Understanding Land Change, Resultant Invasive Species Distribution and Management Potential in a Small Coastal Rhode Island Community

Citation

Witterschein, Jaclyn S. 2023. Understanding Land Change, Resultant Invasive Species Distribution and Management Potential in a Small Coastal Rhode Island Community. Master's thesis, Harvard University Division of Continuing Education.

Understanding Land Change, Resultant Invasive Species Distribution and Management Potential in a Small Coastal Rhode Island Community

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A Thesis in the Field of Sustainability and Environmental Management

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

May 2023

Abstract

Invasive species and resultant degradation of native ecosystems is the most significant threat to biodiversity on the planet (GBO3, 2010, as cited by Hawthorne et al., 2015). In New England, the establishment of invasive flora has been catalyzed by decades of land change, and invasive species are wildly consuming the suburban landscape. Understanding relationships between land cover and land use history, site characteristics, and invasive species establishment is critical to curtailing dynamics that could further deplete native systems.

This research investigated the relationship between land change and distribution of four invasive species on Conimicut Point, a developed suburban peninsula in central Rhode Island. Historic aerial imagery from 1939, 1997, and 2022 was used to categorize land cover and land use for 435 parcels; simultaneously, an unmanned aerial vehicle (UAV) was deployed to capture current extent of four dominant invasives: *Ailanthus altissima*, tree of heaven; *Phragmites australis*, common reed; the herbaceous shrub *Reynoutria japonica*, Japanese knotweed; and the shrubbing vine *Rosa multiflora*, multiflora rose.

Data collection and analysis examined three hypotheses: 1) populations of *A. altissima*, *R. japonica*, and *P. australis* are limited in range as a function of growth and reproductive habits, while *R. multiflora* is dispersed in greater density across the peninsula, integrated with both native and non-native species assemblages; 2) invasive species density persists in unmanaged areas with significant natural and anthropogenic

disturbances over 80+ years; and 3) natural, unmanaged properties predict a higher rate of infestation; despite the vigorous growth habits of the four focus species, private property owners will limit further spread in developed parcels.

Aerial images were mapped in ArcGIS Pro to calculate land change since 1939. A deployed UAV captured images of invasive flora at critical phenological events, which were then imported into ArcGIS Pro and stitched into orthomosaics. Infestations were located and drawn on resulting maps. Invasives extent was then analyzed with land history to find relationships between change and species presence and abundance.

A. altissima was found to cover a wide distribution, in natural, unmanaged parcels across the peninsula, typically in clonal groups. Species distribution was restricted for *P. australis*, to transitional wetland areas along elevation lines, as anticipated. Although *R. japonica* was found randomly distributed, it exists in large swaths, and 50% of occupied parcels are developed/residential-use, more than any other species, thus presenting threat to even well-managed properties. As predicted, *R. multiflora* distribution was wide, but less dense, and more prevalent in transitional, succession areas adjacent to open water.

Rampant spread of invasive species in suburban areas is strongly linked to site disturbance (Ibáñez et al., 2009a). Research results echo this understanding, with a caveat: infested parcels appear to have been developed/residential-use in 1939, unmanaged in 1997, and continue to be unmanaged or publicly conserved by 2022: conservation land, even if protected, is critically vulnerable if historically disturbed. Analysis further demonstrates that developed/residential-use curbs the expanse of these species, supporting community-level preventative and management strategies, and further, warranting invasive species policy shifts in Rhode Island.

Acknowledgments

Research that follows is truly the result of care and support from many places. Mark Leighton, my research advisor, gently encouraged me to keep working—after many years, through two very different proposals, the birth of my two children, amid a pandemic. Mark has been an inspiration to me and my DCE peers. I am so grateful for his unwavering guidance and grace throughout this process. My immense thanks to Wendy Guan, my thesis director, who, to the very end, provoked thoughtful discussion of this content; her patience and steady advocacy has driven me to persevere, helping me to build better research practices and more thorough analyses.

Colleagues at the University of Rhode Island Coastal Institute offered enthusiastic encouragement and flexibility to finish even as I worked full-time, and partners at the URI Environmental Data Center provided technical and data assistance without hesitation. Our neighbors in Conimicut Point were understanding as a drone traced paths over their homes spanning many months, even providing additional information about plant species on their properties. My family and good friends were long suffering as I threw myself at my computer and all but ignored them for long stretches but continued to cheer for me. Finally, I would be lost without my partner, Matthew, for being there from the beginning—reading, listening, questioning, telling me to reach further, to know everything. Thank you.

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Definition of Terms

Adventive: a species not native and usually not established within a new location or range.

Allelopathic toxins: biological chemicals produced by a plant to inhibit the growth and function of surrounding species.

ArcGIS: a desktop mapping and analysis software developed by Esri, Redlands, CA, used to generate maps and analyze data.

Biological control: the regulation of one living organism via functions of other living organisms in the same ecosystem.

Brackish: mixture of fresh water and salt water, as in marshes and estuaries.

GIS: acronym for Geographic Information System; a system that analyzes and stores geographically referenced information.

Haplotype: exhibiting a group of alleles inherited from a single parent plant.

Invasive: a non-native and/or exotic species introduced to a new ecosystem, causing harm to native species.

Litter: grounded detritus from leaves and other dead, decomposing plant matter.

Senescence: age and deterioration of an individual or group of plants.

Subdioecious: some, but not all, plants of a species reproduce via male and female reproductive organs on separate plants.

Succession: the change of species composition over time, primarily in reference to progression of wetland to forest.

UAV: unmanned aerial vehicle; for this research, a personal drone.

Chapter I

Introduction

Worldwide, native ecosystems are routinely displaced and destroyed by invasive species. In North America, more than one thousand unique invasive plant species have been identified—and are destructive to the tune of $137 billion per year in the US alone (Morse et al., 1995 as cited by Gavier-Pizarro et al., 2010; Huang & Asner, 2009). Regular land disturbance provides ideal conditions for the encroachment of non-native species, and unmitigated clearing and wild establishment reduces native flora, a significant concern for the future of valuable ecological communities. In particular, coastal communities are susceptible to land change resulting from storms and floods as well as a continual threat of low-density development. However, insufficient modeling has been implemented in small coastal communities where private property owners may have high impact potential on invasive species creep.

Rhode Island is the only state in New England without regulatory measures to prevent, manage, and eradicate invasive species populations (Environmental Law Institute, 2010). Localized invasions may only be managed with a continuum of surveillance and restoration, and thus invasive management in small communities without appropriate infrastructure is easily undermined (Hawthorne et al., 2015). Furthermore, continual fragmentation through suburban development promotes expansion of adventive species, edging out native communities and contributing to the collapse of ecosystem functions and services (Merow et al., 2011; Ibáñez et al., 2009b; Allen et al., 2013).

Research Significance & Objectives

My research examined the relationship between land cover, land use, site characteristics and invasive species abundance on the Rhode Island peninsula of Conimicut Point. In this small seaside community, clear-cutting for low-density development is common practice. With few imposed regulatory measures, properties that remain unpurchased languish, inviting non-native flora to first creep and then overtake entire parcels. My research findings will aid in assessing invasive species impact and potential, and further support the need for engagement at the community level. Understanding invasive species within managed and unmanaged parcels will inform best practices for Conimicut, but more broadly, apply to communities not regulated by policy, on land where neighbors become practitioners.

The objectives of this research were:

- to examine land use and invasive species on a small coastal peninsula with high ecological value;
- to map distribution of dominant invasive species and analyze the relationship between historical land change and their establishment; and
- to understand the potential for invasive species expansion as a result of land change, site characteristics, and community management practices.

Background

Globally, invasive species are decimating native ecosystems most readily in areas of disturbance and land change (Vitousek et al., 1997). Thus, thoughtful land management is the most important tool in mitigating further spread of invasive species.

Most research models interpret invasions on a large scale, but smaller, local models, particularly in locations where regulatory measures do not exist, may provide greater understanding and impact at the parcel-by-parcel level.

New England annals of land-use history are the most extensive of any region in the US (Mehrhoff, 2000). Following agricultural expansion in the nineteenth century, forests of late-successional shade species reestablished (Thompson et al., 2013; Eisen & Barker Plotkin, 2015). However, since 1985, residential, low-density development has consumed over 800,000 acres in New England, forging suitable habitats for roughly 1000 exotic species, over 10% of which are invasive (Duveneck & Thompson, 2019; Mehrhoff, 2000; Farnsworth, 2004). Invasive species establishment results largely from anthropogenic introductions and land use/land change, and in New England, invasive richness is most prevalent in edges—the boundaries between development and undisturbed environments (Gavier-Pizarro et al., 2010; Allen et al., 2013).

Even though 23% of land in New England is conserved, the dearth of land use policies between political boundaries causes frequent and haphazard fragmentation (Meyer et al., 2014; Duveneck & Thompson, 2019). Rhode Island (RI) is the only state in New England without regulatory restrictions on the sale and planting of invasive species. While several organizations, including the University of Rhode Island, the Rhode Island Natural History Survey, and the Rhode Island Wild Plant Society maintain lists of invasive species and provide information for management, no centralized regulatory body or unified set of resources exists. In RI municipalities like Warwick, protection of parcels relies separately on land trusts, NGOs, and private homeowners, who are rarely working in concert. Best practices, if at all, can only be enacted from the bottom up.

Study Site and Species

Conimicut Point peninsula is located at the mouth of the Providence River on Narragansett Bay, Rhode Island, within 41.7185- and 41.7119-degrees N and -71.3722- and -71.3559-degrees W (Figure 1). Conimicut Point is part of the Narragansett Bay Watershed and Pawtuxet Watershed, and the Warwick Comprehensive Plan has designated wetlands and surrounding areas of importance for protection, currently permitting only low-density residential development (City of Warwick, 2021).

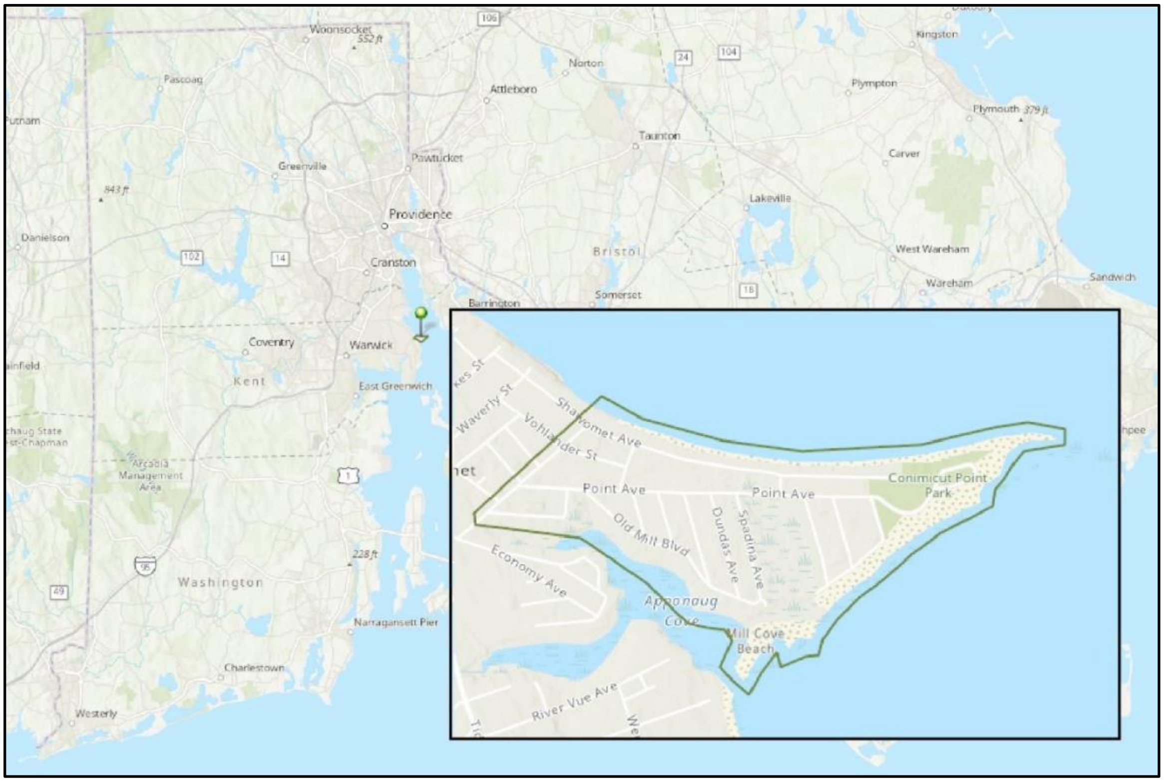

Figure 1. Study area: Conimicut Point peninsula.

Map of Rhode Island; Conimicut Point peninsula location and inset (adapted from ESRI, 2021).

The peninsula is split from the mainland by Buckeye Brook and Mill Cove on the west, a brackish waterway and spawning ground for blueback herring (*Alosa aestivalis*) and alewife (*Alosa pseudoharengus*), which winds south to tidal mud flats (Buckeye Brook Coalition, 2021; City of Warwick, 2021). Thirteen parcels protected by the city unite a small salt marsh in the center of the peninsula, where smooth cord grass (*Spartina alterniflora*) and salt marsh hay (*Spartina patens*) provide breeding grounds for horseshoe crab (*Limulus polyphemus*), and habitat for ribbed mussels (*Geukensia demissa*) and fiddler crabs (*Uca pugilator*) (City of Warwick, 2021). Shore birds like great blue heron (*Ardea herodias*) and egrets (*Egretta thula*, *Ardea alba*) nest in and around swaths of bayberry (*Myrica pensylvanica*), beach grass (*Ammophila breviligulata*), goldenrod (*Solidago sempervirens*) and milkweed (*Asclepias tuberosa*) (pers. obs.). Upland shrub areas with successional woody species, including eastern red cedar (*Juniperus virginiana*) staghorn sumac (*Rhus typhina*) and Virginia creeper (*Parthenocissus quinquefolia*), support various bird and small mammal populations (pers. obs.).

While many invasive species have assimilated on Conimicut Point, this research focused on four dominant species: *Ailanthus altissima*, Tree of Heaven; *Phragmites australis*, common reed; *Reynoutria japonica*, Japanese knotweed; and *Rosa multiflora*, multiflora rose.

<u>*Ailanthus altissima*, Tree of Heaven.</u> *Ailanthus altissima* is native to central China and was introduced to the US around the turn of the 19th century (Hu, 1979 as cited by Landenberger et al., 2007). The species was promoted by William Hamilton of

Philadelphia as a novel street tree because of its adaptation to urban environments (Del Tredici, 2017; Landenberger et al., 2007). Throughout the nineteenth century, *A. altissima* further established as Chinese immigrants planted it for medicinal use, and by 1888, it had expanded into surrounding states (Aldrich et. al, 2010; Call & Nilsen, 2003).

Figure 2. *Ailanthus altissima*.

Plant Image Library from Boston, USA, CC BY-SA 2.0 <https://creativecommons.org/licenses/by-sa/2.0>, via Wikimedia Commons.

An early successional, shade-tolerant tree (Figure 2), *A. altissima* is disposed to rapid growth through both sexual reproduction and vigorous clonal expansion of roots and suckers, which can form to dense groves of undergrowth, particularly in edge habitats (Mergen, 1959; Pan & Bassuk, 1986; Aldrich et al., 2010).

Soil compaction aids enhanced root growth, which is further catalyzed by the sucker survival response of *A. altissima* to disturbance and thus profuse and condensed juvenile growth (Pan & Bassuk, 1985; Heisey, 1990; Call & Neilsen, 2003).

Early reproduction, within the first two years of growth, is facilitated by production of paper-like samaras, wind-borne seed cases that broadcast as many 300,000 seeds per individual per season (Aldrich et al., 2010; Call & Nilsen, 2003; Bory & Clair-Maczulajtys, 1980 as cited by Landenberger et al., 2007). In the eastern US, seeds are dispersed via turbulent winds September through May and can infiltrate gaps in the canopy as far as 100m from an individual (Landenberger et al., 2007). Exploiting “gap-obligate recruitment” (Knapp & Canham, 2000), seeds demonstrate high germination rates in disturbed areas under a variety of growing conditions (Kota et al., 2007; Hu, 1979 as cited by Landenberger et al., 2007).

The capability of *A. altissima* to invade and establish dense thickets without the threat of faunal herbivory allows it to easily exclude native plants (Heisey, 1990; Mergen, 1959; Knapp & Canham, 2000). Additionally, allelopathic toxins present in every part of the plant inhibit establishment and growth of natives, including approximately 70 woody tree species (Heisey, 1990; Mergen, 1959). Toxins from leaching litter and root excretion allow recruited or sucker *A. altissima* to reach the canopy quickly, dominating the landscape (Heisey, 1990; Gómez-Aparicio & Canham, 2008). Further, *A. altissima* has been shown to decrease soil microbial activity and lead to faster mineralization, eventually favoring nitrogen-sink invasive species in the understory (Motard et al., 2015).

<u>*Phragmites australis*, Common Reed.</u> While the native *Phragmites australis* (spp. *americanus*) is part of the North American fossil record dating back to the Paleolithic age, the invasive haplotype of *Phragmites australis* (*P. australis*) was likely introduced to brackish marshes on the East Coast of the US in the early 19th century via detritus from ship ballasts (Goman & Wells, 2000; Saltonstall, 2002). From there, its range expanded along the Atlantic coastline, and is now found in every state in the US (Saltonstall, 2002). The native species is no longer present in New England (Saltonstall, 2002).

Swaths of this tall, perennial grass are found primarily in upland marshes and on the edges of freshwater bodies (Saltonstall, 2002) (Figure 3). While *P. australis* expands both through seed dispersal and vegetative clones, reproduction is the primary means to spread, particularly in areas of regular disturbance in upper marsh in New England, making established invasion swift and successful (Amsberry et al., 2000; Belzile et al., 2010; Kettenring et al., 2016).

As with aforementioned invasives, *P. australis* is a plight on native ecosystems in New England, diminishing native species diversity and thus ecology and ecosystem services (Amsberry et al., 2000). Land disturbance contributes to its expansion, as the removal of woody vegetation and/or marsh wrack provides bare mudflats via which *P. australis* can seed, contributing to viability through cross-pollinating and resulting genetic diversity (Minchinton & Bertness, 2003; Minchinton, 2002; McCormick et al.,

Figure 3. *Phragmites australis*.

With cattails, Typha angustifolia*, in foreground. Laval University, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons.*

2020). Where nitrogen loads from runoff and shoreline disturbance would typically burn and kill native flora, the invasive *P. australis* haplotype cycles nitrogen into aboveground production and seeding (Minchinton & Bertness, 2003; Silliman & Bertness, 2004). Additionally, while research has typically shown that *P. australis* is limited in lower salt marsh by water salinity, some studies suggest that clonal reproduction can allow *P. australis* to expand from upper marsh into lower marsh further than originally thought, where not limited by native species (Amsberry et al., 2000).

Effects of climate change, including increases in temperature and CO_2, as well as storm events that bring more precipitation and natural land disturbance, will provide suitable conditions for *P. australis* expansion into previously uninvaded areas (Saltonstall, 2002; Brisson et al., 2008; Eller et al., 2014; Minchinton, 2002).

Reynoutria japonica, Japanese Knotweed. *Reynoutria japonica*, also referred to as *Fallopia japonica* and *Polygonum cuspidatum* (Del Tredici, 2017b), is widely recognized as one of the most destructive invasive species on the planet, in adventive ranges dominating the landscape (Engler et al., 2011). Native to eastern Asia, *R. japonica* was introduced to the U.S. on at least three separate occasions in the mid-nineteenth century: via Philip von Siebold from the Netherlands, who first brought the species to Europe, and by Thomas Hogg, who shipped specimens from Japan between 1862 and 1875 (Del Tredici 2017a; Del Tredici, 2017b). Advertisements for cultivated *R. japonica* first appeared in an 1868 issue of *American Agriculturist* (Del Tredici, 2017b).

R. japonica is a clumping herbaceous perennial, with hollow bamboo-like stems that survive in mild climates for approximately three years (Fennell et al., 2018) (Figure 4). *R. japonica* leafs in early spring, ending its growing season with senescence in early October (Forman & Kesseli, 2003). Canes grow two to three meters in height, and vigorous rhizomes can reach two meters underground and spread two to 20m laterally from the stem (Fennell et al., 2018; Barney et al., 2006).

Morphological *R. japonica* in New England is subdioecious, although only females produce tens of thousands of seeds during August inflorescence (Forman & Kesseli, 2003; Grimsby et al., 2007). While vegetative growth is the primary means of expansion, sexual reproduction in some populations of *R. japonica* is possible, and seeds dispersed to open areas may overwinter and germinate irrespective of soil and light conditions (Engler et al., 2011; Forman & Kesseli, 2003).

Figure 4. *Reynoutria japonica*.

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R. japonica reproduces easily via rhizome or stem fragments, and clonal growth is most responsible for invasive spread, in some cases expanding to a biomass six times that of the native flora (Engler et al., 2011; Aguilera et al., 2010). Management strategies, manual, herbicidal, or biological, are generally ineffective, and expansion is aided by allelopathy that suppresses surrounding species (Barney et al., 2006; Murrell et al., 2011).

In Europe, canes are all derivative of one female plant, thus preventing sexual reproduction, but multiple introductions in North America have increased genetic diversity and the ability of *R. japonica* to hybridize to F. × *bohemica* (Fennell et. al., 2018; Forman & Kesseli 2003; Grimsby et al. 2007; Groeneveld et al., 2014). Extensive and rampant *R. japonica* swaths quash species diversity and richness in the native understory, as well as modify food webs and nutrient cycles, and further invasiveness of *R. japonica* is possible as it continues to hybridize (Aguilera et al., 2010; Fennell et al., 2018; Kappes et al., 2007; Engler et al., 2011).

Rosa multiflora, Multiflora Rose. *R. multiflora* was introduced to the US around the turn of the 19th century. The Elgin Botanic Garden in New York, established by physician David Hosack in 1801, featured *R. multiflora* as a medicinal plant in its garden catalog in 1811 (Rehder, 1946 and Hedrick, 1950, as cited by Del Tredici 2017a). Distribution was further catalyzed by touted usefulness as hedging fence on farmland (Steavenson, 1946).

R. multiflora is a highly adaptable woody perennial in New England, leafing out as early as April, displaying a fragrant inflorescence in May, and continuing viable photosynthesis well into the fall (Dlugos, 2015) (Figure 5). *R. multiflora* can quickly spread in two ways: plant establishment from seeds via rose hips, dispersed by birds and other small mammals, and expansion laterally from the roots of the parent plant (Klimstra, 1956; Jesse, 2010).

Figure 5. *Rosa multiflora*.

Famartin, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons.

R. multiflora most likely invaded New England because of consistent natural and anthropogenic disturbances, prior to 1960 in agricultural areas, but later into forests aided by suburban sprawl (Merow et al., 2011). Land change has increased the appearance of lianas in the US, and New England edge habitats prone to flooding with near-neutral soil pH are susceptible to invasion (Allen et al., 2007; Silveri et al., 2001). While availability of light may be a limiting factor, dispersal of *R. multiflora* seed via canopy gaps can lead to establishment over a long growing season, even without consistent availability of water and other resources (Dlugos, 2015; Murphy, 2019). *R. multiflora* can invade and smother seedlings and shrubs in successional areas (Fike and Niering, 1999).

Models of Invasive Spread

Invasions are highly unpredictable because of site conditions, species spread mechanisms and growth habits. Structured monitoring and management of a small area is often required for comprehensive understanding of distribution of target species. Merow (2011) utilized herbarium records from Mehrhoff et al. (2003) to predict spread of *C. orbiculatus*; inventories were first recorded in Derby, Connecticut (1916), Falmouth, Massachusetts (1919), and New Durham, New Hampshire (1938). Ibáñez et al. (2009a) used the same records to evaluate spread of *C. orbiculatus* over a defined area, and while a total distribution could not be determined, density at least surpassed historical herbarium records. Huebner et al. (2003) found that *A. altissima* survival was 70% in previously invaded areas, but less than 15% of canopy opening limited new germination and spread. In the low marsh, where native *Spartina alterniflora* limits it, *P. australis* has been observed to spread between 5 and 10 cm over one growing season; alternatively, clear-cutting of native species in the high marsh resulted in more than 30 cm expansion over the same period (Silliman & Bertness, 2004; Amsberry et al., 2000). Another study from Kettenring et al. (2016) found *P. australis* cover changed as much as 46% per year. Study after study has found land change—clear-cutting, disturbance of native flora—drives invasive occupation.

<u>Pruning the Model.</u> While existing models have provided a comprehensive view of invasions, and in general conclude that disturbance promotes further spread, these have

seldom considered the impact of land change on a small scale. A broad presumption is that all land change is detrimental, and yet, private property owners, armed with knowledge of species growth patterns and adaptability, may play an important role in intervention. Analysis of land change and invasive cover of small area, such as Conimicut Point, promotes a clearer understanding of implementing mitigation land management strategies at the local level.

Research Questions, Hypotheses, and Specific Aims

My research addressed the following questions and associated hypotheses:

- What has been the land change of Conimicut Point peninsula from 1939 to present?
- What is the current density of four prevalent species, *A. altissima*, *P. australis*, *R. japonica*, and *R. multiflora* on Conimicut Point?
    - Hypothesis: Populations of *A. altissima*, *P. australis*, and *R. japonica* are thick and dense, but generally limited in range as a function of growth and reproductive habits; *R. multiflora* is dispersed in greater population across the peninsula, integrated with both native and non-native species assemblages.
- What is the relationship between land cover, land use, and land change and distribution of these species over time?
    - Hypothesis: Invasive species density persists in unmanaged areas with significant natural and anthropogenic disturbances since 1939.

- How might invasive plant species expand further within the peninsula under existing rates of land change and with which catalyzing site characteristics?
    - Hypothesis: Natural, unmanaged properties will predict a higher rate of infestation; despite the vigorous growth habits of the four focus species, private property owners will limit further spread in developed parcels.

Specific Aims

The aims of this research were to:

1. Isolate a comprehensive set of GIS aerial maps spanning 80+ years of Conimicut Point peninsula and categorize parcels into land cover and land use categories.
2. Calculate land cover, land use, and resulting land change, per parcel and overall, since 1939.
3. Categorize the presence of each species in each parcel.
4. Deploy a UAV (unmanned aerial vehicle) to capture images of Conimicut Point and presence of invasive flora: *A. altissima, P. australis, R. japonica,* and *R. multiflora*.
5. Create orthomosaics with UAV imagery in ArcGIS and use it to isolate infestation polygons and calculate approximate extent of each species.
6. Analyze invasive species against land history to determine relationship between land classifications and species abundance.

Chapter II

Methods

Several analyses were conducted to understand the relationship between land characteristics and invasive species on the Conimicut Point peninsula.

GIS Data Collection and Classification: Land Cover and Land Use

Georeferenced aerial photos were compiled from the Rhode Island Geographic Information System (RIGIS), a partnership of the Rhode Island Division of Statewide Planning and the University of Rhode Island (RIGIS, 2021). Tile layers from 1939, 1997, and 2022 (Figure 6) were overlaid with parcel data of Conimicut Point peninsula sourced from RIGIS. The Select Tool was deployed to isolate polygon parcels on Conimicut Point, and result was exported as a feature layer for further manipulation (ConimicutParcelsALL).

While initially this research planned an analysis of a time series of 26 different historical image layers, to focus the analysis, the number of years was significantly scaled down to find correlations after active periods. Data from these selected years demonstrated the impact of major natural disturbances, like hurricanes, shoreline shift, and sea-level rise to Rhode Island shorelines, as well as the renewal of low-density development on the peninsula in the 1980s and 1990s.

Figure 6. Conimicut Point Peninsula over time.

Aerial maps of Conimicut Point peninsula, from 1939 (top), 1997 (center), 2022 (bottom) (RIGIS, 2022).

Each of the 435 parcels was manually classified for land cover and land use categories (Table 1). Initially, land cover/land use categories were married, but later separated to draw a clear distinction between habitat type and use status in resultant analysis. When categorizing land cover, the descriptive categories were limited to efficiently represent similar classification areas: “developed/lawn/garden” identifies parcels characterized by houses, driveways, other structures, as well as adjacent cleared property; “grass/woody perennials” represents parcels of low density, brush vegetation; “trees/shrubs” identifies parcels of dark, dense canopy; “upland/freshwater wetland” represents transitional parcels of land to freshwater; and “upland/salt marsh” represents transitional parcels of land to salt marsh.

The aerial tile layer photos from 1939 were captured following the 1938 hurricane and are the earliest mapped images of Rhode Island in the electronic record. The map layer image is low resolution and is georeferenced but not perfectly aligned because it is assembled from physical photos.

To classify land cover parcels for low resolution 1939 images, evidence of paths from the street or to the water, as well as strictly geometric features were used to determine parcels with development. Instances of dark, solid areas with no evidence of water (e.g., a stream) were marked as trees/shrubs. Parcels with visible streams or adjacent to the ocean were marked as upland. Grass/perennial parcels were identified if the parcel was of a light gray value; in rare cases the identification was difficult and uncertain.

Table 1. Land cover/land use for parcels.

PARCELID	**LC39**	**LU39**	**LC97**	…
333-0008				
333-0009				
333-0010				
333-0011				
333-0012				
333-0013				
333-0014				
333-0015				
333-0016				
333-0017				
333-0018				
333-0019				
333-0020				
333-0021				
333-0023				
333-0024				
…				

	Land Cover Class
1	developed/lawn/garden
2	grass/woody perennials
3	trees/shrubs
4	upland/freshwater wetland
5	upland/salt marsh

	Land Use Class
1	developed/residential
2	unmanaged
3	public/conservation

Land cover/land use class assignments, Conimicut Point peninsula, 1939, 1997, and 2022 (adapted from Meroni et al., 2017).

Invasive Mapping with UAV

Next, an unmanned aerial vehicle (UAV) was deployed to capture imagery of the four target invasive species. UAV images were used to create orthomosaics, a composite of area images stitched together using geographic references, which can then be interpreted to identify polygons of each species (Cruzan et al., 2016). UAV flights were completed during species-specific phenological events that provide high spectral differentiation from surrounding species (Huang & Asner, 2009; Cruzan et al., 2016; Bradley, 2009).

An initial ground field survey was conducted on 5/14/22 to understand the approximate locations of species. Using ArcGIS Quick Capture 1.16.294 (Esri Inc., 2022) individuals and groups of species were ground mapped on feature layers using points and polygons, respectively. General locations of *A. altissima*, *P. australis*, and *R. japonica* were captured, imported into ArcGIS Pro 3.0, and then summarized into polygons. Manual correction was completed post-capture for erroneous indicators, based on author observation. The purpose of the ground survey was to guide the mapping of the general locations of each species and thus focus seeking for final orthomosaics. *R. multiflora* was not mapped during the ground survey; the species was visibly identified in the orthomosaic post-processing and added to the analysis at that time.

UAV

Image capture was initiated with a Holystone HS100, a relatively inexpensive drone with moderate flight time of 18 min and the ability to capture nadir (-90°) images at resolution of 1280x720 pixels at a constant altitude. However, the large frame and weight of the HS100 resulted in poor control in wind, even in minor gusts, which are frequent with long fetch at Conimicut Point. Further, lack of drone control shortened battery life to approximately 10 min per flight, and poor camera stability resulted in blurry and unmappable images.

Thus, a Parrot ANAFI drone (ANAFI), moderately priced with extended capabilities, was purchased and deployed for the bulk of the research. ANAFI, a lightweight drone with wind resistance 50 km/h and gust resistance of up to 80 km/h, was well-suited for most flight conditions on Conimicut Point. Images were captured as JPEG in 4608x3456 pixels at nadir and gimbal stabilization at ±0.004° precision. Additionally, ANAFI can complete and reiterate pre-determined flight paths for automated mapping.

Planning and Plotting

While the ANAFI controller and accompanying software application (FreeFlight 6.7.5, Parrot Drone SAS, 2022) is equipped with a flight planning function, this research utilized ANAFI-compatible Pix4DCapture (Pix4D SA, 2022) for convenient and adaptable flight plotting.

Total area plot was based on Warwick parcels located east of Shawomet Avenue, and created based on the amount of time allocated per flight. While ANAFI has a maximum flight time of 25 min, at maximum speed flight distance, the battery typically was spent at a maximum of 15 min. Nearly 20 iterations of plotted segments were created until reaching a final plot of four separate segments (Figure 7, Table 2).

Figure 7. Flight maps.

Pix4D flight maps and specifications (Pix4D SA, 2022).

Table 2. Flight plots.

segment ID	description	coverage area (m)	flight length (m)	flight time, projected (m:s)	path legs (switchbacks)	images, projected
00019	Conimicut Point Park	436x320	2494	7:57	14	94
00020	Conimicut Point Park west to Spadina	429x451	4793	12:16	15	186
00021	Talcott west to Shawomet	475x360	2531	6:48	8	86
00022	Spadina west to Talcott	531x555	5091	13:51	17	181

Pix4D flight specifications (Pix4D SA, 2022).

Flights were designed with general guidelines in mind, including optimal distance for Bluetooth connection to controller and to minimize the number of flights so as not to disturb private property owners, many of whom were aware of the research but still wary of drone photography above their properties. Considerations were also made to conduct flights at midday when the sun was close to zenith, to minimize shading and maximize reflective properties of the plants. The iPhone application UAV Forecast 2.8.0 (Matthew Lloyd, 2022) was consulted to plan flights at least a week in advance, based on weather conditions, wind gusts under 25 mph, and locked satellites.

Altitude was a concern from the outset, as optimal resolution is required to observe specific species phenological events (leafing, inflorescence, fruiting, etc.). A ground survey was completed to approximate the highest tree canopy on Conimicut Point. Using the iPhone application Arboreal 3.5 (Arboreal AB, 2022), the canopy height was determined to be approximately 25 m. Thus, plotted flights were programmed and initially completed at 30.5 m. Unfortunately, during a May flight, ANAFI collided with an outlier tree bough and was totaled. A second ANAFI was purchased, and flights thereafter were successfully completed at an altitude of 33 m.

ANAFI was flown at 33 m elevation along plotted routes resulting in a ground sample distance (GSD) of 1.10 cm/pixel and overlapped images 30% front to back and 30% side-to-side. The percentage overlap was lower to shorten life and maximize air time using available battery. FreeFlight6 was used to create conditional settings for Sport Mode, maximum altitude of 37 m and maximum distance 557 m, a speed of approximately 15 m/s and rotation speed of 20°/s. The camera mode was set to single capture with 16-megapixel image size at 72 dpi.

Images were captured automatically on the plotted map using the Pix4DCapture application installed on iPhone 8 (Apple, Inc.). ANAFI captured GPS EXIF (exchangeable image file format) data for latitude, longitude, and altitude for each image. JPEGs captured per flight record, per segment were downloaded from microSD and saved into a directory labeled by flight name/segment name (Table 3).

Processing for Orthomosaic

Resultant aerial imagery was then processed using ArcGIS Pro 3.0 (Esri Inc., 2022). A new ortho mapping workspace was created with the flight record name and then images were imported under the following conditions:

- Sensor: Generic
- Geolocation: [Loaded from EXIF]
- Spatial reference: WGS_1984_UTM_Zone_19N / VCS: WGS_1984
- Camera Model: Anafi

Images captured on the same day, within the same 3-hour time span were imported and processed as a lot. Flight segments or segment parts captured outside of the 3-hour window or on subsequent days were processed separately. At first mosaics were created using all images from all days, but later, they were orthomosaicked by day and then stitched together later to preserve integrity of data and color balancing as much as possible (available light, time of day, etc.)

At the start of importing, all images were brought in together using the standard settings for import. Elevation Source was determined via Average Elevation from Image Metadata. A standard block adjustment was applied post-import, and although the camera

Table 3. Flight record.

				observed species (phenological event)			
flight name	**segment dates (mm/dd)**	**launches**	**images**	***A. altissima***	***P. australis***	***R. japonica***	***R. multiflora***
01_MayJune*	5/21, 5/23, 5/30, 6/4, 6/11	5	965				
02_EarlyJune**	6/4, 6/11	5	600	X (spring leafing)	X (spring leafing)	X (spring leafing)	X (inflorescence)
03_EarlyJuly	7/9, 7/10	4	543	X (samara presence)	X (spring leafing)	X (spring leafing)	
04_EarlySept***	9/2, 9/3	5	573	X (samara presence)		X (inflorescence)	
05_LateNovember	11/23, 11/28	5	537		X (senescence)		

*Invasive species phenological observances and corresponding UAV flights (adapted from Müllerová et al., 2017). * Constitutes duplicative images over several days because of a drone collision. ** Includes subset images of R. multiflora from 6/4 in location not captured on 6/11. *** Flight route 00020 split over two days and images duplicated because of low battery.*

was calibrated prior to each flight, I allowed ArcGIS to recalibrate within the adjustment. However, after several imports, I encountered image loss during the block adjustment. To deter some of this loss, the input settings were adjusted to reflect a constant elevation of 32 m (to adjust for some images taken below the set height of 33 m). Additionally, I adjusted preprocessing settings to calculate statistics and build pyramids (both with default settings) to improve image quality later. Changing these settings mitigated some, but not all image loss.

Following the block adjustment, an orthomosaic was created with the Voronoi method. The resulting file was saved in cloud raster format.

Any “unsolved images” removed in the block adjustment were retained in the workspace within the flight path and as image boundaries, but not displayed as images. To attempt to recapture unsolved images, each “unsolved” image was selected, and a table exported. The images were pulled into a separate directory using the same conditions (same-day, 3-hour groupings). Each directory was imported as a new workspace in the same flight record project, with the same import and adjustment settings. I was able to recover some images. Resultant sub-orthos were then stitched with the master ortho using the Mosaic tool to create a final cloud raster file.

Locating Invasives

Following a visual review of all orthomosaics, 01_EarlyMay was dropped because of variable spectral quality after stitching, likely due to multiple flights over several weeks following the drone collision. Flight 02_EarlyJune was used to begin invasive delineation.

Initially, I attempted to use the Classify Raster tool to locate species. Training samples were established, and the model was run several ways, but resulting resolution was noise, and not adequate for identifying spectral characteristics of each species.

To exercise the most control over the invasive identification, I opted to manually create polygon segments via visual interpretation of the image. All orthomosaics were loaded into the workspace, overlaid with the ConimicutParcelsAll, and viewing between 1:90 and 1:140 aspect ratio, I systematically worked through each parcel with the Editor tool to draw polygons. The initial ground survey was referenced to understand relative locations of each species, but no parcels were omitted from review because of the field survey. Although manually drawing polygons was a time-intensive process, the goal was to capture all individuals and groups, so that resultant data would assist in the understanding of possible infestations or parcels at risk for future invasions (Figure 8). The mapping protocols for each species were as follows:

- *A. altissima*: Beginning with the 02_EarlyJune map, the unique compound leaf shape with a dark blue-green coloration was used to find individuals and patches. Unfortunately, in some areas, *A. altissima* cohabitates with native sumacs, which have a similar leaf shape and growth form. Orange samaras seen in 03_EarlyJuly and 04_EarlySept flights were used to verify crowns of the target species. Ground truthing provided more information—native sumacs develop distinctive, conical seed-heads flowers in the summer and thus could be eliminated based on locations from the survey. When unable to confidently identify *A. altissima* using the aforementioned methods, the individual or group was omitted from the drawn polygons.

- *P. australis*: The unique leaf color was used to begin identification in 02_EarlyJune. Verification was made with subsequent maps that featured leaves or senescence (05_LateNovember). In some areas, individual reeds have encroached on private property and were only visible in a ground survey— these individuals were not captured; only stands visible in the orthomosaics were recorded within a polygon.
- *R. japonica*: Leaves were relatively simple to identify, beginning with 02_EarlyJune, by a uniquely uniform leaf shape, bright color, and pattern within expansive stands. Continuity under tree canopy and shadow was difficult to detect, so again, polygons were drawn only where visible within the orthomosaics. A yellowish inflorescence, perhaps due to drought conditions, as captured in 04_EarlySept, was ultimately not usable for confident identification.
- *R. multiflora*: Bright white inflorescences were identified, and circular polygons were drawn around each instance. Flight 02_EarlyJune is the only flight set where the inflorescence was visibly captured.

In rare instances, where “unsolved” images were lost from the orthomosaic, I referenced the original photo to clearly identify phenological traits. A few individual plants of target species were identified when drawing and/or verifying other species.

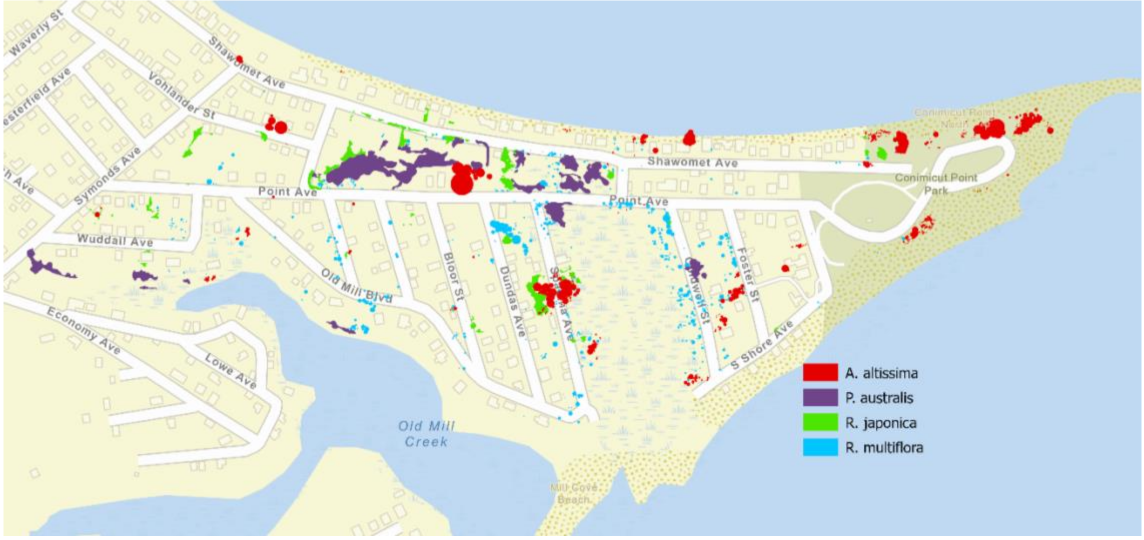

Figure 8. Invasive extent.

Drawn invasive species polygons on Conimicut Point peninsula.

Limitations of UAV and Image Processing

As mentioned, canopy and shadow cover likely impacted the ability to capture the entire extent of some species, in particular, *R. japonica*. In addition, flights did not fully capture the parcel on the southwestern tip of the peninsula. Satellite imagery was used to identify *P. australis* where possible, but no other species. And as previously mentioned, unsolved images during the orthomosaic creation resulted in unanticipated image loss, which hindered confident capture when drawing polygons.

Relative georeferencing between the orthomosaics was not exact—sometimes photos were shifted a few degrees north, south, east or west, which caused some discrepancies between relative locations of species. I attempted to mitigate this by using 02_EarlyJune to draw initial locations, as this mapping found all species and most individuals identifiable. Subsequent orthomosaics were used to verify location or find other polygons. In hindsight, using a slower flight speed with more overlap (50% or more) may have prevented some of the import and orthomosaic challenges.

Site Characteristics

Understanding additional site characteristics can determine synergistic factors that may have led to the existing density of invasive flora and promote further understanding regarding conditions and management practices that may curb invasive species extension on Conimicut Point peninsula. Several other datasets from the Rhode Island Geographic Information System Data Distribution System were imported into the project:

- Soils: soil type based on natural feature (Figure 9)
- National Wetland Inventory (NWI) for Rhode Island: proximity to fresh/brackish water
- Coastal Waters: proximity to open ocean/salt water
- Contour Lines: 2- foot: elevation (Figure 10)

Pairwise Clip was used to isolate layers to ConimicutParcelsALL.

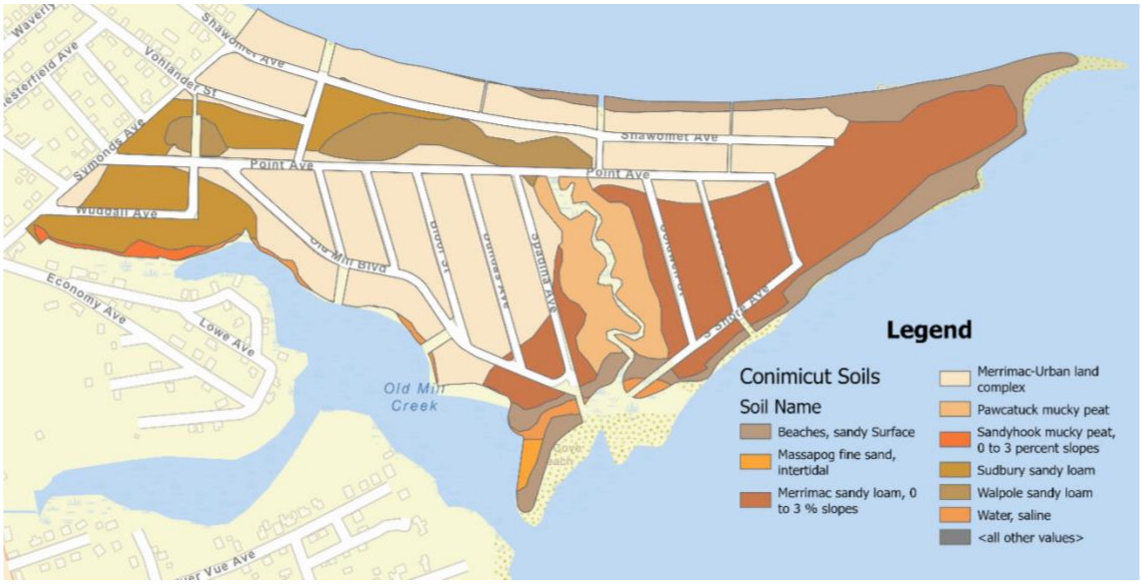

Figure 9. Soils.

Soil types on Conimicut Point peninsula.

Figure 10. Contour lines.

Contours (2-foot: elevation) on Conimicut Point peninsula.

Analysis

Land cover and land use were analyzed with mapped invasive species extent.

Land Cover/Land Use

ConimicutLayersALL was exported into six separate feature layers, to represent land cover data for 1939, 1997, 2022 (LC39, LC97, and LC22) and land use data for 1939, 1997, and 2022 (LU39, LU97, LU22). A land cover or land use field was added to the respective Attribute Table, and the category for each parcel was appended manually. The Summarize Attributes tool was deployed for each layer to obtain parcel count, area, and percentage of area, and then a simple calculation was implemented to determine the percentage change area from year to year (Table 4).

To understand the categorical changes between years, the Feature to Raster tool was used to convert each layer into a raster format representing the class values. Subsequently, the Compute Change Raster tool was implemented to delineate the class changes between LC39/LC97, LC97/LC22, and LU39/LU97, LU97/LU22. Output maps were utilized to look at infested parcels within later analysis.

Invasive Species

Two groups of invasive polygons were created—one to include individually-identified plants (DrawnPolys), and one in which the adjacent plants are integrated, using Pairwise Dissolve (DissolvePolys). Summarize Within was completed for the dissolved layer of each species. Each Attribute Table was then filtered by invasive polygon presence, and results were exported into excel to capture parcel presence, size of infestation across all parcels, and calculated percentage area.

Table 4. Land cover/land use change.

Land Cover	**1939 parcel units**	**1939 area (ac)**	**% of total**	**1997 parcel units**	**1997 area (ac)**	**% of total**	**% change 1939 to 1997**	**2022 parcel units**	**2022 area (ac)**	**% of total**	**% change 1997 to 2022**	**acreage change 1939 to 2022**	**% change 1939 to 2022**
developed/lawn/garden	165	42.14	49.72%	200	47.55	56.10%	6.38%	277	58.44	68.95%	12.84%	16.30	19.23%
grass/woody perennials	38	5.59	6.59%	80	9.75	11.50%	4.90%	15	1.86	2.19%	-9.30%	-3.73	-4.40%
trees/shrubs	105	13.03	15.37%	53	6.74	7.96%	-7.41%	57	6.74	7.95%	0.00%	-6.29	-7.42%
upland/freshwater wetland	17	2.45	2.89%	29	4.16	4.90%	2.01%	34	4.78	5.63%	0.73%	2.33	2.74%
upland/salt marsh	110	21.55	25.43%	73	16.56	19.54%	-5.89%	52	12.95	15.27%	-4.26%	-8.60	-10.15%

Land Use	**1939 parcel units**	**1939 area (ac)**	**% of total**	**1997 parcel units**	**1997 area (ac)**	**% of total**	**% change 1939 to 1997**	**2022 parcel units**	**2022 area (ac)**	**% of total**	**% change 1997 to 2022**	**acreage change 1939 to 2022**	**% change 1939 to 2022**
developed/residential	165	42.14	49.72%	199	33.30	39.29%	-10.43%	274	44.00	51.91%	12.62%	1.85	2.19%
unmanaged	270	42.62	50.28%	235	37.21	43.90%	-6.38%	112	19.68	23.22%	-20.68%	-22.94	-27.06%
public/conservation	0	0.00	0.00%	1	14.25	16.81%	16.81%	49	21.08	24.87%	8.06%	21.08	24.87%

Statistics of land change on Conimicut Point peninsula, 1939, 1997, 2022 (adapted from Lundgren et al., 2004; Alawamy et al., 2020).

DrawnPolys and DissolvePolys were replicated. The Pairwise Buffer tool was deployed to include a 1 m buffer to account for under-canopy and under-soil growth, creating two new feature groups, DrawnPolysBuffer and DissolvePolysBuffer.

To quickly understand the extent of statistically significant invasive clusters, Optimized HotSpot Analysis was deployed for each species within the DrawnPolysBuffer. Optimized HotSpot Analysis interpreted areas reflected via polygons; traditional density analysis, requiring point values, was not possible (Figure 11). The Optimized Outlier Analysis was run to validate the results of the HotSpot analysis.

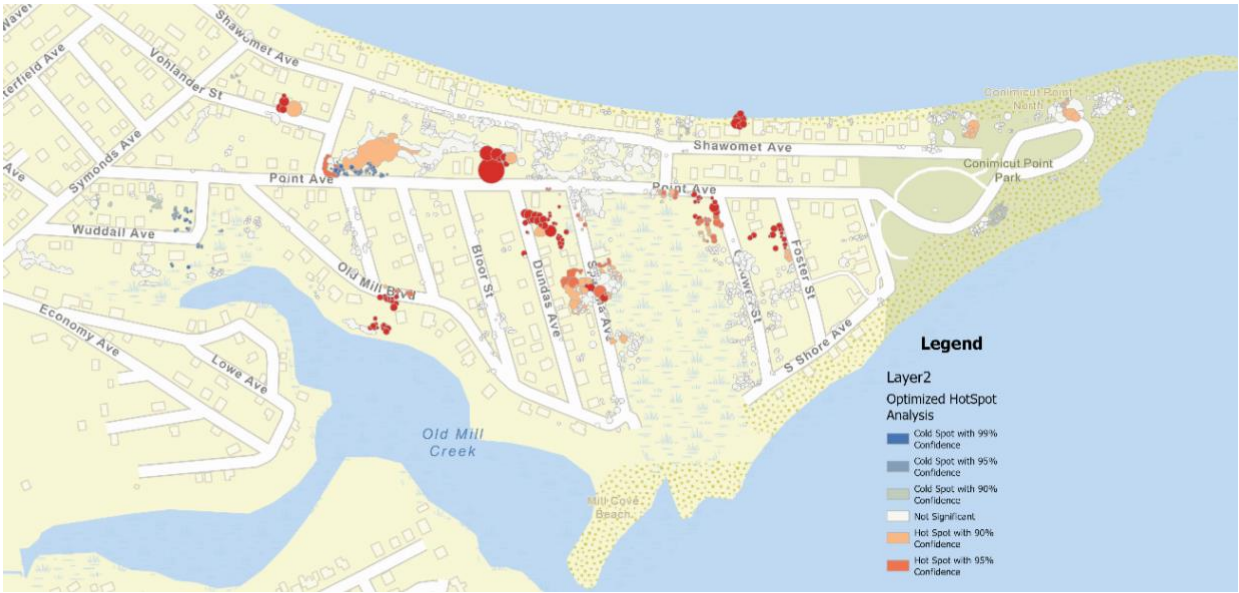

Figure 11. Optimized HotSpot analysis.

Statistically hot and cold spots of invasives on Conimicut Point.

To understand the relationship between the invasive parcels, land cover, land use, and site characteristics, Pairwise Intersect was deployed to combine ConimicutParcelsALL with each DissolvePolysBuffer layer to create a ParcelIntersect layer for each species. Last, the following Spatial Joins were executed on within each Target Feature ParcelIntersect (one to one):

- Wetlands within a distance of 1 m;
- Wetlands within a distance of 3 m;
- Coastal Waters within a distance of 3 m;
- Coastal Waters within a distance of 5 m;
- Downstream Trace (water flow) within a distance of 1 m;
- Soils intersect to understand hydric and seasonally high water tables;
- Elevation contours intersect;
- Roads within a distance of 3 m;
- Land cover for 1939, 1997, 2022; and
- Land use for 1939, 1997, and 2022.

Chapter III

Results

Research results determined the relationship between land history, site characteristics, and species extent.

Presence and Abundance of Invasives

A Spatial Join was executed to combine ConimicutParcelsALL with the four invasive layers to determine species presence and absence. Out of 435 parcels, 176 parcels were free from the target invasives; 159 contained at least one species; 65 contained two species, 34 contained three species, and only one parcel was infested by all four (adapted from Mosher et al., 2009). *R. multiflora* occurred most frequently with *A. altissima*, in 45 parcels, followed closely by *R. japonica* and *A. altissima* in 44 parcels.

Each parcel was also analyzed to understand abundance within; parcels invaded from 0-25% were considered a low invasion, 26-50% moderately invaded, and more than 51%, highly invaded.

Overall, the targeted invasive species covered only a small fraction of the Conimicut Point peninsula, but as a group were widespread and sometimes dense where they occurred. As expected, *P. australis* and *R. japonica* formed close clonal thickets, mostly confined to areas of already-existing infestations. Both *A. altissima* and *R. multiflora* were distributed widely across the peninsula; the former, likely because of wind-borne samaras, and the latter result of hip dispersal by birds and small mammals.

A. altissima was identified in 70 parcels, covering a total area of 1.79 acres, or 7% of the parcel area and 2% of all Conimicut. Eight parcels constituting 0.38 acres had moderate invasion, and three parcels constituting 0.29 acres were highly invaded.

Land coverage history for invaded parcels were primarily developed/lawn/garden since 1939, although by 2022, 31% of invaded parcels had been conserved.

Table 5. Land cover/land use for *A. altissima*.

Land Cover	**LC39**	**LC97**	**LC22**
developed/lawn/garden	70%	57%	67%
grass/woody perennials	4%	10%	1%
trees/shrubs	14%	1%	9%
upland/freshwater wetland	0%	14%	9%
upland/salt marsh	13%	18%	15%

Land Use	**LU39**	**LU97**	**LU22**
developed/residential	70%	18%	28%
unmanaged	30%	43%	17%
public/conservation	0%	39%	31%

Percentage of parcels attributed to land cover and land use categories in 1939, 1997, and 2022, for A. altissima.

Approximately 28% of *A. altissima* occurred within one meter of a wetland, and only approximately 5% was found within three meters of the coast. Interestingly, it was found in nearly equal distribution between areas of hydric and dry soils, loam and sand, typically at an elevation of 6-8 feet. Nearly 63% of this species existed within one meter of downstream water flow. Conimicut Park public conservation parcel constituted 38% of the total extent of *A. altissima* on the peninsula.

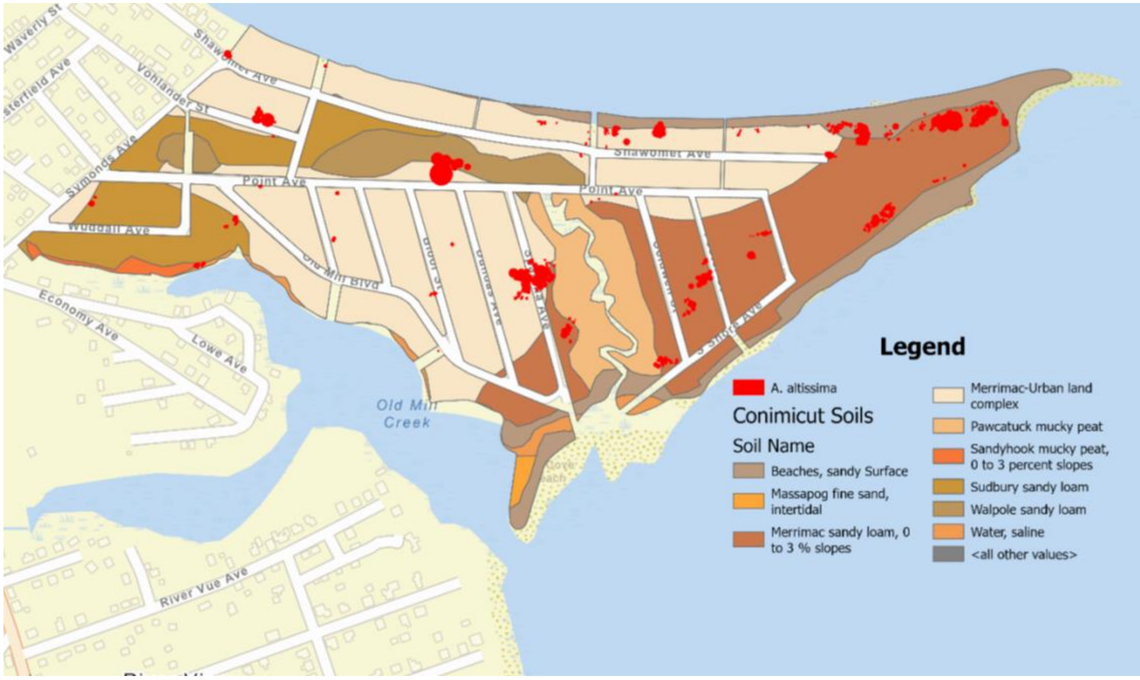

Figure 12. *A. altissima* extent over soils.

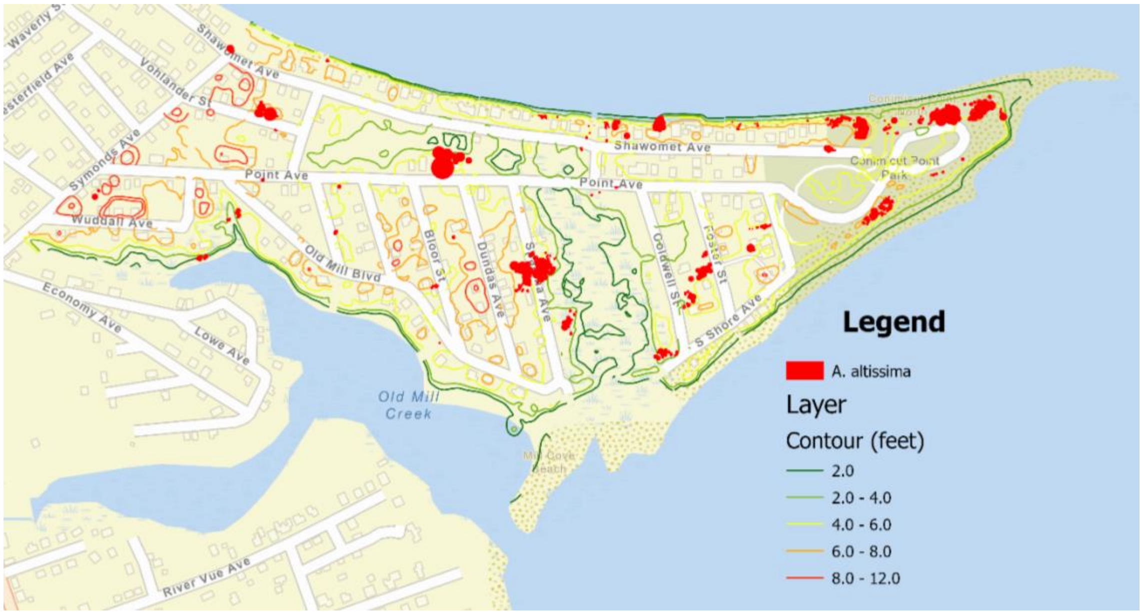

Figure 13. *A. altissima* extent over contours.

P. australis was sited within 55 parcels, covering a total area of 2.14 acres, or 25% of the parcel area and 3% of all Conimicut. Sixteen parcels constituting 0.93 acres were moderately invaded, and 10 parcels constituting 0.82 acres were highly invaded, resulting in nearly 80% of the parcel acreage sustaining at least a moderate invasion.

Likely a function of its relegation to freshwater and saltwater uplands, *P. australis* was rarely found associated with developed land; as of 2022, most occurrences appeared in unmanaged or public conservation parcels.

Table 6. Land cover/land use for *P. australis.*

Land Cover	**LC39**	**LC97**	**LC22**
developed/lawn/garden	17%	8%	14%
grass/woody perennials	0%	23%	0%
trees/shrubs	5%	18%	8%
upland/freshwater wetland	46%	44%	72%
upland/salt marsh	33%	8%	7%

Land Use	**LU39**	**LU97**	**LU22**
developed/residential	17%	8%	14%
unmanaged	83%	92%	33%
public/conservation	0%	0%	53%

Percentage of parcels attributed to land cover and land use categories in 1939, 1997, and 2022, for P. australis.

P. australis was closely correlated with wetlands, with 67% of coverage occurring within three meters of a wetland and downstream water flow, and 69.21% occurring in loamy, hydric soil at transitional elevation between two and four feet.

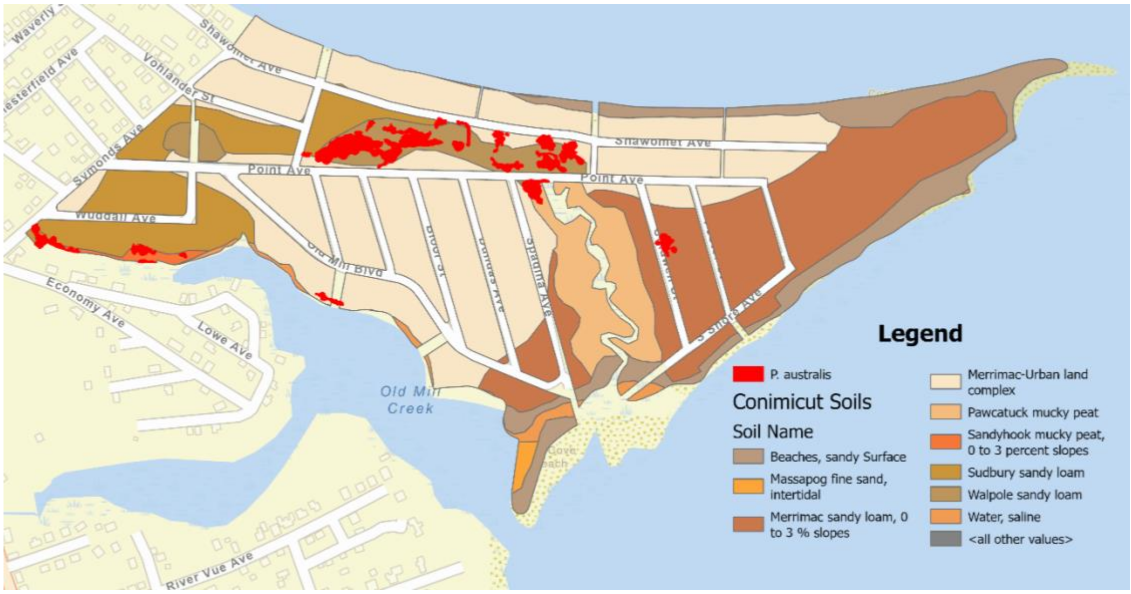

Figure 14. *P. australis* extent over soils.

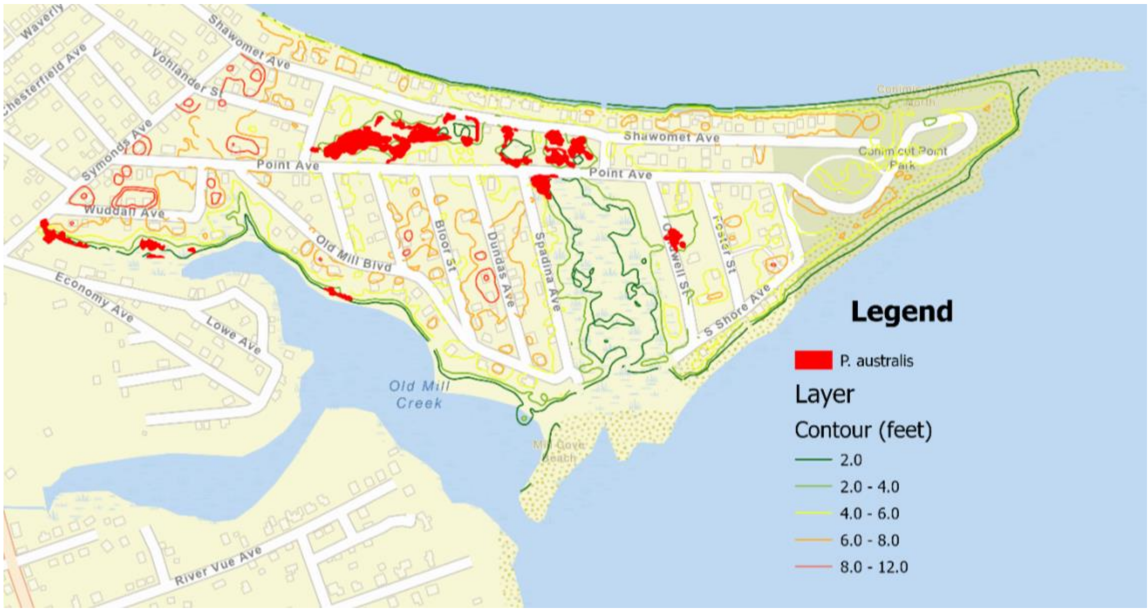

Figure 15. *P. australis* extent over contours.

R. japonica was identified in 73 parcels, covering a total area of 0.86 acres, or 3% of the parcel area and 1% of all Conimicut. Small patches of *R. japonica* were widespread, and only four parcels contained moderate to high invasion.

The extent of *R. japonica* was mapped largely in developed/lawn/garden land coverage areas and prevailed in developed/residential-use parcels as of 2022.

Table 7. Land cover/land use for *R. japonica*.

Land Cover	**LC39**	**LC97**	**LC22**
developed/lawn/garden	46%	51%	58%
grass/woody perennials	3%	16%	0%
trees/shrubs	39%	17%	25%
upland/freshwater wetland	11%	8%	11%
upland/salt marsh	0%	8%	7%

Land Use	**LU39**	**LU97**	**LU22**
developed/residential	46%	43%	50%
unmanaged	54%	8%	21%
public/conservation	0%	49%	29%

Percentage of parcels attributed to land cover and land use categories in 1939, 1997, and 2022, for R. japonica.

Only twenty percent of *R. japonica* extent was established within one meter of a wetland, but none was found within five meters of the coast. Nearly 50% of stands occurred in non-hydric, sandy loam between four- and eight-feet elevation.

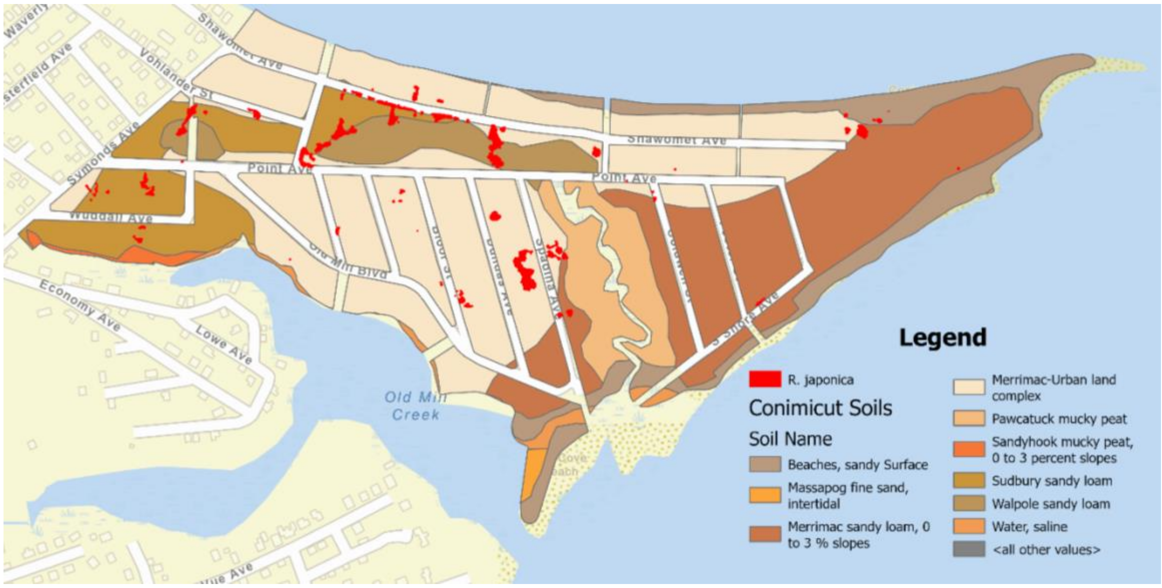

Figure 16. *R. japonica* extent over soils.

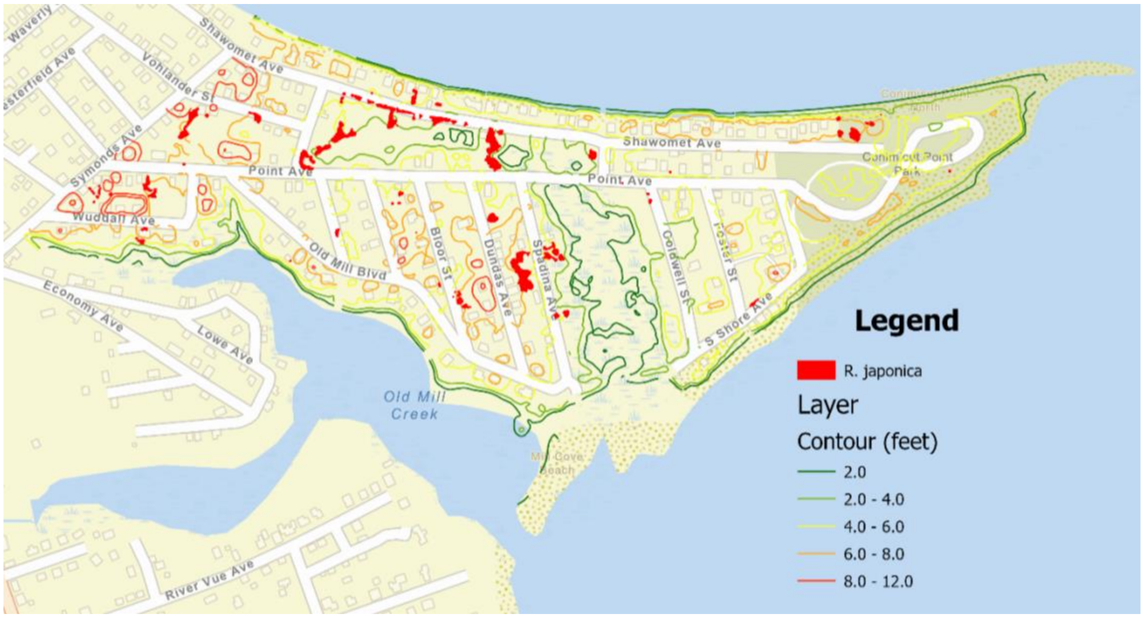

Figure 17. *R. japonica* extent over contours.

R. multiflora was identified in 159 parcels, covering a total area of 1.03 acres, or 3% of the parcel area and 1% of all Conimicut. All but two parcels were infested at a low invasion of less than 25%.

As anticipated via seed dispersal and growth habit, *R. multiflora* was distributed evenly across land cover categories, however, persisted in largely unmanaged or public conservation parcels.

Table 8. Land cover/land use for *R. multiflora*.

Land Cover	**LC39**	**LC97**	**LC22**
developed/lawn/garden	28%	9%	20%
grass/woody perennials	4%	31%	12%
trees/shrubs	18%	12%	24%
upland/freshwater wetland	10%	12%	14%
upland/salt marsh	41%	36%	30%

Land Use	**LU39**	**LU97**	**LU22**
developed/residential	28%	7%	19%
unmanaged	72%	91%	17%
public/conservation	0%	1%	65%

Percentage of parcels attributed to land cover and land use categories in 1939, 1997, and 2022, for R. multiflora*.*

Thirty-six percent of *R. multiflora* occurred within three meters of wetlands, and less than 1% occurred within three meters of the coast. Over half was found within one meter of watershed, and nearly 80% of the extent persists in dry, sandy loam, distributed across elevations.

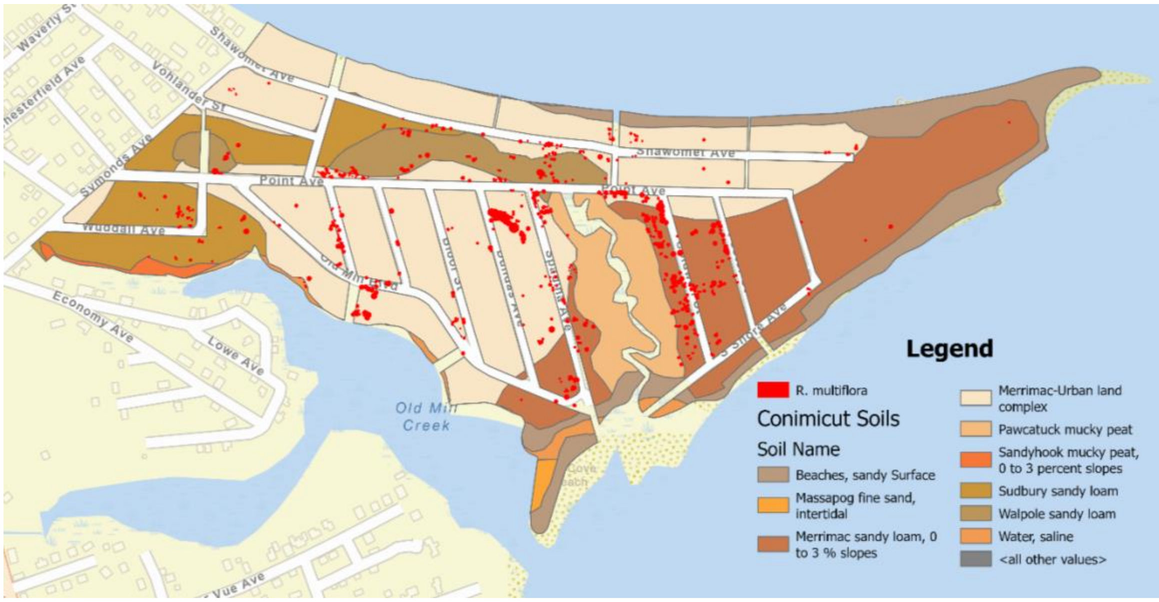

Figure 18. *R. multiflora* extent over soils.

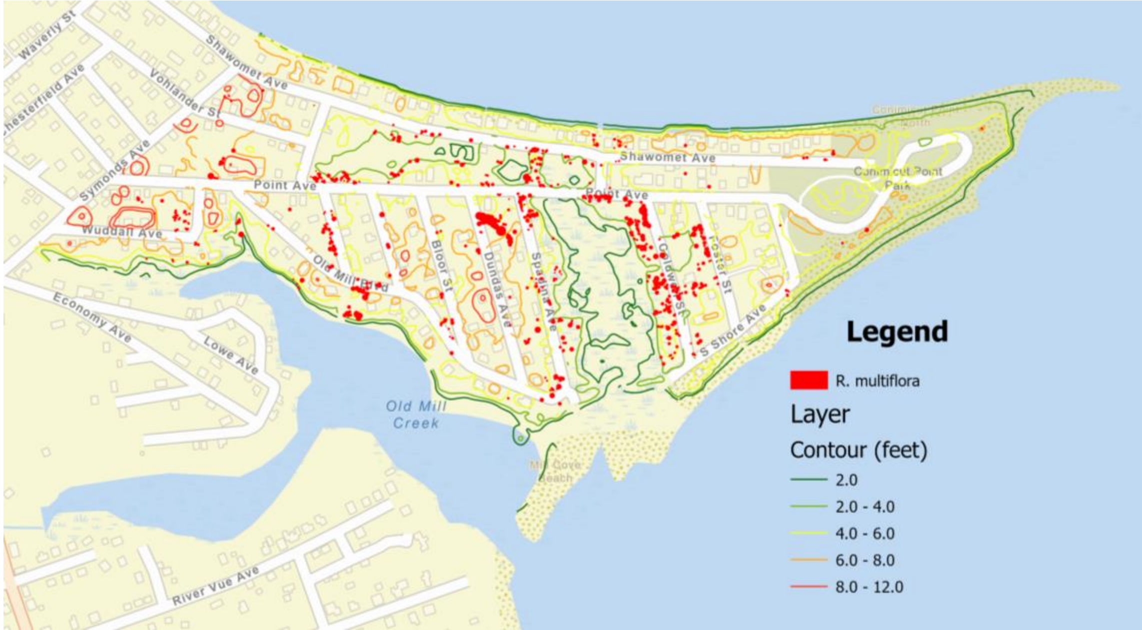

Figure 19. *R. multiflora* extent over contours.

While Rhode Island roads data was anticipated to be useful for determining edge effect, utilization within ArcGIS Pro did not produce accurate results—queries of invasives within road distance of 3 m and 5 m did not capture stands directly on the roadways (pers. obs.); thus, results were omitted at final writing.

Land Cover/Land Use

Land cover and land use may have implications for resultant extent of the target species. Invasive presence occurs in land cover parcels of open canopy because of proximity to open water areas.

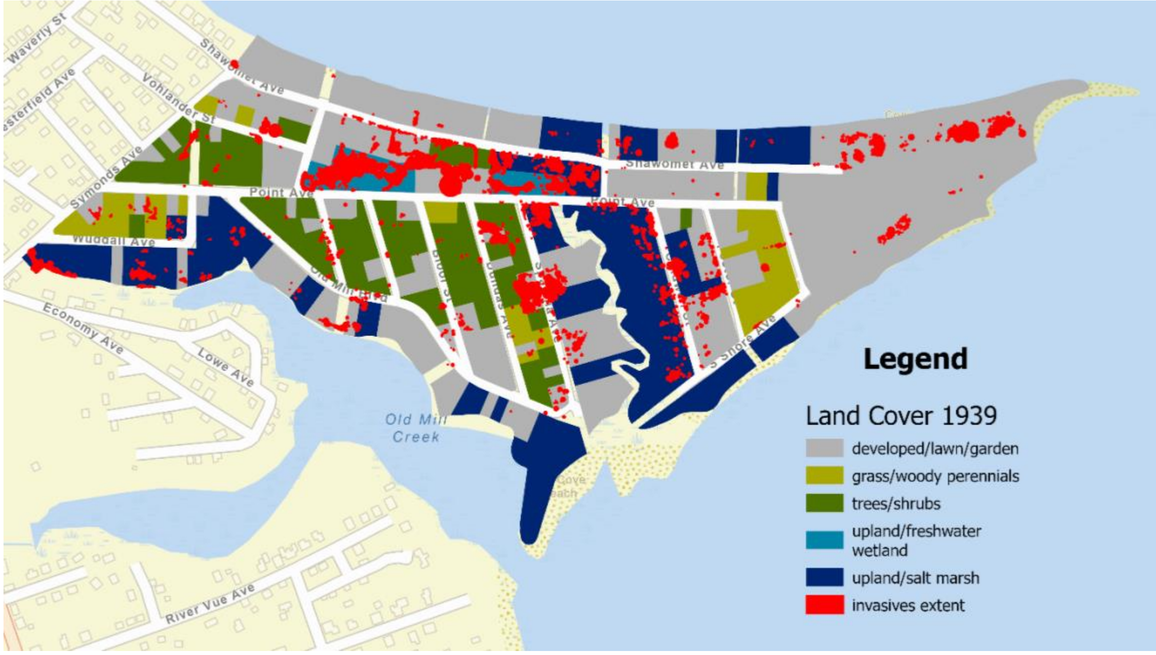

Figure 20. Land cover 1939.

Land cover parcel classification for 1939 and invasives extent.

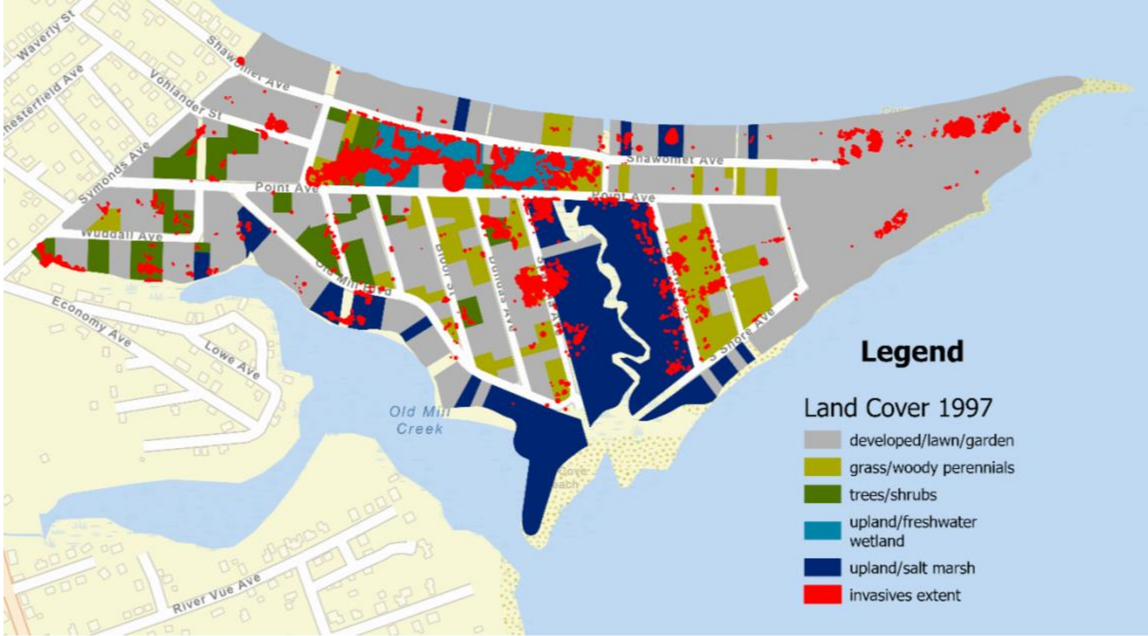

Figure 21. Land cover 1997.

Land cover parcel classification for 1997 and invasives extent.

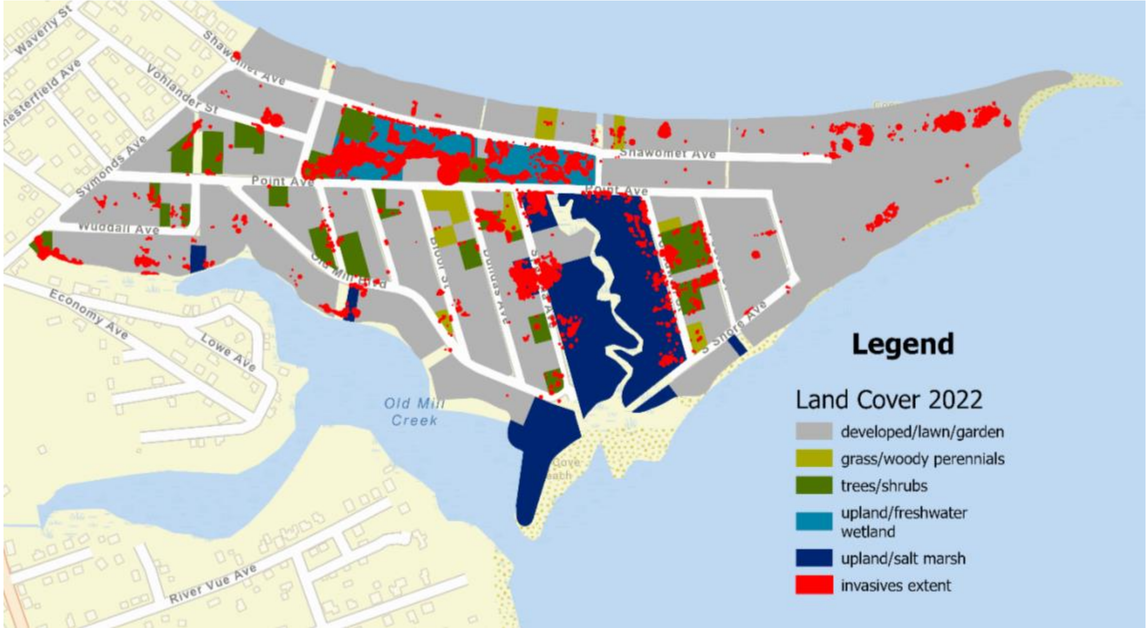

Figure 22. Land cover 2022.

Land cover parcel classification for 2022 and invasives extent.

Land use history and invasive extent demonstrated a general trend; infested parcels in 2022 in large part appeared to have been developed in 1939, unmanaged in 1997, and then still unmanaged or publicly conserved by 2022.

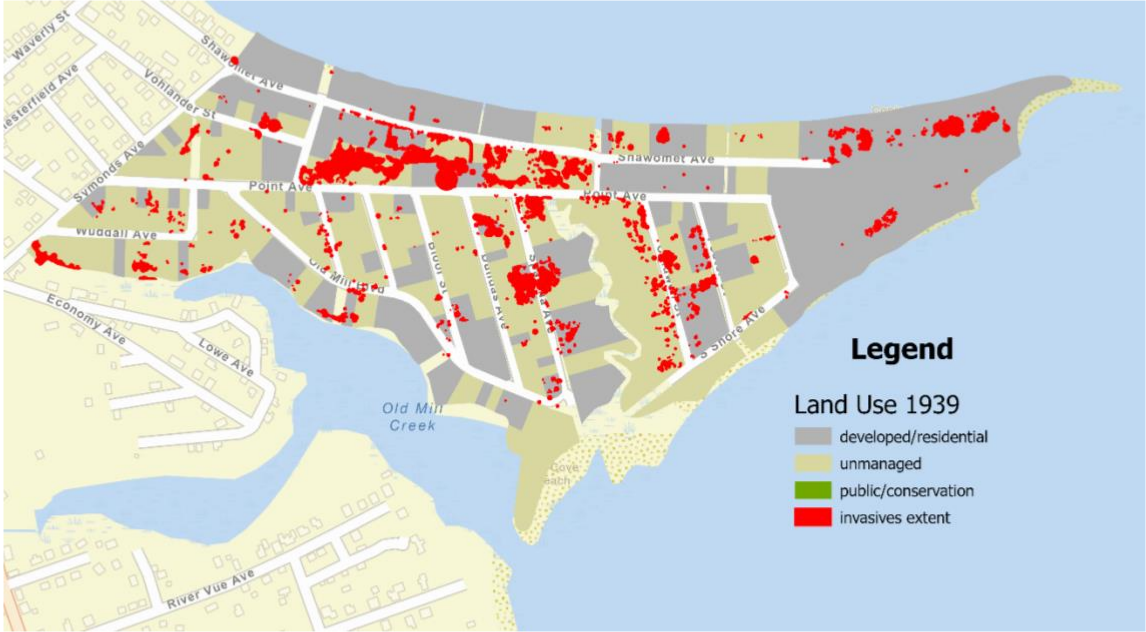

Figure 23. Land use 1939.

Land use parcel classification for 1939 with invasives extent.

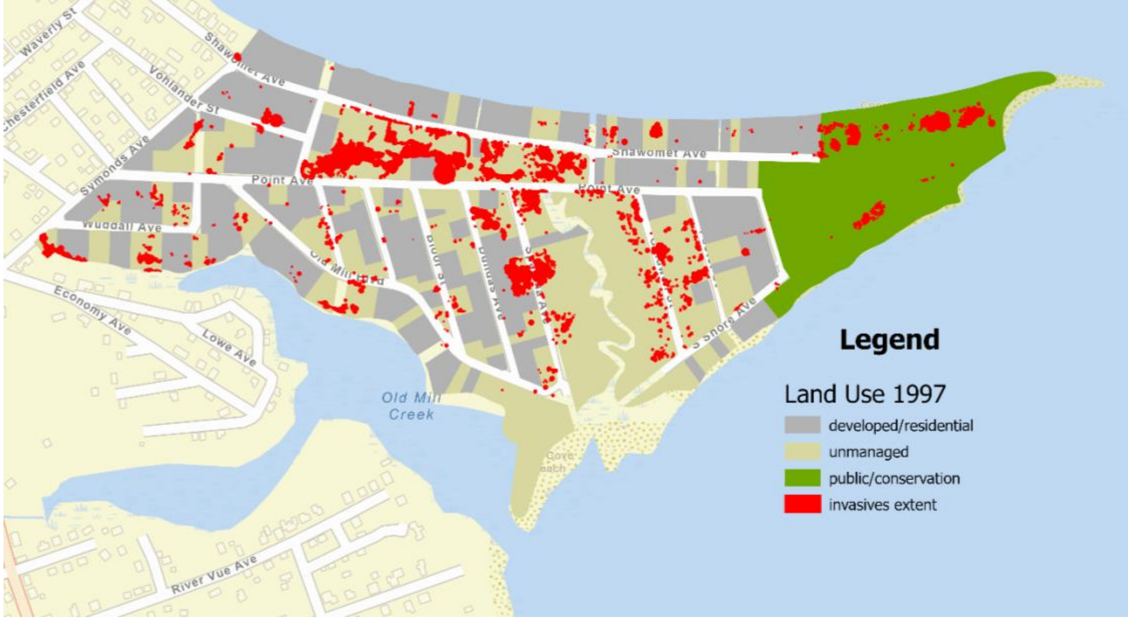

Figure 24. Land use 1997.

Land use parcel classification for 1997 with invasives extent.

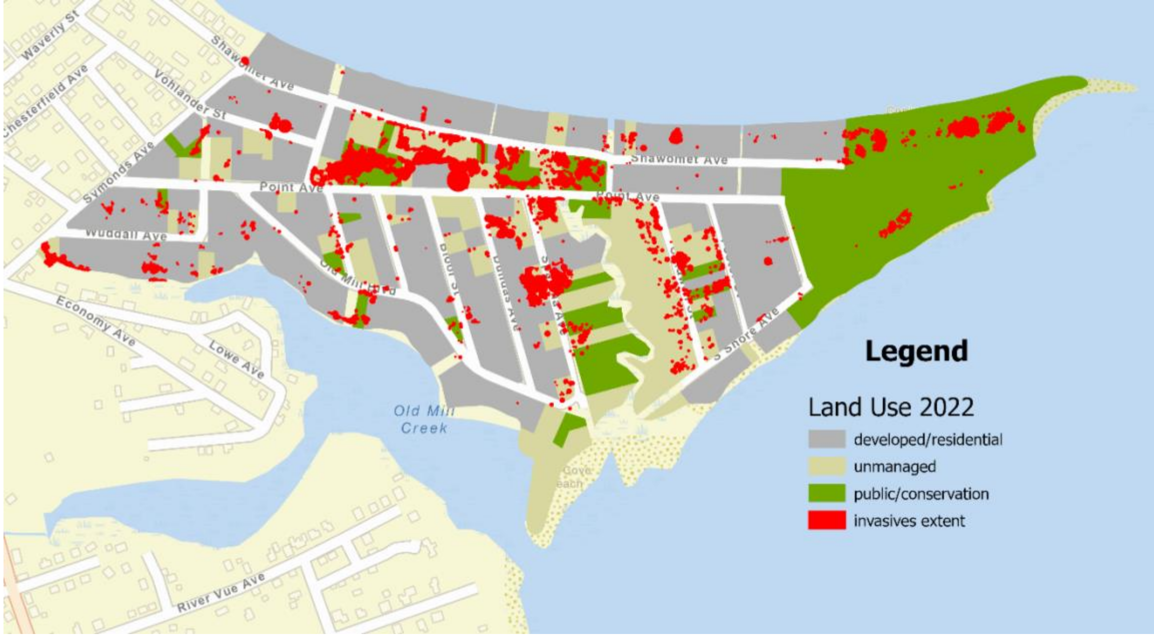

Figure 25. Land use 2022.

Land use parcel classification for 2022 with invasives extent.

Regression Analyses

The amount of categorical data collected with respect to each species prompted the completion of a few simple linear regressions, at minimum to find any statistical relationships between parcel characteristics and invasive presence (Table 9). Spatial Joins for each were exported to feature classes, and joins were converted to binary expressions or numeric categorical expressions for presence or occurrence. The ArcGIS Generalized Regression Tool was used to analyze the variables. Binary (Logistic) regression was run for the site characteristics, and Count (Poisson) regression was used to evaluate land cover and land use.

Table 9. Regression variable matrix.

Dependent	**Explanatory Variables**	**Regression Model**
A. altissima presence per parcel; *P. australis* presence per parcel; *R. japonica* presence per parcel; *R. multiflora* presence per parcel	wetlands within a distance of 1m; wetlands within a distance of 3m; coastal waters within a distance of 3m; coastal waters within a distance of 5m; downstream trace (water flow) within a distance of 1m; hydric soils	Binary (Logistic)
A. altissima presence per parcel; *P. australis* presence per parcel; *R. japonica* presence per parcel; *R. multiflora* presence per parcel	land cover category; land use category	Count (Poisson)

Dependent variables, explanatory variables, and regression type used to understand parcel characteristics that may explain the presence of each species.

While relationships may exist between the variables and invasive presence, there was little statistical significance found in the regressions. *A. altissima* appearance demonstrated no relationship to any of the parcel site characteristics or land history. *P. australis* was highly correlated to wetland habitat and hydric soils, but appearance was also statistically significant with relation to 1939 land cover (upland/freshwater wetlands) and 2022 land use (primarily public/conservation).

Regression also found a relationship between the occurrence of *R. japonica* and both land cover and developed/residential-use in 1939; unmanaged properties in recovery post-hurricane may have prompted the invasion of *R. japonica*; this species has escaped eradication in both developed/residential-use and unmanaged parcels to date. *R. multiflora* demonstrated little statistical significance with the exception of proximity to wetlands within three meters, which can be explained by seed dispersal by local birds traveling across open water habitats.

Given more time for this research, a more robust set of regressions would provide a better understanding of relationships between land, site characteristics, and invasive presence. Multiple regressions for invasive presence as related to land cover and land use change from 1939 to 1997, 1997 to 2022, and 1939 to 2022 may further demonstrate the significance of parcel transitions, particularly between developed/residential-use and unmanaged. Furthermore, regressions with site characteristics, as well as the occurrence of invasives in tandem, might reveal synergistic impacts of species location and mutually beneficial relationships.

Chapter IV

Discussion

The main points of discussion from research results include implications for invasive distributions as catalyzed by climate change, the protection and management of uninvaded parcels, as well as further research that would be beneficial to invasive mitigation on Conimicut Point peninsula.

Implications for Climate Change

Conimicut Point peninsula, as a reach into Narragansett Bay, is prone to storms from all sides, and experiences regular inundation during storm surges (Figures 26 and 27). Habitat decimation from the Hurricane of 1938 likely had a lasting impact on rampant species invasion of unmanaged parcels rebuilding and in recovery; future storms will do the same. Furthermore, hydrological shifts may impact the future distribution of species (Karberg et al., 2018). *P. australis* occupies much of the freshwater wetland parcels on the peninsula but does not pose a threat as significant as other species because of its limitation to brackish environments; in fact, more frequent storm surges and salt-water flushing with increasing sea-level rise will likely diminish its reach. However, storm impacts on canopy cover and spread of detritus will likely further the spread of these invasives, particularly in unmanaged and/or public conservation areas. Furthermore, longer growing seasons and enhanced productivity as a result will lead to greater competition for native species (Duveneck & Thompson, 2017).

Figure 26. Storm surge on Old Mill Blvd.

Old Mill Blvd., Conimicut Point peninsula, washed out during storm surge on December 23, 2022.

Figure 27. Flooded parcels on Old Mill Blvd.

Old Mill Blvd., Conimicut Point peninsula, parcels flooded during storm surge on December 23, 2022.

Protection and Management

Natural, unmanaged parcels will continue to spread invasive extent, as all four species utilize clonal reproduction. This is of particular importance for properties that have been publicly conserved—because they are protected does not necessarily mean they are managed —and apart from the public park, can be considered unmanaged parcels. With the exception of *R. japonica*, much of the existing invasive extent occurs in public conservation land that was converted from private property; developed/residential-use parcels appear to be keeping the vigorous growth habits of three focus species at bay.

Site characteristics will likely continue to play a role in the rate of infestation. Open, exposed areas of edge habitat across the peninsula, particularly around wetlands with minimal canopy, will harbor the highest threat of future invasion, in particular, of *A. altissima*, *R. japonica*, and *R. multiflora* via seed dispersal. *A. altissima* seeding female trees live on the northern and southern reaches of the peninsula, exposed regularly to prevailing, long wind fetch—ideal for the spread of samaras. Further, these three species demonstrate wide tolerances for establishment in all soil types and varied elevations.

As mentioned previously, developed/residential-use parcels, in large part, have mitigated the spread of at least *A. altissima* and *R. multiflora*; private property owners will limit further spread in developed parcels (Figure 28). Targeted community education about *R. japonica* may help stem further spread. Most of *R. japonica* was located within developed parcels, often tucked behind sheds, or utilized as a privacy hedge. While difficult to remove, property owners in uninfested parcels might benefit from knowing more about early prevention. *P. australis* will continue to be limited as a function of growth habit in brackish, hydric soils.

Figure 28. Non-invaded parcels.

Invasive-free parcels with encroaching invasive species extent.

Further Study

Research focused on the four selected species because of edge visibility and obvious prominence on Conimicut Point peninsula. However, future research would benefit further investigation of the extent of other invasives, including *Celastrus orbiculatus* (Oriental bittersweet), which was removed from this study because of low visibility at flight heights, but considering its growth habit and dispersal methods, would likely display distribution patterns similar to *R. multiflora*. Other observed species of concern are *Acer platanoides* (Norway maple), *Elaeagnus umbellate* (autumn olive) and *Microstegium vimineum* (Japanese stilt grass), as well as developed/residential-use parcel plantings of *Euonymous alatus* (burning bush), *Rosa rugosa* (beach rose), and *Bambusa multiplex* (common bamboo).

Further understanding of the mutually beneficial relationships of *A. altissima* and *R. japonica*, which seem to establish easily in the same areas, as well as the roles of *A. altissima* and *Robinia pseudoacacia* (black locust) in successional uplands would be helpful in future management (Call & Nilsen, 2003).

During analysis, a land cover category, unvegetated/recently cleared, was removed because it was based on author observations of ongoing parcel development, and in particular, properties cleared that were recently invaded by *R. japonica*. Understanding this species as a result of land history warrants further monitoring of these parcels and adjacent parcels at risk for future infestation.

Conclusions

In total, target species covered only 7% of the area of Conimicut Point, but each was distributed threateningly across the entire peninsula. After analysis, *P. australis* was the only invasive limited by growth and reproduction, relegated to areas of hydric soils within transitional brackish marsh. Research predictions regarding *A. altissima* and *R. japonica* were fundamentally incorrect. *A. altissima* was found thriving across land characteristics, and may pose a significant threat via wind-borne samaras, catalyzed further by allelopathic clonal spread after establishment. *R. japonica* was established in many locations only visible in aerial surveys—dense in abandoned space at parcel edges, against fences, and behind sheds, regardless of site conditions. As predicted, *R. multiflora* occurrences were widespread and irregular, advantageously established in canopy or brush gaps near open water, prospering with both native and nonnative species.

Nearly 50% of Conimicut Point peninsula was developed/residential-use in 1939, and since then has only increased by 2%. As anticipated, parcels that were previously developed but left to languish were found laden with invasives. Many infested parcels appear to have been developed/residential-use in 1939, unmanaged in 1997, and continued to be unmanaged or publicly conserved in 2022. Nearly 25% of Conimicut Point peninsula is public conservation land, and high rates of invasion demonstrate that protected parcels are critically vulnerable, particularly if they have a history of land disturbance.

Unmanaged parcels (and by proxy, public conservation parcels) predicted a very high rate of infestation, as hypothesized, accounting for an average of 66% of occurrences. Regarding established *A. altissima*, *P. australis*, and *R. multiflora*, developed/residential-use parcels, to a great extent, avoid infestation. However, half of *R. japonica*-invaded parcels were private property, rendering it a threat even in well-managed areas.

As mentioned, land management practices in the area remain unregulated; disturbances, both natural and anthropogenic, have encouraged uninhibited establishment of these invasive species and others throughout the peninsula. Understanding the extent and occurrence of each of these invasive species is essential to future land management and infestation prevention, and early detection is critical to prevention of establishment (Gavier-Pizarro et al., 2010).

Land cover, land use, land change, and site characteristics impact the establishment of invasive infestations. However, in areas where invasives are already embedded within the plant community, standardized practices for property management should be facilitated at the community level (Mehrhoff et al., 2003). The implication of "developed land" is that it is beyond restoration—but engagement and education in invasive species prevention and management strategies, particularly for publicly-conserved spaces, might be enough to mitigate further spread.

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