assign data-deficient species a conservation status and design effective management approaches (Bini et al. 2006; Butchart and Bird 2010; Bohm et al. 2013). Although data deficiency is most commonly used as a status classification for entire species (IUCN 2001), subsets of species ranges and individual populations may also suffer from the knowledge shortfalls that contribute to data deficiency and impede local conservation efforts.

Amphibians are especially predisposed to data deficiency given their cryptic behavior, low detectability in many habitats, and occurrence in geographic regions that are characterized by rugged topography and geographic isolation. Nearly one quarter (24.5%) of all amphibian taxa are formally listed as data deficient by the International Union for the

Fig. 1. The Green Salamander (*Aneides aeneus*) is rarely seen in the field due to its tendency to use refugia in exposed rock formations, most typically deep crevices within the interior portions of rock outcrops. The individual seen here was encountered moving across the exterior portion of a rock face from a nearby refugium (visible in the background). Photograph by Walter H. Smith.

Conservation of Nature's (IUCN) Red List (IUCN 2015), and biogeographic knowledge gaps are especially common areas of local or regional data deficiency cited in assessments of amphibians in many U.S. states (Redmond and Scott 1996; Mitchell and Reay 1999). Work addressing this data deficiency can expand the biogeographic knowledge base of understudied amphibian taxa and lead to new conservation insights; for example, recent work in this arena has uncovered new hotspots for herpetofaunal diversity in areas that had been overlooked previously by biologists, even in areas located near major population centers (Graham et al. 2010).

The Green Salamander (*Aneides aeneus*; Fig. 1) is one amphibian species that suffers from the combined effects of data deficiency and population declines. This species is an arboreal cliff specialist distributed primarily across the Appalachian Mountains, particularly the Appalachian Plateau and Valley and Ridge ecoregions on the western Appalachian front (Gordon 1952). Disjunct populations occur along the Blue Ridge Escarpment in North Carolina, South Carolina, and Georgia, as well as in southern Indiana. Documented local declines and extirpations of this species (Snyder 1991; Corser 2001), coupled with its presumed rarity and sensitivity to anthropogenic disturbance, have resulted in *A. aeneus* having formal protected status in six states (MDNR 2005; MMNS 2005; IDNR 2006; NCWRC 2014; ODNR 2014; PGCPBFC 2015), with all other remaining states across its range listing the species as of special conservation concern (GDNR 2005; SCDNR 2005; TWRA 2005; VDGIF 2005; ADCNR 2005; WVDNR 2005; KDFWR 2013). The species' preferred habitats (steep, isolated cliff and bluff systems; Fig. 2) and solitary behavior of seeking refugia in deep, inaccessible rock crevices have also predisposed this species to local data deficiency that hinders conservation efforts, especially in the Cumberland Mountains Province of the central Appalachian Mountains. In the Appalachian Region of far southwestern Virginia, for example, records containing publicly accessioned voucher specimens exist from only 14 localities for *A. aeneus* (GBIF 2015), despite an assumed possible

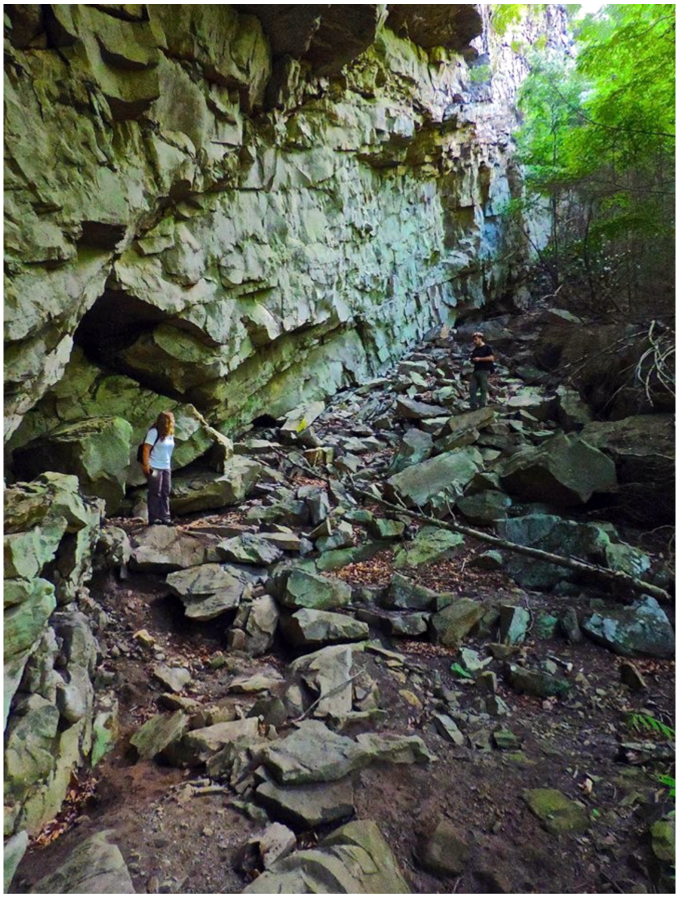

Fig. 2. Typical Green Salamander (*Aneides aeneus*) habitat in the Cumberland Mountains of Virginia, with two co-authors included for scale. Habitats in the study region are most commonly composed of sandstone escarpments and associated boulderfields found within mixed mesophytic hardwood forests. Heavy Hemlock (*Tsuga canadensis*) and Rhododendron (*Rhododendron maximum*) cover frequently are present, especially within riparian habitats.

distribution for this species across 10 counties encompassing 11,891 km^2 (VDGIF 2005). These records, coupled with additional scattered, anecdotal reports, form the only current biogeographic knowledge of *A. aeneus* in Virginia (VDGIF 2014), with few recent surveys existing to verify the continued persistence of the species at historic localities.

Given increasing concerns about the impacts of habitat loss and pathogens on amphibians in the Appalachian Region, basic studies must be initiated to address data deficiency in this species to produce the basic biogeographic data needed to inform conservation, management, and monitoring plans. These studies frequently are hindered, however, by the fact that many putative Green Salamander populations are located in extremely rugged areas rarely visited by biologists or exist on privately owned lands that are inaccessible to traditional biotic surveys. In response to these challenges, we developed a citizen-science initiative designed to tap into local landowners' and residents' knowledge as an alternative approach to improving the biogeographic knowledge of Green Salamanders in southwestern Virginia, and following these reports with verification surveys in the field. Herein we report the results of these surveys and discuss the potential promise and challenges related to this approach for the Green Salamander across the remainder of its range.

Methods

Educational Initiative.—Beginning in April 2012, we designed a regional educational effort around *A. aeneus* as part of a larger initiative to disseminate knowledge on Appalachian biodiversity to rural residents across a four-county region in the Cumberland Mountains of southwestern Virginia (Wise, Lee, Dickenson, and Scott Counties). This effort specifically used digital tools (websites, smartphone applications) to communicate information on local taxa from the scientific literature to rural Appalachian residents that may not otherwise interact with professional biologists, visit science centers or museums, or complete a college education. Digital tools were built around public lands (National Forests, State Parks) that were known or were likely to harbor *A. aeneus*. We built four such guides in 2013 for hiking trails in the aforementioned study area that delivered ecological information on *A. aeneus* to local recreational users; trails were selected for guide development based on their proximity to known populations of *A. aeneus* or with habitat features known to be associated with the presence of the species.

Digital educational guides were constructed using the EveryTrail software package. EveryTrail is a freeware approach to digital guide development that allows for the location of various points of interest on a trail (e.g., trail junctions, scenic features) to be mapped alongside a user's current location, as determined from the native GPS incorporated into a user's smartphone. We mapped the treadway of each trail using a Garmin GPSMap 60CS GPS unit and imported resulting shapefiles into the EveryTrail software package, along with major points of interest including trailheads, trail junctions, and scenic features such as waterfalls, cliff systems, and overlooks. We then added placeholders to each guide in the EveryTrail platform describing *A. aeneus,* its conservation status, and relevant ecological topics, guiding users in informal, free-choice learning at habitat features within each site (Fig. 3a). We were careful not to direct users to specific localities with a known *A. aeneus* presence or to describe survey methods for the species in order to minimize the risk of inadvertently increasing impacts from poaching. Users were also directed to follow Leave-No-Trace outdoor ethics (http://www.lnt.org) at each site to minimize impacts to wildlife and habitat.

Each digital guide was then marketed to local residents through a partnership with multiple state agencies, educational institutions, and local communities. Quick response (QR) codes linking to each guide were installed on trailhead and interpretive signage at each site (Fig. 3b), and guide information was additionally included in regional outdoor recreation bro-

Fig. 3. Examples of: (A) Digital educational content, as viewed by users in the field at one focal site from this study, and (B) quick-response (QR) code promotion of educational guides on local trailhead signage. Users would see and have access to high-quality digital photographs, educational videos, and hyperlinks to broader conservation information on the Green Salamander (*Aneides aeneus*) by state conservation agencies, beyond the screenshot seen here.

chures produced through the Virginia Tourism Corporation and Heart of Appalachia Regional Tourism Authority. Content may be found online via the region's outdoor recreation website (http://southwestvirginiacsi.wix.com/clinch).

Citizen Science Initiative.—Each of the aforementioned digital guides was linked to a regional project developed to catalogue citizen reports of *A. aeneus* using the iNaturalist platform (http://www.inaturalist.org), a global citizen-science platform that allows users to upload georeferenced wildlife observations and interact with professional biologists and other users. This particular platform was chosen due to: (i) Its incorporation of independently corroborated observations into the Global Biodiversity Information Facility (http://www.gbif.org) as accessioned natural history collections supported by photographic vouchers, and (ii) its ability to obscure the specific location of observations referring to species of high conservation concern. Users of each digital guide were prompted to share their observations of *A. aeneus* and other amphibian taxa from both public lands and private property either through the iNaturalist platform or by directly contacting the project's principal investigator (WHS). Similar prompts were made on the initiative's website and on hardcopy materials distributed to local residents.

All educational guide users and citizen observers were invited to complete an informal survey following participation in the project to evaluate users' motivations for participation and attitudes toward biodiversity. Questions were designed to collect participants' demographic information, their history of interaction with biologists and similar initiatives, and perceptions of and interest towards biodiversity following participation. Participants submitting citizen-science observations for *A. aeneus* also were invited to complete informal interviews with project leaders to share additional information about the context of their observation (e.g., how observations were made, if organisms were handled) and users' perceptions toward biodiversity conservation as a result of their interaction with the species.

Verification of Citizen Reports and Opportunistic Surveys.—Citizen reports for *A. aeneus* were independently verified by field-surveys in 2013–2014. All surveys took place during April–October and were conducted by searching available rock faces and tree trunks at the locality reported for the presence of *A. aeneus*. Rock faces were searched by visually inspecting open rock surfaces and crevices with an LED headlamp. Installing burlap bands on standing tree trunks is a common and effective survey technique for *A. aeneus* (Thigpen et al. 2010) but was not used in our field surveys due to a local tendency for these structures to be destroyed by wildlife, presumably Black Bears (*Ursus americanus*). We conducted time-constrained surveys of 30 minutes per site or until all available cliff surfaces and standing trees within 20 m of the rock face had been searched, and each site was searched a maximum of two times (with visits at least one month apart) if individuals were not located on the initial visit. We additionally performed opportunistic surveys of major rock outcrop systems located on public conservation lands within an approximately 10-km radius of each citizen report to search for additional populations. Survey methods at these sites were identical to those described above for citizen-reported localities. All resulting new localities were accessioned in GBIF through the iNaturalist platform and/or were reported to the Virginia Department of Game and Inland Fisheries.

Results

Users downloaded or otherwise accessed digital educational content a total of 788 times (unique views and downloads). In return, citizens contributed 106 photographic observations of amphibian taxa from across the project's four-county study area, including 14 incidental observations of *A. aeneus*. Although this represents a small sample size, this equals the

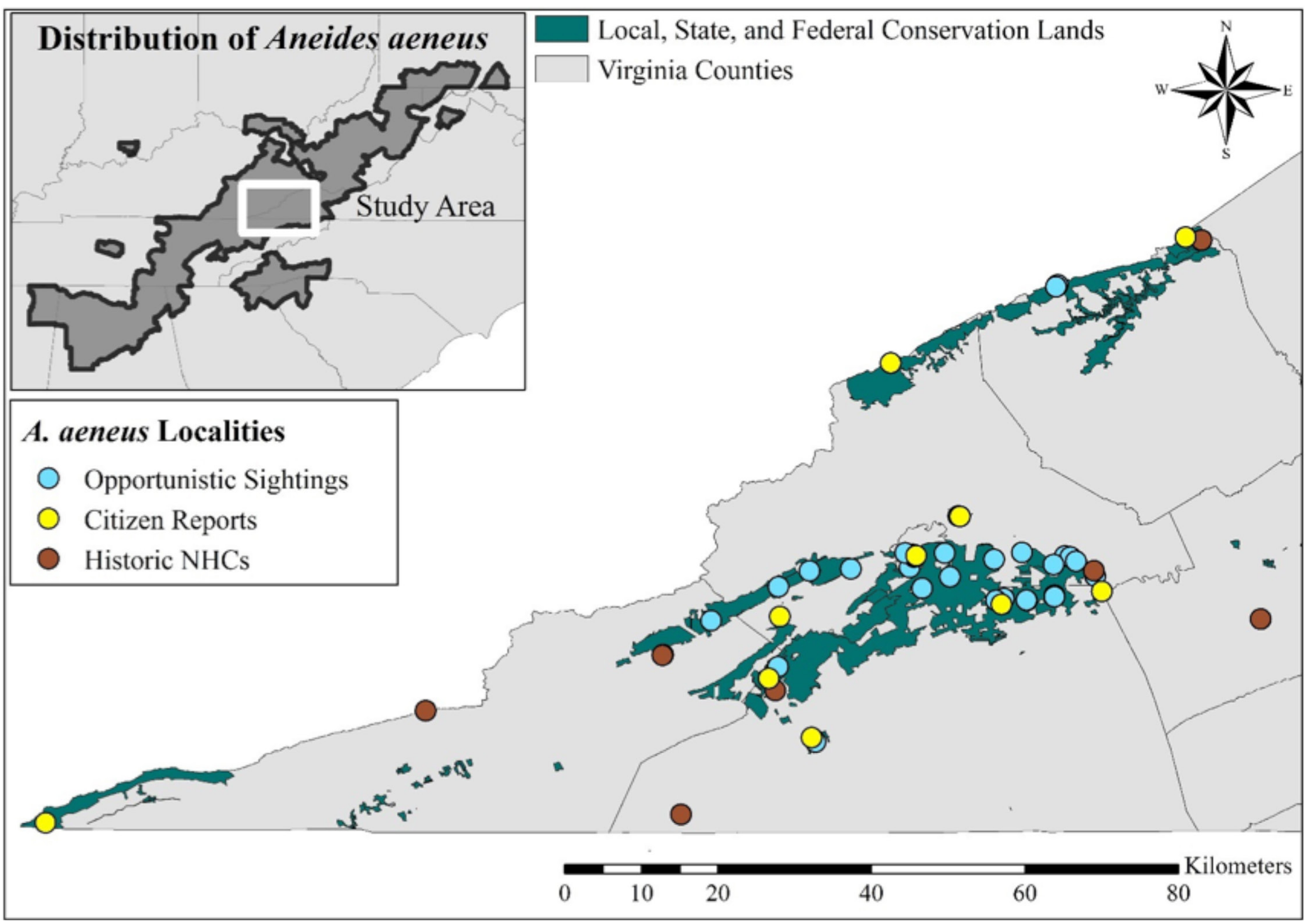

Fig. 4. Location of the study area across four counties in the Cumberland Mountains of southwestern Virginia, USA, showing citizen observations, opportunistic sightings made during verification of citizen records, and pre-existing vouchered collections from global natural history collections databases (historic NHCs).

Fig. 5. Citizen-submitted observation of a Green Salamander (*Aneides aeneus*) occupying a constructed concrete retaining wall at a private residence within the study area. This observation represents a novel finding regarding this species' use of anthropogenic refugia that could enhance local conservation plans. Photograph by W. Harris (used with permission).

total number of localities with formally vouchered specimens recorded from 1879 to 2013 from the entire state of Virginia and made available through major public biodiversity databases. Opportunistic surveys of rock outcrops located near citizen reports uncovered an additional 26 populations (Fig. 4).

Citizen observations both verified the continued persistence of *A. aeneus* at historic localities and led to the discovery of previously unknown populations. Specifically, citizens observed *A. aeneus* at four historic localities supported by vouchered natural history collection specimens. Thirty-six previously unknown populations were also discovered through citizen observations and nearby opportunistic surveys, many in areas that did not previously have any nearby (>15 km) known populations of the species. Verification efforts were successful at every site with reported citizen observations, with six (43%) of the sites also showing evidence of reproduction in the form of females actively guarding nests, courting pairs, and/or the presence of neonates. Citizen observations also yielded insight into *A. aeneus* behavior, including long-term occupancy of a single crevice over two years and the use of refugia in an artificially constructed retaining wall throughout the active season (Fig. 5).

Citizen-science participants (N = 42) were split evenly by sex (50% male, 50% female) and half of respondents were less than thirty years of age. Most respondents (88%) reported having at least some college education, with remaining respondents having completed high school or a general educational development (GED) program. Among those with a college education, seven (17%) had completed graduate or professional school programs. These respondents reported being active in outdoor recreation activities such as hiking or mountain biking, with 74% reporting engaging in outdoor activities at least several times per month. Only 26% of respondents, however, reported having previously communicated or worked with biologists in the region. Following participation, these same respondents reported an increased interest in biodiversity, a better personal knowledge of local conservation issues, and an increased desire to collaborate with regional conservation biologists on similar citizen science or volunteer initiatives in the future (Table 1).

Most participants contributing *A. aeneus* observations (86%) reported making observations incidentally during recreational activities such as hiking or rock climbing, while the remaining 14% reported observing individuals while performing work on their own private property. None of the individuals reported handling individual salamanders during observations, instead reporting photographing animals at a distance only. All but one individual reported not being aware of this species' existence prior to engagement with the project, whereas those who had made observations prior to the project period reported having seen the species before but they could not identify it and were unaware of its conservation status.

Table 1. Prior attitudes toward biodiversity conservation among citizen-science project participants (N = 42) and perceptions toward biodiversity and conservation following participation in the project. Numbers indicate percent of respondents.

As a result of participation:	**Strongly Agree/ Agree**	**Neutral/ No Opinion**	**Strongly Disagree/ Disagree**
Feel more personally involved in conservation science	93	7	0
More comfortable communicating with regional biologists	83	17	0
More informed about local conservation issues	86	14	0
Would continue participation in citizen science initiatives or volunteer conservation projects	93	7	0
More likely to seek out information on biodiversity conservation	90	10	0
Attitudes towards conservation:			
It is important to protect regional biodiversity and associated habitats	100	0	0
Public (government) money should be spent to fund research and conservation of local biodiversity	79	19	2
Biodiversity is an important component of local communities and associated economic growth	93	7	0

Discussion

Our study was designed to determine if and how citizen science can inform the conservation of rare species of concern through the reconciliation of data deficiency. While citizen science is already a heavily used and widely documented technique with broad applications in amphibian conservation (Pittman and Dorcas 2006; Oscarson and Calhoun 2007; Costentino et al. 2014; Biggs et al. 2015), fewer studies have specifically evaluated if narrower, targeted approaches can apply to improving the knowledge base for rare taxa and/or those considered to be abnormally difficult to detect and observe. Our results support this applicability, given that citizen observers alone reported in three years ten new localities for *A. aeneus* across southwestern Virginia, equaling the number of vouchered localities collected over two centuries for this species across the study region. These findings suggest that this species, while considered rare, secretive, and difficult to study, is nonetheless seen incidentally with high frequency by the public in ways that can advance the ecological knowledge required for this species' conservation. More broadly, this also suggests that assumptions that amphibian species encountered infrequently by biologists are also encountered infrequently by the public might not be applicable. Public conservation outreach and educational campaigns can therefore be a valuable tool for the conservation and management of such species, in this case especially when targeted towards members of the public engaged in outdoor recreation or other activities that place them in suitable habitat.

Citizen observers not only reported new observations of *A. aeneus* through this study but also contributed observations that substantially enhanced the regional natural history knowledge of this species. A majority (56%) of the new populations located by citizens and those found nearby during follow-up surveys were located more than 15 km from any other previously known populations of this species, filling significant gaps in the species' biogeographic distribution across Virginia. Many of these new populations are located along riparian zones and linear plateau escarpments that suggest connections between historic populations that have been previously considered to be highly disjunct. For example, a substantial proportion of populations located through this study form a near-continuous swath along the northern escarpment of Stone and Cumberland Mountains in Wise and Lee Counties, Virginia — an area which previously was thought to harbor only a small number of highly isolated *A. aeneus* populations, based on accessioned specimens and anecdotal reports (VDGIF 2014). The escarpments of these ridges are the result of extensive thrust-faulting along the eastern extent of the Appalachian Plateau and, as a result, form a continuous belt of forested sandstone cliff and bluff habitat over a linear extent of more than 120 km (Mitra 1988; Wickham et al. 2007). We were able to identify a consistent swath of *A. aeneus* localities extending along this escarpment from near the highest elevation of the Cumberland Mountains (1,287 m above sea level) to a population located on the banks of the Clinch River at this physiographic province's eastern edge (429 m above sea level), forming a physical link between populations on the Appalachian Plateau and relative lowlands in the adjacent Valley and Ridge. This area may be a key focal point for future surveys to determine if apparently abundant and numerous populations in the Cumberland Mountains extend into the Valley and Ridge or, alternatively, if sparse historic localities in the Valley and Ridge indeed reflect highly disjunct Green Salamander populations.

Fig. 6. The Cumberland Mountains are the result of extensive thrust-faulting of sedimentary rock strata along the eastern portion of the Appalachian Plateau, creating a series of rugged, parallel ridge systems extending over 100 km through Virginia, Kentucky, and Tennessee. This geologic activity and subsequent erosion created nearly continuous linear escarpments of exposed rock strata that form ideal substrate for Green Salamander (*Aneides aeneus*) populations.

These new *A. aeneus* populations and their locations along linear ridge systems also suggest putative corridors for gene flow along exposed cliff systems and ridgelines that may be key for regional conservation efforts. Many of these landscape features provide potential connections to the location of larger, seemingly stable populations in eastern Kentucky (Snyder 1991), suggesting that the status of *A. aeneus* as rare and highly disjunct across the study area may be reflective of little more than sampling deficiency by biologists. While we are cautious about making conclusions about the true conservation status and abundance of *A. aeneus* in this region given the scarcity of current data, our results at least suggest that more intensive study is warranted and support the conclusion that the distribution and local abundance of *A. aeneus* in Virginia and adjacent portions of Tennessee and Kentucky may be vastly underestimated at present. Further, the aforementioned cliff systems in the Cumberland Mountains and adjacent physiographic provinces — such as those found on Pine, Cumberland, and Clinch Mountains — might form valuable natural laboratories for studies of gene flow and other landscape genetic parameters that are essential to understanding the conservation status of Green Salamanders across the region, given their apparent continuity of intact habitat, linear nature, and the presence of existing Green Salamander populations.

Citizen observations additionally provided further insight into the natural history of *A. aeneus* that is typically absent from traditional biotic surveys. Specifically, a number of citizen observations provided photographic documentation of habitat use and behavior that, to our knowledge, had not been documented previously for this species. Two participants reported Green Salamanders living within or beneath anthropogenic refugia, including a terra cotta flowerpot on a participant's porch and the colonization of crevices in a concrete-block retaining wall adjacent to a participant's home. The latter observer reported occupancy of Green Salamanders within this retaining wall during the species' active season (locally April–October), despite being located at a distance of over 2 km from any natural rock outcrop system that could be identified during follow-up verification surveys and examination of aerial orthoimagery. These observations suggest that Green Salamanders may make greater use of non-natural refugia than is currently assumed and highlight an added value of incorporating citizen observations into surveys of understudied taxa.

The ability for citizen observers to address significant knowledge gaps in the regional biogeography of *A. aeneus* suggests that citizen science approaches, when designed carefully, can be a successful approach to addressing data deficiency with amphibian species that are difficult to study and are of high conservation concern. However, our results do highlight several key considerations for the application of this approach to other species. Perhaps of most direct importance is the risk of citizen science efforts accidentally disseminating knowledge on the specific location of species of concern, especially those that are considered at risk of poaching and overcollecting. *Aneides aeneus* is a species that has been cited as being at-risk of localized overcollecting (Snyder 1991; Corser 2001), even leading some researchers to obscure the location of study sites in the scientific literature (Waldron and Humphries 2005). We were sensitive to these concerns in the design of our project and ensured that participants were not informed of specific *A. aeneus* localities in educational materials and that the locations of citizen observations were obscured in the online platform for submitting observations, therefore making the exact location of *A. aeneus* reports known only to the principal investigators and the individual(s) contributing each observation. While we cannot prevent individual observers from communicating the location of their own observations to others, the majority of these observations were made prior to engagement with our project and would have run this risk regardless. Since our survey data indicate an increased awareness of conservation issues among project participants following participation, those participants might be even more unlikely to share these localities with the public as a result of increased awareness of this species' conservation status. We are therefore confident that our approach did not lead to any unintended communication of the location of new or historic *A. aeneus* populations, although those designing similar projects for other species may want to take this consideration into account.

A second major consideration for the design of citizen-science projects surrounding rare species of high conservation concern involves the engagement of participants beyond simply collecting citizen-observed data. In our project, engagement between participants and biologists led to several key insights that moved our initiative beyond simply serving as a tool for enhanced data collection. First, participants reported becoming more engaged with *A. aeneus,* local biodiversity, and associated conservation initiatives as a result of participation in the project. While most participants reported having an interest in biodiversity prior to participation in our project, the vast majority of these participants reported not previously being aware of *A. aeneus* prior to participation, and several interviewees reported a desire to adapt their own behavior to enhance conservation of this species following engagement with the project. For example, one respondent — a local citizen leading the development of rock climbing routes throughout the region — originally submitted a citizen observation of *A. aeneus* made while preparing a site for climbing development. This participant was unaware that the species existed and was considered of high conservation concern prior to participation with the project, although after participation he reported adjusting his group's climbing development practices to avoid disturbing sites with suitable *A. aeneus* habitat. While our survey data do suggest that the audience for this project was biased toward those with a pre-existing interest in outdoor recreation, these results underscore the fact that citizen science can be a powerful conservation outreach tool when targeted toward such communities.

In addition, one of the newly located populations of *A. aeneus* from our study is located on land owned and managed by a local city government. Individuals in this population are unusually abundant, with encounter rates of over 50 individuals per hour during several visits. In addition, an individual found during verification surveys was the largest known *A. aeneus* on record (Blackburn and Smith 2014). Dialogue between city managers and biologists has led to significant interest within the city government in managing this property for the conservation of *A. aeneus*, with conservation activities even receiving formal endorsement by the city's elected Council. Such engagement is often uncommon to even impossible without the participation and interest of citizens, and citizen-science approaches such as those reported here provide an added value to not only addressing data deficiency in understudied species but enhancing the local conservation of species of high concern.

Fig. 7. Example of low-elevation Green Salamander (*Aneides aeneus*) habitat in the study area, most typically large blocks of sandstone dislocated from surrounding cliff faces associated with riparian corridors dissected into the eastern edge of the Appalachian Plateau. Note the presence of extensive fracturing and associated crevices.

Acknowledgments

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Literature Cited

Biggs, J., E. Ewald, A. Valentini, C. Gaboriaud, T. Dejean, R.A. Griffiths, J. Foster, J.W. Wilkinson, A. Arnell, P. Brotherton, P. Williams, and F. Dunn. 2015. Using eDNA to develop a national citizen science-based monitoring programme for the Great Crested Newt (*Triturus cristatus*). *Biological Conservation* 183:19–28.

Bini, L.M., J.A.F. Diniz-Filho, T.F.L.V.B. Rangel, R.P. Bastos, and M.P. Pinto. 2006. Challenging Wallacean and Linnean shortfalls: Knowledge gradients and conservation planning in a biodiversity hotspot. *Diversity and Distributions* 12:475–482.

Blackburn, M.N and W.H. Smith. 2014. *Aneides aeneus*. Maximum size. *Herpetological Review* 45:108.

Böhm, M., B. Collen, J.E.M. Baillie, J. Chanson, N. Cox, G. Hammerson, M. Hoffmann, S.R. Livingstone, M. Ram, A.G.J. Rhodin, S.N. Stuart, P.P.l.

van Dijk, B.E. Young, L.E. Afuang, A. Aghasyan, A.G. Aguayo, C. Aguilar, R. Ajtic, F. Akarsu, L.R.V. Alencar, A. Allison, N. Ananjeva, S. Anderson, C. Andrén, D. Ariano-Sánchez, J.C. Arredondo, M. Auliya, C.C. Austin, A. Avci, P.J. Baker, A.F. Barreto-Lima, C.L. Barrio-Amorós, D. Basu, M.F. Bates, A. Batistella, A. Bauer, D. Bennett, W. Böhme, D. Broadley, R. Brown, J. Burgess, A. Captain, S. Carreira, M. Castaneda, F. Castro, A. Catenazzi, J.R. Cedeño-Vázquez, D. Chapple, M. Cheylan, D.F. Cisneros-Heredia, D. Cogalniceanu, H. Cogger, C. Corti, G.C. Costa, P.J. Couper, T. Courtney, J. Crnobrnja-Isailovic, P.-A. Crochet, B. Crother, F. Cruz, J. Daltry, R.J.R. Daniels, I. Das, A. de Silva, L. Dirksen, T. Doan, K. Dodd, J.S. Doody, M.E. Dorcas, J. Duarte de Barros Filho, V.T. Egan, E.H. El Mouden, D. Embert, R.E. Espinoza, A. Fallabrino, X. Feng, Z.-J. Feng, L. Fitzgerald, O. Flores-Villela, F.G.R. França, D. Frost, H. Gadsden, T. Gamble, S.R. Ganesh, M.A. Garcia, J.E. García-Pérez, J. Gatus, M. Gaulke, P. Geniez, A. Georges, J. Gerlach, S. Goldberg, J.C.T. Gonzalez, D.J. Gower, T. Grant, E. Greenbaum, P. Guo, S. Haitao, A.M. Hamilton, K. Hare, B. Hedges, N. Heideman, C. Hilton-Taylor, R. Hitchmough, B. Hollingsworth, M. Hutchinson, I. Ineich, J. Iverson, F.M. Jaksic, R. Jenkins, U. Joger, R. Jose, Y. Kaska, J.S. Keogh, G. Köhler, G. Kuchling, Y. Kumluta , A. Kwet, E. La Marca, W. Lamar, A. Lane, B. Lardner, C. Latta, G. Latta, M. Lau, P. Lavin, D. Lawson, M. LeBreton, E. Lehr, D. Limpus, N. Lipczynski, A.S. Lobo, M.A. López-Luna, L. Luiselli, V. Lukoschek, M. Lundberg, P. Lymberakis, R. Macey, W.E. Magnusson, L. Mahler, A. Malhotra, J. Mariaux, B. Maritz, O.A.V. Marques, R. Márquez, M. Martins, G. Masterson, J.A. Mateo, R. Mathew, N. Mathews, G. Mayer, J.R. McCranie, J. Measey, F. Mendoza-Quijano, M. Menegon, S. Métrailler, D.A. Milton, C. Montgomery, S.A.A. Morato, T. Mott, A. Muñoz-Alonso, J. Murphy, T.Q. Nguyen, G. Nilson, C. Nogueira, H. Núñez, H. Ota, J. Ottenwalder, T. Papenfuss, S. Pasachnik, P. Passos, O.S.G. Pauwels, V. Pérez Mellado, N. Pérez-Buitrago, E.R. Pianka, J. Pleguezuelos, C. Pollock, P. Ponce-Campos, R. Powell, F. Pupin, G.E. Quintero Díaz, R. Radder, J. Ramer, A.R. Rasmussen, C. Raxworthy, R. Reynolds, N. Richman, E.L. Rico, E. Riservato, G. Rivas, P.L.B. Rocha, M.-O. Rödel, L. Rodríguez Schettino, W.M. Roosenburg, J.P. Ross, R. Sadek, K. Sanders, G. Santos-Barrera, H.H. Schleich, B. Schmidt, A. Schmitz, M. Sharifi, G. Shea, R. Shine, T. Slimani, R. Somaweera, S. Spawls, P. Stafford, R. Stuebing, S. Sweet, E. Sy, H. Temple, M. Tognielli, K. Tolley, P.J. Tolson, B. Tuniyev, S. Tuniyev, N. Üzüm, G. van Buurt, M. Van Sluys, A. Velasco, M. Vences, M. Veselý, S. Vinke, T. Vinke, G. Vogel, M. Vogrin, R.C. Vogt, O.R. Wearn, Y.L. Werner, M.J. Whiting, T. Wiewandt, J. Wilkinson, B. Wilson, S. Wren, T. Zamin, K. Zhou, and G. Zug. 2013. The conservation status of the world's reptiles. *Biological Conservation* 157:372–385.

Brito, D. 2010. Overcoming the Linnean shortfall: Data deficiency and biological survey priorities. *Basic and Applied Ecology* 11:709–713.

Butchart, S.H.M. and J.P. Bird. 2010. Data Deficient birds on the IUCN Red List: What don't we know and why does it matter? *Biological Conservation* 143:239–247.

Corser, J.D. 2001. Decline of disjunct Green Salamander (*Aneides aeneus*) populations in the southern Appalachians. *Biological Conservation* 97:119–126.

Costentino, B.J., D.M. Marsh, and K.S. Jones. 2014. Citizen science reveals widespread negative effects of roads on amphibian distributions. *Biological Conservation* 180:31–38.

Georgia Department of Natural Resources (GDNR). 2005. *A Comprehensive Wildlife Strategy for Georgia*. Georgia Department of Natural Resources Wildlife Resources Division, Social Circle, Georgia.

Global Biodiversity Information Facility (GBIF). 2015. *Aneides aeneus* (Cope and Packard, 1881). GBIF Backbone Taxonomy. <http://www.gbif.org/species/2431719>.

Gordon, R.E. 1952. A contribution to the life history and ecology of the plethodontid salamander *Aneides aeneus* (Cope and Packard). *The American Midland Naturalist* 47:666–701.

Graham, S.P., D.A. Steen, K.T. Nelson, A.M. Durso, and J.C. Maerz. 2010. An overlooked hotspot? Rapid biodiversity assessment reveals a region of exceptional herpetofaunal richness in the southeastern United States. *Southeastern Naturalist* 9:13–34.

Indiana Department of Natural Resources (IDNR). 2006. *Indiana Comprehensive Wildlife Strategy.* Department of Natural Resources Division of Fish and Wildlife, Indianapolis, Indiana.

International Union for the Conservation of Nature, Species Survival Commission. 2001. *IUCN Red List Categories and Criteria. Version 3.1*. Gland, Switzerland and Cambridge, UK.

International Union for the Conservation of Nature. 2015. IUCN Red List. Version 2015.2. <http://www.iucnredlist.org>.

Kentucky Department of Fish and Wildlife Resources (KDFWR). 2013. *Kentucky's Comprehensive Wildlife Conservation Strategy.* Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky.

Kozlowski, G. 2008. Is the global conservation status assessment of a threatened taxon a utopia? *Biodiversity Conservation* 17:445–448.

Maryland Department of Natural Resources (MDNR). 2005. *Maryland Wildlife Diversity Conservation Plan.* Department of Natural Resources Wildlife and Heritage Services, Annapolis, Maryland.

Mississippi Museum of Natural Science (MMNS). 2005. *Mississippi's Comprehensive Wildlife Conservation Strategy.* Mississippi Department of Wildlife, Fisheries and Parks, Mississippi Museum of Natural Science, Jackson, Mississippi.

Mitchell, J.C. and K.K. Reay. 1999. *Atlas of Amphibians and Reptiles in Virginia.* Special Publication Number 1, Wildlife Diversity Division. Virginia Department of Game and Inland Fisheries. Richmond, Virginia.

Mitra, S. 1988. Three-dimensional geometry and kinematic evolution of the Pine Mountain thrust system, southern Appalachians. *GSA Bulletin* 100:72–95.

North Carolina Wildlife Resources Commission (NCWRC). 2014. *Protected Wildlife Species of North Carolina.* North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

Ohio Department of Natural Resources (ODNR). 2014. *Ohio's Endangered Species.* Ohio Department of Natural Resources Division of Wildlife Publication 5356, Columbus, Ohio.

Oscarson, D.B. and A.J.K. Calhoun. 2007. Developing vernal pool conservation plans at the local level using citizen-scientists. *Wetlands* 27:80–95.

Pennsylvania Game Commission and Pennsylvania Boat and Fish Commission (PGCPBFC). 2015. *Current List of Pennsylvania's Endangered, Threatened and Candidate Species (PA Code Chapter 75).* Pennsylvania's State and Wildlife Commission, Harrisburg, Pennsylvania.

Pittman, S.E. and M.E. Dorcas. 2006. Catawba River Corridor Coverboard Program: A citizen science approach to amphibian and reptile inventory. *Journal of the North Carolina Academy of Sciences* 122:142–151.

Redmond, W.H. and A.F. Scott. 1996. *Atlas of Amphibians in Tennessee.* Miscellaneous Publication Number 12, Center for Field Biology. Austin Peay State University, Clarksville, Tennessee.

South Carolina Department of Natural Resources (SCDNR). 2005. *Comprehensive Wildlife Conservation Strategy.* South Carolina Department of Natural Resources, Columbia, South Carolina.

Snyder, D.H. 1991. The Green Salamander (*Aneides aeneus*) in Tennessee and Kentucky, with comments on the Carolinas' Blue Ridge populations. *Journal of the Tennessee Academy of Science* 66:165–169.

Tennessee Wildlife Resource Agency (TWRA). 2005. *Tennessee's Comprehensive Wildlife Conservation Strategy.* TWRA Wildlife Technical Report 05-08. Nashville, Tennessee.

Thigpen, T.F., W.J. Humphries, and J.C. Maerz. 2010. Effectiveness of using burlap bands to sample arboreal Green Salamander populations in the Blue Ridge Mountains of Georgia and North Carolina. *Herpetological Review* 41:159–162.

Virginia Department of Game and Inland Fisheries (VDGIF). 2005. *Virginia's Comprehensive Wildlife Strategy.* Virginia Department of Game and Inland Fisheries, Richmond, Virginia.

Virginia Department of Game and Inland Fisheries (VDGIF). 2014. *Virginia Fish and Wildlife Information Service Database.* Virginia Department of Game and Inland Fisheries, Richmond, Virginia.

Waldron, J.L. and W.J. Humphries. 2005. Arboreal habitat use by the Green Salamander, *Aneides aeneus*, in South Carolina. *Journal of Herpetology* 39:486–492.

West Virginia Division of Natural Resources (WVDNR). 2005. *West Virginia Wildlife Action Plan.* West Virginia Division of Natural Resources Wildlife Resources Section, Charlestown, West Virginia.

Wickham, J.D., K.H. Riitters, T.G. Wade, M. Coan, and C. Homer. 2010. The effect of Appalachian mountaintop mining on interior forest. *Landscape Ecology* 22:179–187.

Wildlife and Freshwater Fisheries Division, Alabama Department of Conservation and Natural Resources (ADCNR). 2005. *Conserving Alabama's Wildlife: A Comprehensive Strategy.* Alabama Department of Conservation and Natural Resources, Montgomery, Alabama.

Whittaker, R.J., M.B. Araujo, P. Jepson, R.J. Ladle, J.E.M. Watson, and K.J. Willis. 2005. Conservation biogeography: Assessment and prospect. *Diversity and Distributions* 11:3–23.