PETITION TO LIST

The loopy five firefly

***Photuris forresti* (Lloyd), 2018**

AS AN ENDANGERED SPECIES UNDER THE U.S. ENDANGERED SPECIES ACT

Photuris forresti photographed in Walton County, Georgia, 2022. Photo by Richard Joyce/Xerces Society.

Submitted by

The Xerces Society for Invertebrate Conservation

Prepared by Richard Joyce, Sharon Selvaggio, and Candace Fallon

21 March 2023

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PETITIONER

The Xerces Society for Invertebrate Conservation is a nonprofit organization that protects wildlife through the conservation of invertebrates and their habitat. For fifty years, the Society has been at the forefront of invertebrate protection worldwide, harnessing the knowledge of scientists and the enthusiasm of citizens to implement conservation programs.

The Xerces Society has worked with researchers and other partners to evaluate the conservation status and extinction risk of 130 North American firefly species and publish initial IUCN Red List and NatureServe Explorer assessments for these species, and published a State of the Fireflies of the USA and Canada report in 2022. Xerces convenes regional working groups for firefly conservation and has developed and published guidance for sustainable firefly tourism and best management practices for firefly conservation. In addition, Xerces has launched a Firefly Atlas (www.fireflyatlas.org) to engage others in tracking and conserving North America's firefly fauna. Xerces conservation biologists conduct inventories for rare, imperiled, and data deficient fireflies.

The Honorable Deb Haaland
Secretary, U.S. Department of Interior
1849 C Street, NW Washington, DC 20240

Dear Secretary Haaland,

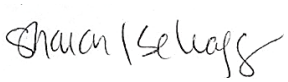
Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. § 1533(b); Section 553(e) of the Administrative Procedure Act, 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14(a), the Xerces Society for Invertebrate Conservation hereby petitions the Secretary of the Interior, through the United States Fish and Wildlife Service ("FWS," "Service"), to protect the loopy five firefly (*Photuris forresti* Lloyd, 2018) under the ESA as an endangered species. Petitioner also requests that critical habitat be designated for the loopy five firefly concurrently with the listing, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12.

Fireflies are iconic insects that perform important functions in ecosystems and are awe-inspiring parts of our natural and cultural heritage. The loopy five firefly—a recently described species found only in open wetlands of the Southern Piedmont and Valley and Ridge regions of the southeastern U.S.—is threatened by urban development, artificial light at night, wetland degradation, pesticide exposure, and climate change. Existing regulations are inadequate to protect this species from the threats it faces. Based on the factors discussed in this petition, it is clear that ESA protection is necessary to prevent the extinction of this species.

We are aware that this petition sets in motion a specific process placing definite response requirements on the U.S. Fish and Wildlife Service and very specific time constraints upon those responses. 16 U.S.C. § 1533(b). We will therefore expect a finding by the Service within 90 days regarding whether our petition contains substantial information to warrant a full status review.

Sincerely,

Richard Joyce



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Executive summary

The loopy five firefly, *Photuris forresti*, is a rare, range-restricted firefly species that was described by Dr. James E. Lloyd in 2018. This nocturnal, flashing species is an open freshwater wetland specialist that has only been documented at 8 localities found in three states: South Carolina, Georgia, and Tennessee. Of these 8 localities, one population is extirpated due to a golf course development. An additional two localities have not been confirmed with definitive flash-pattern measurements. The loopy five firefly can be distinguished from other *Photuris* species by its distinctive vertically-oriented flash pattern, which consists of 4-11 (typically 5-7) light pulses emitted over 2.5-3 seconds. This rising and falling flash pattern is the source of inspiration for its common name, the loopy five firefly.

The loopy five firefly is imperiled by multiple threats including habitat loss, fragmentation and degradation, light pollution, pesticides, climate change, modified hydrology, invasive species, and a lack of protective regulatory mechanisms, among other factors. While this species has been recorded on state and county conservation lands, most of its potential habitat is on private lands, and there are no species-specific management activities aimed at protecting this species. Additionally, the passive protection afforded from state and county managed conservation lands cannot protect this species from new and emerging threats such as climate change. In sum, the loopy five firefly is particularly threatened by ESA listing factors 1) The present or threatened destruction, modification or curtailment of its habitat or range; 4) The inadequacy of existing regulatory mechanisms; and 5) Other natural or anthropogenic factors affecting its continued existence (including pesticides, light pollution, and climate change), with potential threats from 2) Overutilization for commercial purposes and 3) Disease or predation.

Accordingly, we hereby request that the Service list the loopy five firefly (*Photuris forresti*) as an endangered species and concurrently designate critical habitat. Once listed, we recommend that the Service streamline the permitting process for activities that are essential to the conservation of this species, such as scientific research and monitoring, community science monitoring, and limited collection for scientific identification and educational purposes.

Introduction

Fireflies are highly charismatic beetles revered among the public with significant cultural (Bascom 1979; Schuettler 2007; Faust 2017; Lewis et al. 2020), biological (Woods et al. 2007; Bauer et al. 2013, Oba and Schultz 2022), and economic importance (Bauer et al. 2013; Lewis 2016; Lewis et al. 2020). Fireflies are often associated with summer nights (Lewis 2016), and viewing fireflies is a pastime shared around the world (Laurent and Ono 1999; Faust 2010; Vance and Kuri 2017). Recreational viewing of fireflies is growing significantly globally, bringing fireflies even further into the public's attention (Faust 2010; Vance and Kuri 2017; Lewis et al. 2021).

Fireflies belong to the order Coleoptera and can be found on every continent except Antarctica (Lewis 2016). Globally, there are over 2,000 species of fireflies (Coleoptera: Lampyridae), with at least 170 of these species residing in North America, classified into 4-5 subfamilies and 16 genera (Stanger-Hall et al. 2007, Faust 2017, Lloyd 2018, Heckscher 2021, Ferreira et al. 2022). Only some genera exhibit the characteristic flashing as adults, but larvae of all known species produce light (Faust 2017). Firefly larvae use bioluminescence to warn predators of unpalatable steroids they contain (Underwood et al. 1997). Firefly adults use bioluminescence as a form of mate communication (Faust 2017). In the United States, fireflies (also called lightning bugs) can thus be categorized into three distinct groups based on their communication behavior: the flashing fireflies, the glow-worms, and the daytime dark fireflies, which are non-luminescing as adults and are diurnal species (Faust 2017).

Fireflies, like many insect groups, have undergone population declines globally in the past few decades (Khoo et al. 2009; Wong and Yeap 2012; Lewis 2016; Lewis et al. 2020), prompting firefly researchers at the 2010 International Firefly Symposium in Selangor, Malaysia, to sign the Selangor Declaration, a document that calls for urgent action to conserve fireflies (Fireflyers International Network 2012). Causes of firefly decline are thought to include loss of habitat (De Cock 2009, Gardiner and Didham 2020, Lewis et al. 2020), water pollution (Lewis et al. 2020), pesticides (Lewis et al. 2020), commercial harvesting (Bauer et al. 2013, Lewis et al. 2020), and light pollution (Owens and Lewis 2018, Thancharoen and Masoh 2019, Mbugua et al. 2020, Lewis et al. 2020), among others.

Recent assessments of North American fireflies have revealed that up to a third of U.S. species may be at risk of extinction, and approximately half of the assessed species are so poorly understood that they have been classified as data deficient (Fallon et al. 2021). The loopy five firefly (*Photuris forresti*), one of 64 described fireflies in its genus in the United States (Lloyd 2018, Faust and Davis 2019), is one of these imperiled species. The habitats that the loopy five firefly use – freshwater marshes and shrub wetlands of middle elevations in southern Appalachian states—are threatened by urban development, habitat degradation, and habitat fragmentation. In addition, this species, as all species, has intrinsic value and a right to exist that is codified into U.S. law by the Endangered Species Act. Without ESA listing of this firefly, we will lose this species, succumbing to extinction via habitat fragmentation, light pollution, climate change, and pesticides. With this, we also lose a unique piece of southeastern biological heritage.

Conservation status and listing history

The loopy five firefly (*Photuris forresti*) has no legal protection under the U.S. Endangered Species Act nor any state endangered species statutes. It has never been petitioned for listing under the Endangered Species Act and it has no federal status. This species has been assessed as G1 or Critically Imperiled by NatureServe (NatureServe 2022). It has also been categorized as Endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species based on an area of occupancy of less than 500 km^2 and an observed and inferred decline in the area of occupancy, area, extent and/or quality of habitat, and number of locations or subpopulations (Walker & Faust 2022).

Natural history

Taxonomic status

There is no dispute over the taxonomic validity of *Photuris forresti* Lloyd, 2018. It is a member of the order Coleoptera, superfamily Elateroidea, family Lampyridae, subfamily Photurinae, and tribe Photurini (Integrated Taxonomic Information System 2022). The taxonomy and species delimitation of the genus *Photuris* are dynamic, with male courtship flash behavior playing a key role in distinguishing between species. The characteristic flash pattern and habitat specificity of *Photuris forresti* have been used to validate *Photuris forresti* as a species.

Description

The loopy five firefly was formally described in 2018 by firefly expert Dr. James E. Lloyd, who collected the holotype on 13 June 1986. Adults of the species are approximately 11-12 mm long and 2.9 wide (Lloyd 2018, Faust 2017)). Morphologically, it is very similar to the sympatric *Photuris tremulans* (Lloyd 2018, p.179), having dark elytra with absent or inconspicuous elytral vittae (wing stripes), an arrow or anchor-shaped pronotal marking, and dark-colored hind coxae (Figure 1). It can be distinguished by its distinctive flash train emitted low over open wetlands. In contrast, the flash patterns of *Photuris tremulans* include single flashes and trembling flickers and are usually emitted in treetops or in open upland areas.

Figure 1. Dorsal, lateral and ventral views of adult male *Photuris forresti*, showing pale patch in center of segment anterior to lanterns, dark hind coxae, pale femora getting darker distally, and dark tibia. Photo: Luiz Felipe da Lima Silveira.

The common name of *Photuris forresti*, loopy five firefly, refers to the firefly's distinctive flash pattern—a series of 4-7 pulses emitted over approximately 3 seconds while rising and falling (Faust 2017; see Figure 2). The vertical orientation of the flight trajectory while flashing is suspected to be an adaptation for increasing visibility of displaying males to females perched in

grassy marsh habitats (Lloyd 2018). The dark period of the loopy five firefly's flash pattern is relatively long (>10 seconds), which makes it difficult to track individuals for more than one flash pattern. Unlike many species in its genus, *Photuris forresti* does not appear to have an adjunct (additional) flash pattern (Lloyd 2018 p.179).

The larval stage of the loopy five firefly has not been described.

Population size and structure

While the current and historic population size and structure of *Photuris forresti* are not precisely known, approximate counts of adult males at four *P. forresti* sites in Georgia in late May and early June 2022 found between 11 and 50 displaying adult males at each site, with sampled habitat patches ranging area from 0.05 to 0.75 hectares (Xerces Firefly Atlas unpublished data 2022). Because of its specialization on freshwater marshes and open wetlands (which occur as relatively small patches along riparian corridors on the landscape), its presumed low dispersal ability, and the history of intense agriculture, soil erosion, and wetland modification in the Piedmont region, it is likely that *Photuris forresti* populations are highly fragmented.

Life cycle and behavior

The loopy five firefly is a holometabolous beetle, meaning that it has four distinct life stages: egg, larva, pupa, and adult. Female fireflies will lay an average of 28 eggs, typically a few at a time over multiple days to weeks (Faust 2017, Lloyd 2018). Eggs will eclose a few weeks after being laid (Faust 2017). Generally, fireflies will spend the majority of their lifetime as larvae, spending roughly 1-2 years as a larva and undergoing 4-7 growth stages called instars (Faust 2017, Lloyd 2018).

Photuris larvae are generalist predators consuming worms, slugs, snails, and soft-bodied invertebrates (Faust 2017). Larvae pupate in constructed chambers under the soil surface or under logs and emerge as adults a few weeks later (Faust 2017, Lloyd 2018). The larvae of *Photuris forresti* have not been described, and larvae of the genus are generally not identifiable to species without rearing to adulthood.

Adult fireflies typically do not eat, with the exception of *Photuris* spp. females that will mimic other fireflies to lure them in to eat (Faust 2017). These females will then use the chemicals acquired from their prey to pass on to their young (Faust 2017). Adults of some species have also been observed consuming plant material including berries, milkweed nectar, and apple slices (Buschman 1984, Faust 2017). Adult *Photuris* will live between 3-4 weeks (Faust 2017).

Figure 2. A long-exposure photograph captures the rising and falling trajectory of the *Photuris forresti* flash pattern. Photo: Radim Schreiber/ fireflyexperience.org

The adult display period occurs between mid-May and early July, depending on local climate conditions. At a loopy five firefly locality in Walton County, Georgia, the adult flight period in 2022 lasted from May 16th to June 10th. Faust reports the modified growing degree day range (86/50

formula, March 1st start date) for flashing activity as 1189-1690, based primarily on records from a locality in Jefferson County, Tennessee (2017, p.201). In Monroe, Georgia, in 2022, the display start date corresponded to 945 modified growing degree days. Modified growing degree days (mGDD) is a measure of the accumulation of heat over the course of the growing season and is used to monitor and predict the timing of phenological phenomena (such as the emergence of insect species). Roughly speaking, 0-999 mGDD indicates spring, 1,000-1,799 indicates early summer, and 1,800-3,000 or more indicates summer into autumn (Faust 2017 p.32).

Habitat

Loopy five fireflies are found in and adjacent to palustrine wetlands, including freshwater ponds, freshwater emergent wetlands, and freshwater shrub swamps in middle elevations of the southern Appalachians (Figure 3). Elevations of known extant and historic sites range from 600-1,040 feet (~180-315 meters) above sea level. Common vegetation components include broadleaf arrowhead (*Sagittaria latifolia*), arrow arum (*Peltandra virginica*), yellow pond lily (*Nuphar lutea*), cattails (*Typha* spp.), jewelweed (*Impatiens capensis*), sedges (Cyperaceae), cutgrass (*Leersia* sp.), sensitive fern (*Onoclea sensibilis*), willows (*Salix* spp.), red maple (*Acer rubrum*), and smooth alder (*Alnus serrulata*). Sites typically occur along streams with low slope and annual mean velocity (Table 1).

Figure 3. Loopy five firefly habitat at the inlet of a small pond in Walton County, Georgia, with arrow arum (*Peltandra virginica*), broadleaf arrowhead (*Sagittaria latifolia*), and willow (*Salix* sp.). Photo: Richard Joyce/Xerces Society.

Known sites fall into the natural community categories of **Piedmont Wet Meadows and Marshes** in the Georgia classification system (Natural Communities of Georgia, n.d.), **Shoal and Stream Bar** in the South Carolina classification system (Nelson 1986), and **shallow emergent marsh** in Tennessee (Tennessee-Kentucky Plant Atlas 2021).

Several of the known loopy five firefly localities have a history of artificial impoundment by dams or roadbeds. Given that beavers (*Castor canadensis*) create similar open wetlands, it is

likely that *Photuris forresti* occurrence has historically been associated with beaver-influenced wetlands. Green tree frogs (*Hyla cinerea*) and cricket frogs (*Acris* sp.) are often heard in the vicinity of *Photuris forresti* adult courtship display areas (R. Joyce, pers. obs.).

Table 1. Modeled stream characteristics of *Photuris forresti* localities for which NHD flow data are available. Data source: National Hydrography Dataset Version 2.1.

Site	Annual Mean Flow (cubic feet/second)	Annual mean velocity (feet/second)	Slope (percent)
Alcovy River Tributary	<1	0.72	1.36
Sandy Creek	82	0.83	0.01
Calls Creek	5	0.88	0.06
Wolf Creek	2	0.58	0.04
Blue Spring Branch	Not calculated	0.31	<0.01
Oolenoy River	15	0.96	0.57
North Enoree	11	0.98	0.93

Range, population distribution and status

Photuris forresti occurs in South Carolina, Tennessee, and Georgia. It was first collected by James E. Lloyd in June 1986 and later formally described by him in 2018. The 1986 type locality was a marsh near the intersection of Routes 11 and 178 at an elevation of ~1030 feet, in Pickens County, South Carolina. This site was bulldozed as part of the construction of a golf course shortly after its discovery, and the species has not been relocated at the site (Lloyd 2018, p.179). For over 25 years, this destroyed location was the only known site where the (as yet undescribed) species occurred. Then in 2012, firefly researcher Lynn Faust discovered a second population in the Lost Creek-Holston River sub-watershed in Jefferson County, Tennessee, ~950 ft above sea level and approximately 80 miles from the Pickens County site. This site is a marsh formed by a road bed that dammed a spring-fed stream (Faust 2017, p.203). Despite multi-year searches in similar habitats in Jefferson, Anderson, Overton, and Morgan counties in east Tennessee by Lynn Faust and other biologists, this is the only population that has been detected in the state (Faust pers. comm. 2022).

In June 2018, the type locality was revisited, with no detection of the species' presence, but a second South Carolina population was found nearby in marshy wetlands along Wolf Creek south of the town of Pickens in Pickens County (Faust pers. comm. 2022). Just three years later, in May 2021, a population was discovered by a private landowner in Walton County, Georgia, at the marshy inlet of a human-made pond (Grubbs pers. comm. 2022).

Concerted efforts to find new populations of the species were spearheaded by Xerces Society staff in 2022, as part of the Xerces Firefly Atlas (www.fireflyatlas.org). Between May 16th and June 14th 2022 (within the known adult activity period of the species), biologists and volunteers surveyed for *Photuris forresti* at 20 wetlands in Georgia, South Carolina, and North Carolina, which ranged from 350-3,840 feet in elevation. Sites were selected based on the presence of open palustrine wetland habitats as identified on recent aerial imagery, as well as practical

constraints such as landowner permission and physical access. Populations were found and confirmed at four of these locations in Georgia, at elevations between 600 and 740 feet above sea level (Table 2), and were identified by the species-specific male courtship flash-patterns and body morphology of captured individuals. At an additional two sites in South Carolina (elevations 600 and 980 ft), flash patterns that matched *P. forresti*'s were observed at low densities, but could not be confirmed with photographs or detailed flash pattern measurements. Surveys at freshwater emergent wetlands at lower elevations (~345-515 ft above sea level) in Newberry, Laurens, and Union counties in South Carolina did not lead to detections of *Photuris forresti*.

As a result of these surveys, *Photuris forresti* is now known to be extant at at least 7 sites, with 2 additional suspected sites in the following states and counties: South Carolina (Pickens, Greenville, Spartanburg), Tennessee (Jefferson), and Georgia (Walton, Morgan, Clarke, Oconee). Although the species is more widespread than initially documented, it remains patchily distributed. Extensive survey efforts over 10 years (2012-2022) within the known and suspected range of the species have turned up only 7 extant sites and two suspected sites (Table 2). Geographic coordinates of *Photuris forresti* localities and non-detection survey sites are made available to the FWS in spreadsheets accompanying this petition. These localities fall within the Southern Outer Piedmont (45b), Southern Inner Piedmont (45a), and Southern Limestone/Dolomite Valleys and Low Rolling Hills (67f) Level IV EPA Ecoregions and within the Upper Ocmulgee, Upper Oconee, Seneca, Enoree, Tyger, and Holston HUC 8 sub-basins (EPA 2013; USGS Watershed Boundary Dataset). Protected areas in these regions tend to be sparse and fragmented (Figure 4).

Table 2. Loopy five firefly (*Photuris forresti*) localities. Localities with status "unconfirmed" denote potential observations of this species that should be further verified, as they were unconfirmed by flash pattern measurements or photographs, but *P. forresti*-like flash patterns were briefly observed.

State	County	Location	Elev. (ft)	Ownership	Status	# males observed	Approx. size of habitat patch (ha)	Reference
SC	Pickens	Rte. 11, NE of intersection w/ Rte. 175	1040	Private	Extirpated as of 1986, also surveyed 2018	Unknown	Unknown	coll. J.E. Lloyd, Lloyd 2018
TN	Jefferson	Blue Spring Branch	950	Private	Extant as of 2022	Unknown	Unknown	L. Faust, Faust 2017
SC	Pickens	Wolf Creek, Pickens	920	Private/ Municipal	Extant as of 2022	11-50	1	L. Faust
GA	Walton	Mountain Creek tributary, Monroe	795	Private	Extant as of 2022	11-50	0.05	A. Grubbs, pers. comm.
GA	Walton	Alcovy R. tributary, Monroe	740	Private	Extant as of 2022	Unknown	0.5	A. Grubbs, pers. comm
GA	Morgan	Hard Labor Creek State Park	600	State	Extant as of 2022	11-50	0.2	R. Joyce, Xerces Society
GA	Clarke	Sandy Creek Nature Center	620	County	Extant as of 2022	11-50	1.9	R. Joyce, Xerces Society
GA	Oconee	Harris Shoals Park	655	County	Extant as of 2022	11-50	1.7	R. Joyce, Xerces Society
SC	Greenville	Belvue Springs Heritage Preserve	980	State	Unconfirmed as of 2022	<5	0.8	R. Joyce, Xerces Society
SC	Spartanburg	Croft State Park	600	State	Unconfirmed as of 2022	1	1	R. Joyce, Xerces Society

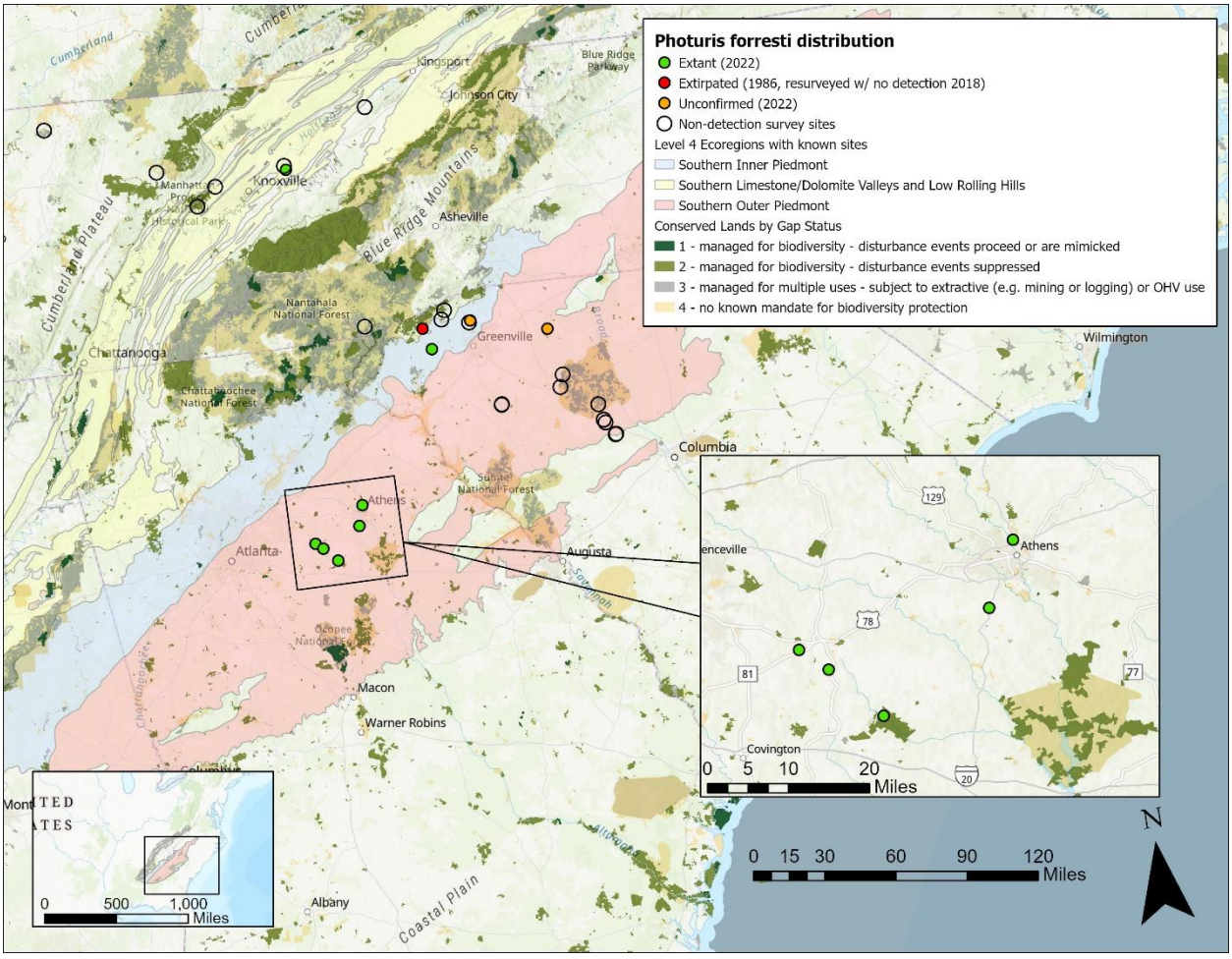


Figure 4. Distribution of the loopy five firefly, showing confirmed localities (green circles), sites where surveys did not find *P. forresti* (hollow circles), unconfirmed localities (orange circles), and an extirpated site (red circle). Extant sites were all confirmed as extant in 2022, and unconfirmed localities were first surveyed in 2022. Non-detection surveys (including at the extirpated site) occurred between 2015 and 2022. All known localities are within the Southern Inner Piedmont, Southern Outer Piedmont, and Southern Limestone/Dolomite Valleys and Low Rolling Hills Level IV EPA Ecoregions, which stretch from southern Virginia to central Alabama. Protected lands are relatively sparse and fragmented in these regions.

Current and potential threats – An assessment of factors

The ESA states that a species shall be determined to be endangered or threatened based on any one of five factors (16 U.S.C. 1533 (a)): 1) the present or threatened destruction, modification, or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) the inadequacy of existing regulatory mechanisms; and 5) other natural or manmade factors affecting its continued existence. The loopy five firefly is most imperiled by factors one, four, and five, and is potentially imperiled by factors two and three.

1. The present or threatened destruction, modification, or curtailment of its habitat or range

Urban development and sprawl

The ecoregions in which *Photuris forresti* is found overlap with large, growing metropolitan areas, including Atlanta, Greenville, Charlotte, Greensboro, and Knoxville. As a region, the Southeast has been one of the fastest-growing in the country, with a population growth rate that is 40% larger than the rest of the U.S. (Terando et al. 2014). The impact of this population growth on the landscape is compounded by automobile-centric patterns of development that convert ever-increasing areas of rural land to low-density urban land covers. Southeastern cities are ranked as some of the most sprawling metropolitan areas in the country (Ewing & Hamidi 2014). Projections based on recent patterns of growth predict that by 2060, metropolitan areas in the Southern Piedmont will converge into an urban "megalopolis" (Terando et al. 2014). The majority of currently known loopy five firefly localities fall within the boundary of this predicted urban sprawl (Figure 5). Even low-density development that maintains green spaces can destroy loopy five firefly habitat: the population at the type locality (in Pickens County, SC) has already been lost to the development of a golf course (Lloyd 2018 p.179)

Between 1992 and 1997, 59% of the wetland area lost in the U.S. was located in the South (Gutzwiller et al. 2011). Proximity to large urban areas has been shown to be a predictor of wetland loss in the Southeast (Gutzwiller 2011). Urbanization is also associated with degradation of streams, with urban streams experiencing less stable flows, increased contaminants, lower dissolved oxygen, higher temperatures, and more channelized, unstable banks (Van Metre et al. 2019, Walsh et al. 2005). As such, predicted urban development presents a major threat to the continued existence of the loopy five firefly.

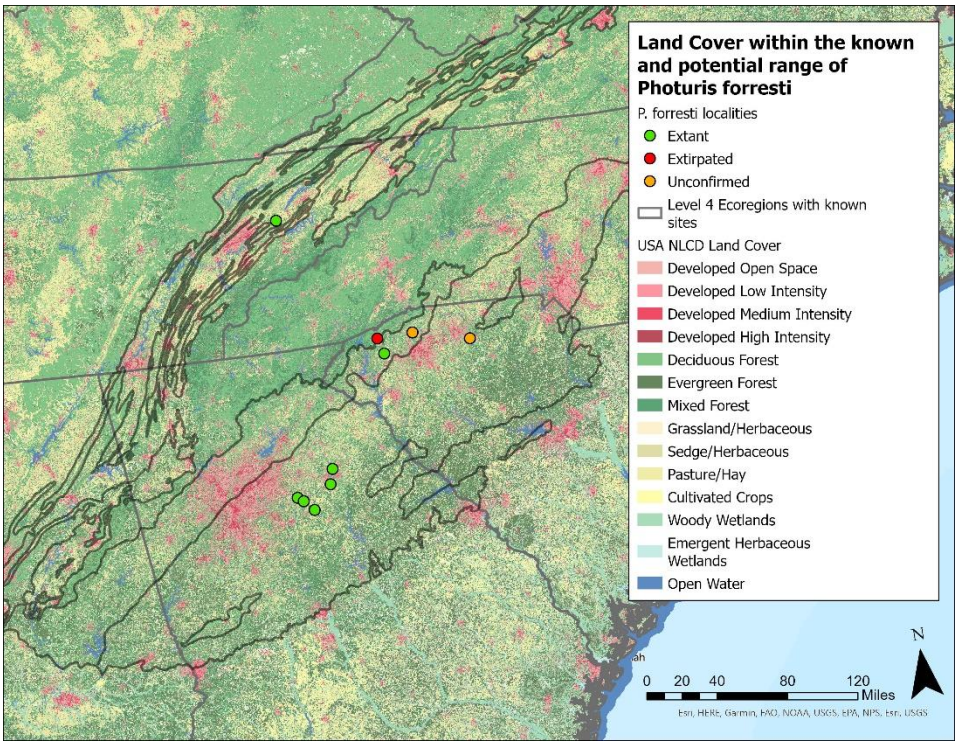


Figure 5. Landcover within Level 4 EPA Ecoregions (gray boundaries) where *P. forresti* (green dots) is found. Most of the few known populations are close to growing metropolitan areas such as Atlanta, Greenville-Spartanburg, and Knoxville. Imagery source: National Land Cover Database, 2019.

Alteration of natural hydrology

Dams and impoundments

Waterways in the southeastern U.S. have been dramatically altered by human-made dams, which range from large hydroelectric dams to small earthen dams forming farm ponds. There are more than 4,600 dams reported in Georgia (GSWCC 2014), at least 10,000 dams in South Carolina (SCEMD n.d.), and over 2,000 in Tennessee (Bullard 2020). Actual numbers of dams are likely vastly higher than some of these state-wide estimates, as many small, privately-owned dams are not recorded in government inventories. For example, just in the 208-square-mile Upper Oconee sub-basin, which is home to three extant *P. forresti* sites, there are 5,467 impoundments (Merrill et. al 2001).

While some of these dams may be compatible with *Photuris forresti* habitat and may even enhance the firefly's habitat (particularly at impoundment inlets and in basins with gently sloping topography), others have inundated low-gradient, open riparian habitats that the species likely formerly relied upon. For example, reservoirs such as Lake Hartwell, Lake Keowee, Lake Lanier, and Lake Cherokee consist primarily of open habitat with only a small proportion of their banks supporting palustrine emergent or shrub wetlands.

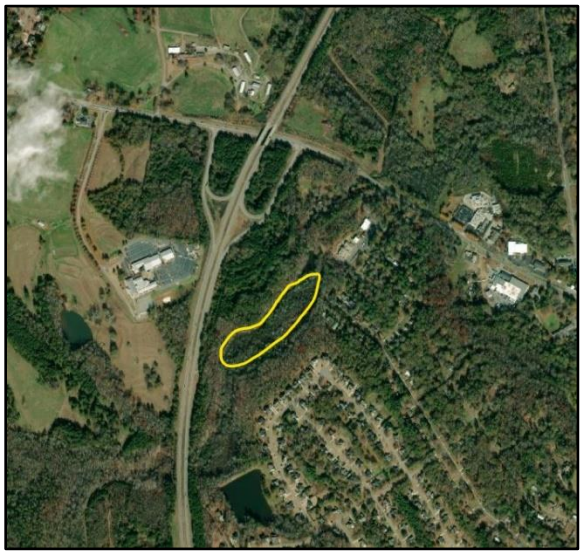
Many of the extant localities of *Photuris forresti* have a history of disturbance, such as impoundments from dams or road-crossings. For example, the Tennessee marsh locality is

impounded by a road causeway, at least two Georgia sites are upstream from small dams, and one of the unconfirmed South Carolina localities is upstream from a beaver dam built at the inlet of a culvert in a raised roadbed. Dams or other barriers may create or augment open wetland habitat, but they can also permanently inundate riparian areas, making them unsuitable as habitat for *Photuris forresti*, especially if water is deep enough to reduce the cover of emergent vegetation. Furthermore, in anthropogenic ponds that do provide potential habitat, periodic draw-downs (due to fishery management, dam maintenance or technical issues) may create conditions that are not conducive to firefly larvae and their prey. For example, a technical issue with a dam at Lake Edwin Johnson in Spartanburg, South Carolina, led to the complete draining of the lake (Radebaugh 2022).

Habitat fragmentation

The open wetlands occupied by *Photuris forresti* occur as relatively small patches on the landscape, distributed along stream drainages and separated by upland habitats. The size and connectivity of these already fragmented wetland patches is further reduced by urban, agricultural and commercial land uses and transportation corridors. Furthermore, the conversion of upland forested habitats to agricultural and residential land-uses within watersheds can lead to excess nutrients and degraded water quality(Houlahan et al. 2004).

Loopy five firefly larvae are flightless and adults are short-lived (active for approximately 2-4 weeks) and not known to disperse very long distances (Lewis 2016 p.121), so the dispersal potential of this species is limited. Successful dispersal between patches is critical for the survival of species with small, distributed populations (Pulliam 1988 p.652-654), allowing for recovery from stochastic events and re-establishment of temporarily extirpated populations.



Loopy five firefly localities where wetlands are not threatened by conversion to other land covers can still be susceptible to fragmentation, making populations vulnerable to local extinction from climactic or disease events. For example, Harris Shoal Park in Watkinsville, Oconee County, Georgia, supports a loopy five firefly population, but is bounded by roads and residential development (Figure 6).

Figure 6. Aerial imagery of a loopy five firefly wetland site (outlined in yellow) in Watkinsville, Georgia that is bounded by roads to the north and west, residential development to the southeast, and a dam to the south. World Imagery sources: Esri, Maxar, Earthstar Geographics, and the GIS User Community.

Beaver control and eradication

The loopy five firefly favors open, low-gradient wetlands with emergent herbaceous and shrubby vegetation, conditions which are often created or maintained by the presence of beavers (*Castor canadensis*). In fact, beavers are known to co-occur in at least three of the nine extant and unconfirmed *Photuris forresti* localities (Joyce pers. obs. 2022). Beavers were either entirely or nearly extirpated from southeastern Piedmont states by the late 1800s, followed by re-introductions in the late 1930s and 1940s. While beavers have once again spread across the Piedmont of Georgia, North Carolina, and South Carolina, they are often targeted for removal by landowners because of the actual and perceived risks posed by beaver activity to agriculture, infrastructure, and trees (Gregory & Waters 2008; South Carolina DNR 2016). The maintenance of open vegetated wetland habitats by beavers is threatened by increased pressures to remove beavers in urban and suburban areas, and that, in turn, likely threatens the loopy five firefly.

Invasive species

Invasive plants

Many known *Photuris forresti* sites are already impacted by invasive plants, including marsh dayflower (*Murdannia keisak*) and Japanese stiltgrass (*Microstegium vimineum*) (Joyce pers. obs. 2022). Invasive plants can outcompete native vegetation, changing habitat structure and reducing native plant diversity (Greene and Blossey 2012), having various effects on invertebrate communities (McCary et al. 2016), including increasing densities of hunting spiders (Landsman et al. 2021) that may prey upon the loopy five firefly.

Invasive spiders

Spiders are some of the dominant predators of fireflies (Lewis et al. 2012; Faust 2017). Various non-native species of spider have spread across the Southern Piedmont, including the golden silk spider (*Trichonephila clavipes*) and the more recently-established Joro spider (*Trichonephila clavata*) (Chuang et al. 2022). Because these are web-weaving spiders, their webs may be cause mortality of *Photuris forresti* even if the spiders do not actually consume the fireflies.

2. Overutilization for commercial, recreational, scientific, or educational purposes

Fireflies were collected commercially by the millions in the eastern USA during the 1900s for extraction of their bioluminescent enzyme luciferase (Lewis 2016 pp. 128-132). Although luciferase is now produced synthetically, a few companies continue to sell wild-caught firefly products (Lewis 2016 pp.130-131). Collectors did not discriminate between species, so it is impossible to determine the degree to which *Photuris forresti* may have been impacted.

To the best of the petitioner's knowledge, the loopy five firefly is not produced or sold commercially, though this threat cannot be ruled out. Adults and larvae may still be collected for research purposes, but the scale of this activity does not pose a threat to the overall survival of the species.

3. Disease or predation

Many firefly species produce toxic defense chemicals called lucibufagins and betaines to protect themselves from predators, particularly vertebrate predators such as birds (Eisner et al. 1978, Eisner et al. 1997, Lewis & Cratsley 2008). However, despite the presence of these compounds

and ability to flash as a warning to predators, fireflies are consumed by many animals (Lewis et al. 2012, Faust 2017). Spiders are a well-known predator of fireflies (Lloyd 1973, De Cock et al. 2014, Long et al. 2012) along with other invertebrates including harvestmen and assassin bugs (Lewis et al. 2012, Faust 2017).

Fireflies are known to suffer from reproductive bacterial parasites (*Wolbachia*) that can alter sex ratios by causing an increase in female eggs being produced or by killing male eggs (Faust 2017). Fireflies can also be afflicted by nematodes that can kill both larvae and adults (Faust 2017). Agricultural biocontrol agents can include the use of nematodes to control unwanted pest populations, however this can have the unintended consequence of killing larval fireflies in the ground (Faust 2017). Fungus, mites, and multiple species of parasitic fly also affect firefly health (Faust 2017).

While it is unknown if the loopy five firefly is threatened by disease or site-specific predators, for species like this that are already experiencing declines within highly localized ranges, natural predation and disease rates can compound existing threats.

4. The inadequacy of existing regulatory mechanisms

The loopy five firefly has been recorded on county (Sandy Creek Nature Center), city (Harris Shoals Park), and state (Hard Labor Creek State Park) lands. While conservation lands confer some level of passive protection, this firefly is not protected from the many threats it faces. Furthermore, no existing regulatory mechanisms adequately protect the loopy five firefly at the federal, state, or local level. Accordingly, the lack of effective regulatory mechanisms for loopy five fireflies, in combination with the species' limited range and anticipated decline in quality and availability of habitat, underscores the critical need to provide this firefly with protection under the Endangered Species Act. Receiving listing under the ESA would protect the loopy five firefly and its critical habitat through protective restrictions on management activities and other actions that could degrade or eliminate habitat.

Federal mechanisms

National Environmental Policy Act of 1970

The National Environmental Policy Act (commonly known as NEPA) requires that federal agencies prepare environmental assessments and environmental impact statements before moving forward with proposed actions, such as the construction of buildings and transportation infrastructure. NEPA requires that agencies consider potential impacts on the environment. Therefore NEPA documents routinely examine effects to federally endangered, threatened, or candidate species, but rarely probe further into the specific needs of unlisted species. Thus, NEPA cannot adequately protect the loopy five firefly or its habitats.

Clean Water Act

Section 404 of the Clean Water Act regulates the discharge of dredged or fill material into waters of the United States, including wetlands, and requires permits from the U. S. Army Corps of Engineers or an approved program for the discharge of said materials. This regulation may prevent or mitigate the filling of wetlands occupied by the loopy five firefly, but does not

adequately protect the species, and permitted activities may still significantly impact firefly habitat.

Listing of species with nearby ranges under the Endangered Species Act

Aquatic mollusk and fish species such as the fluted kidneyshell (*Ptychobranchus subtentus*), frecklebelly madtom (*Noturus munitus*), and Carolina heelsplitter (*Lasmigona decorata*) have critical habitat designated in Georgia, South Carolina, and Tennessee. However, the critical habitats of these species do not overlap with any known *Photuris forresti* localities and protections for these species fail to protect *Photuris forresti* from decline and extinction.

Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)

Under FIFRA, the U.S. Environmental Protection Agency (EPA) licenses the sale and use of pesticides. FIFRA directs EPA to register a pesticide only upon determining that "when used in accordance with widespread and commonly recognized practice it will not generally cause unreasonable adverse effects on the environment". Unfortunately, to date, EPA has not considered the broad suite of population-level impacts on fireflies (or other insects) like those described herein as an "unreasonable adverse effect on the environment," or otherwise as a basis for denying, suspending, or re-classifying pesticide registration approvals, despite having the ongoing authority to take such actions. Seeds coated in pesticides (often with persistent, systemic insecticides) are not regulated as pesticides under FIFRA, but rather are exempted as treated articles (U.S. EPA 2022). Thus, FIFRA's regulatory measures, as implemented by EPA in registering and labeling the large number of insecticidal products at issue, have been wholly inadequate to protect this species.

Furthermore, pesticides are generally not tested directly on fireflies or other beetles as part of the registration process, but rather on surrogate invertebrate species such as the western honeybee (*Apis mellifera*), water fleas (*Daphnia*), and scud (*Gammarus fasciatus*). None of these three invertebrate species inhabit the soil for any part of their life cycle, nor are they beetles, so they are likely inadequate surrogates for fireflies. Furthermore, the EPA does not require that the additive, or synergistic effects of pesticides to be considered, even though pesticides are typically found in the environment in combination, not singly.

State, county and municipal regulatory mechanisms

State Wildlife Agency Management Authority to Conserve Insects

The loopy five firefly occurs in three states, yet one of these states is not authorized to work to conserve this species. The Tennessee Wildlife Resources Agency (TWRA), which typically would be the state agency that conserves and manages imperiled wildlife, in order to avoid the need to list species under the ESA, does not have management authority over insects. The definition of wildlife that extends to TWRA includes only "wild vertebrates, mollusks, crustaceans, and fish" (Tenn. Code Ann. § 70-1-101). This lack of insect management authority in Tennessee represents a major gap in regulatory mechanisms that leaves the loopy five firefly vulnerable.

State Park Systems in Georgia, South Carolina, and Tennessee

State park systems in the southeastern U.S. protect habitats from residential and commercial development, while providing outdoor recreation opportunities. However, state parks must respond to numerous, sometimes competing interests, such as generation of revenue, timber management, public safety, and demands for recreation amenities. Outdoor recreation infrastructure such as cabins, parking lots, campgrounds, road and trails, reservoir dams, golf courses, and lighting, may all negatively affect *Photuris forresti* and its habitats. The loopy five firefly is not mentioned in any park management plans, and management plans often fail to address the threat of artificial light at night. As such, *Photuris forresti* is not protected from extinction simply by existing in state parks.

Outdoor lighting codes and ordinances

Various counties (Clarke County, Georgia; Greenville, South Carolina; Spartanburg, South Carolina) within the range of the loopy five firefly have outdoor lighting standards as part of their zoning and development standards, which are aimed at minimizing light pollution in the form of glare, light trespass, and sky glow. However, in some cases these codes and standards require outdoor lighting for safety reasons or provide exemptions for sources of light pollution for safety reasons and do not adequately curtail light pollution and its impacts on fireflies. For example, radiance values as measured by satellite in 2021 of loopy five sites in Clarke County and Oconee County, were 4.5 and 8 nanowatts/cm^2/sr, respectively (lightpollutionmap.info). To put these values in perspective, the interiors of larger conservation areas such as Piedmont National Wildlife Refuge and Okefenokee National Wildlife Refuge had radiance values of 0 nanowatts/ cm^2/sr in 2021, while the 2021 radiance value for the University of Georgia in Athens was 63.9 nanowatts/ cm^2/sr. During field surveys in 2022, Xerces Society staff noted artificial light sources of various types affecting loopy five firefly habitats. Existing lighting codes and ordinances do not have the explicit goal of protecting *Photuris forresti* or other nocturnal insects from harmful artificial light at night.

Georgia Erosion and Sedimentation Control Act of 1975

The Georgia Erosion and Sedimentation Control Act aims to prevent soil erosion and sedimentation of waterways by regulating land-disturbing activities along waterbodies and establishing minimum vegetation buffer widths. While the act may help to mitigate the impacts of activities in upland areas adjacent to loopy five firefly habitats, there are numerous exceptions allowed, and because of the wording of the law, in 2015 the Georgia Supreme Court upheld an interpretation that undercut its application in lower gradient areas with slower flows that lack "wrested vegetation" or a clear line between the flow of water and adjacent vegetation (Donohue 2016). This means that, in many cases, landowners may clear vegetation right up to the waterline, destroying or degrading loopy five habitat.

As demonstrated in this petition, the threats faced by the loopy five firefly are not adequately addressed by any existing regulatory mechanisms.

5. Other natural or anthropogenic factors affecting its continued existence

Several additional factors threaten the loopy five firefly's continued existence, including pesticides, light pollution, climate change impacts, and small populations, as described in detail in the following sections.

Pesticides and other pollutants

Pesticides are identified as a serious threat to firefly conservation in North America, second only to habitat loss and fragmentation, according to a survey of firefly experts (Lewis et al. 2020). The preferred wetland habitats occupied by *P. forresti* may experience contamination from drift or runoff of pesticides from adjacent agricultural, urban, or woodland landscapes, or may sometimes be affected directly by insecticides (for example if occupied sites are treated for mosquitoes). Fireflies may absorb pesticide through direct contact with airborne pesticides, or through contact with contaminated surfaces, sediments, surface water and/or groundwater. Consumption of contaminated prey or nectar is another potential route of exposure.

Within the counties where *P. forresti* has been identified, land use is largely divided between pastureland, cropland and woodlands, each typically occupying about 30% of the area. Within croplands, forage (hay/haylage) crops predominate in these counties, occupying about 80-90% of crop acreage. Soy, corn, wheat, orchards, and nursery comprise most of the remaining crop acres.

Urban/developed landscape uses occupy a small percentage of each county where *P. forresti* has been found. However, several occurrences are within close proximity of developed landscapes. For example, the location at Sandy Creek Nature Park in Clarke County is near residential and commercial areas; the site at Hard Labor State Park in Morgan County is downstream from a golf course; the site at Harris Shoals Park is sandwiched between residential areas and a highway; the extirpated type locality in Pickens County near routes 11 and 178 was displaced by a golf course; and the site at Belvue Springs Heritage Preserve is near residential neighborhoods. As described under Factor 1, the urban footprint is predicted to expand into the areas where *P. forresti* occurs.

Pesticides used within the region for urban, agricultural, or forestry purposes and for mosquito control make their way into habitats that may contain *Photuris forresti*, threatening the species with increased mortality and harmful sub-lethal effects, as well as harmful effects on prey species such as worms and snails. The best available evidence for this exposure comes from U.S. Geological Survey (USGS) studies. The USGS conducted intensive weekly examination of stream ecosystems across the U.S. in 2014, including 54 wadeable stream locations in the Southeast Piedmont (Bradley et al. 2019). This effort revealed hundreds of different contaminants with cumulative maximum concentrations ranging from 1,922–162,346 ng/L (1.9-162 ppb) per site. Contaminant occurrence was significantly correlated to urban land use. Urban areas are a significant source of pesticide input into aquatic systems because towns and cities are often dominated by hardened surfaces, which causes rapid and elevated storm runoff, and homeowners frequently use pesticides. A survey of Georgia homeowners (Varlamoff et al. 2001) found that 76% treat their yards for fire ants and 42% apply herbicides to their landscapes.

The USGS study revealed dozens of pesticides contaminating aquatic habitats within the Piedmont, with the herbicide atrazine and the insect repellent DEET detected at every site. Imidacloprid (a neonicotinoid) was detected in about 59% of water samples and exceeded regulatory thresholds at 61% of sites. Fipronil and degradates were detected in about 60% of Piedmont water samples and exceeded EPA regulatory thresholds at 13% of sites. The ten pesticides with the overall highest median concentrations included 7 herbicides and their metabolites, 2 fungicides and 1 insecticide. In order: 4-hydroxychlorothalonil (metabolite of the fungicide chlorothalonil), 2,4-D, sulfometuron-methyl, atrazine, triclopyr, simazine, CAAT (a degradate of atrazine, propazine, and simazine), carbendazim, bromacil, and imidacloprid.

Documented effects of some of these compounds on fireflies, beetles, and other non-target invertebrates, as well as information about the uses and routes of exposure of these chemicals are laid out below. Pyrethroids are also discussed since nationwide, in both surface waters and sediments, they are the class of insecticides most likely to occur at concentrations higher than regulatory thresholds (Wolfram et al. 2018). However, these pesticides may be missed by sampling programs that focus exclusively on water sampling, since pyrethroids partition into sediments.

Neonicotinoids: Neonicotinoid insecticides used and/or detected in the environment in the southeastern states where *Photuris forresti* occurs include imidacloprid, clothianidin, and, to a lesser degree, thiamethoxam (Figures 7, 8 and 9). Imidacloprid is commonly applied in corn, soybean, and other row crops as a foliar insecticide or applied as a coating on seeds. Large-scale planting of treated seeds can result in contamination of soils, waterways, and nontarget plants in row crop landscapes (Bonmatin et al. 2015). Imidacloprid is also used in tree farms, forestry, and urban sites. In 2019, the highest agricultural application rates for imidacloprid (not including treated seed) for counties where the loopy five firefly occurs were in Clarke County (GA) and Walton County (GA), with lower volumes applied in other counties where the species is found (Wieben 2021).

Using the U.S. Geological Survey data on pesticide presence and biotic assemblages in 54 wadeable streams in the Southeast Piedmont, Waite et al. (2019) found that insecticides, particularly imidacloprid and fipronil (a phenylpyrazole), exerted strong negative effects on aquatic insect richness, particularly Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies - excluding the Family Hydropsychidae). Both of these insecticides are highly toxic to insects, including beetles (Choudhury et al. 2020; Martínez et al. 2014), and persistent, with half-lives in soil of over 100 days (Bonmatin et al. 2015).

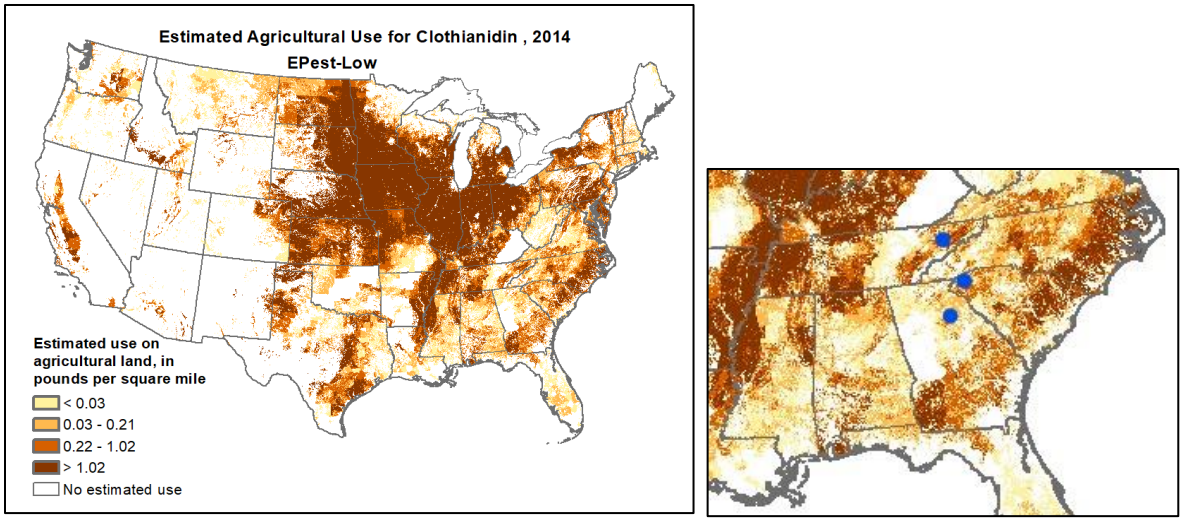


Figure 7. Lower-bound estimated agricultural application rates of the neonicotinoid clothianidin in the year 2014. A map for 2014 is provided because estimates from after 2014 do not include seed treatments, which is one of the primary uses of the compound. Note that clothianidin was applied in eastern Tennessee, the South Carolina Piedmont, and northeast Georgia, where *Photuris forresti* is known to occur (blue dots) Map from U.S. Geological Survey Pesticide National Synthesis Project.

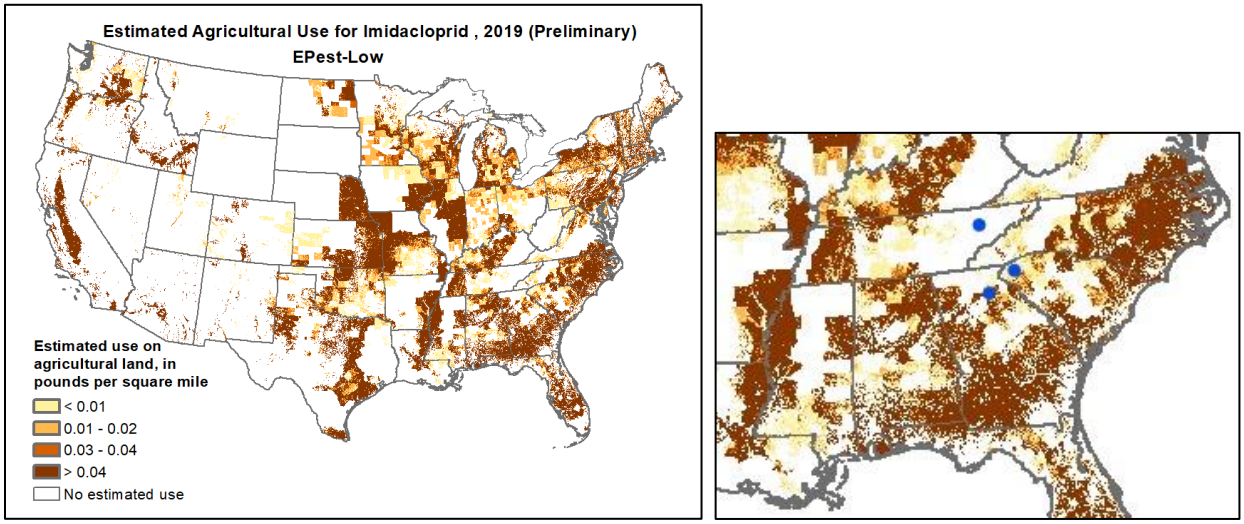


Figure 8. Preliminary lower-bound estimated agricultural application rates of the neonicotinoid imidacloprid in the year 2019. Note that imidacloprid is used within the range of *Photuris forresti* in northeast Georgia and the South Carolina Piedmont (blue dots). Estimates from after 2014 do not include seed treatments, which is a significant use of the compound. Map from U.S. Geological Survey Pesticide National Synthesis Project.

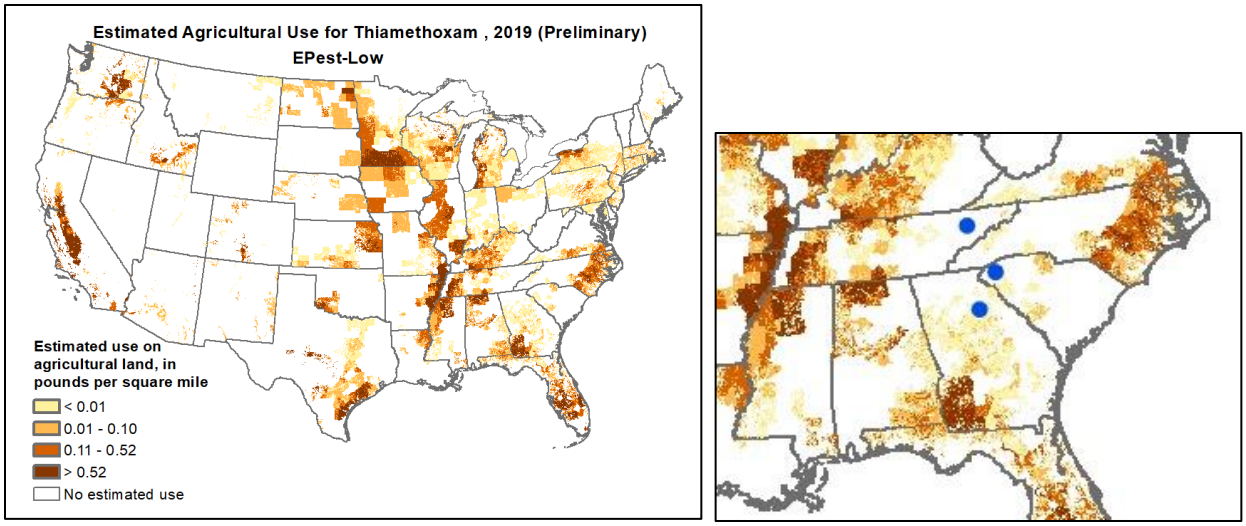


Figure 9. Preliminary lower-bound estimated agricultural application rates of the neonicotinoid thiamethoxam in the year 2019. Note that thiamethoxam is used within the range of *Photuris forresti* in northeast Georgia and the South Carolina Piedmont. Estimates from after 2014 do not include application of coated seeds, which is a major use of this compound. Map from U.S. Geological Survey Pesticide National Synthesis Project.

Soils contaminated with neonicotinoids have been shown to have negative impacts on fireflies and/or other beetles. Disque et al. (2018) captured seventy percent fewer adult fireflies in plots planted with corn seed coated with the neonicotinoid clothianidin, compared to untreated plots, an effect attributed to impacts on firefly larvae. A laboratory study on the effects of clothianidin on the North American fireflies *Photinus pyralis* and *Photuris versicolor* found sublethal behavioral effects, including reduced feeding and soil-chamber building (Pearsons et al. 2021).

Wang et al. (2022) studied the effects of imidacloprid applied topically to larval *Pyrocoelia analis* fireflies at concentrations of 0.025-0.4 mg/L (approximately 25-400 ppb, within the range of concentrations commonly seen in soil field residue studies) and found destructive changes in midgut and fat cell tissues, and persistent luminescence.

Laboratory experiments conducted on an Asian firefly species, *Aquatica lateralis*, showed that, at recommended concentration, the neonicotinoid thiamethoxam caused more than 80% mortality to both adults and larvae and significantly reduced egg hatching (Lee et al. 2008). Carabid beetle species exposed to corn seedlings coated with imidacloprid, thiamethoxam or clothianidin had nearly 100% mortality (Pisa et al. 2015). Several beetle species also showed sublethal effects from contact with soil treated with imidacloprid (Pisa et al. 2015). Application of imidacloprid to a lawn to target white grubs was found to reduce non-target species including beetles by 50% or more over three years (Pisa et al. 2015).

Larval fireflies may also be exposed to neonicotinoids through their prey, which include gastropods such as slugs. Slugs are relatively insensitive to some insecticides, but residues in slug bodies can be transmitted to their predators. Researchers examining predaceous slug-

consuming beetles found that slugs were unaffected by thiamethoxam but transmitted the insecticide to the beetles feeding on them, impairing or killing more than 60% of the beetles (Douglas et al. 2015). Similar pathways could occur with snails, which have been shown to become contaminated with certain pesticides (Druart et al. 2011).

These studies suggest that the loopy five firefly is threatened by mortality and sub-lethal negative effects from exposure to neonicotinoids used for agricultural, forestry, and landscaping uses within its range. These insecticides are widespread both in their level of application and their presence in wetlands, and their persistence and toxicity to fireflies are particularly concerning.

Pyrethroids: Pyrethroids have a wide range of uses in agricultural, urban, and non-crop (such as mosquito management) arenas. Nowak et al. (2017) reported that beetles (as a group) comprise the 2nd most targeted pest by agricultural pyrethroid users, indicating the efficacy of pyrethroids on Coleoptera in general. While pasture and hay are typically lower input land uses than other cropland, some pasture, hay, and forage crop acreage in the Piedmont region are treated with pyrethroids and other insecticides for insect pests such as fall armyworms and grasshoppers (Crouch et al. 2017). Nationwide, 56% of alfalfa acres are treated with foliar applications of pyrethroids (Nowak et al. 2017). Additionally, pyrethroids are applied on golf-courses and lawns in southeastern states to treat fall armyworm (Golf Club of Georgia 2021; Gore 2021).

Peterson et al. (2016) observed high mortality for adult lady beetles contacted by ground-based ULV mosquito spraying with permethrin. Beachley (2008) assessed pyrethroid mosquito abatement ULV sprays on non-target insects. Survival rates for exposed lady beetles (*Hippodamia convergens*) placed 25 m from the spray were significantly lower 1, 12, and 24 hours post-spraying compared to non-exposed controls. Permethrin applied together with piperonyl butoxide (PBO) was 3.4X more toxic to adult and larval Colorado potato beetle (Silcox et al. 1985). Bifenthrin is a pyrethroid used in South Carolina and Georgia for agricultural, landscaping, and residential purposes (Wieben 2019; Wieben 2021; see Figure 10), and its presence in stream sediments has been linked to reduced abundance of benthic stream insects (Carpenter et al. 2016).

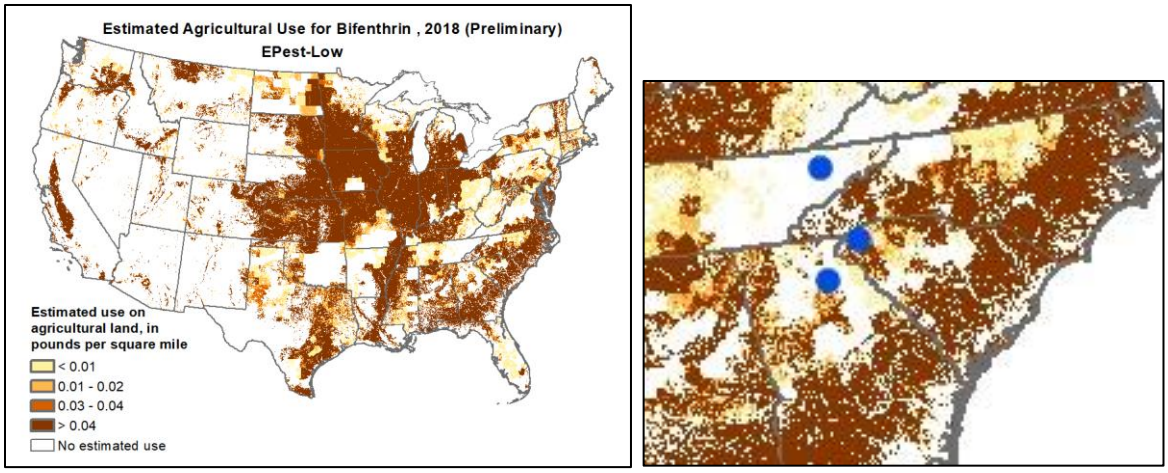


Figure 10. Preliminary lower-bound estimated agricultural application rates of the pyrethroid bifenthrin in the year 2018. Note that bifenthrin was applied in the Piedmont of South Carolina and Georgia, where *Photuris forresti* is known to occur (blue dots). Map from U.S. Geological Survey Pesticide National Synthesis Project.

Pyrethroids are generally the insecticide of choice when doing ground-level spraying for adult mosquito control, used both by vector control districts and by pest control companies treating individual properties. Within the Southeast, residential mosquito sprays may comprise a significant percentage of home pesticide treatments. The vegetated perimeters of residential properties are often sprayed by homeowners and/or pest control companies, killing mosquitoes that rest in or later contact the vegetation. Home mosquito sprays generate about 20% of pest control company revenues, according to trade data (Flesher 2022). Numerous pest control companies offer residential mosquito control pesticide treatments in towns and counties where the loopy five firefly occurs.

Since pyrethroids effectively kill other types of beetles, they are likely effective at killing fireflies including the loopy five firefly. Pyrethroids are used within the range of the loopy five firefly for landscaping, agricultural and mosquito control purposes, and therefore pose a significant threat to the continued existence of the loopy five firefly.

Organophosphates: Several organophosphates have been shown to kill fireflies at use rates recommended by the manufacturer on the label, including acephate, fenthion and diazinon (Lee et al. 2008). In 2019, acephate was applied at an estimated annual rate of 1.319 pounds per square mile in Morgan County, Georgia and 0.022 pounds per square mile in Jefferson County, Tennessee (Wieben 2021; see Figure 11).

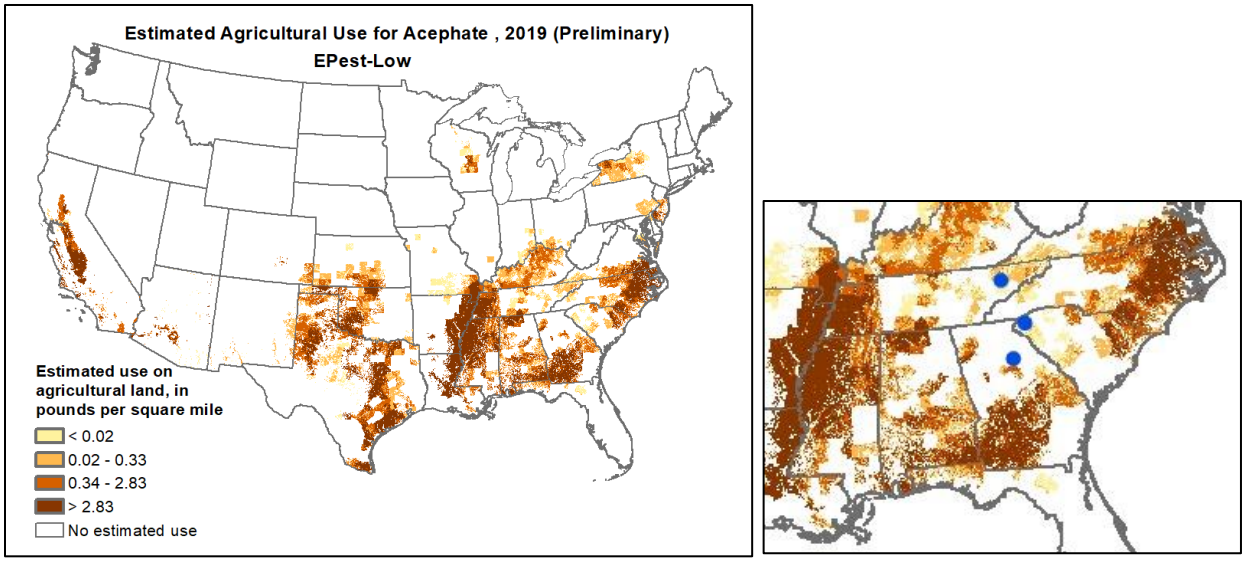


Figure 11. Preliminary lower-bound estimated agricultural application rates of the organophosphate acephate in the year 2019. Note that acephate is used within the range of *Photuris forresti* in northern Georgia and eastern Tennessee (blue dots). Map from U.S. Geological Survey Pesticide National Synthesis Project.

Other organophosphates that are broadly toxic to insects and used for adult mosquito control by vector districts include malathion and naled. Both of these chemicals may be sprayed as aerosols by aerial means, or by ground-based truck "foggers," resulting in substantial drift. Naled may be present in the air for many days after a mosquito adulticide spray, exposing adult fireflies and other flying insects; according to the EPA, naled's half-life in air is 57.8 hours, meaning detectable levels could last for approximately 10 days after a spray. Naled was also implicated in a high-profile incident that killed millions of honey bees as a result of an aerial application in South Carolina in 2016 (Guarino 2016). Because honey bees are much larger in size than mosquitoes, this incident illustrates that lethal impacts from naled applications are not limited to small-bodied insects.

While studies have found minimal mortality of caged crickets in naled spray zones two hours after a single application by truck (Schleier & Peterson 2010) and very limited impacts to overall insect community composition after five aerial naled applications (Rochlin 2022), Zhong et al. (2010) found increased mortality of Miami blue butterfly larvae and higher naled residues within naled spray zones compared to areas outside of spray zones. The chronic, sub-lethal and additive effects of naled remain a concern for the loopy five firefly, particularly because the nocturnal flight period of the firefly lines up with typical mosquito control spray times.

Mosquito larvicides and repellents: Spinosad and methoprene (an insect growth regulator) are two larvicides commonly used for mosquito control by government and commercial entities in Georgia (Gray 2020). Galvan et al. (2006) found that, when applied at maximum field rate, spinosad residues were toxic to nearly 40% of larval lady beetles (*H. axyridis*) within 2 days after treatment, but only about 10% of adults died when exposed to this treatment. Methoprene is toxic to beetle species in some situations (Liu et al. 2012).

While there is not available documentation of mosquito control efforts at known loopy five firefly sites, the prevalence of mosquito control companies in several of the counties where *Photuris forresti* occurs suggests that the firefly's wetland habitats may be increasingly exposed to mosquito larvicides (as well as adulticides). Potential negative impacts of mosquito larvicides on firefly larvae represent a threat to the loopy five firefly, the larvae of which may be particularly vulnerable because of their smaller body size and their use of moist habitats for foraging and shelter.

While there are not studies specifically on its effects on beetles, DEET has been associated with negative effects to midges and caddisflies (Campos et al. 2016) as well as phytoplankton (Martinez et al. 2016), raising concerns about its widespread presence in Piedmont streams (and possibly wetlands) and potential impacts on *Photuris forresti*. Additionally, DEET has been shown to interfere with the regulation of light organ activity in *Photinus* fireflies (Swale et al. 2014), an effect that could have negatively affect firefly reproduction.

Impacts of pesticides on larval food sources

Photuris larvae consume worms, snails or slugs for their diet. Pesticide use that affects these invertebrates can reduce the food sources that larval fireflies need to develop.

Snails, whether aquatic or terrestrial, consume plant material and algae, which may be affected by herbicides. Herbicides in the Photosystem II (PSII) family, such as atrazine, metribuzin and diuron degrade slowly in surface water with hydrolysis half-lives on the order of 30 days to more than 1 year (Schuler and Rand 2007). Atrazine is applied for agricultural uses in the regions of Tennessee, Georgia, and South Carolina where *Photuris forresti* occurs (Figure 12). The long exposure and high concentrations of atrazine and its degradates in Piedmont surface waters may have adverse effects on aquatic plants and algae in the region, with potential effects on snails.

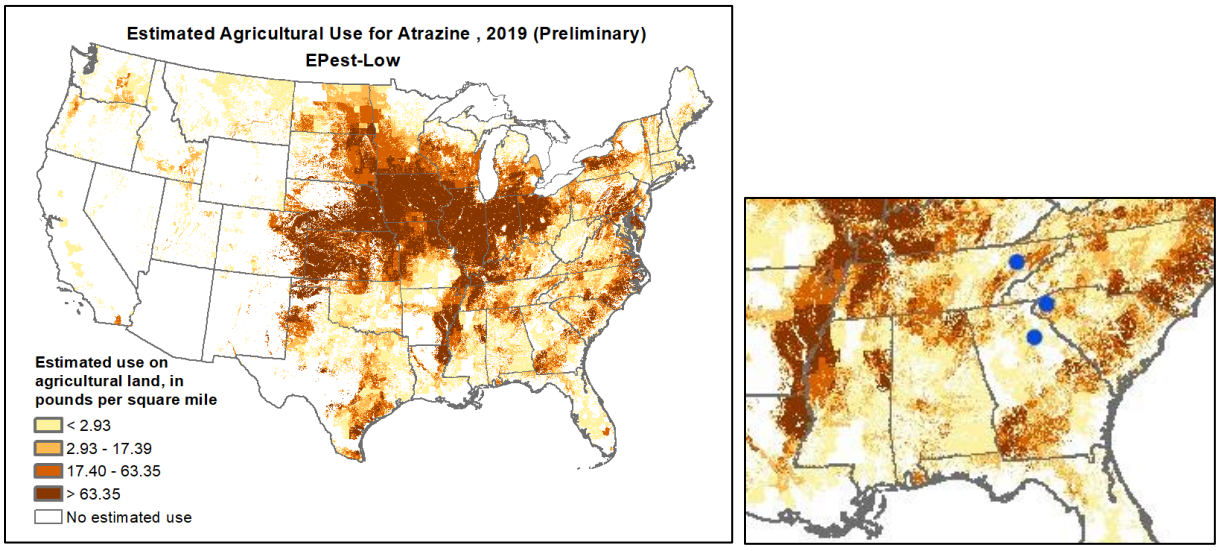


Figure 12. Preliminary lower-bound estimated agricultural application rates of the herbicide atrazine in the year 2019. Note that atrazine is used within the known range of *Photuris forresti* in Tennessee,

Georgia, and South Carolina (blue dots). Map from U.S. Geological Survey Pesticide National Synthesis Project.

Other water contaminants

In seasonal wetlands located in the lower Blue Ridge and upper Piedmont ecoregions of northwestern South Carolina, Yu et al. (2015) found that total dissolved nitrogen (TDN) in small, seasonal wetlands in urbanized areas was strongly influenced by wetland surface water connections and the surrounding land use. TDN was about 3-4X higher for connected wetlands in urbanized areas than for isolated wetlands in these areas. Nitrogen pollution is a recognized threat to numerous imperiled species (Hernández et al. 2016), and is a potential stressor to *Photuris forresti* wetland habitats in both urban and rural landscape settings.

Lee et al. (2008) tested the effects of fertilizer ingredients on the larval fireflies in the species *Luciola lateralis*, finding that urea fertilizer and ammonium fertilizers resulted in 27% and 56% mortality of the tested subjects, respectively.

Ridenhour (2022) found that fertilizer use in urban landscapes was associated with lower abundance of *Photinus pyralis* in the Atlanta, GA metro area, with a stronger effect if fertilizer applications had occurred for three years or more.

Bradley et al. (2019) documented the widespread occurrence of numerous pharmaceuticals, wastewater indicators, and volatile organic chemicals in the Piedmont stream study undertaken by USGS in 2014, indicating that exposure from these chemicals may also be impacting *P. forresti* via contamination of its habitats.

Contamination of wetland habitats with fertilizers and other non-pesticide pollutants threatens the loopy five firefly because of negative impacts on fireflies and the food webs upon which they rely.

Light pollution

Artificial light at night (also known as light pollution) negatively affects the reproductive success of nocturnal firefly species that require darkness for their courtship displays (Owens and Lewis 2018, Lewis et al. 2020) and is increasing globally (Sánchez de Miguel et al. 2021). Artificial light at night can interfere with the behavior of nocturnal fireflies in a multitude of ways, including temporal disorientation (courtship behavior failure to be triggered because the ambient light levels never reach necessary thresholds), positive phototaxis (fireflies being drawn to lights), and disruption of light signal reception (fireflies failing to respond to the signaling of potential mates because the signal is drowned by artificial light) (Owens & Lewis 2018; Owens & Lewis 2022). Loopy five fireflies do not begin their courtship displays until 60 minutes after sunset (Faust 2017, p.201), so they are especially vulnerable to disruption from artificial light at night.

Loopy five fireflies occur relatively close to rapidly growing metropolitan areas (Atlanta, Greenville-Spartanburg, Knoxville), which are associated with elevated levels of artificial light at night (see Figure 13.) Several known loopy five firefly localities have nearby sources of artificial light at night, including vehicle headlights (Jefferson Co., TN; Pickens Co., SC),

streetlights (Oconee Co., GA), lighted signs (Pickens Co., SC; see Figure 14) and sports facilities (Walton Co., GA). While the populations of loopy five at these sites still appear to persist with modest levels of nearby artificial light at night, the lack of population monitoring over time makes it impossible to determine if increases in artificial light at night may have reduced populations from historic levels or contribute to ongoing declines. Increasing levels of artificial light, which would accompany expected urban growth in the region, and/or reduced vegetation buffering could easily cause future disruption and harm to these populations.

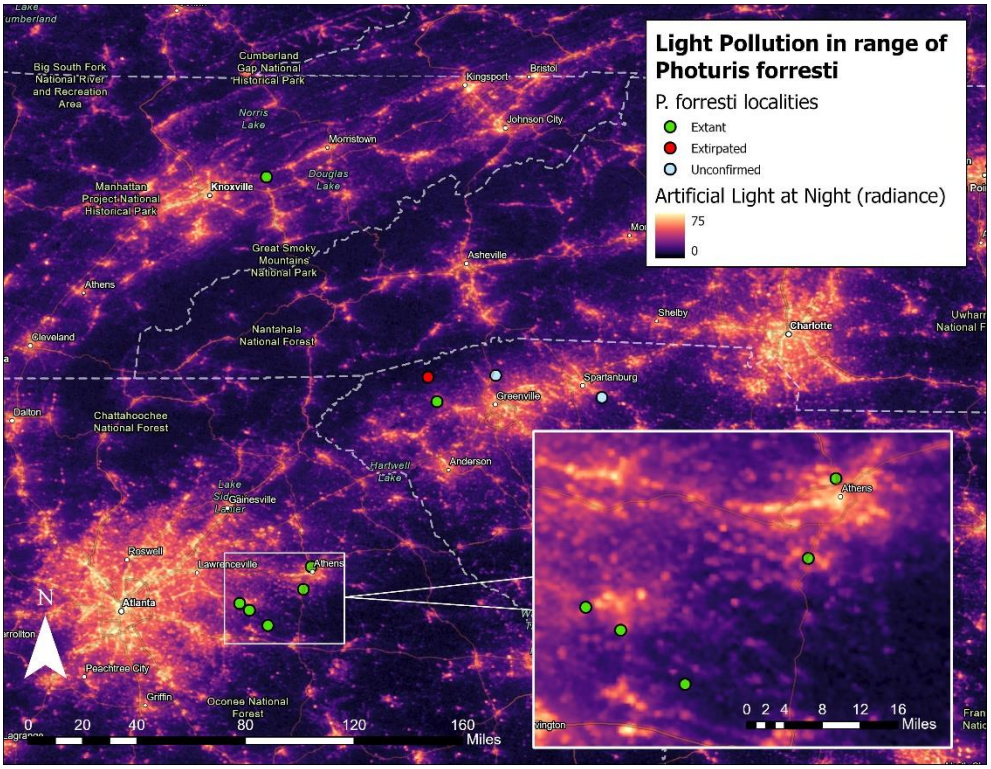


Figure 13. Light pollution in the Southern Appalachian Piedmont collected by the Visible Infrared Imaging Radiometer Suite (VIIRS). Visible on the map are several metropolitan areas, including Atlanta (bottom left), Greenville-Spartanburg (center), Knoxville (upper left), and Charlotte (upper right). Colors represent increasing amounts of artificial light ranging from black (low amounts of artificial light) to yellow (high amounts of artificial light). Light is measured in radiance (10^{-9} Watts/cm^2/steradian). The inset map shows the proximity of areas of high light pollution to five *P. forresti* localities east of Atlanta, Georgia. Radiance imagery from the Earth Observation Group, Payne Institute for Public Policy.

Figure 14. Lighted signs and parking lot lighting across the road from a loopy five firefly wetland in Pickens County, South Carolina, are visible from the firefly's courtship display area. Photo: Richard Joyce/Xerces Society.

Climate change

Global climate change has caused measurable changes to weather patterns in the southeastern U.S.A. and is projected to cause increased temperatures and more extreme precipitation events. These impacts are likely to affect loopy five firefly populations and habitats.

Global climate change is predicted to cause an increase in the frequency of extreme precipitation events, where a significant proportion of an area's normal precipitation occurs within a single precipitation event (U.S. EPA 2022). This pattern means an increase in the moisture extremes experienced by habitats, with droughts punctuated by intense rain that often leads to flooding. Though *Photuris forresti* is adapted to wetland habitats and areas in the floodplains of waterways, intense flooding is likely to wash away, bury, or kill developing eggs, larvae, and pupae. Conversely, drought has been shown to depress firefly populations, presumably through reduced prey populations and lower survival of larvae (Faust 2017 p.28; Matheny 2017).

By mid-century, areas of known loopy five firefly localities are predicted to experience an additional 17-19 days each year with heat indexes of 100° F or higher, as well as longer stretches of high heat (Amodeo et al. 2022). While warmer temperatures can speed up larval development of fireflies (Bauer et al. 2013), thermal stress is known to negatively impact beetle survival, reproductive development, and fertility (Sales et al. 2021), and fireflies are susceptible to desiccation during all life stages.

Small populations and the Allee effect

Fireflies have complex mating systems involving bioluminescent lighting displays, pheromones, and nuptial gifts (Lewis & Cratsley 2008, Lewis 2016). As firefly sex ratio is near 1:1, any lack of males will result in lower female fecundity (Bauer et al. 2013). Small firefly populations due to habitat fragmentation and degradation can lower mating chances, an effect known as the Allee effect (Gascoigne et al. 2009, Bauer et al. 2013). For insects, if a population is demonstrating an

Allee effect, populations may no longer be sustainable and can become extirpated (Gascoigne et al. 2009).

For fireflies, females need enough males in order to choose adequate mates to maximize fecundity and pass high quality genes onto offspring (Rooney and Lewis 2002, Lewis and Cratsley 2008, Bauer et al. 2013). Females can also benefit from more fit mates, by receiving nuptial gifts from males (Lewis and Cratsley 2008, Lewis 2016). Nuptial gifts are nutritious spermatophores that females can then use for survival and reproduction (Lewis and Cratsley 2008, Lewis 2016). Thus, females with more mate options and the ability to mate with more males will have higher fecundity, survival, and fitter offspring than females with reduced mate choices (Rooney and Lewis 2002, Lewis et al. 2004, Lewis and Cratsley 2008, South and Lewis 2012). Any loss in male population due to habitat degradation and fragmentation puts the loopy five firefly at further risk of extinction due to lower reproductive output.

Request for critical habitat designation

We request the Service to designate critical habitat for the loopy five firefly in concurrence with its listing. Critical habitat is defined in Section 3 of the ESA as (i) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of section 1533 of this title, on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of section 1533 of this title, upon a determination by the Secretary that such areas are essential for the conservation of the species (16 U.S.C. § 1532 (5)).

A fundamental goal of the ESA is to ensure that "the ecosystems upon which endangered species and threatened species depend may be conserved." 16 U.S.C. § 1531 (b). Thus, critical habitat is an effective and important component of the ESA, without which the loopy five firefly's chance for survival significantly diminishes. Petitioners therefore request that the Service propose critical habitat in concurrence with the species listing.

Conclusion

The petitioners have carefully assessed the most current and accurate scientific information available for the loopy five firefly regarding the historic, present and future threats of the species and have determined that the loopy five firefly is in imminent danger of extinction throughout its range. The loopy five firefly is a rare habitat specialist found in just seven confirmed sites in three states. The petitioners urge the listing of this imperiled species. The ESA requires that the Service promptly issue an initial finding as to whether this petition "presents substantial scientific or commercial information indication that the petitioned action may be warranted" 16 U.S.C. § 1533 (b)(3)(A).

The petitioners assess that listing the loopy five firefly is warranted under the ESA as it is imperiled by 1) the present or threatened destruction, modification, or curtailment of its habitat or range; 4) the inadequacy of existing regulatory mechanisms; and 5) other natural or manmade

factors affecting its continued existence, as well as by potential threats of 2) overutilization for commercial, recreational, scientific, or education purposes; and 3) disease or predation. There are no existing regulatory mechanisms which are adequate to protect the loopy five firefly from extinction. Listing the loopy five firefly is the only way to provide continued existence for a species that would otherwise succumb to the combined threats of habitat degradation, light pollution, climate change, and pesticides. Conserving this firefly and its habitat would in addition protect palustrine wetlands in the Southern Piedmont and Ridge and Valley regions that provide critical ecosystem services and are home to many native species. A prompt decision is required to save this species from extinction.

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References cited

Amodeo, M., Bauer, M., Bryant, K., Cawley, H., Chadwick, S., Eby, M.,... Yong, R. (2022). The 6th National Risk Assessment: Hazardous Heat. First Street Foundation. Available online: https://report.firststreet.org/6th-National-Risk-Assessment-Hazardous-Heat.pdf.

Atwood, Donald, and Claire Paisely-Jones. 2017. "Pesticides Industry Sales and Usage: 2008-2012 Market Estimates." U.S. Environmental Protection Agency, Biological and Economic Analysis Division, Office of Pesticide Programs.

Babendreier, D., P. Jeanneret, C. Pilz, and S. Toepfer. 2015. "Non-target effects of insecticides, entomopathogenic fungi and nematodes applied against western corn rootworm larvae in maize." *Journal of Applied Entomology* 139 (6). https://doi.org/10.1111/jen.12229.

Barber, H.S. 1951. North American fireflies of the genus Photuris. Smithson. Misc. Collect. 117: 1-58. Bascom W. 1979. African folktales in America VII. Research in African Literatures **10**:323-349.

Bauer CM, Nachman G, Lewis SM, Faust LF. and Reed JM. 2013. Modeling effects of harvest on firefly population persistence. Ecological modelling **256**:43-52.

Beachley, Michelle D. 2008. *Responses of non-target insects to mosquito abatement insecticide exposure in seasonal wetlands*. M.S. Thesis, California State University, Sacramento.

Bonmatin, J-M, C. Giorio, V. Girolami, D. Goulson, D. P. Kreutzweiser, C. Krupke, M. Liess, et al. 2015. "Environmental Fate and Exposure; Neonicotinoids and Fipronil." *Environmental Science and Pollution Research International* 22 (1): 35–67. https://doi.org/10.1007/s11356-014-3332-7.

Bradley, Paul M., Celeste A. Journey, Jason P. Berninger, Daniel T. Button, Jimmy M. Clark, Steve R. Corsi, Laura A. DeCicco, et al. 2019. "Mixed-Chemical Exposure and Predicted Effects Potential in Wadeable Southeastern USA Streams." *The Science of the Total Environment* 655 (March): 70–83.

Buschman, L.L. 1984. Larval biology and ecology of Photuris fireflies (Lampyridae: Coleoptera) in Northcentral Florida. Journal of the Kansas Entomological Society 57(1): 7-16.

Bullard, R. (2020, September 14). *Rethinking Tennessee Dams*. The Nature Conservancy. https://www.nature.org/en-us/about-us/where-we-work/united-states/tennessee/stories-in-tennessee/dam-removal-opens-up-roaring-river/.

Carpenter, K. D., Kuivila, K. M., Hladik, M. L., Haluska, T., & Cole, M. B. (2016). Storm-event-transport of urban-use pesticides to streams likely impairs invertebrate assemblages. *Environmental Monitoring and Assessment*, *188*(6), 345.

Choudhury, R. A., Sutherland, A. M., Hengel, M. J., Parrella, M. P., & Douglas Gubler, W. (2020). Imidacloprid Movement into Fungal Conidia is Lethal to Mycophagous Beetles. In *bioRxiv* (p. 2020.01.11.901751). https://doi.org/10.1101/2020.01.11.901751.

Chuang, A., Deitsch, J. F., Nelsen, D. R., Sitvarin, M. I., & Coyle, D. R. (2022). The Jorō spider (*Trichonephila clavata*) in the southeastern U.S.: an opportunity for research and a call for reasonable journalism. *Biological Invasions*. https://doi.org/10.1007/s10530-022-02914-3.

Crouch, J., Beer, B., and R. Bellinger. 2017. Pasture and hay insect management. In: South Carolina Pest Management Handbook for Field Crops. https://www.clemson.edu/extension/agronomy/pestmanagement17/insect%20control%20in%20forages.pdf.

De Cock, R. (2009). Biology and behaviour of European lampyrides. In V. B. Meyer-Rochow (Ed.), *Bioluminescence in Focus - A Collection of Illuminating Essays*. Research Signpost.

De Cock R, Faust L, Lewis S. 2014. Courtship and mating in *Phausis reticulata* (Coleoptera: Lampyridae): male flight behaviors, female glow displays, and male attraction to light traps. Florida Entomologist **97**:1290-1307.

Disque, Heather H., Kelly A. Hamby, Aditi Dubey, Christopher Taylor, and Galen P. Dively. 2018. "Effects of clothianidin-treated seed on the arthropod community in a mid-Atlantic no-till corn agroecosystem." *Pest Management Science*, September. https://doi.org/10.1002/ps.5201.

Donohue, L. (2016). "Wrest" in peace: The effect of the Georgia environmental protection division's "wrested vegetation rule" on coastal salt marshes. *Georgia State University Law Review*, *32*(4). https://readingroom.law.gsu.edu/cgi/viewcontent.cgi?article=2853&context=gsulr

Douglas, Margaret R., Jason R. Rohr, and John F. Tooker. 2015. "Neonicotinoid insecticide travels through a soil food chain, disrupting biological control of non-target pests and decreasing soya bean yield." *The Journal of Applied Ecology* 52 (1): 250–60. https://doi.org/10.1111/1365-2664.12372.

Druart, C., M. Millet, R. Scheifler, O. Delhomme, C. Raeppel, and A. de Vaufleury. 2011. "Snails as indicators of pesticide drift, deposit, transfer and effects in the vineyard." *Science of the Total Environment* 409 (20): 4280–4288.

Eisner T, Goetz MA, Hill DE, Smedley SR, Meinwald J. 1997. Firefly "femmes fatales" acquire defensive steroids (lucibufagins) from their firefly prey. Proceedings of the National Academy of Sciences **94**: 9723-9728.

Eisner T, Wiemer DF, Haynes LW, Meinwald J. 1978. Lucibufagins: defensive steroids from the fireflies *Photinus ignitus* and *P. marginellus* (Coleoptera: Lampyridae). Proceedings of the National Academy of Sciences, **75**:905-908.

Ewing R & Hamidi, S. (2014). *Measuring Sprawl 2014*. Metropolitan Research Center. Available online: https://smartgrowthamerica.org/wp-content/uploads/2016/08/measuring-sprawl-2014.pdf. (Accessed December 23, 2022).

Fallon, C. E., Walker, A. C., Lewis, S., Cicero, J., Faust, L., Heckscher, C. M., Pérez-Hernández, C. X., Pfeiffer, B., & Jepsen, S. (2021). Evaluating firefly extinction risk: Initial red list assessments for North America. *PloS One*, *16*(11), e0259379.

Faust L.F. 2010. Natural history and flash repertoire of the synchronous firefly *Photinus carolinus* (Coleoptera: Lampyridae) in the Great Smoky Mountains National Park. Florida Entomologist **92**:208-217.

Faust, L.F. 2017. Fireflies, Glow-worms, and Lightning Bugs. Identification and Natural History of the Fireflies of the Eastern and Central United States and Canada. University of Georgia Press, Athens, GA.

Faust, L.F. and Davis, J. 2019. A new species of Photuris Dejean (Coleoptera: Lampyridae) from a Mississippi cypress swamp, with notes on its behavior. The Coleopterists Bulletin 73(1): 97-113.

Ferreira VS, Keller O, Ivie MA. 2022. Descriptions of New Species of Chespirito Ferreira, Keller & Branham (Coleoptera: Lampyridae: Chespiritoinae) and the First Record for the Subfamily in the United States. Zootaxa **5124**:230-237.

Flesher J. 2022. Backyard mosquito spraying booms, but may be too deadly. Available online:

https://phys.org/news/2022-08-backyard-mosquito-booms-deadly.html.
Galvan, Tederson L., Robert L. Koch, and William D. Hutchison. 2006. "Toxicity of indoxacarb and spinosad to the multicolored Asian lady beetle, Harmonia axyridis (Coleoptera: Coccinellidae), via three routes of exposure." *Pest Management Science* 62 (9): 797–804. https://doi.org/10.1002/ps.1223.
Gardiner, T., & Didham, R. K. (2020). Glowing, glowing, gone? Monitoring long-term trends in glow-worm numbers in south-east England. *Insect Conservation and Diversity / Royal Entomological Society of London*, *13*(2), 162–174.
Gascoigne J, Berec L, Gregory S, Courchamp F. 2009. Dangerously few liaisons: a review of mate-finding Allee effects. Population Ecology **51**:355-372.
[Golf Club of Georgia] Battling Armyworms and Winning! (2021, September 29). *Golf Club of Georgia*. https://golfclubofgeorgia.com/blogs/-/blogs/battling-armyworms-and-winning-.
[GSWCC] Georgia Soil and Water Conservation Commission. 2014. Watershed Dams. Available online: https://gaswcc.georgia.gov/watersheds-water-resources/watershed-dams. (Accessed: November 11, 2022).
Gray, E. W. (2020). *Mosquito control: Options for commercial and government entities* (Bulletin 28). University of Georgia Extension. https://extension.uga.edu/content/dam/extension/programs-and-services/integrated-pest-management/documents/handbooks/2020-pmh-chapters/Mosquito%20Control.pdf.
Greene, B., & Blossey, B. (2014). Patterns of Privet: Urbanizing Watersheds, Invasive *Ligustrum sinense*, and Performance of Native Plant Species in Piedmont Floodplain Forests. *Ecosystems* , *17*(6), 990–1001.
Gregory, D., & Waters, G. (2008). *Beaver Management and Control in Georgia*. Georgia Department of Natural Resources. https://georgiawildlife.com/sites/default/files/wrd/pdf/management/2008_Beaver_Management_and_Control.pdf
Guarino, B. (2016, September 1). 'Like it's been nuked': Millions of bees dead after South Carolina sprays for Zika mosquitoes. *The Washington Post*. https://www.washingtonpost.com/news/morning-mix/wp/2016/09/01/like-its-been-nuked-millions-of-bees-dead-after-south-carolina-sprays-for-zika-mosquitoes/.
Gutzwiller, K. J., & Flather, C. H. (2011). Wetland features and landscape context predict the risk of wetland habitat loss. *Ecological Applications: A Publication of the Ecological Society of America*, *21*(3), 968–982. Available online: https://www.fs.usda.gov/rmrs/projects/wetland-habitat-persistence-and-transition-southeastern-united-states.
Hancock, Dennis W., Ray Hicks, Jeremy M. Kichler, and Robert C. Smith III. 2018. Georgia Forages: Grass Species. University of Georgia Extension. Bulletin 1351. 32 pp. https://extension.uga.edu/publications/detail.html?number=B1351.
Heckscher CM. 2021. Four New Species of North American Fireflies from Isolated Peatlands with Reference to Species Determination of *Photuris Dejean* (Coleoptera: Lampyridae). Northeastern Naturalist **28**:277-295.
Hernández, D. L., Vallano, D. M., Zavaleta, E. S., Tzankova, Z., Pasari, J. R., Weiss, S., Selmants, P. C., & Morozumi, C. (2016). Nitrogen Pollution Is Linked to US Listed Species Declines. *Bioscience*, *66*(3), 213–222.

Houlahan, J. E., & Findlay, C. S. (2004). Estimating the "critical" distance at which adjacent land-use degrades wetland water and sediment quality. *Landscape Ecology, 19*(6), 677–690.
Integrated Taxonomic Information System. 2022. *Photuris forresti*. Available online: https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=1157768#null. (Accessed December 23, 2022).
IUCN. 2022. The IUCN Red List of Threatened Species. Version 2022-1. Available at: www.iucnredlist.org. (Accessed: 21 July 2022).
Khoo V, Nada B, Kirton LG, Phon C. 2009. Monitoring the population of the firefly *Pteroptyx tener* along the Selangor River, Malaysia for conservation and sustainable ecotourism. Lampyrid **2**:162-173.
Landsman, A. P., Schmit, J. P., & Matthews, E. R. (2021). Invasive Plants Differentially Impact Forest Invertebrates, Providing Taxon-Specific Benefits by Enhancing Structural Complexity. *Frontiers in Ecology and Evolution, 9*. https://doi.org/10.3389/fevo.2021.682140
Laurent EL, Ono K. 1999. The Firefly and the Trout: Recent Shifts Regarding the Relationship Between People and other Animals in Japanese Culture. Anthrozoös **12**:149-156, DOI: 10.2752/089279399787000165.
Lee, Ki-Yeoi, Young-Ho Kim, Jae-Wung Lee, Myng-Kyu Song, and Sang-Ho Nam. 2008. "Toxicity of firefly, *Luciola lateralis* (Coleoptera: Lampyridae) to commercially registered insecticides and fertilizers." *Korean Journal of Applied Entomology* 47 (3): 265–72.
Lewis, S. 2016. Silent Sparks: The Wondrous World of Fireflies. Princeton University Press, Princeton.
Lewis, S. M., & Cratsley, C. K. (2008). Flash signal evolution, mate choice, and predation in fireflies. *Annual Review of Entomology, 53*, 293–321.
Lewis SM, Faust L, De Cock R. 2012. The dark side of the light show: predators of fireflies in the Great Smokey Mountains. Psyche: A journal of Entomology **2012**:1-7.
Lewis, S., Wong, C.H., Owens, A., Fallon, C., Jepsen, S., Thancharoen, A., Wu, C., De Cock, R., Novak, M., Lopez-Palafox, T., Khoo, V. and Reed, J.M. 2020. A global perspective on firefly extinction threats. BioScience 70(2): 157-167.
Lewis, S. M., Thancharoen, A., Wong, C. H., López-Palafox, T., Santos, P. V., Wu, C., Faust, L., De Cock, R., Owens, A. C. S., Lemelin, R. H., Gurung, H., Jusoh, W. F. A., Trujillo, D., Yiu, V., López, P. J., Jaikla, S., & Reed, J. M. (2021). Firefly tourism: Advancing a global phenomenon toward a brighter future. *Conservation Science and Practice, 3*(5). https://doi.org/10.1111/csp2.391.
Light pollution map. (2021). Light Pollution Map. Retrieved January 8, 2023, from https://www.lightpollutionmap.info/.
Liu, S. S., F. H. Arthur, D. VanGundy, and T. W. Phillips. 2016. "Combination of methoprene and controlled aeration to manage insects in stored wheat." *Insects* 7 (2): 7020025.
Lloyd, J.E. 2018. A naturalist's long walk among shadows: of North American Photuris - patterns, outlines, silhouettes… echoes. Self-published, Gainesville, FL.
Lloyd JE. 1973. Firefly parasites and predators. The Coleopterists Bulletin **27**:91-106.
Long SM, Lewis S, Jean-Louis L, Ramos G, Richmond J, Jakob EM. 2012. Firefly flashing and jumping spider predation. Animal behavior **83**:81-86.

Martínez, L. C., Plata-Rueda, A., Zanuncio, J. C., & Serrao, J. E. (2014). Comparative Toxicity of Six Insecticides on the Rhinoceros Beetle (Coleoptera: Scarabaeidae). *Florida Entomologist*, *97*(3), 1056–1062.

Matheny, J. (2017, June 15). *Drought, demolition dims synchronous fireflies in Smokies*. WBIR. https://www.wbir.com/article/news/local/drought-demolition-dims-synchronous-fireflies-in-smokies/51-448323967.

Mbugua, S. W., Wong, C. H., & Ratnayeke, S. (2020). Effects of artificial light on the larvae of the firefly Lamprigera sp. In an urban city park, Peninsular Malaysia. *Journal of Asia-Pacific Entomology*, *23*(1), 82–85. https://doi.org/10.1016/j.aspen.2019.10.005

McCary, M. A., Mores, R., Farfan, M. A., & Wise, D. H. (2016). Invasive plants have different effects on trophic structure of green and brown food webs in terrestrial ecosystems: a meta-analysis. *Ecology Letters*, *19*(3), 328–335.

McClain, Kelly. 2014. Non-agricultural pesticide use in Puget Sound counties. Washington State Dept. of Agriculture. Pub. No. AGR PUB 103-409. 76 pp. http://agr.wa.gov/FP/Pubs/NaturalResourcesAssessmentPubs.aspx.

McDermott, F.A. 1967. The North American fireflies of the genus Photuris Dejean a modification of Barber's key (Coleoptera; Lampyridae). The Coleopterists Bulletin 21(4): 106-116.

Merrill, M. D., Freeman, M. C., Freeman, B. J., Kramer, E. A., & Hartle, L. M. (2001). Stream loss and fragmentation due to impoundments in the upper Oconee watershed. In K. J. Hatcher (Ed.), *Proceedings of the 2001 Georgia Water Resources Conference, held March 26-27* (pp. 66–69). Institute of Ecology, The University of Georgia.

Naeher, Luke P., Nicolle S. Tulve, Peter P. Egeghy, Dana B. Barr, Olorunfemi Adetona, Roy C. Fortmann, Larry L. Needham, Elizabeth Bozeman, Aaron Hilliard, and Linda S. Sheldon. 2010. "Organophosphorus and Pyrethroid Insecticide Urinary Metabolite Concentrations in Young Children Living in a Southeastern United States City." *The Science of the Total Environment* 408 (5): 1145–53. https://doi.org/10.1016/j.scitotenv.2009.10.022.

Natural Communities of North Georgia. (n.d.). *Wet Meadows and Marshes*. Retrieved December 23, 2022, from https://www.naturalcommunitiesofgeorgia.com/wet-meadows-and-marshes.html.

NatureServe. 2022. *Photuris forresti* Lloyd, 2018. NatureServe Explorer [Web Application]. NatureServe, Arlington, Virginia. Available online: https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.1225795/Photuris_forresti. (Accessed: December 23, 2022).

Nelson, J. B. (1986). *The Natural Communities of South Carolina*. South Carolina Wildlife & Marine Resources Department. Available online: https://dc.statelibrary.sc.gov/handle/10827/30179.

Nowak, P., Mitchell, P. D., Hurley, T. (2017). *The value of pyrethroids in U.S. agricultural and urban settings:* AgInformatics, LLC. http://aginfomatics.com/uploads/3/4/2/2/34223974/01_aginfomatics_pyrethroid_execsum_2017.pdf

Oba Y, Schultz DT. 2022. Firefly genomes illuminate the evolution of beetle bioluminescent systems. Current Opinion in Insect Science **26**:100879.

Owens, A.C.S. and Lewis, S.M. 2018. The impact of artificial light at night on nocturnal insects: A review and synthesis. Ecology and Evolution 8: 11337-11358.

Pearsons, K. A., Lower, S. E., & Tooker, J. F. (2021). Toxicity of clothianidin to common Eastern North American fireflies. *PeerJ*, *9*. https://doi.org/10.7717/peerj.12495.
Peterson, Robert K. D., Collin J. Preftakes, Jennifer L. Bodin, Christopher R. Brown, Alyssa M. Piccolomini, and Jerome J. Schleier. 2016. "Determinants of acute mortality of Hippodamia convergens (Coleoptera: Coccinellidae) to ultra-low volume permethrin used for mosquito management." *PeerJ* 4 (June): e2167. https://doi.org/10.7717/peerj.2167.
Pisa, L. W., V. Amaral-Rogers, L. P. Belzunces, J. M. Bonmatin, C. A. Downs, D. Goulson, D. P. Kreutzweiser, et al. 2015. "Effects of neonicotinoids and fipronil on non-target Invertebrates." *Environmental Science and Pollution Research International* 22 (1): 68–102. https://doi.org/10.1007/s11356-014-3471-x.
Pulliam, H. R. (1988). Sources, Sinks, and Population Regulation. *The American Naturalist*, *132*(5), 652–661.
Radebaugh, S. (2022, August 15). *Hundreds of fish killed when Upstate lake accidentally drained*. https://www.wspa.com/news/local-news/hundreds-of-fish-killed-when-upstate-lake-accidentally-drained/.
Ridenhour, Kelly. 2012. "Atlanta Firefly Project: Using community science to explore the effects of land management on the local abundance of the big dipper firefly (*Photinus pyralis*) in city parks and residential yards." Master of Science, University of Georgia.
Rooney, J., & Lewis, S. M. (2002). Fitness advantage from nuptial gifts in female fireflies. *Ecological Entomology*, *27*(3), 373–377.
Sales, K., Vasudeva, R., & Gage, M. J. G. (2021). Fertility and mortality impacts of thermal stress from experimental heatwaves on different life stages and their recovery in a model insect. *Royal Society Open Science*, *8*(3), 201717.
Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S., & Gaston, K. J. (2021). First Estimation of Global Trends in Nocturnal Power Emissions Reveals Acceleration of Light Pollution. *Remote Sensing*, *13*(16), 3311. http://dx.doi.org/10.3390/rs13163311.
Schuettler DJ. 2007. Fireflies in the night: indigenous metaphor in Zapatista folktales. Dissertation, Union Institute and University.
Schuler, Lance J., and Gary M. Rand. 2008. "Aquatic Risk Assessment of Herbicides in Freshwater Ecosystems of South Florida." *Archives of Environmental Contamination and Toxicology* 54 (4): 571–83. https://doi.org/10.1007/s00244-007-9085-2.
Self, Bradley. 2021. "Herbicide Options for Loblolly Pine Management" Publication P3233. Mississippi State University Extension. Available online: https://extension.msstate.edu/sites/default/files/publications//p3233.pdf.
Shaw, J., Estes, D., Ruhfel, B., Morris, A. B., Littlefield, T.R. (2021). Tennessee-Kentucky Plant Atlas. [S.M. Landry and K.N. Campbell (original application development), USF Water Institute. University of South Florida]. University of Tennessee at Chattanooga, Austin Peay State University, University of Michigan, Furman University, and Kentucky State Nature Preserves Commission. Available online: https://tennessee-kentucky.plantatlas.usf.edu/EcologicalCommunities.aspx.
Silcox, Charles A., Gerald M. Ghidiu, and Andrew J. Forgash. 1985. "Laboratory and Field Evaluation of Piperonyl Butoxide as a Pyrethroid Synergist Against the Colorado Potato Beetle (Coleoptera: Chrysomelidae)." *Journal of Economic Entomology* 78 (6): 1399–1405. https://doi.org/10.1093/jee/78.6.1399.
South A, Lewis SM. 2012. Effects of male ejaculate on female reproductive output and longevity in *Photinus* fireflies. Canadian journal of zoology **90**:677-681.

[SCDNR] *Beaver Management and Control in South Carolina*. (2016). South Carolina Department of Natural Resources. Available online: https://www.dnr.sc.gov/wildlife/publications/pdf/BeaverManagementControl.pdf

[SCEMD] South Carolina Emergency Management Division. (n.d.). *Dam Failure*. South Carolina Emergency Management Division. Retrieved October 3, 2022, from https://www.scemd.org/prepare/types-of-disasters/dam-failure/.

Stanger-Hall KF, Lloyd JE, Hillis DM. 2007. Phylogeny of North American fireflies (Coleoptera: Lampyridae): implications for the evolution of light signals. Molecular phylogenetics and evolution **45**:33-49.

Swale, D. R., Sun, B., Tong, F., & Bloomquist, J. R. (2014). Neurotoxicity and mode of action of N, N-diethyl-meta-toluamide (DEET). *PloS One*, *9*(8), e103713.

Terando, A. J., Costanza, J., Belyea, C., Dunn, R. R., McKerrow, A., & Collazo, J. A. (2014). The southern megalopolis: using the past to predict the future of urban sprawl in the Southeast U.S. *PloS One*, *9*(7), e102261.

Thancharoen A, Masoh S. (2019). Effect of camera illumination on flashing behavior of Pteroptyx malaccae (Coleoptera: Lampyridae). In Bioluminescence-Analytical Applications and Basic Biology. IntechOpen.

Underwood TJ, Tallamy DW, Pesek JD. 1997. Bioluminescence in firefly larvae: a test of the aposematic display hypothesis (Coleoptera: Lampyridae). Journal of Insect Behavior **10**:365-370.

[U.S. EPA] United States Environmental Protection Agency. (2022). *Climate Change Indicators: Heavy Precipitation*. https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation.

[U.S. EPA] United States Environmental Protection Agency. (2022, September 28). *EPA Responds to Treated Seed Petition*. Available online: https://www.epa.gov/pesticides/epa-responds-treated-seed-petition.

USDA Forest Service. 1994. "Pest and Pesticide Management on Southern Forests." Management Bulletin R8-MB 60. Southern Region, Atlanta GA. Available online: https://www.srs.fs.usda.gov/pubs/misc/r8_mb060.pdf.

United States Geological Survey. (2021). *USGS NAWQA: The Pesticide National Synthesis Project*. National Water-Quality Assessment (NAQQA) Project: Pesticide National Synthesis Project. https://water.usgs.gov/nawqa/pnsp/usage/maps/compound_listing.php

Vance E, Kuri S. 2017. How fireflies are keeping this tiny Mexican town alive. National Geographic. Available online: https://www.nationalgeographic.com/photography/proof/2017/08/firefly-fields-mexico-tourism-ecotourism/.

Varlamoff, S., W. J. Florkowski, J. L. Jordan, J. Latimer, and K. Braman. 2001. "Georgia Homeowner Survey of Landscape Management Practices." *HortTechnology* 11 (2): 326–31. https://doi.org/10.21273/horttech.11.2.326.Waite et al. 2019

Waite, I. R., Munn, M. D., Moran, P. W., Konrad, C. P., Nowell, L. H., Meador, M. R., Van Metre, P. C., & Carlisle, D. M. (2019). Effects of urban multi-stressors on three stream biotic assemblages. *The Science of the Total Environment*, *660*, 1472–1485.

Wang, Yi-Zhe, Cheng-Quan Cao, and Dun Wang. 2022. "Physiological responses of the firefly *Pyrocoelia analis* (Coleoptera: Lampyridae) to an environmental residue from chemical pesticide imidacloprid." *Frontiers in Physiology* 13: 879216. https://doi.org/10.3389/fphys.2022.879216.

Wieben, C.M., 2019, Estimated Annual Agricultural Pesticide Use for Counties of the Conterminous United States, 2013-17 (ver. 2.0, May 2020): U.S. Geological Survey data release, https://doi.org/10.5066/P9F2SRYH. Available online: https://www.sciencebase.gov/catalog/item/5e95c12282ce172707f2524e.

Wieben, C.M., 2021, Preliminary estimated annual agricultural pesticide use for counties of the conterminous United States, 2019: U.S. Geological Survey data release, https://doi.org/10.5066/P9EDTHQL. Available online: https://www.sciencebase.gov/catalog/item/6081a924d34e8564d68661a1.

Wolfram, Jakob, Sebastian Stehle, Sascha Bub, Lara L. Petschick, and Ralf Schulz. 2018. "Meta-analysis of insecticides in United States surface waters: status and future implications." *Environmental Science & Technology* 52 (24): 14452–60. https://doi.org/10.1021/acs.est.8b04651.

Wong, C. H., & Yeap, C. A. (2012). Conservation of congregating firefly zones (CFZs) in peninsular Malaysia. *Lampyrid*, *2*, 174–187.Woods WA, Hendrickson H, Mason J,

Lewis SM. 2007. Energy and predation costs of firefly courtship signals. The American Naturalist **170**:702-708.

Zhong, H., Hribar, L. J., Daniels, J. C., Feken, M. A., Brock, C., & Trager, M. D. (2010). Aerial ultra-low-volume application of naled: impact on nontarget imperiled butterfly larvae (Cyclargus thomasi bethunebakeri) and efficacy against adult mosquitoes (Aedes taeniorhynchus). *Environmental Entomology*, *39*(6), 1961–1972.