BEFORE THE SECRETARY OF THE INTERIOR

PETITION FOR EMERGENCY LISTING OF THE BETHANY BEACH FIREFLY (*Photuris bethaniensis*) UNDER THE ENDANGERED SPECIES ACT AND TO CONCURRENTLY DESIGNATE CRITICAL HABITAT

Photo by: Christopher M. Heckscher, Delaware State University

NOTICE OF PETITION

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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 Center for Biological Diversity and the Xerces Society for Invertebrate Conservation hereby petition the Secretary of the Interior, through the United States Fish and Wildlife Service ("FWS," "Service"), to protect the Bethany Beach firefly (*Photuris bethaniensis*) on an emergency basis under the ESA. Petitioners believe that emergency listing is warranted, but should FWS fail to provide emergency protections then we urge that the petition still be considered and that a listing proposal be enacted no later than one year from the date of the petition. Based on imminent destruction of a significant portion of its range and degradation in the remaining portion, the Bethany Beach firefly is at immediate risk of extinction.

FWS has jurisdiction over this petition. This petition sets in motion a specific process, placing definite response requirements on the Service. Specifically, the Service must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. § 1533(b)(3)(A). FWS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition."

Petitioner also requests that critical habitat be designated for the Bethany Beach firefly concurrently with the species being listed, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12.

The Center for Biological Diversity ("Center") is a nonprofit, public interest environmental organization dedicated to the protection of imperiled species as well as the habitat and climate they need to survive through science, policy, law, and creative media. The Center is supported by more than 1.6 million members and online activists throughout the country. The Center works to secure a future for all species, great or small, hovering on the brink of extinction.

The Xerces Society for Invertebrate Conservation ("Xerces") is an international nonprofit organization that protects the natural world through the conservation of invertebrates and their habitats. Xerces works to raise awareness about the plight of invertebrates and to gain protection for the most vulnerable species before they decline to a level at which recovery is impossible.

The Center and Xerces submit this petition behalf of our staff and our members who hold an interest in protecting the Bethany beach firefly and its habitat.

Submitted this 15th day of May, 2019

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Executive Summary

Photuris bethaniensis, or the Bethany Beach firefly, is an extremely rare and declining beetle that was described in 1953. The current known range of the Bethany Beach firefly encompasses just in seven interdunal freshwater swales in Sussex County, Delaware within three state parks and one private development. Historically, it was found in freshwater swales along the Atlantic coast of Delaware. Interdunal freshwater wetlands are rare ecosystems that, due to their unique formation criteria, are negatively impacted by human activity and require protections and management to remain healthy. The Bethany Beach firefly is an indicator of wetland function, particularly the availability and quality of freshwater in wetland swales; these ecosystems are of immense importance to a myriad of species, including humans.

The Bethany Beach firefly is a nocturnal firefly that is active after full darkness and is characterized by two bright green flashes given off by males in search of females. As a member of the *Photuris* genus, Bethany Beach firefly females will not only flash back to conspecific males for mating, but also lure in males of other species for consumption. By eating other fireflies, female *Photuris* spp. are able to obtain important protective toxins called lucibufagins that they can then pass on to their offspring. While the adult fireflies only live for a few weeks, Bethany Beach firefly larvae can live up to two years in the soil, hunting soft-bodied invertebrates like worms and slugs. The lucibufagin toxins protect them from predators but, unfortunately, cannot protect them from anthropogenic threats.

The Bethany Beach firefly is greatly imperiled by urbanization, habitat fragmentation, light pollution, climate change, pesticides, small population sizes, recreation, invasive plants, and lack of protective regulatory mechanisms, among other factors. While most of the remaining populations of the firefly are in state parks, these areas are not managed to protect the beetle and activities that threaten its populations are ongoing. The Bethany Beach firefly also faces new and looming threats, including sea level rise and increased incidence of severe storms that destroy its freshwater swale habitat and the mosquito control pesticide spray that follows; both threats are exacerbated by ongoing and future climate change. These threats and their synergies have caused the Bethany Beach firefly to decline to only seven small documented populations. Continuation of threats and lack of protections are causing the demise of this unique firefly species.

On top of these ongoing threats, the Bethany Beach firefly is in immediate danger of losing its largest remaining population due to planned construction within a swale at the Breakwater Beach development (also known as Tower Shores) just north of the town of Bethany Beach. Although abundant individuals were previously documented at this development's swale, that site has recently been and currently continues to be destroyed through housing construction that is directly eliminating this population's habitat. According to the top researcher of this species, "this is a perfect example of why this species needs formal protection" (Heckscher 2019c). With continuing construction, the Bethany Beach firefly will be extirpated from this once thriving habitat. Further, it is present in extremely low abundance in two other swales, with the remaining four populations endangered by the threats outlined in this petition. The Bethany Beach firefly requires emergency listing as endangered under the ESA.

Conservation actions needed to prevent the imminent extinction of the Bethany Beach firefly will require managing key threats such as urban development and pesticide use, mitigating climate change impacts through emissions reductions and habitat creation, and controlling invasive plants.

Critical habitat must be designated to provide connectivity between freshwater swales in close proximity, as fireflies do not disperse well, if at all. The Service must act immediately to protect the Bethany Beach firefly to prevent the extinction of Delaware's only endemic species, and one that indicates health of habitats on which humans depend. Without emergency listing of this firefly, we will lose the last great population and watch the others blink out forever. The only hope to save this remarkable firefly from extinction is for the U.S. Fish and Wildlife Service to list it as endangered under the Endangered Species Act and designate critical habitat immediately.

Introduction

Fireflies are some of our most cherished and celebrated insects, with immense cultural, biological, and economic importance. For centuries, they have captured the hearts of children and adults all around the world. Viewing fireflies is a global pastime, which can foster a shared nostalgia and love for fireflies. Yet despite the near-universal appreciation for fireflies, their populations appear to be in decline, prompting both amateur firefly enthusiasts and professional firefly scientists to notice and declare the loss of fireflies around the globe (Lewis 2016 p. 120).

In 2010, while attending the Second International Firefly Symposium in Selangor, Malaysia, firefly experts from 13 countries signed the Selangor Declaration that states "firefly populations are declining across the world, and there is an urgent need for conservation of their habitats" and calls on governments, local authorities, and agencies to "take measures to preserve the habitats of fireflies" (Kirton et al. 2012 p. 1). Causes of firefly decline cited in the Declaration include loss of habitat, pollution of water systems, pesticides, commercial harvesting, and light pollution (Kirton et al. 2012 p. 2). The Declaration also recognizes the important impact fireflies have had not just in science and biomedical research but also in folklore, cultural traditions, ecotourism, and as indicators of environmental health (Kirton et al. 2012 pp. 1–2).

Fireflies--which are actually beetles--are found on every continent except Antarctica. Globally, over 2,000 species of fireflies (Coleoptera: Lampyridae) have been described (Lewis 2016 p. 5). Up to 170 of these species are known from the United States and Canada, classified into four to five subfamilies and 16 genera (Stanger-Hall et al. 2007 pp. 33–34; Lloyd 2018 pp. 66–344). Although bioluminescence (the natural production of light) is often considered a defining feature of fireflies, the common name firefly includes three rather distinct groups of species: the flashing fireflies, the glow-worms, and the daytime dark fireflies. In the United States, the vast majority of flashing species are found only in the humid eastern portion of the country (Faust 2017 p. 21). While only some genera exhibit the characteristic flashing as adults, larvae of all known species do produce light (Stanger-Hall et al. 2007 p. 35). Bioluminescence is used by firefly larvae as aposematic, or defensive, signaling to warn predators that they contain the unpalatable steroid lucibufagins (Martin et al. 2017 p. 564). Bioluminescence is also used in the adult stage of many firefly species in mating communication (Stanger-Hall et al. 2007 p. 35).

The Bethany Beach firefly (*Photuris bethaniensis*) is one of 60 described species of fireflies in its genus (Lloyd 2018 pp. 66–344; Faust & Davis 2019 p. 97), and has the unique characteristic of flying late at night and living in freshwater swales as Delaware's only recognized endemic species (Delaware Division of Fish and Wildlife 2015 chap. 1, p.89). Freshwater interdunal swales-- the habitat required by

the Bethany Beach firefly-- face numerous threats, including development, excessive groundwater pumping, ditching and draining, construction of dune crossings, modification, and establishment of the invasive species *Phragmites australis* (McAvoy & Clancy 1994 pp. 14–16). As detailed in this petition, the Bethany Beach firefly is found only in a few remaining sites and those populations are in imminent danger of extinction due to a myriad of threats, not least of which, habitat loss, currently threatens its largest remaining population. The loss of this species would be a great loss to science and our ability to study fireflies, their evolution, behavior, and adaptations to their environments and to climate change. In addition, this species, like all species, has inherent value and a right to exist that is codified in to U.S. law in the ESA. Without emergency listing of this firefly, we will lose the last great population and watch the others blink out forever, succumbing to extinction via urbanization, recreation, fragmentation, light pollution, climate change, and pesticides. With this, we also lose a unique piece of Delaware's biodiversity, and one that symbolizes the very habitats that have drawn so many people to this state in the first place.

Natural History

Taxonomy

There is no confusion or dispute over the taxonomic validity of *Photuris bethaniensis* McDermott, 1953; it is a member of the order Coleoptera, superfamily Elateroidea, family Lampyridae, subfamily Photurinae, and tribe Photurini (Integrated Taxonomic Information System 2019 pp. 1–2). Until recently, the Bethany Beach firefly was one of 21 described *Photuris* species, one of 17 species in the *Photuris versicolor* species complex, and one of 11 *Photuris* species in Delaware (Heckscher 2013 p. 93, 2014 p. 1; Faust 2017 p. 181); with the 2018 self-publication of Dr. James E. Lloyd's work in *Photuris* taxonomy, the *Photuris* have been further delineated, mostly by flash pattern, resulting in 60 described *Photuris* species, 51 of which are part of the *Photuris versicolor* species complex (Lloyd 2018 pp. 66–344; Faust & Davis 2019 p. 97). The Bethany Beach firefly is distinguished from the locally sympatric *Photuris salina* by its tendency to emit two flashes versus one, the greater brightness of its flash, morphological differences, and its distinct habitat association, as *P. salina* occurs in brackish salt marshes and the Bethany Beach firefly only in freshwater swales (Heckscher 1998 p. 6, 2014 p. 1; Lloyd 2018 p. 94).

Description

The Bethany Beach firefly was first described in 1953 and is a small species for its genus at 9.0-10.75 mm long by 3.5-4.0 mm wide (McDermott 1953 p. 36). Adult Bethany Beach fireflies have a unique black maculation on the pronotum that enlarges towards the apical margin, which differs from other species of *Photuris* (McDermott 1953 pp. 35–36). The elytra of the Bethany Beach firefly has dark brown coloration with distinct white to yellowish oblique bands extending to three-quarters the length of the elytra as well as yellowish bands as lateral elytral borders, creating an alternating brown-yellowish band sequence (McDermott 1953 p. 37). The sternites are generally brown but the 5th is yellow and the 6th and 7th are luminous in the male and female, the latter having a unique species pattern (McDermott 1953 p. 37). The male courtship flash is distinguished by two bright green flashes three-quarters of a

second apart and repeated every five or more seconds (Faust 2017 pp. 231, 252), although some males have been documented to give off only one green flash (Lloyd 2018 p. 93).

Life Cycle and Behavior

Over her lifetime, a female firefly lays an average of 28 eggs that take two to three weeks to hatch, the resulting larvae live one to two years before pupating for one to three weeks; adults live three to four weeks, on average (Bauer et al. 2013 pp. 45–46; Faust 2017 p. 39). *Photuris versicolor* complex females, such as those of the Bethany Beach firefly, typically lay eggs a few at a time over multiple days or weeks (Lloyd 2018 p. 5). Firefly larvae grow through four to seven instars, entering diapause through winter, and often take over two years to develop, depending on the conditions such as food availability, rainfall, and temperature; by delaying pupation and growing larger, larvae will emerge as larger and more fecund adults (Faust 2017 p. 42). *Photuris* larvae are omnivorous and scavengers that hunt soft bodied organisms such as slugs, snails, earthworms, and other insects by injecting paralyzing fluid before consuming their prey (Faust 2017 p. 29; Lloyd 2018 p. 5). Larvae of *Photuris* spp., such as the Bethany Beach firefly have flattened body segments and hunt on the soil surface, sometimes communally (Faust 2017 p. 45). For pupation, larvae of *Photuris* spp. create chambers either just under the soil surface or under logs, often near other *Photuris* pupae (Faust 2017 p. 47; Lloyd 2018 p. 6).

As adults, male Bethany Beach fireflies fly at night and give off a double green flash followed by a short interval to signal to females who are waiting on vegetation; females respond to males by giving off a frequently repeated but dim flash with a 1-1.5 second delay (McDermott 1953 p. 35; Lloyd 2018 p. 94). Male Bethany Beach fireflies fly "well after sunset" and at full darkness, which is later than other *Photuris* fireflies that occur in the same areas; they can be observed three to five feet above the ground and often from vegetation perches (Heckscher & Bartlett 2004 p. 350; Lloyd 2018 p. 94).

While many firefly species produce an anti-predator toxin called lucibufagin, the *Photuris* species complex, of which the Bethany Beach firefly is a part, acquires the toxin through consumption of other fireflies; specifically, after mating herself, female *Photuris* spp. will mimic the female flash pattern of other (often *Photinus*) species to lure in males for consumption (Lewis 2016 pp. 114–115, 159). In this way, female *Photuris* fireflies accumulate defensive chemicals to protect themselves as well as pass on to their eggs for chemical protection (Lewis 2016 pp. 159–160).

Fireflies are weak fliers and rarely disperse beyond the habitat in which they were born (Lewis 2016 p. 121). During surveys, the Bethany Beach firefly was 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 (Heckscher 1998 p. 5).

Habitat

Bethany Beach fireflies are found in interdunal freshwater wetland swales from 500 to 5000 m^2 in size and within 100-500 m (328-1640 ft) of Delaware's Atlantic shoreline (Heckscher & Bartlett 2004 p. 350). Interdunal swales are an uncommon ecosystem type that forms in barrier beach systems in shallow depressions between sand dunes; they can be found scattered through multiple states along the eastern coast of the United States. In Delaware, interdunal swales receive a Category 1 wetland ranking due to their "unique nature as freshwater, non-tidal wetland systems geographically bordered by tidal,

saline wetland systems," and the fact that they have a very narrow and local distribution limited to the Atlantic coastal strand and barrier islands of Sussex County (McAvoy & Clancy 1994 pp. 16–17).

In Delaware, the freshwater wetlands occur intermittently between the ocean and Delaware Route 1 from Cape Henlopen State Park to Fenwick Island State Park (Heckscher 1998 pp. 3–4, 2019b; Heckscher & Bartlett 2004 p. 349). Interdunal swales are relatively young habitat types, being formed 2,000-5,000 years ago, and are characterized by saturated soils that are seasonally inundated with freshwater from aquifers and recharged with rainfall, distinguishing the Bethany Beach firefly's habitat from the brackish swales more commonly found along the east coast (Odum & Harvey 1988 pp. 149–150; Heckscher & Bartlett 2004 pp. 350–351). Due to their coastal nature, however, they are still subject to shifting sand and saltwater intrusion (Heckscher & Bartlett 2004 pp. 349–350).

The Bethany Beach firefly is restricted to freshwater coastal swales, as surveys for the firefly in areas one mile inland were unsuccessful (McDermott 1953 p. 36). Past records showed a habitat association of the Bethany Beach firefly with dense interdunal vegetation, specifically dense bayberry (*Myrica cerifera*) and Eastern baccharis (*Baccharis halimifolia*), indicating a preference for swales that are temporally stable (McDermott 1953 p. 36; Heckscher & Bartlett 2004 pp. 350–351) with relatively shallow water levels (Odum & Harvey 1988 p. 153). The lack of disturbance in temporarily stable interdunal swales allows for buildup of organic matter which provides habitat for larvae of the Bethany Beach firefly (Heckscher & Bartlett 2004 p. 352). During surveys from 1998-2001, the Bethany Beach firefly was found in seven swales: four in which bayberry and baccharis were the dominant vegetation and three in which rushes (*Juncus* spp.) were the dominant vegetation but with bayberry and baccharis present (Heckscher & Bartlett 2004 pp. 351–352) (Figure 1).

Figure 1. Freshwater interdunal swale habitat of the Bethany Beach firefly. Photo by William A. McAvoy, Delaware Division of Fish and Wildlife.

Historic and Current Distribution

The Bethany Beach firefly was first collected at the north end of Bethany Beach town in 1949 and, two years later, two miles south of Bethany Beach (McDermott 1953 p. 35). Additional individuals of Bethany Beach fireflies were collected in 1968 near Bethany Beach and despite surveys in New Jersey and Virginia, the firefly has not been found outside of Delaware (Heckscher & Bartlett 2004 p. 349; Heckscher 2019a). Heckscher and Bartlett (2004 p. 350) surveyed for the Bethany Beach firefly from 1998-2001 to document the beetle's occurrences and preferred habitat characteristics; they visited 18 total swales (from 100 m^2 to 5000 m^2) at Fenwick Island State Park (four swales), Delaware Seashore State Park (five swales), Tower Shores development (one swale), and Cape Henlopen State Park (eight swales). The Bethany Beach firefly was found in seven out of the 18 swales surveyed (Heckscher & Bartlett 2004 p. 350). The original firefly sites in Bethany Beach documented by McDermott in 1949 are now lost (Lloyd 2018 pp. 94, 287).

The seven swales indicated in Heckscher and Bartlett (2004 p. 350) correspond to eight "sites" within swales from the Heckscher (1998 p. 6) report, with the Bethany Beach firefly present in three sites at Fenwick Island State Park (no indication of abundance), three sites at Delaware Seashore State Park (one site with "abundant" individuals and one site with "1 individual"), one site at the Tower Shores development (with "abundant" individuals), and one site at Cape Henlopen State Park (with "1 individual" only). In personal communication with Dr. Christopher Heckscher, he said that if there is any discrepancy between the 1998 report and the 2004 publication that the 2004 publication is more accurate (Heckscher 2019d). As such, as the 2004 publication reports seven swales, we report here that the Bethany Beach firefly is only found in seven swales between the four locations: three swales at Fenwick Island State Park, two swales at Delaware Seashore State Park, one swale at the Tower Shores Community, and one swale in Cape Henlopen State Park (Figure 2).

The Bethany Beach firefly's current known range is a 32 km stretch in Delaware's Sussex County at sites less than 0.5 m (1.6 ft) above sea level within 100-500 m (328-1640 ft) from the Atlantic Ocean shoreline (Heckscher 2014 p. 1). From a recent (1/29/2019) email with Dr. Christopher Heckscher, he confirmed that the Bethany Beach firefly "is only known from a handful of coastal sites... It has not been found in nearby MD, VA or NJ despite some inventory effort" (Heckscher 2019a). In a follow-up email, Dr. Heckscher confirmed that two potential records of "*P. bethaniensis*" outside of Delaware from the California Academy of Sciences, one in Florida and one in Texas, represent a potential sister species (possibly *P. Douglasae*) and a different *Photuris* species, respectively (Lloyd 2018 pp. 93, 147; Heckscher 2019e).

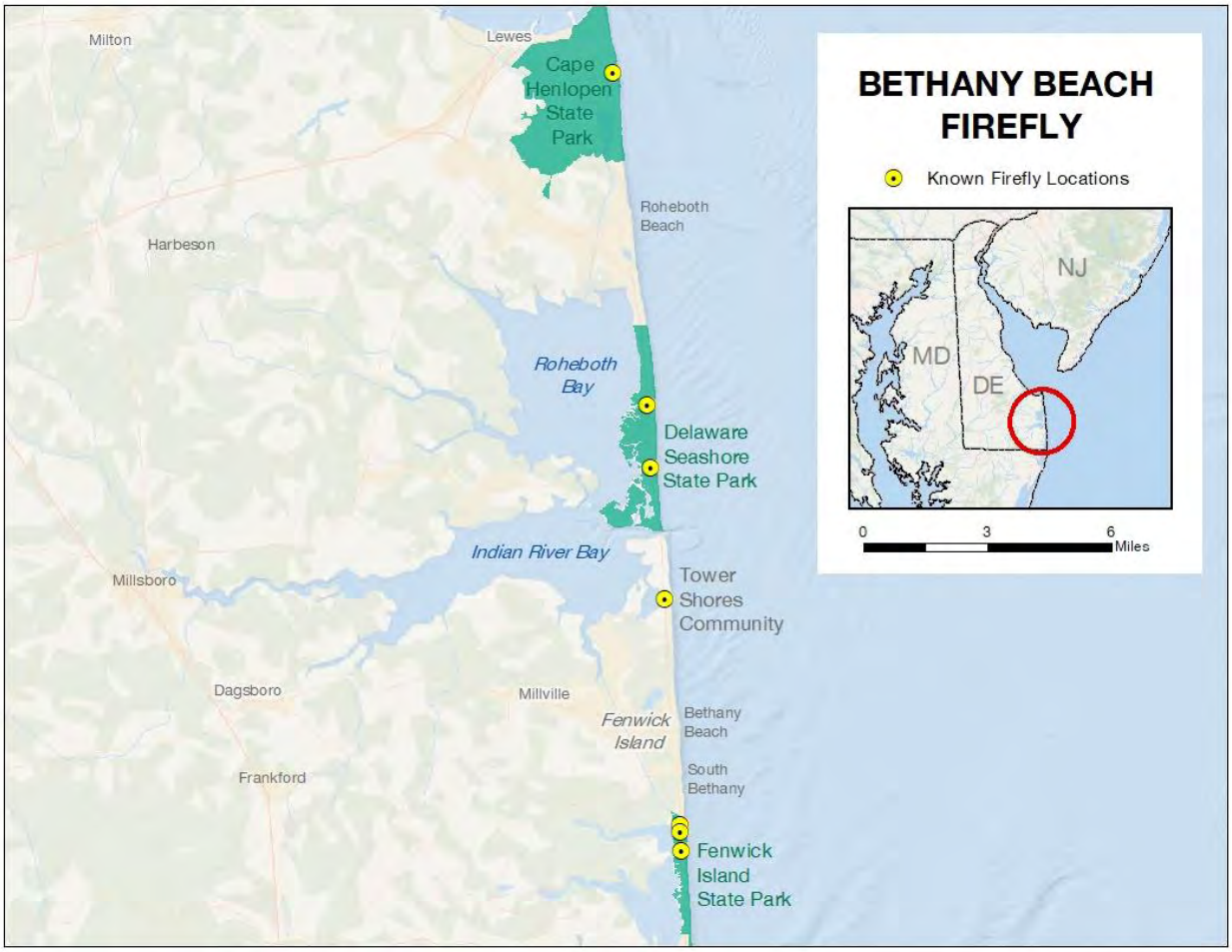


Figure 2. Current distribution of the Bethany Beach firefly.

Conservation Status and Warranted ESA Protection

The ESA is a "comprehensive scheme with the 'broad purpose' of protecting endangered and threatened species." Ctr. for Biological Diversity v. U.S. Bureau of Land Mgmt., 698 F.3d 1101, 1106 (9th Cir. 2012) (quoting Babbitt v. Sweet Home, 515 U.S. 687, 698 (1995)). Congress' plain intent in enacting the ESA was "to halt and reverse the trend toward species extinction." Tenn. Valley Auth. v. Hill, 437 U.S. 153, 184 (1978). In doing so, the ESA requires that "all Federal departments and agencies *shall* seek to conserve endangered species and threatened species and shall utilize their authorities in furtherance of [these] purposes." 16 U.S.C. § 1531(c)(1) (2012). Endangered and threatened species are "afforded the highest of priorities." Tenn. Valley Auth., 437 U.S. at 174. Endangered species are species that are "in danger of extinction throughout all or a significant portion of its range," and threatened species, species that are "likely to become endangered species within the foreseeable future" and are listed for protection pursuant to section 4 of the ESA. 16 U.S.C. § 1532(6), 1532(20), 1533.

The Bethany Beach firefly is in danger of extinction throughout all of its range and must be immediately listed as an endangered species under the ESA to protect it from further loss. As discussed above, the Bethany Beach firefly is only found in seven swales along the southeast Delaware shoreline.

In one of the four sites, Cape Henlopen State Park, the firefly is scarcely present, as only one individual was found; this was also the case for one swale in Delaware Seashore State Park. Although abundant individuals were previously documented at the Tower Shores development swale, that site has recently been and currently continues to be destroyed through housing construction that is directly eliminating this population's habitat. According to Dr. Heckscher, "this is a perfect example of why this species needs formal protection" (Heckscher 2019c). As such, the Bethany Beach firefly is nearly extirpated or only present in extreme low abundance in three out of seven swales, with the remaining four endangered by the threats outlined in this petition.

The Bethany Beach firefly has been recognized as imperiled or needing protection by international and state entities. The firefly has a global NatureServe rank of G1, or critically imperiled, with all known occurrences in danger of sea level rise and invasive species (NatureServe 2018 p. 1). The Bethany Beach firefly is listed as an endangered species at the state level by the Delaware Division of Fish and Wildlife (Delaware Division of Fish and Wildlife 2013a p. 4). The Delaware Endangered Species code allows for the designation of species listed as endangered if they are "seriously threatened with extinction as endangered species" (Delaware Division of Fish and Wildlife 2013b p. 1); however, beyond stating the prohibition of the possession or sale of endangered species, there is no population or habitat protection sections for listed species. As such, the Bethany Beach firefly has already been recognized as an imperiled species at the international and state level, but these designations do not provide protections or enforcement needed to prevent its extinction.

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)): 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 Bethany Beach firefly is imperiled by all five factors, but most significantly by factors one, four, and five and potentially factor two, as fireflies can be overutilized for commercial, recreational, scientific, or educational purposes; its habitat is most certainly significantly overutilized for commercial and recreational purposes. Thus, the Bethany Beach firefly warrants protection under the Act. The best available science shows that the Bethany Beach firefly is endangered in its entire range and in danger of extinction due to a very restricted range with a limited number of populations, very low abundances, reliance on a rare habitat type, and imminent threats of development, sea level rise, and pesticides, among others, that will destroy its entire habitat if immediate conservation measures are not taken to protect the species. A prompt decision to move forward with the emergency listing of the Bethany Beach firefly is required to save this species from extinction.

Threats

The Present or Threatened Destruction, Modification, or Curtailment of its Habitat or Range

Urbanization

The Atlantic coast of Delaware includes the cities of Rehoboth Beach, Bethany Beach, Fenwick Island, and adjacent smaller towns. Bethany Beach and Rehoboth Beach grew quickly between 1950 and 1970 during a real estate boom after the completion of the Chesapeake Bay Bridges, which created beach access for motorists and vacationers from Baltimore and Washington D.C. (Delaware Department of Natural Resources and Environmental Control 2004 p. 27). This period saw rapid development and urbanization of beach-front property. Nearly all of the land adjacent to the Atlantic has been built-up from this time to the present, save for three Delaware State Parks along the coast. Coastal development and population growth continues in this area much faster than in other parts of Delaware (Figure 3). The coastal census tracts have increased to 14,320 people (2017 estimate)--an 82% increase from 1980--with a population density of 577.6 people/mi^2 (U.S. Census Bureau 2019a). The state of Delaware has increased 59% in population since 1980 to a state population density of 484.3people/mi^2 in 2017 (U.S. Census Bureau 2019b). This consistent increase in population puts serious pressure on the fragile coastal environment, increasing human disturbances on the coastal dune habitat needed by the Bethany Beach firefly. As a direct result of coastal development, the original sites of the Bethany Beach firefly as documented by McDermott in 1949--including the type locality--are now lost (Lloyd 2018 pp. 94, 287).

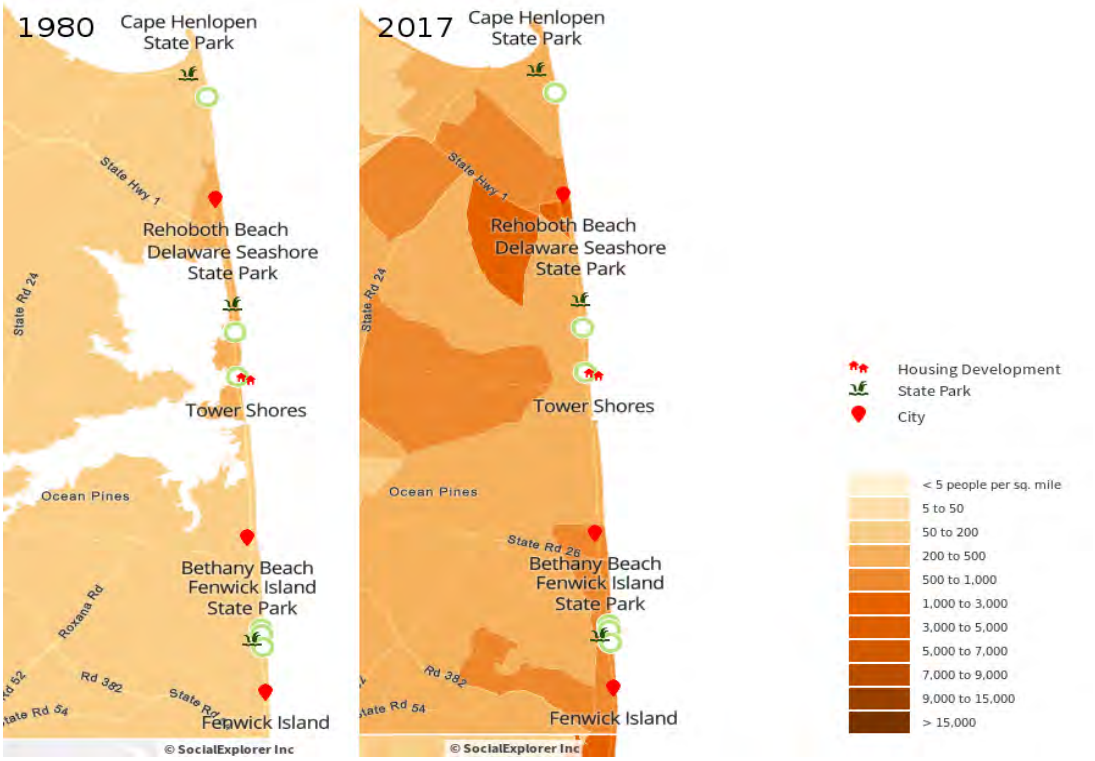


Figure 3. Human population density of Delaware in 1980 (left) and 2017 (right) that shows concentrated growth along the coast through time. Green circles represent occupied Bethany Beach firefly swales.

Coastal development has already taken up a large portion of the potential freshwater swale habitat for the Bethany Beach Firefly and is ongoing. In particular, construction in the Tower Shores Beach Community in the Breakwater Beach Development north of Bethany Beach is directly destroying one of the last remaining populations of the Bethany Beach firefly. Most of the Tower Shores homes were built in the 1960s-1980s, but recent additional development has started in a nearby freshwater swale that is considered by Dr. Christopher Heckscher to be the "exemplary population of this species" (Heckscher 1998 p. 7) and the only one not on state park land.

Aerial and real estate photos and videos of the Tower Shores construction shows new driveways with multiple parking areas for open lots that are meant to be occupied by four bedroom houses (Sotheby's International Realty 2019) (Figure 4). The construction of the raised road and driveways was allowed in the wetland because it was constructed on pilings and claimed to not destroy the wetland, despite the base being coated in blacktop under the roadway (Wilson & Lauria 2019 pp. 1–2). Contrary to neighboring Maryland and New Jersey, Delaware does not have local or state regulations to protect isolated wetlands, like this freshwater wetland, smaller than 400 acres; those areas fall under the jurisdiction of the US Army Corps of Engineers (Wilson & Lauria 2019 p. 4; Lauria 2019 p. 5). However, because the structure was elevated and so not considered filling in a wetland, no permit was required and thus no consideration for sensitive species, such as the Bethany Beach firefly, was made (Wilson & Lauria 2019 p. 5; Lauria 2019 pp. 4–5). Construction of these new beach homes not only destroys habitat, but also directly disturbs the soil and causes mortality of firefly eggs, larvae, and pupae as well as of their prey. Development also increases light and chemical pollution which weakens the remaining firefly population, potentially wiping out an entire population of fireflies (Lewis 2016 p. 122). The Bethany beach firefly is imminently threatened and in need of emergency listing in large part due to the construction in the Tower Shores Beach Community.

Figure 4. Google Earth image showing the constructed elevated driveways for future houses in the Tower Shores development.

Decreased Water Quality

The Bethany Beach firefly requires freshwater swale habitats that are primarily fed by underground aquifers (Odum & Harvey 1988 pp. 149–150; Heckscher & Bartlett 2004 pp. 350–351) that are at risk of depletion and salinization from the increasing anthropogenic pressures of urbanization and agricultural expansion (Konikow & Kendy 2005 p. 317; Brown et al. 2019 p. 219). Coastal freshwater aquifers are a vital resource for human coastal communities like Bethany Beach and Rehoboth Beach that get most of their freshwater from groundwater wells; the ecosystem services provided by Delaware's wetlands are worth $2 billion (Lauria 2019 p. 4).

Urbanization increases demand on freshwater and has been demonstrated to decrease freshwater recharge rates (Konikow & Kendy 2005 p. 317; Carretero et al. 2014 p. 180). For example, Partido de la Costa, Argentina experienced a six-fold increase in water demand with a population growth of 12,000 to 70,000 people, resulting in a 10% reduction in recharge from observation wells (Carretero et al. 2014 p. 180). The Delmarva Peninsula (Delaware and parts of Maryland and Virginia) may also experience this freshwater stress as it continues to grow in population; this region is forecast to experience a 10% decrease in freshwater yield by 2046-2070 while the area is forecast to increase 80%-100% in freshwater demand by 2045-2070 (Brown et al. 2019 p. 225). A decrease in freshwater yield will lower the water table which will result in more frequent drought events for these swales.

As urbanization increases, freshwater is also drawn from aquifers for lawn and golf course irrigation (Odum & Harvey 1988 p. 154). Runoff from lawns and golf courses is also a significant source of excess nutrients as well as pesticides which can end up in these fragile freshwater swales. Mesic, temperate regions of the northeast United States, like Delaware, can experience, on average, up to nine g/ha of pesticide runoff from lawns and golf courses and as much as 15 g/ha of runoff from golf course fairways (Haith & Duffany 2007 pp. 440, 445). There are nine golf courses within five miles of Delaware's Atlantic coast and an increasing amount of green lawn which significantly increases the risk of toxic stress for the Bethany Beach firefly and other invertebrates.

Climate change-induced severe storms as well as topographic change due to development also increase the risk of salt water overwash into freshwater swales (Anderson 2002 p. 419). Overwash increases salinity in swales until freshwater flushes out the system which can take anywhere from weeks to months (Anderson 2002 pp. 415–417) or up to years (Odum & Harvey 1988 p. 151). Salt water intrusion and overwash into freshwater swales alter vegetative communities in a way that makes them more susceptible to invasive species and decreases prey populations, degrading Bethany Beach firefly habitat suitability (Delaware Coastal Programs 2012a p. 38).

Recreation

The rapid increase in development along Delaware's Atlantic coast would likely have been more extensive if not for three state parks located along this 26 mile stretch of the state: Cape Henlopen, Delaware Seashore, and Fenwick Island State Parks. These three parks host nearly all remaining habitat for the Bethany Beach firefly. While park boundaries can offer land use stability, the lack of site-specific protection for the Bethany Beach firefly, coupled with increasing numbers of visitors to Delaware's parks and associated infrastructure, place these remaining populations at risk.

Delaware welcomes nine million visitors a year as part of a $3.4 billion dollar tourism industry, and this number is expected to grow (Delaware Tourism Office 2017 p. 3). Approximately five million

people visit Delaware's state parks annually, many of whom flock to the sandy beaches found along the Atlantic coastline (Lauria 2018 p. 1). As coastal beaches bear the weight of increased use for recreational activities such as fishing, boating, swimming, clamming, and sunbathing, the future of the Bethany Beach firefly and its few remaining habitats is uncertain.

Recreation may be particularly detrimental to the Bethany Beach firefly's survival due to trampling of adults and larvae in fragile dune habitats. Because fireflies can remain in a larval state for up to two years (Faust 2017 p. 42) and *Photuris* larvae hunt on the ground and pupate in shallow earthen burrows or under logs (Faust 2017 pp. 29, 47; Lloyd 2018 pp. 5–6), the Bethany Beach firefly may be particularly susceptible to ground-disturbing recreational activities such as hiking and beach access for surf fishing. Compaction of soil caused by humans walking over the surface of the sand can kill invertebrates (Defeo et al. 2009 p. 3), in some cases significantly decreasing the number of larvae found in an area (Cornelisse & Hafernik 2009 p. 498). Trampling of adult females and larvae, destruction of fragile microhabitats that support fireflies, and increased light pollution have all been identified as risks associated with increased numbers of visitors in parks in other parts of the country (Faust 2010 pp. 213, 215; Lewis 2016 p. 14).

As these prominent parks will see greater numbers of visitors in the future, they will have to meet this demand with parking lots, interpretive centers, roads, trails, restrooms, campgrounds, and maintenance infrastructure. This type of development can destroy Bethany Beach firefly habitat. Future development must be done in a sustainable way that takes into account the needs of Delaware's only endemic species (Delaware Division of Fish and Wildlife 2015 chap. 1, p. 89), but this can only be ensured with enforceable action under the ESA. Additionally, if park lands were ever sold or modified for a different use, federal ESA protection for the Bethany Beach firefly would ensure that the species could survive even under different land ownership.

Habitat Fragmentation

Fragmentation due to urban land use and agriculture decreases the size of and connectivity between wetland areas, leading to a decrease in connectivity between firefly populations. Because fireflies are weak fliers and rarely disperse beyond the habitat in which they were born, it is unlikely that they will disperse to an area that is heavily impacted by human activity; instead, they will become locally extirpated (Lewis 2016 p. 121). Insects with limited dispersal abilities tend to exist in patchy populations or metapopulations (Franzén & Nilsson 2009 p. 79). Dispersal between patches, known as patch dynamics, is crucial to the survival of a species with patchy populations (Pulliam 1988 pp. 652–654). Even small habitat patches of lower quality, often known as sinks, and the ability of an individual to disperse to sinks, are of vital importance to the survival of the species as a whole; sinks can act as spill over areas for less competitive individuals to obtain higher fitness (Pulliam 1988 p. 659; Howe et al. 1991 p. 251). Thus, extirpated sites (represented by unoccupied suitable habitat in and outside of State Parks) are extremely important to the survival of the Bethany Beach firefly, as they provide the only way for it to expand and recover over time.

The Bethany Beach firefly's wetland habitat is fragmented throughout its range. Wetlands are very important to wildlife in Delaware, but they are under threat from agricultural and urban expansion (Tiner et al. 2011 p. 21). Wetlands make up about 18% of total state land area in Delaware, with freshwater tidal wetlands accounting for 3.5% of total wetland area, or 7773 acres (Tiner 1985 p. 26). It

is estimated that Delaware has lost up to 54% of all wetland area since the 1780s (Tiner et al. 2011 p. 20). Hardisky and Klemas (1983 p. 342) calculated that from 1973 to 1979 alone, human activities destroyed an average of 8.1 ha (20.0 acres) of tidal wetlands per year. Since that time, wetland loss increased by as much as 50% from 1992 to 2007, with a net loss of 1265 ha (3126 acres) of tidal wetland statewide (Tiner et al. 2011 p. 20).

The Bethany Beach firefly's habitat is not only fragmented at a landscape scale, but locally, as freshwater wetland swales become partially destroyed or broken up. For example, the synergy of recreation and urbanization has increased the creation of pedestrian crossings over dunes to connect parking areas to beach access; one pedestrian crossing at Cape Henlopen State Park bisected the center of an interdunal wetland before being rerouted due to its ecological impact (McAvoy & Clancy 1994 p. 15). These types of local habitat fragmentation likely occur throughout the Bethany Beach firefly's range, as its habitat is solely found between the only main access road, Delaware Route 1, and the beach. This threat will continue to increase with projected growth in recreation and urbanization.

The Bethany Beach firefly currently survives in populations that are restricted to areas primarily within state parks that are separated by urban expanses. If a population were to go locally extinct at one park or swale, there would be no way for individuals from a different site to recolonize the area without human assistance. Further, loss of a large population in the center of the firefly's range would break down any remaining metapopulation dynamics. The Tower Shores Bethany Beach firefly habitat, at least during the last survey, contained the healthiest population and connects the populations in the south at Fenwick Island to those in the north at Delaware Seashore and Cape Henlopen State Parks (Figure 2). Loss of the Tower Shores population due to ongoing construction will be a disproportionate loss because of its value as a connecting source population. Further, the most isolated population at Cape Henlopen, if still present, is in very low abundance (only one individual at last survey). Thus, habitat fragmentation is jeopardizing the Bethany Beach firefly as a species and it requires emergency listing as endangered under the ESA to ameliorate this threat.

Small Populations and the Allee Effect

Fireflies are known to have a complex mating system characterized by pheromones, bioluminescent signaling, and nuptial gifts that are a result of polyandry, or the females mating with multiple males, and female mate choice (Lewis & Cratsley 2008 pp. 294–315). Female fireflies mate an average of twice in their lifetimes, a rate that is dependent on the number of males available for mating in the population; as firefly sex ratio is close to one to one, the lack of males will result in lower female fecundity (Bauer et al. 2013 p. 47). Thus, low firefly mating probability is exacerbated by small populations resulting from habitat fragmentation and reduction, a phenomenon known as the allee effect (Gascoigne et al. 2009 pp. 360–361; Bauer et al. 2013 p. 51). There is evidence in insects that once a population is reduced to the point that mates are scarce, or demonstrating the allee effect, the population could reach a threshold at which it is no longer able to be sustained and will go extinct (Gascoigne et al. 2009 p. 362).

The degree of sexual selection and its importance in shaping firefly natural history is founded on the basis that females have enough males from which to choose for an adequate mate that will maximize her fecundity. Female preferences for male signals are an adaptation that results from females gaining a fitness benefit by selecting more fit males; in the case of fireflies, fit males can pass on good

genes to offspring (indirect benefit to female fitness), but also provide direct benefits to females in the form of nuptial gifts, or nutritious spermatophores used for survival and reproduction (Lewis & Cratsley 2008 pp. 300–308). In addition, females that mate with more males have been shown to have higher fecundity (Lewis & Cratsley 2008 p. 300). As a result, loss of males in a population due to curtailment of the Bethany Beach firefly's habitat due to urbanization, recreation, and other modification puts the species at further risk of extinction due to low reproductive output.

Light pollution

Many firefly species rely on bioluminescent light to find mates and to ward off predators, and their flash color, length, and frequency are distinctive among firefly species. Adult fireflies are sensitive to ambient brightness and use brightness as the cue to begin courtship and mating activities. Artificial light changes the evening and night time ambient brightness and has been shown to change the intensity and timing of firefly flashes (Owens & Lewis 2018 p. 13). Light pollution is a serious consequence of urbanization and it affects fireflies differently, but significantly throughout their life cycle (Owens & Lewis 2018 p. 8). At least one study showed a negative correlation between the extent of urbanization and firefly abundance (Picchi et al. 2013 p. 797).

Artificial light at night, or light pollution, reduces the reproductive rate of the Bethany Beach firefly by drowning out mating signals, preventing males and females from detecting each other and/or preventing males from receiving the correct light cues to begin their nocturnal flashing display (Lewis 2016 p. 127). Bethany Beach firefly males are strongly phototactic, meaning they readily come to light of any kind, including artificial light (Lloyd 2018 p. 94). As such, as has been shown for other fireflies, artificial light at night can interfere with a male firefly's ability to locate females (Ineichen & Rüttimann 2012 pp. 34–35). With the rampant urbanization of the areas in and around the few remaining Bethany Beach firefly habitats, light pollution no doubt interferes with its mating, reducing reproductive output for this already imperiled insect (Figure 5).

The effect of light pollution varies with species and the type of lighting (Owens & Lewis 2018 p. 13). Older mercury vapor and sodium vapor lamps tend to emit light with longer wavelength in the yellow and red part of the visible spectrum, while LEDs tend to emit shorter wavelength light in the blue and green end of the spectrum. For example, males of a firefly species from Taiwan flashed brighter and less frequently when exposed to wavelengths < 533 nm (cyan/green), but showed no difference when exposed to light > 595 nm (amber/red) (Owens et al. 2018 p. 9). One study by Costin and Boultin (2016 p. 85) in the Piedmont region of Maryland showed a 50% reduction in firefly flashing in lighted trials using a mercury vapor lamp. An experiment conducted in the Shenandoah Valley of Virginia tested plots with introduced LED light and found that the lighted trial reduced flashing activities of *Photuris versicolor* by 70% (Firebaugh & Haynes 2016 p. 1207). This experiment also showed that artificial light reduced courtship behavior and mating success in *Photinus pyralis* (Firebaugh & Haynes 2016 p. 1209).

Firebaugh and Haynes (2016 pp. 1209–1210) noted that *P. versicolor* tends to fly later in the evening and flashes green, comparable to the Bethany Beach firefly, suggesting LED lights may similarly reduce Bethany Beach firefly flashing. In addition, low-pressure sodium lights may have a less negative effect because they produce more light in the yellow part of the spectrum (Hagen et al. 2015 p. 24), competing less with the green spectrum that the Bethany Beach firefly relies on for communication.

Regulations on outdoor lighting and limits on urbanization are necessary steps to take to protect the nighttime activities of the Bethany Beach Firefly.

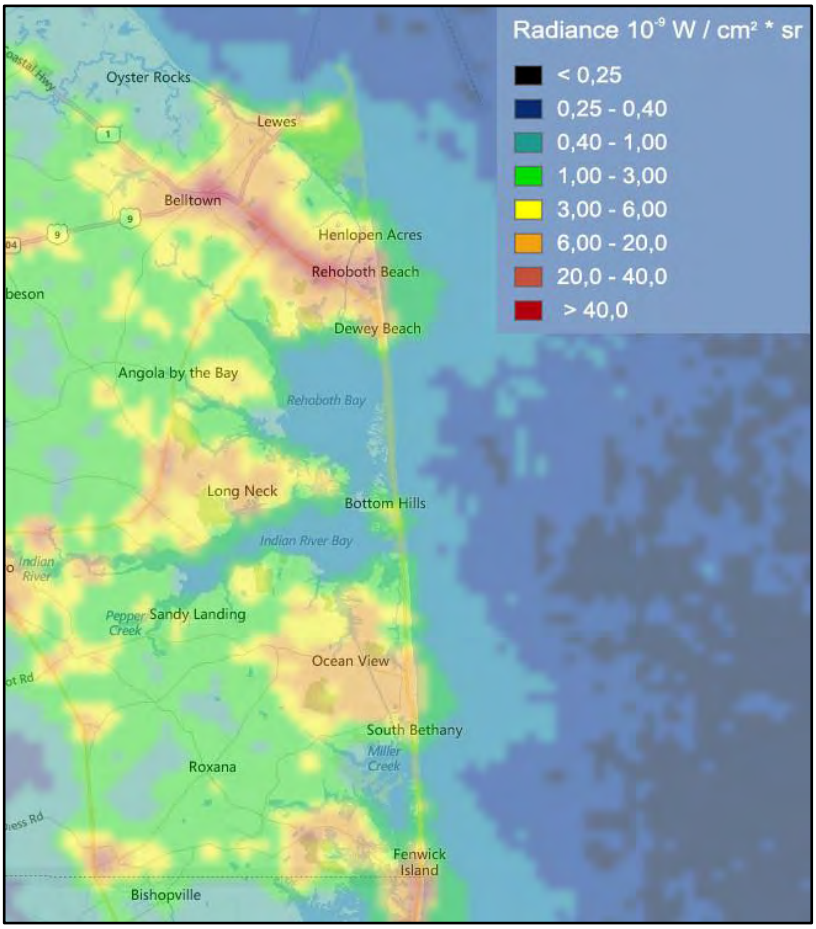


Figure 5. Light pollution of coastal Delaware. Colors represent increasing amounts of artificial light from black (low amounts of artificial light) to red (high amounts of artificial light). Light is measured in units of radiance (10^{-9}Watts/cm^2/sr). Data from the Earth Observation Group, NOAA National Geophysical Data Center 2019. Image from light pollution map.info.

Climate Change

Human activities have increased global average temperatures 0.8-1.2°C above pre-industrial levels with a trend of about 0.2°C per decade due to past and current emissions (Intergovernmental Panel on Climate Change 2018 p. 4). At current emissions rates, global temperatures will increase by 1.5°C between 2030-2052, resulting in further sea level rise, increased incidence of severe weather events, and loss of ecosystems (Intergovernmental Panel on Climate Change 2018 pp. 4, 8). Sea levels will increase between 0.3-0.76 m (1-2.5 ft) by 2100 even without further emissions. This will expose low-lying coastal areas to saltwater intrusion and flooding (Intergovernmental Panel on Climate Change 2018 p. 5,10). The Bethany Beach firefly is found on the largest estuarine complex in North America, made up by the Chesapeake and Delaware estuaries, lands greatly threatened by climate change (Delaware Coastal Programs 2012b; Heckscher 2014 p. 1).

Sea Level Rise

The entire known range of the Bethany Beach firefly occurs at less than 0.5 m (1.6 ft) above sea level within 100-500 m (328-1640 ft) of the Atlantic Ocean shoreline (Heckscher 2014 p. 1). Global sea level rise averaged 0.18 cm (0.07 in) per year over the last century, while sea levels in Delaware have been rising twice as fast at 0.33 cm (0.13 in) per year (Delaware Coastal Programs 2012a p. 7). The shoreline in some areas of Delaware is retreating upwards of 5-10 meters (16.4-32.8 ft) per year, 5-10 times the average loss in the United States, which greatly hastens the inundation caused by sea level rise (Delaware Coastal Programs 2012a p. 6). Depending on future emissions, Delaware's sea level will rise 0.5, 1.0, or 1.5 m (1.6, 3.3, or 4.9 ft) above sea level by the year 2100, corresponding to low, medium, and high global warming scenarios; even with no further emissions, Delaware's sea level will rise by about 3.3 m (1.0 ft) due to committed warming (Delaware Coastal Programs 2012a p. 8).

Despite action from storms, erosion, and sediment accumulation, high sea levels are becoming the dominant force shaping sandy shoreline dynamics, greatly threatening freshwater tidal wetland habitat; 84-98% of freshwater wetlands could be impacted by sea level rise by 2100 (Delaware Coastal Programs 2012a pp. 5, 20, 25) (Figure 6). Bethany Beach freshwater swales are maintained by freshwater aquifers that can become contaminated with saltwater during high sea levels from rises, flooding, or storms, in turn making the swale brackish and no longer suitable for the Bethany Beach firefly (Odum & Harvey 1988 p. 151; Delaware Coastal Programs 2012a pp. 24–25). Salt-water intrusion into swales can kill establishing vegetation and prevent the swale from progressing from herbaceous vegetation to vegetation dominated by woody shrubs, the preferred habitat of Bethany Beach fireflies (Heckscher & Bartlett 2004 p. 351). In addition, the lack of vegetation build up caused by salt water intrusion prevents the formation of an organic layer thereby limiting or eliminating, depending on the severity, Bethany Beach firefly larval habitat.

In addition to direct impacts to the Bethany Beach firefly's habitat, competition for freshwater, such as through groundwater aquifers, will amplify as the more freshwater resources become increasingly saline due to climate change. Delaware's groundwater is currently used and central to the provision of freshwater for societal uses; within the firefly's range, groundwater serves 100% of Delaware's domestic water supply and 98% of that used for agricultural irrigation (Delaware Coastal Programs 2012a p. 31). As more freshwater is required to replace saline water upstream for human uses, less will make it to the coastal freshwater swales, increasing the salinity and thus hastening the destruction of the Bethany Beach firefly's habitat, diminishing suitable habitat availability.

Freshwater tidal wetlands accumulate organic material, maintaining their stability. However, the rapid pace of sea level rise due to climate change will alter these accumulation dynamics, threatening the stability of the wetland. Further, dunal wetlands can maintain their area during sea level rise by naturally migrating, or transgressing, landward depending on the geomorphology of adjacent lands and their land uses (Delaware Coastal Programs 2012a pp. 34–35). Unfortunately, the freshwater wetland swales that make up the Bethany Beach firefly's habitat are limited in their landward migration due to human infrastructure that act as barriers, especially houses and roads (Najjar et al. 2000 p. 223; Delaware Coastal Programs 2012a p. 35).

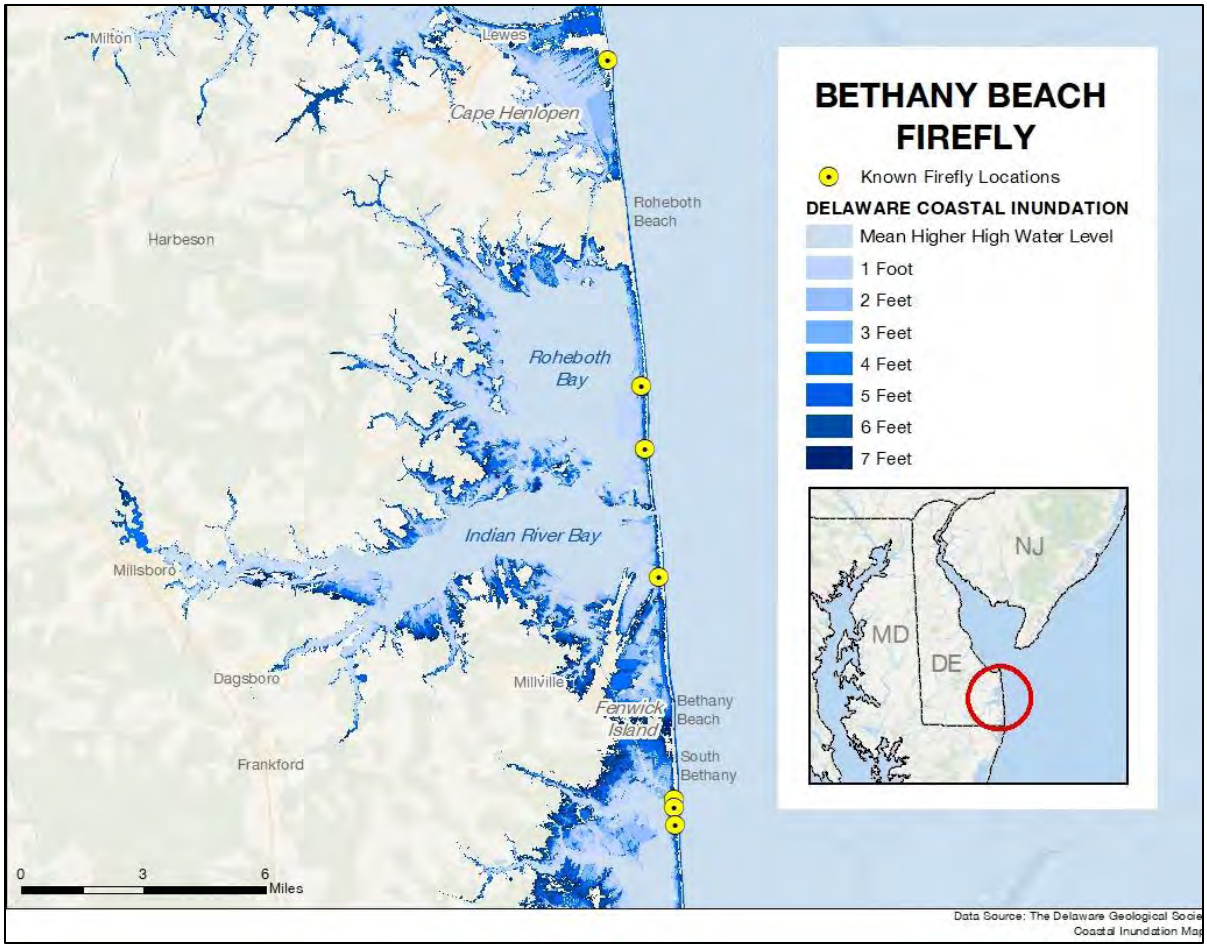


Figure 6. Delaware coastal inundation at varying sea level rise projections; yellow dots indicate the known locations of the Bethany Beach firefly.

Increased Incidence of Severe Storms

At the current, conservative predicted warming of 1.5°C by 2030-2052 temperature and precipitation extremes will be exacerbated and storm events more frequent in eastern North America (Intergovernmental Panel on Climate Change 2018 pp. 8–10). Climate change has already increased storm frequency and intensity over the last 30 years and will continue to do so into the future especially along the North Atlantic coast of the United States (Emanuel 2005 p. 687). At current sea levels, destructive coastal storms cause surges between 0.61-1.2 m (2.0-4.0 ft) along Delaware Bay and Atlantic coasts, heights that are comparable to expected sea level rise by 2100 alone (Delaware Coastal Programs 2012a p. 4-5). At such high sea levels, further increases in frequent, intense storms with high surges will devastate the ecological and human communities along the Delaware coast.

Storm surges will cause flooding and salt water inundations at levels disproportionately higher than past levels due to sea level rise (Najjar et al. 2000 p. 222). High dune ridges lower the chance of overwash and aquifer contamination, and thus reduce salt water intrusion (Odum & Harvey 1988 p. 151). However, dune loss after hurricanes is correlated with prior dune size and presence of foredunes (Pries et al. 2008 p. 172), indicating that increased frequency in storms will result in disproportionate dune loss as storms continually decrease dune height. Researchers believe that dunes once dominated

by normal wind and wave activity are shifting to a state in which frequent storm disturbance dictates dune structure and vegetation communities (Pries et al. 2008 p. 174). Thus, in combination with sea level rise, storm surges are likely to result in further loss of high dune ridges and result in more salt water intrusion into interdunal freshwater swales, destroying the Bethany Beach firefly's habitat.

Increased Temperature and Phenology Changes

Depending on the climate scenario modeled, between 2050 and 2099 Delaware is expected to experience 20-60 more exceptionally hot days with temperatures higher than the 1950-1999 90th percentile daily maximum temperatures (Ning et al. 2015 p. 3300). There is a high reliability that the average temperature in Delaware will be at least 1.3°C higher in 2030 compared to 1990 (Najjar et al. 2000 p. 220); considering the recent reports, the increase is more likely to be > 1.5°C (Intergovernmental Panel on Climate Change 2018 p. 4). This trend will negatively impact the Bethany Beach firefly, as increased temperature impacts firefly breeding (Bauer et al. 2013 p. 45), egg and larval survival during development (Evans et al. 2019 p. 6), and habitat suitability (Whigham et al. 2019 p. 620).

Freshwater interdunal wetlands require that freshwater aquifer recharge plus precipitation be greater than evapotranspiration in order for the water to remain fresh (Odum & Harvey 1988 p. 151). Increased temperatures that increase evapotranspiration with decreased precipitation will thus eliminate freshwater swales. Any increased incidence of drought will also exacerbate low aquifer recharge levels, the quality of which is duly threatened by sea level rise caused salt water intrusion (Delaware Coastal Programs 2012a p. 32; Whigham et al. 2019 p. 620).

Fireflies respond to degree days, or the accumulation of thermal energy in the environment, often the number of days that have a low above 50°F; they can be used to predict onset of male emergence, female emergence, and peak display (Faust & Weston 2009 pp. 1506, 1509; Faust 2017 pp. 32–33). The increase in temperature, therefore, will alter firefly phenology by advancing the dates of male, female, and/or peak emergence and/or display time. The synchronous fireflies, *Photinus carolinus*, now have their peak display 10 days earlier than they did 20 years ago (Lewis 2016 p. 133), with female emergence and good display advancing significantly and at a faster rate than male emergence, which was not significant (Faust & Weston 2009 pp. 1509–1510). This initial study on firefly phenology and temperature changes indicates that climate change could create a mismatch between male and female emergence dates, potentially reducing the window for Bethany Beach firefly mating, and thus reducing their reproductive output and populations.

Firefly larvae can take two years to develop; weather patterns can change the abundance of adult fireflies by impacts to larvae development through soil moisture, temperature, and precipitation more than 12 months before adult emergence (Evans et al. 2019 p. 6). Firefly eggs are susceptible to changes in microclimate and can dry out or become moldy if the humidity and temperatures are not suitable (Faust 2017 p. 40). There is an optimal range of precipitation and soil moisture for larval development that impacts subsequent adult firefly abundance (Evans et al. 2019 p. 6); high maximum temperatures in winter and spring result in lower adult abundance the following summer (Evans et al. 2019 p. 6). As such, increase in temperature and corresponding changes in soil moisture can negatively impact Bethany Beach firefly abundance and for at least a two year period.

Pesticides

Pesticides have been implicated in the declines of many insect species (Sánchez-Bayo & Wyckhuys 2019 pp. 20–21). While there is some research showing that pesticides negatively affect fireflies directly, their vulnerability can also be assessed from research on similar predaceous beetles, on firefly prey, and observations of firefly researchers, such as that fireflies can be killed by commonly used broad-spectrum insecticides like malathion and diazinon, for example (Lewis 2016 pp. 132, 142). Since the Bethany Beach firefly relies on moist habitats, they are vulnerable to pesticides moving through water and soil. They are thus exposed to toxic pesticides in the soil as eggs, larvae, and pupae and on vegetation and in the air as adults as a result of direct applications to their habitat as well as runoff from agricultural or ornamental applications.

Although fireflies are most often noticed as flashing adults, pesticide use can affect all life stages throughout the year. For species like the Bethany Beach firefly that have long, soil-dwelling larval periods, this life stage is likely the most vulnerable to prolonged exposure to pesticides. Firefly larvae eat soft-bodied arthropods like worms, slugs, and snails that are the target of many ornamental pesticide applications, potentially a cause of Bethany Beach firefly absence in urbanized areas within its range. As the larval stage of the Bethany Beach firefly is the primary nutrition gathering stage for individuals, pesticide impacts on these food sources will negatively affect firefly growth and survival.

Insecticides

Insecticides can directly harm fireflies since they are designed to target insects, including beetles. Exposure to several organophosphates and neonicotinoids resulted in more than 80% mortality of the Asian firefly *Aquatica* [*Luciola*] *laternalis* (Lee et al. 2008 p. 265). Additional laboratory experiments conducted on this species showed that several common insecticides (including thiamethoxam, acephate, fenthion, diazinon and others) are toxic to both adults and larvae (Lee et al. 2008 p. 268-269). In a field study on the effects of corn seed coated with clothianidin, a neonicotinoid, on arthropod communities, researchers identified declines in predator groups that included fireflies (Disque et al. 2018 p. 974). A follow-up communication with the authors revealed that 70% fewer adult fireflies were captured in the treated plots compared to the untreated plots, likely due to the impact of clothianidin on firefly larvae (Dively 2019). Together, these studies suggest that common neonicotinoid and organophosphate insecticides directly harm fireflies.

Neonicotinoids, the most commonly-used class of insecticide, are broad-spectrum, can persist in the environment for months to years, and are applied in both agricultural and residential settings. In agriculture, neonicotinoids can be applied to crops as seed coatings before they are planted or sprayed during the growing season. Lee et al. (2008 p. 268) found that thiamethoxam (a type of neonicotinoid) showed toxicity to firefly larvae. Other research on neonicotinoids (imidacloprid, thiamethoxam, and clothianidin) has shown that carabid (family of predaceous ground beetles) species exposed to corn seedlings coated with these insecticides had nearly 100% mortality (Mullin et al. 2005 p. 1630). Several beetle species also showed sublethal effects from contact with soil treated with imidacloprid (Pisa et al. 2015 p. 83). In residential settings, neonicotinoids are commonly used to control white grubs (the larvae of various beetle species) in lawns. 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 (Peck 2009 p. 292).

The Bethany Beach firefly is no doubt exposed to neonicotinoids in Delaware, as 30% of the state land area is used for agricultural production (Delaware Department of Agriculture 2018 p. 4). Neonicotinoids are commonly used prophylactically as corn seed treatments and it is estimated that 70-100% of conventional corn seeds in the United States are treated with neonicotinoids (Bredeson & Lundgren 2019 p. 222). In 2017, corn for grain was planted on 180,000 acres in Delaware, making it the largest crop by value and acre in the state; 106,000 of those acres are in Sussex County (Delaware Department of Agriculture 2018 p. 5), home to the Bethany Beach firefly. Further, neonicotinoids are used in and on a variety of additional crops, particularly soybeans, which were planted on 75,600 acres in Sussex County in 2017 (Delaware Department of Agriculture 2018 p. 7). Neonicotinoids persist in the environment for years and, as they are highly water soluble, can spread via groundwater (Bredeson & Lundgren 2019 p. 222), such as freshwater aquifers that feed the Bethany Beach firefly's swale habitat, making them a threat to the Bethany Beach firefly.

Mosquito Spraying

The use of insecticides, both larvicides and adulticides, to control mosquito populations is a widespread practice in Delaware with potentially significant effects on Bethany Beach firefly populations. Delaware's Mosquito Control Spray Policy allows for adulticides to be sprayed aerially by "twin-engine aircraft or helicopter" or "truck-mounted London Fog Ultra Low Volume ground foggers" and for larvicides to be applied "aerially by twin engine aircraft or helicopter, or from the ground using truck-mounted sprayers or hand application methods," with application method dependent on the pesticide (Delaware Mosquito Control Section 2019 pp. 12–14). Pyrethroids, naled (an organophosphate) and methoprene are approved for use in the state of Delaware under the Mosquito Control Spray Policy (Delaware Mosquito Control Section 2019 pp. 12–14).

The pyrethroid permethrin binds to organic matter and has a low vapor potential, allowing it to persist in the soil and on foliage for nearly a year, with its insecticidal activity remaining for nearly a month (Hoang & Rand 2015 p. 254). Permethrin drifts up to 240 m (790 ft) when aerially sprayed and bioaccumulates in aquatic insects (Hoang & Rand 2015 p. 254), meaning predators like fireflies are exposed to higher concentrations through their diet. Pyrethroid insecticides are particularly harmful to aquatic insects including aquatic beetles (Mian & Mulla 1992 p. 73). In one examination of beetle mortality from permethrin mosquito spraying, Peterson et al. (2016 p. 8) observed acute mortality of the convergent lady beetle, *Hippodamia convergens*, predaceous as an adult and larvae. Naled can drift up to 750 m (2400 ft) when aerially sprayed and because naled is sprayed frequently during a mosquito outbreak, it can cause chronic toxicity to non-target insects (Hoang & Rand 2015 p. 254, 259). Methoprene, a juvenile hormone mimic and common larvicide used to target larval mosquitoes, has been shown to be toxic to some beetle species (Wijayaratne et al. 2012 p. 718).

The Bethany Beach firefly prefers the same moist habitats with standing, ephemeral pools that are sprayed for mosquitoes, placing the firefly at risk due to pesticide overspray (Delaware Division of Fish and Wildlife 2015 chap. 1, p. 91). The Delaware Pesticide Discharge Management Plan specifically mentions the Bethany Beach firefly's interdunal swale habitat as potential areas for mosquitos and their control via insecticides (Delaware Mosquito Control Section 2012 p. 17). In addition, Insecticide applications for adult mosquito control impact adult fireflies because spraying is often done at dusk or at night when adults are active. Thus, the Bethany Beach firefly is threatened by pesticide-based mosquito

control throughout its life cycle, as both a larva and an adult. Insecticidal spraying for mosquito outbreaks can and perhaps has resulted in local extirpation of the Bethany Beach firefly, exacerbating the threats of habitat loss and fragmentation.

The threat of insecticide spraying is anticipated to worsen with increased incidence and severity of storms, as the frequency of mosquito control increases the weeks following storm events (Center for Disease Control and Prevention 2018a p. 1). In particular, the insecticide naled is frequently used to control mosquitos after hurricanes (Center for Disease Control and Prevention 2018b p. 1). Thus, with the increased frequency and severity of storms, more water will remain post-storm causing increase use of insecticide use as climate change worsens. As a result, the Bethany Beach firefly is threatened with extinction by the synergy of climate change and pesticide spraying. Listing the Bethany Beach firefly as an endangered species is the only way these synergistic threats will be addressed or mitigated.

Impacts on larval food sources

Firefly larvae eat soft-bodied invertebrates including earthworms, snails, and slugs. Pesticide use that affects these prey species can reduce the food sources that larval fireflies need to develop. Earthworms are affected by neonicotinoids in a similar manner to insects - both groups share the same neural pathways that are disrupted by this class of insecticides (Pisa et al. 2015 p. 84). Neonicotinoid toxicity to earthworms is particularly concerning because these chemicals can persist in many soil types for months to years (Wood & Goulson 2017 pp. 17291–17295). Neonicotinoids have also been shown to bioaccumulate and cause DNA damage in earthworms from exposure to environmentally-relevant concentrations in soil (Chevillot et al. 2017 p. 842). Other common pesticides (organochlorines, pyrazoles, carbamates, and certain fungicides) are also toxic to earthworms (Wang et al. 2012 p. 487). Slugs can be contaminated by exposure to many insecticides. In one study looking at predaceous beetles that consume slugs, researchers 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 p. 5). These results suggest that while slugs may not be harmed by the insecticides, feeding on contaminated slugs could be a source of pesticide exposure for firefly larvae. Similar pathways could occur with snails, which have been shown to become contaminated with certain pesticides (Druart et al. 2011 p. 4285).

Herbicides

Herbicides are also a threat to the Bethany Beach firefly, from both agricultural and land management uses in Delaware. As mentioned above, corn and soybeans crops are common in Sussex County. All or nearly all conventionally grown corn and soybeans in the United States are genetically modified to resist herbicides- particularly glyphosate and increasingly dicamba and 2,4-D- so that these products can be liberally sprayed in fields without damaging the crops (Freydier & Lundgren 2016 p. 1270). In addition, 2,4-D, dicamba, and glyphosate are approved for use by the Delaware Department of Transportation to control plants in vegetative buffer zones (Delaware Department of Transportation 2009 pp. 152–153). Both 2,4-D and dicamba are frequently in volatile formulations that travel from application sites as vapor drift (Egan et al. 2014 p. 194). With the Bethany Beach firefly's entire range occurring adjacent to the Delaware Coastal Highway (DE Route 1) in Sussex County, herbicide use in roadsides can eliminate vegetation needed by the firefly for shelter, forage, overwintering, and mating.

Herbicides can be toxic to animals as well in a way that can negatively impact the Bethany Beach firefly. Glyphosate has been shown to reduce the weight of earthworms by 50%, while exposure to 2,4-D caused 30-100% earthworm mortality, depending on the concentration; both herbicides also resulted in morphological abnormalities and significantly lowered reproductive output by earthworms (Correia & Moreira 2010 pp. 265–266). Thus, use of these herbicides in and around Bethany Beach firefly habitat can reduce or eliminate important larval prey.

Like the Bethany Beach firefly, lady beetles are members of the order Coleoptera and are predators as larvae. Lady beetles are also used as indicator species for testing the effect of herbicides on non-target insects, like fireflies. Lady beetle larvae treated with a commercial formulation of 2,4-D had significantly shorter larval durations and those treated with the active ingredient of dicamba alone and 2,4-D combined with dicamba were significantly physically smaller (Freydier and Lundgren 2016 p. 1273). Further, larvae treated with field levels of a commercial formulation of 2,4-D, the active ingredient of dicamba, and 2,4-D combined with dicamba died significantly sooner compared to control treatments (Freydier and Lundgren 2016 p. 1272-1273). The 2,4-D commercial formulation, what would be purchased and sprayed by applicators, caused 80% mortality of lady beetles (Freydier and Lundgren 2016 p. 1274), indicating the use of 2,4-D products could cause mortality of the Bethany Beach firefly.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

Prior to the mid-1990s, fireflies were collected in numbers reaching over three million per year for at least 50 years in 25 states the United States for chemical extraction of luciferase, their light producing enzyme (Lewis 2016 pp. 128–132). Luciferase is use to detect if a cell is living or dead through its use of adenosine triphosphate as a source of energy, a chemical reaction used in medical and food safety research beginning in the 1940s (Lewis 2016 p. 128). Although scientists now produce luciferase synthetically, at least one company is still selling firefly products and at least one different company paid collectors for 40,000 wild caught fireflies as recently as 2014 (Lewis 2016 pp. 130–131).

Firefly harvest generally targets the more visible males but because the sex ratio is assumed to be one to one and females only mate, on average, twice in their lifetimes, the lack of males will result in lower female fecundity (Bauer et al. 2013 p. 47). Male harvesting causes population extinctions, especially if the mating efficiency of the firefly population is low (Bauer et al. 2013 p. 48), which is to be expected in the very rare Bethany Beach firefly. Because fireflies generally do not disperse, any repeated collection of the Bethany Beach firefly for commercial purchases in any of its habitats will result in increasingly lower abundances due to lower mate availability and fecundity and, in turn, local extinction. It is not known if the Bethany Beach firefly is directly threatened with commercial harvesting, but it cannot be ruled out as threat (Bauer et al. 2013 pp. 43–44).

Other Natural or Manmade Factors Affecting its Continued Existence

Loss of prey

Regional and local declines in terrestrial mollusks may further impact firefly larvae, which rely on soft-bodied snails and slugs (as well as earthworms and other invertebrates) for food. Larvae are voracious predators, requiring a steady food supply to support their development to adulthood.

However, their food sources face many of the same threats, including habitat loss and fragmentation and pesticide use. Climate change also poses a serious threat to terrestrial mollusks, including drought, temperature extremes, and increased frequency of extreme weather events (Nicolai & Ansart 2017 pp. 1–17). Non-marine mollusks (both freshwater and terrestrial species) are among the most imperiled animals on the planet. This group has the highest number of documented extinctions of any major taxonomic group in the world; 42% of the 693 recorded extinctions of animal species between the years 1500 and 2003 are mollusks (Lydeard et al. 2004 p. 322). Yet actual numbers of extinctions are likely much higher, given the relatively little research and conservation attention that invertebrates receive and the fact that many species remain undescribed or unknown to science. The status of Delaware's mollusks is not well known, yet twenty-one species of land snails (nearly 30% of all documented species) and five species of freshwater snails are listed as Species of Greatest Conservation Need in the state's Wildlife Action Plan (Delaware Division of Fish and Wildlife 2015 chap. 1, pp. 97-99)

Invasive species

Invasive plants can severely threaten the long-term health of natural ecosystems, especially vulnerable habitats such as wetlands. Nearly a quarter of the world's most invasive plants are wetland species, many of which form dense monocultures that crowd out native species, lower biodiversity, and alter ecological processes (Zedler & Kercher 2004 p. 445). Coastal freshwater swales in the mid-Atlantic are characterized by high plant diversity dominated by *Juncus* spp. (rushes) and to a lesser extent *Euthamin tenuifolia*, *Mikania scandens*, and *Polygonum* sp. within *Myrica-Baccharis* shrub thickets (Heckscher and Bartlett 2004 p. 351). These swales are commonly invaded by non-native plants such as *Typha angustifolia* (cattail), *Phragmites australis* (European or common reed), and *Phalaria arundinacea* (reed canary grass) as well as *Pinus thunbergiana* (Japanese black pine) (McAvoy 2018 pp. 6–7). Clonal, invasive *Typha* sp. and *Phragmites* sp. are difficult to control, form dense stands that outcompete native vegetation, and provide little to no food or shelter for native species (Whigham et al. 2019 pp. 625–626, 635). Further, their invasion is enhanced by prior disturbance like dredging or changes in the water level due to aquifer drawdown (Odum & Harvey 1988 p. 154) or sea level rise. Because the Bethany Beach firefly depends on these specific wetland habitats, invasive plants threaten the survival of its populations by degrading or eliminating required habitat.

Dense stands of invasive European or common reed *Phragmites australis*, in particular, are dominant along the Atlantic coast. Common reed is responsible for animal community changes wherever it gets established and has been identified as a threat to *Pyractomena ecostata* fireflies that inhabit brackish tidal marsh areas along the Delaware coast (Heckscher & Lloyd 2015 p. N36). In salt marshes in nearby New Jersey where common reed has replaced native *Spartina alternifolia* (cordgrass), the arthropod communities have shifted from herbivores to detritus and algae feeders, indicating that there are few natural herbivores of common reed (Gratton & Denno 2006 pp. 627–628). Another study on the Lower Connecticut River found that epifaunal gastropods were less abundant where common reed had invaded salt marshes previously dominated by *Spartina patens* and *Juncus gerardi* (Talley & Levin 2001 p. 58). Gastropods are the main prey for the Bethany Beach firefly and if they struggle in invaded swales then the firefly will not have the resources to sustain populations. Restoration efforts can be successful and are needed to return arthropod and plant communities to native conditions

(Gratton & Denno 2005 pp. 364, 366) that will allow the Bethany Beach firefly to thrive in remaining and restored habitats needed for recovery of this endangered species.

Disease or Predation

Many fireflies produce or obtain defensive compounds known as lucibufagins--highly toxic chemicals that protect them from predators. Yet despite the bad taste afforded by these chemicals, and the warning glows and cautionary colors that many species advertise, fireflies contribute to the diets of a number of other animals, particularly invertebrates. Spiders are the most well documented invertebrate predators of fireflies (Lloyd 1973 pp. 101–102). For example, De Cock et al. (2014 p. 1296) observed numerous instances of spider predation on *Phausis reticulata* by orb weavers and sheet web weavers. Under daylight conditions in the lab, Long et al. (2012 p. 84) noted predation by jumping spiders. Numerous other invertebrates have been observed feeding on fireflies, including harvestmen, cobweb spiders, assassin bugs, and hangingflies (Lewis et al. 2012 pp. 2–3). Vertebrate predators appear to be more affected by firefly toxins and predation by these animals occurs less frequently.

It is unknown if the Bethany Beach firefly is threatened by disease or site-specific predators. However, for species like the Bethany Beach firefly that are already experiencing decline within an extremely limited range, natural rates of predation and disease can compound existing threats.

The Inadequacy of Existing Regulatory Mechanisms

To the extent that any non-regulatory mechanisms exist to protect the Bethany Beach firefly, FWS cannot rely on such measures to deny listing of species. Unenforceable conservation efforts are simply *per se* insufficient as "regulatory mechanisms" under 16 U.S.C. 1533(a)(1)(d):

> [T]he Secretary may not rely on plans for future actions to reduce threats and protect a species as a basis for deciding that listing is not currently warranted . . . . For the same reason that the Secretary may not rely on future actions, he should not be able to rely on unenforceable efforts. Absent some method of enforcing compliance, protection of a species can never be assured. Voluntary actions, like those planned in the future, are necessarily speculative . . . . Therefore, voluntary or future conservation efforts by a state should be given no weight in the listing decision (*Oregon Natural Resources Council v. Daley,* 6 F. Supp.2d 1139, 1154-155 (D. Or. 1998).

As demonstrated in this petition, the threats faced by the Bethany Beach firefly are not adequately addressed by any existing regulatory mechanisms. The only adequate regulatory mechanism available to save the Bethany Beach firefly starts with listing it under ESA.

The 26 miles of Atlantic coastline in Delaware encompasses a variety of barrier islands and estuary systems that share space with several cities and state parks. Currently, three state parks in Delaware protect about 3200 ha (8000 acres) of these coastal ecosystems including: Cape Henlopen State Park, Delaware Seashore State Park, and Fenwick Island State Park. The Bethany Beach firefly is primarily found in these three parks and in one area north of Bethany Beach imminently threatened by development. As such, the potential regulations that could impact Bethany Beach firefly conservation include State Park regulations as well as the Delaware State Endangered Species Act, Delaware Wildlife

Action Plan (DWAP), Delaware State Comprehensive Outdoor Recreation Plan (SCORP), and the Delaware Pesticide Discharge Management Plan.

The Bethany Beach firefly is listed as an endangered species by the Delaware Division of Fish and Wildlife at the state level, yet despite knowledge of the perilous state of this firefly the Delaware state endangered species program and state park management plans do not provide any significant or species specific regulations regarding the conservation of the Bethany Beach firefly. The Delaware Endangered Species code allows for the designation and removal of species listed as endangered and also contains a section (§601 of Title 7) that declares: "the importation, transportation, possession or sale of any endangered species of fish or wildlife, or hides or other parts thereof, or the sale or possession with the intent to sell of any article made in whole or in part from the skin, hide or other parts of endangered species of fish or wildlife is prohibited, except under license or permit from the Division" (Delaware Division of Fish and Wildlife 2013b p. 1). Beyond prohibiting the possession or sale of endangered species, there are no other protections, including no population or habitat protections. In addition, while this could potentially provide protection for the threat of commercial overutilization of the Bethany Beach firefly, there is no enforcement language or mechanism for monitoring the transportation, possession or sale of the firefly.

The overarching management plan for rare species in Delaware is the Delaware Wildlife Action Plan (DWAP). The DWAP "...provides information on the distribution and abundance of species, including low population and declining species, which is indicative of the diversity and health of wildlife in a state" (Delaware Division of Fish and Wildlife 2015 chap. 1, p.7). The DWAP highlights the Bethany Beach Firefly as a species of greatest conservation need and is listed as a Tier 1 species (Delaware Division of Fish and Wildlife 2015 p. iv). There is clear concern that Delaware could lose its only endemic species (Delaware Division of Fish and Wildlife 2015 chap. 1, p.89), however the DWAP is only an informational document for land managers and state employees, has no recommended concrete actions, and its use is voluntary. The DWAP does not have the force of law, nor has it resulted in any enforceable laws or regulations regarding habitat designation, take, pesticide application, or even monitoring programs for the Bethany Beach firefly.

The state of Delaware recognizes that the Bethany Beach firefly is particularly vulnerable to losing its specific freshwater, interdunal habitat, "[t]hese wetland systems are particularly vulnerable to sea level rise and will unlikely persist without direct habitat management" (Delaware Division of Fish and Wildlife 2015 p. iv). The DWAP outlines several recommendations for endangered species regarding the threats of lack of habitat planning, loss of interdunal swales, disturbance from recreation and residential development (Delaware Division of Fish and Wildlife 2015 chap. 4, p.152). There are no local or state protections for freshwater wetlands in the state of Delaware (Wilson and Lauria 2019 pp. 4, 6; Lauria 2019 p. 5). The DWAP suggests that "coordinated monitoring...can be undertaken to adaptively manage the habitat..." (Delaware Division of Fish and Wildlife 2015 pp. iv–v). Despite this suggested action, there is no current monitoring program for the Bethany Beach firefly or its habitat. Without monitoring it is impossible to track the status of the population as it responds to the threats outlined in this petition. Suggested actions and recommendations are not regulatory mechanisms and *per se* inadequate for species conservation.

At the level of state parks in Delaware, the State Comprehensive Outdoor Recreation Plan is concerned primarily with regulating the recreational pursuits of state park patrons. This plan does not

mention the Bethany Beach firefly or any specific endangered species. The primary conservation tool for the state is the Open Space Program through the Delaware Land Protection Act which has the goal to connect wildlife habitat by purchasing more land for the state park system but also does not contain language on the Bethany Beach firefly or endangered species in general. Additionally, the Delaware Pesticide Discharge Management Plan offers no specific regulations for endangered species despite knowledge that "All fireflies are suspect of being sensitive to pesticide application" (Delaware Division of Fish and Wildlife 2015 chap. 1, p. 91).

The state of Delaware is home to two federally-listed endangered species, the leatherback sea turtle and the hawksbill sea turtle, and four federally-listed threatened species: the Red Knot, northern long eared bat, piping plover, and the bog turtle. These species have no critical habitat in Delaware nor are they offered any protections or concessions in state park management plans. There are no other federally listed species that have designated critical habitat within the range of the Bethany Beach Firefly. Several species have overlapping ranges, but without critical habitat designation and listing on the federal ESA, the voluntary actions recommended by the DWAP or any other land management plans discussed above will not protect the Bethany Beach firefly or the specific interdunal freshwater swale habitat required for this species.

Lack of Threat Amelioration

Existing regulations fail to protect interdunal swale habitats necessary for the firefly's survival, especially considering the threats of urbanization, habitat loss, and fragmentation, pesticide use, climate change, and overall pollution. The firefly's freshwater swale habitat is classified as ephemeral wetlands and interdunal swales. These need blanket protection from development and dredging, as do the aquifers that supply freshwater (Odum & Harvey 1988 pp. 153–154). Current proposed weakening of the Clean Water Act would directly impact the Bethany Beach firefly, as the Act would no longer protect ephemeral wetlands (University of New Hampshire 2019 p. 1; Lauria 2019 pp. 5–6).

While six out of seven last known remaining populations of the Bethany Beach firefly occur on state park land, this is a passive protective measure that will not protect the beetle from many threats, including the sea level rise that imminently threatens the species in these areas (Heckscher 2014 p. 1). State parks in Delaware are at risk of losing 37-44% of their protected land to sea level rise by 2100, depending on the climate scenario (Delaware Coastal Programs 2012b p. 54) (Figure 7). Listing under the ESA would protect critical habitat, restrict pesticide use, control disturbance, provide for mitigation, and raise awareness of this rare firefly throughout its range, providing the only adequate regulatory mechanism for its protection.

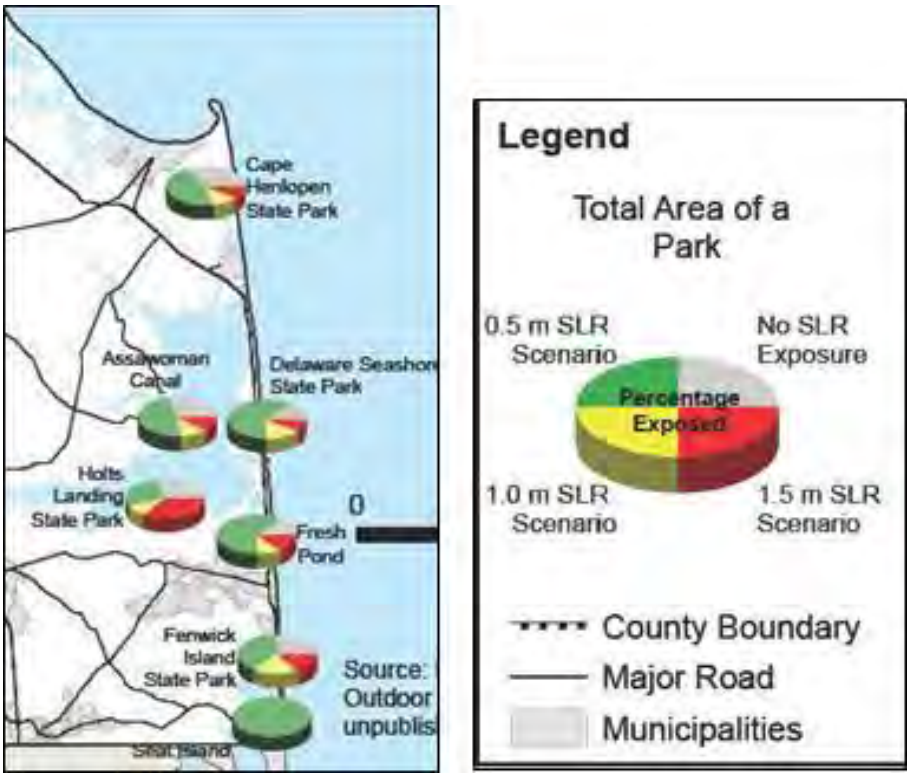


Figure 7. Projected inundation of State Parks in Sussex County, Delaware at low, medium, and high climate change scenarios corresponding to 0.5, 1.0. 1.5 m (1.6, 3.3, 4.9 ft) sea level rise, respectively. The State Parks are inundation with even 0.5 m rise (From Delaware Coastal Programs 2012b p. 58).

Delaware state regulates pesticide spraying at the state level through the Department of Natural Resources and Environmental Control (DNREC). This body approves larvicide and adulticide applications in state parks for mosquito control as well as on county land and private land if there is adequate threat to public health. The DNREC relies on spraying standing pools as well as fog trucks and aerial spraying. The guiding documents for mosquito control in Delaware are the Delaware Pesticide Discharge Management Plan and Chapter 19 of the state health and safety code. These documents mention the impact to "non-target" species as a concern, but fail to provide provisions that lend protection to particular species or endangered species. Title 16-Chapter 19 regarding mosquito control merely states that "control measures...not be injurious to pets, livestock or wildlife" (State of Delaware 2019 p. 150).

Delaware recognizes that collateral damage to non-targets from mosquito spraying is inevitable and acknowledges that "...Mosquito Control Section is of course very concerned that there are no unacceptable non-target impacts...whenever we must conduct our spray operations" (Delaware Mosquito Control Section 2012 p. 42). In addition, applicators are able to decide "[w]hat might be any special non-target species concerns...are there threatened or endangered species concerns?" (Delaware Mosquito Control Section 2012 p. 48). However, this concern does not imply any oversight or regulation as to how and when pesticide use may be curtailed to protect imperiled or endangered species. Without specific language that applicators are not allowed to conduct mosquito control operations that can adversely harm an endangered or rare species or their habitat, this language is per se inadequate for protecting the Bethany Beach firefly.

Lack of Connected Quality Habitat

Connectivity is essential to the protection and recovery of the Bethany Beach firefly, as freshwater interdunal swales occurred up and down the coastline prior to the current anthropogenic habitat destruction that restricts the firefly to areas primarily within state parks separated by urban expanses. If a population were to go locally extinct at a site, individuals from different sites are unlikely to recolonize the area without human assistance since fireflies are weak fliers and rarely disperse beyond the habitat in which they were born.

The Bethany Beach firefly needs ESA protection to ensure a metapopulation support system of stepping stone habitats so that it is able to recolonize suitable habitat if a local extinction occurs, especially as is imminent at the Tower Shores development. The loss of the Tower Shores population will impact the entire species due to the loss of a key source population connecting the other remaining populations. Loss of the Tower Shores population, which is about 8.9 km (5.6 miles) and 5.3 km (3.3 miles) from Fenwick and Delaware Seashore State Parks, respectively, would put the two State Park populations 14.2 km (8.9 miles) apart, a significant distance for any insect, let alone a weak flying and low dispersing firefly. The most isolated population at Cape Henlopen, if still present, is in very low abundance (only one individual at last survey) and it is at least 14.3 km (9.0 miles), away from the nearest population in Delaware Seashore State Park.

In addition, within sites, the Bethany Beach firefly has specific microhabitat requirements that require research, monitoring, and management for its survival, both in and around the state parks to protect and expand its range for recovery. For example, interdunal freshwater swales could be restored or created and maintained by drilling wells into confined freshwater aquifers (Odum & Harvey 1988 p. 151) in conjunction with removal of invasive species and protection from recreational pressures. These management activities are required to create quality habitat for increased local and landscape connectivity. Listing the Bethany Beach firefly under the ESA is the only way to provide its habitat and populations with appropriate monitoring and management within the parks but also give it the chance to survive and recover in its entire historical range.

Request for Critical Habitat Designation

We urge the Service to designate critical habitat for the Bethany Beach firefly concurrent with its listing. Critical habitat as defined by Section 3 of the ESA is: (i) the specific areas within the geographical area occupied by a 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) the 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)).

Congress recognized that the protection of habitat is essential to the recovery and/or survival of listed species, stating that: “classifying a species as endangered or threatened is only the first step in ensuring its survival. Of equal or more importance is the determination of the habitat necessary for that species’ continued existence… If the protection of endangered and threatened species depends in large

measure on the preservation of the species' habitat, then the ultimate effectiveness of the Endangered Species Act will depend on the designation of critical habitat." H. Rep. No. 94-887 at 3 (1976).

Critical habitat is an effective and important component of the ESA, without which the Bethany Beach firefly's chance for survival significantly diminishes. Petitioners thus request that the Service propose critical habitat for the firefly concurrently with its listing.

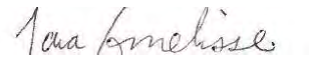
Conclusion

In this petition, we have carefully assessed the best scientific and commercial information available regarding the Bethany Beach firefly, including the historic, present, and future threats faced by the beetle and have determined that the species is in imminent danger of extinction throughout its range and in immediate danger of extinction with the destruction of its biggest population at the Tower Shores development and presence in very low abundances in the most isolated population at Cape Henlopen. Thus, we urge emergency 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 indicating that the petitioned action may be warranted" 16 U.S.C. § 1533(b)(3)(A).

There is no question that protecting the Bethany Beach firefly is warranted under the Act 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 potentially threatened by 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation;. The Bethany Beach firefly is imperiled by all five factors, but most significantly by factors one, four, and five, as evidenced in this petition. There are no existing regulatory mechanisms which are adequate to protect the Bethany Beach firefly. Listing of the Bethany Beach firefly as an endangered species is the only way to provide continued existence for a species that would otherwise be a guaranteed victim of the synergistic threats of urbanization, habitat degradation, climate change, and pesticides. Conserving this firefly would in turn conserve the unique dune and swale ecosystems of the Mid-Atlantic Coast of the United States. A prompt decision to move forward with the emergency listing of the Bethany Beach firefly is required to save this species from extinction.

Please contact me at 971-717-6425 and/or tcornelisse@biologicaldiversity.org if you have any questions or need any clarification on the above information.

Sincerely,



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