

FIREFLY SPECIES FACT SHEET:
Bethany Beach firefly (*Photuris bethaniensis*)



Bethany Beach firefly from a site in Delaware (Richard Joyce/Xerces Society).

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Scientific Name:

Photuris bethaniensis McDermott, 1953

Phylum: Arthropoda
Class: Insecta
Order: Coleoptera
Family: Lampyridae
Subfamily: Photurinae
Tribe: Photurini
(ITIS 2023)

Synonyms: None

Common Name:

Bethany Beach firefly

Taxonomic Note:

The Bethany Beach firefly was first collected from Delaware, USA, in 1949, but not formally described until a few years later (McDermott 1953). It is named for Bethany Beach, Delaware, where it was first found (Faust 2017).

Prior to the extensive taxonomic work published by Herbert Barber and Frank McDermott in the 1950s and 60s, *Photuris* fireflies were largely lumped into a single species complex called *Photuris pennsylvanica* (Faust 2017). After their publications, numerous *Photuris* fireflies were described and the larger complex was split into two groups - *versicolor* and non-*versicolor* (Faust 2017). *Photuris bethaniensis* is a member of the large *P. versicolor* species complex, so named due to the variable colors of its members (Faust 2017). While the Bethany Beach firefly can be reliably identified using morphological and behavioral traits, genetic and cladistics research to help clarify taxonomic relationships within this species complex are ongoing (Faust 2017).

Conservation Status:

Global Status: G1 – Critically Imperiled (last reviewed 21 December 2021)

National Status (United States): NNR – Not ranked

State Statuses: S1 – Critically Imperiled (DE, MD, VA)

(NatureServe 2023)

Federal Status (United States): Under Review (U.S. Fish and Wildlife Service 2023a)

State Status (United States): Endangered (DE) (Delaware Division of Fish and Wildlife 2023)

IUCN Red List: Critically Endangered (Heckscher et al. 2021b)

Species of Greatest Conservation Need (Tier 1): Delaware (Delaware Division of Fish and Wildlife 2015)

Technical Description:

Adult:

The Bethany Beach firefly is a member of the *Photuris versicolor* complex, which contains many closely related species best distinguished by observed flash pattern, as there are few morphological differences to tell them apart (Faust & Davis 2019). Most species within this group exhibit the following characteristics: humpback posture; long legs; red, yellow, and black pronota; and pronotal markings in the shape of an arrow, T, or anchor (Faust 2017). The elytra are often striped. Dissection of adult male genitalia, which can often help with species-level identification in morphologically similar firefly species, does not yield enough differentiation in this group to confidently assign identifications.

While these characteristics can make identification of *Photuris versicolor* species difficult, there are several key features that, combined with habitat association and flash pattern details, can help with identification to the species level for the Bethany Beach firefly. *Photuris bethaniensis* is relatively small for the genus, with adults typically 9-10.75 mm in length and 3.5-4 mm wide (McDermott 1953; Faust 2017; Lloyd 2018). Although this species is very similar in appearance to sympatric *Photuris*, such as *P. salina* and *P. hebes*, the central dark marking on *P. bethaniensis*' pronotum is widened apically (Figures 1 and 2). In contrast, the typical pronotal marking in *P. salina* is an hourglass shape and the pronotal marking in *P. hebes* is often narrow and divided into anterior and posterior sections (Figure 2). While *P. hebes* and *P. salina* generally have pale-colored hind coxae, the hind coxae of *P. bethaniensis* have a darker brown coloration (Figures 3a and b). Furthermore, the labrum of *P. bethaniensis* is dark brown and tridentate (having three teeth) (Figure 4).

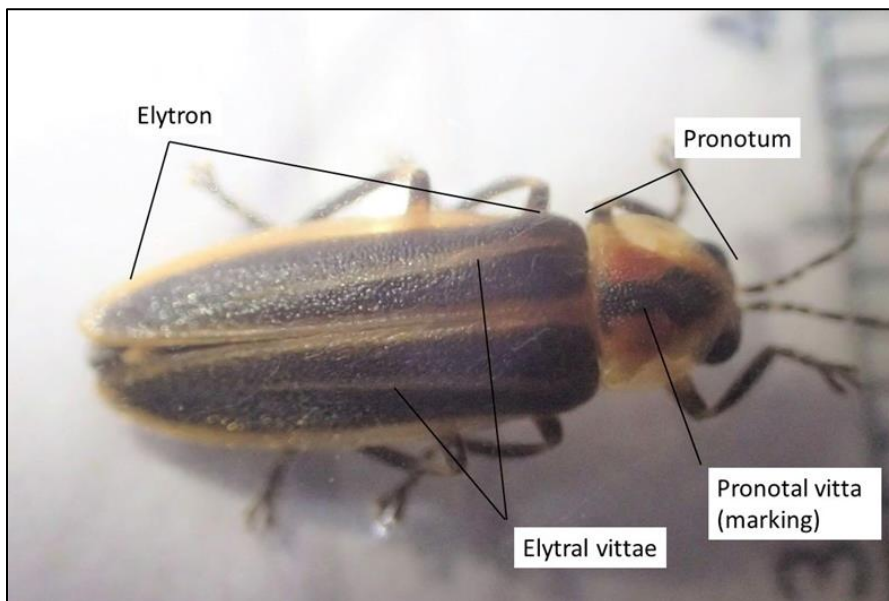


Figure 1. Dorsal view of a female *Photuris bethaniensis* captured at Delaware Seashore State Park, Sussex County, DE, on 6 July 2022. The elytral vittae (yellow diagonal stripes) extend down about three quarters of the elytral length. The dark pronotal marking is widened apically and narrowed basally. (Richard Joyce/Xerces Society)



Figure 2. Comparison of pronotal markings on specimens of *Photuris bethaniensis* (left), *Photuris salina* (middle), and *Photuris hebes* (right). (Richard Joyce/Xerces Society).

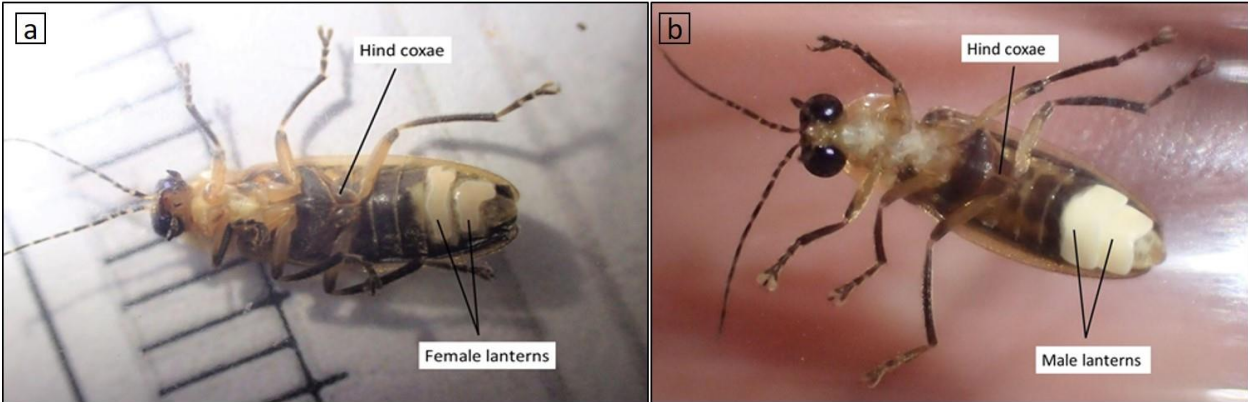


Figure 3. (a) Ventral view of a female *Photuris bethaniensis* with a misshapen lantern on the 6th segment, captured at Delaware Seashore State Park, Sussex County, Delaware, on 6 July 2022. Note the dark brown color of the hind coxae (most basal leg segments). (b) Ventral view of a male *Photuris bethaniensis* captured at Delaware Seashore State Park, Sussex County, Delaware, on 6 July 2022. Note long legs, dark hind coxae, and pale patch on segment 5. (Richard Joyce/Xerces Society)



Figure 4. Close-up of the head of a female *Photuris bethaniensis* captured at Delaware Seashore State Park on 6 July 2022. The frons ("forehead") is yellow and the labrum is dark brown with three teeth. (Richard Joyce/Xerces Society)

Immature

The immature life stages of the Bethany Beach firefly have not been described. However, in general, *Photuris* larvae can be recognized by their flattened, oval body shape (Figure 5), and are usually detected by the glow that they emit while foraging on the soil or leaf litter surface at night. All known firefly larvae are bioluminescent (Lloyd 2018), an adaptation thought to warn potential predators that they are distasteful (Lewis 2016). The same is likely true of Bethany Beach firefly larvae.



Figure 5. A larval *Photuris* feeds on a snail in Tennessee. (Photo by [Will Kuhn CC BY 4.0](#))

Life History:

Flash behavior and phenology

Flash pattern and activity period can also be used as a distinguishing feature from other fireflies in the area. Adults of the Bethany Beach firefly are active well after sunset in full darkness from late June to July (Heckscher 1998; Faust 2017). Males of this species emit a bright, greenish, double flash to prospective mates about every five seconds (McDermott 1953 p. 19; Faust 2017; Figures 6 and 7). Recent analysis of flash pattern videos taken with stereo GoPro cameras has validated this description and provided more detail (Martin et al. 2023). For example, the inter-flash gap was found to be 0.13 ± 0.11 seconds (Martin et al. 2023). Note that other *Photuris* that co-occur with *P. bethaniensis* (e.g. *P. hebes* and *P. salina*) could occasionally give two successive single flashes that might be perceived as a double flash. Thus, before making a final species determination, individuals should be observed for enough time (3-5 sets of double flashes) to ensure that they are consistently giving a repeated double flash characteristic of the Bethany Beach firefly.

The female flash pattern has not been well recorded, but Lloyd (2018) reports seeing a single female responding to the flash of a perched male with a short flash of her own at 1-1.5-sec delay. Female flash patterns can be difficult to ascertain due to the aggressive mimicry utilized by some female *Photuris*. This behavior, in which adult females mimic the female flash patterns of other firefly species, attracts males which are then eaten by the females. In doing this, female *Photuris* fireflies sequester protective toxins, called lucibufagins, which are produced by other firefly species and can be passed on to their offspring (Faust 2017).



Figure 6. The greenish, double flash pattern of *Photuris bethaniensis* captured in a 25-second exposure (Linda Rosenbluth).

	0	1	2	3	4	5	6	Seconds
♂	[Green bar]		[Green bar]				[Green bar]	→ Long double-flash over two seconds, repeated at five second intervals
♀	[Diagonal lines]		[Diagonal lines]		[Diagonal lines]	[Diagonal lines]	[Diagonal lines]	→ Female response unknown*

* Due to the aggressive mimicry utilized by some “femme fatale” firefly species—some of which have been documented using multiple flash-pattern responses—it has been difficult to determine which flash-patterns are used to attract mates or, alternately, to lure in unsuspecting prey males from other firefly species.

Figure 7. Flash pattern of *Photuris bethaniensis* (from Fallon et al. 2022).

Dispersal capacity

Fireflies are weak fliers and rarely disperse beyond the habitat in which they were born (Lewis 2016), although some species, such as *Photinus signaticollis*, are capable of dispersing across large distances (Koken et al. 2022). Although *Photuris* fireflies in general may have greater dispersal capacity than other firefly genera due to their larger size, the smaller Bethany Beach firefly has primarily been found within the perimeter of its required swale habitat, with only single individuals observed over dry dunes on a few occasions, potentially indicating that individual Bethany Beach fireflies rarely disperse beyond these swales (Heckscher 1998).

Life cycle

Photuris bethaniensis seems to be associated with shallow water swales that are temporally stable; these swales are filled with ample organic matter, which provides ideal habitat for larval fireflies (Heckscher & Bartlett 2004; Figure 9). Most of the firefly life cycle is spent in the larval stage—up to two years—whereas adults typically live for just two to four weeks (Faust 2017). After mating, females lay their eggs in moist soil, duff, leaf litter, or rotting wood. Eggs, which may glow dimly, are deposited singly or in batches over the course of several days to weeks (Lloyd 2018). Two to three weeks later, these eggs hatch into larvae that live in leaf litter, underground, or in rotting wood. In northern latitudes, such as the Mid-Atlantic, larvae become inactive underground during the winter months. Although larvae are rarely seen, the intermittent glows of foraging *Photuris* can sometimes be seen on dark nights in fall and spring. When fully grown, most firefly larvae pupate in chambers just under the soil surface or under rotting logs. Depending on the temperature and species, pupation can last one to three weeks (Lloyd 2018), with firefly adults typically emerging in late spring or early summer.

Diet

It is unknown what Bethany Beach firefly larvae eat, but other larvae in the genus are known to be dietary generalists, consuming snails, worms, other soft-bodied invertebrates, and even plant material, such as berries (Buschman 1984).

Range, Distribution, and Abundance:

Type locality: Bethany Beach, Del. (McDermott 1953)

Range: The Bethany Beach firefly occurs on barrier islands along the Atlantic coasts of Delaware, Maryland, and Virginia.

Distribution: The Bethany Beach firefly was first collected in 1949 and 1951, formally described in 1953, and collected again in 1968 (McDermott 1953; Lloyd 2018). It was not reported again until 1998, when targeted surveys for the species led to its detection within seven interdunal swales (shallow wetlands that occur between coastal sand dunes—the firefly’s only known habitat association; see Figure 9) along Delaware’s coast (Heckscher 1998). The firefly was thought to be confined to these seven sites along a

32 km (~20 mi) stretch of the Atlantic Coastline through 2019, when Xerces and conservation partners filed a petition to list this firefly under the US Endangered Species Act (ESA). In the following years, the Delaware Department of Natural Resources and Environmental Control (DNREC) and the US Fish and Wildlife Service (USFWS) expanded survey efforts to include surveys of nearly 60 historic and potential sites (Table 1). Efforts by other agencies in Maryland and Virginia have led to additional observations, so that this firefly is now documented from 35 swales along a non-contiguous 274 km (~170 mi) stretch of the Atlantic coastline in Delaware, Maryland, and Virginia (Table 1; Figure 8).

Table 1. Known locations of Bethany Beach firefly (BBFF) populations in the Mid-Atlantic (courtesy of USFWS).

State	County	Site name (land manager)	# swales BBFF present	# swales surveyed
DE	Sussex	Cape Henlopen State Park (Delaware Dept of Natural Resources & Environmental Control)	1	10
DE	Sussex	Delaware Seashore State Park (Delaware Dept of Natural Resources & Environmental Control)	13	33
DE	Sussex	Private land N. of Bethany Beach (private)	0	2
DE	Sussex	Fenwick Island State Park (Delaware Dept of Natural Resources & Environmental Control)	3	13
MD	Worcester	Assateague Island National Seashore (National Park Service)	8	13
VA	Accomack	Chincoteague National Wildlife Refuge (US Fish and Wildlife Service)	5	8
VA	Accomack	NASA Wallops Island Flight Facility (NASA)	1	10
VA	Virginia Beach	False Cape State Park (Virginia Dept of Conservation & Recreation)	4	6

Delaware

Although the species appears to be extirpated from several formerly occupied sites, including the 1968 site that Lloyd (2018) reported, Delaware remains the state with the largest number of occupied sites for the Bethany Beach firefly. During surveys conducted between 1998 and 2000, Heckscher and Bartlett (2004) identified seven interdunal swales, ranging in size from 500 m² to about 5,000 m², occupied by *P. bethaniensis*. Six of these occurrences were within three state parks: Cape Henlopen, Delaware Seashore, and Fenwick Island. The remaining site, known as the Tower Shores Development, was on private land (Heckscher & Bartlett 2004). This private site has undergone substantial development in recent years, and the population there—which was once the largest known for the species—is now suspected to be extirpated. Survey efforts increased dramatically from 2019 to 2023, when DNREC biologists, along with several fellows from the U.S. Fish and Wildlife Service, surveyed 58 swales along

the coast of Delaware, including the Tower Shores development (Table 1). Bethany Beach fireflies were located at 17 swales, only three of which had previously been documented in the 1998-2000 surveys by Heckscher and Bartlett (2004). No fireflies were found at the Tower Shores development. All 17 currently occupied swales remain in the three aforementioned state parks.

The three Delaware state parks where this species occurs are at least 11 km apart from one another. While *Photuris* species are strong fliers relative to other firefly genera, it is unlikely they are capable of dispersing distances greater than 10 km. Furthermore, because the Bethany Beach firefly is so rarely seen outside of its interdunal wetland habitat boundaries, Heckscher (2021b) suggests it may be an ineffective long-distance disperser. Whereas the site at Tower Shores once acted as an important bridge between occurrences at Delaware Seashore State Park and Fenwick Island State Park (being 4 km from the former and 8 km from the latter), the destruction of this site has now made dispersal between these sites unlikely.

Maryland

In 2020, surveys were conducted for the Bethany Beach firefly on Assateague Island National Seashore, Maryland, leading to the first record of this species outside of Delaware. Additional surveys in 2022 and 2023 have resulted in eight occupied swales reported for the state, all on Assateague Island National Seashore, a protected area on Assateague Island (a barrier island) managed by the National Park Service (Table 1).

Virginia

The Bethany Beach firefly has also been reported from ten swales on three sites in Virginia: Chincoteague National Wildlife Refuge, NASA Wallops Island Flight Facility, and False Cape State Park (Table 1). These newly documented populations expand the species' known range to the south by approximately 142 non-contiguous km (88 mi) (Figure 8).

Documented:

The Bethany Beach firefly has been documented from the following public lands:

- Delaware: Cape Henlopen State Park, Fenwick Island State Park, Delaware Seashore State Park
- Maryland: Assateague Island National Seashore
- Virginia: Chincoteague National Wildlife Refuge, False Cape State Park

Suspected:

This firefly is suspected from interdunal swale habitats on additional barrier islands off the coast of New Jersey and New York:

- New Jersey: North Brigantine State Natural Area, Forsythe National Wildlife Refuge (Holgate Beach Wilderness and Little Beach Island)

- New York: Hither Hills State Park (Napeague Dunes), Sound View Dunes Park, Peconic Dunes Park, Goldsmith's Inlet Park, Soundview Avenue Preserve, Fire Island National Seashore, Amagansett National Wildlife Refuge



Figure 8. Bethany Beach firefly distribution in the Mid-Atlantic. Each orange dot represents the approximate midpoint of occupied sites (e.g., state parks or wildlife refuges) listed in Table 1 and is not representative of individual occupied swales.

Abundance: While detailed estimates of abundance are not yet available for this species, surveyors looking for this species in Delaware in the 1990s noted that “the abundance of *P. bethaniensis* at individual sites ranged from ‘extremely abundant’ to none at all” (Heckscher 1998). The firefly is currently found in very low abundance at all remaining known sites (Heckscher et al. 2021a). Recent surveys (in the last five years) at several sites have resulted in observations of approximately 1-50 individuals (Fallon pers. obs. 2022; Davis pers. comm. 2023).

Habitat Associations:

Photuris bethaniensis is a habitat specialist, restricted to interdunal freshwater swales (Heckscher & Bartlett 2004). Interdunal swales are a rare ecosystem type that forms as freshwater from groundwater and rain collects in the shallow depressions between coastal sand dunes. As they are geographically bordered by saline tidal wetland systems, they are very susceptible to rapid degradation by saltwater intrusion (Cornelisse et al. 2019). Swales are characteristically covered in dense vegetation including species such as bayberry (*Myrica cerifera*) and Eastern baccharis (*Baccharis halimifolia*) (Heckscher & Bartlett 2004).

Several types of interdunal wetland communities have been described from Delaware, based on dominant vegetation. During targeted surveys for the Bethany Beach firefly in the 1990s, surveyors only found the species in *Juncus scirpoides*-*Scirpus pungens* interdunal swales with *Myrica*-*Baccharis* shrub thickets, although it is unclear whether other community types were surveyed (Heckscher 1998; Heckscher & Bartlett 2004). Furthermore, not all swales of these types were occupied, suggesting that other factors, such as salinity, temporal stability, and water table depth influence their occurrence (Heckscher 1998). Swales occupied by *P. bethaniensis* ranged in size from 500 m² to 5,000 m² and all were found within 500 m of the Atlantic Ocean (Heckscher & Bartlett 2004). The firefly was found primarily within the swales themselves and rarely outside of the swales in surrounding dunes or shrub thickets (Heckscher & Bartlett 2004). These habitat associations have remained consistent during more recent surveys throughout the state, and occupied sites in Maryland have all similarly been interdunal swales with *Juncus*, *Scirpus*, *Myrica*, and *Baccharis* vegetation components.



Figure 9. Bethany Beach firefly interdunal swale habitat on Assateague Island National Seashore, MD (Candace Fallon/Xerces Society).

Threats:

The most significant threats to this species include habitat loss and fragmentation due to coastal development, sea level rise and storm surges, invasive plants, light pollution, and the loss or contamination of groundwater aquifers. There has been a continuing decline in the area, extent, and quality of the Bethany Beach firefly's habitat; projected continuing decline in number of occupied locations as sea level rises; and an inferred decline in the number of mature individuals, due to the recent loss of a large site to development. Other threats include recreational activities, increased frequency of severe storms that lead to saltwater intrusion, succession of woody and herbaceous open swales to late-successional woody-dominated shrublands, and aerial application of insecticides for mosquito control. Several sites, including the largest known site at Tower Shores, Delaware, have been extirpated due to residential development.

Coastal development

Human populations and coastal development along the Atlantic coasts of Delaware, Maryland, and Virginia have increased substantially since the 1950s (World Population Review 2023), putting pressure on fragile coastal ecosystems. Several cities in proximity to occupied Bethany Beach firefly sites in Delaware, including Rehoboth Beach, Bethany Beach, and Fenwick Island, have experienced rapid growth over that time period (Carey et al. 2004). Most of the land along the Atlantic Coast in Delaware has been developed, with the exception of three state parks, where all remaining Delaware Bethany Beach fireflies reside. Documented sites in Maryland and Virginia are similarly within protected areas such as state and national parks and wildlife refuges.

Development has myriad effects on firefly populations, ranging from complete destruction of habitat to more indirect impacts from threats such as artificial light at night or increased pesticide use. For example, the largest documented Bethany Beach firefly population in Delaware is now thought to be extirpated due to construction of a housing development known as the Tower Shores Beach Community (Cornelisse et al. 2019; Figure 10). This site has become inhabitable for fireflies presumably due to destruction of habitat, disturbance of eggs and larvae and their invertebrate prey in the soil, and increased light and chemical pollution, such as pesticide use. No fireflies were observed at this site in 2019 (Heckscher et al. 2021b).



Figure 10. Construction of the Tower Shores housing development led to the destruction and loss of the largest known Bethany Beach firefly population in Delaware. (Photo on left by Emily May; image on right from Google Maps 2023)

Development also increases demand for freshwater from aquifers, which lowers the water table and can make interdunal swales—which fluctuate seasonally and annually as a reflection of changes in groundwater levels (New York Natural Heritage Program 2023)—more vulnerable to drying out. Increased water use for residential irrigation of lawns and golf courses also creates pesticide and fertilizer runoff, which damages wetland ecosystems. In addition, the state and national parks along the coasts of Delaware, Maryland, and Virginia are large tourist attractions and are not managed to protect fireflies. Visitation to some of these sites is quite high. For example, visitation to Delaware’s seventeen state parks and Brandywine Zoo has grown dramatically in recent years, from 6.1 million visitors in 2017 to 7.9 million in 2021 (a 30% increase), and is up 78% over the last decade (Delaware Department of Natural Resources and Environmental Control 2022). In 2022, visitation surpassed 8 million, with Cape Henlopen State Park (where the Bethany Beach firefly occurs) being the most highly visited park, seeing 1.9 million visitors in that one year alone (Delaware Department of Natural Resources and Environmental Control 2023). Ground dwelling larvae and adult females are susceptible to trampling by visitors (Lewis et al. 2020). In addition, in recent years, several swales have been lost due to sand migration, construction, and park maintenance activities (Heckscher et al. 2021b).

Light pollution

Many firefly species are dependent on bioluminescent courtship patterns to locate mates and do not use other visual or chemical cues (Lloyd 1966; Stanger-Hall & Lloyd 2015; Owens & Lewis 2022). Flashing fireflies are thus sensitive to light and use ambient darkness as a cue to time their flashing behavior (Lewis 2016), making light pollution from urbanization and infrastructure a serious threat to species like the Bethany Beach firefly that display at night rather than at dusk

Increased light pollution has been shown to adversely impact mating success of nocturnal firefly species like the Bethany Beach firefly, which require dark conditions for courtship displays (Owens & Lewis 2018; Lewis et al. 2020). High levels of light pollution in developed areas, such as along Route 1 on Delaware’s Delmarva Peninsula, fragment and encroach upon the firefly’s habitat and may be affecting

firefly courtship behavior, with potentially negative repercussions for their reproductive success. For example, staff with the Delaware Department of Natural Resources and Environmental Control observed that Bethany Beach firefly activity had diminished at a swale that was previously documented to be occupied by the species. The swale at this site, which is located along Route 1, was lit by a bright streetlamp. After work within the power company turn the light off temporarily, firefly activity resumed (Heckscher et al. 2021b).

Sea level rise and storm surges

The rate of sea level rise on the Atlantic seaboard is three or four times higher than the global average, leaving vast portions of the coast vulnerable to higher storm surges, increased incidence of flooding, and deterioration of beaches and wetland habitats (Sallenger et al. 2012). It is projected that Delaware's sea level will rise by between 0.5 and 1.5 meters by 2100 (Delaware Coastal Programs 2012); this is particularly troubling given that most if not all known occurrences of the Bethany Beach firefly are less than 0.5 meters above sea level (Heckscher 2014), and coastal development in some areas may limit or eliminate any possibility for fireflies and their habitats to migrate to higher ground. Furthermore, freshwater interdunal swales are especially susceptible to saltwater intrusion, which can temporarily disrupt the progression of plant communities from herbaceous-dominated to woody shrub-dominated (Heckscher & Bartlett 2004). *P. bethaniensis* is associated with stable swales that have a high number of woody shrubs, as stable swales are filled with ample organic matter which is necessary to form ideal habitat for larval fireflies (Heckscher & Bartlett 2004).

Invasive plants

Non-native invasive plant species are a growing threat to biodiversity worldwide. They not only compete for limited natural resources such as water, soil, light, and space, but they can also displace native species and rapidly change diverse natural plant communities into monotypic stands that have little ecological value. One of the most serious invaders in freshwater wetland habitats in the Mid-Atlantic region is the European common reed, *Phragmites australis*. Common reed is a vigorously growing plant that forms dense stands that outcompete native plants, alter wetland hydrology, and degrade wildlife habitat. The spread of this species is problematic across many coastal tidal marshes in the Mid-Atlantic region and tidal wetlands invaded by common reed typically have reduced biodiversity, altered ecosystem structure, and reduced overall biomass (Chambers et al. 1999). It appears that at least one, if not several of the Bethany Beach firefly sites documented in 1998, have been lost or severely altered due to *Phragmites* invasion (Heckscher et al. 2021b). Common reed has been cited by land managers as a major issue in many of the swales where the Bethany Beach firefly has been documented, from Delaware to Virginia. In Sussex County, Delaware, alone, common reed occupies over 1,000 acres (Delaware Division of Fish and Wildlife 2015), threatening the ecological integrity and community viability of the habitats in which it is found.

Pesticide use

Pesticides are identified as a serious threat to fireflies in North America, second only to habitat loss and fragmentation, according to a survey of firefly experts (Lewis et al. 2020). Drift, runoff, or groundwater movement of pesticides from adjacent agricultural and urban landscapes are the most likely ways in which contaminants enter Bethany Beach firefly habitat. Fireflies may absorb pesticide through direct contact with airborne pesticides, or through contact with contaminated surfaces, sediments, surface water, and/or groundwater. Larvae, which spend approximately two years in the soil, may experience chronic contact and oral exposure to soils that contain pesticides, especially those pesticides that are persistent in soil such as neonicotinoids. Consumption of contaminated prey and contact with contaminated vegetation are other potential routes of exposure.

Of all pesticides, insecticides are the type most likely to harm fireflies as many are “broad-spectrum” (i.e. toxic to a wide variety of insects) and some are designed to target pests within the beetle order Coleoptera. Pesticide uses in terrestrial sites (such as agricultural and urban areas) could pose a significant threat to the Bethany Beach firefly because these pesticides are regularly transported via runoff into groundwater. These polluted waters likely result in chronic exposure to Bethany Beach fireflies and their prey.

Mosquito control is another chronic source of pesticide exposure that poses a serious risk to fireflies. Mosquito control methods in the region can include helicopters, planes, and ground-based truck foggers that spread insecticides targeted at either larval or adult mosquitoes, depending upon the season. These pesticides can make their way into Bethany Beach firefly habitats, threatening the species with increased mortality and harmful sub-lethal effects, as well as harmful effects on prey species such as worms and snails. Pyrethroids are generally the insecticide of choice when doing ground-level spraying for adult mosquito control. Because these insecticides effectively kill other species of beetles (Babendreier et al. 2015; Peterson et al. 2016), it is likely they kill fireflies as well.

Conservation Recommendations:

Photuris bethaniensis is listed as a State of Delaware Endangered Species, which protects the species from transport, possession, or sale; however, there is no population or habitat-level protection for state-listed species (Delaware Division of Fish and Wildlife 2015). It is not listed in Maryland or Virginia, where it has only recently been documented on federal and state lands. This species is the only North American firefly to be categorized as Critically Endangered on the IUCN Red List of Threatened Species (Heckscher et al. 2021b). In order to protect this firefly and its habitat from continued development and other threats, Xerces and conservation partners submitted a petition in May 2019 to list the Bethany Beach firefly under the federal ESA and concurrently designate critical habitat (Cornelisse et al. 2019). A positive 90-day finding was announced in December 2019 (U.S. Fish and Wildlife Service 2019), and a full status review has been initiated to assess this species. A listing decision is expected in 2024 (U.S. Fish and Wildlife Service 2023b).

Research

Despite recent work to assess the Bethany Beach firefly's conservation status and compile a comprehensive database of known occurrence records, our understanding of this species' distribution, abundance, and population trends is poorly understood or completely unknown, which hinders our ability to effectively conserve the species. Basic details regarding this firefly's life history, microhabitat requirements, and vulnerability to various threats are also largely unknown, further complicating efforts. Work by Heckscher and Bartlett (Heckscher 1998; Heckscher & Bartlett 2004) focused on increased survey efforts to inform the species' distribution in the Mid-Atlantic and better understand its habitat associations, and recent work by the Delaware Department of Natural Resources and Environmental Control and others has further illuminated the range of the species. However, there remain a number of data gaps that must be addressed to better inform conservation efforts for the Bethany Beach firefly. Key research topics include:

Natural history

- What is the larval diet? Are they generalists or specialists?
- What microhabitat features are important to adults? To the larvae?
- What microhabitat associations and factors affect the persistence of *P. bethaniensis* populations within interdunal swales?
- Are certain seral stages of the swales more likely than others to support *P. bethaniensis* populations?

Species range and distribution

- What is the full extent of this species' range?
- Does this species occur in New York or New Jersey?
- Does the species occur any further south?
- What can species distribution modeling tell us about focusing future survey efforts?
- Can we use occupancy modeling to determine the survey- and site-level variables that influence the detection and presence of fireflies at known sites?
- What is the dispersal capacity of this species?

Population size, trends, and abundance

- What are the global and local population sizes and trends for this species?
- What monitoring protocols and/or programs do we need to develop to answer this question?
- What is the most reliable index of abundance for this species?
- What is the geographic pattern of genetic differentiation?

Threats

- To what extent do known threats impact the species?
- Can we model the impacts of sea level rise, storm surges, and other climate change impacts on their populations? What about the impacts of increasing coastal development and light pollution?

Conservation impacts

- How do different management activities impact firefly populations?
- How can we use this information to guide conservation and restoration activities?

Inventory and monitoring

In addition to addressing data gaps, continued surveys of stable, well established interdunal freshwater swales are needed throughout the Atlantic Coast to determine the full extent of this species' range (Heckscher & Bartlett 2004). Targeted surveys for the Bethany Beach firefly have increased since the 2019 ESA petition was filed, resulting in 28 newly documented sites and the first records outside of Delaware. The species is suspected to occur in interdunal swales along the coast of New Jersey and New York's Long Island (Lloyd 2018), which should be targets for additional surveys. A species distribution model might narrow survey areas in New York (where interdunal habitat is rare) and other parts of the species' known or suspected range. As core sites for this species are discovered, land managers could also work to establish long-term monitoring programs to better understand population size, dynamics, and trends. This is especially important for understanding the status of a critically endangered species like the Bethany Beach firefly (Martin et al. 2023).

Management actions

The Bethany Beach firefly is now known to occur in 35 swales across 8 different state and national parks and wildlife refuges. Although these are all considered Protected Areas, the passive protection afforded by such designations are inadequate to protect the Bethany Beach firefly from extinction. Therefore, targeted protection and restoration of the habitats where they are known to occur is crucial. Land managers can play a key role in ensuring that known and potential Bethany Beach firefly habitat is not disturbed by recreation, development, harmful pesticide applications, light pollution, or other management activities. Key actions that could help this firefly include:

- establishing and maintaining natural buffers around interdunal wetlands to reduce stormwater, pollution, and nutrient run-off and protect groundwater resources,
- rerouting roads and trails around sensitive habitat areas,
- installing boardwalks or bridges if passage through the site is required,
- removing or modifying artificial light sources such as streetlights that may be negatively impacting populations (e.g., using motion sensors on existing lights, or replacing bright LEDs with dim red bulbs that don't interfere with firefly flash communication),
- protecting occupied sites from excessive or unnecessary pesticide application,

- removing invasive plants such as the common reed *Phragmites australis*, which may alter interdunal swale plant communities and make them uninhabitable for fireflies,
- monitoring freshwater aquifers, which can be depleted due to residential and commercial development projects adjacent to protected areas where this species occurs,
- restoring natural hydrology by removing impoundments and ditches,
- fencing off sensitive swale habitat that might be impacted by feral horses or recreationists,
- managing vegetation and tree encroachment to offset succession in older swales that could become too forested for the Bethany Beach firefly
- setting up long term monitoring programs at a subset of occupied sites to gather baseline population data to better understand population trends and conservation status of this species over time, as well as insights into the impacts that various management activities have on firefly health and abundance.

Survey Protocol:

Where:

- Maritime freshwater interdunal swales along the Mid-Atlantic coast of the US

When:

- Surveys should begin 30-40 minutes after sunset in June and July
- Minimum air temperature for activity is not known, but 65° Fahrenheit (18° Celsius) is likely a good threshold
- Beaufort wind scale should be 3 or lower (8-12 mph) if adults are being targeted
- Moon phase should ideally be last quarter, waning crescent, new moon, or waxing crescent

How:

- Review survey protocols and print data sheets from the Firefly Atlas (www.fireflyatlas.org)
- If needed, secure the appropriate permits and/or site access permissions prior to conducting surveys
- Walk slowly along the edges of interdunal swales looking for bright green double flashes; minimize disturbance to fragile swale habitat by not walking through the swales if possible
- Diagnostic morphologic features to look for in the adults include a relatively small size (9-10 mm long), an apically widened central dark marking on the pronotum, darker brown hind coxae, and a dark brown tridentate labrum.
- Consider recording observations using a voice memo app on a cell phone or a voice recorder, using the data sheet as a guide
- If permitted, net several individuals and take high quality dorsal and ventral photos, including a scale to show the length of the firefly. Photos will enable validation of species identification by a Firefly Atlas administrator or relevant species expert.

- Use artificial light sparingly to maintain night vision and avoid disturbing fireflies; a dim red headlamp or a flashlight wrapped in red cellophane can be used as needed to navigate the site
- Submit survey data and photographs to the Firefly Atlas (regardless of whether fireflies were observed)

Additional Resources:

Species-specific

- Petition for the Emergency Listing of the Bethany Beach firefly under the US Endangered Species Act: <https://www.xerces.org/publications/policyposition-statements/petition-for-emergency-listing-of-bethany-beach-firefly>

Firefly conservation

- Conserving the Jewels of the Night: Firefly-Friendly Lighting Practices : <https://xerces.org/publications/fact-sheets/firefly-friendly-lighting>
- Conserving the Jewels of the Night: Guidelines for Protecting Fireflies in the United States and Canada: <https://xerces.org/publications/guidelines/conserving-jewels-of-night>
- State of the Fireflies of the United States and Canada: Distributions, Threats, and Conservation Recommendations: <https://xerces.org/publications/scientific-reports/state-of-fireflies-of-united-states-and-canada>

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