PETITION TO LIST

The Florida Intertidal Firefly

***Micronaspis floridana* Green, 1948**

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

Male *Micronaspis floridana* photographed in Collier County, Florida, May 2022.
Photo: Richard Joyce/Xerces Society.

Submitted by

The Xerces Society for Invertebrate Conservation

Prepared by Richard Joyce, Sharon Selvaggio, and Candace Fallon

28 March 2023

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PETITIONER

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

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

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

Dear Secretary Haaland,

Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. § 1533(b); Section 553(e) of the Administrative Procedure Act, 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14(a), the Xerces Society for Invertebrate Conservation hereby petitions the Secretary of the Interior, through the United States Fish and Wildlife Service ("FWS," "Service"), to protect the Florida intertidal firefly (*Micronaspis floridana* Green, 1948) under the ESA as a threatened or endangered species. Petitioner also requests that critical habitat be designated for the Florida intertidal firefly concurrently with the listing, pursuant to 16 U.S.C. § 1533(a)(3)(A) and 50 C.F.R. § 424.12.

Fireflies are iconic insects that perform important functions in ecosystems and are awe-inspiring parts of our natural and cultural heritage. Recent research has revealed that a number of North American firefly species are at risk of extinction, due to threats including habitat loss and degradation, climate change, and light pollution. The Florida intertidal firefly—a species found only in Florida and the Bahamas— once occupied much of the Florida coast, but habitat loss and light pollution have shrunk its distribution, while sea-level rise and continued coastal development threaten its continued existence. Existing regulations are inadequate to protect this species from the factors that threaten its survival. The factors discussed in this petition illustrate that ESA protection is needed in order to protect this species from extinction.

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

Sincerely,

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Executive summary

Micronaspis floridana, also known as the Florida intertidal, mangrove, or fiddler crab firefly, is a range-restricted habitat specialist firefly species described by J. W. Green in 1948. This nocturnal, flashing species occurs only in Florida and the Bahamas, where it is found in intertidal wetlands such as mangrove swamps and salt marshes. It is the sole member of its genus in the United States, with just one congener described from Brazil. It can be distinguished from other fireflies in Florida by the headshield (pronotum) that is mostly translucent with a dark, inverted T-shaped marking on adults and the spiked dorsal plates of larvae.

The Florida intertidal firefly is imperiled by multiple threats including habitat loss, degradation and fragmentation; light pollution; pesticide exposure; climate change (in particular the impacts of sea level rise, increased temperatures and increased intensity of hurricanes); invasive species; and a lack of protective regulatory mechanisms, among other factors. While this species has been recorded on federal, state, county and private conservation lands, there are no species-specific management activities aimed at protecting this species. Additionally, the passive protection afforded by these managed areas cannot protect this species from new and emerging threats including sea level rise and increased frequency and severity of storms that can destroy or degrade the intertidal wetlands upon which this firefly depends. In sum, the Florida intertidal firefly is particularly threatened by ESA listing factors 1) the present or threatened destruction, modification or curtailment of its habitat or range; 3) disease or predation; 4) the inadequacy of existing regulatory mechanisms; and 5) other natural or manmade factors affecting its continued existence, although all five factors may be impacting the species.

Accordingly, we hereby request that the Service list the Florida intertidal firefly (*Micronaspis floridana*) as an endangered species and concurrently designate critical habitat. Once listed, we recommend that the Service streamline the permitting process activities to facilitate activities that promote the conservation of the species, such as scientific research and monitoring, community science monitoring, and limited collection for research purposes.

Introduction

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

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

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

Recent assessments of North American fireflies have revealed that up to a third of US species may be at risk of extinction, and approximately half of the assessed species are so poorly understood that they have been classified as data deficient (Fallon et al. 2021). The Florida intertidal firefly (*Micronaspis floridana*) is one of these species. Assessed as Endangered by the IUCN Red List of Threatened Species (Fallon and Walker 2021), it is one of over 50 species of firefly in Florida and the only member of its genus in the United States (Lloyd 2018, Vaz et al 2021). It is unique in that it is endemic to low-energy intertidal habitats of Florida and the Bahamas. The habitats that the Florida intertidal firefly uses—mangrove swamps and salt marshes—are threatened by sea level rise and increased storm surges from climate change (Fallon and Walker 2021). Light pollution, pesticide use, introduced entomopathogenic nematodes, and invasive species also threaten this species and its habitat. This species, as all species, has inherent value and a right to exist that is codified into U.S. law by the Endangered Species Act. In addition, the loss of this species would be a tremendous loss to science and our ability to study fireflies, their evolution, behavior, bioluminescence, and adaptations to their environments and to climate change. Without ESA protection, we will lose this species to extinction, and with it, a unique component of Florida's biodiversity.

Conservation status and listing history

The Florida intertidal firefly (*Micronaspis floridana*) has no legal protection under the U.S. Endangered Species Act nor any state endangered species statutes. It has never been petitioned for listing under the Endangered Species Act and it has no federal status. However, between 1984 and 1994, *Micronaspis floridana* appeared four times in the Federal Register Fish and Wildlife Service Notices of Review as a category 2 species, "taxa for which information now in possession of the Service indicates that proposing to list as endangered or threatened is possibly appropriate, but for which conclusive data on biological vulnerability and threats are not currently available to support proposed rules" (49 FR 21664 21675; 54 FR 554 579; 56 FR 58804 58836; 59 FR 58982 59028).

Micronaspis floridana appeared as a Species of Greatest Conservation Need in the 2011 Florida State Wildlife Action Plan (SWAP; Florida Fish and Wildlife Conservation Commission 2011 p. 91), specifically as "Biologically Vulnerable," but did not appear in the 2019 SWAP, which featured a narrower list of species than the 2011 plan and took a more habitat-based approach (FFWCC 2019 p.8). There are no laws regulating its use, possession or harvesting.

In March 2023, Florida Natural Areas Inventory biologists re-ranked the Florida intertidal firefly as G3S3 (vulnerable), based on a re-assessment of the degree of documented decline (NatureServe 2023).

Micronaspis floridana was categorized as Endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species based on area of occupancy being estimated to be less than 500 km^2, few known extant localities being severely fragmented, and observed declines in extent of occurrence, area of occupancy, and area, extent and/or quality of habitat (Fallon & Walker 2021). While additional occurrence records have emerged from undigitized specimen collections, citizen science observations, and surveys by Xerces Society staff, the species would likely still meet the threshold for the Endangered category because documented area of occurrence remains below 500 km^2.

Natural history

Taxonomic status

All fireflies belong to the family Lampyridae in the beetle order Coleoptera. There is no confusion or dispute over the taxonomic validity of *Micronaspis floridana* Green, 1948 (Integrated Taxonomic Information System, 2022). The genus was formerly believed to be monospecific, but recently another member of its genus, *Micronaspis gabrielae*, was discovered and described in Brazil, and distinct, undescribed species of *Micronaspis* have been found in Panama and Jamaica (Vaz, et al. 2021 pp. 82-83). In contrast to *M. floridana*, these fireflies use rocky shorelines with higher wave energy and are not known to occupy mangrove or salt marsh habitats.

Common names for *Micronaspis floridana* include Florida intertidal firefly, mangrove firefly, and fiddler crab firefly (Faust 2017, Lloyd 2018).

Description

Adults are approximately 8-12 mm long and are distinctive for their mostly clear pronotum (head shield) with a dark inverted T-shaped marking (see cover photo). Elytra (wing covers) are pubescent and dark grayish brown with wide pale margins. The legs and ventral segments are dark-colored, except for the lanterns (light organs) and two lateral pale patches distal to the lanterns in males (Figure 1). The anterior tarsal claws on the front and middle legs are forked, a diagnostic trait. Adult females tend to be larger and have a single lantern (Green 1948 p.63-64, Faust 2017).

Figure 1. Ventral view of adult male *Micronaspis floridana*. (Photo: Richard Joyce/Xerces Society)

Bright orange eggs are laid in a clump and develop for three weeks, gradually fading in color (Vaz et al. 2021 p.73).

The larvae grow up to 11-13 mm long, with four spiked projections on each tergite (dorsal plate) and translucent patches on the anterior edge of the pronotum (McDermott 1954).

Larvae have several adaptations for inhabiting the intertidal zone. Hooked pygopodia (terminal appendages used as a holdfasts) and abundant setae (bristle-like structures) likely help the larvae anchor to substrates in tidal currents; it is hypothesized that the tergal tubercles act as gills (Vaz 2021 p.81). Larvae curl into a canoe shape to float on the surface when dropped into water (Vaz 2021 pp.73, 80).

The pupae of *Micronaspis floridana* have not been described.

Population size and structure

The population size and structure of *Micronaspis floridana* are not well studied. However, it has been observed that they do not occur at high densities—up to 50 adult males in a half-mile stretch of habitat (Faust 2017 p.89) or about 50 adult males in 2.2 hectares of habitat (Xerces 2022, unpublished data). Because of their narrow coastal habitat, Lloyd (2001 pp.595-596) noted that gene flow between populations is likely slow and linear, with coastal urban centers creating additional barriers to connectivity.

Life cycle and behavior

Florida intertidal fireflies, like all beetles, are holometabolous, meaning that they go through four distinct life stages—egg, larva, pupa and adult. Females lay at least 15 orange-colored eggs in a single clump, which develop for approximately three weeks (Faust 2017). Larvae feed at night on snails in and near the intertidal zone (Vaz et al. 2021). Observations of larvae in captivity suggest that they will feed on other sources (e.g. raw meat and fish, berries) opportunistically (McDermott 1954, Faust 2017), but it is not known to what extent *Micronaspis floridana* presents this generalist predator or detritivore behavior in the wild. The larval stage typically lasts for at least 3.5 months and pupation has been recorded to last 14 days (Vaz et al. 2021, McDermott 1954). Pupal cells of captive *Micronaspis floridana* were found in burrows 1-2 cm under the soil (McDermott 1954, p.59), and it is suspected that pupae are located in similar places in the wild. Adults can live for at least 24 days (Faust 2017 p.90).

Figure 2. A Florida intertidal firefly larva crawls across upper intertidal substrate in Collier County, FL. (Photo: Richard Joyce/Xerces Society).

In Cedar Key, Florida, which is thought to be close to the northern edge of its range, the Florida intertidal firefly is active from late April to early October (Lloyd 2018, p.423). Elsewhere, adults and larvae can be found year-round, with multiple instars of larvae co-occurring. Aside from the occasional consumption of nectar from flowers (and predation on other fireflies by female *Photuris* species), fireflies typically do not eat as adults, and this is likely true for *Micronaspis floridana*.

The courtship flash pattern consists of a single or bimodal flash repeated at intervals ranging from 1.5-4 seconds, averaging 2.5 seconds (Lloyd 2018 p.423, Faust 2017 p.86). Males flash while flying at low to moderate heights and females respond from low vegetation or rocky substrates (Faust 2017 p.86).

Habitat

Florida intertidal fireflies are found in and adjacent to mangrove swamps and salt marshes along the Florida peninsula, in the Florida Keys, and on Grand Cay, Bahamas (Faust 2017, Lloyd 2018). Dominant vegetation in these habitats includes black mangrove (*Avicennia germinans*), red mangrove (*Rhizophora mangle*), white mangrove (*Laguncularia racemosa*), and salt marsh cordgrass (*Sporobolus alterniflorus*). In the northern parts of the Florida intertidal firefly's range, black-needle-rush (*Juncus roemerianus*) salt marshes seem to be a preferred habitat (Lloyd 2018 p.423-424). Larvae are confined to the upper intertidal zone and areas immediately above the high tide line where their snail prey are found (see Figure 3), whereas adults also occupy upland habitats adjacent to intertidal wetlands (Faust 2017). The common name fiddler crab firefly points to the occurrence of larvae in areas with burrows of fiddler crabs (family Ocypodidae) (Lloyd 2018 p. 423).

Figure 3. A roadside *Micronaspis floridana* site in Collier County, FL. Larvae were found after dark in the bare substrate of the upper intertidal zone among black mangrove (*Avicennia germinans*) pneumatophores. (Photo: Richard Joyce/Xerces Society).

Range, population status and distribution

The confirmed range of the Florida intertidal firefly includes Florida and the Bahamas (Faust 2017, Vaz et al. 2021). In Florida, it is documented from the following counties: Dixie, Levy, Citrus, Hernando, Pasco, Pinellas, Hillsborough, Manatee, Charlotte, Collier, Monroe, Miami-Dade, Broward, Saint Lucie, Indian River, and Volusia (see Figure 4.). Faust (2017, p.89) incorrectly refers to a record from Seminole County; this observation was near the town of Seminole in Pinellas County.

In addition to confirmed locations in Florida and the Bahamas, recent examination of specimens suggests that *Micronaspis floridana* could be more broadly distributed, though these additional areas of the species' range are not yet confirmed. Adult specimens that were determined to belong to the *Micronaspis* genus and appeared similar to *Micronaspis floridana* have been found in the National Museum of Natural History collection currently on loan at the University of

Florida, Gainesville. The localities of specimens include the following coastal areas in Mexico and Central America: Progreso, Yucatán, Mexico; Twin Cays, Stann Creek, Belize; and Panama City, Panama (L. Faust pers. comm. 2022). Additionally, *Micronaspis* larvae were photographed on Isla Coiba, Panama (Vaz et al. 2021 pp. 71, 80-81) and Santa Catalina, Soná, Panama (Luke Foster, 2022) and a larva of an undescribed *Micronaspis* was collected in Jamaica (McDermott, 1954; Vaz et al., 2021). However, none of these specimens have been determined to be *Micronaspis floridana*, so while the genus extends beyond Florida and the Bahamas, the current, confirmed range of this species is limited to Florida and the Bahamas. Further examination of specimen collections may reveal that *M. floridana* is more broadly distributed.

The Florida intertidal firefly was first collected on Key Largo in Monroe County, FL, in 1898, though the species was not formally described until 1948 (Green 1948). The holotype specimen was collected in Cedar Key, Levy County, FL, in 1939 (Green 1948 p.64). The species has been documented along the Florida coast from Dixie County on the Gulf Coast to Volusia County on the Atlantic coast, as well as throughout the Florida Keys and on Deep Water Cay near Grand Bahama (Figures 4, 5, 6 & 7).

The northernmost known locality for *Micronaspis floridana* on the Atlantic coast of Florida is in Volusia County (Lloyd 2001 p.595). Lynn Faust and other firefly experts spent five nights surveying in the vicinity of Matanzas Inlet in St. Johns County in August 2014 and did not detect *Micronaspis floridana*. In March 2021, Faust surveyed in Big Bend Wildlife Management Area in Taylor County (approximately 50 miles northwest of the Cedar Key Shell Mound locality) and found neither adults nor larvae, though cold and windy conditions likely reduced the detectability of any Florida intertidal fireflies occupying the habitat at the time of the survey (L. Faust per. comm., April 13, 2022).

All known records and localities for this species in Florida are presented in Table 1, and have been obtained from the following sources:

- Florida State Collection of Arthropods (FSCA)
- Smithsonian National Museum of Natural History firefly collection (USNM), held at the University of Florida, Gainesville
- Dr. James E. Lloyd personal collection, held at the University of Florida, Gainesville
- California Academy of Sciences Entomology Collection
- iNaturalist.org
- BugGuide.net
- Personal collections and observations of firefly expert Lynn Faust
- Published scientific articles (Lloyd 1966, Simberloff 1976, Lloyd 2018, Vaz 2021)
- Field surveys by Xerces Society staff in May 2022

These records resulted from targeted searches for *Micronaspis floridana* as well as incidental captures and observations, including those of adults attracted to blacklights or captured by beating vegetation and those of glowing larvae detected by chance. Email correspondence with the National Park Service South Florida Collections Management Center on March 8th, 2023 revealed that Everglades National Park is the only Florida national park unit with catalogued Lampyridae specimens in its collections, and the fourteen Everglades National Park specimens were all identified as *Photuris* fireflies, not *Micronaspis floridana* (pers. comm. with B. Ciolino).

While the hazards and nuisances of *Micronaspis floridana* habitats (such as mosquitoes, alligators, and muddy terrain) may deter nocturnal survey efforts, the species is fairly detectable due to its bioluminescence and year-round activity of both adults and larvae, which suggests that the scarcity of specimens in collections and observations in community science databases reflects scarcity on the landscape, not just lack of sampling effort.

Table 1. Documented localities of the Florida intertidal firefly in Florida. Sea-level rise is not listed under the likely threats column because it will affect all sites.

Location	County	Year(s) of record	References	Ownership	Status	Potential and likely threats
Key Largo	Monroe	1898	Paratype, coll. Pollard & Collins, Green 1948, USNM collection	Vague locality	Unknown	Light pollution, Mosquito pesticides
Miami	Miami-Dade	1935	Allotype, coll. F. Young, Green 1948	Vague locality	Unknown	Habitat loss/degradation, Light pollution, Mosquito pesticides, Agricultural Pesticides
Coconut Grove, Miami	Miami-Dade	1953, 1965	Coll. H. Field, McDermott 1954, California Academy of Sciences Entomology Collection; Coll. J. E. Lloyd, Lloyd 1966 p. 85	Private (Henry Field estate); locality too vague	Likely extirpated	Habitat loss/degradation, Light pollution
Everglades National Park	Monroe	1955	Coll. J. G. Peay, FSCA	Federal, NPS	Likely extant	Agricultural pesticides
Stock Island	Monroe	1957, 1962	Coll. W. W. Warner, FSCA; Coll. F.A. Buchanan, USNM	Vague locality	Unknown	Light Pollution, Mosquito pesticides, Habitat loss/degradation
New Smyrna Beach	Volusia	1968	Coll. J. E. Lloyd, J.E.L. personal collection	Federal, NPS	Likely extant	Mosquito pesticides
0.5 mi W. Junct 24 & 347	Levy	1969	Coll. J. E. Lloyd, J. E. L. personal collection	Vague locality, possibly state protected	Unknown	Mosquito pesticides
Keys around Waltz Key Basin	Monroe	1969, 1970, 1971	Simberloff 1976 p.645	Federal, FWS	Likely extant	Unknown

Location	County	Year(s) of observation	References	Ownership	Status	Potential and likely threats
Rt. 44 West marsh	Citrus	1975	Coll. J. E. Lloyd, J. E. L. personal collection	Vague locality, but likely state-owned	Likely extant	Unknown
Emerson Point	Manatee	1991	Coll. R. Morris, in Vaz et al. 2021	County preserve	Likely extant	Agricultural pesticide run-off
Everglades National Park	Miami-Dade	1991	Coll. R. Morris, in Vaz et al. 2021	Federal, NPS	Likely extant	Agricultural pesticide run-off
Virginia Key	Miami-Dade	1991	Coll. M.C. Thomas, FSCA and https://bugguide.net/node/view/881143	Vague locality, possibly city protected	Unknown	Habitat loss/degradation, Light pollution
Black Point Park	Miami-Dade	1993	Coll. Morris & Skillman, Vaz et al. 2021	County	Likely extant	Agricultural pesticide run-off, Mosquito pesticides, Light pollution
No Name Key	Monroe	1998	Coll. L. Hribar, FSCA	Vague locality, but island is mostly owned by FWS	Unknown	Unknown
Key Haven	Monroe	2007	Coll. J. Pieper, FSCA	Private, unprotected	Unknown	Habitat loss/degradation, Light pollution, Mosquito pesticides
Leffis Key	Manatee	2009	Faust 2017 p. 89	County preserve	Possibly extirpated	Agricultural pesticide run-off, entomopathogenic nematodes
The Narrows, Intracoastal Waterway	Pinellas	2012	T. McCrae, https://www.inaturalist.org/observations/142536854	Private, unprotected	Extant as of 2012	Light pollution; agricultural pesticides; mosquito pesticides

Location	County	Year(s) of observation	References	Ownership	Status	Potential and likely threats
Little Gasparilla Island	Charlotte	2014	D. Fulton, https://bugguide.net/node/view/916272	Vague locality	Extant as of 2014	Light pollution
Cedar Key	Levy	1939, 2014	Holotype, coll. P. W. Owen, Green 1948, USNM collection; L. Faust, pers. comm. with R. Joyce, Xerces Society April 2022	State protected	Extant as of 2014	Unknown
Marco Island	Collier	2016	S. L. Snyder, https://bugguide.net/node/view/1482097	Vague locality, but likely federal protected	Extant as of 2016	Light pollution, habitat degradation, mosquito pesticides
Biscayne National Park Ranger Station, Homestead	Miami-Dade	2019	C. W. Chandler, https://www.inaturalist.org/observations/31070480	Federal, NPS	Extant as of 2019	Agricultural pesticide run-off, Invasive snails
Biscayne National Park, Mangrove Preserve, Homestead	Miami-Dade	2021	nature_is_awesome, https://www.inaturalist.org/observations/72498753	Federal, NPS	Extant as of 2021	Agricultural pesticide run-off, Invasive snails
Wabasso Island	Indian River	2021	S. Piotter, https://www.inaturalist.org/observations/74895836	Private protected	Extant as of 2021	Light pollution, Mosquito pesticides
Dove Sound, Tavernier, Key Largo	Monroe	2021	J. Roney, https://www.inaturalist.org/observations/87144382	State protected	Extant as of 2021	Unknown
Chokoloskee I. Causeway	Collier	2022	Firefly Atlas 2022, C. Fallon & R. Joyce	Federal, NPS (edge)	Extant as of 2022	Light pollution

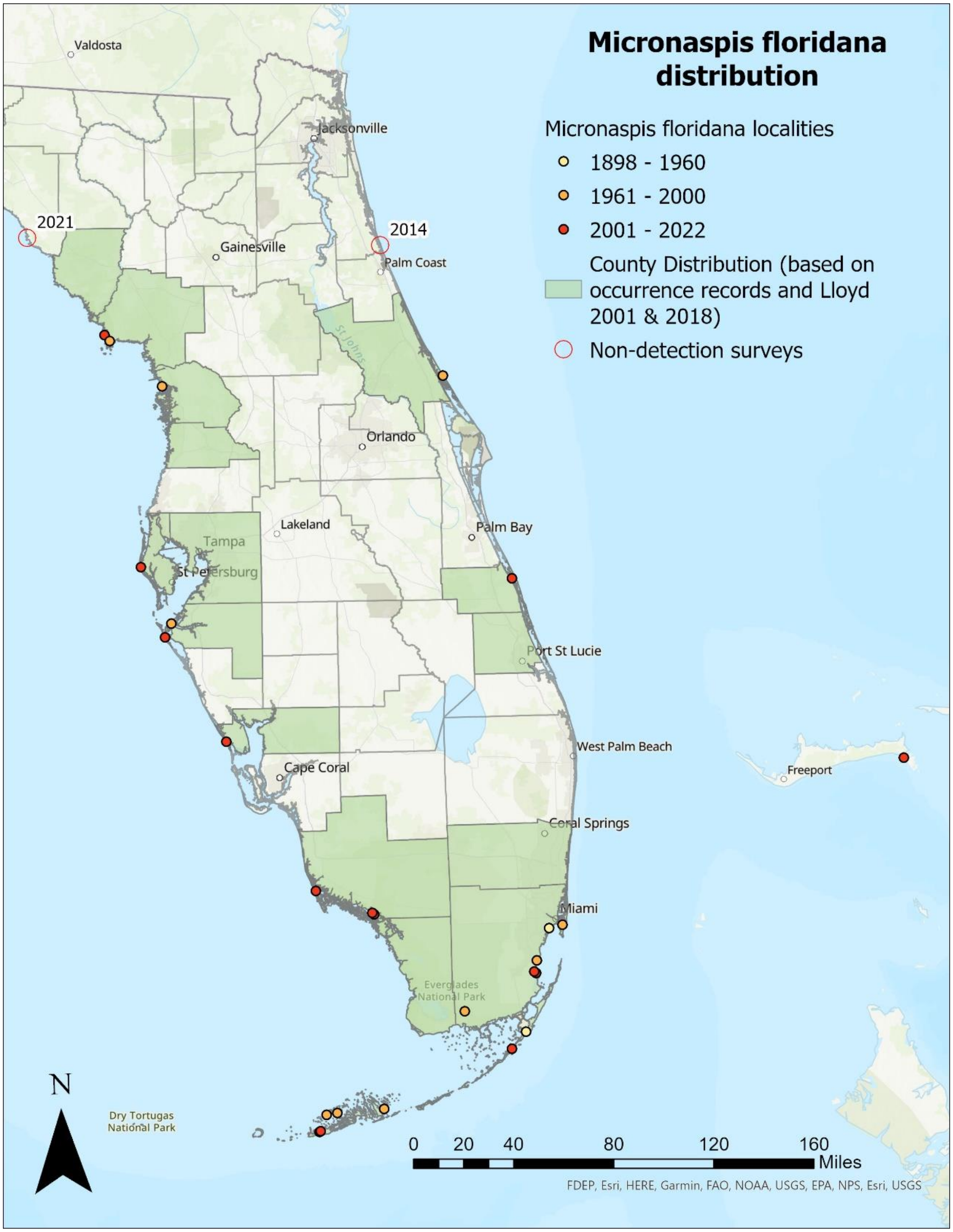


Figure 4. Known distribution of the Florida intertidal firefly (*Micronaspis floridana*), showing localities of specimen records and observations as well as additional counties reported in Lloyd (2001, 2018) that lack specific locality data (Dixie, Hernando, St. Lucie, and Broward). Non-detection surveys (open red circles) represent documented searches beyond northernmost localities.

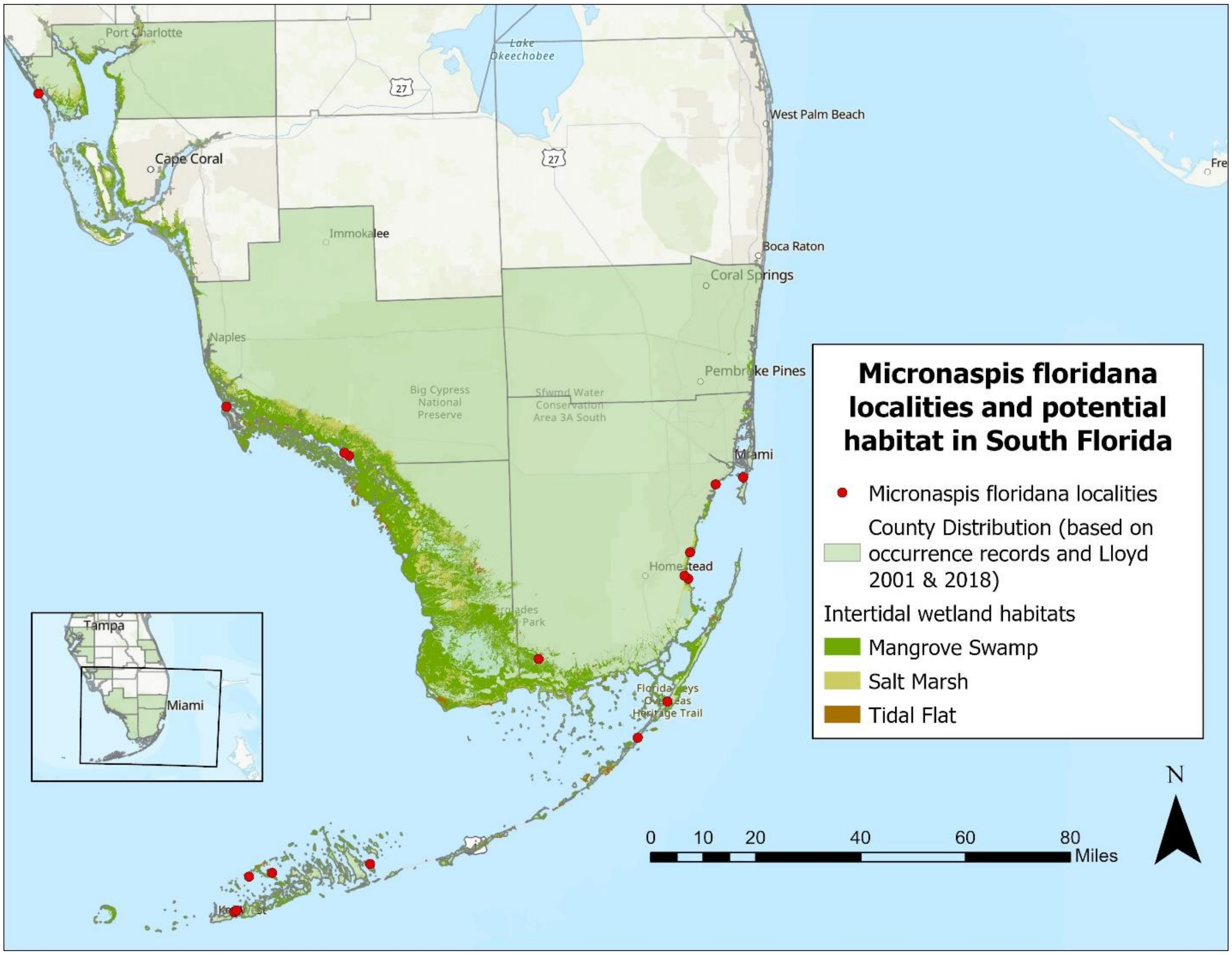


Figure 5. Intertidal habitats (mangrove swamp, salt marsh, scrub mangrove, tidal flat) and recorded locations of the Florida intertidal firefly (*Micronaspis floridana*) in South Florida. Red points are recent and historic records (collections and observations). The mangroves of Everglades National Park and Ten Thousand Islands National Wildlife Refuge likely hold many unrecorded populations of *M. floridana* and could be strongholds for the species, but systematic surveys have not been undertaken. Note the scarcity of mangrove and salt marsh habitats north of Miami on the Atlantic coast compared to southwest Florida. Land cover data from Florida Cooperative Land Cover, version 3.5 (FFWCC/FNAI, 2021).

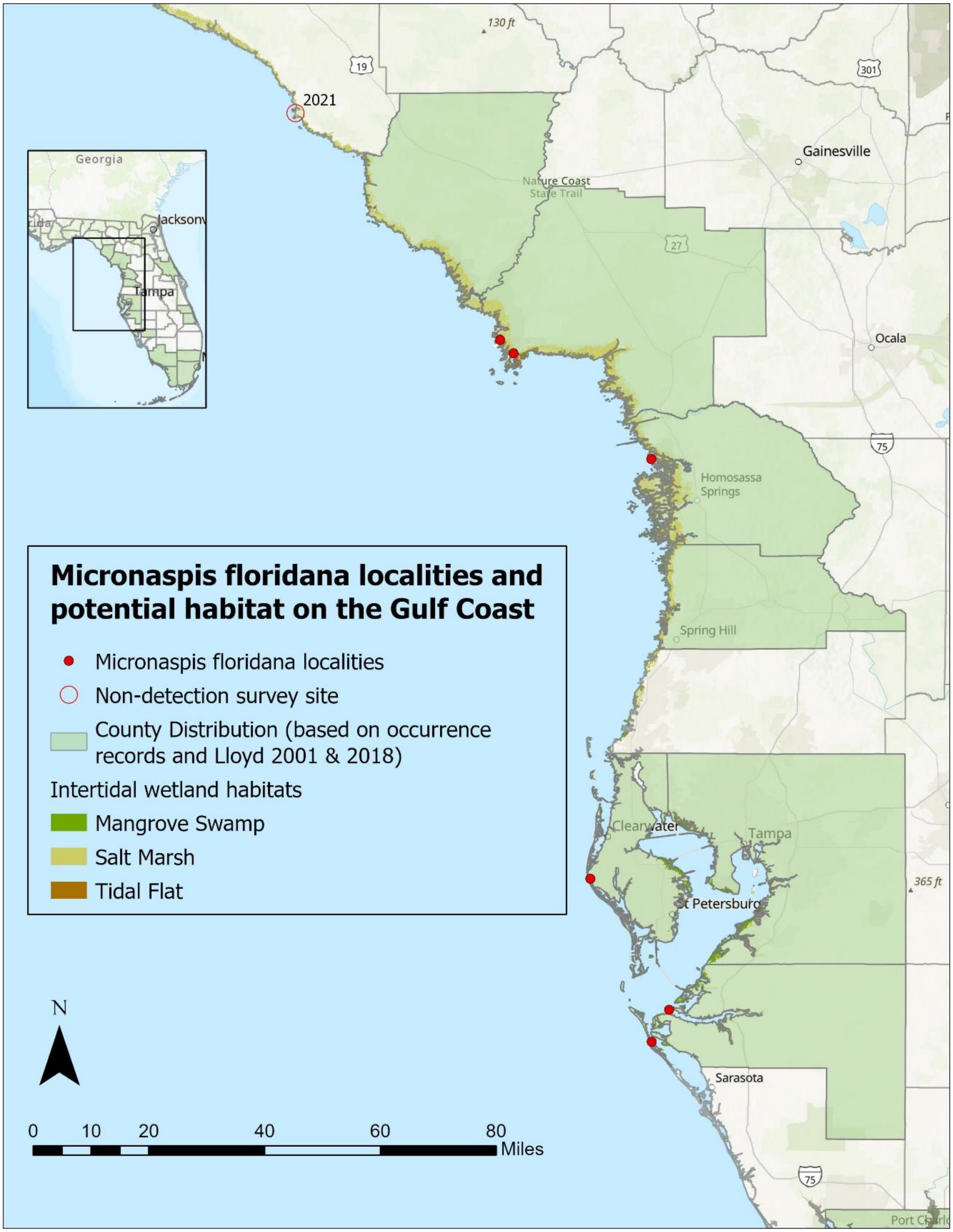


Figure 6. Known localities of the Florida intertidal firefly (*Micronaspis floridana*) and intertidal wetlands potentially providing habitat to the species on the Gulf Coast of Florida. The northernmost confirmed locality for the species is the Shell Mound Area at Cedar Key, Levy County (last confirmed in 2014). The mapped non-detection survey was at Hagens Cove Park, Big Bend Wildlife Management Area, Taylor County. North of Tampa Bay, dominant estuarine wetlands transition from mangroves to salt marsh. Land cover data is from Florida Cooperative Land Cover version 3.5 (FFWCC/FNAI, 2021).

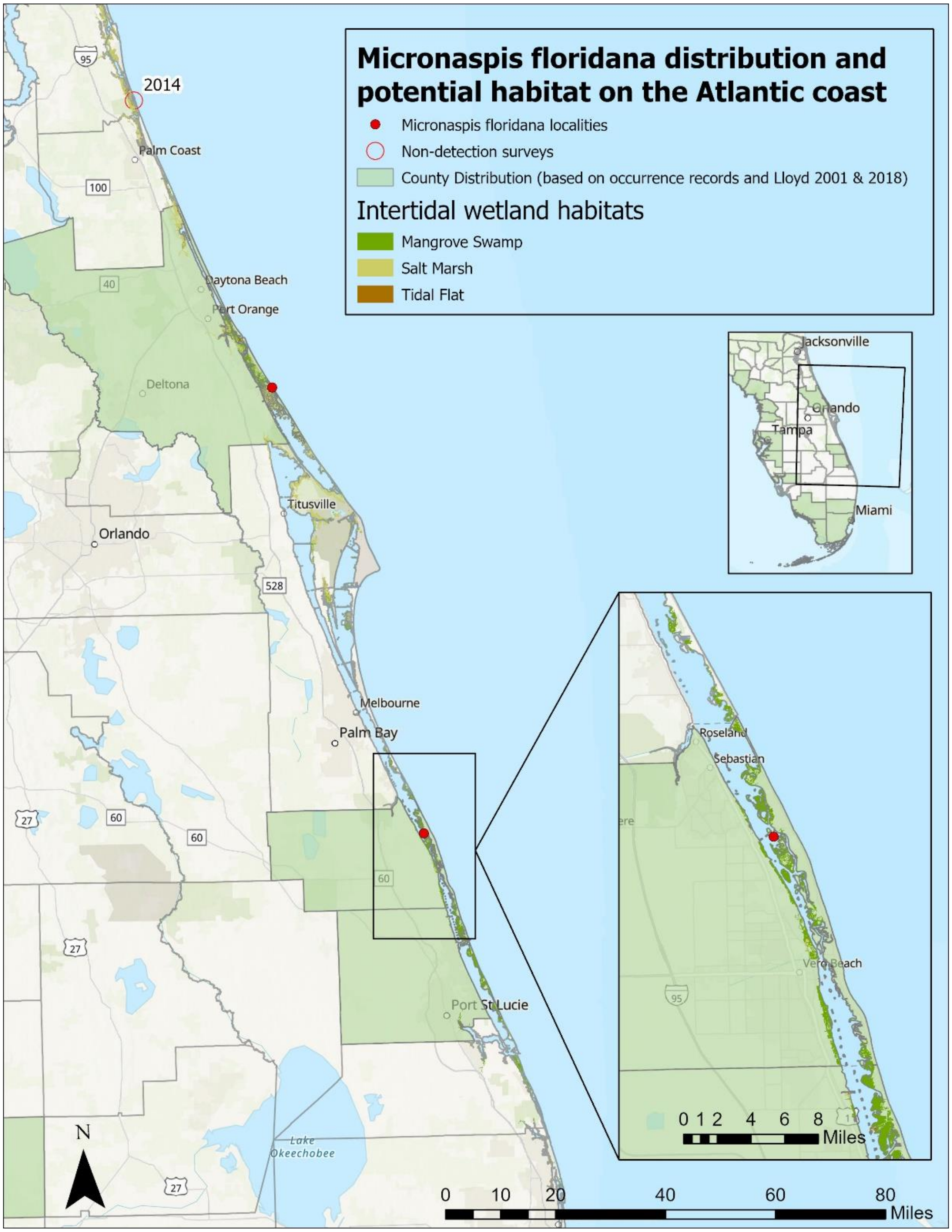


Figure 7. Potential habitat for the Florida intertidal firefly (*Micronaspis floridana*) on the Atlantic Coast of Florida (St. John's County to Palm Beach County). The two records available with sub-county-level precision (red dots) include a 2021 observation on Wabasso Island in Indian River County and a specimen from south of New Smyrna Beach, Volusia County in 1968. The Indian River Lagoon supports about 8,000 acres of mangrove and has a recent record of *M. floridana*, but is also in an urbanized landscape context and has a history of significant wetland modification. Survey efforts in August 2014 near Matanzas Inlet (open red circle) did not lead to any detections of the species. Land cover data from Florida Cooperative Land Cover version 3.5 (FFWCC/FNAI, 2021).

Current and potential threats – An assessment of factors

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

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

According to the 2019 Florida State Wildlife Action Plan, there are 614,097 acres of mangrove swamp in Florida and 378,677 acres of salt marsh, which total to 992,774 acres (4,018 square kilometers) (FFWCC 2019 p.98). However, much of the salt marsh acreage is beyond the current known range of *Micronaspis floridana* — in colder, more northern areas such as the Big Bend Area on the Gulf coast and Nassau, Duval, and St. Johns Counties on the Atlantic coast. Within the range of *Micronaspis floridana*, intertidal habitats have shrunk from their historic extent and face further degradation and loss through various mechanisms outlined below.

Urbanization, coastal wetland destruction, and modified hydrology

Florida is the third most populous state in the nation and has one of the fastest growing human populations, increasing from 2.8 million in 1950 to 21.5 million in 2020 (United States Census Bureau 2021). Much of this growth has been concentrated in coastal counties within the range of the Florida intertidal firefly. For example, between 1950 and 2020, Collier County grew from 6,488 to 375,752 residents (World Population Review 2023a); Charlotte County rose from 4,286 to 186,847 residents (World Population Review 2023b; Monroe County rose from 29,957 to 82,874 residents (World Population Review 2023c; Hillsborough County grew from 249,894 to over 1.45 million residents (World Population Review 2023d); and Miami-Dade County grew from 495,084 to over 2.7 million residents (World Population Review 2023e). Florida had had the seventh highest growth rate (1.37%) in the country from 2010-2020 (Rosewicz et al. 2021) and grew at a rate of 1.9% in 2021-2022, the highest of any state (U.S. Census Bureau 2022).

With this population growth has come the rapid expansion of urban development along Florida's coasts and loss of coastal wetlands. Steep declines in the acreage of non-vegetated intertidal wetland (sand and mudflats) and estuarine emergent wetland (salt marsh) occurred during the 1950s and 1970s (Dahl 2005, p. 41) as dredge and fill operations replaced wetlands with housing developments. During the second half of the 20th century, the Upper Florida Keys lost 15 percent of their original (mid 1900s) mangrove cover (Strong & Bancroft, 1994). Lewis et al. (1985 p.316) estimated that 23% of Florida's historical mangrove cover was destroyed by development by the 1980s.

While wetland loss and degradation from development has slowed in recent years, it continues. Thirteen of the 21 counties in the range of *Micronaspis floridana* experienced net losses of saltwater estuarine wetlands between 1996 and 2016 (Table 2) and the state as a whole saw a 19% increase in urban development as a landcover (NOAA C-CAP, accessed November 2022).

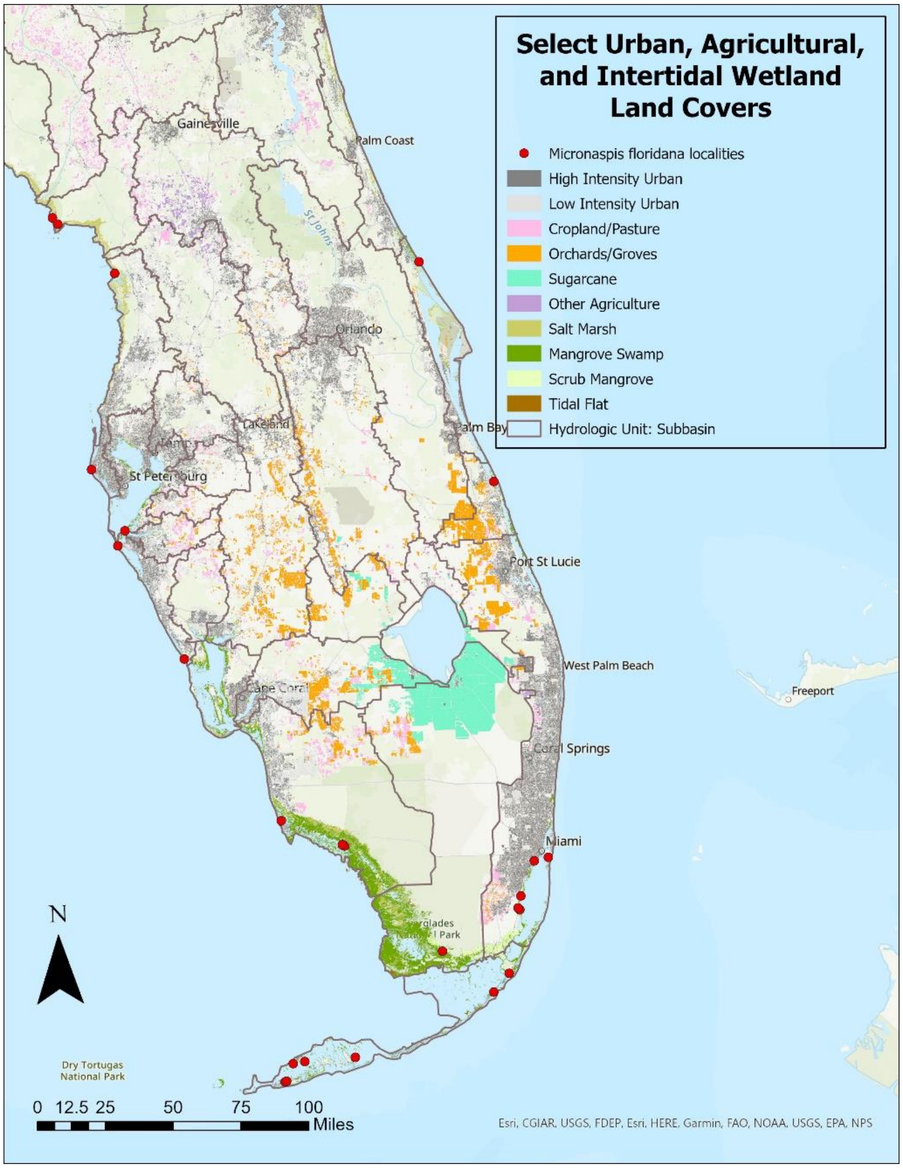
Loss and degradation of salt marsh and mangrove from urbanization may result from indirect impacts (such as obstructions to tidal flow) rather than direct displacement (Radabaugh et al. 2017).

Furthermore, while mangrove cover has increased in recent years, with a net increase of 1,240 hectares on the east coast of Florida between 1984-2011, most of this expansion represents conversion of salt marsh to mangrove (Cavanaugh et al. 2014). Thus, it does not mean that there was a net increase in actual or potential *Micronaspis floridana* habitat.

Table 2. Percent change in land cover of saltwater estuarine wetland from 1996-2016 in Florida counties within the known range of *Micronaspis floridana*. Data from NOAA Coastal Change Analysis Program (C-CAP Atlas, accessed November 2022).

County	**Net percent change of saltwater estuarine wetland cover from 1996-2016**
Palm Beach	-10.01
Hillsborough	-5.92
Broward	-3.5
Pinellas	-2.29
Brevard	-1.8
Monroe	-1.31
Lee	-1.29
Manatee	-1.05
Sarasota	-1.05
Charlotte	-0.61
Hernando	-0.12
Volusia	-0.07
Levy	-0.05
Citrus	0.05
Collier	0.12
Pasco	0.17
Dixie	0.28
Martin	0.28
Miami-Dade	0.29
Indian River	0.76
St. Lucie	1.23

In addition to urban growth and associated wetland loss, the drastic modification of South Florida’s hydrology by canal and levee systems has altered nutrient, salinity, and flow dynamics, replacing southward sheet flow across the Everglades with discharges from Lake Okeechobee to the east and west (Harvey et al. 2019). Thus, many mangroves around Florida Bay in South Florida are deprived of freshwater inputs, while the Caloosahatchee and St. Lucie estuaries are overwhelmed with contaminated, nutrient-rich water from agricultural areas (see Figure 8), with negative implications for survival and development of *Micronaspis floridana* and its gastropod prey.



Esri, CGIAR, USGS, FDEP, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS

Figure 8. Map showing urban developed, agricultural, and intertidal wetland land covers within the known range *Micronaspis floridana* in Florida. While Everglades National Park and other protected areas in southwest Florida protect significant acreage of intertidal wetlands, other coastal areas are heavily dominated by urban development. Agricultural land covers and sub-basin boundaries illustrate source areas for excess nutrients and agricultural pesticides. Land cover data from Florida Cooperative Land Cover version 3.5 (FFWCC/FNAI, 2021).

Modification of marsh and mangrove habitats for mosquito control

In some areas where mangroves were not cleared or converted to urban land-uses, impoundments for mosquito management have flooded large areas of the upper intertidal zone for prolonged periods, with consequences for habitat connectivity, nutrient dynamics, and salinity, as well as negative impacts on fish and invertebrates. More than 40,000 acres of marsh and mangrove were impounded in the second half of the 20th century in order to limit the reproduction of salt marsh mosquitoes, which require mud or other damp, exposed substrates to lay their eggs (Indian River Lagoon Species Inventory: Mosquito Impoundments, n.d.; see Figure 9 for example imagery of historic impoundment). While many of these impoundments now utilize Rotational Impoundment Management to restore more natural tidal flows (Brockmeyer et al. 2022), these systems still show differences from natural mangroves, such as the presence of non-native, invasive plant species on perimeter dikes and spoil sites, lower cover of native black mangrove, and increased retention of leaf litter (Brockmeyer et al. 1996).

It is unknown what impacts these impoundments and related source reduction methods such as rotary ditching have on Florida intertidal fireflies and their gastropod prey, but the seasonal timing of mosquito management impoundment inundation (May-September) may be detrimental to Florida intertidal firefly larvae, as it occurs when larval production is likely highest, based on peaks of adult courtship activity between March and May (Faust 2017 p.87). It is not known if *Micronaspis floridana* eggs can withstand prolonged submersion (longer than a tidal cycle), nor whether filling of impoundments could potentially drown *Micronaspis floridana* eggs. As such, wetland alterations associated with mosquito control have the potential to substantially threaten *Micronaspis floridana.*

Figure 9. Aerial imagery and land cover of Sebastian Inlet State Park in Indian River County, FL, illustrating wetland alteration by mosquito impoundments. Mangrove (green) and salt marsh (blue) habitats are impounded by a perimeter dike that cuts these areas off from the estuary. Dikes alter normal tidal flow and facilitate invasion by non-native vegetation (Brockmeyer et al. 1996). Land cover data from Florida Cooperative Land Cover version 3.5 (FFWCC/FNAI 2021).

Habitat fragmentation

There is some evidence that Florida intertidal fireflies are able to disperse across expanses of water and recolonize habitats where they have been extirpated (Simberloff, 1976 p. 645 and

Faust, 2017 p.90). Larvae have been observed to curve their bodies in order to float on the surface of water, and it has been hypothesized that this could allow for larval dispersal across waterbodies.

However, fireflies are generally weak fliers as adults and poor dispersers (Lewis 2016 p.121), and habitat fragmentation poses a threat to the resilience, integrity, and long-term viability of populations. Successful dispersal between patches is essential for the survival of species with small, distributed populations (Pulliam 1988 p.652-654), allowing for recovery from stochastic events and re-establishment of temporarily extirpated populations.

In southeast Florida, some blocks of mangrove habitat are separated by distances of over 10 miles and stretches of urban development (see Figures 5, 7 and 8), likely reducing the chances of successful dispersal between fragments. Light pollution (discussed in detail later in this petition) likely increases the impermeability of these urban barriers between habitat segments for adult *Micronaspis floridana*, as this is seen in other nocturnal insects known to be attracted to lights (Camacho et al. 2021, Degen et al. 2016).

Sea level rise

Global sea level is rising at an increasing rate (Hayhoe et al. 2018). The 2022 NOAA sea level rise projections estimate that the relative sea level rise from 2005-2060 will be 0.55 meters (21.7 inches) for Virginia Key in southeast Florida and 0.7 meters (27.6 inches) for St. Petersburg on the west coast of Florida (Sweet et al. 2022 p.49). Because the Florida intertidal firefly occupies the upper intertidal area during its larval stage (and presumably egg and pupal stages), even modest amounts of sea level rise will permanently flood the lower elevations of the areas that it currently occupies, likely resulting in a significant loss of this firefly’s habitat.

While it may be possible for some coastal wetlands to persist despite sea level rise through vertical accretion and horizontal migration, the ability of mangroves and salt marshes to migrate and adapt to rising sea levels is greatly constrained by coastal development and infrastructure (Osland et al. 2022 p.2). Furthermore, coastal wetland migration is not a given: the collapse of freshwater wetland peat soils and accretion rates that do not keep pace with sea level rise are two factors that could lead to wetlands being submerged rather than migrating or transitioning from freshwater or brackish to saline (Chambers et al. 2019, Parkinson & Wdowinski, 2022).

There is significant potential for coastal wetlands to migrate in the Everglades of South Florida and the Big Bend area of the Gulf Coast, where mangroves and salt marshes are buffered by large expanses of freshwater wetlands and upland forest (Osland et al. 2022 p.2, Raabe & Stumpf 2018). However, the coastline of Florida is extensively armored, including approximately 3,600 miles of reinforced and pre-stressed concrete seawall (Nolan et al. 2018) and demand for seawalls will likely increase with rising sea levels (Pabon 2019). This not only reduces intertidal area but also prevents landward wetland migration (Beever et al. 2012 p.262). Furthermore, many of the salt marshes of the Big Bend area are beyond the known distribution of *Micronaspis floridana*, so migration of marshes in this region may be irrelevant to the survival of the firefly. In general, highly developed counties on the Florida Peninsula are poorly buffered and increasingly armored, thus presenting barriers to migration of existing marshes and mangroves.

Sea level rise and associated loss of intertidal habitat is a significant threat to *Micronaspis floridana*, which occupies intertidal habitats during its entire larval stage. This threat is projected to continue and increase for the coming century and beyond.

Coastal eutrophication, harmful algal blooms, and hypoxia

Excess nutrients enter Florida's coastal waters from developed and agricultural areas (see Figure 9 for agricultural landcovers and sub-basin watershed boundaries), causing various types of harmful algal blooms, hypoxia, fish kills, and broad ecosystem impacts (Millette et al. 2019, Beck et al. 2021, Boesch 2019, Medina et al. 2022, Metcalf et al. 2021). While the specific impacts of harmful algal blooms on *Micronaspis floridana* and its gastropod prey are not known, the effects are likely negative, as the toxic red tide dinoflagellate *Karenia brevis* has been shown to have sublethal negative effects on marine gastropods (Clark 2021) and microcystin toxins from cyanobacteria accumulate in the reproductive organs of freshwater snails (Lance et al. 2010). Algal blooms potentially harm firefly larvae and their snail prey through toxins, low dissolved oxygen, and smothering of intertidal areas. Nutrient-rich water from Lake Okeechobee is periodically released via canals to the St. Lucie and Caloosahatchee rivers, frequently causing harmful algal blooms. For example, in 2018, the mangrove shorelines of the St. Lucie River estuary were coated with toxic blue green algae (Phlips et al. 2020) from Lake Okeechobee, which now experiences blue-green algae blooms on an annual basis.

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

Fireflies were collected commercially by the millions in the US during the second half of the 20th century for extraction of their bioluminescent enzyme luciferase (Lewis 2016 pp. 128-132). The harvesting of luciferase from fireflies occurred in at least 25 states for 50 years (Lewis p.130). Although luciferase is now produced synthetically, a few companies continue to sell wild-caught firefly products (Lewis 2016 pp.130-131), suggesting that fireflies are still being actively harvested.

Firefly harvesters target male fireflies due to males being more visible with more complex light displays than female fireflies (Bauer et al. 2013). Male harvesting can lower female fecundity and survival by removing mate choice, reducing spermatophores available for females to acquire, reducing mating efficiency, and lowering reproductive output (Rooney and Lewis 2002, Lewis et al. 2004, Lewis and Cratsley 2008, South and Lewis 2012, Bauer et al. 2013).

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

3. Disease or predation

Parasites and pathogens are increasingly recognized as factors in global insect declines (Goulson et al. 2015, Wagner 2020, Sanchez-Bayo et al. 2019), and have been implicated in the declines of several native North American bumble bees (Cameron et al. 2011). Higher mortality of native insects can result from both introduced parasites and pathogens and increased transmission of, or susceptibility to, native parasites and pathogens. Known parasites and parasitoids of fireflies include bacteria (*Wolbachia*, *Spiroplasma*, *Mesoplasma*, *Serratia*, and *Entomoplasma*), fungi, mites, phorid flies, tachinid flies, and nematodes (Faust 2017 p.55-58, Green et al. 2021, Lower et al. 2022), while predators include assassin bugs, spiders, and harvestmen (Faust 2018 p.58-59). Although the extent to which the Florida intertidal firefly is threatened by disease or predation is unknown, for species like this that are already experiencing declines within highly localized ranges, natural predation and disease rates can compound existing threats.

Infection by entomopathogenic nematodes

Introduced nematodes have been shown to be a stressor and possible cause of extirpation for some populations of the Florida intertidal firefly (Faust 2017). In 2009, *Micronaspis floridana* larvae collected at Leffis Key, Manatee County, were found to have been infected and killed by nematodes in the genus *Steinernema* (Faust 2017 p.56). The site of collection was within 2.5 km of agricultural areas across Sarasota Bay that produce ornamental plants, prompting researchers to speculate that the nematodes had originated from local agricultural systems. Firefly researcher Lynn Faust notes in her 2017 book:

"In attempting to study a group of threatenened Florida mangrove fireflies (*Micronaspis floridana*) larvae in 2009, colleagues John Tyler in Britain, Joe Cicero and Patricia Stock in Arizona, and I were dismayed to discover once-healthy larvae suddenly consumed from the inside out by *Steinernema* sp., a microscopic roundworm used to fight beetle bests in the vast agricultural regions that drain into the mangroves and mudflats of Sarasota Bay, Florida, where our Fireflies had been caught." (p.56)

As of 2007, there were four species of *Steinernema* nematodes commercially available to the floriculture industry in Florida: *S. carpocapsae*, *S. feltiae*, *S. kraussei*, and *S. riobrave* (Price et al. 2007). Entomopathogenic nematode species are used as alternatives to pesticides to control pests in agricultural systems, but can negatively impact non-target insects (Rojht et al. 2009). *Steinernema carpocapsae* is a generalist entomopathogenic nematode that is commercially available and used against a variety of agricultural, horticultural, and landscaping pests (including Coleoptera) in Florida (Tofangsazi et al. 2012). This species has been shown to be salt tolerant—surviving at electrical conductivities (a measure of soil salinity) up to 20 deciSiemens/meter (Das 1977, cited in Thurston et al. 1994) and successfully infecting wax moth larvae at 16 deciSiemens/meter (Oetting et al. 1991, in Thurston et al. 1994). Electric conductivity of soils in mangroves may fall below this threshold (Ceron-Breton et al. 2011, Khadim 2017), which suggests that *S. carpocapsae* could survive and infect *Micronaspis floridana* larvae in saline coastal soils.

Steinernema riobrave, another entomopathogenic nematode, has been routinely applied to citrus orchards in Florida to treat infestations of the citrus root weevil (*Diaprepes abbreviates*) and at the peak of its use in 1999 was applied to 19,000 hectares (73 sq miles) in Florida (Dolinski et al. 2012).

While there are several native species of *Steinernema* nematodes native to Florida, including *S. khuongi*, *S. diaparepesi*, *S. phyllophagae* and *S. glaseri* (Stock et al. 2019), none of these has been documented from intertidal habitats.

Native and introduced predators

Many firefly species produce or ingest toxic defense chemicals called lucibufagins to protect themselves from predators, particularly vertebrate predators such as birds (Eisner et al. 1978, Eisner et al. 1997). However, despite the presence of these compounds and ability to flash as a warning to predators, fireflies make up the diet of many animals (Lewis et al. 2012, Faust 2017). Spiders are a well-known predator of fireflies (Lloyd 1973, De Cock et al. 2014, Long et al. 2012). While the direct impacts of spider predation on *Micronaspis floridana* are unknown, the presence of multiple introduced species of spider in Florida and Everglades National Park (Draney et al. 2021) is of potential concern.

4. The inadequacy of existing regulatory mechanisms

There are numerous federal, state, and local regulations that are relevant to the habitats and threats of the Florida intertidal firefly, but none of them, individually or in combination, adequately protect the species from the threats it faces from habitat loss or modification, artificial light at night, parasites, pesticides and other contaminants, and climate change, including sea level rise. At the federal level, these mechanisms include the National Environmental Policy Act of 1970, the Coastal Barrier Resources Act of 1982, the Clean Water Act, the Wilderness Act of 1964, the National Park System, the regulation of pesticides by the Environmental Protection Agency, and protection of co-occurring species under the Endangered Species Act.

At the state level, these mechanisms include the Mangrove Trimming and Preservation Act (1996), the Beach and Shore Preservation Act (1965), Model Lighting Ordinance for Sea Turtle Protection, state regulation of pesticides by the Florida Department of Agriculture and Consumer Services, and Chapter 388, Section 4111 of the Florida Statutes, which address arthropod control on public lands. No current regulations offer the Florida intertidal firefly explicit legal protected status at the federal or state level.

Micronaspis floridana is recognized as imperiled by international and state entities (IUCN 2022, NatureServe 2022), but these designations do not confer legal protection and are solely for informational purposes. As demonstrated in the following sections, the threats faced by the Florida intertidal firefly are not adequately addressed by any existing regulatory mechanisms.

Federal mechanisms

National Environmental Policy Act of 1970

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

Coastal Barriers Resource System of 1982

The Coastal Barriers Resource Act is aimed at conserving ecologically valuable and storm-prone coastal lands and preventing waste of federal resources by restricting federal spending related to development within these areas, including coverage under the National Flood Insurance Program. While this mechanism does limit development and create incentives for conservation on certain stretches of Florida's coast, it has not and does not adequately protect the Florida intertidal firefly from urban development in many of its coastal habitats, nor threats from pesticide application, contaminants, artificial light at night, sea level rise, or invasive species.

Clean Water Act of 1972

Section 404 of the Clean Water Act regulates the discharge of dredged or fill material into waters of the United States, including wetlands, and requires permits from the U. S. Army Corps of Engineers or an approved program for the discharge of said materials. This regulation may prevent or mitigate the filling of salt marshes, mangrove swamps, and other intertidal areas occupied by the Florida intertidal firefly, but does not adequately protect the species or its habitat, and permitted activities may still significantly impact firefly habitat.

The Wilderness Act of 1964

While federal wilderness areas in coastal areas of Florida (such as the Marjory Stoneman Douglas Wilderness, Florida Keys Wilderness, Cedar Keys Wilderness, Pelican Island Wilderness, and J. N. Ding Darling Wilderness) do protect intertidal wetland habitats from development and certain other activities, they do not adequately protect the Florida intertidal firefly from pesticide run-off, artificial light from neighboring developed areas, sea-level rise, introduced parasites, or climate change.

The National Park Service Organic Act and the National Park Service System

The National Park Service Organic Act of 1916 created the United States National Park Service and established its purpose as a federal agency. Florida intertidal fireflies have been found in multiple National Park Service units, including Everglades National Park and Biscayne National Park. However, the NPS does not specifically or explicitly protect the Florida intertidal firefly, nor does it offer protection to populations of Florida intertidal fireflies beyond the borders of its units.

Listing of species with overlapping ranges under the Endangered Species Act

Various species listed as federally endangered or threatened under the Endangered Species Act have designated critical habitat that overlaps with areas known or suspected to be occupied by the Florida intertidal firefly, such as the smalltooth sawfish (*Pristis pectinate*), American crocodile (*Crocodylus acutus*), and loggerhead sea turtle (*Caretta caretta*) (NMFS ESA Critical Habitat Mapper n.d.), However, the designation of these critical habitat areas does not specifically nor adequately protect the Florida intertidal firefly from the threats it faces.

Pesticide regulation by the Environmental Protection Agency (EPA)

Under FIFRA, the U.S. Environmental Protection Agency (EPA) licenses the sale and use of pesticides. FIFRA directs EPA to register a pesticide only upon determining that "when used in accordance with widespread and commonly recognized practice it will not generally cause unreasonable adverse effects on the environment". Unfortunately, to date, EPA has not considered the broad suite of population-level impacts on fireflies (or other insects) like those described herein as an "unreasonable adverse effect on the environment," or otherwise as a basis

for denying, suspending, or re-classifying any pesticide registration approvals or use determinations, despite having the ongoing authority to take such actions.
Furthermore, pesticides are not tested directly on fireflies or other beetles, but rather on surrogate invertebrate species such as the western honeybee (*Apis mellifera*), water fleas (Daphnia), and scud (*Gammarus fasciatus*). None of these three invertebrate species inhabit the soil for any part of their life cycle, nor are they beetles, so they are likely inadequate surrogates for fireflies. Furthermore, the EPA does not require that the additive or synergistic effects of insecticides, herbicides or fungicides be considered, even though pesticides are normally found in combination, not singly.

State and local mechanisms

Florida Administrative Code 68A-27 Rules Relating to Endangered or Threatened Species

This chapter of the Florida Administrative Code regulates state Endangered, Threatened, and special concern species, and includes language stating that "No person shall take, possess, transport, or sell any species of special concern…" However, the Florida intertidal firefly is not currently listed as being endangered, threatened, or of special concern in the state of Florida.

Florida State Parks System

Many Florida State Parks contain and protect the types of intertidal wetland habitats used by Florida intertidal fireflies. However, no Florida State Park Unit Management Plan mentions *Micronaspis floridana*, many management plans do not address artificial light, and several state parks have Arthropod Control Plans with local mosquito districts that allow for ground adulticiding within park boundaries (Call 2016). Furthermore, public access for resource-based recreation opportunities is central to the mission of state parks and can entail the development of infrastructure such as boat landings, campgrounds, parking lots, trails, roads, and associated outdoor lighting, with negative impacts on Florida intertidal fireflies and their habitats.

Mangrove Trimming and Preservation Act (1996)

The Mangrove Trimming and Preservation Act of 1996 is aimed at protecting mangroves from cutting by landowners while prescribing the situations and processes through which some trimming can occur. While it does provide very limited, indirect protection for *Micronaspis floridana* habitat, this protection is narrow and does not address the multitude of other threats facing the species, such as light pollution, sea level rise, coastal armoring, and pesticide use.

Florida Statutes Chapter 62B-55: Model Lighting Ordinance for Sea Turtle Protection

In 1993, the Florida Department of Environmental Protection created a Model Lighting Ordinance aimed at protecting nesting sea turtles from artificial lighting of beaches, which multiple Florida counties and municipalities have used as the basis for local regulations. However, these ordinances focus narrowly on sea turtle nesting beaches, are unevenly implemented and enforced, and do not comprehensively address artificial light at night affecting Florida intertidal firefly habitats.

Beach and Shore Preservation Act (1965)

Chapter 161, parts I and II of Florida Statutes aim to protect and manage Florida's coastline by regulating items such as permitting of coastal construction and beach nourishment activities (depositing sand on eroded beaches). It does not specifically nor adequately protect the Florida intertidal firefly or its habitat, as it primarily regulates activities near sandy beaches with high erosion potential, not the lower-energy salt marsh and mangrove habitats that *Micronaspis floridana* occupies.

5. Other natural or anthropogenic factors affecting its continued existence

Several other factors threaten the Florida intertidal firefly's continued existence, including pesticides, light pollution, invasive species, climate change impacts, and small populations, as described in detail in the following sections.

Pesticides

Pesticides are identified as a serious threat to firefly conservation in North America, second only to habitat loss and fragmentation, according to a survey of firefly experts (Lewis et al. 2020). The preferred intertidal habitats occupied by *M. floridana* may be subjected to pesticide applications directly (to combat mosquitoes), and may experience contamination from drift or runoff of pesticides from adjacent agricultural and urban landscapes. Fireflies may absorb pesticides through direct contact with airborne pesticides, or through contact with contaminated surfaces, sediments, surface water, and/or groundwater. Consumption of contaminated prey or nectar is another potential route of exposure. It is unclear whether or how much *M. floridana* consume nectar, but adults have been observed on inflorescences of sea grape (*Coccoloba uvifera*) (Abreu 2021) and fireflies of other species are known to consume nectar, if this species of firefly does feed on nectar, then it is possible that it could be exposed to pesticide-treated plants.

Scott et al. (2022) reported that insecticide application in South Florida is nearly double the national average, reflecting the large numbers of insects (termites, mosquitoes, fire ants, and other unwanted insects) associated with the region.

M. floridana occupies habitat that may receive pesticide applications directly (for example for mosquito control.) Some of the habitats available for *M. floridana* are also in close proximity to extensively developed urban areas, which commonly receive herbicide and insecticide applications to lawns, landscapes, and structures (Tran et al. 2020; McClain 2014). Florida's Atlantic coastline, and portions of the Gulf coast, are extensively developed (Figure 9). While nationwide or statewide statistics on residential and urban pesticide use are lacking, what studies exist indicate that residential pesticide uses for lawn and landscaping care (and mosquito control in some states) can be extensive and result in significant pollution due to the substantial runoff associated with lawns and developed environments. EPA estimated that more than 1 in 4 households in the United States used insecticides in 2012 (Atwood and Paisley-Jones 2017), but routine household pesticide use may be higher in Florida and the rest of the Southeast than other regions of the country (Naeher et al. 2010). Harmful concentrations of numerous pesticides are routinely found in urban waterways (Stehle et al. 2019; Stone et al. 2014).

Finally, *M. floridana* habitat likely is affected by pesticides applied in agricultural areas (see Figure 8 on p. 26), even those distant from coastal areas (see Figure 8 on p.26), because of pesticides in runoff. Major agricultural crops that contribute pesticides to surface runoff in South Florida include sugar, citrus, and a variety of row crops such as tomato, bell pepper, and watermelon.

Florida intertidal fireflies may be exposed to pesticides from inland areas because an extensive system of canals and levees was developed over the decades to provide flood protection, drainage, and irrigation across South Florida. Canals collect urban and agricultural storm runoff and treated wastewater that is discharged into the Atlantic Ocean and Gulf of Mexico. These structures enable rapid, long-distance transport of aquatic pollutants into estuaries and nearshore habitats, including insecticides, herbicides, fungicides, nutrients, pharmaceuticals, plasticizers, flame retardants, and polycyclic aromatic hydrocarbons, sometimes at concentrations toxic to wildlife or plants (Harvey et al. 2019; Silvanima et al. 2018; Scott et al. 2002; McPherson et al. 2000; Goodman et al. 1999). Estuaries in Florida also receive discharge from aquifers (Barlow 2003; Kroening 2008), meaning that contaminated groundwater could reach the intertidal habitats of *Micronaspis floridana*.

Pesticides in Florida surface waters and sediments

Multiple studies have documented widespread pesticide contamination of surface waters, sediments, and organisms within freshwater and estuarine habitats in Florida (Table 3) and of groundwater resources. These studies show that:

- South Florida aquatic pesticide contamination includes current-use insecticides, herbicides, and fungicides.
- Detected contaminants also include discontinued "legacy pesticides" which are classified as "persistent organic pollutants" (POPs) under the Stockholm Convention, with qualities that pose long-term concerns for environmental health, including persistence in the environment, bioaccumulative properties, demonstrating long range environmental transport, and causing adverse effects to human health and the environment.
- Contamination occurs in surface waters in canals, streams and rivers draining to estuary and nearshore habitats, as well as in sediments, biota, and groundwater.
- Certain pesticides routinely or occasionally exceed thresholds established by EPA to protect aquatic life.
- Over time, insecticides have shifted from chlorinated pesticides (now discontinued but still detected) to organophosphates, pyrethroids and neonicotinoids.

Table 3. Florida studies documenting aquatic and sediment pesticide contamination (most recent studies first). Basins, drainages, and canals whose estuaries or outlets are within the known distribution of *M. floridana* are in bold.

Authors	Location	Matrices Examined	Chemicals Analyzed	Findings
Silvanima et al. 2022	Statewide	surface water	neonicotinoid insecticides	Imidacloprid was detected at 75% of 77 sampling stations in 2015, with concentrations ranging from 2-660 ng/L, and was associated with urban land uses and orchards. Concentrations high enough to produce mortality for aquatic invertebrates (exceeding EPA's acute aquatic life benchmark – ALB) were documented at **Indian River Lagoon**, Lake Worth Lagoon–Palm Beach Coast, **Sarasota Bay–Peace–Myakka**, and **Tampa Bay tributaries**. Higher concentrations capable of causing mortality coincided with hurricane season, associated rainfall, and peak agricultural activities. Within thirteen basins, imidacloprid median values exceeded the US EPA chronic ALB of 10 ng/L (**Everglades West Coast**, Fisheating Creek, **Indian River Lagoon**, Lake Worth Lagoon–Palm Beach Coast, Lower St. Johns, Middle St. Johns, Ocklawaha, Perdido, **Sarasota Bay–Peace–Myakka**, **Southeast Coast–Biscayne Bay**, Springs Coast, **Tampa Bay**, and **Tampa Bay Tributaries**). Results indicate that **Tampa Bay**, **Sarasota Bay**, **Charlotte Harbor**, and the **Indian River Lagoon** are receiving consistent neonicotinoid loads above the US EPA chronic freshwater aquatic life benchmarks. Clothianidin also exceeded the EPA chronic ALB at three sites: Belcher Canal, **Little Manatee River** and **Charlie Creek.**
Silvanima et al. 2018	Statewide	flowing waters, lakes, and unconfined aquifers	imidacloprid	Of 528 aquatic sampling sites, the authors detected imidacloprid within 60% of canal, 52% of stream, and 70% of river sampling sites statewide, with concentrations ranging up to 520, 390, and 480 ng/L, (0.52, 0.39, and 0.48 ppb) respectively. The authors found a significant direct relationship between imidacloprid detections and agricultural and urban land use. Multiple sites showed concentrations exceeding EPA aquatic life benchmarks for aquatic invertebrates. The highest median values were found in the **Tampa Bay** (16 ng/L), Caloosahatchee (14 ng/L), **Indian River Lagoon** (7 ng/L), **Sarasota Bay–Peace–Myakka** (6.35 ng/), and **Springs Coast** (6.25 ng/L) basins.
Lewis and Russell 2015	**East Tampa Bay**, mangrove and seagrass-	surface water, sediment, flora and conch, blue crabs, and fish	chlorinated pesticides, DDT metabolites, atrazine	Legacy chlorinated pesticides (POPs) were detected in 56% of sediment samples. Faunal samples contained chlorinated pesticides. Contaminants in sediments did not exceed proposed individual sediment quality guidelines.

Authors	Location	Matrices Examined	Chemicals Analyzed	Findings
	vegetated habitats			
Schuler and Rand 2008	South Florida	surface water	herbicides	Based on data collected through ambient pesticide monitoring by the South Florida Water Management District, the authors found that ambient concentrations of the herbicide diuron likely poses acute risk to aquatic plants/algae in St. Lucie County. Additionally, St. Lucie County, together with Lee and Martin counties also showed potential for risk to aquatic plants and algae from the combined risk of herbicide mixtures in surface waters, particularly mixtures of diuron, norflurazon, and bromacil stemming from use in citrus orchards.
Carriger et al. 2006	South Florida freshwater canals	sediments	pesticides	DDT, DDD, DDE, chlordane and endosulfan (all POPs) exceeded sediment quality standards at 20 sites. Endosulfan had the highest potential chronic risk for arthropods in the **C-111 canal system**, followed by DDD in the Everglades Agricultural Area.
Harmon-Fetcho et al. 2005	Biscayne Bay and nearby canals	surface water	pesticides	The authors measured surface water pesticide residues along canals in an intensively farmed area near Homestead, as well as a control site in **Biscayne Bay** and a remote site on Adams Key. Atrazine, metolachlor, chlorothalonil, chlorpyrifos, and endosulfan were detected in greater than 66% of all samples analyzed. The control site on the east side of **Biscayne Bay** exhibited detections of multiple pesticides.
Scott et al. 2002	the C-111 canal system and associated estuarine sites in Florida Bay	surface water, oyster and fish tissues, and semipermeable membrane devices	pesticides	The authors measured pesticide residues in surface water, sediments, and tissues from bivalves and fishes in the C-111 canal and **Florida Bay**. Residues in both canal and bay surface water occasionally exceeded EPA water quality criteria, and some samples contained contaminants at levels toxic to clams and to copepods even 10 miles away from the canal confluence with Florida Bay.

Mosquito control by public agencies

Applications of pesticides for mosquito control often occur in Florida intertidal firefly habitats, creating opportunities exposure to the fireflies. Coastal salt marshes produce salt marsh mosquitos (*Aedes spp.)* and biting midges *(Culicoides* spp., commonly known as no-see-ums*)*, and have been targeted for mosquito control since the 1800s. The first mosquito control districts were formed in Indian River, St. Lucie County and Martin County. However, freshwater habitats, temporarily flooded areas, and containers are also utilized by mosquitoes and were eventually included in mosquito control efforts. Chemical agents applied aerially and by ground have changed over the years: from waste oil and Paris green dust (containing arsenic) employed in the early 1800s to DDT and malathion in the mid-20th century, to the suite of larvicides and adulticides used today.

Larvicides available in Florida include insect growth regulators (especially methoprene, but also pyriproxyfen and diflubenzuron); microbial pesticides *Bacillus thuringiensis israelensis* (*Bti*), *Bacillus sphaericus* (*Bs*), and spinosad; the organophosphate temephos (discontinued though stocks may still be drawn down); surface oils and films; and combinations of the above (Lloyd et al. 2018).

Adulticides used in Florida include the organophosphates malathion, naled, chlorpyrifos; and the pyrethroids permethrin, resmethrin, sumithrin (d-phenothrin), etofenprox, deltamethrin, and other products. Adulticide applications may occur year-round, although are most commonly used from May through October, and are commonly applied during the crepuscular hours, when adult fireflies are also active. At present, pyrethroids are the chemical treatment of choice for ground adult mosquito control in Florida (Lloyd et al. 2018) and pyrethroids such as permethrin, resmethrin, and sumithrin, are synergized with piperonyl butoxide (PBO) for greater efficacy.

Mosquito adulticides are intended to remain suspended in air for some time to target flying adults, hence the use of aerosol fogging or Ultra Low Volume (ULV) technology for adulticides (and some larvicides), which results in very fine droplets being dispersed into the air. Both ground and aerial applications of insecticides using ULV technology can result in substantial drift of the insecticide. Naled drift was measured as far as 750 m in a study in Florida (Hennessey et al. 1992). Schleier et al. (2012) found that an average of only 10.4% of ground-based ULV-applied insecticides settled out within 180 m (591 ft.) of the spray source in flat grassland sites. According to the authors, these results are similar to measurements in other studies of ground-based ULV applications using both pyrethroid and organophosphate insecticides, which found that only 1 to 30% of the insecticide sprayed deposits on the ground within 100 m (328 ft) of the spray source. The off-site contamination can include adjacent aquatic sites; Pierce et al. (2005) found permethrin at concentrations ranging from 5.1 to 9.4 µg/L (5.1-9.4 ppb) in surface canal waters adjacent to a truck-based application route.

Once in the water, tidal transport may also convey mosquito pesticides to non-target sites. Pierce et al. (2005) found naled and its degradation product dichlorvos in subsurface offshore water (unsprayed areas of the Florida Keys National Marine Sanctuary) at 0.1 to 0.6 µg/L (0.1-0.6 ppb) 14 hours after application, attributing this to tidal transport subsequent to aerial applications.

The earlier sections documented information on the presence of pesticides in and near Florida intertidal firefly habitats and in the upstream basins of these habitats, showing that a wide variety of insecticides, herbicides and fungicides have been documented in aquatic and intertidal habitats in South Florida, even at remote sites. This subsequent section focuses on the toxicity of widely used pesticides to fireflies, other beetles, and non-target insects generally.

Figure 10. Florida intertidal firefly (*Micronaspis floridana*) adults and larvae share habitats with mosquitoes, as illustrated by this Black salt marsh mosquito *(Aedes taenirhynchus*, left*)* landing beside a *M. floridana* larva (right) held in an open petri dish in Collier County, FL, in May 2022. Photo: Richard Joyce/Xerces Society.

Pyrethroids: Pyrethroids have a wide range of uses in agricultural, urban, and non-crop (such as mosquito management) arenas. Nationwide, in both surface waters and sediments, pyrethroids are the class of insecticides most likely to occur at concentrations higher than regulatory thresholds (Wolfram et al. 2018); however, these pesticides may be missed by sampling programs that focus exclusively on water sampling, since pyrethroids partition into sediments.

Mitchell (2017) reported that beetles (as a group) comprise the 2nd most targeted pest by agricultural pyrethroid users, indicating the efficacy of pyrethroids on Coleoptera in general. Peterson et al. (2016) observed high mortality for adult lady beetles contacted by ground-based ULV mosquito spraying with permethrin. Beachley (2008) assessed pyrethroid mosquito abatement ULV sprays on non-target insects. Survival rates for exposed lady beetles (*Hippodamia convergens*) placed 25 m from the spray were significantly lower 1, 12, and 24 hours post-spraying compared to non-exposed controls. The pyrethroid bifenthrin, is widely used in Florida, including near coastal areas and within the range of *Micronapsis floridana* (Wieben 2019, see Figure 11). In other regions of the U.S.A, its presence in stream sediments has been linked to reduced benthic insect abundance and species richness (Carpenter et al. 2016). Permethrin applied together with piperonyl butoxide (a combination that is used in adult mosquito control in Florida) was 3.4X more toxic to adult and larval Colorado potato beetle (Silcox et al. 1985).

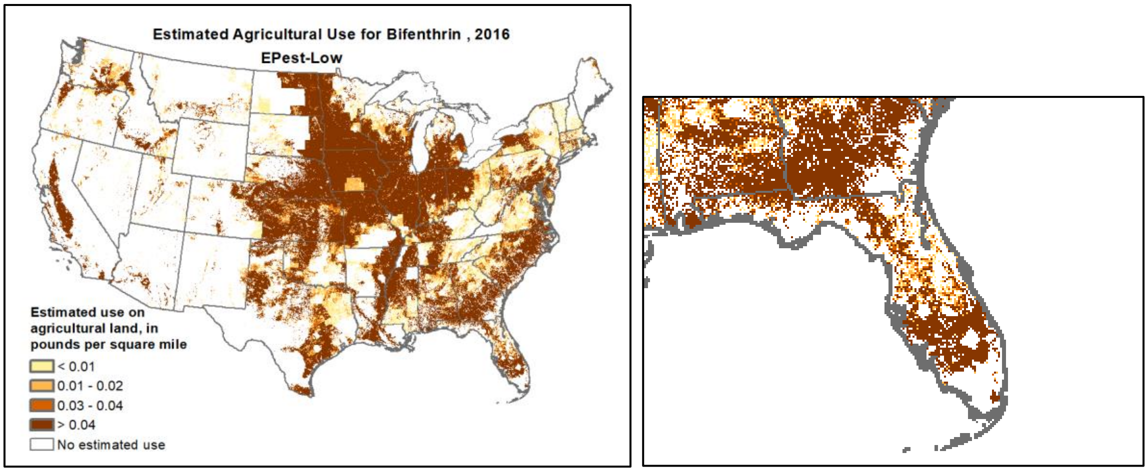


Figure 11 . Lower-bound estimated agricultural application rates of the pyrethroid bifenthrin in 2016, a year of relatively high usage in Florida. Note that bifenthrin was applied in Florida basins upstream from where *Micronaspis floridana* is known to occur, including close to the coast in Miami-Dade County (lower right orange spot on the map). Map from U.S. Geological Survey Pesticide National Synthesis Project.

Pyrethroids are generally the insecticide of choice when doing ground-level spraying for mosquito control. In Florida, residential mosquito sprays may comprise a significant percentage of home pesticide treatments. The vegetated perimeters of residential properties are often sprayed by homeowners and/or pest control companies, killing mosquitoes that rest in or later contact the vegetation. Home mosquito sprays generate about 20% of pest control company revenues, according to trade data (Flesher 2022). Numerous pest control companies offer residential and commercial mosquito control pesticide treatments in areas where the Florida intertidal firefly occurs.

Since pyrethroids effectively kill other types of beetles, they are likely effective at killing fireflies. We know that they are used within the range of the Florida intertidal firefly for residential, landscaping, agricultural, and mosquito control purposes; therefore, pyrethroids pose a significant threat to the Florida intertidal firefly.

Neonicotinoids: Neonicotinoid insecticides, which are highly-toxic and long-lasting, are used widely for agricultural purposes in watersheds upstream from where the Florida intertidal firefly occurs (see Figures 12, 13 & 14). Homeowner surveys outside of Florida indicate that neonicotinoids are also commonly selected for use in landscaping and residential sites, though comprehensive data on the location and amount of homeowner use of insecticides does not exist. Sampling of waterways indicates that Tampa Bay, Sarasota Bay, Charlotte Harbor, and the Indian River Lagoon (all basins within *Micronaspis floridana*'s range) are receiving consistent neonicotinoid loads above the US EPA chronic freshwater aquatic life benchmarks (see Table 3 and Silvanima 2022).

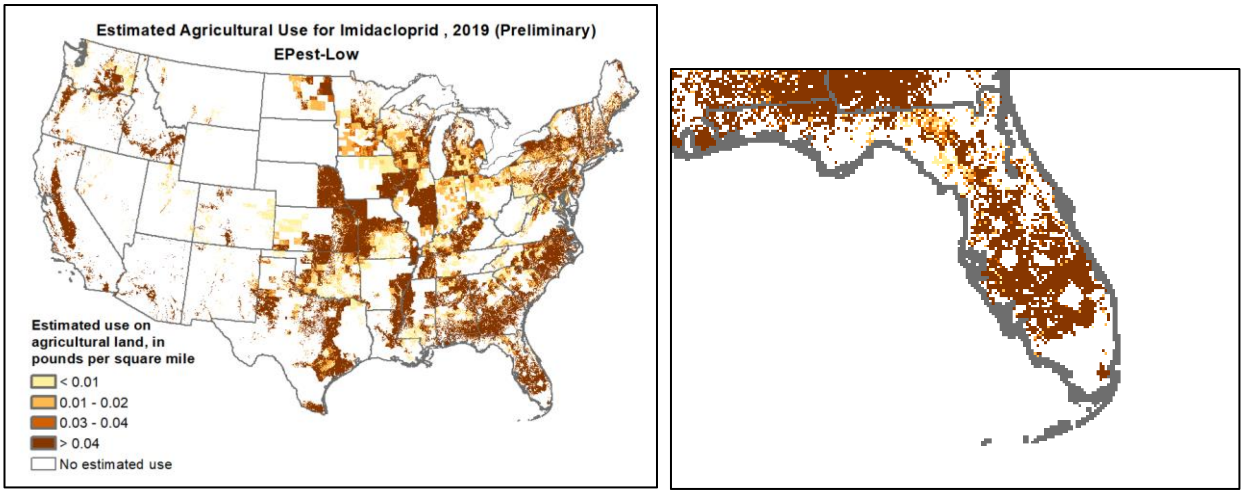


Figure 12. Preliminary lower-bound estimated agricultural application rates of the neonicotinoid imidacloprid in the year 2019. Imidacloprid is used widely in areas that drain to coastal habitats within the range of the Florida intertidal firefly. Note that the insecticide use presented in this figure is likely an underestimate, as pesticide use estimates from after 2014 do not include seed treatments, which is one of the primary uses of imidacloprid. Map from U.S. Geological Survey Pesticide National Synthesis Project.

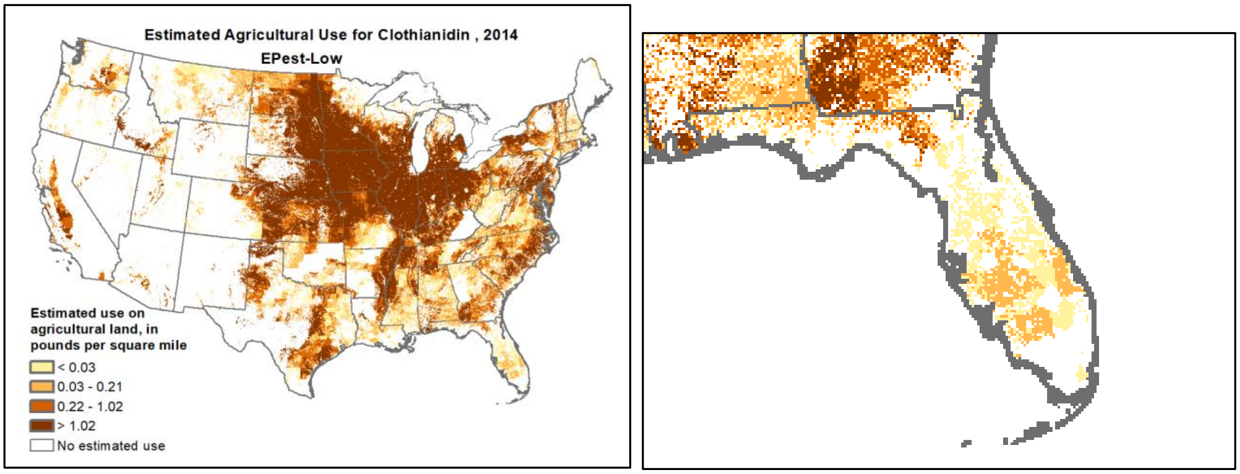


Figure 13. Lower-bound estimated agricultural application rates of the neonicotinoid clothianidin in the year 2014. Clothianidin is used in areas of Florida that drain to coastlines in the range of the Florida intertidal firefly. Since clothianidin is primarily used as a seed treatment, the maps presented above are from 2014, since pesticide use estimates from after 2014 do not include seed treatments. Map from U.S. Geological Survey Pesticide National Synthesis Project.

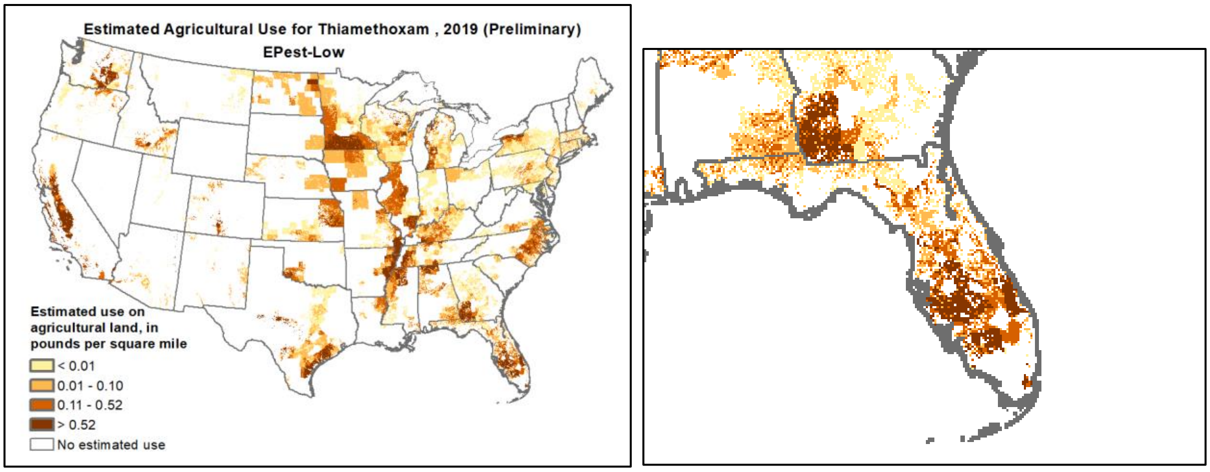


Figure 14. Preliminary lower-bound estimated agricultural application rates of the neonicotinoid thiamethoxam in the year 2019. Note that the insecticide use presented in this figure is likely an underestimate, as pesticide use estimates from after 2014 do not include seed treatments, which is one of the primary uses of the compound. Thiamethoxam is used heavily in areas of Florida that drain to coastlines in the range of the Florida intertidal firefly. Map from U.S. Geological Survey Pesticide National Synthesis Project.

Exposure to neonicotinoids has been shown to have harmful effects on fireflies and other beetles. Disque et al. (2018) captured seventy percent fewer adult fireflies in plots planted with corn seed coated with the neonicotinoid clothianidin, compared to the untreated plots, and the authors attributed this result to impacts that clothianidin had on ground-dwelling firefly larvae. Carabid beetle species exposed to corn seedlings coated with imidacloprid, thiamethoxam or clothianidin had nearly 100% mortality (Pisa et al. 2015). Several beetle species also showed sublethal effects from contact with soil treated with imidacloprid (Pisa et al. 2015). Application of imidacloprid to a lawn to target white grubs was found to reduce non-target species including beetles by 50% or more over three years (Pisa et al. 2015).

Pearsons et al. (2021) tested the effect of soil contaminated with clothianidin on two species of *Photuris* firefly larvae. At concentrations above 1,000 ng/g (1000 ppb), larvae exhibited long-term immobility and mortality. Decreases in feeding and reduced time spent in protective soil chambers were also observed at higher concentrations. Wang et al. (2022) studied the effects of imidacloprid applied topically to larvae of an Asian firefly, *Pyrocoelia analis*, at concentrations of 0.025-0.4 mg/L (approximately 25-400 ppb, within the range of concentrations commonly seen in soil field residue studies) and found destructive changes in midgut and fat cell tissues and persistent luminescence. The authors also determined an LC_{10} level (concentration that caused mortality to 10% of exposed larvae) for imidacloprid of 0.1 mg/L (100 ppb), which is less than concentrations of imidacloprid found in many Florida aquatic samples.

Laboratory experiments conducted on an Asian firefly species, *Aquatica lateralis*, showed that, at the label recommended concentration, the neonicotinoid thiamethoxam caused more than 80% mortality to both adults and larvae and significantly reduced egg hatching (Lee et al. 2008).

Morrissey et al. 2015 reviewed acute and chronic toxicity of neonicotinoids to 49 species of aquatic insects and arthropods, and recommended that water concentrations be below 200 and 35 ng/L (0.2 and 0.035 ppb). The data from Silvanima et al. 2018 presented in Table 3 shows that acute concentrations of imidacloprid do sometimes exceed these levels within Florida's canals, streams, and rivers, including waterbodies that drain to estuaries with *M. floridana* populations.

Larval fireflies may also be exposed to neonicotinoids through their prey, which include gastropods such as slugs and snails. Slugs are relatively insensitive to some insecticides, but residues in slug bodies can be transmitted to their predators. Researchers examining predaceous slug-consuming beetles found that slugs were unaffected by thiamethoxam but transmitted the insecticide to the beetles feeding on them, impairing or killing more than 60% of the beetles (Douglas et al. 2015). Similar pathways could occur with snails, which have been shown to become contaminated with certain pesticides (Druart et al. 2011).

Neonicotinoid insecticides are demonstrably harmful to fireflies and other beetles, are used widely within, and have been shown to move from the area of treatment to be within, the range of the Florida intertidal firefly (Figures 12, 13, and 14), and pose a significant threat to this species.

Organophosphates: Organophosphate insecticides are used in Florida for agricultural purposes, adult mosquito control (vector control districts), and for landscape insect control. Diazinon is used widely for agricultural purposes in Florida including in counties within the range of *Micronaspis floridana* and in basins that drain to estuaries with *M. floridana* habitat (Wieben 2021, see Figure 15). Organophosphates used for adult mosquito control include malathion and naled.

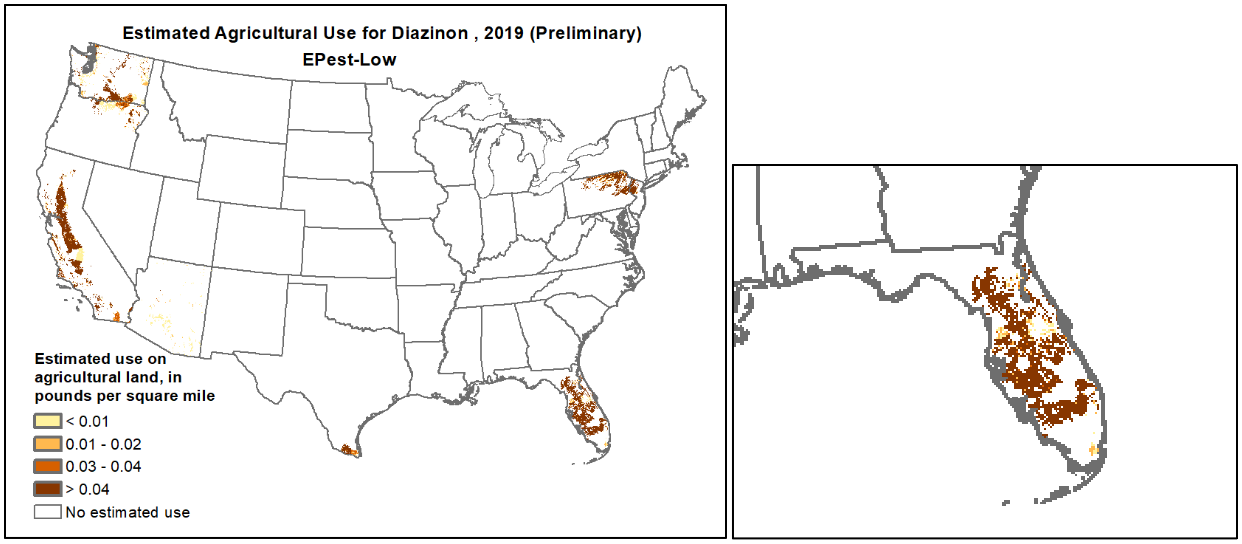


Figure 15. Preliminary lower-bound estimated agricultural application rates of the organophosphate diazinon in the year 2019. Diazinon is used widely in areas of Florida that drain to coastlines in the range of the Florida intertidal firefly, as well as in counties where the firefly occurs. Map from U.S. Geological Survey Pesticide National Synthesis Project.

Organophosphates are broadly toxic to insects; several organophosphates have been shown to kill fireflies at label-approved rates, including acephate, fenthion, and diazinon (Lee et al. 2008). Naled may be present in the air for many days after a mosquito adulticide spray, exposing adult fireflies and other flying insects; according to the EPA, naled's half-life in air is 57.8 hours, meaning detectable levels could last for approximately 10 days after a spray. Naled was also implicated in a high-profile incident that killed millions of honey bees as a result of an aerial application in South Carolina in 2016 (Guarino 2016). Because honey bees are much larger in size than mosquitoes, this incident illustrates that lethal, non-target impacts from naled applications are not just limited to small-bodied insects.

While studies have found minimal mortality of caged crickets in naled spray zones two hours after a single application by truck (Schleier & Peterson 2010) and very limited impacts to overall insect community composition after five aerial naled applications over the course of a season (Rochlin 2022), Zhong et al. (2010) found increased mortality of Miami blue butterfly (*Cyclargus thomasi bethunebakeri*) larvae and higher naled residues within naled spray zones compared to areas outside of spray zones.

Mosquito adulticides are sprayed using ultra-low volume aerosol technology (ULV), resulting in substantial potential for drift (Schleier et al. 2012). Pierce et al. (2005) found naled and its degradation product dichlorvos in subsurface offshore water (unsprayed areas of the Florida Keys National Marine Sanctuary) at 0.1 to 0.6 µg/L (0.1-0.6 ppb) 14 hours after application, attributing this to tidal transport subsequent to aerial applications. The chronic, sub-lethal and additive effects of naled and malathion applications for mosquito control remain a concern for the Florida intertidal firefly, particularly because of the overlap in habitat and flight periods of the firefly with targeted mosquito species. Figure 10 illustrates the habitat overlap of *M. floridana* with salt marsh mosquitoes.

Mosquito larvicides: Mosquito larvicides are often applied directly to the intertidal wetland habitats where Florida intertidal firefly larvae live and feed. Larvicides available in Florida include insect growth regulators (especially methoprene, but also pyriproxyfen and diflubenzuron); microbial pesticides *Bacillus thuringiensis israelensis* (*Bti*), *Bacillus sphaericus* (*Bs*), and spinosad; the organophosphate temephos (discontinued though stocks may still be drawn down); surface oils and films; and combinations of the above (Lloyd et al. 2018).

Galvan et al. (2006) found that, when applied at maximum field rate, spinosad residues were toxic to nearly 40% of larval lady beetles (*H. axyridis*) within 2 days after treatment, but only about 10% of adults died when exposed to this treatment. *Bacillus thuringiensis* subspecies *israelensis* (Bti) is likely not a large concern for direct effects as it does not contain the proteins considered most toxic to coleopterans (Domínguez-Arrizabalaga 2020). Methoprene is toxic to beetle species in some situations (Liu et al. 2012). Because of the known toxicity of methoprene and spinosad to beetle larvae and the overlapping habitats of *Micronaspis floridana* and salt marsh mosquitoes during their larval stages, these larvicides pose a potentially significant threat to the Florida intertidal firefly.

Impacts of pesticides on larval food sources

M. floridana larvae consume snails for their diet. Pesticide use that affects snails can reduce the food sources that larval fireflies need to develop. Many snails, whether aquatic or terrestrial, consume plant material and algae, which may be affected by the herbicides which are frequently detected in South Florida waters. Schuler and Rand (2008) noted that herbicides in the Photosystem II (PSII) family, such as atrazine, simazine, metribuzin and diuron are among the most heavily used in Florida (see Figure 16 for a map of estimated 2019 agricultural use of atrazine) and are commonly detected in Florida's surface waters. Within the Everglades Agricultural Basin sampling locations, atrazine was detected in 75% of the samples and at concentrations exceeding EPA water quality criteria for fresh water plants. PSII herbicides degrade slowly in surface water with hydrolysis half-lives on the order of 30 days to more than 1 year (Schuler and Rand 2008). The long exposure and concentrations above benchmarks highlight the potential for adverse effects to aquatic plants and algae in south Florida surface waters, with potential effects to the snail prey of *M. floridana*. Exposure to herbicides can also have direct negative impacts on snail health. Atrazine has been shown to have endocrine disruption and cellular toxicity effects in freshwater snails (Omran and Salama 2016).

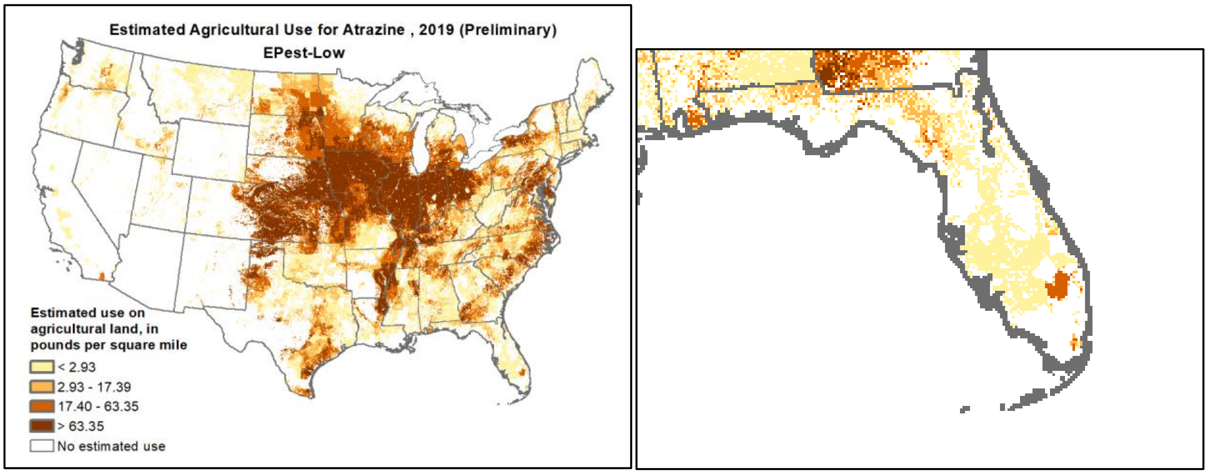


Figure 16. Preliminary lower-bound estimated agricultural application rates of the herbicide atrazine in the year 2019. Atrazine is used widely in areas of Florida that drain to coastlines in the range of the Florida intertidal firefly, as well as in counties where the firefly occurs. Map from U.S. Geological Survey Pesticide National Synthesis Project.

In sum, pesticides present a serious threat to the persistence of Florida intertidal fireflies because of direct mortality, sublethal negative impacts, and impacts on prey species.

Light pollution

Artificial light at night (also known as light pollution) negatively affects the reproductive success of nocturnal firefly species that require darkness for their courtship displays (Owens and Lewis 2018, Lewis et al. 2020, Owens and Lewis 2022) and is increasing globally (Sánchez de Miguel et al. 2021; Kyba, Kuester, et al. 2017). Artificial light at night can interfere with the behavior of nocturnal fireflies in a multitude of ways, including temporal disorientation (courtship behavior failure to be triggered because the ambient light levels never reach necessary thresholds), phototaxis (fireflies being drawn to lights), and disruption of light signal reception (fireflies failing to respond to the signaling of potential mates because the signal is drowned by artificial light) (Owens & Lewis 2018; Owens & Lewis 2022).

The Florida intertidal firefly displays 45-90 minutes after sunset (Faust 2017, p. 87), so it is vulnerable to disruption from artificial light at night. Even bright moonlight appears to limit the flight and display activity of adult Florida intertidal fireflies (Faust 2017, p.90). Illuminance from a full moon is approximately 0.3 lux or less (Kyba, Mohar, et al., 2017 p.32), a level often far exceeded by the streetlights and vehicle headlights (Gaston & Holt 2018, Owens et al. 2022) that encroach on Florida intertidal firefly habitats.

Urbanization has led to high levels of artificial light at night in many areas of coastal Florida (Figure 17, Table 4), as measured in radiance by satellite equipment. Between 1992 and 2012, artificial light levels increased in Florida overall and had mixed trends along sea turtle nesting beaches (Weishampel et al. 2016), with conservation areas and local ordinances helping to counteract the statewide trend. However, coastal habitats are often vulnerable to light pollution as an edge effect because both because of their smaller size and more-complex-shape and because of urbanization pressures on coasts (Sung 2022, Aguilera & González 2023).

While radiance values obtained through remote-sensing may be indirect and coarse proxies for on-the-ground, biologically relevant artificial light at night, they are a strong indicator of the baseline sky glow, light trespass, and glare that fireflies are exposed to in their habitats. Khattar et al. (2022) found that even low levels of artificial light (single digit radiance values) could alter the community composition of bioluminescent fireflies. Even in sparsely populated areas, bright headlights of passing vehicles can overwhelm the light signals of *M. floridana* in habitats near roads (Figure 17). Headlights of newer vehicles emit light at intensities that measure in thousands of lux (2,000-8,000, Gaston & Holt 2018) and the number of registered vehicles in Florida grew by 14.7% between 2015 and 2020 (U.S. FHWA 2017; U.S. FHWA 2022), so roadways near intertidal wetlands have the potential to introduce disruptive amounts of artificial light into *Micronaspis floridana* habitats.

Table 1. Nighttime radiance values (a measure of light pollution) from select *Micronaspis floridana* localities in urban settings in Florida. For comparison, most sites within Everglades National Park have measured radiance values of 0. Data are from VIIRS 2021, lightpollutionmap.info.

Locality (County)	**2021 Radiance Values (10^{-9}Watts/cm^2/sr)**
Coconut Grove (Miami-Dade)	48.2
The Narrows, Intracoastal Waterway (Pinellas)	17
Marco Island (Collier)	13.7
Virginia Key (Miami-Dade)	8.6 to >36, depending on area of the island

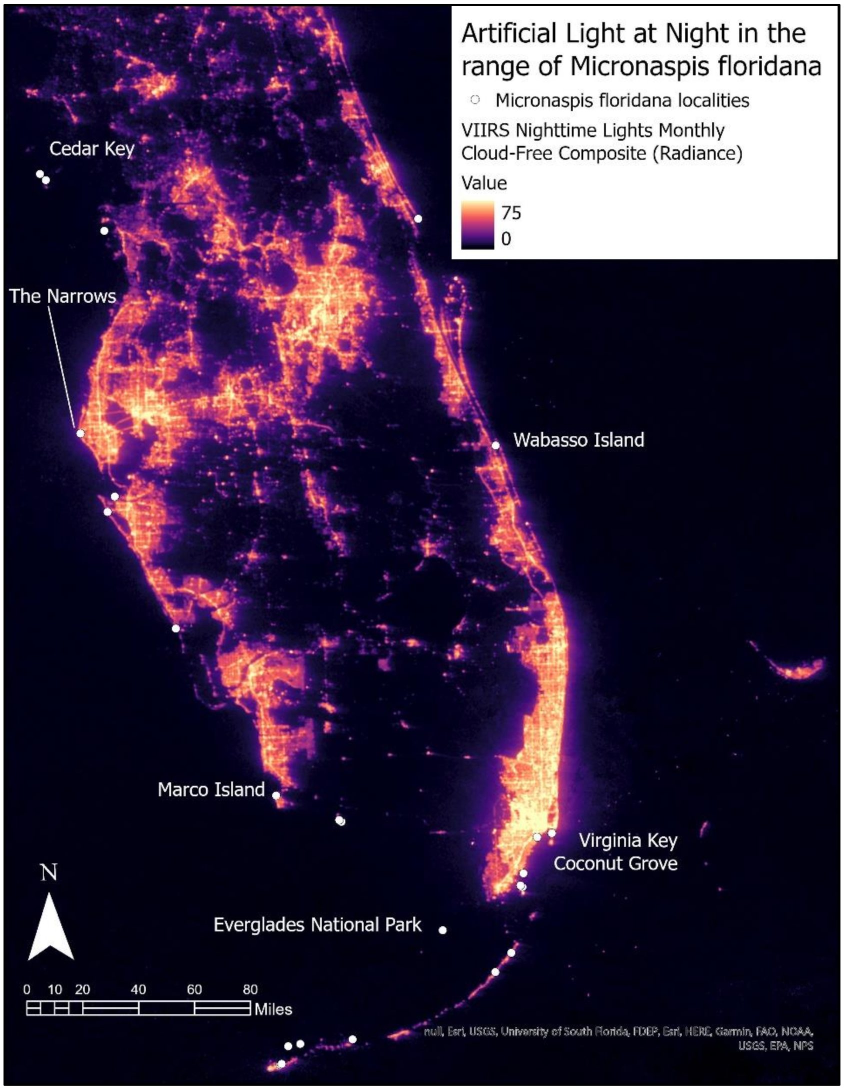


Figure 17. Light pollution in Florida in 2021, collected by the Visible Infrared Imaging Radiometer Suite (VIIRS). Colors represent increasing amounts of artificial light ranging from black (low amounts of artificial light) to yellow (high amounts of artificial light). Light is measured in radiance (10^{-9} Watts/cm^2/sr), a proxy for biologically relevant, on-the-ground light pollution conditions. Aside from Everglades National Park and Cedar Key, most known localities are close to areas of high artificial light at night. Imagery from the Earth Observation Group, Payne Institute for Public Policy.

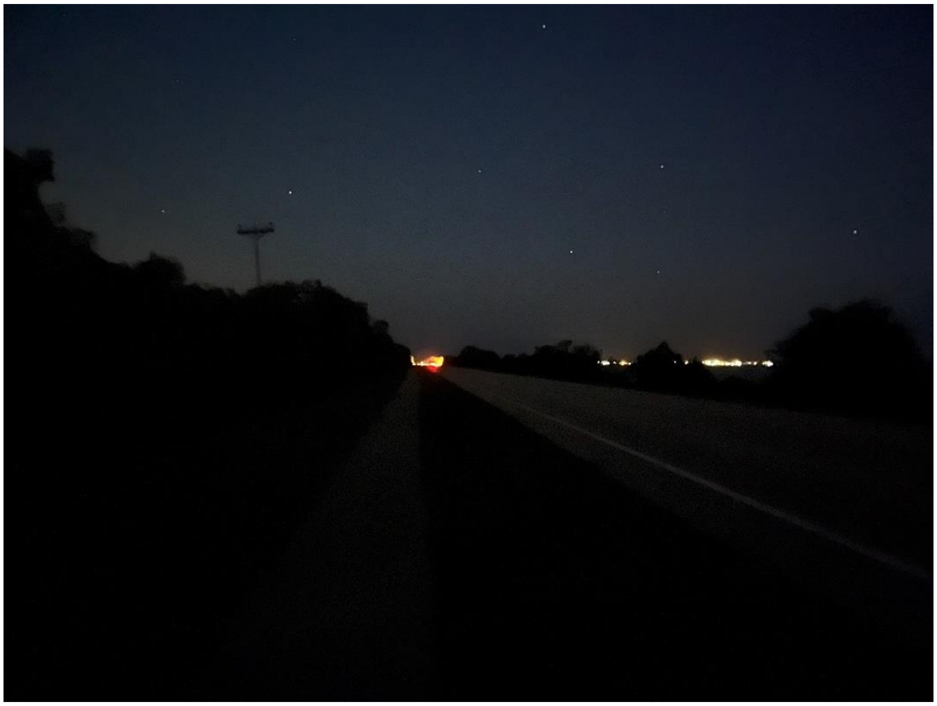


Figure 18. A nighttime roadside scene at the edge of Everglades National Park in Collier County, FL illustrates that even in areas of low human population density, vehicle headlights and urban lights encroach on *Micronaspis floridana* habitat. Photo by Richard Joyce/Xerces Society.

Stressors affecting Florida intertidal firefly prey species

The Florida intertidal firefly is a predator specializing on gastropods such as snails in the intertidal zone (Lloyd 2018 pp. 5, 423). Two significant stressors acting upon the prey species of the Florida intertidal firefly include ocean acidification and invasive mollusks.

Ocean acidification

Ocean acidification due to increasing atmospheric carbon dioxide levels has been shown to impact the growth and strength of the calcium carbonate shells in marine and intertidal mollusks (Barclay et al. 2019, Coleman 2014), as well as their ability to detect predators through chemical cues (Jellison et al. 2016) and to re-right themselves after disturbance (Manríquez et al. 2013). Effects of ocean acidification on populations of intertidal gastropod prey species will likely have negative cascade effects on Florida intertidal fireflies.

Invasive snail species

Several species of non-native, invasive mollusks are present in Florida, including the Giant East African Snail (*Lissachatina fulica*), apple snails (Ampullariidae) (Roda et al. 2016), and the red-rimmed melania snail (*Melanoides tuberculatus*) (Wingard et al. 2008). At Black Point in Biscayne National Park, a known locality for *Micronaspis floridana*, the red-rimmed melania snail is the dominant mollusk species at certain sites (Wingard et al. 2008). It is not known whether Florida intertidal firefly larvae are able to exploit this species as prey, but it is suspected that *M. tuberculatus* may be outcompeting native gastropods (Wingard et al. 2008). Invasive gastropods may pose a double threat to Florida fireflies by competing with native gastropod prey species (if *Micronaspis floridana* are not able to consume the invasive species) and by prompting the use of molluscicides such as metaldehyde that impact both native and invasive snail species (Ciomperlik et al. 2013), and reduce the available food for the Florida intertidal firefly.

Other Invasive species

A large number of non-native, invasive species have become established within the Florida intertidal firefly's range and habitats, ranging from plants like Brazilian pepper (*Schinus terebinthifolius*), non-native black mangrove (*Lumnitzera racemosa*) and Australian pine (*Casuarina* spp.), to reptiles like Burmese pythons (*Python bivittatus*) and brown anoles (*Anolis sagrei*), to invertebrates of diverse taxa. Invasive species like these displace native species and disrupt food webs and ecosystem processes.

While the direct impacts of invasive species on *Micronaspis floridana* are not known, there are multiple possible pathways. For example, feral pigs (*Sus scrofa*), which are found in every county in Florida (FWC n.d.), have been shown to negatively impact salt marshes by trampling, rooting, and consuming vegetation, and by eating mussels that are mutualists of salt marsh cord grass (Persico et al. 2017, Hensel et al. 2021).

Increased temperature and extreme temperature events

Between 2023 and 2053, Florida is projected to see an increase of 25-38 more days with heat indexes of 100°F or higher (Amodeo et al. 2022). This change will impact the Florida intertidal firefly, its prey species, and its habitat. Thermal stress is known to negatively impact beetle survival, reproductive development, and fertility (Sales et al. 2021). High temperatures affect firefly reproduction (Bauer et al. 2013 p. 45) and survival of eggs and larvae (Evans et al. 2019 p. 6). While many intertidal gastropods have physiological and behavioral adaptations to temperature extremes (Leung et al. 2019), these organisms may already be close to their thermal limits (Tomanek & Zuzow 2010), and embryonic intertidal gastropods are particularly susceptible to high temperatures (Przeslawski 2004 p.49).

Furthermore, heat waves are a source of mangrove mortality, with temperatures over 38-40 °C (100.4-104 °F) causing stress to mangrove trees by inhibiting photosynthesis (Sippo et al. 2018). Mangrove mortality likely increases heat stress to fireflies and their prey by reducing the shade and habitat structure that provide thermal refugia. Mangrove trees and roots have been shown to provide essential thermal refugia for intertidal invertebrates such as fiddler crabs and snails (Chou et al. 2019, Lathlean et al. 2017, Ng et al. 2017)

Just as a warming climate increases the number of extremely hot days, it also increases the likelihood of cold snaps through stretched stratospheric polar vortexes (Cohen et al. 2021). The northernmost known localities (Levy and Dixie Counties) for *Micronaspis floridana* fall into Plant Hardiness Zone 9a (USDA 2012), with average annual extreme minimum temperatures between 20° and 25° F (-6.7° and -3.9° C). Cold snaps with temperatures below 20° F (-3.9°C) may restrict the ability of *Micronaspis floridana* to expand its range northward as mean temperatures rise, even if climate conditions are suitable during the remainder of the year.

Increased intensity and proportion of severe storms

Hurricanes are a natural part of the region where the Florida intertidal firefly is endemic, and the species appears to have adaptations that allow it to persist in areas struck by hurricanes. For example, adult *Micronaspis floridana* were observed at Deep Water Cay, Grand Bahama, one month after the devastating impact of category-5 Hurricane Dorian in 2019, suggesting that at least some adults, pupae, or late-stage larvae are able to survive intense tropical cyclones (Faust pers. comm., in Vaz et al. 2021).

However, it is not known what the short-term effects are on non-adult life stages nor the medium-term and long-term effects of such storms are on firefly populations, particularly in combination with other stressors. As the ocean and atmosphere warm due to anthropogenic climate change, tropical cyclones are projected to have deeper storm surge, more intense winds and precipitation, a greater proportion of category 4 and 5 storms, and slower translation speeds (Knutson et al. 2020).

While the long-term effects of hurricanes and other severe storms on *Micronaspis floridana* have not been studied, we know that hurricanes can dramatically affect the habitats that the firefly relies upon. For example, Hurricane Irma in 2017 led to 10,760 hectares of complete mangrove dieback within the range of *Micronaspis floridana* in Southwest Florida, with low-lying black mangrove areas especially affected by ponding and hyper salinization in the aftermath of the storm surge (Lagomasino et al. 2021). Other mechanisms for mangrove degradation by storms include sulfide soil toxicity, peat collapse, soil compression, and soil erosion (Gilman et al. 2008).

Small populations and the Allee effect

Fireflies have complex mating systems involving bioluminescent lighting displays, pheromones, and nuptial gifts (Lewis and Cratsley 2008, Lewis 2016). As firefly sex ratio is near 1:1, any lack of males will result in lower female fecundity (Bauer et al. 2013). Small firefly populations due to habitat fragmentation and degradation can lower mating chances, an effect known as the Allee effect (Gascoigne et al. 2009, Bauer et al. 2013). For insects, if a population is demonstrating an Allee effect, populations may no longer be sustainable and can become extirpated (Gascoigne et al. 2009).

For fireflies, females need enough males in order to choose adequate mates to maximize fecundity and pass high quality genes onto offspring (Rooney and Lewis 2002, Lewis and Cratsley 2008, Bauer et al. 2013). Thus, females with more mate options and the ability to mate with more males will have higher fecundity, survival, and fitter offspring than females with reduced mate choices (Rooney and Lewis 2002, Lewis et al. 2004, Lewis and Cratsley 2008, South and Lewis 2012). Any loss in male population due to habitat degradation and fragmentation puts the Florida intertidal firefly at further risk of extinction due to lower reproductive output.

Request for critical habitat designation

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

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

Conclusion

Fireflies are highly regarded among the public due to significant cultural, biological, and economic importance. The petitioners have carefully assessed the most current and accurate scientific information available for the Florida intertidal firefly regarding the threats this species has faced historically, faces presently, and will face in the future and have determined that the species is in imminent danger of extinction due to threats it faces in Florida. The Florida intertidal firefly is a range-restricted habitat specialist documented from fewer than 25 localities in 15 counties, and some of these populations are suspected to be extirpated due to development and light pollution. The petitioners urge the listing of this imperiled species. The ESA requires that the Service promptly issue an initial finding as to whether this petition "presents substantial scientific or commercial information indication that the petitioned action may be warranted" 16 U.S.C. § 1533 (b)(3)(A).

The petitioners assess that listing the Florida intertidal firefly is warranted under the ESA as it is imperiled by 1) the present or threatened destruction, modification, or curtailment of its habitat or range; 3) disease or predation; 4) the inadequacy of existing regulatory mechanisms; and 5) other natural or manmade factors affecting its continued existence, as well as potential threats by 2) overutilization for commercial, recreational, scientific, or education purposes. There are no existing regulations which are adequate to protect the Florida intertidal firefly. Listing the Florida intertidal firefly is the only way to provide continued existence for a species that would otherwise succumb to the combined threats of habitat degradation, light pollution, climate change, and pesticides. A prompt decision is required to save this species from extinction.

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