Using Submerged Aquatic Vegetation to Assess Riverfront Areas and Ecological Condition

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Jayce McG

A Thesis in the Field of Sustainability and Environmental Management

for the Degree of Master of Liberal Arts in Extension Studies

Harvard University

March 2018

Abstract

Current regulations dictating development on the banks of river systems found throughout Massachusetts are scientifically incomplete and result in unproductive arguments between landowners and local governments. According to the Massachusetts Wetlands Protection Act and Rivers Protection Act, a 25-foot or 200-foot riverfront area (depending on the density of the surrounding municipality) is established to protect the critical habitat bordering these freshwater systems. While this law restricts development along the banks of streams and rivers within the riverfront area, not only is it still permissible to develop on that land if approved by a local Conservation Commission, but also there seems to be no scientific data supporting 25-foot or 200-foot areas as adequate barriers for development.

In this study, I developed a procedure to rapidly assess the ecological condition of the Swift River in central Massachusetts by testing to determine if either submerged aquatic plant species richness or percent cover can act as an indicator of impact due to development in a riverfront area. I hypothesized that samples near developed riverfront areas would exhibit both lower species richness and vegetative percent cover, as well as lower cover of *Vallisneria americana*, a common plant found in a variety of freshwater systems. An undeveloped and a developed section of the Swift River were sampled once in September and once in October using 15 randomized throws of a one-square-meter quadrat over 100-meter distance following the flow of the river. Comparing the undeveloped sample site to the developed revealed a statistical difference in the number

of species present for both September (n=15; t=-2.346; p=0.03) and October (n=15; t=-4.012; p=0.001), though there was no statistical difference in percent cover for either September. Percent cover of *V. Americana* showed a difference between undeveloped and developed sample site for September (n=15; t=-2.317; p=0.04), but not for October (n=15; t=-1.623; p=0.13).

Current Massachusetts regulations and development decisions in the area sampled have therefore impacted species diversity in the riverbeds near the developed sample site. This is the first step in quantitatively addressing the riverfront areas outlined by the Rivers Protection Act, but further analyses are needed of other river systems in Massachusetts to corroborate these results. This could result in the need to readdress current Massachusetts regulations allowing for development within a riverfront area and whether there is adequate distance to prevent sediment and/or nutrient runoff from entering a river and negatively impacting its ecological health. If a Conservation Commission has access to a rapid assessment, conflicts between developers and their neighbors can be quickly settled.

Acknowledgments

This project marks the culmination of my time and research conducted while attending Harvard Extension School, and although there exist far more individuals that deserve recognition for the help or support they have given me through the years, I would be remiss to not mention the following individuals.

As my Thesis Director, Dr. Jennifer Cole provided constant help and guidance over the past year and a half. Thank you for all you have done. Your class on Wetland Science and Policy sparked a greater interest in freshwater systems and was the inspiration for this thesis.

As my Research Advisor, Dr. Mark Leighton provided crucial direction on how to develop an adequate research design. Thank you for taking the time to meet with me and review various aspects of this project. Additionally you were one of the first professors I had at Harvard Extension School; your passion for the environment and ecology in part led me to apply to be part of the Sustainability program.

Thank you to Thomas Coote and Matt Byrne for assisting with identification of plants that became a larger challenge than anticipated and to Jacqueline Nuñez and Mat Berman for assisting with some data collection in the field.

Finally, a thank you to my wife, Sarah McG, and my parents. Sarah has always been there to support me in good times and stressful ones. She aided with data collection and consistently supported my work at Harvard Extension School. My parents have also always supported my drive for higher education. I love all three of you.

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Definition of Terms

Buffer Zone: A protected zone extending 100-feet from the delineated edge of any wetland in Massachusetts. Individuals wishing to develop within this area must file a Notice of Intent to their local Conservation Commission.

Conservation Commission: Each town throughout the Commonwealth of Massachusetts has a group of individuals charged with protecting the town's natural resources. These individuals review development projects to determine if they will significantly impact natural resources within the town.

Conservation and Prioritization System (CAPS): A landscape based assessment of the ecological condition of wetlands conducted by the Commonwealth of Massachusetts. CAPS uses Geographic Information Systems data and aerial photography to generate Indices of Ecological Integrity.

Environmental Protection Agency (EPA): A federal agency that is tasked with protecting the environment and human health. The EPA imposes guidelines for states to follow that will protect natural resources and residents within individual states.

Geographic Information System (GIS): A computer based system that catalogs datasets and allows users to plot these metrics on a map to analyze changes to variables across a given landscape.

Hydrophytic vegetation: Plants that can tolerate partially or continually submerged conditions and anoxic soils.

Index of Biological Integrity (IBI): Intensely developed scores from various metrics collected in the field over numerous years. IBIs are generated through Site Level Assessments and are meant to validate or challenge indices of ecological integrity developed in CAPS.

Index of Ecological Integrity (IEI): A score from 0 to 1 that is a prediction about the stress on a wetland and its resiliency, with higher scores representing more ecologically sound areas. IEIs are generated through CAPS.

Notice of Intent (NOI): A form that must be submitted to a Conservation Commission in order to request approval of a development project that will occur within the buffer zone to a wetland.

Rivers and Streams: Flowing bodies of water that originate from runoff from precipitation, meting snow, on an underground spring. Rivers are typically larger, deeper, and transport large volumes of water, while streams are narrower, shallower, and transport smaller volumes of water.

Riverfront Area: A wetland resource area located adjacent to rivers and streams in Massachusetts. This is either a 25-feet or 200-feet area measured parallel from the banks of the river or stream. This distance depends on the population density of the surrounding municipality.

Site Level Assessment Methods (SLAMs): Very intensive, long-term studies conducted by the Commonwealth of Massachusetts that generate Indices of Biological Integrity for wetland ecosystems and verify the IEI scores determined through CAPS.

U.S. Fish and Wildlife Service (USFWS): A federal agency tasked with protecting various fish, plant, and other wildlife species and the habitats in which they reside.

Vallisneria americana: A common freshwater wetland plant found throughout North America. Its common names include tape grass, eelgrass, and water celery. Found in depths of 4 to 6 feet, it grows horizontally through the sediment and produce ribbon-like leaves upwards.

Wetland: Any area of the land that is partially or continually submerged in water, contains unique, anoxic soils, and hydrophytic vegetation.

Chapter I

Introduction

The Massachusetts Wetlands Protection Act, originally established in 1972 and revised in 1985, is designed to protect a vital resource to the Commonwealth. The Act states that individuals may not "remove, fill, dredge, or alter" any wetland in the Commonwealth without first filing a Notice of Intent (NOI) to a local Conservation Commission (CONCOM) for approval. (MGL c. 131 § 40; 310 CMR 10.00) The area protected is the wetland itself and a buffer zone that extends 100-feet from the border of the wetland. In 1996, an amendment called the Massachusetts Rivers Protection Act was added to the Wetlands Protection Act that established a protected riverfront area extending either 25-feet or 200-feet the bank of the river depending on the density of the population in the surrounding town or city.

Herein lies the problem: there does not seem to be any scientific basis to support 100-feet as a sufficient buffer to protect a wetland or a 25-foot or 200-foot riverfront area to protect a river system. Additionally, if individuals wish to develop their land within this buffer zone or riverfront area, they must contact a wetland scientist or consultant to delineate the border of the wetland; further problems arise here as wetlands water levels vary seasonally due to water fluxes and are therefore more appropriately delineated by hydrophytic vegetation, plants that can tolerate anoxic soils and partially submerged periods of time. This can complicate the process further as different wetland consultants may delineate borders differently, leading to possible legal battles between neighbors or other members of the community when a development project is in its planning phases.

Wetlands provide critical ecosystem services to humans, including water storage, flood control, and the preservation of biodiversity, so it is in the best interest of humans to protect these valuable resources. Pursuant to the Clean Water Act of 1972, states are required to maintain the water quality of any open water source, which includes wetlands, streams, and rivers. (Clean Water Act, 2002)

The Environmental Protection Agency (EPA) suggests that states monitor the ecological condition of their wetland areas in a three-level approach in which states can choose to do any or all of the levels of assessment: a Level 1 computer based Geographic Information System (GIS) landscape assessment, a Level 2 rapid field assessment designed to take no more than a few days of experimentation and data analysis, and a Level 3 intensive site assessment designed to take months to years to generate metrics to analyze ecological condition. Massachusetts currently conducts a Level 1 landscape assessment called the Conservation and Prioritization System (CAPS) that uses GIS data and aerial photography to generate an Index of Ecological Integrity (IEI); the IEI is a prediction about the stress on a wetland and its resiliency. (Jackson et al., 2015) Massachusetts also conducts Level 3 site level assessment methods (SLAMs) that generate an Index of Biological Integrity (IBI); IBIs are intensely developed scores that validate or challenge the IEI determined in CAPS (McGarigal et al., 2013).

Overall, these metrics determine whether or not a wetland is in fair or poor ecological condition. There seems to be no connection between the established buffer zone or riverfront area and wetland ecological integrity. If the goal of CAPS and SLAMs are to ultimately preserve wetlands across the Commonwealth of Massachusetts, pursuant to the Wetlands Protection Act (MGL c. 131 § 40) and their regulations (310 CMR

10.00), should the regulations for developing near or within buffer zones or riverfront areas also be evaluated to see if they are sufficient? Can these boundaries be evaluated to more accurately portray the distance development should occur from the boundaries of wetlands? Also, these metrics seem to focus on either terrestrial biota or simple abiotic factors in general. There does not seem to be a submerged aquatic vegetation component. Ultimately, can the buffer zone or riverfront area distance be appropriately analyzed by looking at the growth of submerged aquatic vegetation?

This study focuses on how and if the short-term growth of submerged aquatic vegetation in a river system is impacted by development within its riverfront area. The Swift River, located in central Massachusetts south of the Quabbin Reservoir and bordered by the towns of Belchertown, Ware, and Bondsville is the site of this study. Some submerged aquatic vegetation found growing in the Swift River, such as *Vallisneria americana* (Figure 1), commonly named tape-grass, is limited by sunlight, therefore less sunlight reaching *V. americana* will result in less plant cover on the riverbed (Findlay, Strayer, Smith, & Curri, 2014). More sediment runoff, from developed land in close proximity to the wetland or river system, will increase turbidity and may decrease *V. americana* cover, as well as other submerged aquatic plants. Additionally, nutrient loading, from developed land in close proximity to the wetland or river system, can increase phytoplankton growth, decrease light penetration through the water column, and therefore may decrease plant cover.

Figure 1. *Valisneria americana* collected at the Swift River in June 2017 (photo by author, 2017).

Research Significance and Objectives

The ultimate goal of this research was to find a way to rapidly analyze if development within a riverfront area causes measurable impacts on the biodiversity of its riverbed. By developing a rapid assessment that measures species richness and percent cover of submerged aquatic vegetation, I proposed that a developed site can be compared to a pristine undeveloped region of the river. The objective was to determine if the current Massachusetts regulations allowing for development within a riverfront area provide an adequate distance to prevent sediment and/or nutrient runoff from entering a river and therefore negatively impacting its ecology.

A second objective was to reduce conflict between developers and their neighbors and begin generating better metrics for Conservation Commissions to determine appropriate development within these areas. Since confrontations and disagreements tend to arise between multiple parties involved in development decisions, access to data from a rapid assessment could be very valuable. Instead of arguing based on belief, parties can use these metrics to know exactly how to develop without causing unintended harm to the riparian ecosystem.

Most importantly, this research will continue efforts to preserve and better understand a critical resource to the Commonwealth of Massachusetts. There exists a gap in knowledge documenting submerged aquatic plants in freshwater systems, particularly river systems. This research transformed into the beginnings of cataloging and understanding the ecology of submerged aquatic vegetation found in the rivers of Massachusetts, and specifically the Swift River.

Background

Wetlands are unique ecosystems found throughout the planet that provide numerous services for not only the surrounding environment, but also any humans living in nearby areas. Aside from providing habitat to countless organisms, wetlands help humans by protecting and purifying water supplies and providing flood and storm control. The biogeochemical interactions as water flows through the anoxic, vegetated soils creates unique and important conditions that cannot be replaced by human innovation.

Three distinguishing features identify wetlands: water, soil, and hydrophytic vegetation. As the name indicates, wetlands are areas of land that are saturated by water; typically the water exists at or above ground level, but often only the root zone will be saturated. The permanent or temporary presence of water in the soil drive rapid use of the available oxygen in the water, making wetlands ecosystems distinguishable by unique soil conditions that are almost always anoxic. The hydrophytic plants that live in these saturated, anoxic soils are used to growing in these stressful conditions and have a multitude of adaptations to allow them to survive (Mitsch & Gosselink, 2015).

River, or riparian, systems rely on surrounding wetlands to help reduce sediment and nutrient load entering the river. These wetlands are found directly adjacent to the riverbanks, typically within the area Massachusetts has designated as riverfront area. Wetlands are critical for preserving water quality and ecosystem health within a river (Mitsch & Gosselink, 2015).

Defining Wetlands

Though this fairly straightforward distinction of submerged anoxic soils with hydrophytic vegetation may seem to simplify the ability to define a location as a wetland, humans have historically struggled to agree on one unifying definition (Mitsch & Gosselink, 2015). This is due to numerous reasons, but some that stand out include the fact that these ecosystems may go months without water or different organizations may need to classify a wetland for different purposes. The first formal definition in the United States occurred in 1956 by the U.S. Fish and Wildlife Service (USFWS); the publication referred to as Circular 39 emphasized that wetlands were vital for various waterfowl species and also identified twenty types of wetlands (Shaw & Fredine, 1956).

Though this was an important step in beginning to classify and ultimately protect wetlands, the definition laid out by Circular 39 was not a full description of what these ecosystems are and how they service many other ecosystems. In 1979, the USFWS further classified these ecosystems in the publication Classification of Wetlands and Deepwater Habitats of the United States; this was an important step as this was the first formal mention of unique soils and vegetation found in wetlands (Cowardin, 1979). Even though these revised definitions gave more understanding to this crucial ecosystem, they still resulted in numerous regulatory controversies as individuals around the country got into a variety of legal battles due to a continued lack of what truly qualified as a wetland ecosystem (Mitsch & Gosselink, 2015).

The U.S. National Academy of Sciences was tasked with developing a comprehensive regulatory definition and in 1995 released a report titled Wetlands: Characteristics and Boundaries, generating a comprehensive description of wetlands found throughout the United States and how to identify them (National Research Council, 1995). This definition very accurately portrays how to identify wetlands, yet the need for this was generated by past, incomplete definitions that are still in use by some organizations; these include a definition used by the U.S. Army Corps of Engineers from the 1977 amendments to the Clean Water Act (Clean Water Act, 2002) and a definition used by the U.S. Department of Agriculture for food security (Glaser, 1986). It is evident that different organizations to this day classify wetlands in a non-collaborative manner.

Although there is still disagreement on classification of various wetlands types, we can more easily define and distinguish the wetland areas in this study. Riparian systems include an actively flowing river or stream channel, the exposed and sometimes near vertical banks on the edges of the channel, and the flatter surrounding saturated land that exists in the floodplain of the system. Rivers and streams can be bordered by various types of wetlands including small vernal pools that appear seasonally with precipitation changes or snow pack melt, wet meadows that are larger field areas, forest and shrubs swamps that are dominated by woody vegetation, or marsh land that is dominated by grassy vegetation (Cole, 2016).

Riparian systems are critically important to the health and diversity of the connected river or stream, as well as bordering land and areas further down stream. Root structures of trees, shrubs, and grasses that grow on the edges of the channel stabilize the bank by preventing erosion of sediment; in addition, they hold onto newly deposited, nutrient-rich soils when the water overflows into the floodplain. Precipitation runoff and groundwater flow through the soils removes harmful pollutants and excessive nutrients; the ability to cycle and hold onto large amounts of nutrients makes this habitat highly productive and diverse in life. Furthermore, the large volumes of wood from tree growth impacts communities within the channel. Cover from trees impacts light penetration, and therefore temperature and photosynthesis. Also, any downed branches or trees can completely change how life behaves in the river or stream due to new habitat and a change to the flow of water.

Wetland Environmental Services

So why bother defining and protecting wetlands? To the layman, a wetland may seem like a stagnant pool of water whose sole purpose is breeding mosquitoes or a soggy patch of land when a river runs high. While that is not entirely inaccurate, these ecosystems in fact provide a multitude of ecosystem services to both humans and the surrounding environment. As defined by the Massachusetts Wetland Protection Act (MGL c. 131 § 40) and regulations imposed by the Commonwealth (310 CMR 10.00):

> M.G.L. c. 131, § 40 sets forth a public review and decision-making process by which activities affecting Areas Subject to Protection under M.G.L. c. 131, § 40 are to be regulated in order to contribute to the following interests:
>
> - protection of public and private water supply
> - protection of groundwater supply
> - flood control
> - storm damage prevention
> - prevention of pollution
> - protection of land containing shellfish
> - protection of fisheries
> - protection of wildlife habitat

These numerous services are therefore what make protecting wetlands in the best interest of humans. Wetlands act as filters of pollutants, with water typically flowing very slowly through these systems allowing for ample time for biogeochemical reactions to process nutrients. Additionally, wetland vegetation is known to uptake heavy metals and other harmful pollutants (Mitsch & Gosselink, 2015). Depending on the organic matter content in the soils and the type of vegetation, wetlands act as water storage and can resupply groundwater reserves. Wetlands can also take the brunt of water from a storm event as its soils and certain types of vegetation act like sponges; the water is then slowly released into the surrounding area mitigating flash flood events (Mitsch & Gosselink, 2015).

In relations to river and stream systems, water outflow into these larger aquatic systems is typically preceded by flow through wetland areas. The wetlands remove pollutants (sediment, nutrients, etc.) prior to reaching these larger systems and therefore allow for better water quality (Mitsch & Gosselink, 2015). Many species also use wetlands for year round or seasonal habitat. Waterfowl use these as important feeding grounds during migrations and various amphibian species use them for reproduction (Mitsch & Gosselink, 2015).

Regulating Wetland Development

With all of these important services, how have wetlands fared across the United States? Wetlands in North America have been dramatically disturbed and affected by human development. From the 1600s to the mid-1950s, approximately half of the wetlands covering the United States had been destroyed by human activity and development (Cox & Peron, 2002). This destruction continued and 10% of remaining wetlands perished from 1955-1975; since then, wetlands have shrunk approximately 5% per year. (Cox & Peron, 2002) According to a U.S. Fish and Wildlife Report (Dahl, 1990), 22 states have lost at least 50% of their wetlands by the 1970s and 1980s, with 10 states losing 70% or more (Felix, 2016). Massachusetts stands out from this group and is in fact one of the better-managed states in the union; approximately only 20-33% of wetlands have been compromised since colonial settlement (Felix, 2016).

Although nearly one-third of wetland ecosystem loss across the Commonwealth may be a startling amount, Massachusetts has been able to protect the majority of wetlands compared to other states due to effective legislation that predated the U.S. National Academy of Science's definition of wetlands by decades. In 1963, Massachusetts passed the Jones Act, which required any resident to obtain a permit prior to filling in or building on coastal wetlands (Felix, 2016). Two years later, the Hatch Act was passed to extend the protection of the Jones Act to inland wetlands (Felix, 2016) and in 1972 these laws were combined to become the Massachusetts Wetlands Protection Act (MGL c. 131 § 40) While this law required any individual that wished to develop on a wetland to complete a Notice of Intent, it did have some issues: it did not determine jurisdictional boundaries, outlining where the land ended and the wetland began, and it did not limit the amount of wetlands that could be destroyed or altered throughout the Commonwealth (Felix, 2016).

In 1985, the Revised Wetlands Regulations (310 CMR 10.00) fixed this problem and established a 100-foot boundary, called a buffer zone, around wetlands. Additionally, the revised regulations outlined detailed descriptions and definitions of various wetland types found throughout Massachusetts making regulation and protection of the wetlands more efficient. In 1996, the Wetlands Protection Act was again amended with the addition of the Rivers Protection Act. This act provided protection to river and stream systems by defining an area adjacent to these bodies of water, know as a riverfront area, that would be granted the same protection as inland and coastal wetlands. Riverfront areas extend 200-feet from the high-water line of a river or stream, or 25-feet in densely developed municipalities; densely developed municipalities are those with a population greater than 90,000 or a population density greater than 9,000 per square mile (MGL c. 131 § 40; 310 CMR 10.58).

Wetland Ecological Assessment

In order to adhere to these regulations and effectively assess the ecological condition of wetlands throughout the Commonwealth, Massachusetts follows two types of monitoring assessments suggested by the Environmental Protection Agency (EPA).

The EPA, pursuant to the Clean Water Act (Clean Water Act, 2002), suggests that states throughout the country monitor wetlands in a three level approach, though states are not required to complete any or all of the suggested assessments as these are merely guidelines recommended by the EPA. Each level of assessment varies in both type of research and overall time commitment.

Level 1 assessments, called Landscape Assessments, are meant to be completely conducted using pre-existing Geographic Information System (GIS) data and aerial photography. Additionally, states conducting a Level 1 Landscape Assessment classify any wetlands being surveyed during this evaluation. Level 1 assessments do not require any field-testing and are meant to only pool pre-existing data to assess wetland ecological condition. In a Level 2 Rapid Assessment, quick in-the-field assessments of the ecological condition are conducted on specific wetlands. These assessments are intended to take no more than a day’s worth of fieldwork and a day’s worth of data analysis. Level 3 Intensive Site Assessments are meant to take months to years to complete. In these, scientists compile numerous datasets to develop multi-metric indices of biodiversity and ecological condition of wetlands (EPA, 2016).

Massachusetts currently conducts Level 1 and Level 3 assessments of wetlands across the Commonwealth. The Level 1 Conservation Assessment and Prioritization System (CAPS) uses GIS data and aerial photography to generate an Index of Ecological Integrity (IEI). An IEI is a prediction about the stress on a wetland and its resiliency (McGarigal et al., 2011). The Level 3 Site Level Assessment Methods (SLAMs) generate an Index of Biological Integrity (IBI). IBIs are intensely developed scores that validate or challenge the IEIs determined in CAPS (McGarigal et al., 2013).

To determine the IEIs as part of CAPS, the Commonwealth was first analyzed to determine what areas were developed and undeveloped lands. From there, numerous landscape metrics were applied to every point on the landscape; these landscape metrics included various stressor and integrity metrics. Stressor metrics include development and roads metrics including habitat loss, watershed habitat loss, wetland buffer insults, road traffic, mowing & plowing, and microclimate alterations, pollution metrics including road salt, road sediment, and nutrient enrichment, biotic alteration metrics including domestic predators, edge predators, invasive plants, and invasive earthworms, hydrologic alteration metrics including imperviousness and dams, and coastal metrics including salt marsh ditching, coastal structures, beach pedestrians, beach off-road vehicles, and tidal restrictions. Integrity metrics include connectedness, aquatic connectedness, and similarity. The result of combining these metrics is a score called an index of ecological integrity (IEI). Scores range from 0 to 1, with a higher score representing a more ecologically sound system, and are applied to every point on the landscape of Massachusetts (McGarigal et al., 2011).

Site Level Assessment Methods (SLAMs) are meant to be very intensive, long-term studies to validate or challenge the IEI scores determined through CAPS (McGarigal et al., 2013). Biotic data was collected throughout the Commonwealth of Massachusetts in various forested wetlands, coastal salt marshes, and wadable freshwater streams. From 2008-2009, 219 forested wetlands were sampled for various vascular plant species, bryophytes, epiphytic macrolichens, diatoms, and macroinvertebrates. From 2009-2011, 130 coastal salt marshes were sampled for various vascular plant species and macroinvertebrates. Additionally, 490 wadable freshwater streams were evaluated based on macroinvertebrate data provided by the Massachusetts Benthic Macroinvertebrate database and collected from 1983-2007. Indices of biological integrity (IBIs) were generated for each of the above-mentioned groups and cross-referenced with stressor metrics from the three ecosystems analyzed. Of the IBIs generated by this SLAM, 8 of 9 were deemed reliable for streams, 48 of 120 deemed reliable for forested wetlands, and 4 of 35 deemed reliable for coastal wetlands (McGarigal et al., 2013).

Though these methodologies are meant to assess the ecological condition of wetlands and surrounding area throughout the Commonwealth of Massachusetts, they do not take into account the dilemma of when it may be permissible to develop within a buffer zone or riverfront area. How can these methodologies be improved? Should a level 2 rapid assessment be developed? Additionally, can submerged aquatic vegetation be used as a metric?

Vallisneria americana as an Indicator Species

Vallisneria Americana, a common aquatic plant found throughout Massachusetts, is referred to as tape-grass, eelgrass, or water celery. Narrow, flat leaves emerge from a thin stem that grows horizontally in the sediment (Magee, 1981). *V. americana* exists in freshwater systems throughout North America, ranging as far north as Nova Scotia, Quebec, and North Dakota to as far south as Florida and Texas (Magee, 1981). It is found in lakes, ponds, and slowly flowing streams and rivers at depths of 4-6 feet.

V. americana reproduces by flowers growing under water, breaking off and floating to the surface where pollen is released. Pollen floats to stigmas that are near the surface; the plant then retracts the long stem to gestate under water (Cox & Peron, 2002). Studies have shown that the main limiting factor on the growth of *V. americana* is light (Kreiling, Yin, & Gerber, 2007; Findlay et al., 2013). Kreiling et al. (2007) found that higher light availability in the Upper Mississippi River generates greater shoot biomass in *V. americana*. Findlay et al. (2013) have additionally found that *V. americana* patch size in the Hudson River, New York, was limited by light. This in turn was impacted by the amount of suspended sediment due to regional runoff.

In lab studies, *V. americana* has been shown to have an effect on ecosystem structure and function. In the absence of *V. americana*, there was an observed increase in phytoplankton, filamentous algae, and bacterial colonies (Wigand et al., 2000). Additionally, there were fluctuations in pH and levels of productivity. When *V. americana* was present, there were no major fluctuations on the structure and function of the system (Wigand et al., 2000).

As *V. americana* growth has been shown to be limited by the amount of sunlight it receives (Keiling et al., 2007; Findlay et al., 2014), it is expected that developed land may increase sediment runoff and thereby increase turbidity, leading to a decrease in *V. americana* density. Microalgae and macroalgae growth is significantly reduced in wetlands containing *V. americana* (Wigand et al., 2000) and related species, such as *Vallisneria spiralis L.*, are known to control sediment biogeochemistry (Soana & Bartoli, 2014). Heavy nitrogen loading into a wetland causes an increase in microalgae growth and a decrease in growth of another species related to *V. americana*, *Vallisneria spinulosa* (Zhang et al., 2016). It is therefore expected that developed land within a riverfront area may cause an increase in nutrient runoff into a river system and thereby increase algal growth, which will decrease light penetration into the water and *V. americana* density.

Therefore, *V. americana* appears to play a crucial role in wetland, stream, and river ecosystems as a regulator. In its absence, it is possible that the associated aquatic ecosystem may degrade. An analysis of how development near or within riverfront areas to determine the effects on *V. americana* is needed. This may prove to show that V. *americana* is a reliable indicator species for assessing ecosystem health.

Other Important Submerged Aquatic Vegetation

Various plant species thrive under the flowing water of the Swift River, the site selected for this research. In addition to *V. Americana*, two of the most encountered submerged plants are Bladderwort (*Utricularia vulgaris*) and Pondweed (*Potomogeton* sp.). *U. vulgaris* (Figure 2) exists in freshwater systems throughout most of North America. It is found in lakes, ponds, and slowly flowing streams and rivers at depths up to four feet. Narrow, branching, forked leaves covered in small bladders emerge from a long, thin stem (Magee, 1981). *Potomogeton* (Figure 2) exists in freshwater systems in the northern reaches North America. It is typically found in shallow ponds and slowly flowing streams and rivers. Its narrow, bushy, forked leaves emerge from long, thin stems (Magee, 1981).

Additional plants (Figure 3) found growing on the bed of the Swift River include Hortwort (*Ceratophyllum demersum*), Watercress (*Nasturtium offcianale*), Water-Milfoil (*Myriophyllum humile*), Waterweed (*Elodea canadensis*), Quillwort (*Isoetes muricata*), Water-Lily (*Nuphar variegatum*), a moss species, and two unidentifiable types of algae. One algae is fuzzy in appearance and grew in mats, the other formed finger-shaped nodules that appeared calcareous.

Figure 2. *Utricularia vulgaris* and *Potomogeton* sp. *Utricularia vulgaris* (left) and *Potomogeton* sp. (right) were collected at the Swift River in June 2017. (photo by author, 2017).

Figure 3. Other submerged aquatic plants found at the Swift River. *Ceratophyllum demersum* (top left), *Nasturtium offcianale* (top right), *Myriophyllum humile* (middle left), *Isoetes muricata* (middle right), and *Nuphar variegatum* (bottom) were collected at the Swift River in June 2017 (photo by author, 2017).

The Swift River area of the Commonwealth has seen significant development for such a rural area. Towns have been abandoned and larges areas of land flooded, while the Swift itself has been leveed and dammed to control its flow for agriculture and industry. This study intends to look at how development like this in riparian wetland systems impacts ecological communities.

Research Questions, Hypotheses, and Specific Aims

This research is intended to determine if development within a riverfront area can impact the biodiversity of the riverbed in a measureable way. The main three questions I address in my research are:

1. Does human development near the edge of a river or stream, either at or within Massachusetts' regulation of a riverfront area, impact the species richness of submerged aquatic plants found on covering the riverbed?
2. Does human development near the edge of a river or stream, either at or within Massachusetts' regulation of a riverfront area, impact the amount of riverbed covered by any submerged aquatic plant?
3. Does human development near the edge of a river or stream, either at or within Massachusetts' regulation of a riverfront area, impact the amount of riverbed covered of *V. americana*?

My research therefore examines the three hypotheses related to these questions: When compared with streambed samples near undeveloped areas, vegetation samples near developed streamside areas will exhibit: 1) lower species richness of aquatic plants, 2) lower vegetative percent cover, and 3) lower cover of *V. americana*.

Specific Aims

To address these hypotheses and my research goals, I pursued the following steps:

1. Develop a rapid ecological assessment for river and stream systems that corroborates the results of CAPS. This assessment was designed to take no more than two days of sampling at two site locations (developed and undeveloped riverfront), separated by 1-2 months to see if impact can be quantified.
2. Select comparative matched study sites on a representative Massachusetts river, one impacted by development, the other relatively pristine.
3. Collect data from replicated samples in each of the two sites.
4. Statistically compare the variables from the two different sites.

Chapter II

Methods

The intent of this project was to generate a rapid assessment, using submerged aquatic plant species richness and percent cover, as well as using *Vallisneria americana* as an indicator species, to analyze if a 25-foot or 200-foot riverfront area is a sufficient distance to filter runoff entering a stream or river system.

Sample Site Selection

In order to analyze the potential impact on a river system from development within a riverfront area, decision rules on site selection were first established. These rules were combined with CAPS data and field surveys to determine if a selected river system was a candidate for analysis.

Decision Rules

For this short term, seasonal study limited to the fall of 2017, one major river was analyzed. To effectively compare future sites to this study, the following decision rules were followed:

1. The stream/river system chosen was included both undeveloped and developed land within the riverfront area. Developed land was considered any human altered land, including but not limited to private homes, parks, industrial buildings, commercial buildings, and roads. Undeveloped land was undisturbed temperate

seasonal forest. This can include small trails used by local hikers, fishermen, hunters, etc.

2. The riverfront area size was constant for all chosen sites, i.e. they followed Massachusetts regulations and all were 25-feet (MGL c. 131 § 40; 310 CMR 10.58).
3. One developed site and one undeveloped site were analyzed.
4. *Valisneria americana* must be present in the stream at each selected site.

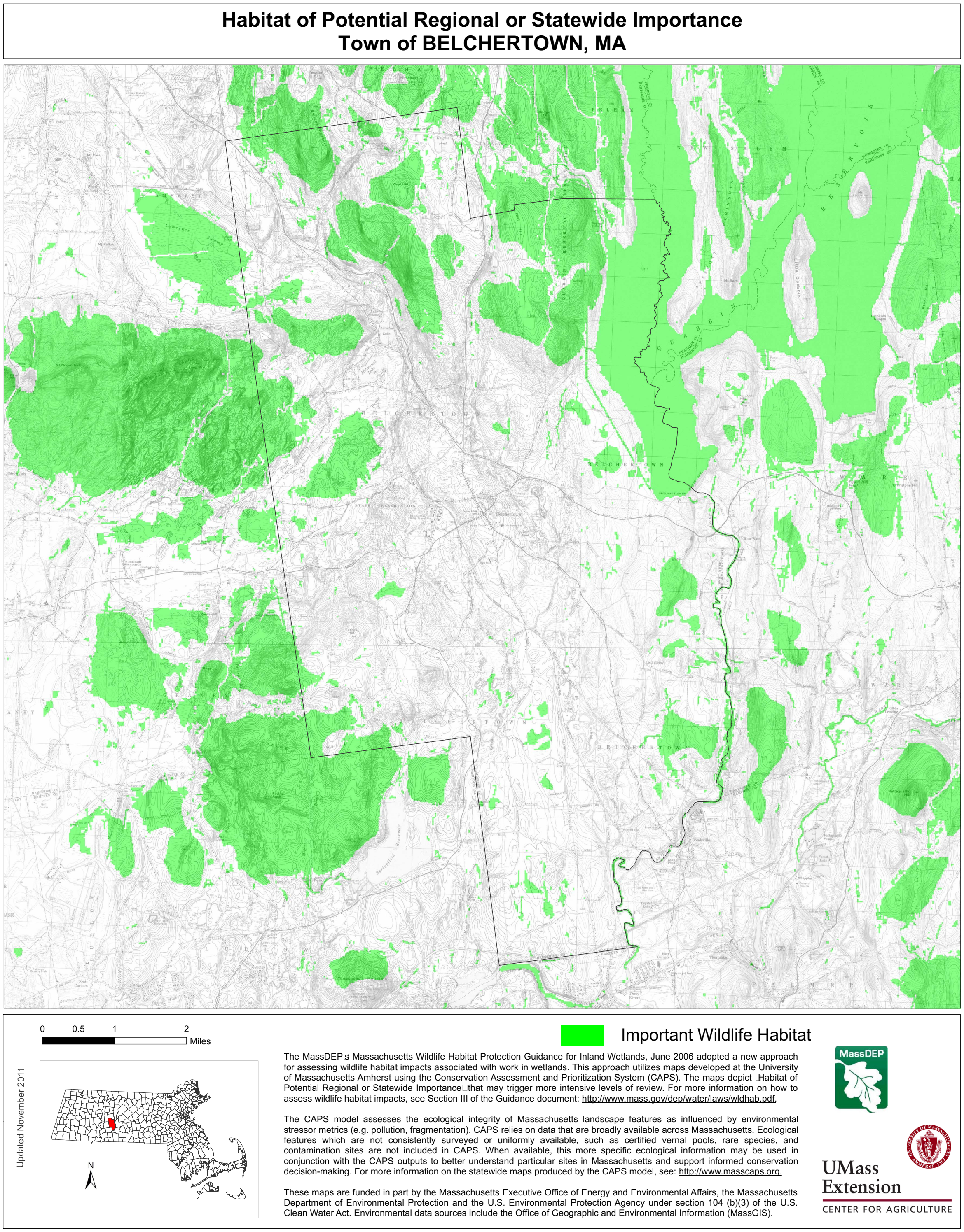
Study Site: Swift River, Massachusetts

The Swift River is located in central Massachusetts and is the southern outflow of the Quabbin Reservoir. This reservoir acts as the major source of drinking water for Massachusetts and the greater Boston area and was constructed between 1926-1946 (MWRA, n.d.). During the 1920s, the Commonwealth of Massachusetts made the decision to dam a portion of the Swift River and allow the watershed valley to fill, which required four separate towns existing in the valley, Prescott, Greenwich, Dana, and Enfield, to be abandoned and deconstructed. By 1939, the 2,500 individuals previously living in those towns had be forced to leave by the Commonwealth, and the Swift was dammed to reap the benefits of what would become the world's largest man-made reservoir (Herwick III, 2014). South of the Quabbin Reservoir, the sampling sites along the Swift River are surrounded by the towns of Belchertown, Ware, and Bondsville, which have historically provided agricultural and industrial services to Massachusetts. Much of the surrounding land is currently farmland and many abandoned and collapsing factories can be found lining the banks of the Swift River.

The Swift River and CAPS Data

In deciding on a river system to study, the first decision I made was to choose one with a riverfront area size of 25-feet. I made this choice based on research limitations that will be addressed in a subsequent section. The towns of Belchertown, Ware, and Bondsville, which border the Swift River south of the Quabbin Reservoir, have populations well below 90,000 and therefore have riverfront areas of 25-feet. Bondsville allows for access to the Swift River near development within the riverfront area, while further north Belchertown and Ware provide access to the river surrounded by temperate seasonal forest. In addition to meeting the requirements of the decision rules, the Swift River is the site of a historical environmental decision made by the Commonwealth of Massachusetts, coupled with its current importance to locals for recreation and other services, makes it an ideal location for sampling.

Comparing the map of transect locations (Figure 6) to data from the MassDEP (Figure 4) shows the undeveloped site is classified as “Important Wildlife Habitat”, while the developed site is not. (UMASS, 2006). Additionally, the undeveloped site (Figure 7) has a high IEI (Figure 5), while the developed (Figure 8) has a low IEI (Figure 5) (UMASS, 2011).

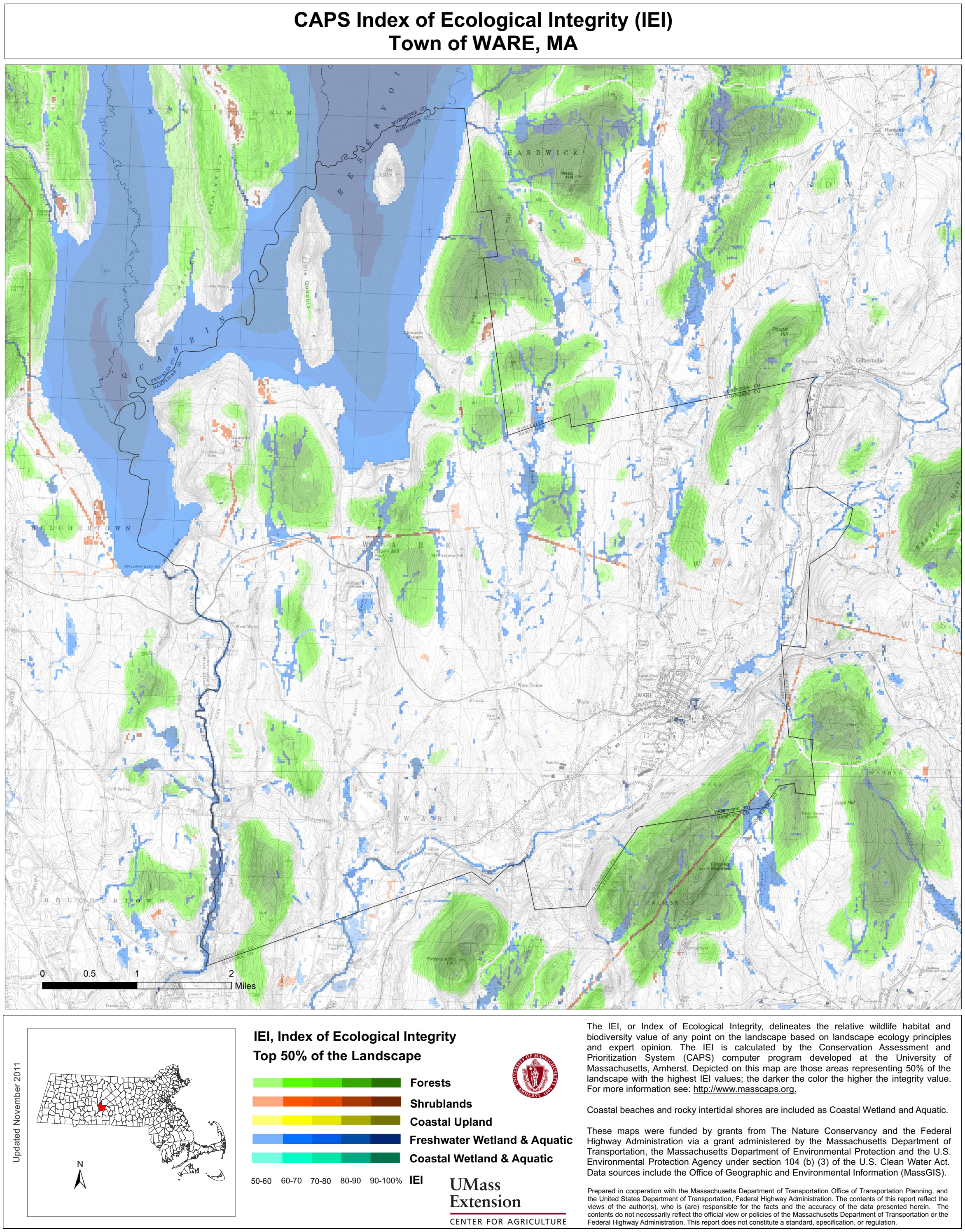


The MassDEP’s Massachusetts Wildlife Habitat Protection Guidance for Inland Wetlands, June 2006 adopted a new approach for assessing wildlife habitat impacts associated with work in wetlands. This approach utilizes maps developed at the University of Massachusetts Amherst using the Conservation Assessment and Prioritization System (CAPS). The maps depict “Habitat of Potential Regional or Statewide Importance” that may trigger more intensive levels of review. For more information on how to assess wildlife habitat impacts, see Section III of the Guidance document: http://www.mass.gov/dep/water/laws/wldhab.pdf.

The CAPS model assesses the ecological integrity of Massachusetts landscape features as influenced by environmental stressor metrics (e.g. pollution, fragmentation). CAPS relies on data that are broadly available across Massachusetts. Ecological features which are not consistently surveyed or uniformly available, such as certified vernal pools, rare species, and contamination sites are not included in CAPS. When available, this more specific ecological information may be used in conjunction with the CAPS outputs to better understand particular sites in Massachusetts and support informed conservation decision-making. For more information on the statewide maps produced by the CAPS model, see: http://www.masscaps.org.

These maps are funded in part by the Massachusetts Executive Office of Energy and Environmental Affairs, the Massachusetts Department of Environmental Protection and the U.S. Environmental Protection Agency under section 104 (b)(3) of the U.S. Clean Water Act. Environmental data sources include the Office of Geographic and Environmental Information (MassGIS).

Figure 4. Land designated “Important Wildlife Habitat” surrounding the Swift River.



The IEI, or Index of Ecological Integrity, delineates the relative wildlife habitat and biodiversity value of any point on the landscape based on landscape ecology principles and expert opinion. The IEI is calculated by the Conservation Assessment and Prioritization System (CAPS) computer program developed at the University of Massachusetts, Amherst. Depicted on this map are those areas representing 50% of the landscape with the highest IEI values; the darker the color the higher the integrity value. For more information see: http://www.masscaps.org.

Coastal beaches and rocky intertidal shores are included as Coastal Wetland and Aquatic.

These maps were funded by grants from The Nature Conservancy and the Federal Highway Administration via a grant administered by the Massachusetts Department of Transportation, the Massachusetts Department of Environmental Protection and the U.S. Environmental Protection Agency under section 104 (b) (3) of the U.S. Clean Water Act. Data sources include the Office of Geographic and Environmental Information (MassGIS).

Figure 5. Indices of ecological integrity (IEI) surrounding the Swift River.

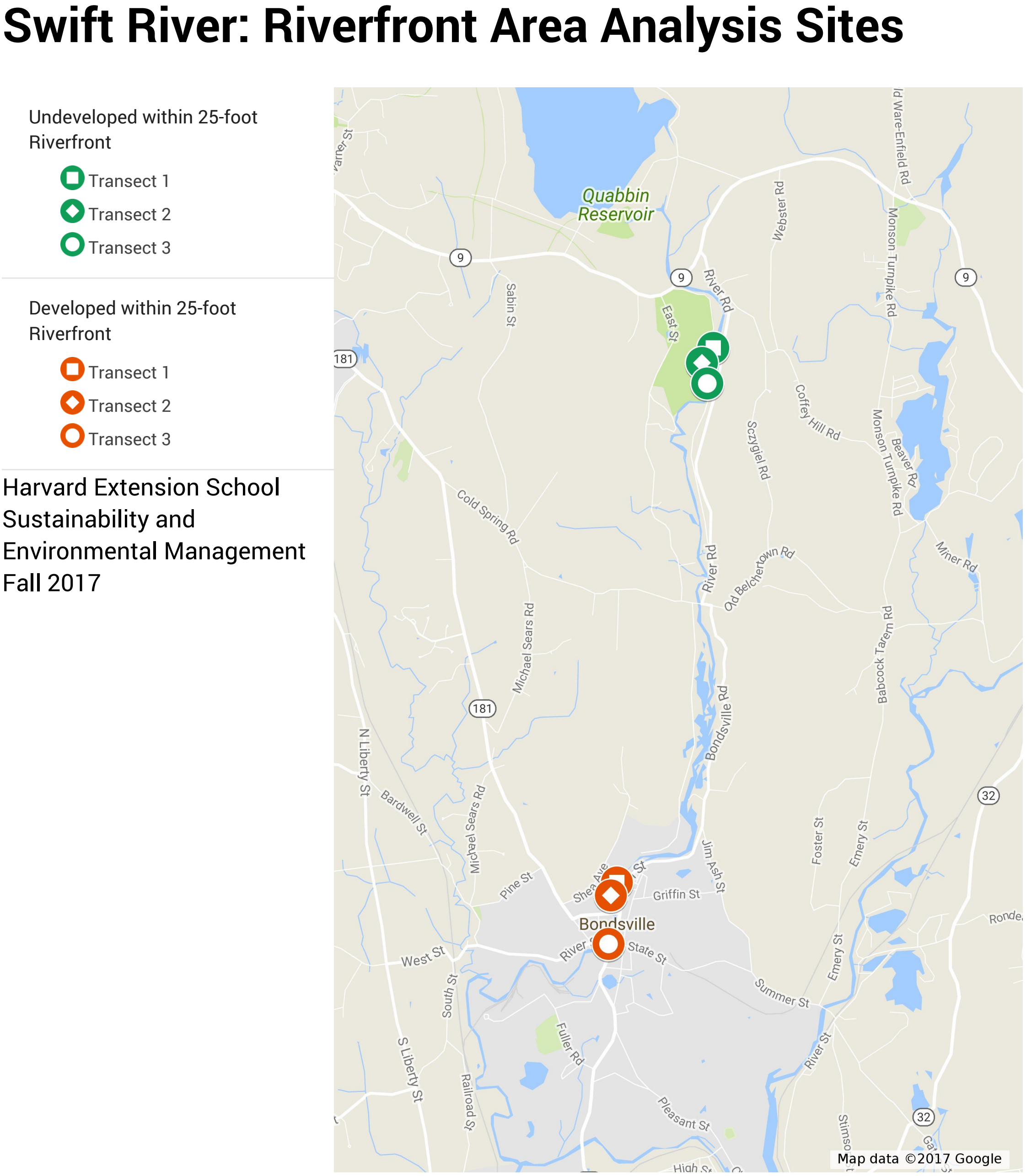


Figure 6. Map of the undeveloped and developed sample sites at the Swift River. The undeveloped site is located between Belchertown (west) and Ware (east), while the developed site is all within Bondsville (Google, 2017).

Swift River: Riverfront Area Analysis Sites

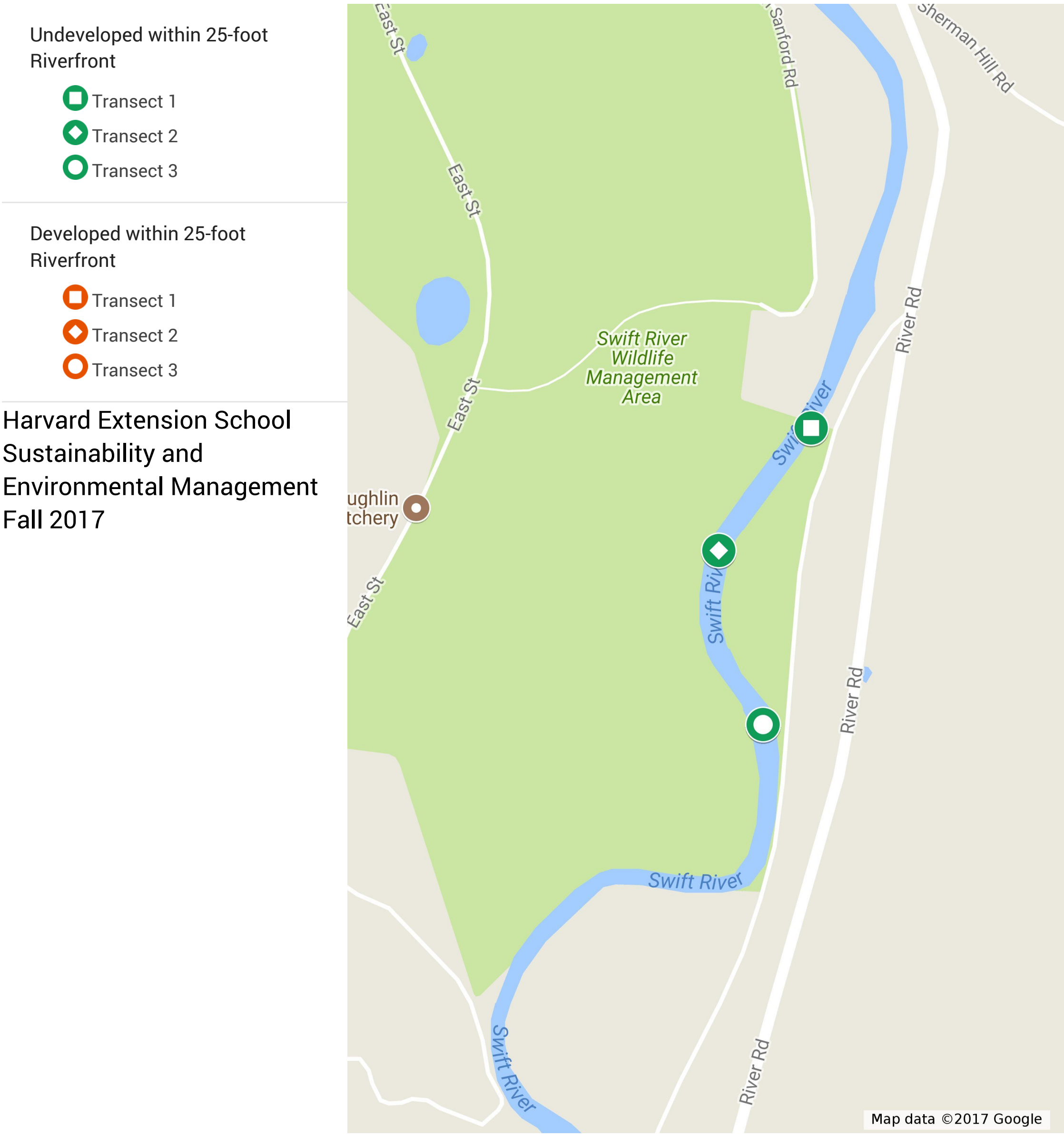


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Figure 7. Map of the undeveloped sample site at the Swift River. The undeveloped site is surrounded by temperate seasonal forest with no development within the 25-foot riverfront area (Google, 2017).

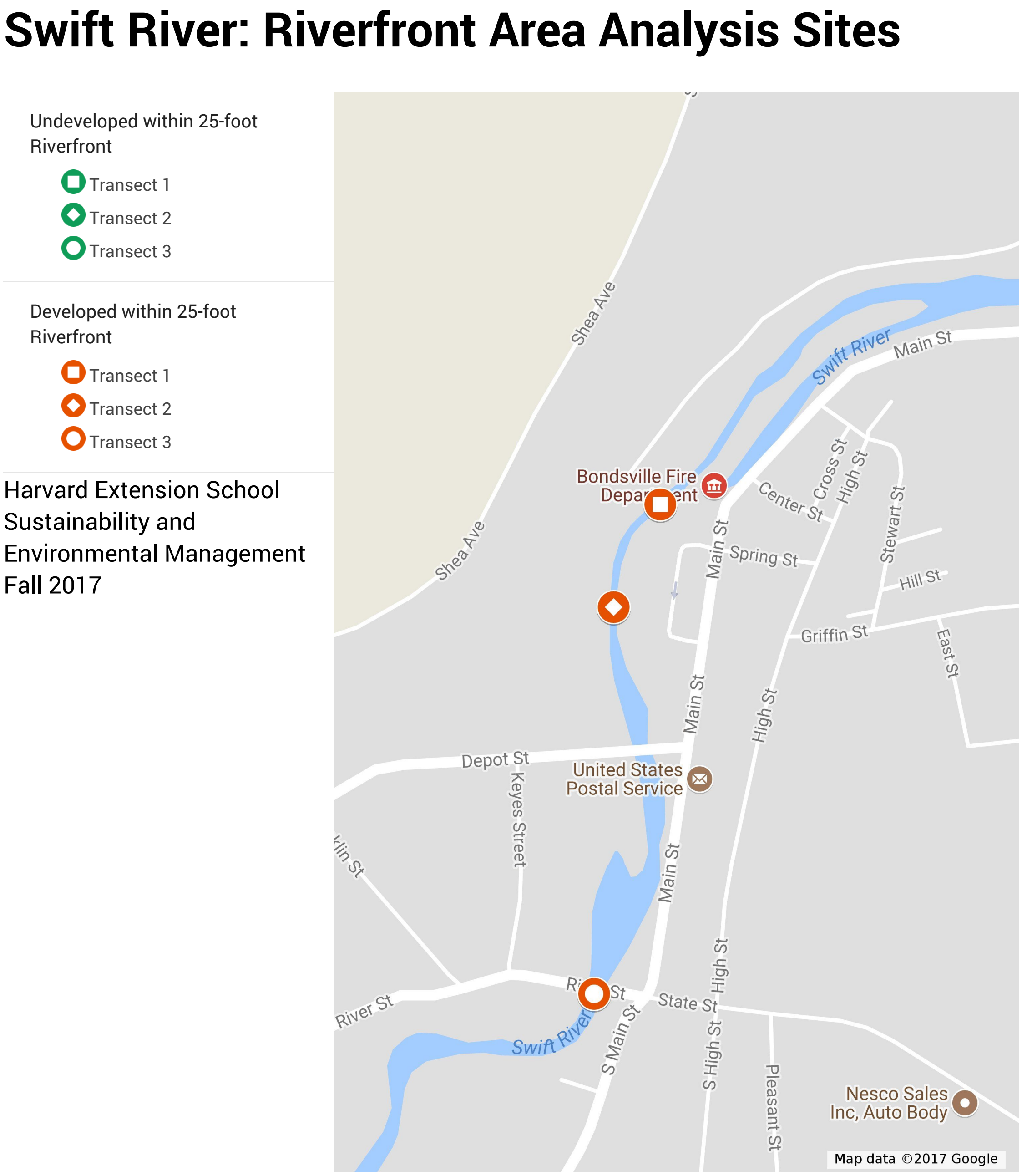


Figure 8. Map of the developed sample site at the Swift River (Google, 2017).

The chosen undeveloped site along the Swift River (42°16'03.5"N, 72°19'58.5"W) is between the towns of Belchertown and Ware (Figure 7). The location does not have development within the 25-foot riverfront area and is bordered by the Swift River Wildlife Management Area. Temperate seasonal forest surrounds both edges of the river. The nearest development are homes with lawns well over 200-feet away from the eastern edge of the river (Figure 9). *V. americana* is found in the Swift River at this sample location. Reviewing CAPS data from the University of Massachusetts Extension Center for Agriculture (Figures 5 & 6) reveals that this site is designated as “Important Wildlife Habitat” and has a high IEI.

Figure 9. Area surrounding the Swift River in the undeveloped sample site. There is no development in this region of the Swift River. I am measuring distance down stream using the edge of the one-square-meter quadrat as a guide (photo by author, 2017).

The chosen developed site along the Swift River (42°12'59.7"N 72°20'43.4"W) is within the town of Bondsville (Figure 8). The location has development within the 25-foot riverfront area on the eastern edge of the Swift. Development includes the Bondsville Fire Department, numerous homes, a park and basketball court, multiple roads/bridges crossing the river, as well as one dam. *Vallisneria americana* is found in the Swift River at this sample location. All transects were bordered by a small forest on the western side, but have development within the 25-foot riverfront area on the eastern side (Figure 10). Reviewing CAPS data from the University of Massachusetts Extension Center for Agriculture (Figures 5 & 6) reveals that this site is not designated as "Important Wildlife Habitat" and has a low IEI.

Figure 10. Area surrounding the Swift River in the developed sample site. This panorama looking north of the developed sample site shows development within the 25-foot riverfront area along the eastern edge of the Swift River. The western edge is bordered by a large wall (possible levee), trail, and small section of temperate seasonal forest. (photo by author, 2017).

Site Selection Limitations

A consistent difficulty in site selection was finding accessible entry points into the Swift River. As the next section will detail, data collection involved physically entering the water, deploying a quadrat, and calculating percent cover of submerged aquatic vegetation as I peered under the surface of the water using a mask and snorkel. If there was no way to access an undeveloped riverfront area due to densely grown forest, lack of trails, or inability to travel downstream via boat, then a site could not be surveyed. Additionally, some developed riverfront areas were inaccessible due to private property owner's preferences or a human made structure that was impassible. The river itself was also too deep or flowing too quickly to allow for proper analysis in some stretches. Despite these limitations, I am confident that the selected sites adhere to the site selection rules and do not bias comparisons.

Data Collection

In order to construct an adequate rapid assessment, I first sampled species to determine what organisms exist in the Swift River ecosystem (e.g., Figures 2 & 3). After identification, I sampled both developed and undeveloped sites on the same day by dropping a one-square-meter quadrat at various cross-sections within the river and recording plant species richness and percent cover of each.

Species Identification

When sampling for species within an aquatic ecosystem, identification while in the field is the preferred method of species identification. This is often difficult due to environmental conditions; therefore it is sometimes necessary to collect specimen samples. It is important to make sure that any specimen collection does not leave a lasting negative impact on the ecosystem. As Cox & Peron (2002) have advised, samples should only be collected if there is an abundance of that species in the area and never if there is only one individual of a particular species. If a small patch of individuals is discovered, it is best to continue looking for a larger patch to collect from.

My preliminary trip in late June 2017 to sample the species present in the Swift River yielded a large diversity of submerged aquatic vegetation. A total of ten separate species were identified, though only one was identifiable in the field; *V. americana* was present at multiple locations and easily recognizable. The other species were collected following the guidelines of Cox & Peron (2002). Samples were placed in plastic containers, submerged in the river water in which they were collected, and transferred to a refrigerator. The following day, I photographed all species exposed to air and then planted in a freshwater aquarium to be analyzed while submerged.

At this point, identification became a small problem. Some plants were easily identifiable using existing guides and literature, but there were some species that did not seem to have any existing identification. With the assistance of Dr. Jennifer Cole of Harvard Extension School and Dr. Thomas Coote of Bard College at Simon's Rock, I was successfully able to identify all of the species collected, but came to the realization that there exists a gap in identification information in general for submerged aquatic plants.

Determination of Species Richness and Percent Cover

At each sample site, I collected data along three 100 m long transects running parallel to the bank of the Swift River and progressing down stream. For each 100 m transect, I randomly threw a one-square-meter quadrat, allowing to sink to the riverbed, with throws occurring at perpendicular cross-sections at 0, 25, 50, 75, and 100 m along the transect. As the Swift River consistently changes width progressing downstream, in lieu of exact distances perpendicular to the riverbank, I made three consistent throws at each stop along the transect: Throw 1 towards the western edge of the river, Throw 2 towards the center of the river, and Throw 3 towards the eastern edge of the river.

After each throw, I determined species richness and percent cover by utilizing snorkeling gear to peer below the water. I counted species present, but I did not count number of individuals as this was not possible with the equipment used, is different for each species, and would take a greater amount of time negating my intent to generate a rapid assessment. Percent cover of each species is based on the two-dimensional space occupied by each species, i.e., area occupied by the bottom, but not height of growth. I made this estimation using the spatial guides of the quadrat.

This procedure can be completed by an individual researcher, though is optimized for two. It is recommended that one researcher conduct the determination of species present and percent cover in the water, while the other follows on the stream bank recording data and other necessary measurements. Data for developed and undeveloped sites should be collected on the same day.

Seasonal Study

This rapid assessment is intended to be applicable to a wide range of future areas of research that will be discussed in greater detail in Chapter IV. My study was limited to a fall season analysis of the Swift River. The first data collection occurred in early September with the second occurring in late October. My intent was to record two comparable groups of mean values for both species richness and percent cover to determine if there was an observable change to the ecology of the submerged aquatic plants in the Swift River in either an undeveloped or developed riverfront.

Chapter III

Results

The submerged aquatic plant species I found in the Swift River were either collected on the June 2017 sampling trip or discovered while collecting data in the fall of 2017 (Table 1). Species found include many common species found throughout freshwater systems in Massachusetts, but others had no record of identification.

Table 1. Submerged aquatic plants found in the Swift River.

Common Name	Scientific Name
Algae	Unknown
Bladderwort	*Utricularia vulgaris*
Calcareous algae	Unknown
Hornwort	*Ceratophyllum demersum*
Moss	Unknown
Pondweed	*Potomogeton* sp.
Quillwort	*Isoetes muricata*
Tape grass, Water Celery, Eelgrass	*Vallisneria americana*
Watercress	*Nasturtium offcianale*
Water-Lily	*Nuphar variegatum*
Water-Milfoil	*Myriophyllum humile*
Waterweed	*Elodea canadensis*

Identifications made utilizing Magee (1981), Cox & Peron (2002), and discussions with Jennifer Cole, Thomas Coote and Matt Byrne.

Undeveloped Riverfront Area

Direct observation of the riverbed in the undeveloped riverfront section of the Swift River revealed a lush bottom (Figure 11) that contained numerous species identified on the June sampling trip. I hypothesized that there should be no difference between the means of either species richness or percent cover from September to October. *Vallisneria americana* cover was expected to be in high abundance at this sample site.

Figure 11. Data collection in the undeveloped sample site. Most of the Swift River in this section had an observable vegetated bed as the river is clear and relatively shallow (photo by author, 2017).

Species Richness

The species richness of the Swift River when surrounded by undeveloped riverfront area averaged 2.3-2.8 species per quadrat throw in September and 2.2-3.0 species per throw in October (Table 2). The total number of species at any given river cross-section (out of three throws) averaged 4.7 species in September and 4.1 species in

October. It seems that on average, 2-3 species occupy any given square-meter on the riverbed, with just over 4 species coexisting within a cross-section of the Swift River for both September and October.

Table 2. Average number of species counted per transect in undeveloped riverfront area

9/9/2017	**Average Number of Species**			
Transect	Western Edge	Center	Eastern Edge	Total
1	2.4	1.8	1.8	2.8
2	3	3.2	2	4.6
3	2	3.4	3	3.8
Average	2.5	2.8	2.3	4.7

10/22/2017	**Average Number of Species**			
Transect	Western Edge	Center	Eastern Edge	Total
1	1.8	2.8	3.2	4.2
2	2.8	3	1.4	4.4
3	2	3.2	2.6	3.6
Average	2.2	3.0	2.4	4.1

A paired t-test of the mean number of species counted per cross-section of the Swift River in the undeveloped riverfront area showed there was no change from September (mean = 4.7) to October (mean = 4.1) (n=15; t=0.837; p=0.42) (Table 2).

Percent Cover of Submerged Aquatic Vegetation

The percent cover of submerged aquatic vegetation of the Swift River when surrounded by undeveloped riverfront area averaged 34-61% cover per quadrat throw in September and 37-60% cover per throw in October (Table 3). The total percent at any given river cross-section (out of three throws) averaged 48% cover in September and 45% cover in October.

Table 3. Average percent cover per transect in the undeveloped riverfront area

9/9/2017	**Average Percent Cover**			
Transect	Western Edge	Center	Eastern Edge	Total
1	36%	53%	25%	38%
2	71%	65%	13%	50%
3	34%	66%	65%	55%
Average	47%	61%	34%	48%

10/22/2017	**Average Percent Cover**			
Transect	Western Edge	Center	Eastern Edge	Total
1	9%	43%	60%	37%
2	70%	73%	15%	53%
3	32%	63%	39%	44%
Average	37%	60%	38%	45%

A paired t-test of the mean percent cover per cross-section of the Swift River in the undeveloped riverfront area showed there was no change from September (mean = 48%) to October (mean = 45%) (n=15; t=-0.697; p=0.50) (Table 3). Additionally, a paired t-test of the mean percent cover of *V. americana* per cross-section of the Swift River in the undeveloped riverfront area showed there was no change from September (mean = 4%) to October (mean = 3%) (n=15; t=-0.803; p=0.44).

Developed Riverfront Area

Direct observation of the riverbed in the developed riverfront section of the Swift River revealed a more barren riverbed (Figure 12), though most of the identified species from the June sampling trip were present at this site. I hypothesized that there should be no difference between the means of either species richness or percent cover from September to October. *Vallisneria americana* cover was expected to be in low abundance at this sample site.

Figure 12. Data collection in the developed sample site. Most of the Swift River in this section had a barren riverbed or dominance of one species. The river at this location appeared more turbid and was deeper than the undeveloped sample site. A wall seen in the top of the image exists on both sides of the river. This image was taken facing east, towards the development in Bondsville.

Species Richness

The species richness of the Swift River when surrounded by developed riverfront area averaged 1.1-1.3 species per quadrat throw in September and 1.3-1.7 species per throw in October (Table 4). The total number of species at any given river cross-section (out of three throws) averaged 2.2 species in September and 2.8 species in October. It seems that on average, 0-2 species occupy any given square-meter on the riverbed, with just over 2 species coexisting within a cross-section of the Swift River for both September and October.

Table 4. Average number of species counted per transect in the developed riverfront area

9/9/2017	**Average Number of Species**			
Transect	Western Edge	Center	Eastern Edge	Total
1	2.2	2.2	2.6	4
2	0.8	0.8	0.6	1.4
3	0.2	1	0.2	1.2
Average	1.1	1.3	1.1	2.2

10/22/2017	**Average Number of Species**			
Transect	Western Edge	Center	Eastern Edge	Total
1	2	3	2.6	4
2	1	0.8	1.4	2.2
3	0.8	1.2	1	2.2
Average	1.3	1.7	1.7	2.8

A paired t-test of the mean number of species counted per cross-section of the Swift River in the developed riverfront area showed there was a change from September (mean = 2.2) to October (mean = 2.8) (n=15; t=2.358; p=0.03) (Table 4).

Percent Cover of Submerged Aquatic Vegetation

The percent cover of submerged aquatic vegetation of the Swift River when surrounded by developed riverfront area averaged 26-32% cover per quadrat throw in September and 33-43% cover per throw in October (Table 5). The total percent at any given river cross-section (out of three throws) averaged 30% cover in September and 40% cover in October.

A paired t-test of the mean percent cover per cross-section of the Swift River in the developed riverfront area showed there was no change from September (mean = 30%) to October (mean = 40%) (n=15; t=1.538; p=0.15) (Table 5). Additionally, a paired t-test of the mean percent cover of *V. americana* per cross-section of the Swift River in the

Table 5. Average percent cover per transect in the developed riverfront area

9/9/2017	**Average Percent Cover**			
Transect	Western Edge	Center	Eastern Edge	Total
1	88%	73%	72%	78%
2	8%	10%	6%	8%
3	1%	10%	0%	4%
Average	32%	31%	26%	30%

10/22/2017	**Average Percent Cover**			
Transect	Western Edge	Center	Eastern Edge	Total
1	58%	75%	75%	69%
2	35%	32%	35%	34%
3	7%	20%	20%	16%
Average	33%	43%	43%	40%

undeveloped riverfront area showed there was no change from September (mean = 1%) to October (mean = 1%) (n=15; t=-0.868; p=0.40).

Comparing Undeveloped and Developed Riverfront Areas

One of the ultimate goals of this project is to determine if this procedure can produce data that acts as a rapid assessment of ecological condition. If the data analysis rejects the null hypothesis, a metric is identified as an indicator of some form of impact on the ecosystem.

Species Richness

Species richness for the undeveloped and developed sample sites was compared for both sample dates (Tables 2 & 4). A paired t-test of the mean number of species counted per cross-section of the Swift River in September showed that the undeveloped sample site mean (3.7) was significantly greater than the developed sample site mean (2.2) (n=15; t=-2.346; p=0.03). Additionally, a paired t-test of the mean number of species counted per cross-section of the Swift River in October showed a similarly significant difference (undeveloped sample site mean = 4.1, vs. developed sample site mean = 2.8) (n=15; t=-4.012; p=0.001).

Percent Cover of Submerged Aquatic Vegetation

Percent cover for the undeveloped and developed sample sites was compared for both sample dates (Tables 3 & 5). A paired t-test of the mean percent cover of submerged aquatic vegetation per cross-section of the Swift River in September showed there was no difference between the undeveloped sample site (mean = 48%) and the developed sample site (mean = 30%) (n=15; t=-1.458; p=0.17). Additionally, a paired t-test of the mean percent cover per cross-section of the Swift River in October showed there was no difference between the undeveloped sample site (mean = 45%) and the developed sample site (mean = 40%) (n=15; t=-0.542; p=0.60).

Percent cover per cross-section of the Swift River in September of *V. americana* was greater in the undeveloped (mean = 4.2%) vs. the developed sample sites (mean = 0.5%) (n=15; t=-2.317; p=0.04). In contrast, the difference in percent cover of *V. americana* per cross-section October was not significantly different (undeveloped sample site mean = 3.1%; developed sample site mean = 0.8%) (n=15; t=-1.623; p=0.13).

Chapter IV

Discussion

First, an interpretation of the results will be explored to understand how development within a riverfront impacts species richness, percent cover of submerged aquatic vegetation, and percent cover of *V. americana*. Second, future applications of this low-cost, rapid assessment will be examined to see the potential research that can assist in better understanding and regulating river and stream systems.

Impact of Development within the Swift Riverfront Area

During my research and planning phases of this project, I hypothesized that development within a riverfront area would potentially lead to a decline in the submerged aquatic vegetation growing on the bed of the Swift River. If this is in fact true, reduced vegetation could lead to large changes throughout the trophic web of life within the Swift River. Additionally, a sign of impact in the ecology of the Swift River due to development within its riverfront area indicates that activity within the 25-foot riverfront area distance may not provide an adequate barrier of soil and vegetation for filtering runoff entering the Swit River.

Analysis of Hypotheses

Differences in submerged aquatic plant species richness within the two sites sampled along the Swift River are consistent with a negative effect of development within its riverfront area. Comparing the undeveloped sample site to the developed revealed a statistical difference in the means of the number of species present for both September and October. The sampled section of the river surrounded by temperate seasonal forest had greater species richness than the sampled section surrounded by homes, parks, and other development. Higher levels of disturbance potentially cause lower species richness at the developed location. Increased sediment, nutrient or other pollutant runoff is more likely at the developed location as the distance water has to filter through the soil and vegetation before reaching the Swift River is dramatically shorter than the undeveloped location. It should be noted that other development upstream might additionally cause chemical changes to the river system; this may be an area for future research. The developed location is also a portion of the river that local fishermen are allowed to catch and keep certain fish. This added pressure may put stress on the rest of the trophic web.

Seasonal effects due to the beginning of fall were not evident in the species richness data for the undeveloped site as there was no statistical change in the means from September to October. In contrast, a seasonal effect on species richness was seen in the developed site; there was a slight increase in the average number of species present from 2.2 species per river cross-section in September to 2.8 species in October. This increase is potentially due to the increased presence of algae and moss found on the riverbed. It is possible that increased rainfall during the fall months, coupled with higher than average temperatures allowing for continued decomposition and nutrient cycling, increased the nutrient load into the Swift River. This may have allowed for the greater abundance of algae. Additionally, the Swift River was noticeably deeper and running faster on the October sample date. It appears that determination of submerged aquatic plant species richness can act as a rapid ecological assessment of a river system.

Percent cover of submerged aquatic vegetation within the two sites sampled along the Swift River has not shown to be affected by development within its riverfront area, though statistical analysis is fairly close to a significant p-value in some cases. Comparing the undeveloped sample site to the developed revealed no statistical difference in the means of percent cover for both September and October. Though the null hypothesis is accepted, the lower p-values in September versus October are intriguing. The difference in p-values between the two months is most likely due to the increased presence of algae and moss in the developed region in October.

Seasonal effects due to the beginning of fall were not evident in the percent cover data for the undeveloped site as it had no statistical change in the means from September to October. Similarly, a seasonal effect on percent cover was not seen in the developed site from September to October. It is entirely likely that the species present on the riverbed vary over the course of the year, but the percent cover remains similar due to some limiting factor affecting the carrying capacity of the river. Further research is needed to determine if percent cover determination can act as a rapid assessment of river ecological assessment.

Percent cover of *V. americana* within the two sites sampled along the Swift River might be affected by development within its riverfront area, as it was lower during September but not October. It is possible that *V. americana* can act as an indicator species for rapid ecological assessment of a river system. Its low abundance in the developed section of the Swift River indicates that runoff may indeed be impacting this species.

Seasonal effects due to the beginning of fall were not evident in the percent cover of *V. americana* data for the undeveloped site as it had no statistical change in the means from September to October. Similarly, a seasonal effect on percent cover of *V. americana* was not seen in the developed site from September to October. Therefore, *V. americana* is potentially not a good indicator of seasonal change over this short time scale.

Conclusions

This research acts as a first step in quantifying the effect on a river system due to development within a riverfront area defined by the Massachusetts Rivers Protection Act. It is evident that species richness is impacted when development occurs within a riverfront area, but the impact on percent cover of total submerged aquatic vegetation and only *V. americana* is inconclusive an potentially unaffected. Further research is needed to continue to analyze how the ecology of a river system is potentially impacted by development. Sufficient research and analysis may eventually provide a definitive formula for calculating an effective riverfront area distance.

The limitations of this project allowed for a short-term, seasonal study that yielded promising results and possibilities for future research based on the data. In addition to a continued seasonal study of the Swift River, this field comparison can be applied to other sections of the Swift River or completely different river systems.

Research Limitations

As this study required in-the-field testing of shallow, freshwater bodies in Massachusetts, weather and time of year impacted the ability to sample. Sampling dates were restricted to weekends in the fall of 2017; this was due to a research, planning, and preliminary sampling period that lasted from March-August 2017. The fall dates were further restricted by weather on any given weekend; heavy rainfall and thunderstorms occurred multiple times throughout the fall.

This sampling technique is low-cost and independently funded, so sampling was limited to the ability of the researcher. This experiment can be run with nothing but a PVC-quadrat, a snorkel set, a note-keeping device with GPS, and transportation. Data collection additionally could be impacted by the conditions of the river itself. If the river had no access point, it was also potentially impossible to traverse down trough the river to a sample site. Sample sites were therefore restricted to accessible areas. Furthermore, if the river at a site was too deep or had an extremely rapid current, sampling was impossible with the low-cost gear used for this experiment.

Further Research

This study was limited to the early fall months of 2017. The next logical step would be a yearlong seasonal study to compare the effects of spring, summer, and the die-off before winter in the undeveloped and developed sample locations. A spring study could test the impact development within a riverfront area has on the first species to emerge as the river thaws and longer, sunlit days return to Massachusetts. Based on winter snowpack melt, increased river depths and stream flow could impact overall growth and species richness. Couple this with rising temperatures causing the restart of decomposition in surrounding soils, nutrient load could increase in developed areas leading to a change in the riverbed ecology.

A study throughout the summer would most likely show the impacts of fertilizer on the Swift River ecosystem. Much of the surrounding land in Belchertown, Ware, and Bondsville is agricultural land, and many of the homes have green lawns that are most likely fertilized. Is it possible that development within a riverfront area allows for less filtration of nutrient runoff entering the Swift River and could this impact the submerged aquatic vegetation?

A study of the winter die-off of submerged aquatic vegetation may also yield some insight on the impacts of development. If lower species richness or less percent cover exists in a developed riverfront area during the winter die-off, it is possible that connected ecological cycles are impacted.

Application to Other River Systems

As this study only focused on portions of the Swift River within the towns of Belchertown, Ware, and Bondsville, there are still multiple accessible locations in other sections of the river that can be analyzed to determine the potential impact of development along its banks. Further analyzing the Swift River can potentially support the findings of this research that development impacts species richness. By choosing close sites in this study, the impacts of few neighboring towns can been studied. Expanding this to other areas may results in different impacts due to how a neighboring town treats and develops their land.

There are also a vast amount of river and stream systems throughout the Commonwealth of Massachusetts that can be analyzed using this research design. In order to truly determine if this technique is a rapid ecological assessment of a river or stream system, this procedure must be replicated at other sites independent of the Swift River system but still obeying the decision rules outlined in Chapter II. The only consistent issue with this procedure is the possibility that a river sample site is inaccessible due to topography, river depth, or stream flow. Additional equipment, such as a boat, underwater camera to capture images of quadrat throws for further computational analysis, or scuba gear would allow for the expansion of this procedure into deeper and currently inaccessible river areas.

Documentation of Submerged Aquatic Plant Species

It became apparent during this study that very little identification literature exists for submerged aquatic plants species in the Commonwealth of Massachusetts. What does exist are mostly regional identification guides, which often the species collected or observed at the Swift River did not match what was previously reported for a certain species. This study serves as a first step in beginning to comprehensively document the species found growing on the bed of the Swift River. A completely different but related study could be conducted to determine the species diversity throughout the Swift River system that attempts to document every species present.

Since there still exists an issue when it comes to defining wetlands, this would be an important step is beginning to appropriately classify riparian systems and distinguish them from other wetland areas. This could allow for more appropriate legislation for specific ecosystems, instead of broad definitions and laws governing all forms of wetlands. Different wetlands need different protections; therefore knowing exactly what hydrophytic vegetation grows in these ecosystems can act as a way to quickly identify them from one another and allow for appropriate application of state or federal regulations.

Climate Change Connections

Impacts of climate change on freshwater systems in Massachusetts could be analyzed using the procedure outlined in this study. If continued climate change increases the frequency and intensity of precipitation events, river systems like the Swift would swell with additional water. If development already exists within a riverfront area, a consistently swollen river would result in a reduced barrier of soils and vegetation between river and developed land. This could potentially result in more sediment, nutrients, and other pollutants entering the water and thereby change the ecology of the riverbed.

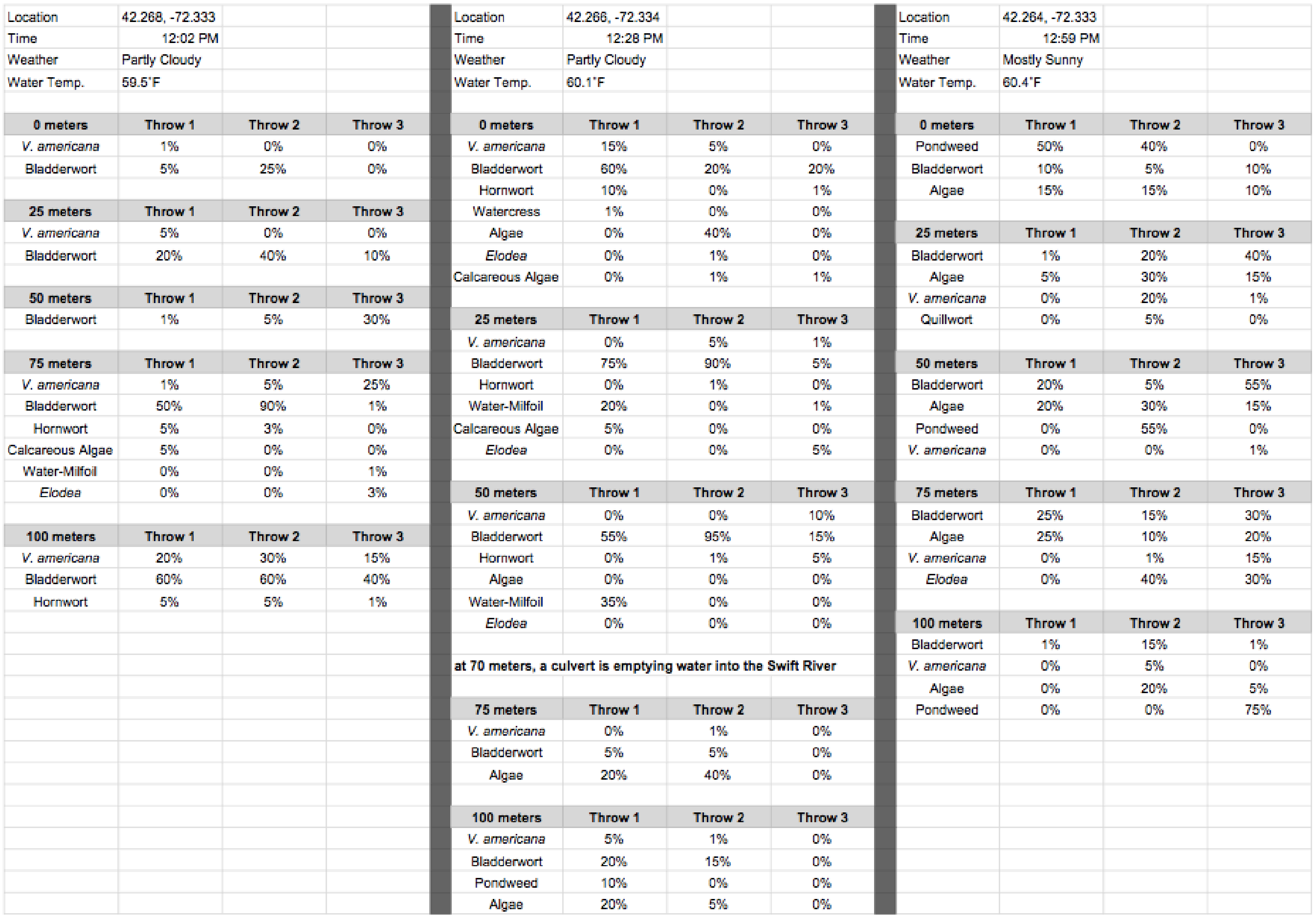
If continued climate change produces more instances of droughts due to lower amounts of precipitation, rivers could shrink, increasing the distance between the water and developed land. Could the increased distance for water filtration improve the species richness near a developed area? Or could the pollutants that reach the reduced water level become concentrated due to lower river volume, depth, and flow? In either case, conducting this study throughout the years would show potential impact of climate change correlated to development within a riverfront area.

Ultimately the goal of this research is to find ways to more effectively protect and preserve valuable riparian wetland systems for years to come through quick and simple analysis. Further research will allow us to fine tune our understanding of these ecosystems, so that appropriate climate precautions can be taken and necessary changes to regulations can be made so that coexisting with wetlands and their perception changes from a burden to a privilege and luxury.

Appendix 1.

Raw Data Species Richness and Percent Cover Data

Table 6. Undeveloped riverfront area sample site: collected 9/9/2017.

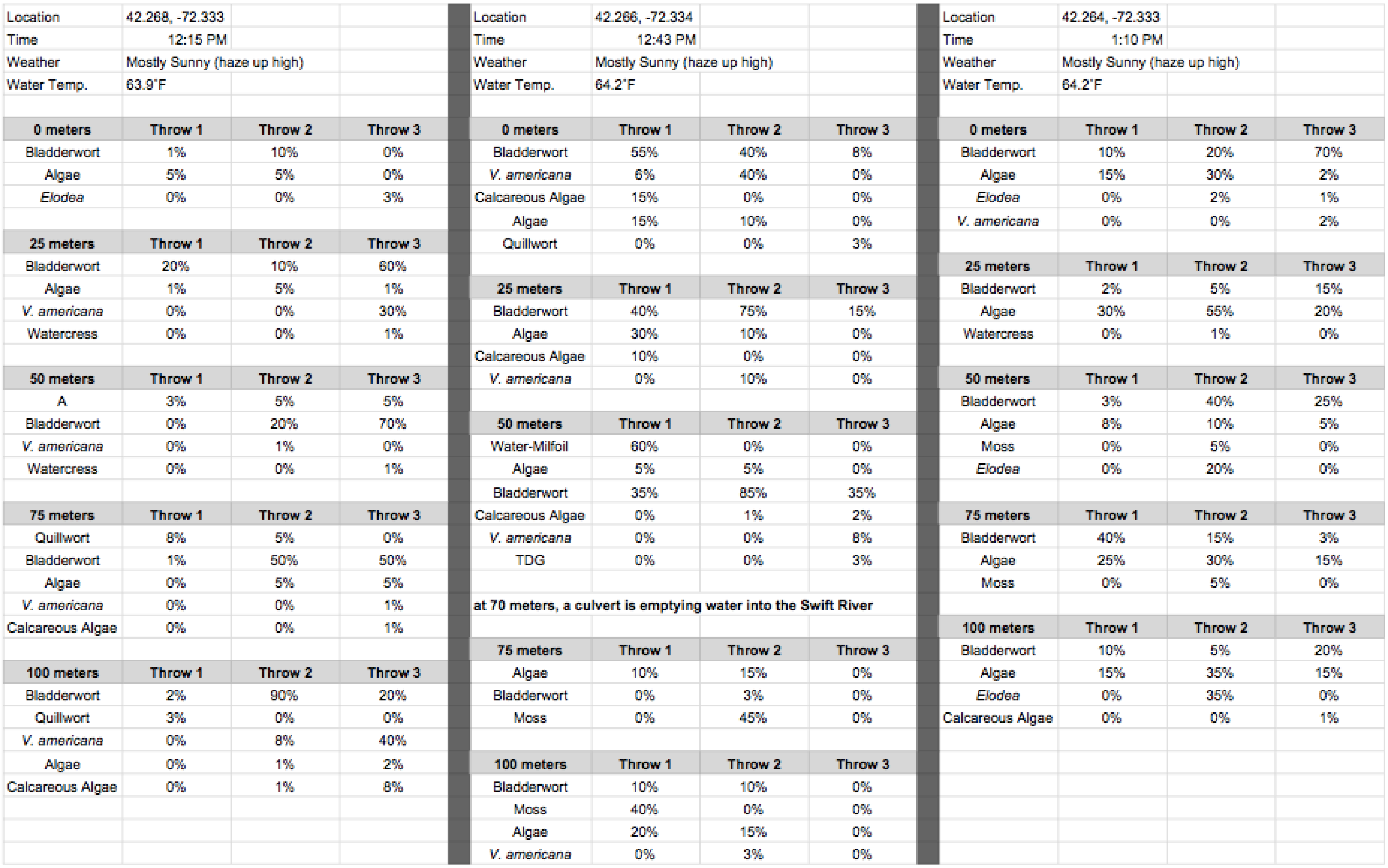


Location	42.268, -72.333		
Time	12:02 PM		
Weather	Partly Cloudy		
Water Temp.	59.5˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	1%	0%	0%
Bladderwort	5%	25%	0%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	5%	0%	0%
Bladderwort	20%	40%	10%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	1%	5%	30%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	1%	5%	25%
Bladderwort	50%	90%	1%
Hornwort	5%	3%	0%
Calcareous Algae	5%	0%	0%
Water-Milfoil	0%	0%	1%
Elodea	0%	0%	3%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	20%	30%	15%
Bladderwort	60%	60%	40%
Hornwort	5%	5%	1%

Location	42.266, -72.334		
Time	12:28 PM		
Weather	Partly Cloudy		
Water Temp.	60.1˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	15%	5%	0%
Bladderwort	60%	20%	20%
Hornwort	10%	0%	1%
Watercress	1%	0%	0%
Algae	0%	40%	0%
Elodea	0%	1%	0%
Calcareous Algae	0%	1%	1%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	0%	5%	1%
Bladderwort	75%	90%	5%
Hornwort	0%	1%	0%
Water-Milfoil	20%	0%	1%
Calcareous Algae	5%	0%	0%
Elodea	0%	0%	5%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	0%	0%	10%
Bladderwort	55%	95%	15%
Hornwort	0%	1%	5%
Algae	0%	0%	0%
Water-Milfoil	35%	0%	0%
Elodea	0%	0%	0%
at 70 meters, a culvert is emptying water into the Swift River			
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	0%	1%	0%
Bladderwort	5%	5%	0%
Algae	20%	40%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
V. americana	5%	1%	0%
Bladderwort	20%	15%	0%
Pondweed	10%	0%	0%
Algae	20%	5%	0%

Location	42.264, -72.333		
Time	12:59 PM		
Weather	Mostly Sunny		
Water Temp.	60.4˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	50%	40%	0%
Bladderwort	10%	5%	10%
Algae	15%	15%	10%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	1%	20%	40%
Algae	5%	30%	15%
V. americana	0%	20%	1%
Quillwort	0%	5%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	20%	5%	55%
Algae	20%	30%	15%
Pondweed	0%	55%	0%
V. americana	0%	0%	1%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	25%	15%	30%
Algae	25%	10%	20%
V. americana	0%	1%	15%
Elodea	0%	40%	30%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	1%	15%	1%
V. americana	0%	5%	0%
Algae	0%	20%	5%
Pondweed	0%	0%	75%

Table 3. Undeveloped riverfront area sample site: collected 10/22/2017.



Location	42.268, -72.333		
Time	12:15 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	63.9°F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	1%	10%	0%
Algae	5%	5%	0%
Elodea	0%	0%	3%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	20%	10%	60%
Algae	1%	5%	1%
V. americana	0%	0%	30%
Watercress	0%	0%	1%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
A	3%	5%	5%
Bladderwort	0%	20%	70%
V. americana	0%	1%	0%
Watercress	0%	0%	1%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Quillwort	8%	5%	0%
Bladderwort	1%	50%	50%
Algae	0%	5%	5%
V. americana	0%	0%	1%
Calcareous Algae	0%	0%	1%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	2%	90%	20%
Quillwort	3%	0%	0%
V. americana	0%	8%	40%
Algae	0%	1%	2%
Calcareous Algae	0%	1%	8%

Location	42.266, -72.334		
Time	12:43 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	64.2°F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	55%	40%	8%
V. americana	6%	40%	0%
Calcareous Algae	15%	0%	0%
Algae	15%	10%	0%
Quillwort	0%	0%	3%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	40%	75%	15%
Algae	30%	10%	0%
Calcareous Algae	10%	0%	0%
V. americana	0%	10%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	60%	0%	0%
Algae	5%	5%	0%
Bladderwort	35%	85%	35%
Calcareous Algae	0%	1%	2%
V. americana	0%	0%	8%
TDG	0%	0%	3%
at 70 meters, a culvert is emptying water into the Swift River			
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Algae	10%	15%	0%
Bladderwort	0%	3%	0%
Moss	0%	45%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	10%	10%	0%
Moss	40%	0%	0%
Algae	20%	15%	0%
V. americana	0%	3%	0%

Location	42.264, -72.333		
Time	1:10 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	64.2°F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	10%	20%	70%
Algae	15%	30%	2%
Elodea	0%	2%	1%
V. americana	0%	0%	2%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	2%	5%	15%
Algae	30%	55%	20%
Watercress	0%	1%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	3%	40%	25%
Algae	8%	10%	5%
Moss	0%	5%	0%
Elodea	0%	20%	0%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	40%	15%	3%
Algae	25%	30%	15%
Moss	0%	5%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Bladderwort	10%	5%	20%
Algae	15%	35%	15%
Elodea	0%	35%	0%
Calcareous Algae	0%	0%	1%

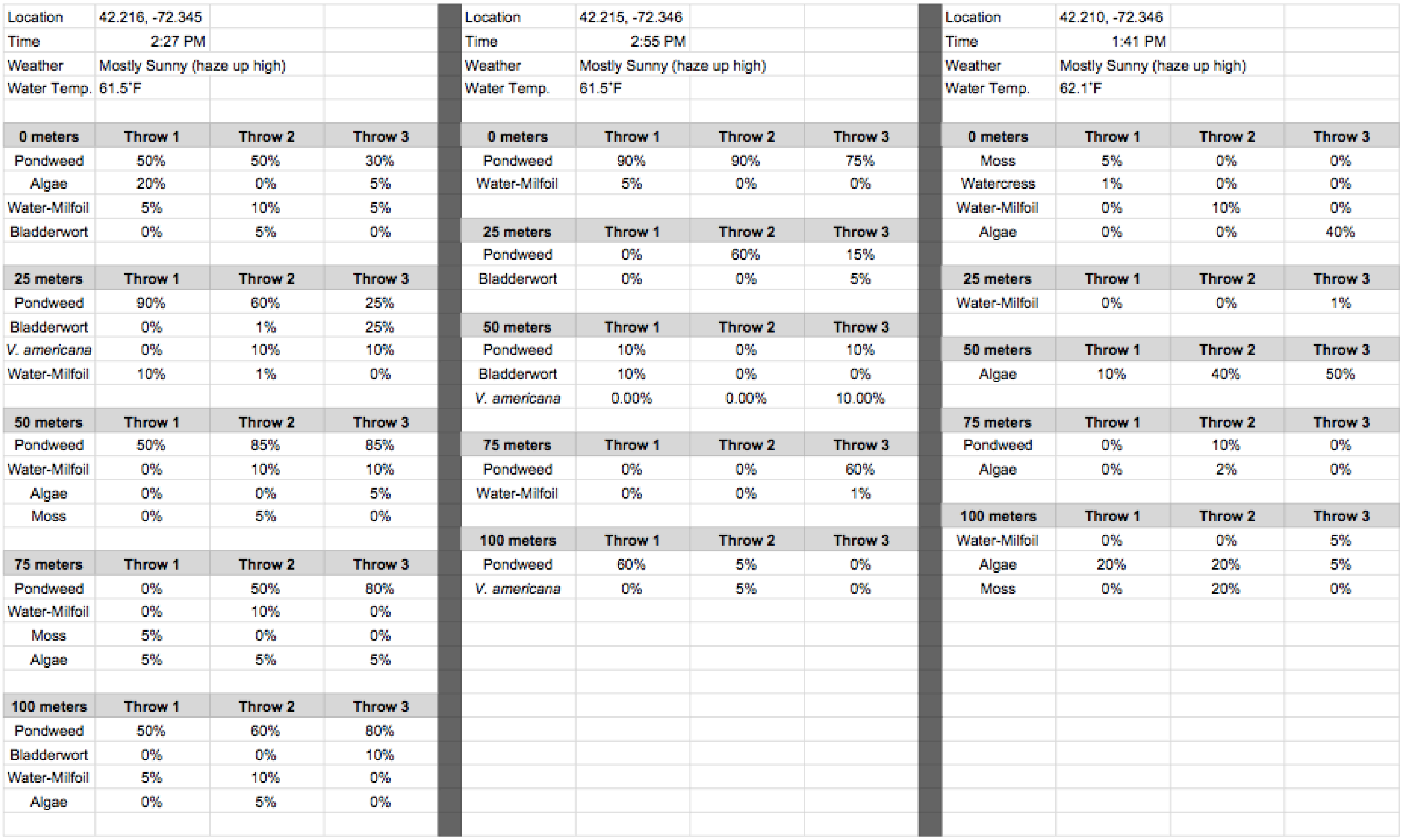
Table 4. Developed riverfront area sample site: collected 9/9/2017.

Location	42.216, -72.345		
Time	1:51 PM		
Weather	Partly Cloudy		
Water Temp.	61.5˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	50%	70%	40%
V. americana	1%	5%	0%
Water-Milfoil	10%	0%	10%
Bladderwort	0%	1%	0%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	90%	0%	30%
V. americana	0%	10%	5%
Algae	0%	5%	0%
Water-Milfoil	0%	0%	5%
Bladderwort	0%	0%	5%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	90%	100%	90%
Water-Milfoil	1%	0%	5%
Algae	1%	0%	0%
V. americana	0%	0%	1%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	100%	70%	90%
Water-Milfoil	0%	5%	5%
Algae	0%	1%	0%
V. americana	0%	0%	1%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	95%	95%	75%
Water-Milfoil	1%	0%	0%
Bladderwort	1%	1%	0%

Location	42.215, -72.346		
Time	2:15 PM		
Weather	Partly Cloudy		
Water Temp.	61.5˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	20%	15%
Bladderwort	0%	1%	10%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	5%	10%	0%
Bladderwort	5%	0%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	5%	0%	0%
Pondweed	0%	20%	5%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	25%	0%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
N/A	Nothing	Nothing	Nothing

Location	42.210, -72.346		
Time	2:51 PM		
Weather	Partly Cloudy		
Water Temp.	62.4˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	5%	5%	0%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	0%	5%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
N/A	Nothing	Nothing	Nothing
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	10%	0%
Water-Milfoil	0%	10%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	20%	1%

Table 5. Developed riverfront area sample site: collected 10/22/2017.



Location	42.216, -72.345		
Time	2:27 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	61.5˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	50%	50%	30%
Algae	20%	0%	5%
Water-Milfoil	5%	10%	5%
Bladderwort	0%	5%	0%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	90%	60%	25%
Bladderwort	0%	1%	25%
V. americana	0%	10%	10%
Water-Milfoil	10%	1%	0%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	50%	85%	85%
Water-Milfoil	0%	10%	10%
Algae	0%	0%	5%
Moss	0%	5%	0%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	50%	80%
Water-Milfoil	0%	10%	0%
Moss	5%	0%	0%
Algae	5%	5%	5%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	50%	60%	80%
Bladderwort	0%	0%	10%
Water-Milfoil	5%	10%	0%
Algae	0%	5%	0%

Location	42.215, -72.346		
Time	2:55 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	61.5˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	90%	90%	75%
Water-Milfoil	5%	0%	0%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	60%	15%
Bladderwort	0%	0%	5%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	10%	0%	10%
Bladderwort	10%	0%	0%
V. americana	0.00%	0.00%	10.00%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	0%	60%
Water-Milfoil	0%	0%	1%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	60%	5%	0%
V. americana	0%	5%	0%

Location	42.210, -72.346		
Time	1:41 PM		
Weather	Mostly Sunny (haze up high)		
Water Temp.	62.1˚F		
0 meters	**Throw 1**	**Throw 2**	**Throw 3**
Moss	5%	0%	0%
Watercress	1%	0%	0%
Water-Milfoil	0%	10%	0%
Algae	0%	0%	40%
25 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	0%	0%	1%
50 meters	**Throw 1**	**Throw 2**	**Throw 3**
Algae	10%	40%	50%
75 meters	**Throw 1**	**Throw 2**	**Throw 3**
Pondweed	0%	10%	0%
Algae	0%	2%	0%
100 meters	**Throw 1**	**Throw 2**	**Throw 3**
Water-Milfoil	0%	0%	5%
Algae	20%	20%	5%
Moss	0%	20%	0%

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