Species Status Assessment Report

for the

Bethany Beach Firefly (*Photuris bethaniensis*)

February 2024
Version 1.0

Photo credit: Jason Davis, Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife

U.S. Fish and Wildlife Service
North Atlantic Appalachian Region

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EXECUTIVE SUMMARY

The Bethany Beach firefly (*Photuris bethaniensis*) is a small firefly endemic to freshwater interdunal swales within 500 meters of the Atlantic shoreline in Delaware, Maryland, and Virginia. After the discovery of the species in 1949, 1951, and 1968, there were no additional reports until the species was discovered in 8 of 18 interdunal swales surveyed in a 25-km (15.5-mi) stretch of Delaware's Atlantic shoreline from 1998 to 2000. Following the onset of annual surveys for the species in 2019, this species is now found in three Delaware state parks, and was discovered on Assateague Island National Seashore in Maryland in 2020, and three properties in Virginia in 2021. One location on a private property in Delaware is presumed to be extirpated since 1998 following habitat destruction due to development. Due to limited survey effort, neither the historical nor current distribution of the Bethany Beach firefly is well understood, and swales have only been thoroughly mapped and field-verified in Delaware. Therefore, the species may exist in additional locations within the known range, and additional habitat may exist within the range of the species (Maryland and Virginia) or potentially outside of the known range, such as in New York, New Jersey, North Carolina, and South Carolina where interdunal swale habitat has been described with similar plant communities where the species is known to occur.

Bethany Beach firefly habitat consists of swales that form as freshwater from groundwater and rain collect in shallow depressions between coastal sand dunes. Water levels within the swales vary from standing water to saturated soil, and they can become flooded or dry out completely. These communities are dynamic systems and are susceptible to saltwater intrusion and shifting sand formations. For viability, the species requires habitat conditions at the individual level to promote growth, successful reproduction, and survival during its life stages (egg, larvae, pupae, and adult). For a population to be resilient, enough habitat and resources need to be available to meet the needs of the larger population. Species redundancy and representation require a relatively widespread distribution of a large number of populations and adequate connectivity of habitat that allows connected populations to repopulate each other after catastrophes.

The viability of the Bethany Beach firefly is most restricted by a lack of habitat, stemming from urbanization and development of much of its original range. The extant populations are now isolated among properties with presumably no genetic transfer among them, leaving these small populations at increased risk of impacts from random stochastic and unforeseen catastrophic events. While habitat loss from development is mostly a historical threat, habitat loss has been documented in the recent past due to development on private lands; while the threat of continued habitat loss on the public properties from development is less likely, there may be continued habitat loss in areas where habitat has not yet been mapped and in the Delaware State Parks for infrastructure and energy projects. Other habitat stressors resulting from land uses and practices are still ongoing threats to this species, including light pollution and habitat degradation resulting from recreation, use of insecticides (mosquito spraying), and invasive plants.

However, the greatest threat to the Bethany Beach firefly's continued viability is the compounding effects of climate change which includes increasing temperatures and drought, more frequent and severe storm events, and sea level rise. Rising sea levels in addition to more frequent and severe storm events threaten to first degrade and then remove habitat due to increased periodic inundation and then total inundation at some height above current sea levels.

Based on observations of Bethany Beach firefly movements, we assume that swales within 305 m (1,000 feet) of each other are accessible by individuals and close enough that reproduction and gene flow could occur between them and that there is little to no dispersal of individuals between swales greater than this distance apart. Therefore, we grouped swales within that distance into complexes, which were used as our analytical unit, or a proxy for a population. Because swales have not been mapped for Virginia, and we only have detection locations, we grouped the survey locations instead of the swales into complexes if they were within 305 m (1,000 ft) of each other. Given the wide-ranging survey effort rather than repeated surveys at a swale, we consider the entire complex occupied if any swale within that complex has documented detections. We consider the population within each complex "current" if the Bethany Beach firefly was detected there since 2019, the start of the most recent survey period.

Range-wide, we identified 143 swales in 31 complexes, with each complex containing between one and 19 swales. Fifteen complexes are current, having detections since 2019, and these contain 36 total occupied swales (Table 5).

Current condition information for the Bethany Beach firefly consists of presence-only detection information and property-level assessment of threats. Therefore, we are unable to classify resiliency for this species using more typical data of population abundance or trends. While we cannot estimate resiliency in a typical approach, we provide the distribution of occupied swales and complexes across the range and threats by property (Table 5). The Bethany Beach firefly appears to exist as 15 complexes (populations), with between 1 and 5 occupied swales per complex. Most complexes have varying levels of existing stressors, including invasive Phragmites, lighting, mosquito spray, and nearby development; however, two complexes, one each at Chincoteague National Wildlife Refuge and False Cape State Park, have few if any current stressors. Two properties, Delaware Seashore State Park and Assateague Island National Seashore, have over half of the occupied complexes; Delaware Seashore has fewer current stressors than Assateague Island National Seashore (see Table 5).

Redundancy and representation for this species are likely reduced from historical levels, as habitat has been lost to development. However, it is unknown what the full range of this species was historically or is today.

For our estimates of future condition, we accounted for sea level rise (SLR), modeled using recent National Oceanic and Atmospheric Administration (NOAA) projections, and considered the related effects of high tide flooding (HTF). We modeled both threats for 2040, 2070, and 2100 (approximately 15, 45, and 75 years into the future), to estimate the condition of the Bethany beach firefly.

Infrequent HTF is not expected to substantially impact the Bethany Beach firefly, while more frequent HTF could affect this species by keeping areas flooded with saltwater for lengthy periods. As the frequency of HTF is expected to increase in the future, we are using 0.55 m (1.8 ft) of height above the SLR values to account for effects to habitat due to this increasingly frequent HTF. Thus, we added the 1.8 ft of rise to the projected SLR height values to obtain the height above current sea level that is likely to be impacted by HTF in the future at each scenario.

If habitats are inundated by SLR in future scenarios, they are no longer considered habitat, and we assume the Bethany Beach firefly will be extirpated from those areas. Habitats that are projected to experience HTF but not full inundation are considered degraded due to repeated habitat disturbance.

To assess the impact to each complex and the amount of habitat that would be lost or degraded due to SLR for each scenario, we assessed the number of swales that would be lost or degraded by SLR for each complex. We then quantified the relative magnitude of impact to resiliency based on the percentage of swales in each complex that are projected to be lost or degraded by SLR, as shown in Table A. We assume resiliency will decline within a complex if swales are degraded or lost. We assume no resiliency remains if all of the swales are lost to inundation. For complexes known to be occupied, we assume a loss of all potential habitat would indicate extirpation of that complex.

Table A. Relative magnitude of negative impact to resiliency of a complex based on the percent of the swales within it that are degraded or lost due to sea level rise. These impact levels are relative to each other and not meant to portray actual levels of impact.

Impact	Percent of Swales	
	Degraded	Lost
↓	< 50	< 20
↓↓	≥ 50	20 to 50
↓↓↓	NA	> 50
extirpated	NA	100

Under an intermediate climate scenario, 9 of the 15 existing complexes see some level of impacts by 2040, and all but one are impacted by 2070 (Table B). At least one complex is projected to be extirpated by 2070, and at least seven become extirpated by 2100. Only one complex remains without any impacts by those timesteps. We therefore expect resiliency to decline in all populations with impacts. Overall redundancy and representation are also expected to decline by 2070, given these extirpations (Table B).

Under a high climate scenario, 9 of the 15 existing complexes see some level of impacts by 2040, and all but one are impacted by 2070 (Table B). At least one complex is projected to be extirpated by 2040, with at least five projected to be extirpated by 2070. All but two are projected to be extirpated by 2100. All complexes have some level of impacts by 2100. We therefore expect resiliency to decline in all populations with impacts. Overall redundancy and representation are also expected to decline by 2040, given these extirpations (Table B).

Table B. Relative magnitude of negative impact to resiliency of each complex at each timestep and under each scenario for the 15 current complexes of Bethany Beach firefly. Magnitude levels are based on percentages of swales in each complex lost or degraded as provided in Table B.

				Total	2040		2070		2100	
State	Property	Complex	Status	Swales	Int	High	Int	High	Int	High
DE	Cp. Henlopen	DE_CAHE_03	Current	5	↓	↓	↓↓	↓↓	↓↓↓	↓↓↓
	DE Seashore SP	DE_SESP_06	Current	4	↓↓	extirpated	extirpated	extirpated	extirpated	extirpated
		DE_SESP_08	Current	19	↓↓	↓↓	↓↓	↓↓↓	extirpated	extirpated
		DE_SESP_09	Current	5	none	none	↓↓	mod	extirpated	extirpated
		DE_SESP_10	Current	5	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
	Fenwick Is. SP	DE_FENSP_16	Current	14	↓	↓	↓↓	↓↓	↓↓↓	extirpated
MD	Assateague Island	MD_ASIS_01	Current	6	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_02	Current	8	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_03	Current	6	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_04	Current	13	none	none	↓↓	↓↓	↓↓↓	extirpated
VA	Chincoteague	VA_CHIN_04	Current	7	↓↓	↓↓↓	↓↓↓	extirpated	extirpated	extirpated
	Wallops Island	VA_WALL_02	Current	3	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
		VA_WALL_03	Current	3	↓↓	↓↓	↓↓	↓↓↓	↓↓↓	extirpated
		VA_WALL_05	Current	4	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
	False Cape SP	VA_FCSP_06	Current	5	none	none	none	none	none	↓↓

CHAPTER 1 – INTRODUCTION

1.1 Background

This report summarizes the results of a Species Status Assessment (SSA) conducted for the Bethany Beach firefly (*Photuris bethaniensis*), a small firefly endemic to freshwater interdunal swales within 500 meters (1640.42 ft) of the Atlantic shoreline in Delaware, Maryland, and Virginia. We (the U.S. Fish and Wildlife Service (Service)) received a petition from the Center for Biological Diversity (CBD) and Xerces Society for Invertebrate Conservation to list the Bethany Beach firefly as a threatened or an endangered species under the Endangered Species Act (ESA) in May 2019.[1] The Service issued a 'substantial' 90-day finding on December 19, 2019.[2] We prioritized the Bethany Beach firefly status review using the July 2016 methodology[3] for prioritizing status reviews, as a Bin 5 (species for which there is little information on status and threats to inform a petition finding). Accordingly, the current National Listing Work Plan[4] indicates that we are scheduled to make a decision on whether or not the Bethany Beach firefly warrants listing as an endangered species or threatened species under the ESA in Fiscal Year 2024.

1.2 Analytical Framework

The SSA report, the product of conducting a SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the ESA.

This SSA report for the Bethany Beach firefly is intended to provide biological support for the decision on whether or not to propose to list the species as threatened or endangered and if so, whether or not to propose designating critical habitat. The process and this SSA report do not represent a decision by the Service whether or not to list a species under the ESA. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the Bethany beach firefly. The listing decision will be made by the Service after

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[1] The petition is available at https://www.biologicaldiversity.org/campaigns/saving-the-insects/pdfs/Bethany-beach-firefly-petition.pdf.
[2] The 90-day finding is available at https://www.regulations.gov/docket?D=FWS-R5-ES-2019-0088.
[3] Methodology for prioritizing status review and accompanying 12-month findings on petition for listing under the ESA is available at https://www.fws.gov/project/national-listing-workplan-prioritization.pdf.
[4] The FY 22-27 National Listing Work Plan can be viewed at https://www.fws.gov/project/national-listing-workplan.pdf

reviewing this document and all relevant laws, regulations, and policies, and a decision will be announced in the Federal Register.

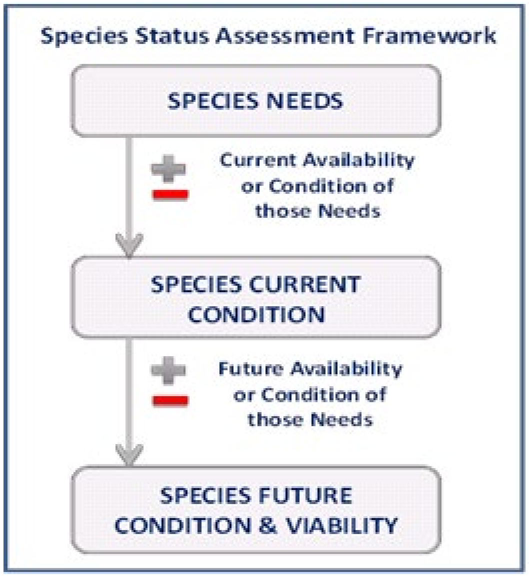

Figure 1. Species Status Assessment Framework

Using the SSA framework (Figure 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Smith et al. 2018, entire). For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in natural ecosystems within a biologically meaningful timeframe.

Resiliency, redundancy, and representation are defined as follows:

Resiliency means having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, population size, if that information exists. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.

Redundancy means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

Representation means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

The decision whether to list a species is based *not* on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the species by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species and forecasting the most likely future condition for each scenario in terms of the 3Rs. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures.

CHAPTER 2 – SPECIES INFORMATION

2.1 Taxonomy and Genetics

Fireflies are beetles (Class Insecta, Order Coleoptera) of the Family Lampyridae. Fireflies that emit light in flashes are termed lightning bugs (Lloyd 2018, p. 15). The Bethany Beach firefly is a member of the *Photuris versicolor* species complex which contains many closely related species distinguishable primarily by flash pattern due to few morphological differences (Barber 1951, entire; McDermott 1953, pp. 35-37; Lloyd 2018, pp. 14). The best available information indicates the Bethany Beach firefly is a unique species and valid taxon (McDermott, 1953, pp. 35 –37; Lloyd 2018, pp. 93–94) based on its small size, distribution of pronotal (a prominent plate-like structure that covers all or part of the thorax of some insects) pigmentation, and flash pattern (number of flashes, duration of the flash, and amount of time between flashes) of the male. The species is listed as a valid taxon in the Integrated Taxonomic Information System (ITIS) database (ITIS 2023).

The Bethany Beach firefly may be part of a species complex (related morphologically and phylogenetically) that occurs within appropriate habitat south to the Florida Everglades (Lloyd pers. comm. In Heckscher and Bartlett 2004, p. 349). Genetic and cladistics research to clarify taxonomic relationships within the species complex are ongoing (Faust 2017, pp. 180-185; Heckscher et al. 2021, p. 2). The University of Massachusetts has been conducting genetic sequencing of Bethany Beach fireflies collected in Delaware, Maryland, and Virginia. Individuals collected from Maryland and Virginia sequenced out closely to the Delaware individuals (Andersen 2023, unpublished data).

The currently accepted classification is (ITIS 2023, entire):

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Coleoptera
Family:	Lampyridae
Genus:	Photuris

2.2 Species Description

The Bethany Beach firefly (*Photuris bethaniensis*) is a small firefly endemic to freshwater interdunal swales within 500 meters (1640.42 feet (ft)) of the Atlantic shoreline in Delaware, Maryland, and Virginia. It measures 9.0-10.75 millimeter (mm) (0.35-0.42 inches (in)) long and 3.5-4.0 mm (0.14-0.16 in) wide. It has a tan to light brown body, with dark brown or black markings. It is distinguished from other Photurid species by its relatively small size and black pronotal mark (black mark on the head) that is densest toward the apical edge. Additionally, it has a distinct flash pattern and coloration, consisting of a double green flash emitted about every 5 seconds. A full description of the species can be found in McDermott (1953, pp. 35-37).

Bethany Beach firefly was first collected in August 1949 from what was described as a grassy area near the Atlantic Ocean north of the town of Bethany Beach, Delaware. In 1951, the species was again collected from the same site and an additional site two miles south of Bethany Beach by Frank McDermott and described in 1953 (McDermott 1953, pp. 35–37). James E. Lloyd collected the only additional Delaware specimens during 1968 near Bethany Beach (Lloyd pers. comm. In Heckscher and Bartlett 2004, p. 349). The exact locations of where these individuals were collected are unknown.

Species Protection Status

The Bethany Beach firefly has a global NatureServe rank of G1, or critically imperiled, with all known occurrences in danger from sea level rise (SLR) and invasive species (Nature Serve 2023, p. 1). In Delaware, the species is listed as an endangered species at the state level by the Delaware Division of Fish and Wildlife (DE Division of Fish and Wildlife 2023, 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 2021, p. 1). The Delaware Division of Fish and Wildlife may designate species as a State Endangered Species if it meets one or more of the following criteria:

1. Appears on the federal list of endangered, threatened, or candidate species; or
2. Ranked as "globally rare" (G1, G2, G3, T1, T2, or T3), which means 100 or fewer populations worldwide; or
3. Is rare or declining within the State and rare or declining in the region, or;
4. Is rare in Delaware and disjunct from known distribution and/or near the extreme northern or southern limits of distribution; or
5. Is imminently threatened by natural or human-made factors that are affecting continued survival of that species within the State.

However, beyond stating the prohibition of the possession or sale or endangered species, there are no population or habitat protection sections in the Delaware Endangered Species code. There is review of projects that are proposed on state lands for these species (Davis pers. comm., 2023a).

In Maryland, the species is currently designated as S1 (critically imperiled/highly state rare), which is defined as "At very high risk of extinction or extirpation due to very restricted range, very few populations or occurrences, very steep declines, very severe threats, or other factors. Typically occurring in five or fewer populations" (MD Natural Heritage Program 2023, pp. 4–6). Species designated as S1 do not receive regulatory protections under the state's Nongame and Endangered Species Conservation Act (Annotated Code of Maryland 10-2A-01 as cited In Maryland Natural Heritage Program 2023, p. 2). On May 6th, 2023, the MD Natural Heritage Program submitted an element decision form that recommended the species change rank from S1 to S1 Endangered. This will be included in the next package of listing changes which should become effective in 2024 (M. Ferlauto pers. comm., 2023). In program review, Maryland Endangered species receive protections from Maryland's State Nongame and Endangered Species Conservation Act (Annotated Code of Maryland 10-2A-01). These protections prohibit the take, possession, transport, and sale of listed species. However, Maryland does not designate critical habitat for endangered species directly.

The species currently has no protective status in Virginia.

2.3 Species Distribution

The Bethany Beach firefly is endemic to freshwater interdunal swales (hereafter referred to interdunal swales or swales) within 500 meters (1640.42 ft) of the Atlantic coast in Delaware, Maryland, and Virginia (Figure 3). After the discovery of the species in 1949, 1951, and 1968, there were no additional reports until the species was discovered in 8 of 18 interdunal swales surveyed in a 25-km (15.5-mi) stretch of Delaware's Atlantic shoreline from 1998 to 2000. At that time, the species was found at Fenwick Island State Park, Delaware Seashore State Park, the Tower Shores development (privately owned land, Figure 2), and Cape Henlopen State Park (Heckscher and Bartlett 2004, pp. 349-352).

Annual surveys for the species were initiated in 2019 (see Section 5.1.1), and this species can now regularly be found in Delaware Seashore State Park, Fenwick Island State Park, and in one swale in Cape Henlopen State Park. Roadside surveys of the Tower Shores development (see Chapter 4, Habitat Loss, Fragmentation, and Degradation) were conducted in 2019 but no fireflies were observed from the road. We assume this interdunal swale has been lost due to the construction of an elevated roadway and cul-de-sac supported by pilings which covers the entire swale (Figure 2) and has likely altered the hydrology and vegetation due to shading.

Figure 2. Elevated road and cul-de-sac at the Tower Shores interdunal swale (private land). Photo from Bright MLS.

In 2020, Bethany Beach firefly was captured at the northern end of Assateague Island National Seashore in Maryland, marking the first record of the species outside of Delaware (J. Davis pers. comm. as cited In Hobson 2021, p. 2). The Assateague Island National Seashore specimens were verified morphologically by Dr. Heckscher of Delaware State University in 2021 (J. Davis, pers. comm as cited In Hobson 2021, p. 2). Surveys occurred in 2022 and 2023 resulting in the discovery of additional interdunal swales in which the species is present (see Chapter 5 Current Condition).

In Virginia, surveys were conducted in 2021, and double flashes were observed at Chincoteague National Wildlife Refuge (Assateague Island in Virginia), National Aeronautics and Space Administration (NASA) Wallops Island Flight Facility, and False Cape State Park. Morphological verification by Dr. Heckscher in 2023 confirmed the NASA Wallops Island Flight Facility, False Cape State Park, and Chincoteague National Wildlife Refuge are Bethany Beach firefly (Davis pers. comm., 2023b). Information regarding presence on each property is summarized in Table 1.

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Table 1. Historic and current presence of Bethany Beach firefly.

State	Property	1951	1998	2020	2021	Presence 2019 to 2023
DE	Fenwick Island State Park	Discovered	Present			Present
DE	Private Land N. of Bethany Beach		Discovered			Absent
DE	Cape Henlopen State Park	no survey	Discovered			Present
DE	Delaware Seashore State Park	no survey	Discovered			Present
MD	Assateague Island National Seashore			Discovered		Present
VA	Chincoteague National Wildlife Refuge				Discovered	Present
VA	NASA Wallops Flight Facility				Discovered	Present
VA	False Cape State Park				Discovered	Present

Thus, the known extant populations in Delaware exist within three Delaware State Parks that are separated by development, as well as limited private properties (Figure 3). The Delaware properties are also separated from Assateague Island National Seashore due to development. Assateague Island National Seashore is adjacent to Chincoteague National Wildlife Refuge, but NASA Wallops Island Flight Facility is separated from Assateague Island by approximately 2.1 km (1.3 mi) of water. False Cape State Park is the most isolated known property, located at the southernmost coast in Virginia, approximately 137 km (85 mi) from NASA Wallops Island Flight Facility, the closest known location of Bethany Beach Firefly (Figure 3).

However, due to limited survey effort and incomplete mapping of swale habitat, the full range of the Bethany Beach firefly is unknown, and the species may exist within additional swales within the known range or in unmapped habitat inside or beyond the known range (see Section 5.1.1, Potential Habitat) such as in New York, New Jersey, North Carolina, and South Carolina where interdunal swale habitat has been described with similar plant communities where the species is known to occur. While the amount of survey effort conducted in New Jersey is unknown, McDermott (1953, p. 36) stated that he had looked for the species and was unable to detect it. And the late Dr. Lloyd had a collection of coastal fireflies from New Jersey but did not find Bethany Beach firefly. However, Lloyd and McDermott had not made the habitat association of Bethany Beach firefly with interdunal freshwater wetlands which occurred in 1998 (Heckscher and Bartlett 2004, entire; Heckscher pers. comm., 2023).

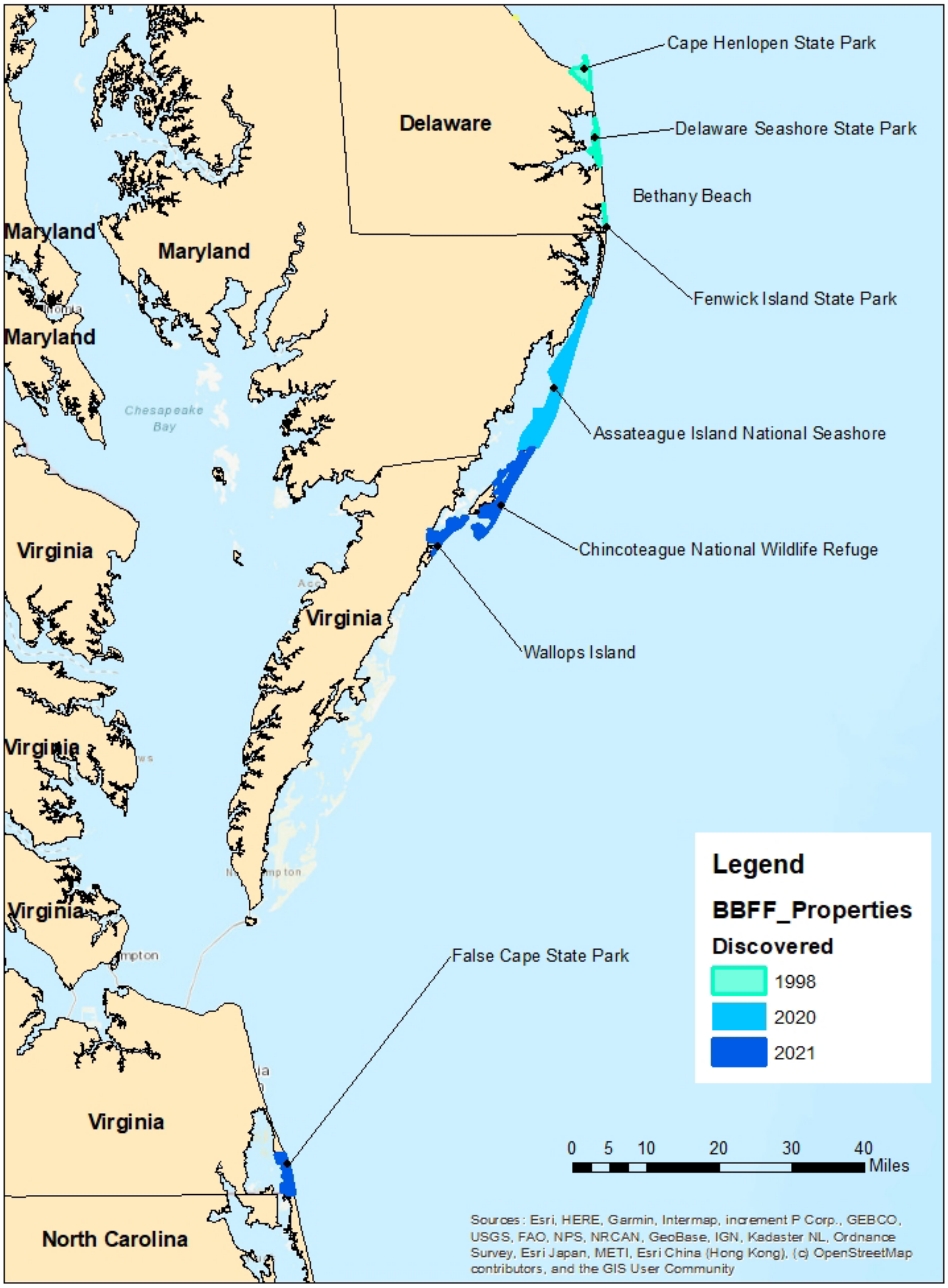

Figure 3. Historical and current distribution of Bethany Beach firefly.

2.4 Biology and Life History

Little information is known or available on the life history of the Bethany Beach firefly. Thus, we have relied on the best available scientific information for other closely related species to help summarize life history characteristics of this species.

Fireflies are widely recognized for their charismatic flashing, though not all adult fireflies produce light. Flashing species can produce light in a variety of yellow, orange, and green colors at varying luminosity (light intensity). They also vary in the timing and frequency of flashes. The variety of flash patterns and colors among species may be an evolutionary adaptation to help conspecifics recognize each other in areas where multiple species may be mating at the same time. In some species, only the females can flash, which they use as a signal to attract mates. In the Photuris genera, both males and females flash. Typically, males flash first and then the females flash in response or emit a low glow (Buschman 2017a, pp. 14–15). Environmental factors, such as air temperature and humidity, may affect the frequency of flashes by increasing the interval between flashes. Periodic flashes were also observed in *Photuris versicolor quadrifulgens* and *Photoris tremulans* in both males and females flying on vegetation. The function of periodic flashes is unknown but could be a warning signal to potential predators (Buschman 2017a, p. 15). Many female Photoris are aggressive mimics using flash signals to lure males of other species which they capture and consume as prey (Lloyd 1965, pp. 653–654). These aggressive mimic flashes can be confused with courtship flashes, particularly when the prey is another Photuris male (Buschman 2017b, p. 41).

Flight patterns can also vary by genus. For example, *Photuris* males typically fly high, around trees and tall shrubs while *Photinus* fly over fields and lawns or hover around low herbs (Faust 2017, pp. 112-179; p. 181).

Fireflies generally have a two-year generation time (Fallon et al. 2022, p. 5) but some larva may develop over a period of 3 to 4 years (Buschman pers. comm., 2023). Like other beetles, fireflies complete metamorphosis with four distinct life stages: egg, larva, pupa, and adult, as shown in Figure 4. The longest stage is the larva stage (Fallon et al. 2022, p. 5, Lloyd 2018, pp. 5–7; Faust 2017, p. 39). Firefly larvae are typically found in habitats containing moisture (Barrows et al. 2008, pp. 49–50). Larvae of *Pyractomena lucifera*, a firefly occurring in freshwater marshes in the eastern U.S., were found to be dietary generalists, consuming snails, worms, other soft-bodied invertebrates, and plant material such as berries (Buschman 1984a, p. 536; Buschman 1984, pp. 14–15). Observations of Photuris larvae in the field have found that they glow while they are motionless, resting, or hiding. The duration and pulses of glow depends on activity and the species (Buschman 2019, pp. 10–11). Response glows (long lasting glows) may be a signal warning of toxic or deterrent chemicals to ward off predators (Buschman 2019, p. 19). Adults are active from mid-late June through early-mid August (Faust 2017, p. 231; Davis pers. comm., 2023c). Most adults do not feed, however, some females of the genus Photuris feed as adults by mimicking the female flash patterns of other firefly species (Photinus*,* Photuris, Pyractomena*,* and Robopus) to lure in males for consumption. In doing this, females sequester toxins called lucibufagins, which are produced by other firefly species (Lloyd 1975, pp. 452–453; Heckscher et al. 2021, p. 4; Faust 2017, p. 54).

As observed in surveys conducted in Delaware since 2019, Bethany Beach fireflies fly fast and high and likely could travel to find another wetland as long as there are no impermeable barriers. They have been observed flying over salt marshes, tall phragmites, and in upland dunes. They have also been observed flying from one wetland to another, then disappearing as they seemingly fly to another wetland out of sight (Davis 2023c, pers. comm.; Heckscher et al. 2021, accessed December 21, 2023).

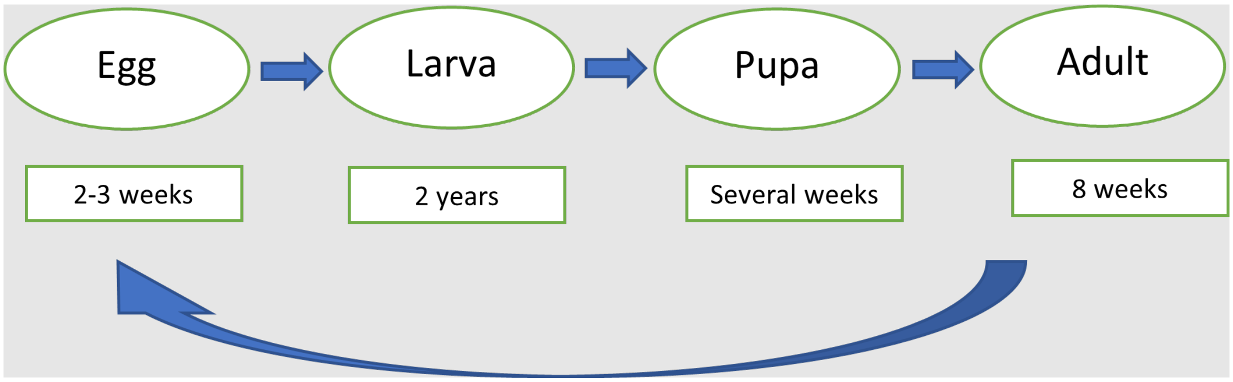

Figure 4. Diagram of Bethany Beach firefly life cycle. From Fallon et al. 2022, p. 5.

2.5 Habitat

Bethany Beach firefly are most commonly found in interdunal swales found within 500 m (1640 ft) from the shoreline (Heckscher and Bartlett 2004, p. 350) (Figure 4). These swales form as freshwater from groundwater and rain collect in shallow depressions between coastal sand dunes (Nature Serve Explorer 2023). Water levels within the swales vary from standing water to saturated soil, and they can become flooded or dry out completely (Heckscher and Bartlett 2004, p. 4). Like other Photuris species, Bethany Beach larvae are likely found most of the time on the moist soil surface or directly under the soil surface to overwinter since they are not well adapted to burrowing underground (Lloyd 2018, p. 6, Fallon et al. 2022, p. 5).

Vegetation in interdunal swales is dominated (> 50 percent cover) by grasses and forbs including common three-square needlerush (*Schoenoplectus pungens)*, needlepod rush (*Juncus scirpoides),* sedges *(Carex* spp.), ferns, raspberry (*Rubus* sp.), common reed (*Phragmites aust*ralis), and a variety of tree species, mostly in the sapling stage. These habitats can also be dominated (> 50 percent cover) by dense shrub thickets of groundseltree (*Baccharus halimifolia)* and bayberry (*Morella cerifera)* or surrounded by these species to form a bowl-like structure to the interdunal swales (McAvoy and Clancy 1994, p. 3). In several Delaware sites and the Maryland site, there is also an abundance of salt marsh hay (*Spartina patens*), particularly at sites that have been influenced by saltwater intrusion (Davis pers. comm. 2023c; Ferlauto pers. comm., 2023) Swales that seemed to maintain the highest numbers of Bethany Beach firefly in Delaware showed evidence of temporal stability as judged by the presence of dense shrub thickets of bayberry and groundsel tree surrounding the swale (Heckscher and Bartlett 2004, p. 350). Once established, bayberry-groundsel tree swales may persist for more than 100 years (Young et al. 1995, p. 638). At False Cape State Park in Virginia, surrounding shrubby vegetation as seen in Delaware, Maryland, and other sites in Virginia (bayberry, groundseltree) was replaced by live oak scrub (*Quercus virginiana*) in some cases (Hobson 2021, p. 8). Interdunal swales in Delaware which Bethany Beach firefly were present during surveys from 1998 to 2000 ranged in size from 500 m^2 (5381.96 ft^2) to 5,000 m^2 (53819.55 ft^2) (Heckscher and Bartlett 2004, p. 350). Some of the swales in Maryland and Virginia in which the species is present are several acres in size (Hobson 2021, p. 3; USFWS 2022, unpublished data).

Interdunal swale communities are dynamic systems and are susceptible to saltwater intrusion and shifting sand formations. The creation of an interdunal wetland plant community likely takes decades. A depression must first form (likely due to extreme winds that blow out unvegetated areas) that is close enough to the groundwater table for water to pond, and/or of sufficient depth to hold precipitation. Wetland plants then become established over time. A thin layer of peat develops from decomposing vegetation and from below ground roots. Natural succession occurs that often fluctuates between open canopy, herbaceous communities, to closed canopy, shrub and tree communities. Woody plants become established when the depression wetlands or swales are dry for consecutive years. So, periods of drought trend towards shrub and tree communities. But if the swales are flooded for consecutive years, then the woody plants die and a herbaceous community then develops from plants that have seed banked. So, successional directions fluctuate over time, from open herbaceous communities, to closed canopy woody communities, to open herbaceous communities. This occurs when the ecosystem is in balance. But when you account for invasive species (*Phragmites australis*) and groundwater pumping (from development), natural processes become disrupted and habitat can be degraded over a shorter time period (several years to a decade) (McAvoy pers. comm., 2024).

Figure 5. Interdunal swale with *Phragmites australis*, *Schoenoplectus pungens*, *Spartina patens*, *Morella cerifera* at the south end of Chincoteague National Wildlife Refuge observed during 2021 Bethany Beach firefly surveys, Accomack County, Virginia. Photo credit: Chris Hobson, VA DCR

2.6 Summary of Species Information

The Bethany Beach firefly is a member of the *Photuris versicolor* species complex which contains many closely related species distinguishable primarily by flash pattern and morphology. Bethany beach firefly is a nocturnal firefly characterized by two bright green flashes given off by males to attract females for mating, while females flash or emit a low glow in response. Adult Bethany Beach fireflies are active from mid-late June through early-mid August and emerge well after sunset. The species is found in interdunal swales that form as freshwater from groundwater and rain collects in shallow depressions between coastal sand dunes. Suitable swale habitat is dependent on an intermediate stage of succession (woody and herbaceous open swales) that is naturally driven by periodic dune overwash from storm surge. The species is now present along the Atlantic Coast in Delaware, Maryland, and Virginia.

CHAPTER 3- SPECIES NEEDS FOR VIABILITY

3.1 Individual-Level Resource Needs

At the individual level, Bethany Beach firefly require suitable conditions to promote growth, successfully reproduce, and survive during each life stage (Table 2). They require temporally stable swale habitat that typically has woody shrubs along the perimeter and that retains shallow freshwater seasonally. Moisture is needed for all of the life stages to prevent desiccation. Stable swales are filled with ample organic matter which provides overwintering and sheltering habitat for larvae (Heckscher and Bartlett 2004, p. 352; Fallon et al. 2022, p. 5). Signaling occurs over woody shrubs and females perch on ground vegetation (Davis pers. comm., 2023c). Wet areas of the swales also support potential larval food sources such as snails, worms, and soft bodied invertebrates (Heckscher et al. 2021, p. 4).

Table 2. Individual needs of the Bethany Beach firefly at each life stage.

Life stage	Habitat	Needs	Citation
Egg	Interdunal swales	Moist soil is needed so eggs don't desiccate	Borrows et al. 2008, p. 47
Pupae	Interdunal swales	Habitat needs are unknown	Lewis, pers. comm., 2023
Larvae	Interdunal swales	Moist soil and decaying wood; potential sources of food include snails, worms and other soft bodied invertebrates, and plant material such as berries	Buschman 1984, p. 536
Adults	Interdunal swales; woody vegetation (*Baccharus/Morella*) surrounding the swale where adults can fly above to find mates.	Males and females are in close enough proximity and able to flash to find and select mates, copulate, oviposite, and disperse.	Lloyd 2018, p. 18

3.2 Population and Species Level Needs

At the population level, the species requires swales that are periodically disturbed through storms and overwash to prevent succession from occurring. Swales will eventually succeed to maritime forest if succession is not offset by periodic saltwater intrusion. Populations are dependent on an intermediate stage of succession (woody and herbaceous open swales). The open nature of these swales allows for buildup of organic matter which provides habitat for larvae. For the Bethany Beach firefly to be viable, there must be resilient populations and adequate redundancy and representation throughout its range. Relatively widespread distribution of populations and suitable habitat are needed for the species to have adequate resiliency. Redundancy improves with increasing numbers of populations; increased distribution of individuals across the species range; and connectivity of habitat that allows connected populations to repopulate each other after catastrophes such as major coastal storms. Representation improves with the persistence of populations spread across the range of environmental conditions, genetic diversity, and ecological diversity within the species. Long-term viability will require resilient populations to persist into the future.

CHAPTER 4 – FACTORS INFLUENCING VIABILITY

In the following discussion, we summarize negative and positive factors that may affect the viability of the Bethany Beach firefly (Figure 6). Information was gathered through firsthand accounts and through published information regarding the species and its habitat areas. As a result, we have identified two major factors affecting viability: habitat loss and fragmentation/ degradation (i.e., development, light pollution, recreation, grazing, insecticide and herbicides, invasive plants, woody plant encroachment, shoreline erosion control, and small population size) and climate change. Two other factors that were also assessed include conservation and predators and pathogens. These factors are not currently influencing the viability of the species.

While definitions will be further described in Chapter 5 (Current Condition), for the purposes of providing context for this chapter, we define the species as "present" if a swale had at least one survey during the 2019 to 2023 survey period where the species was observed and confirmed. If the survey or surveys conducted at a swale did not observe Bethany Beach firefly, the survey result was concluded as "not detected." Those swales never surveyed are identified as "not surveyed."

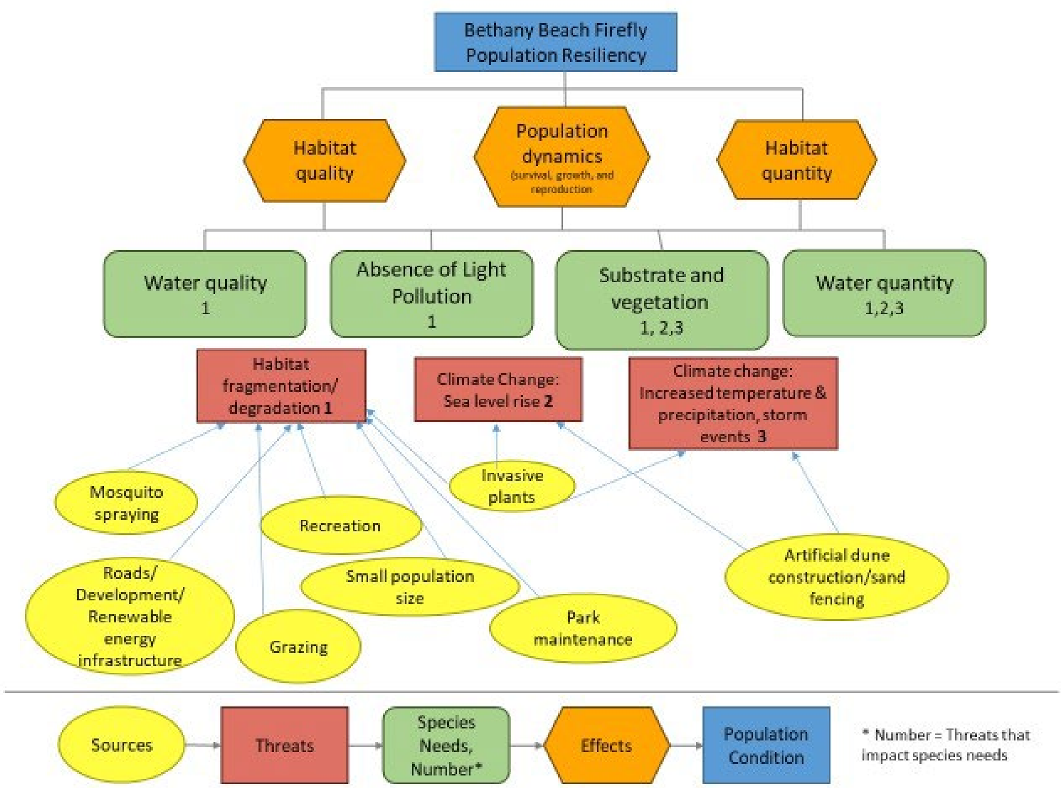

Figure 6. Threats on the needs and viability of Bethany beach firefly and influences driving these threats.

4.1 Habitat Loss, Fragmentation, and Degradation

4.1.1 Development

Because the Bethany Beach firefly is believed to be a habitat specialist restricted to interdunal freshwater swales and likely has limited dispersal (Lewis et al. 2020, p. 159), destruction and degradation of swales results in the loss or decline in populations and decreases connectivity between populations. Sandy ocean beaches are some of the most popular tourist and recreational areas, and constitute some of the most valuable real estate, in the United States (Hapke et al. 2011, p. 2). These Atlantic coastal areas are the sites of high-density residential and commercial development, despite the frequent natural hazards that can occur, including flooding, storm impacts, and coastal erosion. Extensive areas along the Atlantic Coast (Bethany Beach, Dewey Beach, Delaware; Ocean City, Maryland; and Virginia Beach, Virginia), likely contained additional swale habitat prior to development that primarily occurred between 1950 and 1970 after the completion of the Chesapeake Bay bridges (Delaware Department of Natural Resources and Environmental Control 2004, p. 27). There is evidence that the populations of Bethany Beach firefly in Delaware are much reduced from their historic levels. Lloyd (2018, p. 93) noted that the two sites where the Bethany Beach firefly was originally observed and described by McDermott (1953, p. 35) near Bethany Beach, Delaware have been lost to development. When Heckscher and Bartlett conducted surveys from 1998 to 2000 in Delaware (2004, pp. 349-352), the species was found in swales in three state parks but also in a swale located on privately owned land in the Tower Shores Beach Community. The swale in Tower Shores was one of the largest-known global populations, consisting of an estimated 100 or more adults in the 1990s. The property was recently developed, and the population that was previously there is now believed to be extirpated: an elevated roadway has altered hydrology and creates shade, while a cul-de-sac has been built over the entire swale, and lighting from the houses has degraded the surrounding area; no fireflies have been observed in surveys since construction was finished.

Contributing to the loss of these swales is the lack of a rigorous regulatory framework to protect them from development. Although the Clean Water Act regulates the discharge of fill into waters of the United States, habitat utilized by the Bethany Beach firefly likely does not meet the definition of waters of the United States. In 2023, the Supreme Court in *Sackett v. Environmental Protection Agency* narrowed the definition of “waters of the United States,” holding that they consist of streams, oceans, rivers, lakes, and wetlands contiguous with those waterbodies. 598 U.S. 651, 678. Because the interdunal swales on which the species depends are seasonal and separated from the navigable waters by dunes, they are not likely to be considered waters of the United States. As a result, the Clean Water Act in most circumstances would prohibit discharges of fill materials to the swales.

A pre-*Sackett* example of the vulnerability of Bethany Beach firefly habitat is the aforementioned development of the Tower Shores residential community just outside of Bethany Beach. The construction of Tower Shores required the construction of roadways and driveways in interdunal wetlands that were known to contain a population of Bethany Beach fireflies. The Army Corps of Engineers, however, determined that a discharge permit was not required because the roads and driveways would be raised, and therefore would not result in discharges of fill material (Wilson and Lauria 2019, p. 4). Roadside surveys of this wetland were conducted in

2019, after construction of Tower Shores, but no fireflies were observed. As a result, it is believed that this population of Bethany Beach fireflies was extirpated due to loss of suitable habitat (e.g., shading of vegetation and reduced hydrology from the elevated roadway and cul-de-sac, along with light pollution from the houses).

State law also does not prevent destruction of the swales via development. Non-tidal wetlands under 400 acres (161.87 ha) in size are not regulated in Delaware (Delaware Wetlands Act, 7 Del. Code, Chapter 66) and the Wetlands Regulations (7 DE Admin. Code 7502)). Since many of the swales are smaller than 400 acres, the Delaware Wetlands Act would not regulate development of the swales. Non-tidal wetland laws are stronger in Maryland and Virginia but some suitable habitat that occurred historically was likely lost due to development (Ocean City, Maryland and Virginia Beach, Virginia) prior to these laws being established. The Maryland Non-Tidal Wetlands Act (1989) limits development in and around tidal wetlands (Md. Env. Code § 5-907.b). Similarly, in Virginia, developers must obtain a water protection permit before disturbing any wetland, tidal or non-tidal, or stream by clearing, filling, excavating, draining, or ditching. Although non-tidal wetland laws are stronger in Maryland and Virginia, there is still loss of habitat when permits are issued for development. However, the significant habitat loss that occurred prior to these regulations being enacted, has likely limited the Bethany Beach firefly's distribution in these states.

Bethany Beach fireflies are made more vulnerable by their populations' relative isolation from one another. Based on observations from surveys conducted for the species since 2019, we assume that interdunal swales located within 1,000 feet (304.8 m) of an occupied swale would allow for dispersal of the Bethany Beach firefly into that habitat. The known extant populations in the Delaware State Parks have connectivity within each park but not among the parks due to development of the shoreline between state parks. The Delaware Parks are also separated from Assateague Island National Seashore due to development and open water. While Assateague Island National Seashore, Chincoteague National Wildlife Refuge, and NASA Wallops Island Flight Facility are in proximity to one another in Maryland and Virginia, and are not separated by developed areas, dispersal of individuals among these properties is not known to occur due to distances of occupied swales from each other. False Cape State Park is to the south near the North Carolina/Virginia border and is not close to any other known populations of Bethany Beach fireflies. Without additional suitable habitat occurring within the dispersal distance of the species, it is unlikely that Bethany Beach firefly could relocate if their habitat is destroyed (Lewis et al. 2020, p. 159).

Even in the parts of their range that are protected from development, Bethany Beach fireflies also face indirect impacts, such as habitat degradation. With the exception of NASA Wallops Island Flight Facility, which does not allow public access to the shoreline, the sites in which the species is currently present occur primarily on public lands that receive high numbers of visitors for recreational use of the beaches and border developed areas. As a result, the habitat in these areas is not pristine: the public lands themselves have significant infrastructure, such as parking lots, roads, trails, bathrooms, and visitor centers; and these parks are also adjacent to residential development at varying densities, with the highest densities occurring adjacent to the Delaware Parks. Both in-park and adjacent development or infrastructure could destroy or degrade swales, alter swale hydrology, degrade water quality, and decrease connectivity among or between swales. Maintenance operations conducted in the past at the three Delaware State Parks may have impacted, drained, or filled in interdunal swales, notably some with populations of Bethany Beach firefly or other firefly species of conservation concern. Several swales in which the species is present show evidence of filling, ditching, mowing, dumping, and heavy equipment use (Davis pers. comm., 2023d).

However, impacts from development are not equally distributed among all public lands where occupied swales occur. Development is less of a threat where the species occurs in Maryland and Virginia because the density of development surrounding the properties where it occurs is low. Assateague National Seashore is separated from the mainland of Maryland by Chincoteague Bay; therefore, it is not adjacent to any development occurring outside of the park. There is very little infrastructure (e.g., lights, roads and buildings) throughout Assateague, although there are roads and lights from a drive-in campground adjacent to one swale complex. There is also little infrastructure near the occupied swales at Chincoteague National Wildlife Refuge and False Cape State Park in Virginia; only a two-lane road and some buildings occur adjacent to the three occupied swale complexes at NASA Wallops Island Flight facility. This is in contrast to Delaware, which has more infrastructure in the parks, a major highway visible from almost all of the swales running adjacent to two of the parks (Delaware Seashore State Park and Fenwick Island State Park), and a higher density of residential development surrounding the parks. However, four populations at Assateague National Seashore and all the populations at NASA Wallops Island remain vulnerable due to altered hydrology from roads, which is evident due to the presence of the non-native plant species *Phragmites australis* in those swales (see Invasive Plant section below).

Currently, the greatest threat of development is at Delaware Seashore State Park, where a planned desalinization project could entail directional drilling adjacent to an occupied swale and two proposed offshore wind projects with possible landfall locations for the cable route occurring near interdunal swales (3 Rs and Tower Road). It is anticipated that the two wind projects will be constructed within the next 10 years. For the Maryland Wind Biological Opinion, the project description includes avoiding land disturbance, including Horizontal Directional Drilling, within 100 feet (30.5 m) of any swale; a time-of-year restriction for the use of any light sources between June 1 and Sept 1 for any work at the 3Rs parking lot or Tower Road parking lot proposed landfall sites; and avoiding installation of permanent light fixtures at the Tower Road site. With these measures, there would be no anticipated impacts to the Bethany Beach firefly. The Service has not gone through Section 7 consultation yet on the second project. It is unknown whether directional drilling has occurred at the desalinization plant at this time.

Development can disrupt the groundwater regimes that sustain interdunal swales both directly and indirectly. Development directly affects the hydrology of swales by increasing impervious surfaces and compacting soils in adjacent areas, thereby reducing groundwater recharge and eventually lowering the water table (Wright et al. 2006, p. 22). Indirectly, development results in depletion of groundwater by increasing the number of groundwater users in the area. A decrease in groundwater recharge will lower the water table and could result in swales becoming drier over time. Alteration of hydrology can also lead to an increase in invasive plants and woody vegetation, a change in herbaceous vegetation, and succession in the wetland resulting in loss of wetland habitat over time. Development adjacent to the properties in which the species occurs is greatest in Delaware (Delaware Seashore State Park and Fenwick Island State Park).

Stressors on groundwater supply are projected to increase in the future throughout the range of the Bethany Beach firefly. Within the HUC4 basin (Delaware-Mid Atlantic Coastal, which includes coastal areas of Delaware, Maryland, and Virginia) where a majority of the swale complexes are found, freshwater yield (from surface or ground water) is predicted to decrease by 10 percent while the demand is expected to increase 80 to 100 percent between 2046-2070 (when compared to a baseline from 1985-2010) (Brown et al. 2019, p. 225). Much of this is driven by climate change, and its effect on water use in multiple sectors, like agriculture (increased evapotranspiration) and energy use (increased temperatures) (Brown et al. 2019, p. 226). Demands higher than yields can result in reduced groundwater storage, which can reduce the quantity and quality of available swale habitat and decrease the resiliency of Bethany Beach firefly.

More detailed information on the threat of development can be found in the Species Status Assessment (Service 2024, pp. 17 –20).

4.1.2 Light Pollution

Many firefly species, including the Bethany Beach firefly rely on bioluminescent light to find mates and to ward off predators. Their flash color, length, and frequency are unique among the different species. Both male flash patterns and female response are species-specific to prevent hybridization (Lloyd 1966, p. 65; Stanger-Hall and Lloyd 2015 In Owens and Lewis 2022, p. 2). Courtship dialogues are thought to be essential for mate success in nocturnal fireflies, as the males of most species are presumed not to use visual (color) or chemical (pheromone) cues and thus have no other method of locating receptive females (Demary et al. 2005 In Owens and Lewis 2022, p. 2).

Artificial light changes the night-time ambient brightness which can change the intensity and timing of firefly flashes (Owens and Lewis 2018, p. 13). Bethany Beach firefly are phototactic which means they are attracted to light of any kind, including artificial light (Lloyd 2018, p. 94). Artificial light at night can reduce reproduction by affecting mating signals which prevents mates from finding each other and/or prevent males from receiving the correct light cues to begin their nocturnal flashing display (Lewis et al. 2020, pp. 160–161).

The effect of light pollution varies depending on the species and type of lighting (Owens and Lewis 2018, p. 13). The older mercury vapor lighting tend to emit light with longer wavelengths in the yellow and red color spectrum while the newer LED lighting tend to emit shorter wavelength light in the blue and green end of the spectrum. A study conducted in the Piedmont region of Maryland showed a 50 percent reduction in firefly flashing in lighted trials using a mercury vapor lamp (Costin and Boultin 2016, p. 1209). A study conducted in the Shenandoah Valley of Virginia with LED lighting found that a lighted trial resulted in a reduction of flashing by *Photuris versicolor* by 70 percent and reduced courtship behavior and mating success in *Photinus pyralis* (Firebaugh and Haynes 2016, p. 1207, 1209). A more recent study used artificial illumination similar to the intensity of a dim streetlight. Twenty-eight out of twenty-nine males (96.6 percent) preferentially approached the dark control imitation female rather than the imitation female that was illuminated by artificial light (Owens and Lewis 2022, p.8). That same intensity of artificial light supressed mating activity of semi-nocturnal *Photinus obscurellus* pairs in the field, while a brighter intensity completely prevented mating in the laboratory (Owens and Lewis 2022, p. 8). However, permanent artificial light sources had no apparent impact on mate success among the females of two other species, *Photinus pyralis* and *Photinus marginellus*, although these females tended to move away from the most brightly illuminated areas of habitat (Owens and Lewis 2022, p. 8).

Recent research has also found that males are less abundant (Hagen et al. 2015 In Owens and Lewis 2022, p. 2; Owens et al. 2022, p. 200) and less active near artificial light (Owens and Lewis 2021, p. 203; Costin and Boulton 2016, p. 85; Firebaugh and Haynes 2019, p. 1207; Owens et al. 2022, p. 8). When illuminated by artificial light of any color or intensity, male flash rate of *Photinus obscurellus* fireflies decreased significantly to 5.4 ± 0.1 patterns min^{-1} (Z-ratio $= -8.687$, $P < 0.0001$). Males produced the fewest flash patterns under amber light but flashed at approximately the same rate under light of other colors. Light treatment intensity had no effect on male flash nor was there an interaction between light treatment color and intensity (Owens and Lewis 2021, p. 203). Both males and females were found to modify their flash behavior under downwelling illumination, with males tending to increase but females tending to decrease the conspicuousness of their flashes (Owens and Lewis 2021, p. 203; Firebaugh and Haynes 2019, p. 1207; Owens et al. 2022, p. 8). Female responsiveness depended on the color and intensity of the light treatment in question, with dim blue and dim red light being the least disruptive and bright amber light the most disruptive (Owens and Lewis 2021, p. 206).

Previous research also indicates that larval fireflies limit their foraging activity under bright artificial illumination (Wanjiru et al. 2020 In Owens and Lewis 2022, p. 8, Owens and Lewis 2021a, p. 4). However, long-term exposure to artificial light at night (50 lux) did not impact overall survivorship or the duration of egg, larval, and pupal stages in *Photuris spp.* and *Photimus obscurellus* fireflies, both of which spend most of their larval lifespan underground. It did accelerate weight gain of Photuris larvae by possibly prolonging perceived daylength, assessed before or during nightly foraging bouts on the soil surface and thus delaying diapause (Owens and Lewis 2021a, p. 4; Owens et al. 2022, p. 10).

Light pollution is more of an issue in the Delaware parks which are adjacent to development and infrastructure.

Delaware

Delaware Seashore State Park
One light source at the Indian River Life Saving Station is adjacent to two swales where the species is present. This light is used primarily during events or nighttime educational programs and shines light into the swales when used. The state biologist has coordinated with Park staff to put the light on a timer so it doesn't impact fireflies during their flight period. The timer has failed in the past. Park staff are currently looking into options to retrofit the light so it is less intrusive (Davis pers. comm., 2023d).

There is also a light on the air station at Conquest Road that aims directly into two swales. Bethany Beach firefly has not been detected at these swales, but it is likely this light has made these swales unsuitable over time as the habitat is in good condition and there are Bethany Beach firefly present in nearby swales with no light issue (Davis pers. comm., 2023d).

There is a blue light illuminating the fire control tower at Tower Road. It doesn't shine directly into the swales but the illumination with blue light at a high elevation could disrupt mating behavior of the firefly in the nearby swale complex (four swales in which the species is present) located across the road. Additionally, the parking lot that bisects this swale complex gets heavy use at sunset as there is a beach parking lot where visitors can view the sunset. The park closes at sunset but cars drive past these swales until ~ 10PM on some nights and light pollution from cars is heavy at times (Davis pers. comm., 2023d).

There is also a light on a pole illuminating the parking area of the Old Inlet Bait and Tackle shop that is shining into three swales in which the species is present (Davis pers. comm., 2023d).

Fenwick Island State Park
The power company helped replace a light along Route 1 in Fenwick Island State Park that was shining into two swales where the species is present. This helped reduce the light entering the swales but this fixture still needs an additional shroud to further reduce the light. Many of the swales in which Bethany Beach firefly are present are located along Route 1, which consistently has heavy traffic during the flight season of the species. One swale in which the species is present also has residential lighting from the north shining into it (Davis pers. comm., 2023d).

Maryland
There is likely some night-time light from vehicles and campers in the drive-in campground that is adjacent to four swales in which the species is present. Once the area is converted to a walk-in campground, there will be less night-time light from camping (Huslander pers. comm., 2023).

Virginia
There are no lighting sources near swales in which the species is present at Chincoteague National Wildlife Refuge and False Cape State Park. Most external lighting used on NASA Wallops Island Flight Facility is amber to minimize impacts to sea turtles, some of the structures on the island also have FAA-required lighting that may not be amber, and night operations may use white lighting for mission-specific work for as short a duration as possible (Miller pers. comm., 2023).

4.1.3 Recreation and Grazing

Because the species' occurrence is almost entirely on state or federal parkland where visitation is high due to recreational use of the beach, there is the potential for foot traffic in the dunes which could result in trampling adults and larva and if they are using flashlights at night could temporarily impact flashing during mating. Trampling of adult females and larvae, destruction of microhabitat that support fireflies, and increased light pollution have been identified as risks associated with increased numbers of visitors in parks in other parts of the country (Faust 2010, pp. 213, 215; Lewis et al. 2020, pp. 163–164).

Delaware

Over 8 million people visited Delaware State Parks in 2022, many of them going to the parks with beach access. The most visited state park in 2022 was Cape Henlopen with 1.9 million visitors, accounting for almost one in four of all park visits (DNREC 2023). There are two dune crossings located at Fenwick Island State Park. One of those crossings is located 350 feet (106.68 m) from a swale in which the Bethany Beach firefly is present (Davis 2023d, pers. comm.).

Maryland

Assateague Island National Seashore has approximately 3 million visitors each year. There are six dune crossings adjacent to swale habitat where the species is present located near a campground. However, all the other swale habitat where the species is present is located in areas of the island that does not have camping. There are ponies on the island that graze and walk through the swales, damaging the soil and vegetation more than would be expected from visitors walking through the swales (Huslander pers. comm., 2023). Grazing could result in crushing eggs and larvae in the soil.

Virginia

On NASA Wallops Island Flight Facility, All Terrain Vehicle (ATV)/Off Road Vehicle (ORV) access is not permitted in the wetlands (Miller pers. comm., 2023). There is the potential for vehicle or foot traffic in the swales for the purposes of protected species and predator monitoring or wetland delineation. There is also a recreational beach on NASA Wallops Island Flight Facility, but that is only available to installation personnel and is not in close proximity to the swales in which the species is present.

At Chincoteague National Wildlife Refuge and False Cape State Park, there is no potential for people to walk through interdunal swale habitat and there is no ATV or ORV use (Holcomb pers. comm., 2023; Swain pers. comm., 2023). At Chincoteague, ponies do graze north of Southwest Flats where suitable interdunal swale habitat is/may be present.

4.1.4 Pesticide Use

Pesticides are substances that are used to control pests and include herbicides, which are used to control vegetation, and insecticides, which are used to control insects; both have the highest use in agriculture. While some agricultural pesticides have shown negative affects to fireflies in laboratory studies (Wang et al. 2022, entire; Pearsons et al. 2021, entire) the exposure of Bethany Beach fireflies to agricultural use of pesticides and herbicides is minimal at most. Bethany Beach fireflies occur on barrier islands or within 500 m (1,640 feet) of the coastline. These areas do not have agriculture nearby and on barrier islands there is extensive separation from mainland agricultural areas. There may be some garden and home use of pesticides in beach communities on the barrier islands, but the overall use in these areas would be relatively small and the sites occupied by Bethany Beach firefly are primarily on undeveloped public land. Thus, we do not view agricultural pesticide use as a potential threat to Bethany Beach firefly and will not discuss that here. The main source of exposure to pesticides is the spraying to control mosquitoes in some areas and some limited herbicide use.

Although only a few studies have investigated direct effects of herbicides and insecticides on fireflies, broad-spectrum insecticides are known to adversely affect numerous nontarget insects and other taxa (reviewed by Sanchez-Bayo 2011, Pisa et al. 2015).

Herbicides

The Bethany Beach firefly currently faces a low threat from herbicides. There is some control of *Phragmites australis* (common reed) in interdunal swales at Assateague National Seashore, and exposure to herbicides could occur from control of invasive vegetation in and near swales. We expect exposure would be low because the only park that reported control of invasives in interdunal swales was Assateague National Seashore. Imazapyr and glyphosate are active ingredients commonly used to control the invasive vegetation using high pressure or low pressure foliar spray application, primarily during the fall months, although imazapyr can be used at any time during the growing season.

Imazapyr is part of the imidazolinone chemical class, and is a systemic, non-selective, pre- and post-emergent herbicide used for the control of a broad range of terrestrial and aquatic weeds and can damage or kill non-target vegetation. Imazapyr has relatively low toxicity to birds, mammals, fish, and invertebrates (Fisher et al. 2003, pp. 40–50).

Glyphosate is a broad-spectrum systemic herbicide that kills plants by interfering with amino acid synthesis and enzyme production. Glyphosate does not significantly bioaccumulate, bioconcentrate, or biomagnify (Reinert and Rodgers 1987 and Solomon and Thompson 2003 In Breckels and Kilgour 2018, p. 11; Siemering et al. 2008, p. 424), leading the Environmental Protection Agency to conclude that glyphosate is practically non-toxic to non-target organisms (EPA 1993, pp. 4–5).

There is no literature that suggests that there are direct impacts to Bethany Beach firefly from the use of glyphosate and imazapyr. Indirect impacts could be reduction in prey. However, some surfactants used in the application of glyphosate and imazapyr to increase efficacy of these two herbicides are more toxic to fish and aquatic invertebrates than glyphosate and imazapyr themselves (Brodman et al. 2010, pp. 80–81; Sinnott 2015; Breckels and Kilgour 2018, p. 4, Sinnott 2015, entire). The surfactant polyethoxylated tallowamine (POEA), which is used in glyphosate-based herbicides, has been found to cause the direct mortality of amphibians (Brodman et al. 2010, pp. 70; 80–81). However, POEA is not intended for use over water or to control aquatic weeds, so it is not clear how likely these results would be to occur at Assateague. A study of the aquatic surfactant, nonylphenol-polyethylene (NPE), was also found to be moderately toxic to amphibians at concentrations under 1.2 mg/L, however more research is needed (Brodman et al. 2010, pp. 70; 80–81). Based on these results, there could be the potential for indirect effects to Bethany Beach firefly from the use of surfactants with glyphosate or imazapyr through impacts to food sources. However, at this time, there is little exposure overall from herbicide use across the range.

Insecticides for Mosquito Control

The Bethany Beach firefly's exposure to organophosphate adulticides for mosquito control varies across its range. Mosquito spraying is not conducted on Assateague National Seashore in Maryland or at the Virginia park properties where the species occurs (Table 3). However, there is some spraying in areas at the NASA Wallops Island Flight Facility and at the Delaware state parks. At Wallops Island, Bethany Beach firefly exposure to these insecticides is likely low because spraying is only applied on the grass and local brush and not in waterways or storm drain/outfall areas (Levine pers. comm., 2023).

Delaware uses two mosquito control chemicals during the season. Within the Delaware parks, the current agreement with Delaware Fish and Wildlife (DFW) is that there is no spraying of adulticides between June 15 and August 15, when adult Bethany Beach fireflies are most active. During this time, DFW uses Bti, which targets mosquito larvae. Bti (short for *Bacillus thuringiensis* subspecies *israelensis)* is a naturally occurring bacterium found in soils and targets only the larvae of the mosquito, blackfly and fungus gnat (https://www.epa.gov/mosquitocontrol/bti-mosquito-control##4). Bti is considered very safe because it targets only specific insects.

Outside the June 15 to August 15 time frame, Delaware has used Trumpet EC™, a common chemical for mosquito control with an active ingredient called naled. Trumpet EC™ is derived from phosphoric acid and is highly toxic to fish resources and a wide range of aquatic non-target organisms including mayflies, caddisflies, crustaceans, fresh and saltwater chironomids and other marine invertebrates. Organophosphates are also highly toxic to terrestrial insects and aquatic beetles that are naturally occurring predators of mosquito larvae (Laskowski et al. 1999, p. 742; Pinkney et al. 2000, p. 678).

While we do not have data on the effects of Trumpet EC™ specifically on fireflies, Bethany Beach fireflies still occur in swales that have been sprayed by this chemical. Table 1 below describes the swales that have been sprayed over time, mostly in Delaware Seashore State Park, likely because they are near some park facilities. Swales 700, 701, 702, 703 have been sprayed in 11 of the 12 events described in Table 1, starting in 2013 and continuing into 2023. All four swales continue to have Bethany Beach firefly presence with the most recent years of observation being 2021, 2023, 2020 and 2022 respectively. While more information would be helpful, there is no current data to show harmful effects of the Delaware spray regime to Bethany Beach firefly populations.

Table 3: Occupied Bethany Beach firefly swales sprayed with adulticide (outside the adult flight season) since 2013. Swale 59 is Cape Henlopen. All other swales are in the Delaware Seashore State Park (Davis pers. comm., 2023i).

Date	Chemical	Rate	Swale(s)
062313	Trumpet EC	1.0 oz./ac.	700, 701, 702, 703
090916	Trumpet EC	0.8 oz./ac.	59

Date	Chemical	Rate	Swale(s)
091416	Trumpet EC	0.8 oz./ac.	700, 701, 702, 703
060317	Trumpet EC	1.0 oz./ac.	15, 16, 17, 24, 26, 30, 231, 400, 402, 700, 701, 702, 703
080917	Trumpet EC	0.8 oz./ac.	15, 16, 17, 24, 26, 30, 231, 400, 402, 700, 701, 702, 703
073118	Trumpet EC	0.8 oz./ac.	700, 701, 702, 703
092018	Trumpet EC	0.8 oz./ac.	700, 701, 702, 703
091019	Trumpet EC	0.8 oz./ac.	700, 701, 702, 703
082620	Trumpet EC	1.0 oz./ac.	24, 26, 30, 231, 700, 701, 702, 703
091520	Trumpet EC	1.0 oz./ac.	15, 16, 17, 24, 26, 30, 231, 400, 402, 700, 701, 702, 703
091222	Trumpet EC	0.8 oz./ac.	700, 701, 702, 703
091223	Trumpet EC	1.0 oz./ac.	30, 700, 701, 702, 703
100623	Trumpet EC	1.0 oz./ac.	15, 16, 17, 24, 26, 30, 231, 700, 701, 702, 703

More severe storm events and sea level rise (See Section 5.2 of the SSA) could increase the amount of time there is standing water, which could increase mosquito populations and necessitate more frequent use of adulticide (Davis, pers. comm., 2023d).

One additional insecticide used in these areas is GYPCHEK®, used at False Cape State Park to control gypsy moth on an as needed basis. It was used as recently as spring 2023. GYPCHEK® is an insecticide prepared from gypsy moth larvae that have been killed by the nuclear polyhedrosis virus. The active ingredient in GYPCHEK® is the virus, which is embedded in a protein particle called the polyhedron. GYPCHEK® specifically targets the gypsy moth and has no effect on other insects. (Lewis et al. 1979, p. 1).

4.1.5 Invasive Plant Species

Invasive plant species, particularly common reed (*Phragmites australis*, commonly called *Phragmites*), are present in some of the interdunal swales where the species occurs. *Phragmites* is an aggressive and competitive plant that grows rapidly and displaces naturally diverse vegetation communities with dense mono-cultural stands (Wilcox et al. 2003 p. 665; Gilbert 2014, p. 78). Expansion of *Phragmites* populations can be rapid: a single clone can cover an eighth of a hectare (0.31 acre) in 2 years (Hocking et al. 1983 In Asaeda and Karunarathe 2000, p. 302) and the slow decomposition of *Phragmites* detritus can significantly reduce the availability of nutrients, light, and space, making the survival or establishment of other species unlikely (Meyerson et al. 2000, p. 93). A number of studies have shown that once established, *Phragmites* will increase marsh elevation to a greater extent than other marsh species through higher accumulation of organic and mineral matter. This is largely a result of its high biomass production and high rates of litter accumulation (Windham and Lathrop 1999, p. 931; Meyerson et al. 2000, p. 89; Rooth et al. 2003, p. 480).

The direct effects of *Phragmites* on Bethany Beach firefly populations are not known. Adult Bethany Beach fireflies are still observed using interdunal swales dominated by phragmites (Slacum pers comm., 2024). However, there are several ways that *Phragmites* may indirectly reduce habitat quality for fireflies. By elevating the marsh surface, hydrological flow within a marsh is modified. Establishment of monocultures of *Phragmites* in interdunal swales would likely decrease available soil substrate and moisture for larva. In addition, the reduction in plant biodiversity in areas overtaken by *Phragmites* can reduce prey species on which firefly larvae feed. We need a better understanding of larval use of *Phragmites* stands.

Phragmites occurs in many swales in Delaware. Botanical surveys conducted between 2015 to 2017 in Delaware's interdunal swales indicate that at least 34 swales had some level of *Phragmites australis* invasion. Other invasive species such as Japanese black pine (*Pinus thunbergii*) and bermuda grass (*Cynodon dactylon*) are also growing in some of the swales and Delaware Fish and Wildlife discovered silver grass (*Miscanthus* sp.) dumped in a swale (Davis pers. comm., 2023e). There has been limited invasives control using herbicide at an occupied swale in Cape Henlopen State Park for the purposes of protecting a rare plant, but control of invasives in other interdunal swales in Delaware State Parks does not occur unless initiated by Delaware Division of Fish and Wildlife, which is rare (Davis pers. comm., 2023j).

Phragmites are also present in Virginia and Maryland. At Assateague National Seashore, there is *Phragmites* in the occupied swales adjacent to the campground and herbicide is used to control the spread at the park (Huslander pers. comm., 2023). In Virginia, there are thousands of acres of *Phragmites* on NASA Wallops Island Flight Facility, which, unless there is a direct fire threat during launch operations, are not managed (Miller, pers. comm., 2023). At Chincoteague National Wildlife Refuge, it is unknown whether Phragmites occurs near the swales (Holcomb pers. comm., 2023).

The only park in which *Phragmites* is not present in the interdunal swale habitat is False Cape State Park (Swain pers. comm., 2023).

4.1.6 Other Habitat Stressors

Woody Plant Encroachment

Succession of woody species is occurring in some of the interdunal swales in Delaware, resulting in a loss of wetland function, plant species diversity, and wildlife diversity. Interdunal swales are threatened by establishment of tree species such as loblolly pine (*Pinus taeda),* pond pine (*Pinus serotina),* red maple (*Acer rubrum),* sweet gum (*Liquidambar styraciflua),* and Japanese black pine *(Pinus thunbergii)*. Interdunal swales with Bethany Beach firefly are typically shallow depressions (swales) with herbaceous vegetation in the depression and woody species such as southern wax myrtle (*Morella cerifera),* highbush blueberry *(Vaccinium corymbosum)*, and groundseltree (*Baccharis halimifolia)* found along the perimeter of the depression. These woody species don't get as large as the tree species such as Pinus*,* Acer*,* and Liquidambar. Evidently, some swales that have a high occurrence of large trees have lost much of the herbaceous layer below and are now woody thickets (Davis pers. comm., 2023f). At Assateague Island National Seashore, there is little tree encroachment (Huslander pers. comm., 2023). There is some succession occurring at False Cape State Park (Swain pers. comm., 2023). It is unknown if there is tree encroachment occurring at the other two Virginia properties but there is likely some due to a lack of major storms occurring over the last several years.

Shoreline Erosion Control (shoreline erosion control, constructed dunes, sand fencing)

Bethany Beach firefly require temporally stable swales. Swales will eventually succeed to maritime forest if succession is not offset by periodic saltwater intrusion. Under natural conditions, disturbance to prevent succession is driven by periodic dune overwash from storm surge. Construction of shoreline erosion control structures such as rock revetments, jetties, artificial dunes, and placement of sand fencing can reduce the amount of overwash from storm surge.

Delaware

Delaware Department of Transportation maintains the Route 1 highway after storm events and they have replenished the dunes south of an occupied swale at Delaware Seashore State Park.

There are dune crossings with sand fence near seven swales in this park where Bethany Beach firefly has not been detected (Davis pers. comm., 2023g).

Maryland

There are constructed dunes and some sand fencing in front of the swales near the campground. There are no constructed dunes adjacent to occupied and unoccupied swales occurring south of the campground in the over sand vehicle beach area. There is a low likelihood that construction would occur in the future due to the lack of infrastructure and camping areas in the southern part of the island (Huslander pers. comm., 2023).

Virginia

There are no constructed dunes or sand fencing at the Virginia properties (Miller; Holcomb; Swain pers. comm., 2023). There is a constructed dune on NASA Wallops Island Flight Facility which runs the length of the beach fill template. The core of the constructed sand dune is armor stone which is periodically re-covered with sand during Wallops Island beach renourishment events (on average, every 3 to 7 years) (Miller pers. comm., 2024).

Habitat loss, fragmentation, and degradation has occurred in the past, is occurring presently, and will continue to occur in the future. While the known species occurrences are entirely on public lands, there are likely impacts to the species and its habitat due to light pollution, mosquito spraying (DE), recreation, invasive plants, and development occurring for energy projects (DE). Therefore, the magnitude of the threat on species viability is moderate to high.

Small Population Size

Surveys conducted for Bethany beach firefly involve watching for double flashes for a set period of time to confirm presence (see section 5.1). While surveys can quantify the number of double flashes observed which can be compared among different sites, quantifying the actual abundance of individuals is not possible. Based on survey efforts that have occurred, only a few double flashes are observed at most sites, likely indicating small population sizes in these wetlands. Several swales in Delaware have a higher number of observations of double flashing than others but none have been found to be as abundant as the Tower Shores wetland was in 1998, when hundreds of double flashes were observed. Small population sizes and lack of connectivity in certain areas can result in an Allee effect, which occurs when there is a population size or density correlation with some characteristics of individual fitness (Drake and Kramer 2011, p. 2). A strong Allee effect, or density dependence on fitness, means that individuals may be less likely to survive when overall population density is low, and may result in a critical population size below which the population cannot exist. Species with small or sparse populations, such as Bethany Beach firefly, are susceptible to the Allee effect. For instance, where a population is not dense, there may be few males or females available, or there may not be individuals with high fitness, both of which can exacerbate the Allee effect by reducing instances of successful mating and reducing survival of young when mating does occur (Gascoigne et al. 2009, p. 356).

Similarly, the isolation of populations can reduce gene flow, which in turn can reduce the fitness of an entire population. Even a common, widespread firefly species, *Photinus pyralis*, was shown to have little gene flow among populations despite the adults being able flyers (Lower et al. 2018, p. 7). Genetic studies are needed to determine whether there is enough gene flow among Bethany Beach firefly to sustain populations and better assess the threat of the Allee effect. While there is no way to quantify abundance for the species, observations of just a few individuals in most swales likely indicates small population sizes throughout its range. The magnitude of this threat on the species viability is high.

4.2 Climate change

Climate change refers to changes in temperature, precipitation, storm intensity, and sea level rise that are due to rising levels of greenhouse gases in the atmosphere. Individually and collectively, these changes are anticipated to increase stochasticity and reduce habitat quality for the Bethany Beach firefly. Below, we analyze how rising temperatures, increased precipitation, increased storm intensity, and rising seas will affect the firefly.

Temperatures

Since 1901, temperatures in the northeast have risen steadily. The amount of the increase depends on location and ranges from less than 0.6° C (1° F; West Virginia) to about 1.7 °C (3 °F; New England). Temperatures are expected to continue to rise (Dupigny-Giroux et al. 2018, p. 672). As a consequence of warming temperatures, precipitation patterns are expected to become more extreme and less predictable. While total precipitation is expected to increase in the winter and spring, with little change in the summer, hotter and more intense droughts are also forecast. Increases in temperature and droughts could reduce soil moisture and hydrology of the interdunal swales during the summer months, which could result in egg and larval mortality and habitat degradation. Firefly eggs can dry out or become moldy if the humidity and temperatures aren't suitable (Faust 2017, p. 40). High maximum temperatures in winter and spring during larval development have been shown to result in lower adult abundance the following summer (Evans et al. 2019, p. 6). An increase in temperature could also alter firefly phenology by advancing or de-synchronizing the dates of male and female emergence and/or display time. For instance, one firefly species, *Photinus carolinus,* now have their peak mating time 10 days earlier than they did 20 years ago, and females now emerge and display flashes earlier than males (Faust and Weston 2009, pp. 1509-1510). Finally, increasing temperatures could change the ecology of the swales, for instance, by creating conditions conducive to the spread of invasive species (Angel et al. 2018, p. 875)

Increased Precipitation

Rainfall intensity, and consequently risk of flooding, has been increasing over the range of the Bethany Beach firefly and is expected to continue (Dupigny-Giroux et al. 2018, p. 672). The frequency and annual amount of heavy precipitation in the Northeast U.S. has increased over the past 100 years and has become significantly wetter from 1957-2010 (Kunkel et al. 2013 as cited in Collee et al. 2015, p. 133).The number of extreme precipitation events is expected to rise as much as 6-40 percent across the globe and a 10-15 percent increase in the amount of precipitation is expected along the U.S. East Coast by the later twenty-first century (Allan et al. 2008 and Lombardo et al. 2015 as cited in Collee et al. 2015, pp. 133-135). Increased rainfall and floods increase the potential for soil erosion and habitat loss, and droughts can increase the spread of invasive species (Angel et al. 2018, p. 875). Drought can also reduce the hydroperiod, or length of time that standing water exists on the landscape.

Increased Storm Intensity

Additionally, more frequent and severe storm events could result in more frequent saltwater intrusion, flooded swales, and overwash of salt water into the swales, which could result in larval mortality, mortality of prey resources, and a change in vegetation and hydrology in the swales. At current sea levels, coastal storms can cause surges between 0.61-1.2 m (2-4 ft) along the Delaware Bay and Atlantic Coast, heights comparable to expected sea level rise by 2100 (Delaware Coastal Program 2012, p. 4-5). Saltwater intrusion and overwash increases salinity in swales until freshwater flushes out the system, which can take anywhere from weeks to months (Anderson 2002, pp. 415-417; see Sea Level Rise section below). The Delaware, Maryland, and Virginia Atlantic coastline is positioned latitudinally such that it experiences coastal flooding from extratropical (e.g., nor'easters) and tropical storm systems, together numbering about 30 to 35 coastal storms per year (Leathers et al. 2011, p. 10).).

Sea level rise

A recently updated sea level rise report (Sweet et al. 2022, entire) generated global mean sea level (GMSL) projections and scenarios and adjusted these GMSL scenarios to specific regional conditions for the entire U.S. coastline. Local scenarios are provided for two locations within the known range of the Bethany Beach firefly, which estimate between 1.4 and 1.7 feet of sea level rise by 2050, and 4 to 7 ft of rise by 2100 (NOAA 2023, entire).

The impact of sea level rise on the species would be loss and degradation of suitable habitat from more frequent inundation, saltwater intrusion, and the potential for conversion to open water without marsh migration. Marsh migration landward cannot occur where there are physical barriers to migration such as roads and buildings. and where other features of the landscape are not present such as suitable elevation, slope, substrate, and other natural landscape feature required for marsh habitat to establish and thrive. Construction of artificial dunes may increase in areas where there is residential development and/or infrastructure which would also result in changes in vegetation and impact habitat suitability. Constructed dunes are detrimental to Bethany Beach firefly because they hinder the natural disturbance needed to keep the swales open and with herbaceous vegetation surrounded by some shrub-scrub habitat.

Even where habitat is not destroyed, storm events can temporarily inundate swales. At Assateague Island National Seashore, some swales are inundated for an average of 5 days after a storm event (Huslander pers. comm., 2023). Although the species has persisted through these events, and evidently has some ability to endure elevated water levels and elevated salinity levels on a temporary basis, it is unclear whether the species can withstand more frequent or more prolonged inundation.

Along with sea level rise, high tide flooding is projected to increase in frequency through the end of the century (Sweet et al. 2018, p. vii-viii). High tide flooding is minor or "nuisance" flooding, caused by both tidal and non-tidal (e.g., storm surges) factors, and these events have been increasing in frequency and depth over the last several decades. By 2050, days with minor flooding events are expected to increase from approximately 2.5 days/year to between 45 and 130 days/year along the Northeast Atlantic coast (Sweet et al. 2018, p. vii-viii). Such minor flooding events are expected to increase the amount of time that the swales are inundated with salt water. While we know the species can tolerate some saltwater inundation, there is likely an impact on larval survival the longer a swale is inundated.

In addition to more frequent, severe storm events and sea level rise, elevation loss due to subsidence threatens coastal areas and many wetland habitat types and their distribution (Sweet et al. 2017, p. 1; Dupigny-Giroux et a. 2018, p. 17). Subsidence is a gradual settling or sinking of land. Recent considerations of the combined effect of sea level rise and subsidence indicates that subsidence increases the threat to coastal communities from sea level rise and may even triple estimates of potential flooding over the next several decades (Ohenhe et al. 2024, 1).

In summary, the compounding impacts of climate change will alter or destroy habitat and have the potential to change reproductive behaviors throughout the range of the Bethany Beach firefly by 2100. There is uncertainty about the extent and severity of the realized impacts of climate change on Bethany Beach firefly behavior and demography. However, with existing small population sizes at most of the swales, the firefly's vulnerability to these changes, as well as to catastrophic events such as prolonged drought and more severe storms, is expected to increase.

4.3 Conservation

Delaware

There is *s*ome woody vegetation control occurring at Cape Henlopen State Park in swales in which the species is currently not present (Davis pers. comm, 2023h).

Maryland

There are no conservation efforts occurring at this time at Assateague Island National Seashore (Huslander pers. comm., 2023).

Virginia

There are no conservation efforts occurring at this time at the Virginia properties (Miller; Holcomb; and Swain pers. comm., 2023).

There has been little conservation work conducted throughout the species range, therefore, conservation efforts are having no impact on the species' viability currently. More work could be conducted in the future to control invasive plant species such as *Phragmites australis* and manage succession but there is uncertainty about how much work would occur in the future.

4.3 Predators and Pathogens

Pathogens such as reproductive bacterial parasites (*Wolbachia* and *Mollicutes*) can affect the sex ratio of fireflies either by causing more female eggs to be generated or by killing the male eggs of the infected mothers. Rearing of Photuris in the laboratory using soil from the natural habitat, resulted in fungal infections of larva. These infections stopped when artificial substrate was used, which may indicate that there could be a buildup of fungal spores which could impact habitat suitability over time (Buschman pers. comm., 2023). Certain nemotodes or roundworms and fungi can be deadly to larvae and adults. Phorid flies are a common parasitoid of fireflies and tachinid flies deposit eggs within living adult fireflies, eventually resulting in death (Buschman 2019, p. 58). Other common predators include, assassin bugs, hangingflies (genus *Bittacus*), harvestmen (*Leiobunum* sp., daddy longlegs), bats, birds, centipedes, crustaceans, fish, frogs, toads, lizards, snails, and spiders (Barrows et al. 2008, p. 47; Faust 2017, pp. 55-60). Predators of larvae include wolf spider (Lycosidae), giant water bug (Belostomatidae) (feeding on *P. lucifera*), harvestman (Opiliones) (feeding on *Photinus carolinus*, Photuris pupae), birds, frogs, and likely small mammals that root around in the soil and leaf litter (Buschman 2019, pp. 59 – 60). Pathogens and predators have occurred in the past, are occurring presently, and will continue to occur in the future. While there is uncertainty about how much predation and pathogens are impacting the species' viability, we assume that the magnitude of the threat is low but could have a larger impact on populations with degraded habitat and small population size.

4.4 Summary of Factors Influencing Viability

The viability of the Bethany Beach firefly is most restricted by a lack of habitat, stemming from urbanization and development of much of its original range. The extant populations are now isolated with presumably no genetic transfer among them, leaving these small populations at increased risk of impacts from random stochastic and unforeseen catastrophic events. While habitat loss is mostly a historical threat, habitat loss has been documented in the recent past due to development on private lands. While the threat of continued habitat loss on the public properties is less likely, it is occurring with the renewable energy sector (wind) in Delaware Parks. There may also be continued habitat loss in areas where habitat has not yet been mapped.

Other habitat stressors resulting from land uses and practices are still ongoing threats to this species, including light pollution, disturbance and habitat degradation resulting from recreation, mosquito spraying, and habitat degradation from invasive plants.

However, the greatest threat to the Bethany Beach firefly's continued viability is the compounding effects of climate change which includes the potential for increased temperatures and drought to dry out swales, increased storm intensities wiping out dune systems, and resulting saltwater intrusion. Rising sea levels also threaten to first degrade and then remove habitat due to increased periodic inundation and then total inundation at some height above current sea levels with and without storm surges.

CHAPTER 5 – CURRENT CONDITION (Species Viability)

In this section, we first describe potential habitat and define analytical units for the species. Then, using the Bethany Beach firefly's known historical distribution, its known current distribution, and the species needs for viability, we estimate the current condition of the Bethany Beach firefly by characterizing the 3Rs.

5.1 Methods

To complete our analysis, we used the best available information, including state integrated reports, survey data provided by state agencies and academic institutions, and species expert accounts. Species experts were contacted via email, phone, and in-person meetings to discuss details of this assessment and obtain accounts and opinions for analysis.

5.1.1 Potential Habitat and Bethany Beach Firefly

Mapping Potential Habitat - Identification of interdunal swale habitat for surveys varied by state but in general were based on plant associations described in Heckscher and Bartlett (2004, p. 350), McAvoy and Clancy (1994, p. 3) and McAvoy (2018, entire) (see Section 2.5 Habitat). Botanical surveys conducted from 2015 to 2017 by the Delaware state botanist (McAvoy 2018, entire) were used to identify interdunal swales in Delaware. Additional swales were identified by remote sensing in ArcMap GIS and were later confirmed by field surveys. In Maryland, suitable habitat on Assateague Island National Seashore was identified based on vegetation and plant community type layers obtained from the National Park Service, as well as aerial imagery which was later verified in the field by the Delaware state biologist. Thirty-eight swales were then mapped. However, this is not considered to be a full and complete assessment of suitable habitat as other suitable swales may occur on Assateague Island National Seashore and are yet to be mapped. In Virginia, surveys were conducted in 2021 by simple field assessment of suitable habitat, with surveys done from points where that habitat could be observed. Swale habitat was not delineated prior to going out to survey. There were 24 survey points located across the three properties in Virginia.

Surveys for Bethany Beach Firefly Presence – A biologist from the Delaware Division of Fish and Wildlife initiated surveys for this species in the summer of 2019 and continues to survey annually. The goal of these surveys is to determine where Bethany Beach firefly occurs to better understand the range. Surveys commence on or about June 24 and continue until approximately August 5 and in some years are conducted as late as August 20. Surveys occur under optimal weather conditions (wind < 10 knots, temperature > 65° F (18.3° C, 0 percent precipitation). There is an attempt to survey up to three interdunal swales each night if conditions and travel time allow. The first survey of the night begins approximately 35 minutes after sunset and lasts for approximately 30 minutes unless presence of Bethany Beach firefly is confirmed before the 30 minutes is up. The two consecutive surveys last for approximately 20 minutes each or until Bethany Beach firefly is confirmed. The first survey of the night is likely to be the best for detecting Bethany Beach firefly and where swales could be resurveyed, the timing of swales surveyed was changed to enable different swales to be the first surveyed in a night.

Fireflies are only captured and identified if they are observed within or adjacent to an interdunal swale and double flashing is observed several times during flight. In addition to observing flash pattern, a captured specimen is measured and inspected under a hand lens to see if the pronotal vitta (a stripe or marking on the head cover) matches what is published for Bethany Beach firefly (Lloyd 2018, p. 94). The known total length of Bethany Beach firefly is between 9.0 and 10.75 mm (0.35 – 0.42 in) (McDermott 1953, p. 37). This size range combined with the pronotal vitta is used to identify the species by observation of morphological features in addition to flash pattern and habitat. Until a biologist or observer has training and experience with identification, specimens are verified through Delaware State University or Delaware Division of Fish and Wildlife (Davis pers. comm, 2023a).

Due to the limited survey effort conducted before 2019 and most of the recent surveys occurring in Delaware, neither the historical nor current distribution of the Bethany Beach firefly is well understood. Further, swales are not always easily determined from remote sensing or aerial images, and swales have only been thoroughly mapped and field verified in Delaware, indicating additional habitat likely exists within the range of the species. To define potential habitat for this species, we used the swales identified in each state as the best available information, but for all locations, we limited potential habitat to identified swales centered within 500 m (1,640 ft) of the shoreline based on Heckscher and Bartlett (2004, p. 350). The full range of the species is unknown and may include additional states, such as New Jersey and North Carolina. However, while the amount of survey effort conducted in New Jersey is unknown, McDermott (1953, p. 36) stated that he had looked for the species and was unable to detect it. And the late Dr. Lloyd had a collection of coastal fireflies from New Jersey but did not find Bethany Beach firefly (Heckscher pers. comm., 2023). However, Lloyd and McDermott had likely not made the habitat association of Bethany Beach firefly with interdunal freshwater wetlands which occurred in 1998 (Hesckscher and Bartlett 2004) (Heckscher pers. comm., 2023).

5.1.2 Analytical Units

Fundamental to our analysis of the Bethany Beach firefly was the determination of analytical units (populations) at a scale useful for assessing the status of the species. Populations are the basic unit on which resiliency is assessed, however, there is uncertainty as to what constitutes a population of this species. Based on observations of flight patterns of this species, we assume that swales within 305 m (1,000 feet) of each other are close enough that individuals could travel this distance and reproduction and gene flow could occur between them. We assume that there is little to no dispersal of individuals occurring between swales greater than 305 m (1,000 ft) apart. Therefore, we grouped all known swales within 305 m (1,000 feet) of each other into complexes, and these complexes were used as our analytical unit to describe a population. Because swales have not been mapped for Virginia, and we only have detection locations, we buffered the detection locations instead of the swales; therefore, complexes in Virginia are defined by survey locations that occur within 305 m (1,000 ft) of each other.

Since surveys occurred by swale, we consider the entire complex occupied if any swale within that complex has documented detections. We make this assumption because animals present in one swale are likely to move to other swales close by and one survey can miss this species if it happens to be late in the evening or otherwise not ideal conditions. We consider the population within each complex “current” if the Bethany Beach firefly was detected there since 2019, the start of the most recent survey period.

While complexes are used as our analytical unit, all the complexes within a property have similar management activities, habitat characteristics, surrounding land uses, threats, and current stressors. Thus, we discuss and group complexes by property, as each property can have multiple complexes.

Representation is typically based on genetic or ecological differences among populations. There is no evidence of unique genetic distinctions among different populations of Bethany Beach firefly and no apparent ecological differences exist, either. However, we discuss representation as the ability of the species to adapt to changing environmental conditions in terms of its adaptive capacity.

5.1.3 Resiliency

Resiliency is the ability of a species to withstand environmental stochasticity or normal, year-to-year variations in environmental conditions. Population size is one demographic factor often used as an indicator of overall resiliency; typically, the larger a population and the more individuals present, the more resilient the population. However, documenting abundance for the Bethany Beach firefly is problematic because occupied and potential swale habitat have not been sampled regularly, systematically, or equally, and some have not been surveyed at all. Further, time of night, temperature, and humidity can affect our ability to detect the species through observation of flash pattern and timing. In addition, the goal of surveys was to document presence, not relative abundance, as the range of this species is still being understood. Therefore, true abundance and population trend data do not exist. Data are also not available regarding the population structure or demographics of the Bethany Beach firefly, and we also do not have absence data, as surveys are not necessarily repeated and a lack of detection does not necessarily mean absence. We cannot assume that more detections within a complex indicates a larger population, as there have been limited surveys conducted in some individual complexes and more generally in Delaware. Therefore, a full picture of the health and resilience of these populations is uncertain.

To assess current condition of the Bethany Beach firefly, we have very limited, incomplete detection data which only allows us to infer population presence (and not absence). We do not believe this is adequate information to estimate current resiliency of populations or compare population resiliency among complexes.

Thus, we assessed current condition for all known complexes, regardless of survey status or detections. However, as outlined previously, only complexes with detections since 2019 are considered “current” and extant. While we cannot estimate resiliency, we provide the detection and location data, as well as the available habitat, and other qualitative information that summarizes what is known about each complex in terms of potential resiliency.

5.2 Results

5.2.1 Potential Habitat and Populations

Range-wide, we identified 143 swales in 31 complexes (Table 4). Identified complexes each contain between one and 19 swales.

Fifteen complexes are currently occupied, having detections since 2019, and these contain 36 total occupied swales (Table 4). Two properties, Delaware Seashore State Park and Assateague Island National Seashore, each have four occupied complexes containing 21 occupied swales accounting for over half of the occupied complexes and swales range wide. NASA Wallops Island Flight Facility in Virginia has three occupied complexes. The greatest number of occupied swales within a given complex is five, which occurs in one complex at Chincoteague; three additional complexes across the range each have four known occupied swales. Six of the occupied complexes (40 percent) are known to have just one occupied swale each (Table 4).

Ten complexes have had surveys but no detections of Bethany Beach firefly, although survey effort varies among these complexes (Table 4). However, one complex on the private land north of Bethany Beach (DE_PRIV_12) previously had detections of Bethany Beach firefly in 1998, but the species has not been detected since. Habitat in this complex has been noticeably degraded by development and an elevated roadway (Figure 2), making occupancy unlikely.

Forty-eight swales have been identified that have not been surveyed (Table 4). Seven complexes (totaling 10 swales) have not had any surveys in any of their swales.

No complexes cross property boundaries; thus, we assume that there is no dispersal of individuals among Assateague Island National Seashore, Chincoteague National Wildlife Refuge, and NASA Island Flight Facility, despite these properties’ proximity to one another.

Table 3. Known complexes of swales that provide potential habitat to the Bethany Beach firefly by property, listed north to south, with information on the total swales with Bethany Beach firefly (BBFF) presence, number of swales that were surveyed but had no detections, number of swales not surveyed, total swales per complex, and overall complex status. Complexes with “current” status are those with detections since 2019 and are considered to be extant; “not detected” indicates that surveys since 2019 did not produce detections.

State	Property	Complex	# of swales BBFF present	# of swales no detections	# of swales not surveyed	Total swales in each complex	Status
DE	Cape Henlopen	DE_CAHE_01		4	3	7	Not detected
		DE_CAHE_02		1		1	Not detected
		DE_CAHE_03	1	4		5	Current
		DE_CAHE_04			1	1	Not surveyed
		DE_CAHE_05			1	1	Not surveyed
	DE Seashore SP	DE_SESP_06	4			4	Current
		DE_SESP_07		3	5	8	Not detected
		DE_SESP_08	4	10	5	19	Current
		DE_SESP_09	3	2		5	Current
		DE_SESP_10	2	1	2	5	Current
		DE_SESP_11		4		4	Not detected
	Private Land	DE_PRIV_12		1		1	Not detected
		DE_PRIV_13			2	2	Not surveyed
		DE_PRIV_14		1	1	2	Not detected
		DE_PRIV_15			1	1	Not surveyed
	Fenwick Island SP	DE_FENSP_16	3	9	2	14	Current
		DE_FENSP_17		1		1	Not detected
MD	Assateague Island	MD_ASIS_01	2	1	3	6	Current
		MD_ASIS_02	1	1	6	8	Current
		MD_ASIS_03	4	0	2	6	Current
		MD_ASIS_04	1	3	9	13	Current
		MD_ASIS_05			1	1	Not surveyed
		MD_ASIS_06			2	2	Not surveyed
		MD_ASIS_07			2	2	Not surveyed
VA	Chincoteague NWR	VA_CHIN_01		1		1	Not detected
		VA_CHIN_04	5	2		7	Current
	NASA Wallops Island Flight Facility	VA_WALL_02	1	2		3	Current
		VA_WALL_03	1	2		3	Current
		VA_WALL_05	1	3		4	Current
	False Cape SP	VA_FCSP_06	3	2		5	Current
		VA_FCSP_07		1		1	Not detected
	Total	**31**	**36**	**59**	**48**	**143**	

5.2.2 Resiliency

Population resiliency is unknown for the 15 current complexes of Bethany Beach firefly. Over half of the occupied complexes (n = 8) and over half of the occupied swales (n = 21) occur on two properties, Delaware Seashore State Park and Assateague Island National Seashore (Table 5). While some complexes appear to have more occupied swales than others (Table 4), we hesitate to call those more resilient due to the lack of repeated surveys during ideal survey conditions (weather, time of night) for this species (see Section 5.3, Uncertainties, below). Similarly, some properties appear to have more redundancy (more occupied complexes), but a lack of detection does not indicate absence for this species, especially without more recurrent surveys. However, due to apparent habitat destruction within the private land north of Bethany Beach and past detections from 1998 in this complex (DE_PRIV_12, Figure 2), we expect this complex has been extirpated. While complex (population) resiliency is unknown, we describe resiliency in terms of current stressors by property.

Cape Henlopen, Delaware Seashore, and Fenwick Island State Parks have some of the most numerous current stressors, including extensive invasive species in swales, light pollution in more than a third to over half of swales, and mosquito spraying occurring or likely to occur (Table 5). Cape Henlopen and Fenwick Island have only one occupied complex each, while Delaware Seashore State Park has nearly a third of the occupied complexes, including one of the largest complexes with 19 swales (Table 4). Assateague Island National Seashore complexes, four of which are known to be occupied, have lower threats comparatively, with less extensive invasive Phragmites in swales and some lighting at the campground, only. Chincoteague National Wildlife Refuge has similar threats to its one known occupied complex (Table 5). NASA Wallops Island Flight Facility has three known occupied complexes with threats similar to the Delaware State Parks properties, while False Cape State Park, with only one known occupied complex, has no noted threats (Table 5).

Table 4. Summary of surveyed and occupied complexes and swales by property, percent of the rangewide occupied swales in each property, and current stressors for the Bethany Beach firefly.

		Number Complexes			Number swales				Percent of Range wide Occupied Swales	Current Stressors				
State	Property	BBFF Present	Total Surveyed	Percent Occupied	BBFF Present	Total Surveyed	Percent Occupied	Current Status		Obs. habitat loss?	Habitat Degradation	Lighting	Mosquito spray	Development
DE	Cape Henlopen SP	1	3	33	1	10	10	Current	3	no	extensive *Phragmites* in most swales	mentioned for 4 of 10 swales	yes	Moderate; park facilities
DE	Delaware Seashore SP	4	6	67	13	33	39	Current	36	no	extensive *Phragmites* in many swales	mentioned for 13 of 29 swales	yes	Moderate; park facilities
DE	Private Land N. of Bethany Beach	0	2	0	0	2	0	Likely extirpated	0	yes	wetland shaded by structure	surrounded by lit homes and highway	unknown	High; habitat lost
DE	Fenwick Island SP	1	2	50	3	13	23	Current	8	no	extensive *Phragmites* in some swales	mentioned for 9 of 13 swales	unknown, likely	Low; park facilities
MD	Assateague Island National Seashore	4	4	100	8	13	62	Current	22	no	*Phragmites* occurring in some swales	some - campground	no	Low
VA	Chincoteague NWF	1	2	50	5	8	63	Current	14	no	*Phragmites* in some swales ponies - trampling, poop	no	no	Low
VA	NASA Wallops Flight Center	3	3	100	3	10	30	Current	8	no	extensive *Phragmites*	some (amber, periodic white)	yes but nearby	Moderate; some buildings
VA	False Cape State Park	1	2	50	3	6	50	Current	8	no	no *Phragmites* in swales habitat, no ponies	no	no	Very Low
	Total	15			36	95								

5.2.3 Species Redundancy and Representation

The Bethany Beach firefly exists as at least fifteen current known "populations," or complexes of swales containing at least one occupied swale. Additional populations may exist; due to the recent discovery of the species and limited survey efforts, it is likely that the species occurs in additional swales, complexes, and maybe even in additional properties, perhaps extending into New York, New Jersey, North Carolina, and South Carolina where interdunal swale habitat has been described with similar plant communities where the species is known to occur (Edinger et al. 2014, p. 13 (NY); Breden et al. 2001, p. 109 (NJ); Shafale 2012, p. 185 (NC); Nelson 1986, p. 26 (SC). Given the assumed narrow geographic range (approximately 260 km (162 miles) of coastline) and specialized habitat requirements, the species was likely limited in the number of potential historical populations by the availability of swale habitat on these islands. However, the development of these islands around the middle of the 20th century almost certainly decreased the number of populations within the range. One known location was detected in 1998 and supported the largest population of Bethany Beach firefly at the time but has since been presumed extirpated due to development, indicating that redundancy has likely been reduced in the recent past and historically. Swales in the range of the Bethany Beach firefly are limited, localized habitats, so there are not many available populations nearby to provide backup or repopulate areas that become extirpated; this also limits natural expansion of the species into new habitats. While we assume that there is no regular dispersal among complexes, instances where individuals are able to disperse among complexes is possible but assumed to be rare.

Due to the small geographic range, catastrophic events (hurricanes, droughts, etc.) have the potential to have some impact on all the populations at once. For instance, a strong hurricane or other storm could affect the entire range, although this species has evolved with hurricanes and likely has the adaptive capacity to withstand typical impacts from storms. The species is likely able to tolerate repeated flooding by saltwater and persist in place despite some increase in the strength of storms or storm surges; however, it is unknown where the tolerance ends, and if prolonged flooding or too frequent over wash would lead to population decline or extirpation. The species does not have much ability to shift its range in the event of a catastrophic impact to existing habitat, due to the limited availability of habitat and the distance between complexes. Localized threats, such as light pollution, habitat loss, and insecticides (mosquito spraying), are more likely to cause the extirpation of individual populations rather than affect the entire range.

5.3 Summary of Current Condition

Current condition information for the Bethany Beach firefly consists of presence-only detection information as well as property-level assessment of threats. Therefore, we are unable to classify resiliency for this species. There is no information on population sizes or demographics as the goal of surveys was to determine presence and identify the range. Recent surveys found it in more properties and more states than previously thought thus survey efforts emphasized broad surveying rather than repeated surveys. However, we have determined that the Bethany Beach firefly appears to exist as 15 complexes (populations), with between 1 and 5 occupied swales per complex. Most complexes have varying levels of existing stressors, including invasive

Phragmites, lighting, mosquito spray, and nearby development; however, two complexes, one each at Chincoteague National Wildlife Refuge and False Cape State Park, have few if any current stressors. Two properties, Delaware Seashore State Park and Assateague Island National Seashore, have over half of the occupied complexes and swales; Delaware Seashore has more current stressors than Assateague Island National Seashore.

Redundancy and representation for this species are likely reduced from historical levels, as habitat has been lost to development. However, it is unknown what the full range of this species was historically or is today.

5.4 Uncertainties and Assumptions Related to Current Condition

For our analysis of current condition, it was necessary to make certain assumptions to assess the species' current resiliency, redundancy, and representation. These assumptions introduced some uncertainty to our estimates.

Knowledge gaps in our understanding of Bethany Beach firefly populations and their habitat, as well as our survey and analysis methodologies and their limitations, provide several areas of uncertainty which could lead to inaccurate estimates of current condition. The species has knowledge gaps due to the brief period of time it has been surveyed and the limited amount of time surveys can occur during ideal survey conditions (weather and time of night):

- We acknowledge that specific information on the Bethany Beach firefly's biology and demographics is sparse; however, this qualitative approach for assessing the species' condition has been used for other aquatic species in the eastern U.S. and is based on the best available science. Therefore, it was considered an acceptable approach for this SSA report.
- We divided the current/occupied Bethany Beach firefly range into 15 analytical units (complexes) and treated these units as separate populations based on known occurrence records and on the observed flight patterns of this species. For this SSA, our assumption is that these analytical units represent biological populations, or interbreeding groups of organisms that occupy the same geographic area and produce viable offspring. However, there is not much understanding of what constitutes a firefly population, how far the species can disperse (our estimate was based on observations during surveys), or where barriers to dispersal occur. This could lead to over- or under- estimates of overall species redundancy.
- Population sizes and population demographics (especially population trajectory) are unknown, which prohibits accurate estimates of resiliency.
- We based the species' current range on survey records obtained since 2019, or 5 years. Not all known swales/complexes that have been mapped have been surveyed, and this could potentially underestimate overall species redundancy.

- Swales that could provide potential habitat have not been mapped range-wide, and mapping is especially lacking in Virginia. Thus, not all existing swales/complexes have been mapped which could potentially underestimate overall species redundancy.
- The ability to conduct repeated surveys for the species to better assess presence or absence during optimal weather and survey conditions is difficult due to the species' brief mating season, nocturnal activity, and short mating period (time of night). Of the swales that had over 10 individual surveys, none had over 50 percent of the surveys come back positive, indicating that swales with few surveys may still be occupied (Table 6). This could underestimate overall species redundancy. Similarly, a lack of recent detections at previously occupied locations does not necessarily imply extirpation and could be a product of a lack of surveys. This could underestimate overall species redundancy.

Table 5. Survey instances where Bethany Beach firefly was found to be absent, present, and the total number of surveys for seven swales where more than 10 survey events occurred. The percent of surveys that were positive ranged from 0 to 50.

	Surveys			Percent
Swale #	Absent	Present	Total	positive
1	8	5	13	38
2	10	0	10	0
3	10	3	13	23
4	7	3	10	30
5	8	4	12	33
6	5	5	10	50
7	9	1	10	10

CHAPTER 6 – FUTURE SCENARIOS AND SPECIES VIABILITY

We have considered the Bethany Beach firefly needs for viability, the current condition of those needs, and we reviewed the factors that are driving the historical and current conditions of the species. We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, representation, and redundancy to describe the future viability of the Bethany Beach firefly.

6.1 Introduction

The largest threat to the Bethany Beach firefly in the future are the compounding effects of climate change, specifically increased frequency, and intensity of coastal storms and SLR (see Section 4.2).

SLR is an impending threat for coastal areas, and as the sea level rises, Bethany Beach firefly swale habitats will become inundated permanently with seawater. In addition to SLR, beaches will be affected by extreme high tides or flooding events, which are projected to increase in frequency (Sweet et al. 2018, p. vii-viii). Minor flooding events will be the most common and are estimated to impact an additional 0.55 (1.8 ft) of elevation on top of SLR projections for the range of the Bethany Beach firefly (Sweet et al. 2018, p. 41). Repeated HTF events are likely to degrade habitat due to frequent flooding by sea water, even before the sea level is high enough to inundate the habitat. Moderate and major floods will also increase in frequency, although the additional impacts of these events are unknown.

6.2 Methodology

Due to a lack of survey effort in many locations and the low detection probability of this species, we assess the future condition of all identified complexes, including those both with and without surveys and with and without detections. Thus, we consider that any identified habitat has the potential to be occupied. However, we also assess the future impacts for only the complexes that are current and known to be occupied.

For our estimates of future condition, we accounted for SLR, modeled using recent NOAA projections (Sweet et al. 2022, entire), and considered the related effects of HTF (Sweet et al. 2018, entire). We modeled both threats for 2040, 2070, and 2100 (approximately 15, 45, and 75 years into the future) to estimate the condition of the Bethany beach firefly. Given the Bethany Beach firefly's short generation time (approximately 2 years), we chose a short time step, 2040, to capture approximately seven or eight generations (Fallon et al. 2022, p. 5). We also projected out to 2070, which captures the SLR estimates before the SLR scenarios begin to diverge significantly due to uncertainty of the future of human carbon emissions (Sweet et al. 2022, p. 25). And finally, we also include 2100 to provide a more long-term, foreseeable future in terms of the potential impacts of SLR, as 2100 has served as the endpoint for SLR projections based on the best available data.

6.2.1 Sea Level Rise (SLR) and High Tide Flooding (HTF)

To model SLR, we used the most likely scenarios from NOAA, projected out to 2040, 2070, and 2100 (Sweet et al. 2022, pp. 11–12). Our possible future predictions of SLR include: (1) intermediate and (2) high scenarios, which are aligned with emissions-based, conditional probabilistic and global model projections of global mean SLR and bound the upper and lower end of the likely scenarios. We did not include Intermediate Low or Low projections, nor the 2000 extrapolation scenario, due to their high probability of being exceeded; the current NOAA projections also leave out an Extreme scenario due to the low likelihood of it being realized (Sweet et al. 2017, pp. 11–13; Sweet et al. 2022, pp. 11–12). We used the two nearest local scenarios to the Bethany Beach firefly's range (Kiptopeke, Virginia and Lewes, Delaware; NOAA 2023, entire) for specific SLR height values (Table 7).

The NOAA SLR projections already account for normal high tides (average high tide for a given local station). However, NOAA currently defines high tide thresholds that classify minor, moderate, and major flood events. Minor flooding is defined as "more disruptive than damaging" and currently can be expected about twice a year, but the frequency will increase in the future (see Section 4.2). The derived threshold for what counts as a minor flood within the range of the Bethany Beach firefly is 0.55 m (1.8 ft); moderate and major floods that exceed these heights are also likely to occur but at less frequent intervals (Sweet et al. 2018, p. 11).

Infrequent HTF is not expected to substantially impact the Bethany Beach firefly, while more frequent HTF could affect this species by keeping areas flooded with saltwater for lengthy periods. As the frequency of HTF is expected to increase in the future, we are using 0.55 m (1.8 ft) of height above the SLR values to account for effects to habitat due to this increasingly frequent HTF (Sweet et al. 2018, p. 42). Thus, to account for HTF, we added the 1.8 ft of rise to the projected SLR height values to obtain the height above current sea level that is likely to be impacted by HTF in the future at each scenario (Table 7).

Table 6. Sea level rise projected levels (above current sea level) in feet for each scenario (Intermediate (Int) and High, from Sweet et al. 2022, p. 11) at each timestep for the two local scenarios within the range of the Bethany Beach firefly. Additionally, 0.55 m (1.8 ft) is added to the rise to account for the effects of high tide flooding (HTF).

SLR	2040		2070		2100	
	Int	High	Int	High	Int	High
Kiptopeke VA	1.05	1.21	2.23	3.44	4.04	6.92
+ 1.8 ft HTF	2.85	3.01	4.03	5.24	5.84	8.72
Lewes DE	1.05	1.18	2.2	3.41	4.04	6.82
+ 1.8 ft HTF	2.85	2.98	4	5.21	5.84	8.62

If habitats are inundated in future scenarios, they are no longer considered habitat, and we assume the Bethany Beach firefly will be extirpated from those areas. Habitats that are projected to experience HTF but not full inundation are considered degraded due to repeated habitat disturbance. Thus, for each scenario and timestep, we include the height above current sea levels (mean higher high water (MHHW)) where we expect habitat will be degraded by HTF and the height above current MHHW that we expect will result in habitat loss (Table 8).

GIS shapefiles representing area inundated at 1.0 ft rise increments above current MHHW (Sweet et al. 2022, associated data) are available from NOAA and are recognized as the best available data. Using these 1.0 ft (0.30 m) increment shapefiles allows us to visualize points along the continuum of values to evaluate the impact of SLR across the range of scenarios, which is valuable given the uncertainty of the extent of the Bethany Beach firefly's habitat as well as uncertainty regarding SLR values modeled in the future scenarios. Further, these NOAA shapefiles incorporate hydrological connectivity and local-regional tidal variation (NOAA 2017, entire) into their predictions of where inundation will occur, which could not be gleaned from using only digital elevation models. Each SLR value plus the HTF value was rounded to the nearest foot and because both local scenarios rounded the same, we used just one value for each timestep/scenario for the entire range of the Bethany Beach firefly (Table 8).

Table 7. Heights (elevation) above current sea levels where we expect existing habitat for the Bethany Beach firefly will be degraded (higher areas that are periodically flooded by high tide flooding) and lost (areas permanently inundated by seawater) for each scenario at each of the three timesteps, rounded to the nearest foot from Table 7, to correspond with available NOAA shapefiles.

	Intermediate		High	
	Degraded	Lost	Degraded	Lost
2040	3 ft	1 ft	3 ft	1 ft
2070	4 ft	2 ft	5 ft	3 ft
2100	6 ft	4 ft	9 ft	7 ft

6.2.3 Analysis of Future Impacts and Resiliency

To assess the amount of habitat that would be lost or degraded due to SLR for each scenario, we assessed the number of swales that would be lost or degraded by SLR for each complex, regardless of the status of that complex (current, not detected, or not surveyed). We considered a swale impacted if the SLR shapefile intersected the swale at all; because swales are depressions, any overlap would indicate seawater infiltration (Figure 7). We then calculated the percent of swales per complex that are degraded or lost for each scenario at each timestep. We present this first for all complexes, as well as just the complexes known to be current.

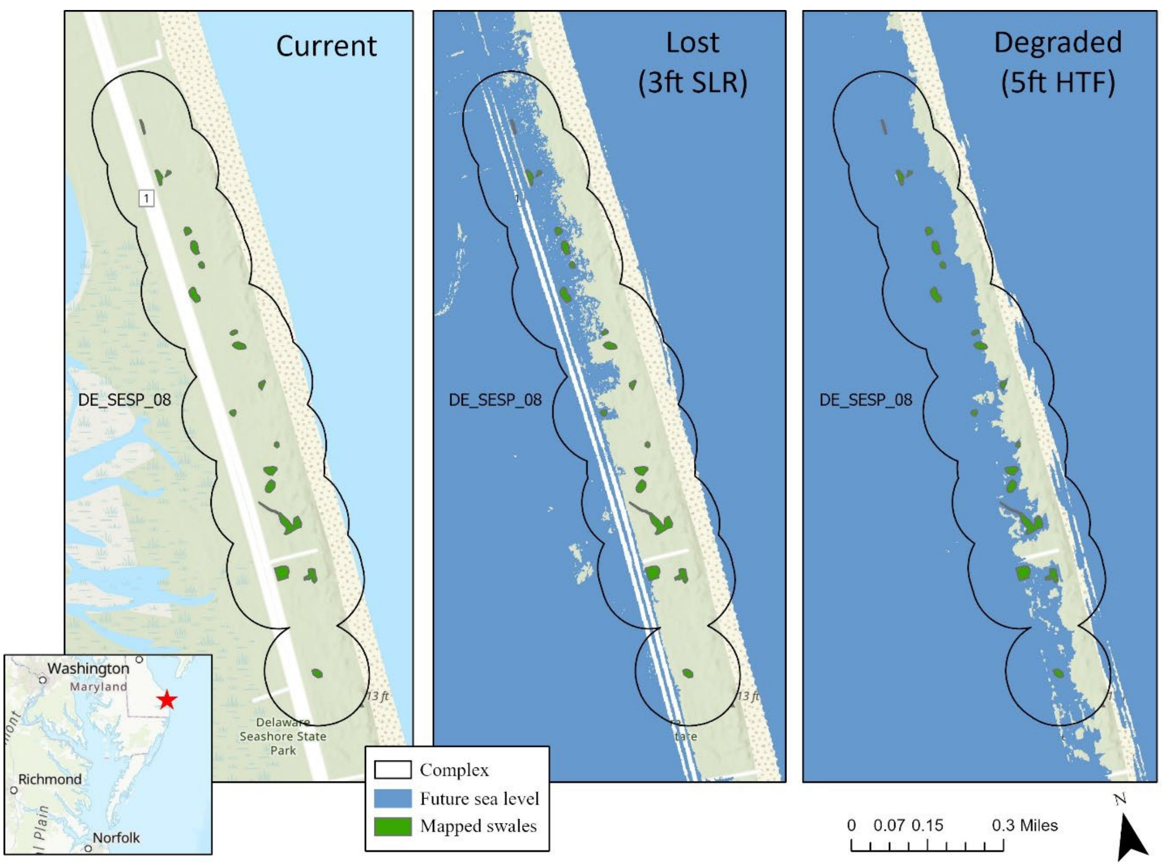

Figure 7. Example of analysis for a complex on Delaware Seashore State Park under a high 2070 scenario. Swales intersected only by the 5 ft high tide flooding are considered degraded, while swales intersected by 3 ft of SLR are lost to permanent inundation.

Due to a lack of available data regarding the true population sizes and distribution of the Bethany Beach firefly, we do not know the current resiliency of complexes, and therefore could not manipulate these to reflect the impacts of SLR. Instead, we quantified the magnitude of the impact of SLR on the resiliency of each complex. If large percentages of potential or occupied habitat is lost, populations are likely to be impacted similarly, regardless of the current resiliency of a population. This methodology allows the focus to be on areas where impacts will be the greatest and allows for easily updated tables in the event that additional populations of Bethany Beach fireflies are found or if future data allows current resiliency to be estimated.

Thus, we quantified the relative magnitude of impact to resiliency based on the percentage of swales in each complex that are projected to be lost or degraded by SLR, as shown in Table 9. We assume resiliency will decline within a complex if swales are degraded or lost. We assume no resiliency remains if all of the swales are lost to inundation. For complexes known to be occupied, we assume a loss of all potential habitat would indicate extirpation of that complex.

Table 8. Relative magnitude of negative impact to resiliency of a complex based on the percent of the swales within it that are degraded or lost due to sea level rise. These impact levels are relative to each other and not meant to portray actual levels of impact.

Impact	Percent of Swales	
	Degraded	Lost
↓	< 50	< 20
↓↓	≥ 50	20 to 50
↓↓↓	NA	> 50
extirpated	NA	100

6.2 Results

6.2.1 Sea Level Rise and High Tide Flooding

By 2040, there is no divergence between climate scenarios. While no swales are lost to inundation, 41 percent of swales are degraded (Table 10). By complex, 12 complexes (39 percent), including 6 that are currently occupied (40 percent), are not impacted by any habitat degradation or loss in 2040, under either scenario (Table 10; Table 11).

By 2070, given an intermediate climate scenario, 15 percent of swales are lost while an additional 61 percent are degraded, and this increases to 41 percent lost and 52 percent degraded given a high climate scenario (Table 10). Seven (23 percent) of the total complexes are completely lost to inundation under an intermediate climate scenario, while 14 (45 percent) are lost under a high scenario (Table 10). Of the current complexes, only one (7 percent) has no impacts by 2070, at False Cape State Park (Table 11). Two complexes (13 percent) are lost given an intermediate scenario, and five (33 percent) are lost under a high scenario; two additional complexes are over 50 percent lost under a high scenario by 2070 (Table 11).

By 2100, 76 percent of swales are lost under an intermediate scenario, while 95 percent are lost under a high scenario (Table 10). All complexes are impacted under a high scenario, with all but three (90 percent) being completely lost, and of current complexes, all but two (87 percent) are completely lost (Table 10; Table 11).

Table 9. Impacts of sea level rise indicating degraded swales from high tide flooding (red shading) and lost swales from inundation (blue shading) affecting current and potential habitat on each complex in the known range of the Bethany Beach firefly at each timestep and for each scenario (Intermediate (Int) and High). Values represent that percentage of swales in each complex that are degraded or lost to inundation for each scenario, as well as the percent of swales that will have any impacts of rising waters (total impacts), representing the sum of the percents degraded and lost.

					2040				2070				2100			
					Int		High		Int		High		Int		High	
				Total	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost
State	Property	Complex	Status	Swales	3ft	1ft	3ft	1ft	4ft	2ft	5ft	3ft	6ft	4ft	9ft	7ft
DE	Cape Henlopen	DE_CAHE_03	Current	5	40	0	40	0	40	20	60	40	20	60	20	80
		DE_CAHE_01	Not detected	7	14	0	14	0	100	0	86	14	0	100	0	100
		DE_CAHE_02	Not detected	1	0	0	0	0	0	0	0	0	0	0	100	0
		DE_CAHE_04	Not surveyed	1	100	0	100	0	0	100	0	100	0	100	0	100
		DE_CAHE_05	Not surveyed	1	100	0	100	0	0	100	0	100	0	100	0	100
	DE Seashore SP	DE_SESP_06	Current	4	100	0	100	0	0	100	0	100	0	100	0	100
		DE_SESP_08	Current	19	53	0	53	0	100	0	47	53	0	100	0	100
		DE_SESP_09	Current	5	0	0	0	0	100	0	100	0	0	100	0	100
		DE_SESP_10	Current	5	100	0	100	0	80	20	0	100	0	100	0	100
		DE_SESP_07	Not detected	8	100	0	100	0	100	0	0	100	0	100	0	100
		DE_SESP_11	Not detected	4	0	0	0	0	0	0	100	0	100	0	0	100
	Private Land	DE_PRIV_12	Not detected	1	0	0	0	0	100	0	100	0	0	100	0	100
		DE_PRIV_14	Not detected	2	0	0	0	0	50	0	100	0	50	50	0	100
		DE_PRIV_13	Not surveyed	2	100	0	100	0	100	0	0	100	0	100	0	100
		DE_PRIV_15	Not surveyed	1	0	0	0	0	100	0	100	0	0	100	0	100
	Fenwick Island SP	DE_FENSP_16	Current	14	7	0	7	0	86	7	93	7	7	93	0	100
		DE_FENSP_17	Not detected	1	0	0	0	0	100	0	100	0	0	100	0	100
MD	Assateague Island	MD_ASIS_01	Current	6	0	0	0	0	33	0	100	0	67	33	0	100
		MD_ASIS_02	Current	8	0	0	0	0	13	0	75	0	88	13	0	100
		MD_ASIS_03	Current	6	0	0	0	0	33	0	100	0	67	33	0	100
		MD_ASIS_04	Current	13	0	0	0	0	69	0	92	0	31	69	0	100
		MD_ASIS_05	Not surveyed	1	100	0	100	0	100	0	0	100	0	100	0	100
		MD_ASIS_06	Not surveyed	2	100	0	100	0	0	100	0	100	0	100	0	100
		MD_ASIS_07	Not surveyed	2	100	0	100	0	0	100	0	100	0	100	0	100
VA	Chincoteague NWR	VA_CHIN_04	Current	7	100	0	100	0	14	86	0	100	0	100	0	100
		VA_CHIN_01	Not detected	1	100	0	100	0	0	100	0	100	0	100	0	100
	Wallops Island	VA_WALL_02	Current	3	100	0	100	0	67	33	0	100	0	100	0	100
		VA_WALL_03	Current	3	67	0	67	0	67	0	33	67	33	67	0	100
		VA_WALL_05	Current	4	100	0	100	0	100	0	0	100	0	100	0	100
	False Cape SP	VA_FCSP_06	Current	5	0	0	0	0	0	0	0	0	0	0	100	0
		VA_FCSP_07	Not detected	1	100	0	100	0	0	100	0	100	0	100	0	100
		Grand Total		143	41	0	41	0	61	15	52	41	19	76	5	95

Table 10. Impacts of sea level rise indicating degraded swales from high tide flooding (red shading) and lost swales from inundation (blue shading) affecting habitat within currently occupied complexes only in the known range of the Bethany Beach firefly at each timestep and for each scenario (Intermediate (Int) and High). Values represent that percentage of swales in each complex that are degraded or lost to inundation for each scenario, as well as the percent of swales that will have any impacts of rising waters (total impacts), representing the sum of the percents degraded and lost.

					2040				2070				2100			
					Int		High		Int		High		Int		High	
				Total	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost	Degraded	Lost
State	Property	Complex	Status	Swales	3ft	1ft	3ft	1ft	4ft	2ft	5ft	3ft	6ft	4ft	9ft	7ft
DE	Cp. Henlopen	DE_CAHE_03	Current	5	40	0	40	0	40	20	60	40	20	60	20	80
	DE Seashore SP	DE_SESP_06	Current	4	100	0	100	0	0	100	0	100	0	100	0	100
		DE_SESP_08	Current	19	53	0	53	0	100	0	47	53	0	100	0	100
		DE_SESP_09	Current	5	0	0	0	0	100	0	100	0	0	100	0	100
		DE_SESP_10	Current	5	100	0	100	0	80	20	0	100	0	100	0	100
	Fenwick Is. SP	DE_FENSP_16	Current	14	7	0	7	0	86	7	93	7	7	93	0	100
MD	Assateague Island	MD_ASIS_01	Current	6	0	0	0	0	33	0	100	0	67	33	0	100
		MD_ASIS_02	Current	8	0	0	0	0	13	0	75	0	88	13	0	100
		MD_ASIS_03	Current	6	0	0	0	0	33	0	100	0	67	33	0	100
		MD_ASIS_04	Current	13	0	0	0	0	69	0	92	0	31	69	0	100
VA	Chincoteague	VA_CHIN_04	Current	7	100	0	100	0	14	86	0	100	0	100	0	100
	Wallops Island	VA_WALL_02	Current	3	100	0	100	0	67	33	0	100	0	100	0	100
		VA_WALL_03	Current	3	67	0	67	0	67	0	33	67	33	67	0	100
		VA_WALL_05	Current	4	100	0	100	0	100	0	0	100	0	100	0	100
	False Cape SP	VA_FCSP_06	Current	5	0	0	0	0	0	0	0	0	0	0	100	0

6.2.2 Future Resiliency

For the majority of the 15 currently occupied complexes of Bethany Beach firefly, resiliency is likely to decline in the future. By 2040, nine (60 percent) of currently occupied complexes have some level of impact to resiliency, regardless of scenario (Table 12). All complexes at Assateague Island National Seashore and False Cape State Park avoid impacts in 2040 (Table 12).

By 2070, only one complex, at False Cape State Park, is not impacted (Table 12). Under an intermediate scenario, one complex is extirpated (7 percent), while five (33 percent) are extirpated under a high scenario. And by 2100, the False Cape State Park complex only avoids impacts under an intermediate scenario. Seven (47 percent) of the complexes are extirpated, with another four having a high level of impact under the intermediate scenario, while a high scenario predicts the extirpation of all but two complexes (87 percent) (Table 12).

Table 11. Relative magnitude of negative impact to resiliency of each complex at each timestep and under each scenario for the 15 current complexes of Bethany Beach firefly. Magnitude levels are based on percentages of swales in each complex lost or degraded as provided in Table 9.

				Total	2040		2070		2100	
State	Property	Complex	Status	Swales	Int	High	Int	High	Int	High
DE	Cp. Henlopen	DE_CAHE_03	Current	5	↓	↓	↓↓	↓↓	↓↓↓	↓↓↓
	DE Seashore SP	DE_SESP_06	Current	4	↓↓	↓↓	extirpated	extirpated	extirpated	extirpated
		DE_SESP_08	Current	19	↓↓	↓↓	↓↓	↓↓↓	extirpated	extirpated
		DE_SESP_09	Current	5	none	none	↓↓	mod	extirpated	extirpated
		DE_SESP_10	Current	5	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
	Fenwick Is. SP	DE_FENSP_16	Current	14	↓	↓	↓↓	↓↓	↓↓↓	extirpated
MD	Assateague Island	MD_ASIS_01	Current	6	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_02	Current	8	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_03	Current	6	none	none	↓	↓↓	↓↓	extirpated
		MD_ASIS_04	Current	13	none	none	↓↓	↓↓	↓↓↓	extirpated
VA	Chincoteague	VA_CHIN_04	Current	7	↓↓	↓↓	↓↓↓	extirpated	extirpated	extirpated
	Wallops Island	VA_WALL_02	Current	3	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
		VA_WALL_03	Current	3	↓↓	↓↓	↓↓	↓↓↓	↓↓↓	extirpated
		VA_WALL_05	Current	4	↓↓	↓↓	↓↓	extirpated	extirpated	extirpated
	False Cape SP	VA_FCSP_06	Current	5	none	none	none	none	none	↓↓

6.3 Future Redundancy and Representation

Redundancy is expected to decrease in the future, as extirpations are projected for the Bethany Beach firefly under both scenarios by 2070. Regarding representation, while there are no known "types" of Bethany Beach firefly, the loss of any single population is likely to decrease the genetic variation of the species. Given the distance between complexes, the species is unlikely to have the adaptive capacity to shift its range in space to avoid the impacts of SLR. While it may be able to persist in place given some impacts of HTF, eventually the frequency of seawater inundation will become too frequent for the species to tolerate. However, it is unknown at what point the species will be unable to tolerate repeated flooding.

6.4 Summary of Future Scenarios and Species Viability

Because SLR is the largest threat to the future viability of the Bethany Beach firefly, we focused our future condition analysis on how the effects of SLR due to climate change will impact the three 3Rs into the future. We evaluated the future condition of the Bethany Beach firefly in 30-year intervals at years 2040, 2070, and 2100 under both an intermediate and a high climate scenario. These scenarios use localized projections of SLR aligned with emissions-based model projections of global mean SLR and bound the upper and lower end of the likely scenarios.

Under either climate scenario, 9 of the 15 existing complexes see some level of impacts by 2040. At least one complex is projected to be extirpated by 2070, and at least seven become extirpated by 2100. Only one complex remains without any impacts by those timesteps. We therefore expect resiliency to decline in all populations with impacts. Overall redundancy and representation are also expected to decline by 2070, given these extirpations.

Under a high climate scenario, 9 of the 15 existing complexes see some level of impacts by 2040, and all but 1 are impacted by 2070. At least one complex is projected to be extirpated by 2040, with at least five projected to be extirpated by 2070. All but two are projected to be extirpated by 2100. All complexes have some level of impacts by 2100. We therefore expect resiliency to decline in all populations with impacts. Overall redundancy and representation are also expected to decline by 2040, given these extirpations.

6.4 Uncertainties and Assumptions Related to Future Condition

For our analysis of current condition, we made certain assumptions to assess the species' current resiliency, redundancy, and representation. These assumptions and the knowledge gaps in our understanding of Bethany Beach firefly populations and habitat introduced uncertainty to our analysis, and those uncertainties also affect the analysis of future condition for the species.

Additionally, the analysis of future condition also includes assumptions and uncertainties that could impact our assessment of the future viability of the Bethany Beach firefly.

Uncertainties include:

- As noted, current condition is mostly unknown; there is uncertainty in the range, extent of available habitat, and occupied habitats of the species. Current condition is based on presence only data. This could underestimate overall resiliency, redundancy, and representation.
- The NOAA shapefiles representing SLR and the elevation models they are based on are not precise and do not account for sediment shifting, beach migration, and dune movements. Thus, the impacts of SLR on individual swales could happen earlier or later than predicted by our models. However, there is high confidence that eventually, and likely within our timesteps, these swales will be impacted by SLR and that permanent inundation will result in loss of habitat.

- The realized impact of HTF on Bethany Beach firefly populations is unknown. We assume that repeated flooding by seawater will have negative impacts due to the fact that the species is associated with freshwater, but it is unknown what frequency and duration of saltwater intrusion would result in larval mortality. We do not know at what point flooding events will become too much: when prolonged inundation of seawater becomes too long, when the interval between flooding events becomes too short, or when the frequency of flooding events becomes too much for Bethany Beach fireflies to tolerate. This could over- or under-estimate the magnitude of impacts on resiliency from habitat degradation due to HTF.
- This future condition analysis does not account for additional impacts, such as small population sizes, lights, invasive species, and insecticides. It is uncertain how these impacts will change in the future or how these threats may already be impacting population viability in occupied complexes.

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