ANTICIPATING CLIMATE CHANGE IN THE MIDWEST

An Assessment of Shrub Compatibility to Climate Change in Missouri

Brianna M. Heese

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The distant nature of climate change,
The failure to link current experiences with future events,
And the difficulty in identifying and implementing adaptation measures,
All suggest that little adaptation to climate change is occurring at individual levels...

- Susanne C. Moser and Julia A. Ekstrom

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APPROVAL

Submitting in partial fulfillment for the Master of Landscape Architecture
Department of Landscape Architecture, University of Oregon

Rob Ribe, Master's Project Chair

Master's Project Chair Approval

Date June 12, 2019 Signature ______________________

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And Riley, for all our walks in the woods.

ABSTRACT

Climate change impacts the world at different rates and scales. This project examines the effects of climate change in the residential landscape in the Midwest, an under-examined—but crucial—topic in climate change studies. Columbia, Missouri is used as a case study for analyzing climate change impacts in residential planting design, specifically focusing on the success and longevity of shrub species which provide both an aesthetic and functional role in the region. This project developed a flow chart and scoring system for critical evaluation of the climate change compatibility of locally available shrubs. Shrub data from four sources in Columbia generated a condensed list of shrubs encompassing different species, cultivars, and varieties. The shrubs were assessed via a two-tiered system: first filtering shrubs by winter hardiness and invasive qualities; and second, those passing the first filters were scored based on compatibility with both current and future climate conditions in Missouri. Of the species examined, 56% were identified as compatible for current and future conditions, 3% were predicted to be compatible for future conditions, 15% were found to be at risk in future conditions, and 26% were considered incompatible as shrubs in Missouri. For those species identified as *at risk* under climate change, climate-compatible alternatives that fulfill similar functional and aesthetic roles were explored as replacement and design strategies. The result was an identification process that opened the door for discussion on the future of landscape aesthetics in the Midwest.

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FIGURES

DEFINITIONS

RESILIENCE - "The capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity" (Brand & Jax, 2007).

SHRUB - a woody plant, smaller than a tree, with persistent woody stems above ground.

THREAT - Climate change variable(s) that can unintentionally damage or kill a shrub beyond recovery.

TRAIT - Requirements for a shrub species to survive, such as water, light, soil type, climate hardiness zone, and climate tolerances. Trait qualities in this project are broken down into intrinsic and external properties.

INTRINSIC TRAIT - a shrub quality directly related to growing conditions and survival, such as water soil moisture, drought, and wet tolerances.

EXTERNAL TRAIT - a shrub quality indirectly related to growth and survival, and often involves outside influence, such as maintenance requirements and pest and disease tolerances.

VULNERABILITY - Having a trait which may be at odds with climate change variables (threats), such as high water needs in face of increasing drought.

INPUT - Human actions which offset a vulnerability to climate change such as maintenance, irrigation, pesticides, or fertilizers. Inputs make up for a lack of compatible traits.

RISK - The potential damage or death of a shrub as a result of future climate change variables affecting a vulnerability without the addition of inputs.

COMPATIBILITY - Having traits favorable to climate change predictions.

COMPATIBLE - Shrubs with traits favorable for current and future climate conditions.

INCOMPATIBLE - Shrubs with traits unfavorable for current or future climate conditions.

AT RISK - Shrubs that are suitable for current climate conditions but whose traits may be vulnerable to future climate conditions.

FUTURE COMPATIBLE - Shrubs incompatible with current climate conditions, but whose traits may favor future climate conditions.

CHAPTER 1

INTRODUCTION

1.1 PROJECT SCOPE

Climate change is a critical topic in today's design conversations. What was once a scientific prediction only decades ago has become a reality for all regions of the world. While it is still unknown whether all climate changes are the direct result of human impact, what is known is that the earth is experiencing global increases in average temperatures and extremes in temperature and precipitation patterns. There are many scientific models which predict global and regional futures under climate change. These models focus on predicting future temperatures, precipitation, and the secondary effects of these temperatures such as drought, sea-level rise, and changing weather patterns. Although varying in severity and timeline, most models predict that temperatures and these secondary effects of climate change are likely to continue to increase over the next century.

Some of the major concerns behind climate change lie in the secondary effects. Sea-level rise threatens coastal cities and resources. Drought, coupled with damage from insects and diseases, may increase agricultural pressures and perpetuate wildfire risk in natural areas. Declining water resources and temperature extremes in some parts of

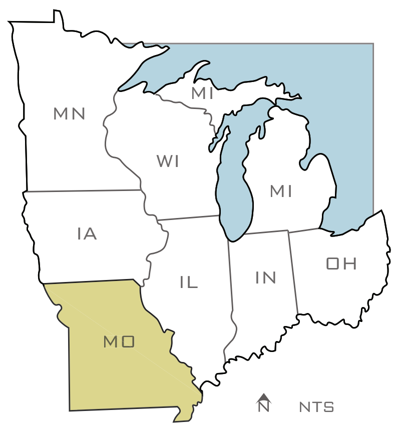


Figure 1.1: The Midwestern region, as defined by the IPCC.

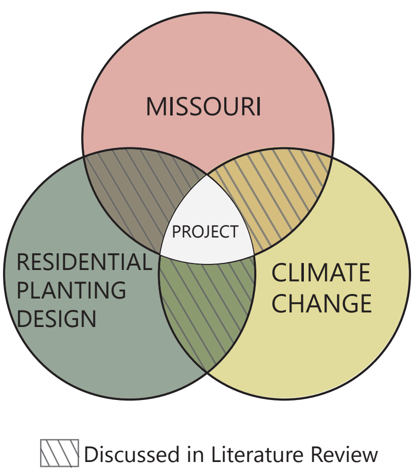


Figure 1.2 The research area lies at the intersection of three larger bodies of research.

the world foreshadow regional migrations. These major issues are at the forefront of global concern and are being studied world-wide.

On a regional scale in the United States, the west and coastal regions are coming to terms with rapid change. For the first time in the summer of 2015, California passed a mandatory restriction on water use for all residents in the state. In an attempt to reduce water usage by 20%, the state defined "wasteful" water consumption and restricted those uses under law[1].

Although many of these impacts must be addressed on the city, state, and national level, there remains a large portion of the United States under private ownership, a fact which elicits a new set of questions. What role does the individual have in a climate change future? What should homeowners anticipate for their property, and what action might a homeowner pursue to be proactive against climate change? How do we anticipate action when less is known about climate change? Relative to areas of major concern, little attention has been given to regions of the country that have thus far been less affected by climate change. This project chooses to look at a landscape that can benefit from proactive measures: the Midwestern United States.

Within the Midwest, there is variation between the northern states of Minnesota, Wisconsin, and Michigan whose climates are affected by the Great Lakes, and the southern part of the region (Missouri and Southwestern Illinois). Because this variation affects local climate change predictions, this project focuses on climate change effects on residential yards in Missouri.

The gap in knowledge exists at the intersection of Missouri's climate change projections, plant risk, and inputs for plant survivorship, all of which are discussed further in the literature review. Through the method created in this project, the hope is to better understand the complexity of climate change on plant survivorship and the potential impacts on design.

1.2 GOALS

The primary goal of this project is to create a transferable method in which plants can be assessed for their compatibility to climate change. A *compatible* plant is one that has *traits* (inherent plant qualities such water requirements or light conditions) which align to a climate change future with minimal homeowner inputs. A plant that will struggle to survive under future climate conditions without human inputs is considered *at risk*. This project takes a homeowner's perspective and assumes that risk can be offset by homeowner action, defined in this project as *inputs* (such as irrigation or pesticide application). The creation of an identification and assessment method through a flow chart and scoring system is the core of this project with the hope of being useful for different types of plants and regions. The secondary outcome of this project is to use this method to assess locally available shrubs and identify shrub compatibly to a climate change future in Missouri. Both goals attempt to answer the question, 'Which shrubs can survive in Missouri now or in 50-100 years and *should* they live there?'. The third goal of the project is to address the aesthetic implications to Missouri's residential landscape when attempting to design for climate change compatibility based on the results of the method.

Goal 1: Create a transferable method in which plants can be assessed for their compatibility to climate change.

Goal 2: Use the method to identify shrubs that are compatible to a climate change future in Missouri.

Goal 3: Address the aesthetic implications to Missouri's residential landscape when attempting to design for climate change compatibility based on the results of the method.

COMPATIBLE - Shrubs with traits suited for current and future climate conditions.

TRAIT - Requirements for a shrub species to survive, such as water requirement, light requirement, soil type, climate hardiness zone. Alternatively, a quality that aids in survival, such as condition tolerances (drought or standing water).

AT RISK - Shrubs that are suitable for current climate conditions but whose traits may be vulnerable to future climate conditions.

INPUT - Human actions which offset a vulnerability to climate change such as maintenance, irrigation, pesticides, or fertilizers.

RISK - The potential damage or death of a shrub as a result of future climate change variables affecting a vulnerability without the addition of inputs.

RESILIENCE - The capacity of a system to experience shocks while retaining essentially the same function, structure, feedbacks, and therefore identity (Brand & Jax, 2007).

1.3 SIGNIFICANCE

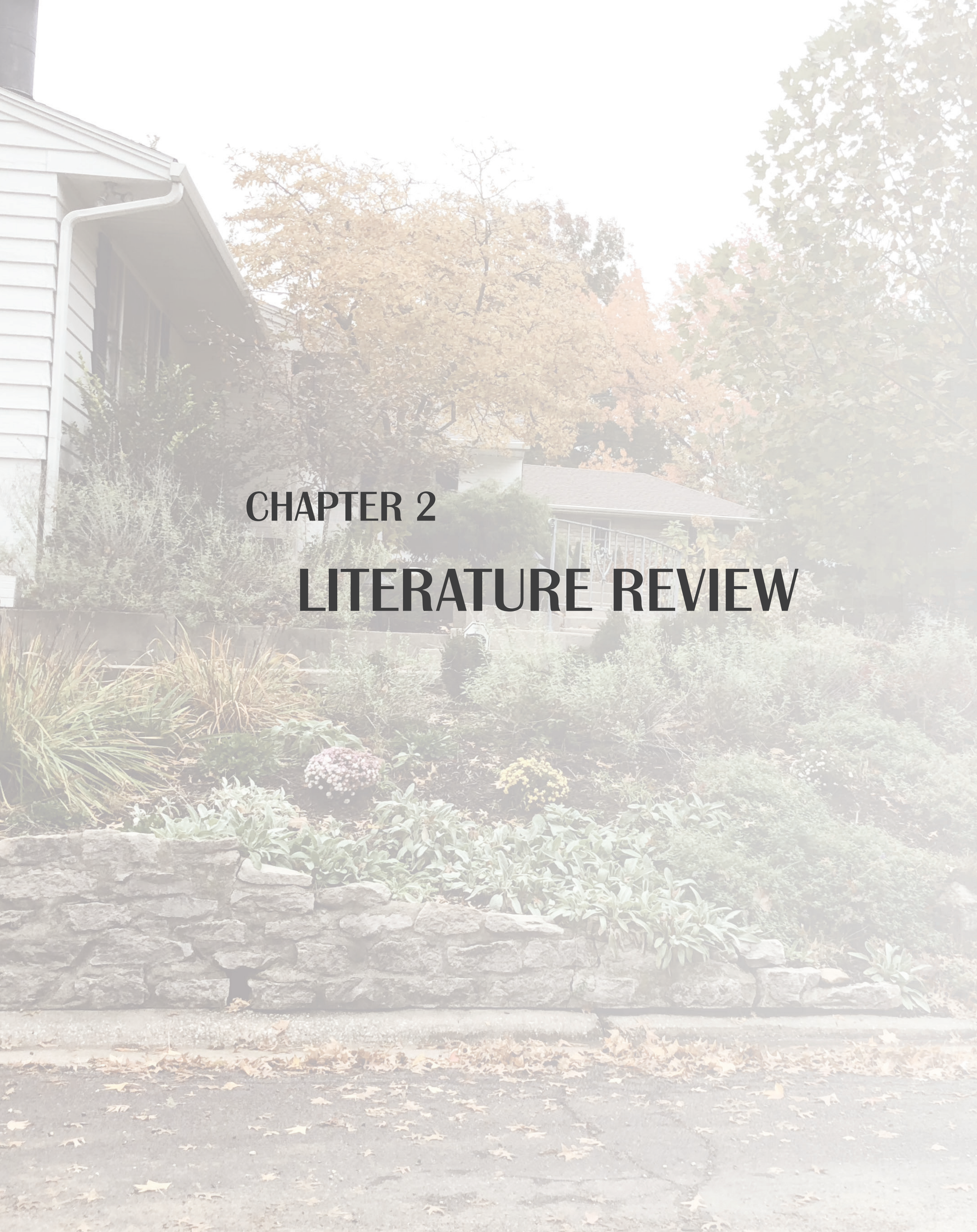
This research is important because there is currently no method for predicting the future success of shrub species under climate change nor on potential effects on residential design in the Missouri. Knowing what plants may or may not survive in the future, or how homeowner inputs might keep them alive, is a critical question homeowners and designers must ask when making landscape decisions.

The method proposed in this research is unique because it assesses the compatibility of plants under future conditions while also considering how human inputs can offset the *risk* of plant survivorship. This approach is unlike previous methods in plant evaluation which looked solely at a plant's level of *resilience* to climate conditions as the baseline "go" or "no go" indicator (Hunter, 2011, Ellison, 2012, Jorgensen, 2016). By separating the scoring system to consider plant traits and human inputs, this project recognizes that with human inputs and care, plants with low compatibility to climate change can survive successfully. The majority of plants deemed at risk are at risk in the absence of inputs.

Additionally, reinforcing plant choice through climate change metrics opens larger conversations about climate change and plant composition. There are many ways a yard can improve local resilience of a property and contribute to healthy residential and urban plant communities (Alizadeh & Hitchmough, 2018). Opening the conversation to ecological resilience, climate conscious energy consumption, and reduction in water use are just a few concepts related to this project. Because of the scale of residential landscapes and the nature of living and learning in such environments, these landscapes can also act as educational resources to promote climate sensitive designs (Wandersman, 1976). If designed thoughtfully with climate change in mind, residential landscapes can shift cultural preferences (Nassauer, Wang, & Dayrell, 2009), increase property values, and be sources of habitat and carbon sequestration (Qian, Follett, & Kimble, 2010).

CHAPTER 1 REFERENCES

1. Nagourney, A. (2015, April 1). California Imposes First Mandatory Water Restrictions to Deal With Drought. New York Times, p. 2.



CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The following sections further establish the parameters of this investigation by discussing current knowledge in the field and identifying gaps in this information. This chapter begins by addressing climate change as a human-induced condition which embodies current theories on the resilience of biotic systems and best practices to reduce climate change impacts.

This chapter then zooms in on the project's specific focus: the residential landscape, where opportunities to address climate change at this scale are established. Columbia, Missouri is introduced as a case study for evaluating climate change on a residential scale, and prior to Chapter 3, the climate change parameters specific to Mid-Missouri are discussed in order to distill requirements for plant evaluation.

2.2 CLIMATE CHANGE DESIGN

ANTHROPOGENIC CLIMATE CHANGE

The recognition of anthropogenic climate change in recent decades has led to concern regarding the effects on human and non-human species. While changes in climate have been occurring throughout the history of the earth, anthropogenic climate change is unique in its accelerated development (Huntley, 1991). Since the 20th Century, anthropogenic climate change, or global warming, has been heavily debated among researchers, scientists, and politicians. Yet in recent decades, most agencies agree that the rate of climate change observed over the past 100-200 years well exceeds climate change patterns from natural causes alone (Figure 2.1). Human-driven factors, notably carbon emissions from the burning of fossil fuels, deforestation, and conversion of carbon-trapping ecosystems, have led to an increase in

Separating Human and Natural Influences on Climate Change

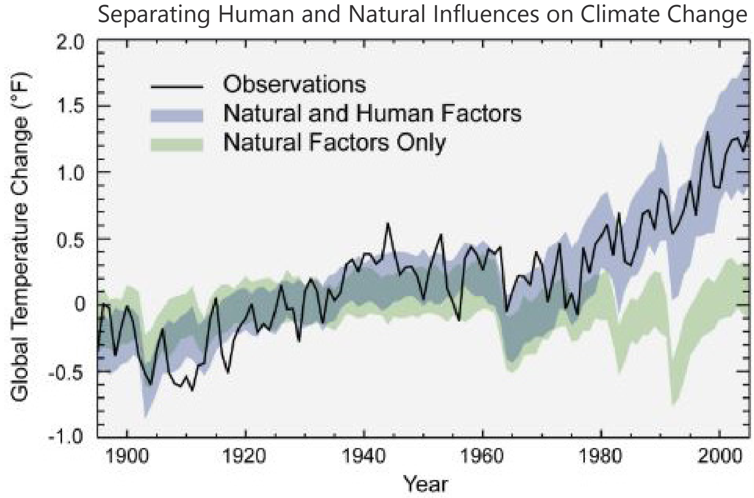


Figure 2.1: The impacts of human action on global temperature change (blue) compared to natural factors alone (green). Figure sourced from the U.S. National Climate Assessment, 2014 (Melillo et al., 2014), as adapted from Huber and Knutti, 2012.

atmospheric carbon dioxide (CO_2) and other warming gases that have caused an unprecedented rise in global average temperature (Melillo, Richmond, & Yohe, Eds., 2014). This in turn has led to deglaciation, sea-level-rise, and an increase in extreme weather patterns. While most aspects of climate change negatively affect the world, there are some observed benefits from increased CO_2 levels, such as longer growing seasons for plants and in some parts of the world increased agricultural yields.

Uncertainty best describes the likelihood of pinpointing climate change trajectory at all scales. Most climate change predictions are the result of complex simulations which assess future conditions under high emissions and low emissions (e.g. widespread conversion to energy efficient power) scenarios. Between the extremes of the scenarios, temperatures could rise an additional 3-10°F by 2099, causing numerous side effects (Melillo et al., 2014). Specific climate projections for the Midwest and Missouri are addressed at the final section of this chapter.

While exact predictions are uncertain, anthropogenic climate change has led to wide-spread concerns for future generations. One of the concerns lies in the realm of plants and the resilience of biotic systems. Alterations in temperature, atmospheric CO_2, precipitation, and nutrients may negatively impact the survival of some plant species while benefitting other, more adaptable species. The following sections discuss current trends of thought when seeking to add climate resiliency in planting design.

At the root of climate change design theories is the notion of adaptation (Stein, Glick, Edelson, & Staudt, 2014). The IPCC has defined adaptation as "the process of adjustment to actual or expected climate and its effects" (Edenhofer et al., 2014). It is important to anticipate changes and have systems in place that can adjust to new circumstances. When it comes to planting design, what is adaptive to climate change appears to be the major point of difference between different fields of thought. Some argue that climate change will favor plants that are more adaptable, while others argue that individual plant resilience means little when simply designing more complex plant communities can provide climate resilience (Alizadeh & Hitchmough, 2018).

NATURALISM AND BIOTIC COMMUNITIES

One of the major climate design theories today is adaptation through "naturalism" and the creation of healthy plant communities. "Naturalism" in this context is equivalent to planting to imitate nature either in species diversity, structural diversity ("messy" or wild), or both. Alizadeh and Hitchmough (2018) note in their review of climate design that acceptance of this practice is increasing in both public and private realms of landscape design. It is not uncommon today to see designed landscapes imitate natural grasslands and meadows, even in the urban realm, which has in turn sparked popularity at the residential scale.

Over the past two decades this movement has gained momentum as a result of supporting research and its adoption in landscape architecture professional practice. Research has recognized the importance of species diversity within plant communities for survival and that both native and non-native species play an important role. While some designers and conservationists may disagree with the use of non-native plants, there is an argument that climate change provides an opportunity to use non-natives to provide the necessary diversity and resilience (Alizadeh & Hitchmough, 2018). Many online resources for climate change design support this approach as well, suggesting that one should design plant groups and communities of compatible species (e.g. needing similar growing conditions or creating a symbiotic relationship). This tactic helps improve the complexity of a biotic system and can buffer extremes of climate change such as wind throw and drought. Additionally, more species diversity improves soil conditions and, when combined with quantity, improves carbon storage[1].

The strategy of "planting to represent nature" is complex and challenges many perceptions on maintenance and aesthetics. The validity of this approach is revisited at the conclusion of this project, along with debates on native and non-native species. In relation to this topic, this project discusses the role of native and non-native plants in design, as well as the potential benefits of shifting yard aesthetics (of the Midwest) to a species diversity approach.

PLANTING NATIVE

Zooming in from a broader discussion about plant communities, there is debate about whether these communities should consist of all native species. There are many popular reasons for adopting this approach. The Audubon Society[2] touts the top reasons to use native plants because they are:

- *Low maintenance.*
- *"Beautiful".*
- *Do not require fertilizers and pesticides because they are adapted to local pests and soil conditions.*
- *Use less resources such as water and maintenance*
- *Provide habitat for native wildlife.*

However, it would be reasonable to say that these are conditional statements, and in the face of climate change these purported benefits may differ. More reasonably, native plants present the following qualities:

- *Theoretically low maintenance, if naturalism is the design aesthetic, however they can be higher maintenance if fit to a formal aesthetic.*
- *Beauty of the shrub depends on its nature and placement in design. Most natives get grouped into "native garden" design,*

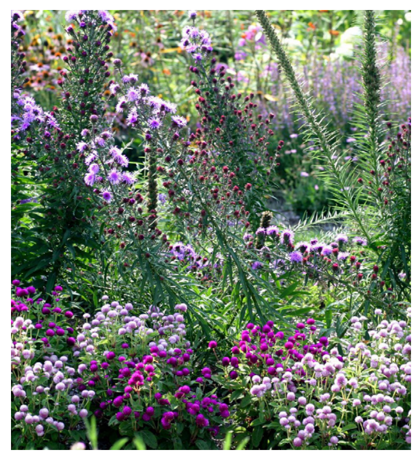


Figure 2.2: Designing with Missouri's native plants can add beauty and diversity as well as support native wildlife.
Image sourced from https://www.kclibrary.org

suggesting that they are more beautiful massed than planted alone, although there are some natives that can be specimens.

- *The need for fertilizer, pesticide, and water use is likely to change for natives and non-natives under climate change conditions. The argument that natives are "adapted to the climate and conditions" is likely to not hold up if climate change surpasses a plant's tolerance or ability to adapt to new conditions.*
- *Native plants are a valuable resource for habitat and have an important relationship with insects and pollinators, feeding into the rest of the food-web complex.*

There are many reasons to use native plants, the most important of which may be for habitat and protection of existing ecosystems (Nassauer, 1997). In a study conducted in 2007, it was found that many landscape architects practicing in the Southeastern United States were using native plants in their designs. Residential design ranked the highest in use of native plants at 30% compared to other categories of design, and the main reason for doing so was because they were seen as "adaptive, hardy alternatives to solve functional site problems" (Brzuszek, Harkess, & Mulley, 2007).

Finally, some native species advocates argue that the combined stress of urbanization and invasive species is adding to climate change stress[3]. In this case, planting natives is seen as a duty to aide these species as they respond to climate change.

Despite the advocacy for native plants, there are counter arguments. While many natives may be better adapted for the climate they evolved in, anthropogenic climate change is pushing adaptation faster than plants can keep up. It may be better to provide more options to see if there are other plants with traits more compatible to climate change. Compatibility to climate conditions is a complex relationship between available CO2, nutrients, temperature, and moisture, and there are an infinite number of ways these factors can combine, and a plant can respond to them (Huntley, 1991). The ability of an individual plant plays a big role in the resilience of a larger landscape. The more adaptive plants present, the more a biological community will be likely to survive. Alizadeh and Hitchmough (2018) suggest it is necessary to include a broader range of native *and non-native* species in design that have traits which prepare them for climate change. Ultimately, success comes down to which plants can handle the extremes of the given climate.

INVASIVE PLANTS AND PESTS

An invasive plant often has characteristics advantageous to survival. Sometimes this is high genetic variability which allows adaptation to occur quickly or effectively through successive generations. Often, though, what makes a plant invasive is a combination of genetic benefits and an ability to outcompete established native or naturalized plant communities for resources[4]. When predicting conditions and identifying potentially invasive species, temperature, soil moisture, and growing season are the main climatic variables. Growth rate, habit, and mode of reproduction are intrinsic traits, allowing these plants to spread and dominate faster or more efficiently than others. Many invasive species have already been identified, but with climate change, there is uncertainty about which plants will take on invasive tendencies. Where, and how the line is drawn between an "invasive", "naturalizing", and "weedy" plant is subjective, and their implementation in design is equally murky. Decisions around invasiveness are further discussed in Chapter 3.

In addition to the potential arrival of new invasive plants, warmer climates and longer growing seasons are likely to increase the spread and effect of insects and diseases (Alizadeh & Hitchmough, 2018). This, along with invasive species and climate variables create a threat to biodiversity, to native species unfamiliar to these pests, to endemic plants with limited dispersal, and even to agricultural production.

Figure 2.3 (left): Invasive landscape plants in Missouri

Nandina domestica
Image sourced from https://www.dawsonsgardenworld.com.au

Berberis thunbergii
Image sourced from www.netpsplantfinder.com/

Euonymus fortunei
Image sourced from www.starnursery.com

ASSISSTED MIGRATION

When pondering the effects of climate change on plants, particularly native plants, the conversation centers around protecting these species and ecosystems. Heavily researched today is the effect and potential of assisted migration, which is the replanting of natives north (or higher elevations) of their current climate boundaries in anticipation of climate change. The theory of assisted migration originated from the mapping and analysis of pollen data from previous deglaciation events. The data revealed that a majority of plants responded to historic climate change events through migration as opposed to adaptive evolutionary changes (Huntley, 1991, Stein et al., 2014).

While it may seem easy to let species migrate as they did in the past, it may very well be impossible now for many to successfully migrate. Climate change rates today are 10-100 times faster than historic events and habitat fragmentation caused by human alterations to the landscape are major barriers to natural plant migration (Huntley, 1991). Assisted migration looks to lend a hand to plants and ecosystems by planting species outside of their current range. Another preservation approach is to collect and store the seed of at-risk plant communities, particularly in the case of rare or endemic species (Vitt, Havens, Kramer, Sollenberger, & Yates, 2010). Beyond simply migrating species to reserves, it is important to incorporate native species into the everyday landscape to improve habitat connections between reserves (Huntley, 1991).

Figure 2.4: Rock Pink blooming on a chert glade in Southwestern Missouri. Only 20-60 acres of Chert Glades remain in Missouri[10] . Image sourced from the Missouri Department of Conservation, credited to Noppadol Paothong.

The main argument against assisted migration center around the introduction of new species into new environments without knowing if they will present invasive qualities. This applies to native as well as non-native species. For example, *Juniperus virginiana*, Eastern Red Cedar, is considered invasive east of the Rocky Mountains even though it is a native of the region. The rapid spreading of this species is largely due to fire suppression, warming climates and excellent drought tolerance (Raeker, Fleming, Morris, Moser, & Treiman, 2010). In a similar way, attempting to use non-native plants that function in southern climates raises concerns about invasiveness. Given the uncertainty of future ecosystems, it is probable that these transportations or migrations will lead to novel ecosystems as the result of plant taxa responding differently to climate conditions (Vitt et al., 2010).

SOCIOCULTURAL INFLUENCES AND AESTHETICS

This project focuses primarily on homeowner action, and therefore must address the complications of individual choice and preference. When it comes to personal property and individual interests, residential landscapes are complicated decision arenas. Many studies have been done concerning "adaptive action" and "resilience" designs (with definitions of both varying) at the planning scale, recognizing that urban landscapes provide opportunities for such action (Pickett et al., 2001, Hunter, 2011). In fact, in a research literature review of residential landscapes, it was found that most studies were based in the natural science disciplines (68% of all 256 studies), with 56% of these studies focusing on ecological properties of yards at the household-scale (Cook, Hall, & Larson, 2012). Other topics included ecological functions and services provided by properties and evaluating potential over several scales of yard size.

However, these landscapes are often driven by socio-cultural factors, such as neighborhood codes, which complicate planning scale goals. Adger et. al. (2009) describe that the adjustment of one's beliefs or habits in relation to environmental agendas is rooted in social systems. This often comes with a single or set of limits, be it ecological, physical, economic, or technological. Essentially, our values are often rooted at the scale of a community or governing body, and thus are hard to deviate beyond covenants or other undefined limits. These limits imply individual levels of risk to deviate from cultural and societal norms and values, individual beliefs, preferences, or control. Ultimately, success for adaptive action

Figure 2.5: Residential Landscapes in Columbia, MO. Each yard, located in different neighborhoods, displays a similar but unique aesthetic.

depends on individual motivation (Moser & Ekstrom, 2010). Moser, directly addressing barriers to climate change action states that "variations in risk perceptions, the distant nature of climate change, the failure to link current experiences with future events, and the difficulty in identifying and implementing adaptation measures all suggest that little adaptation to climate change is occurring at individual levels, other than that driven by non-climatic factors." Even perceptions get in the way of adaptive action. People are less likely to pursue change when they perceive the immediate risk to be low or believe their contribution is insignificant (Grothmann & Patt, 2005).

Cook et al. (2012) also found that across household studies, occupying residents were the fundamental actors in making landscape decisions for their front and back yards despite larger social agendas. Therefore, this research looks to approach adaptive action through the homeowner's individual preference (Figure 2.5) rather than collective group effort.

This approach also coincides with previous preference studies. Individuals make and manage landscapes for how they look, most of the time regardless of other attributes and functions (Nassauer, 1997). Aesthetic expectations from the community are a highly important socio-cultural attribute, and any desired outcome (ecological health and diversity, climate change adaptations, etc.), will typically be aligned with those pre-determined aesthetics (Visscher, Nassauer, & Marshall, 2016). Nassauer, whose studies indicated a large correlation between aesthetic norms and homeowner preferences, argued that for ecological design to become widespread it must be considered "acceptable" through different aesthetic tactics (Nassauer, 1995; Nassauer, Wang, & Dayrell, 2009). However, some studies have found no specific correlation between cultural norms and homeowner preferences. One study conducted in Australia assessed preferences for biodiversity preference in the front yard and found little correlation between aesthetic norms and a homeowner's preference for a biodiversity design (Kurz & Baudains, 2012). The study concluded that the individual's stance on environmental issues seemed to outweigh pre-established norms. In a property-owning country, these studies solidify the need to allow homeowners to express their own interests and aesthetic desires and be aware of larger norms at play. For these reasons, when this project concludes with visualizations of climate compatible designs, both keeping to "the norm" and altering the aesthetic are offered as design solutions. Ultimately, landscape decisions must lie in the hands of homeowners to suit their preferences, willingness to care for a landscape, social agendas, and personal restrictions (health, financial, time, etc.).

2.3 THE RESIDENTIAL LANDSCAPE

URBANIZATION

This project focuses on the residential landscape. According to 2012 USDA land use data, 70,000,000 acres were recognized as developed urban area, making up roughly 3.1% of the country. In 2012 Missouri's percentage of urban area equaled the national average at 3.1% of the state's total acreage[5].

Even with rising populations and limited land, urbanization, including the continuation of low-density housing development is likely to continue increasing. In 2005, the U.S. reached a peak in the number of building permits received for single family detached housing at 1,682,000 permits that year. These numbers dropped during the 2009 Recession but are gradually increasing, now at 817,000 building permits for the year 2017 (Figure 2.6). These numbers show that the single-family housing market is not declining, and that the residential landscape continues to be a growing market even with a rise in multi-unit housing permits.

Gaston et. al. (2005) speculate that residential outdoor space,

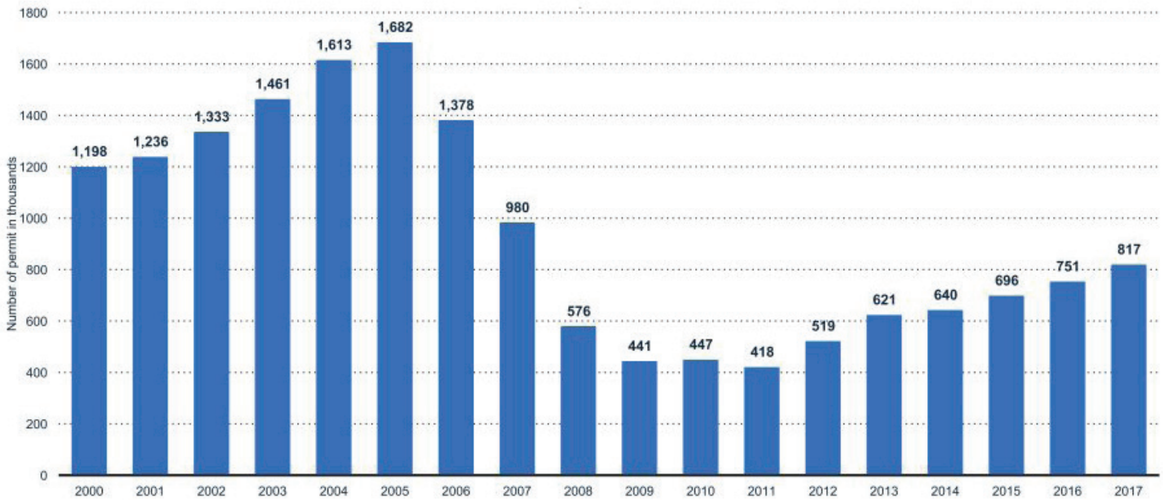


Figure 2.6: Number of single family building permits in the United States from 2000 to 2017 (in thousands). Permits have gradually increased following the 2009 Recession.

particularly residential gardens, cover approximately a quarter of the land within cities based on case studies. This portion of the land in a city can make impactful change, whether through the hands of a landlord, apartment company, or homeowner. Additionally, these lands are under private influence and can only change with direct owner involvement, and thus become more complex when considering landscape changes.

Figure 2.7: The Midwestern region, as defined by the IPCC (Figure 1.1 in Introduction).

2.4 THE STUDY AREA

ABOUT MISSOURI

To ground and fully explore the research questions, this project looks closely at the city of Columbia, Missouri. Partially, this site was chosen for its central location in the state, but as a Columbia native, this project provided the opportunity to study an area near to my heart and experience.

Missouri is on the southern edge of what is designated the "Midwest" by the NOAA 2014 Climate Change Report (Figure 2.7(1.1)). The boundaries for this terminology are not consistent across resources, sometimes including Kansas, Nebraska, and North and South Dakota.

Historically, the state was expansive tallgrass prairie in the northern half (Figure 2.8) which has now been almost fully converted to agriculture and urban land use (<1% of prairie remains today). Hills of oak, hickory, and maple forest occupy half the state as the northernmost border of the Ozark Mountains which run southeast toward the Missouri bootheel. The Ozark hills are unique in geology, ecosystems, and relative amount undeveloped land and protected caves and natural areas to the south.

Missouri's land use in 2012 was 34% forest, 22.3% grassland pasture and range, 35.5% crop land, 0.2% miscellaneous, 3.1% urban (1,345,000 acres), 4.7% special use[6] (Figure 2.9). This project focuses on the 3.1% urban area in the state to narrow the scope to residential land use.

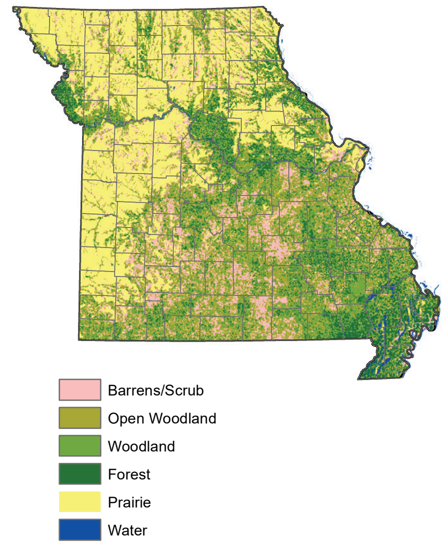


Figure 2.8: Historic landcover in Missouri.

CLIMATE RELATED RESEARCH IN MISSOURI

There is some research on forestry in the state which is indicative of climate change effects on naturally occurring plants, but there is not a consensus on plant vulnerability. Brandt et. al. (2014) predicted that, based on climate change models, general habitat for northern species, such as sugar maple, American beech, and white ash, will decline. There is medium evidence and high agreement that southern species such as shortleaf pine might become more prevalent. Thus far, there is little evidence of drastic change in forest composition. In a 100 year management study, there was some evidence that pine species might increase in forested areas while hickory might decline under certain management conditions (e.g. where old growth hardwood is harvested and not replanted) (Olson, Knapp, & Kabrick, 2017). These forestry assessments are useful in gaining understanding of regional plant concerns since few studies in Missouri have been done on residential (native, ornamental, or non-native) plant species.

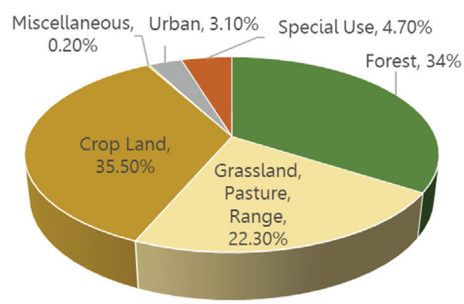


Figure 2.9: 2012 Land Use in Missouri.

It is also important to consider that "while many of Missouri's forests are being lost or degraded each year", the total forest acreage increased from 12.5 million acres to 15.4 million acres since a low point in the 1980s (Olson et al., 2017). Residential areas in urban settings, taking up much less than the 3.1% of total urban area in the state, are therefore not a big threat to native ecosystems or natural areas in Missouri. This information allows the project to take a stance of accepting native and non-native approaches to climate compatible design in Mid-Missouri's residential landscapes.

ABOUT COLUMBIA

Columbia, located in the middle of the state (Figure 2.10), serves as an example of a landscape which lies in wait for change, much of which rests on prediction. Columbia is typical of many midwestern cities, and thus can be used as a template for other assessments.

Columbia was established by pioneers in the early 1800s and was incorporated as a city in 1821. By 1833, the University of Missouri established as the first state University west of the Mississippi. The city grew with top economies in medicine, education, and insurance. Nearly from its inception the universities in Columbia have been integral in the values of the town, offering a progressive hotspot in the middle of the state to match St. Louis to the east and Kansas City to the west. Unlike the other two cities, Columbia has grown relatively slow over the last century with a peak in the last 30 years to arrive at around 120,000 permanent residents in 2017.

Figure 2.10: Columbia, Missouri in relation to the state, major rivers, and major cities.

The homeownership rate in Columbia is 47% and in the metro area 57%. Missouri overall has a homeownership rate of 67%, which is higher than the national average of 64%[7]. This information grounds the focus on residential spaces in the study area. Rather than focus on a particular area in Columbia, this project generates plant lists from locally available resources in the form of nurseries and department stores to define a popular market. Data collection is further discussed in the Section 3.1 of the Methods.

2.5 NARROWING PLANT SELECTION

The following section discusses the main plant typologies often found in a typical residential yard. For each typology, past research and climate considerations will be mentioned. Ultimately, this project chose to focus on shrubs after considering all other elements.

TURFGRASS (EXCLUDED)
It is important to consider lawns in this discussion as they often define low density residential areas and are a controversial matter from ecological and social standpoints.

Lawns can be dated back to pre-medieval times when they were important survival features. Low ground cover meant prospect and safety. Eventually, the upkeep of low grown grasses and perrenial flowers became a symbol of wealth for those who could afford to maintenance them via livestock or servants (Kopec, 2015). Lawns as a major socio-cultural norm escalated in the 1950s with the beginning of suburban housing in Levittown. Lawns and shade trees are often perceived as fulfillment of the American Dream, and this typology is commonplace throughout the United States (Bormann, 2001).

Milesi, Running, Dietz, & Tuttle (2005) found that turfgrass covered about 1.9% of the continental United States, much of which lies in the 3.5-4.9% of the U.S. covered by urban areas. Like many states in the U.S., Missouri's major metro areas allocate many acres to low-density residential lots and vast suburban networks. The Missouri suburbs do not fall outside of a turfgrass-dominated norm. The region utilizes mostly cool-season grass mixes to survive dramatic fluctuations

Figure 2.11: The single, mature tree will define the aesthetic of this yard in the summer months.

Figure 2.12: Fall annuals provide short-term seasonal interest before winter arrives.

in temperatures between the freezing winters and hot, humid summers.

Historically, it has been possible in Missouri to maintain a lawn without summer irrigation or chemical inputs depending on one's tolerance of occasional summer dormancy. However, there is a possibility for drought to increase in the future, potentially causing strains on the traditional lawn. Some climate change projections are doubting the ability of the cool-season grasses to survive in warmer winters and ever hotter and drier summers (Hatfield, 2017). What could happen to turfgrass in the future years is unknown and the predictions are uncertain. This project assumes that due to the importance of turfgrass to the American culture and the option of warm season grasses, turfgrass industries will likely produce an alternative crop that is climate resilient and reasonably sustainable.

TREES (EXCLUDED)

Trees have been the topic of research for most climate change studies to date (Cook et. al., 2012), and for good reason. Trees are the most beneficial landscape element as they have the longest lifespan and provide many ecosystem services to homeowners. This project could easily have focused on trees and their resilience to climate change, as have many projects at the University of Oregon (Ellison, 2012, Voelckers, 2015, Jorgensen, 2016). These past projects would have made an easy template to transfer to trees in Missouri. However, from an economic standpoint, trees are a big investment for homeowners and often serve as a singular addition to the landscape. And as an already a prevalent landscape feature in Missouri (Figure 2.11), there would be little discussion about changes to aesthetics through discovering tree compatibility to climate change. Shrubs offer the perfect midground of longevity and aesthetic influence in a yard, where conversations of biodiversity and habitat can be generated.

ANNUALS AND PERENNIALS (EXCLUDED)

Annuals and perennials appear to be a more dominant feature in the older neighborhoods of Columbia, (Figure 2.12) and therefore are not typical of all houses, especially newer development. Perennials are rather short lived and can easily be swapped out for more climate resilient species at relatively little expense. Annuals and bulbs respond to the climate of each year, adapting over the growing season and then seeding the next generation. It is of little use to evaluate their climate resilience when attempting to assess longer term impacts.

SHRUBS (INCLUDED)

Shrubs fall in as the third most important feature of residential landscape aesthetics in Columbia, and presumably elsewhere in typical residential yards in the United States. They often act as an architectural support by integrating residential buildings with the landscape (particularly in the case of ranch-style, or single-floor housing). Based on site visits and photo-documentation in Columbia, shrubs appear to be significant landscape elements. They are often secondary to trees and define the space around the house. They are a prevalent and pervasive feature for a single-family detached house with a turfgrass lawn (Figure 2.13).

The life span of shrubs allows flexibility and concern. They are not as long lived as trees, thereby making the "right" choice less dire, yet they are also longer lived than perennials, annuals, and bulbs, which can adapt to yearly changes in climate and are more replaceable. Designers and horticulturalists often suggest replacing or removing shrubs every 7-10 years because they can grow out of their desired form (get leggy or woody or overgrown) rather than reach the actual extent of their lifespan. However, this appears to be

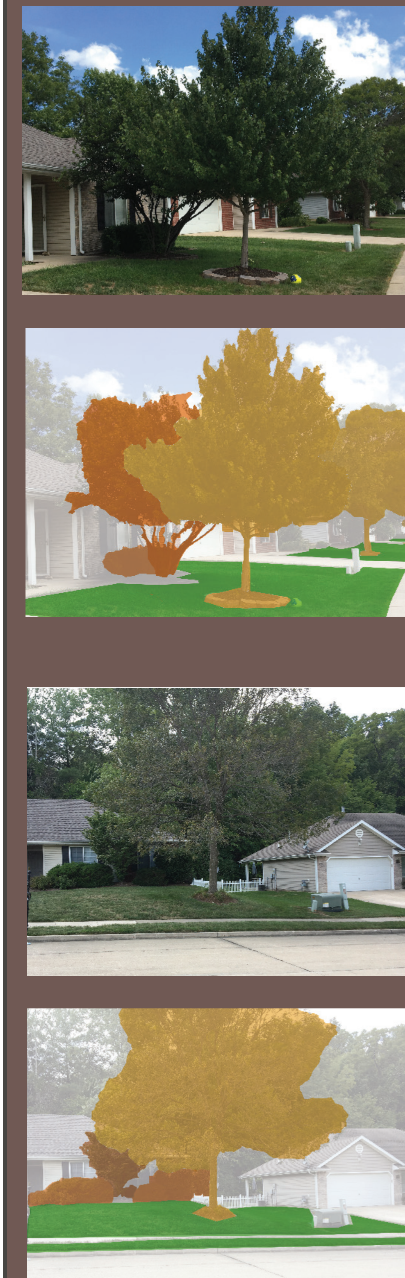


Figure 2.13: Yard composition in a early 2000s built subdivision. Shrubs appear in orange-brown, trees in yellow, and turf in green to show the overall distribution of plant elements. Shrubs, as represented here, are important foundational species particularly in newer development.

Hamamelis x Intermedia
'Arnold Promise'

Common Name: witch hazel
Type: Deciduous shrub
Family: Hamamelidaceae
Zone: 5 to 8
Height: 12.00 to 15.00 feet
Spread: 12.00 to 15.00 feet
Bloom Time: February to March
Bloom Description: Yellow
Sun: Full sun to part shade
Water: Medium
Maintenance: Low
Suggested Use: Hedge
Flower: Showy, Fragrant
Leaf: Good Fall
Other: Winter Interest
Tolerate: Deer, Erosion, Clay Soil

Climate Change Compatibility Score **3**

Figure 2.14: Online catalog plant description sourced from the Missouri Botanical Garden's online database. Growing conditions and aesthetic qualities of the plant are documented from the source, and a climate change compatibility score, as proposed by this project, would be a beneficial addition.

of rare practice, especially to homeowners that are investing in long term benefits. Most people, it can be assumed, replace plants due to decline or when a plant "goes out of style". Given this practice, this project assumes shrubs are likely a shrub to live to experience some climate changes.

Shrubs are not as expensive as trees to buy or remove and can be removed by the resident, making climate-aware decision making more probable. They hold a defined aesthetic function in the residential landscape and require more maintenance than trees but less than perennials and annuals. People would likely feel more invested in a shrub species because of its relative longevity. The methods chapter of this paper goes into more detail on the selection of shrub species, considerations on shrub life span, and how maintenance or "input" requirements are measured.

2.6 A HOMEOWNER APPROACH

Given the current body of knowledge, this project asks how a discussion about climate change and plant risk can be approachable to the everyday homeowner. To accomplish this, an everyday resource, in the form of plant guides and catalogs, is used as a template form of information rely for this project. These sources are presently a common language for many homeowners and resource guides for designers. The hope is that "climate compatibility" will eventually be a metric one might see on a typical plant guide along with soil, zone, and light suitability (Figure 2.14).

2.7 CLIMATE CHANGE IN THE MIDWEST

This section will discuss climate change predictions for the Midwest and Missouri in order to synthesize the most important climate change variables to affect shrub species. Three main sources were used to gather and interpret climate change parameters for the Midwest over the next century, and these sources are listed below and will be referenced throughout the section:

1. EPA Summary Report on Climate Change in the Midwest, 2016: This report summarizes the most recent climate predictions and implications for Missouri.
2. The Intergovernmental Panel on Climate Change (IPCC) Report, 2014: This report discusses impacts in North America and is useful for larger scale comparisons.
3. The NOAA Technical Report, 2013: This report provides the most comprehensive climate data analysis from the past century as well as climate change models for a future under high and low emission scenarios. Since this report creates synthesized projection models averaged from 7-10 modeling methods and addresses specific regions of the United States, it is weighted more heavily in the final analysis.

HISTORIC CLIMATE

The typical climate in the Midwest is seasonally variable. One can typically expect mild, wet springs; hot, humid summers; stormy, cool falls; and cold, cloudy winters with variable precipitation from year to year. Summers are influenced by the warm, humid air from the Gulf of Mexico and have historically been the rainiest season, only experiencing occasional droughts. In the winter, the polar jet stream is often located over the region which causes winter storms, cloudy skies, precipitation, and high winds. The frequency and intensity of jet steam effects decrease further south and away from the Great Lakes

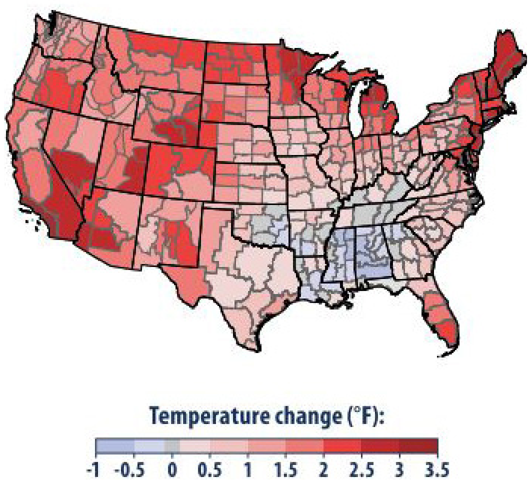


Figure 2.15: Average Temperature Change in the United States since 1900. Missouri has warmed less than other states in the U.S. Adapted from the EPA.

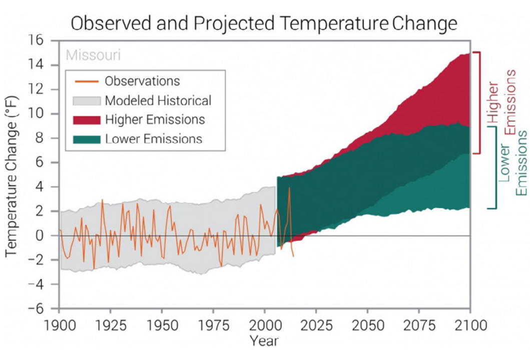


Figure 2.16: Observed and projected temperature change (black line) over time under lower emission (turquoise) and higher emission (red) scenarios based on recent climate trends (grey and orange), adapted from NOAA.

region. In spring, summer, and fall contrasting air masses in temperature, moisture content, and wind direction cause frequent thunderstorms and occasional tornadic events (NOAA, 2013). There has always been annual variability in temperature and precipitation in the Midwest, but there is strong evidence that climate change trends have occurred over the past few decades.

HIGH TEMPERATURES

Midwestern temperatures have changed less than other areas in the United States, averaging a 1.5°F increase in average temperature over the past century (Figure 2.15) (EPA, 2016). There has been an observed trend in the number of days with temperatures above 95°F, but despite this, there is a good amount of uncertainty in the magnitude and volatility of warming for the midwestern region. Consensus among most climate change models is that there will be continued warming compared to historical variations.

The EPA projects an increase in the number of days above 95°F from 5-15 days per year to over 25. NOAA projects a general increase in the number of days with temperatures above 95° as well as an increase in the number of consecutive days over 95°F (NOAA, 2013), and an increase in average temperatures, implicating prolonged heat stress events (see Appendix A). The IPCC, however, projects warming to be "less pronounced and robust in central and southeastern United States", with only some increase in the occurrence of extreme heat and cold events according to season. Across most sources, only high emissions models expect significant temperature increases by 2055, with lower emissions models showing little significant change by mid-century (Figure 2.16). In general, simulations are expecting the next century's warming to be much larger than 20th Century warming, with 70% of years between 2080-2099 experiencing extreme summer heat.

LOW TEMPERATURES

Predicting seasonal low temperatures for the Midwest under climate change conditions is more difficult. The region historically experiences wide extremes of both temperature and precipitation occurring over days, weeks, months, and years, and these extremes are likely to keep occurring (NOAA, 2013). Generally, average temperatures from December to February were between 30-35°F over the last century, but extreme lows appear to be a consistent factor despite average warming (EPA, 2016, NOAA, 2013). The record low for Missouri is -40°F and occurred in Warsaw, MO in 1912. Since then, lows have been recorded to the -20s once every couple of decades. While there has been a decrease in the average annual days with minimum temperatures less than 10°F and 32°F (NOAA, 2013) there are still occasional extremes. The polar vortex of 2014 (and others since) had temperatures down past -20°F in some parts of the state. Winter is a time of large fluctuations between very cold and warmer than average temperatures, especially causing strain on plants that begin to bloom too early. Despite these fluctuations, average winter low temperatures are expected to increase (warm) (see Appendix A). Along with this are predictions that the frost-free period is expected to increase about 4 weeks in the eastern half of the United States (NOAA, 2013, IPCC, 2014).

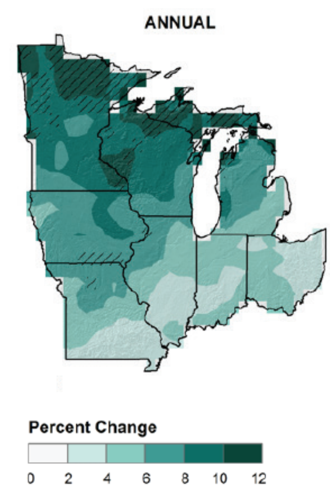


Figure 2.17: Projected change in annual precipitation of the Midwestern Region under high emissions scenarios. The annual annual change of Missouri is less than that of the northern Midwest. Adapted from NOAA.

PROJECTED PRECIPITATION

Currently, Missouri gets an average of 41-45 inches of precipitation per year (NOAA, 2013), yet over the past century there has been an increase (5-10%) in the average annual precipitation (NOAA, 2013, EPA, 2016). Most of this precipitation falls during the spring, summer,

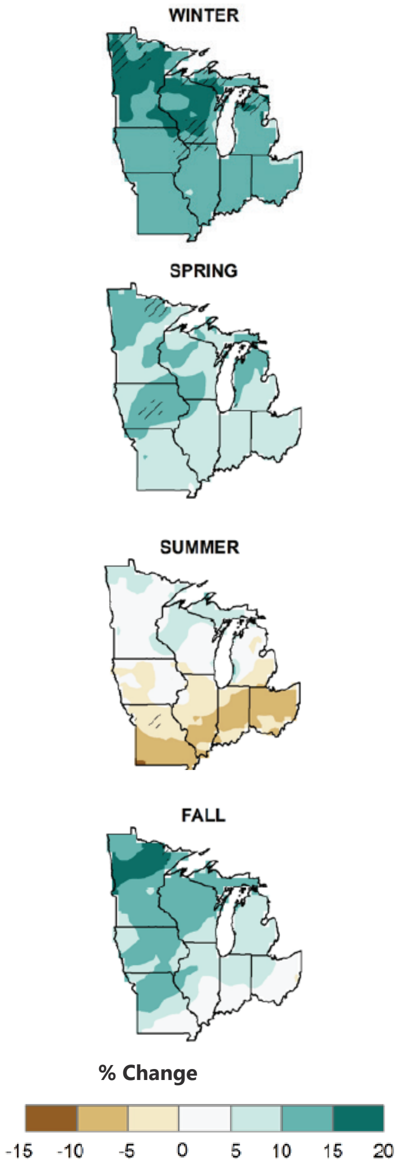


Figure 2.18: Anticipated seasonal precipitation change under high emissions scenarios. Winter, spring, and fall are projected to increase while summer is projected to decrease in precipitation. Adapted from NOAA.

and fall months. Climate change models project that average annual precipitation will continue to increase (Figure 2.17), but there is some uncertainty in the rate of this increase over the next century and how seasonal distribution will change.

The IPCC projects a 5-10% increase in extreme precipitation events in general, while NOAA projects precipitation to increase mostly in the winter and spring with little change to fall and summer norms (Figure 2.18). The EPA suggests that spring is likely to be wetter than historical variations in the past century, and that the 4 wettest days in the year are likely to result in 35% more water volume than the past, thereby increasing the amount of water in streams by more than 20% in the worst floods.

All projections for the Midwest agree that overall precipitation and extreme events will be more extreme in the northern states than in Missouri, which is at the southern end of the "Midwestern" states. Additionally, all sources agree that precipitation is expected to decrease in the summer months and increase in winter, spring, and possibly fall (Figure 2.16), and that frequency and intensity of flood events are likely to increase. All sources acknowledge that projections for precipitation changes are less certain than those for temperature.

DROUGHT

In the last century, there has been high variability in current drought trends. Most of the Midwest is irrigated with groundwater, showing that while seasonal drought may occur, it has not been widespread enough to require additional sourcing[8]. However, there has been a recent increase in sustained drought occurring in one area of the state while other areas receive too much rain, and there is no significant trend between these drought and inundation locations (NOAA, 2013). Summers are projected to have more severe and frequent drought occurrences, which coincides with projections of decreased summer rainfall. This in turn will also reduce summer river flow and increase stress on farms without irrigation due to the cycle of drought and flood events (EPA, 2016). There is currently no trend detected between drought and increases in water shortages besides local anecdotes. In the summer of 2018, a neighborhood outside of Columbia, Missouri, issued a landscape irrigation schedule for homeowners, prohibiting them from watering every day. The residents followed an alternating maintenance regime throughout the summer[9].

PLANT COMPOSITION

Most research concerning plant composition changes in the Midwest under climate change is oriented around forestry and agricultural products. It is unlikely that there will be a reduction in forest cover, but composition of Missouri's hardwood forests may change, likely seeing an increase in pine species and a decline in hickory species (EPA, 2016). Droughts may reduce agricultural and forest productivity, but that might be negated by longer growing seasons.

Globally, research has documented gradual change in plant species and distributions consistent with warming trends as previously discussed in Section 2.2. This northward shift in plants, mammals, birds, lizards, insects, and climate extremes is worrisome for some habitats in the United States (IPCC, 2014). On a local scale, there has been little to no research on urban and suburban plant palettes under climate change scenarios.

OTHER IMPACTS

Climate change is often worse because of its combined effects on an area. For example, increases in temperatures are likely to see an increase in damage from insects and diseases (EPA, 2016). It is important to have sustained frost for insect die-out, so the projected increase in average winter temperatures could mean more insect-related risks.

Dry soils and warm temperatures are associated with an increase in wildfires in the U.S. and Canada in the past decades (IPCC, 2014). Insects, such as the bark beetle, and diseases can increase the amount of fuel material. As of now, the Midwest is less affected by fire risk than more arid regions of the United States, but there may be issues between prolonged drought interrupted by intense precipitation, causing sporadic and intense flood conditions. The IPCC has tracked a loose relationship between storm-related disaster losses and climate related events.

CLIMATE CHANGE SUMMARY

Climate change predictions can allow for proactive measures by homeowners and designers to insure long-term plant survival. The major points of climate change in Missouri, as verifyed in the literature, can be related to the following plant characteristics:

Table 2.1 Expected climate change conditions and associated plant characteristics for future compatibility.

Climate Change Conditions 2020 - 2099	**Plant Characteristics for Climate Change Compatibility**
Increase in average Winter temperatures -possibly by 10°F in 2099	Mid-Missouri USDA hardiness zone goes from 6 to 7. Plants with low hardiness zone of 7 can more likely survive Missouri winters. (e.g. 7-10)
Increase in Summer drought	Tolerance for drought and dry soils desired.
More intense Winter and Spring precipitation	Tolerance for wet soils or poorly drained soils desired.
Increase in average temperatures – possibly by 10°F in 2099.	Heat tolerance and/or high end of USDA zone range at or above 7 desired. (e.g. 5-7, or 6-10)

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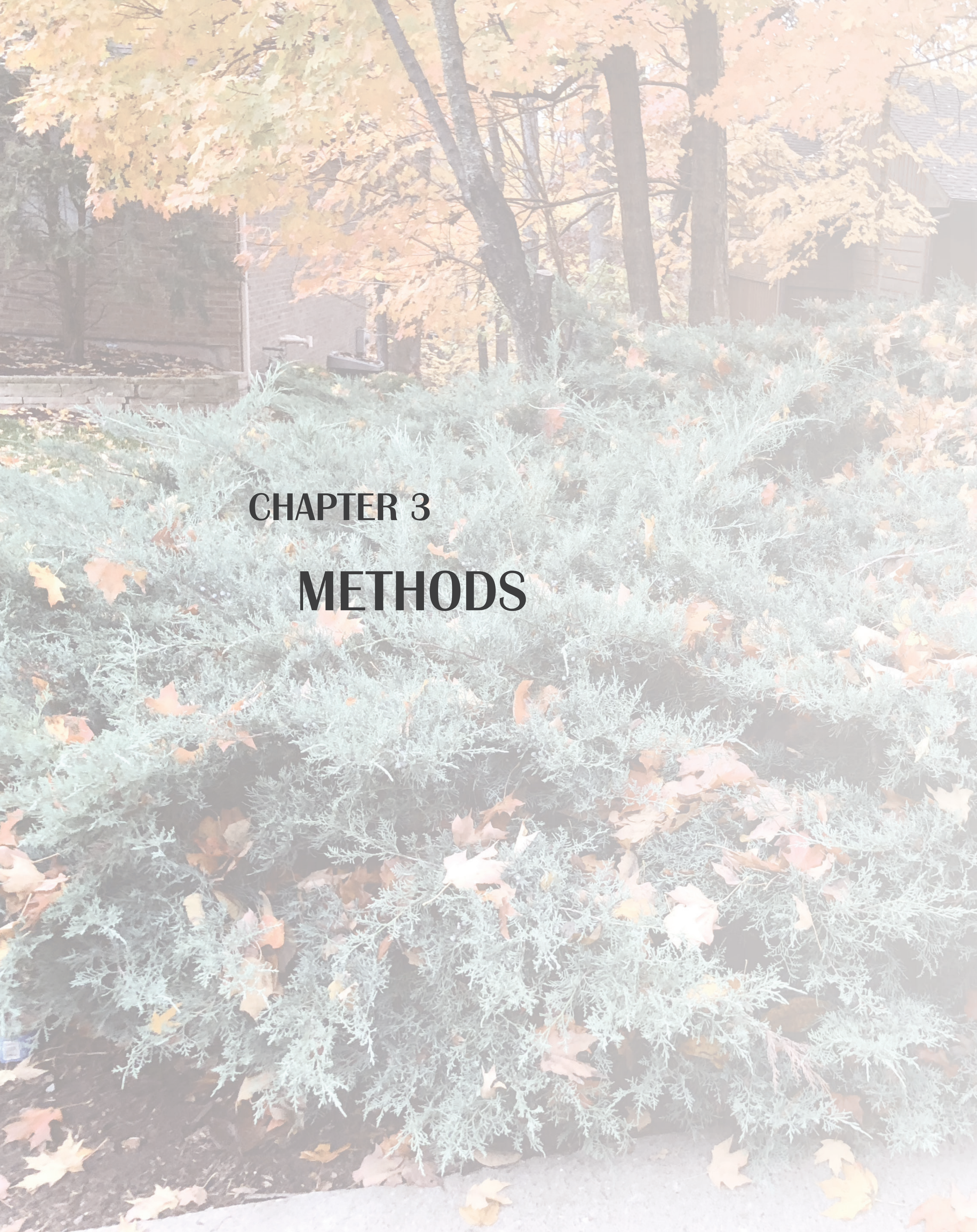


CHAPTER 3

METHODS

3.1 INTRODUCTION

As described in Section 1.2 of the Introduction Chapter, the primary goal of this project is to create a transferable method in which plants can be assessed for their *risk* and *compatibility* to a climate change future in Missouri. Given the stance of this project in favor of homeowner action and decision, it is beneficial to look at planting decisions as financial investments. Landscape decisions are often mainly constrained by economic factors over aesthetic or ecological goals (Cook et. al., 2012). The definitions listed[1] in Table 3.1, many rooted in economic risk management theory, will clarify the relationships that are key to establishing the method of this project.

Table 3.1: Operational Definitions and Economic counterparts.

Term	Economics Definition	Project Definition
Asset	People, property, and information	A shrub species, cultivar group, or variety with unique traits for survival.
Threat	Anything that can exploit a vulnerability, intentionally or accidentally, and obtain, damage, or destroy an asset	Climate change variable(s) that can unintentionally damage or kill a shrub beyond recovery.
Trait		Requirements for a shrub species to survive, such as water, light, soil type, and climate hardiness zone. Alternatively a quality that aids in survival, such as disease resistance or conditional tolerances.
Vulnerability	Weakness or gaps in protection that can be exploited by threats to harm an asset	A trait which may be at odds to climate change variables, such as high water requirements in face of increasing drought.
Inputs	Human actions which offset a financial vulnerability	Human actions which offset a vulnerability to climate change such as maintenance, irrigation, pesticides, or fertilizers.
Risk	The potential for loss, damage or destruction of an asset as a result of a threat exploiting a vulnerability	The potential damage or death of a shrub as a result of future climate change variables affecting a vulnerability without the addition of inputs.
Compatible/ Compatibility		Plants with traits favorable to climate change predictions.

SITUATING AND DEFINING THE RESEARCH

When considering research in the field of Landscape Architecture, this project falls into the category of classification as identified by Deming and Swaffield (2011). The authors identify that classification research "may be used to reveal and refocus attention on specific, meaningful patterns and themes hiding within data." This is a good description for this project, as the goal is to take existing data which can be digested on a case by case basis and reorganize it into a comprehensive list with a clear conclusion. While the plant information is out there, it has not been regrouped and analyzed through the lens of climate change compatibility in Missouri. Furthermore, there is potential in the identification of *compatible* and *at risk* species to open a conversation about design and aesthetic choices for a climate change future.

CONSIDERATIONS

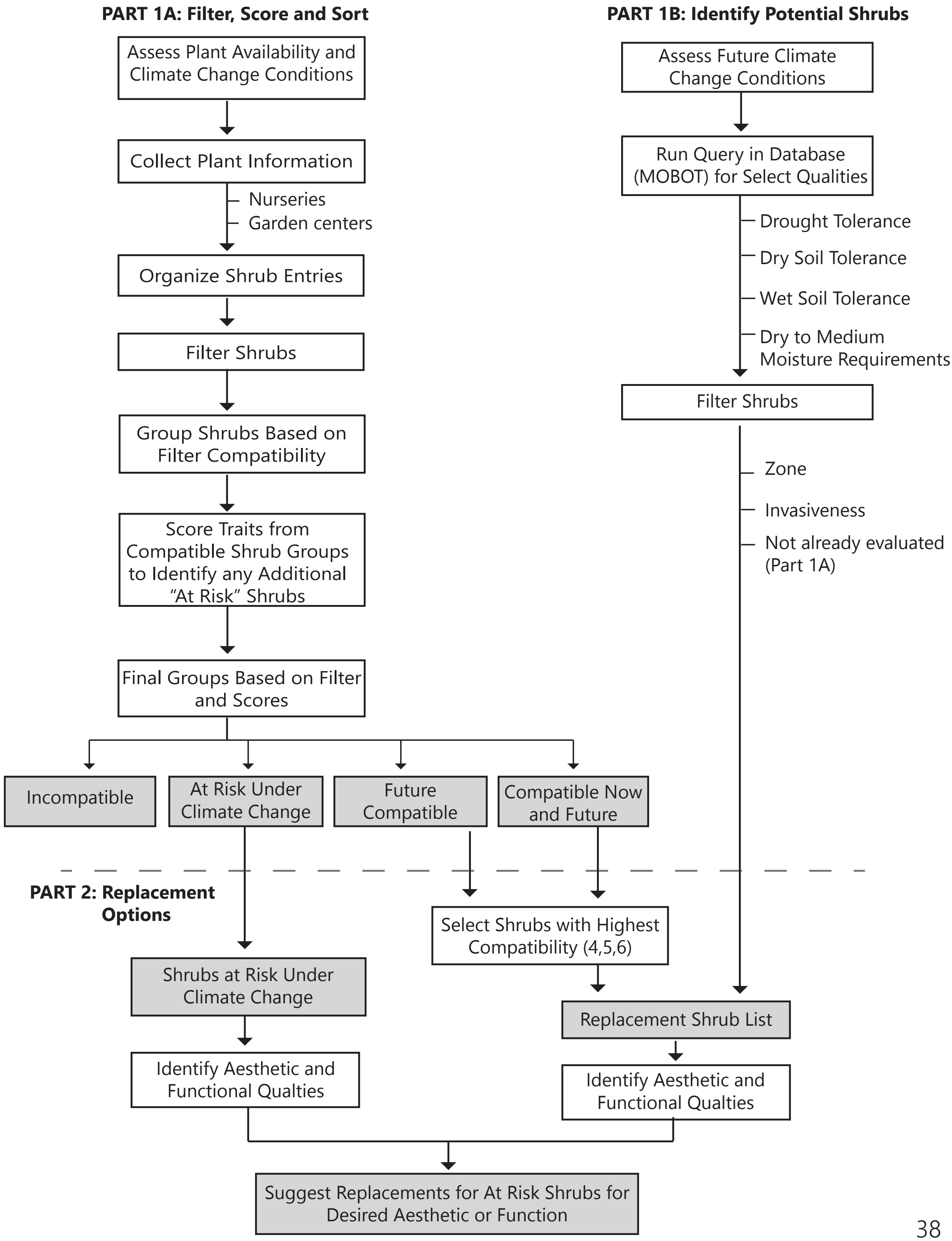
This project takes a stance on climate change and does not aim to predict an exact future scenario. Postulating future conditions is inherently rooted in uncertainty (Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., ... Ayres, M., 2009), thus assumptions must be made to generate results. Under extreme conditions of climate change, rising temperatures, intense precipitation, and prolonged drought events will become more frequent. This project assumed that certain plants which have not been at risk in the past may be at risk due to vulnerabilities. It hypothesized that identifying traits which are vulnerable to future climate conditions can help identify greater risk in the future. Similarly, a plant trait which aligns with future climate conditions, such as the ability to tolerate drought and high temperatures, indicates greater compatibility.

OVERVIEW (FIGURE 3.1)

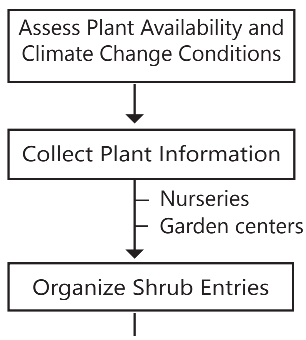
In order to assess the risk and compatibility of shrubs in Mid-Missouri under a climate change future, this project collected and organized a list of commonly available shrubs in Columbia to evaluate their traits. In **Part 1A**, all shrubs were evaluated through two filters, eliminating plants based on criteria of hardiness zone and invasiveness. Shrubs which pass the first filters were then assessed on the compatibility of their traits through a scoring system. This served as a double elimination process by further eliminating plants which lacked climate compatible traits. Simultaneously, **Part 1B** generated a list of plants that are zone compatible but currently are not widely sold in Columbia. **Part 2** used highly compatible shrubs from Part 1A and the potential shrubs generated from the Part 1B query to provide suggested replacements (based on formal and aesthetic qualities) for the species identified as At Risk in Part 1A. The method created here fulfills the primary goal of this project, and the utilization of the method fulfills the secondary goal of this project. The results additionally established grounds for a larger discussion on the aesthetics of a climate change future in Missouri.

Goal 1: *Create a transferable method in which plants can be assessed for their compatibility to climate change.*
Goal 2: *Use the method to identify shrubs that are compatible to a climate change future in Missouri.*

Figure 3.1 (right): Methods Overview. Shrubs are assessed via a two-part system. Part 1A collects information on currently distributed shrubs in Mid-Missouri and assesses them for compatibility to climate change. Part 1B generates a list of shrubs which are not distributed currently and may be compatible replacement species for those identified in Part 1A as At Risk. Part 2 evaluates replacement potential and discusses larger impacts of climate change on the residential landscape in terms of aesthetics and functionality.


PART 1A: Filter, Score and Sort
Assess Plant Availability and Climate Change Conditions
Collect Plant Information
Nurseries
Garden centers
Organize Shrub Entries
Filter Shrubs
Group Shrubs Based on Filter Compatibility
Score Traits from Compatible Shrub Groups to Identify any Additional "At Risk" Shrubs
Final Groups Based on Filter and Scores
Incompatible
At Risk Under Climate Change
Future Compatible
Compatible Now and Future
PART 1B: Identify Potential Shrubs
Assess Future Climate Change Conditions
Run Query in Database (MOBOT) for Select Qualities
Drought Tolerance
Dry Soil Tolerance
Wet Soil Tolerance
Dry to Medium Moisture Requirements
Filter Shrubs
Zone
Invasiveness
Not already evaluated (Part 1A)
PART 2: Replacement Options
Shrubs at Risk Under Climate Change
Identify Aesthetic and Functional Qualties
Select Shrubs with Highest Compatibility (4,5,6)
Replacement Shrub List
Identify Aesthetic and Functional Qualties
Suggest Replacements for At Risk Shrubs for Desired Aesthetic or Function

PART 1A: Filter, Score and Sort



3.2 PART 1A: COLLECTION & ORGANIZATION

SHRUB DEFINITION

The focus on shrub species as opposed to the other primary landscape elements of trees, turf grass, perennials, and annuals was described in the Literature Review. Before data collection could proceed, however, the question, “what is a shrub?” had to be answered. During the initial steps of data collection, it was obvious that the definition of a shrub could be different according to the source of information.

For the purpose of this project, a shrub *is a woody plant which is smaller than a tree with persistent woody stems above ground*[2]. This eliminated trees, grasses, cacti, and for the most part, herbaceous perennials. In the case that the shrub was semi-herbaceous in harsh Missouri winters, they were included on the premise of being more seasonally hardy in future climate conditions. Vines, while fitting the definition of shrub, were also eliminated from evaluation because they lack the structural form of a typical shrub species, thereby entering a different design aesthetic. The subsistence of these shrub species could be deciduous, evergreen (broadleaf and needled), or semi-evergreen.

DATA SOURCES FOR EVALUATING PLANTS

The primary source for shrub trait evaluation came from the Missouri Botanical Garden Plant Database, which self-proclaims the acronym MOBOT. An extensive database with a good reputation for plant research in the St. Louis Area, MOBOT contains information on over 7,500 plants which are currently growing in the Missouri Botanical Garden or have been grown in the Kemper Center display gardens, giving the information a distinctly local insight. There are often anecdotes about plant success locally.

Dirr’s Manual of Woody Plants was used when there were gaps in MOBOT information or to verify information. Dirr was a less valuable resource in determining the traits of specific cultivars than MOBOT but provided good information on overall species characteristics and anecdotal evidence of plant success and failure in different regions.

AVAILABLE PLANT LISTS

The sourcing of plant lists stemmed from a homeowner perspective, focusing on resources that are locally available to the everyday buyer. Wanting to know what could affect people's choices now, this project looked at the current market because it indicates which plants people popularly buy each season. If is safe to assume that while some cultivars might change in popularity or availability from year to year, species distribution in the market will likely be consistent. For this reason, nurseries and garden centers were used as points of data collection to generate a list of available plants in Columbia, Missouri. A benefit of choosing Columbia was that the size of the city condensed the data into a manageable collection compared to the larger cities of St. Louis, Kansas City, and Springfield.

Additionally, observational data were collected in newly built neighborhoods of Columbia to confirm the presence of many nursery and garden center distributed plants. This data was used as an additional point of confirmation. Documentation of data sources and the site observations were used as a form of note taking and were not considered in this project's analysis.

Site visits were conducted in Columbia at different times during the year prior to the completion of this project. However, the focus at the time was on neighborhood-wide designs in anticipation of climate change. The scope of the project narrowed as it became evident that there was a lack of information on climate compatibility at the plant level, making neighborhood planning somewhat ungrounded in information. When the scope of this project refocused to assess plants, many nurseries were closed for the winter so nurseries and garden centers with an online presence were chosen (Figure 3.2).

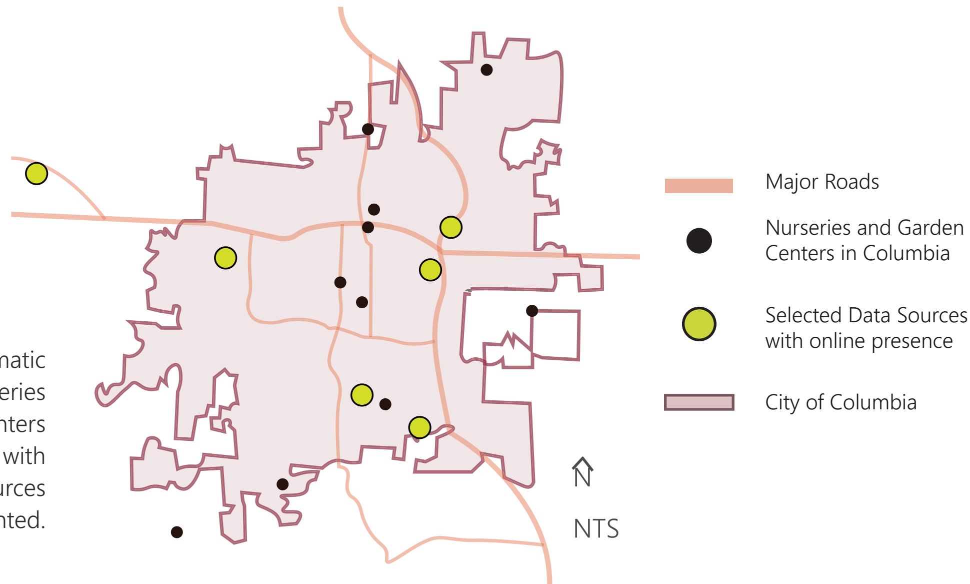


Figure 3.2: Diagrammatic map of nurseries and garden centers in Columbia, with selected data sources represented.

When a search was conducted for plant nurseries in Columbia, Missouri, only two businesses had accessible plant information: Rost Inc. and CMSE Giving Gardens. Generic garden centers were also considered because of their popularity and accessibility for the average homeowner: The Home Depot and Walmart Garden Centers were chosen for this purpose.
About the two nursery suppliers:

1. Rost Incorporated is an all-inclusive local business that contracts landscape design, irrigation, and plant material. In addition to design services, the business has an extensive wholesale nursery which made up a large component of the plant list for evaluation.
2. Central Missouri Subcontracting Enterprise (CMSE) Giving Gardens is a well-loved, local nursery that employs people with disabilities. The 40-year-old retail nursery and therapy garden provides perennials, annuals, herbs, vegetables, and native plants for public sale.

ORGANIZING PLANT LISTS

Data compiled from Rost, CMSE, Home Depot, and Walmart Garden Center led to a list of plants that varied in specificity of scientific categorization (genus, species, cultivar, variety), making it difficult to assess across these descriptions.

Most of the plants that were collected were cultivars and varieties of a species, so it is useful to discuss the differences in classification. "Cultivar" is a term that is short for "cultivated variety", and most commonly refers to plants which are selected for desirable characteristics. Cultivars are often propagated via an alternative method than seed (for example, stem cutting) and can be expected to maintain the phenotype of the parent for only that generation. A "variety", on the other hand, can often be found growing and reproducing naturally and seeds will often be true to the unique phenotypic cross generation after generation, only occasionally crossing back to the original parental expression of the genes. Cultivars derive out of a desire for a new plant trait. These are often a formal or aesthetic trait, such as compact, columnar, dissected leaves, longer lasting bloom time, or unique flower color. Sometimes cultivars stem out of a need to limit invasiveness or pursue drought tolerance. For this reason, it was prudent to consider and look at the details of as many cultivars, species, and varieties as possible within the given list of shrubs when information was provided from a reliable source. The initial list from all four sources generated 242 cultivars and varieties of shrubs (Figure 3.3, see Appendix C for full list).

Figure 3.3: Example of initial data collection across the four distributors with indication of the presence of MOBOT information.

0. GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Data
ABELIA	ABELIA, KALEIDOSCOPE	Abelia x grandiflora	X					Y
	ABELIA, RASPBERRY	Abelia x grandiflora	X					N
ALDER	ALDER, BUCKTHORN	Frangula alnus					X	N
ALTHEA	ALTHEA	Hibiscus syriacus		X				Y
	ALTHEA MINERVA	Hibiscus syriacus	X					Y
	ALTHEA TREE FORM	Hibiscus syriacus	X	X				N
	ALTHEA, APHRODITE	Hibiscus syriacus	X					N
	ALTHEA, AZURRI BLUE SATIN	Hibiscus syriacus	X				X	Y
	ALTHEA, BLUE CHIFFON	Hibiscus syriacus	X				X	N
	ALTHEA, LAVENDER CHIFFON	Hibiscus syriacus	X					Y
	ALTHEA, PURPLE PILLAR	Hibiscus syriacus	X				X	N
	ALTHEA, SUGAR TIP	Hibiscus syriacus	X					Y
AMERICA SILVERBERRY	AMERICAN SILVERBERRY	Elaeagnus communata				X		N
AZALEA	AZALEA	Rhododendron		X				Y
	AZALEA, BLOOM-A-THON	Rhododendron	X					N
	AZALEA, ENCORE	Rhododendron ENCORE	X	X		X	X	Y
	AZALEA, GIBRALTER	Rhododendron 'Gibralter'	X					Y
	AZALEA, GIRARD CAROLINE	Rhododendron 'Girard Caroline'	X					N

Table 3.2: Key Traits Assessed per Shrub Entry

USDA Hardiness Zone
Subsistence
Invasive Qualities
Light Requirement
Water Requirement
Drought Tolerance
Wet Tolerance
Maintenance
Concerns

An initial evaluation was conducted for all entries assessing information over 9 key traits which would serve as filtering and scoring information in Part 1A (Table 3.2). To decrease the chance of redundancy and over-complication of the data, the entries were then reorganized into groups when cultivars shared similarities (Table 3.3), condensing 242 entries to 95 entries for assessing climate compatibility (Figure 3.4).

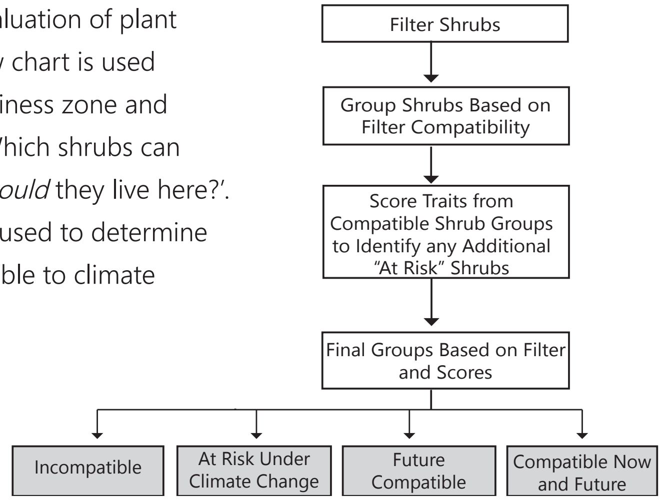
Table 3.3 Reorganization Principles for Shrub Entries

Species Shore juniper, *Juniperus chinensis*	The straight species was used as the listing when it was given in data collection or the cultivar(s) listed lacked information.
Varieties Korean Boxwood, *Buxus sinca var.* *insularis*	Treated as a separate entry than a species since a variety can propagate and pass on unique traits in nature.
Cultivars Smoke Tree cultivars, *Cotinus obovitus**	All key traits (Table 3.2) are the same and can be summarized into a species group with associated cultivars. Small fluctuations in zone range is fine if it still includes hardiness in MO and noted with ( ). (e.g. (3),4,5,6,7 indicates at least 1 but not the majority of cultivars had an extended range down to USDA Zone 3).

Figure 3.4: Reorganized Shrub Entries as Cultivar Groups, Species, and Varieties

0.COMMON NAME	0.LATIN NAME	ROST	CMSE	OBS	WalM	HoDe	SUSTENANCE	ZONE
Glossy Abelia	Abelia x grandiflora	X					Deciduous in MO	(5),6,7,8,9
Chokeberry	Aronia melanocarpa	X					Deciduous	3,4,5,6,7,8
Japanese Barberry*	Berberis thunbergii cultivars	X					Deciduous	(4)5,6,7,8
Butterfly Bush*	Buddleja davidii cultivars	X	X				Deciduous/semi-he	5,6,7,8,9
Common Boxwood*	Buxus sempervirens cultivars						Evergreen	5,6,7,8
Korean Boxwood*	Buxus sinca var. insularis cultivars						Evergreen	4,5,6,7,8,9
Beautyberry, American	Callicarpa americana	X				X	Deciduous	6,7,8,9,10
Beautyberry, Bodinier	Callicarpa bodinieri var. giraldii 'Profusion'						Deciduous	6,7,8
Beautyberry	Callicarpa dichotoma 'Early Amethyst'						Deciduous	5,6,7,8
Sweetshrub*	Calycanthus cultivars	X					Deciduous	5,6,7,8,9
Camellia*	Camellia sasanqua cultivars				X	X	Evergreen	7,8,9

The main tool used in this project to inform evaluation of plant traits is a **flow chart** and **scoring system**. The flow chart is used to filter and sort shrubs based on essentials of hardiness zone and invasiveness. In layman's terms this process asks, 'Which shrubs can survive in Mid-Missouri now or in 100 years, and *should* they live here?'. A deeper assessment with a scoring system is then used to determine which shrubs out of the first filter are more compatible to climate change conditions.



3.3 PART 1A: FILTERING & SCORING FOR COMPATIBILITY

CLIMATE CHANGE EFFECTS IN MISSOURI

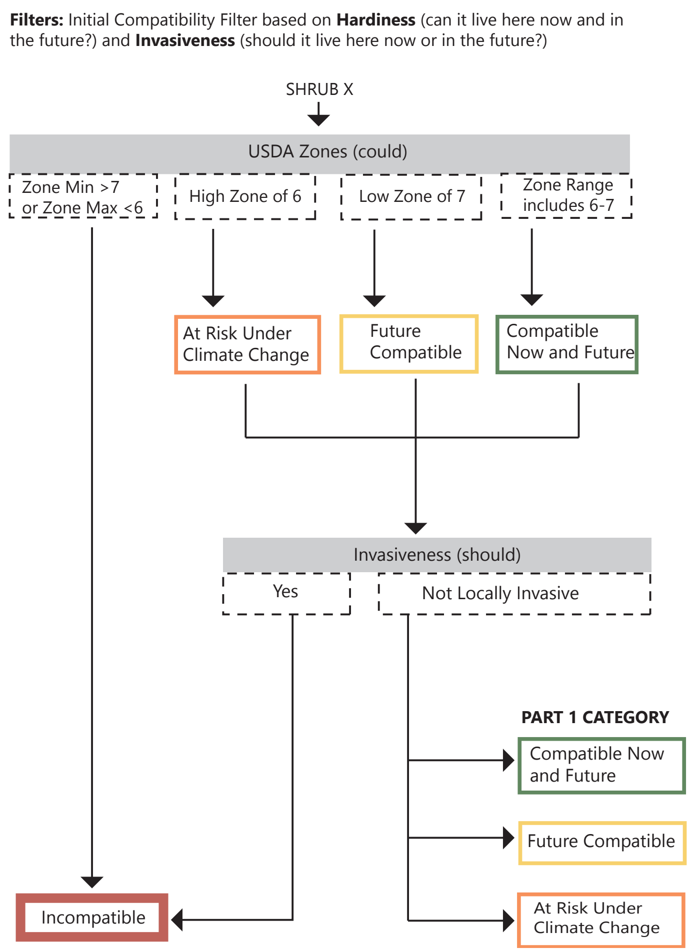
The previously cited climate change data is critical for the selection of traits and the scoring of those qualities. High emission climate change scenarios were synthesized in Section 3.7 of the Literature Review to draw a relationship to plant qualities. Table 3.4 reiterates the summary information.

Table 3.4 Expected climate change conditions and associated plant characteristics for future compatibility.

Climate Change Conditions 2020 - 2099	**Plant Characteristics for Climate Change Compatibility**
Increase in average Winter temperatures -possibly by 10°F in 2099	Mid-Missouri USDA hardiness zone goes from 6 to 7. Plants with low hardiness zone of 7 can more likely survive Missouri winters. (e.g. 7-10)
Increase in Summer drought	Tolerance for drought and dry soils desired.
More intense Winter and Spring precipitation	Tolerance for wet soils or poorly drained soils desired.
Increase in average temperatures – possibly by 10°F in 2099.	Heat tolerance and/or high end of USDA Zone range at or above 7 desired. (e.g. 5-7, or 6-10)

Part 1A is meant to assess currently available plants using databases of plant information. Once a list of shrubs was collected from local distributors and 9 key traits logged (Table 3.2), traits of hardiness zone (*could live here*) and invasiveness (*should live here*) were used as filters to evaluate if the shrub could (and should) survive in the area. By the end of the first two filters, shrubs were categorized into four categories:

- *Compatible Now and in the Future*
- *Future Compatible*
- *Incompatible*
- *At Risk Under Climate Change*



A Note on Category Definitions:
The definition of each of these categories gets altered through each main step of the flow chart. Shrubs considered "Compatible Now and in the Future" after the Zone Filter are compatible because they meet the required zone. Shrubs considered "Compatible Now and in the Future" after the Invasiveness Filter are compatible because they meet the zone requirements *and are not invasive.*

Figure 3.5: Filtering Process for Assessing Climate Compatibility.

FILTER 1: USDA HARDINESS ZONES

USDA Hardiness Zones (see Appendix B) were used as the first filter in determining compatibility. Zones have historically been the main tool used by the everyday gardener to make plant decisions, and thereby holds merit on several levels. A hardiness zone is a summarized numeric value that considers several climate factors, but the average annual extreme minimum temperatures (from the past 30 years) holds the most weight in determining an area's USDA zone value. Depending on the resource, a species of plant will have low zone number (e.g. 5, or "down to zone 5"), meaning that the plant can typically survive in climatic conditions defined by that zone number. For example, a USDA hardiness zone of 5 means that a plant can survive minimum average winter temperatures of -20°F[3], and a plant that has a range from 5-8 technically means it can survive low temperatures of -20°F to 10°F. Occasionally, zones are subdivided into 5 degree increments, with, for example, 6A being -10°F to -5°F, and 6B being -5°F to 0°F (Zone 6 overall meaning -10°F to 0°F tolerance).

It is beneficial to have information on a high end to the zone for several reasons even if it is not the primary reason for the zone indicator. What the upper zone really indicates is a climate with typical winter lows above 10°F, and this is sometimes correlated to warmer summer climates. Additionally, some plants need a certain degree and duration of low temperatures to survive, propagate, or grow and flower regularly the next season. For this reason, plants with a high USDA Zone of 6, which is central Missouri's current zone (see Appendix B) may struggle when future winter lows no longer achieve the lows they need for survival or life cycle. MOBOT provided an upper and lower range to zones for all plants in whole numbers, allowing some ability to recognize high temperatures (or high minimum winter temperatures) as a factor for plant survivorship. Additional comments about a plant's inability to tolerate heat or humidity was taken into consideration.

It is useful to note that zones are a good starting point and reference but are not fine-grained analysis. Many micro-climates can exist within a city, neighborhood, and yard which could alter the "zone" of that location. For the purpose of this project, zone designations are adapted as the starting point when filtering for compatibility since this is likely the approach of the everyday homeowner and common plant manual as well.

Filtering for Zone Compatibility:

- Shrubs that are compatible will have a zone range which includes 6 and 7 to buffer potential changes to Mid-Missouri's current zone of 6. Of the 95 shrub entries, 83 were zone "Compatible Now and in the Future".
- A shrub with a high zone of less than 6 (likely heat intolerant), or a low zone greater than 7 (not winter hardy in near future) was "Incompatible", and 4 shrub entries fell here.
- A shrub with a low zone higher than 7 (not yet winter hardy, but possibly in a climate change future) passaged as "Future Compatible", and 6 shrub entries fit this category.
- Shrubs that are considered "At Risk Under Climate Change" are those at the fringe of the current hardiness zone on the high end (possible intolerance to increased temperatures), and two shrubs fell here with a high zone of 6.

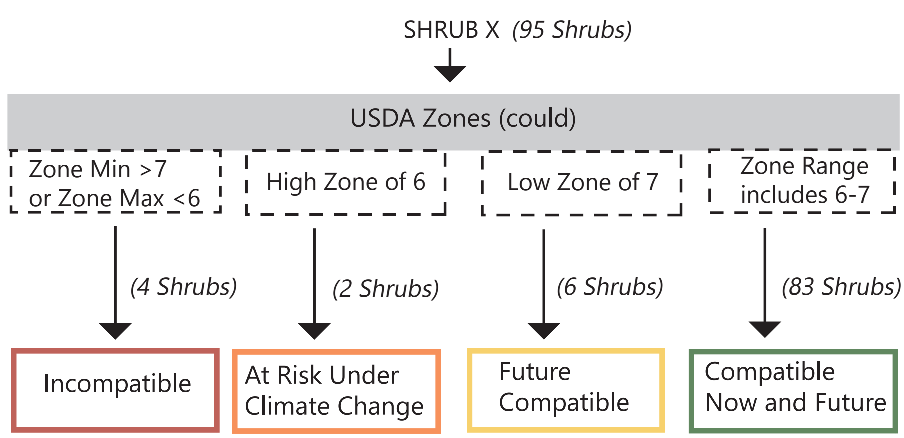
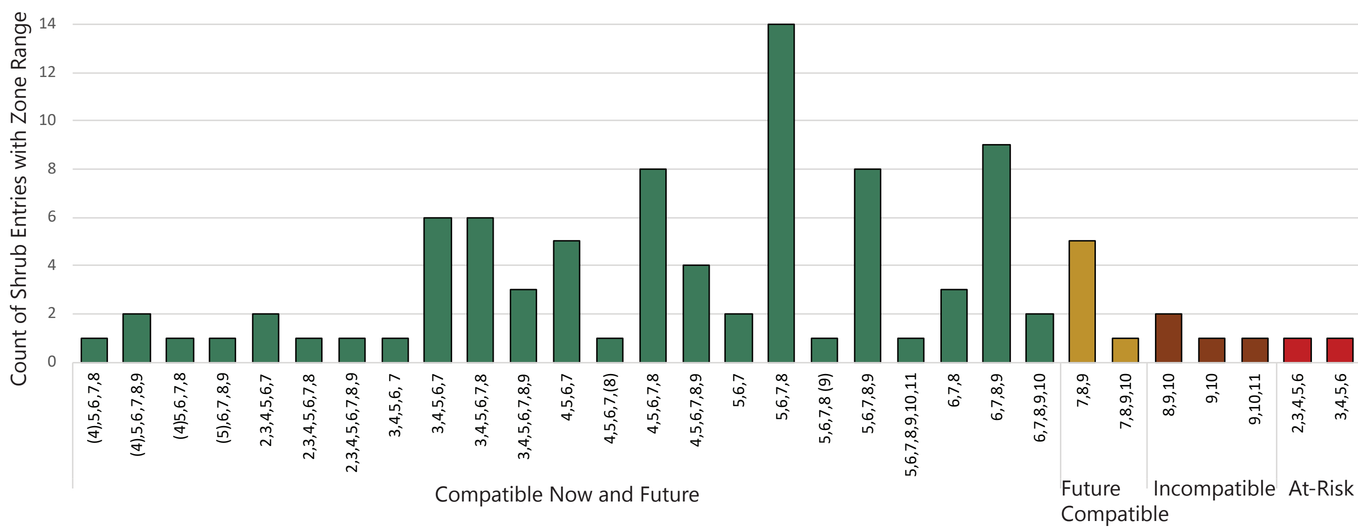


Figure 3.6: Filtering and Organizing Zone Ranges into Compatibility Groups.

Figure 3.7: Count of Shrubs Entering Each Category Based on Zone Range



FILTER 2: INVASIVE QUALITIES

Shrubs that passed the required hardiness levels in the Zone Filter were then filtered based on invasive qualities. Invasiveness is a challenging topic to make judgments on because of the uncertainty of climate change and the response of plants to such changes. It is speculated that climate change will favor plants that are already highly invasive because of their genetic predisposition to adaptations (Dukes et al., 2009). In most situations, it is predicted that invasive plants that are limited currently by winter hardiness will show their zones expand northward, while others may have their ranges decrease because of local decreases in precipitation. Since this uncertainty exists, this project takes precaution against plants that are already invasive or extremely invasive in the United States.

<u>Filtering for Invasiveness:</u>

- A shrub is excluded if...
    - It is already locally invasive
    - It is invasive south of Missouri

> <u>A Note on Terms</u>:
> *Naturalizing* suggests spreading into the wild, but not to the devastating extent as being “invasive”. Naturalizing plants can often be planted in a garden if proper maintenance is conducted to keep the plant in check.

    - It exhibits any tendency to take over native habitat or create monocultures, or it uses animals as a highly effective dispersal method (seeds, berries)
- A shrub passes the filter (remains compatible) if ....
    - It is not invasive
    - It is a non-invasive, or sterile, cultivar of an invasive species
    - It naturalizes or spreads but can be controlled by maintenance and does not remove native habitat
    - It is naturalizing in a habitat very different from Missouri’s and is unlikely to out-compete native species because of this climatic difference
    - It naturalizes in northern zones

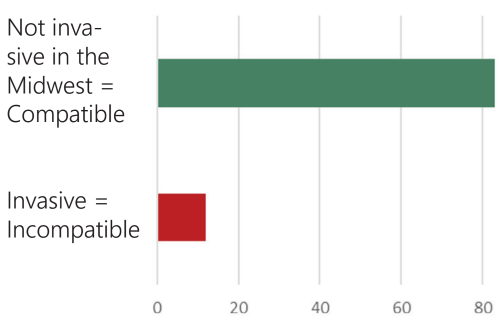


Figure 3.8: Relative number of shrubs identified as invasive out of all shrubs collected from local sources.

With these guidelines, the Invasiveness Filter removed 13 species listed as invasive in the region or with potential to be invasive in the future. These 13 shrubs joined the 4 previously removed from the Zone Filter to complete the Incompatible group with 17/95 (18%) shrubs total (Figure 3.8). At the conclusion of these two filters, 78 shrubs remained, with 71 proclaimed Compatible Now and in the Future, 5 Future Compatible, and 2 At Risk Under Climate Change (Figure 3.9). These organizational groups thus far have been defined only by zone ranges. The following section on scoring takes a deeper look beyond zones at the shrubs defined as Compatible. The 2 shrubs already determined to be At Risk (Elaeagnus commutata and Picea glauca ‘Conica’) do not enter the scoring system because their zone ranges have already indicated stress in current conditions, let alone future conditions. Additionally, this filter was supported by the fact that both shrubs had notes reading ‘struggles in hot, humid conditions’ and range maps confirming a lack of presence south of Missouri. The narrowing of the initial list of shrubs is graphically represented in Figure 3.10.

Filters: Initial Compatibility Filter based on **Hardiness** (can it live here now and in the future?) and **Invasiveness** (should it live here now or in the future?)

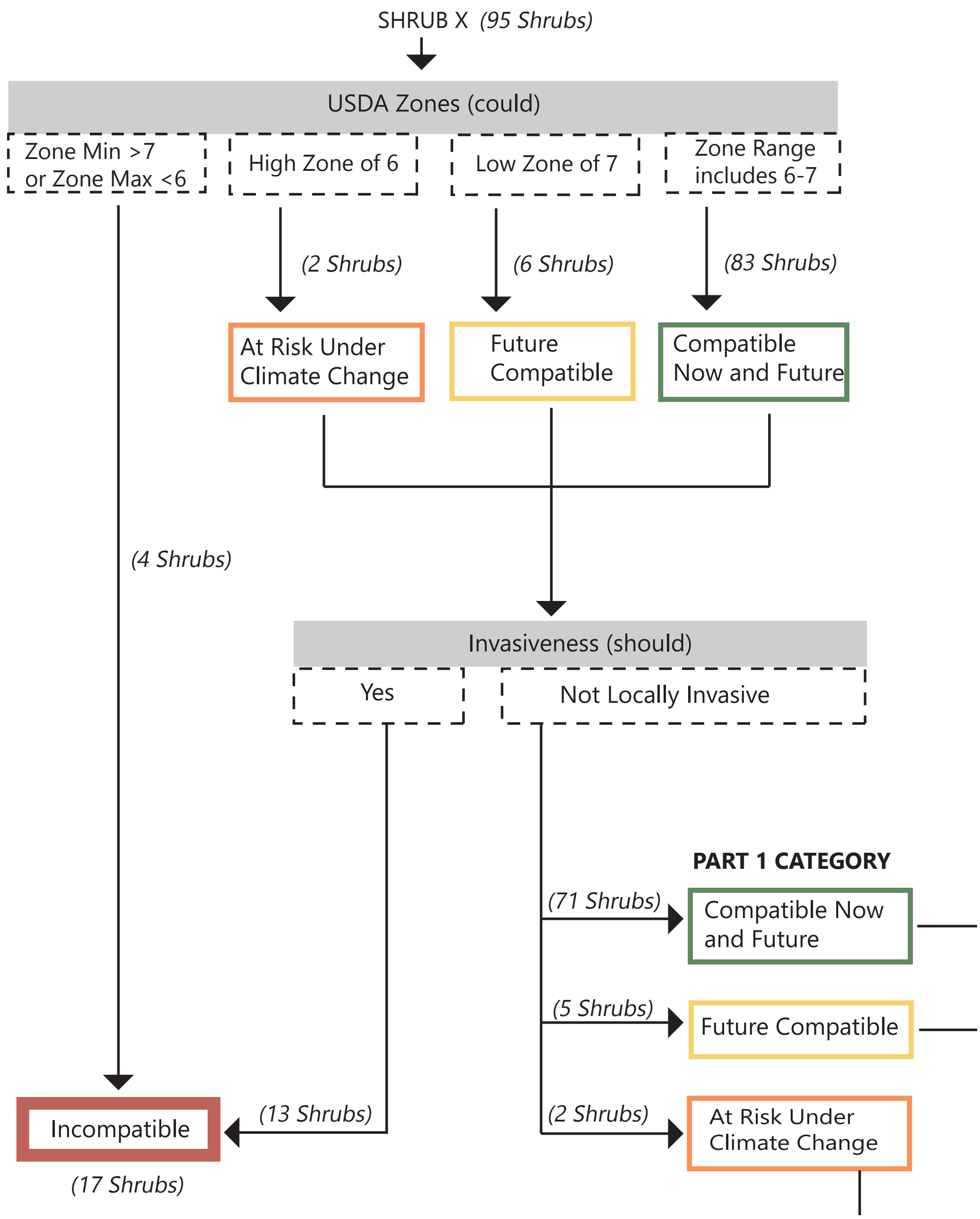


Figure 3.9: Results of Filter 1 and 2 on hardiness zones and invasiveness. One of the 6 Future Compatible shrubs, and 12 of the 83 Compatible Now shrubs were removed due to invasiveness, resulting in the identification of 76 shrubs (78 minus the 2 already at risk) to be further assessed for compatibility.

FILTER 1: USDA ZONES

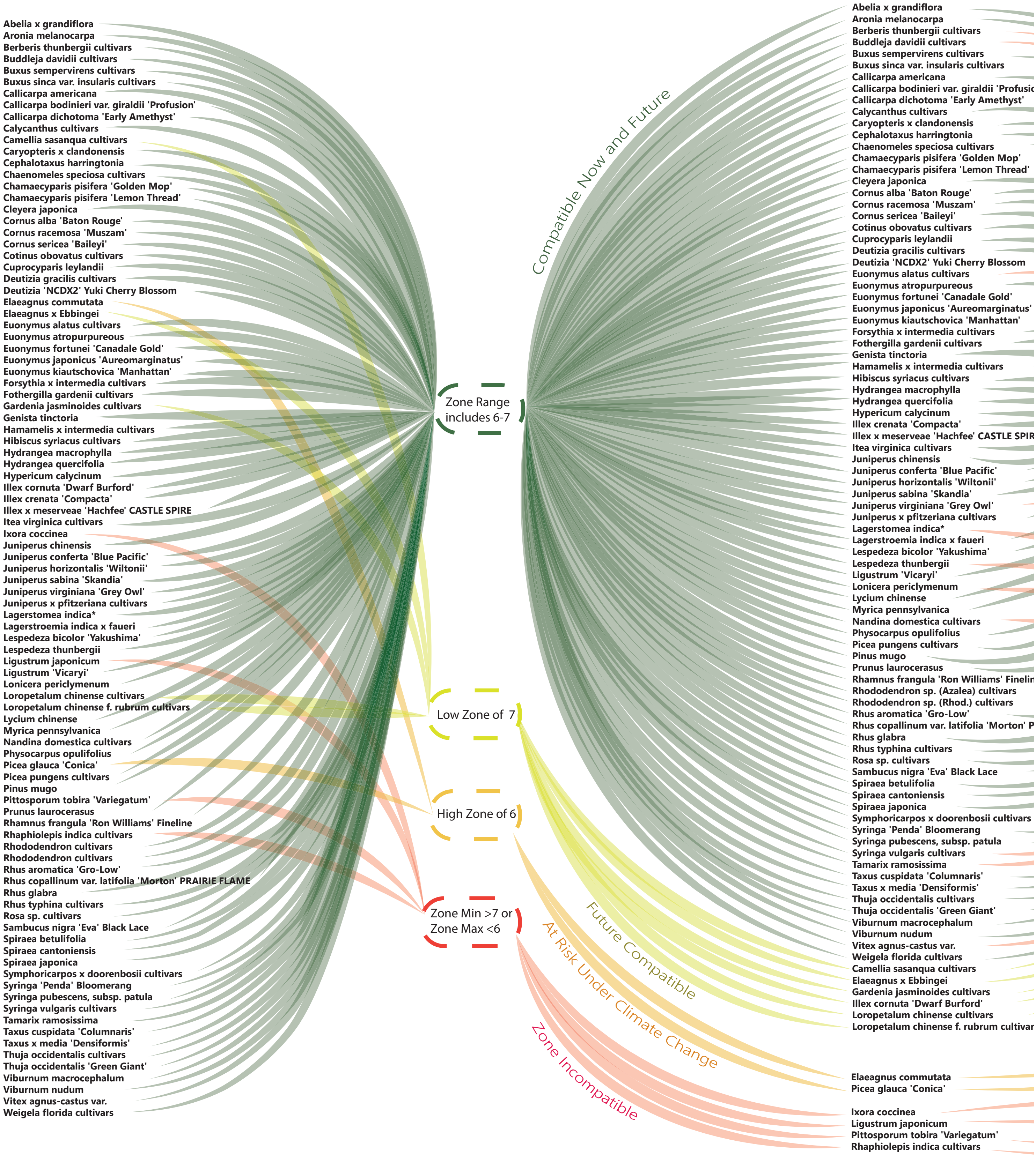
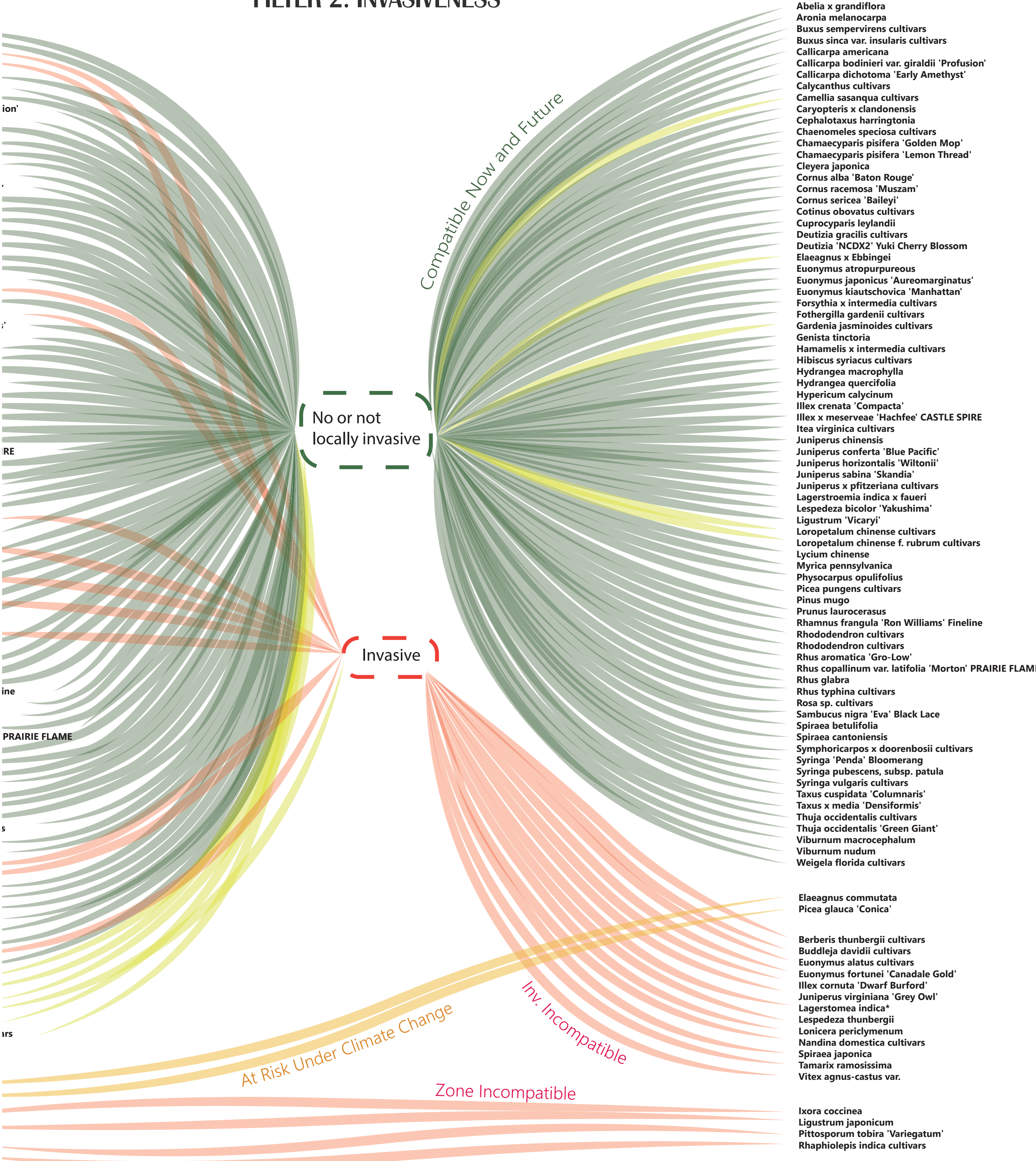


Figure 3.10: Zone and Invasiveness Filters act simultaneously as a removal and organization device.

FILTER 2: INVASIVENESS



SCORING COMPATIBLE SHRUBS FOR ASSESSMENT

All the shrubs entering this next phase can technically (by zone) grow in Missouri now and in a climate change future and theoretically not pose major concerns to the environment in terms of invasiveness. When considering scoring, this project considers all trait vulnerabilities in relation to homeowner inputs. Where a shrub has less climate compatible traits, a homeowner must make up for it in the form of inputs to achieve a level of climate compatibility (Figure 3.11). To future assess plant traits, is helpful to score them based on expected inputs. Traits in this project are divided into two categories: **intrinsic traits** and **external traits**. Intrinsic traits are traits more directly related to inherent plant growth and climate, such as soil moisture, light, water, and climate tolerances. External traits are traits more directly related to homeowner inputs, such as maintenance (concerning growth rate or spreading habit) and pest and disease tolerance. Separating the score allows one to acknowledge which plants are climate compatible due to their unique combination of these traits (Figure 3.12). As with the filters, the resulting scores will be given alongside the method in a step-by-step process.

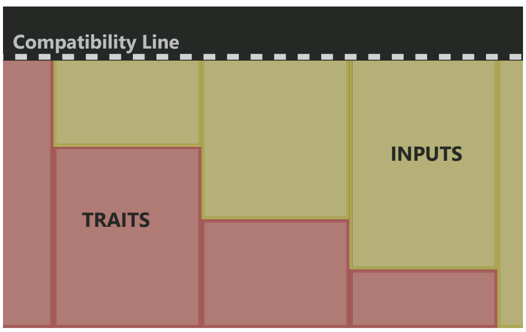


Figure 3.11: Diagram of trait and input relationship to reaching compatibility.

Given the limitations of this project, scoring was directly related to MOBOT data and entries. Figure 3.13 provides an example of the database with important information highlighted and its translation to scoring components.

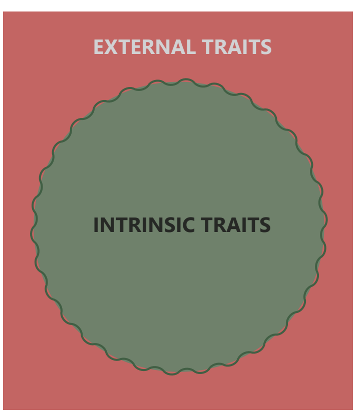


Figure 3.12: Diagram of the intrinsic and external trait relationship.

SCORE 1: INTRINSIC TRAIT SCORE

As described above, the intrinsic score looks at the innate qualities of a plant to survive without inputs. This scoring system identifies three intrinsic traits based on climate change factors for Missouri which could increase a shrub's chance of survival: soil moisture requirement, drought tolerance, and wet soil tolerance. This scoring system intentionally weighs the prospect of increased temperatures and dry

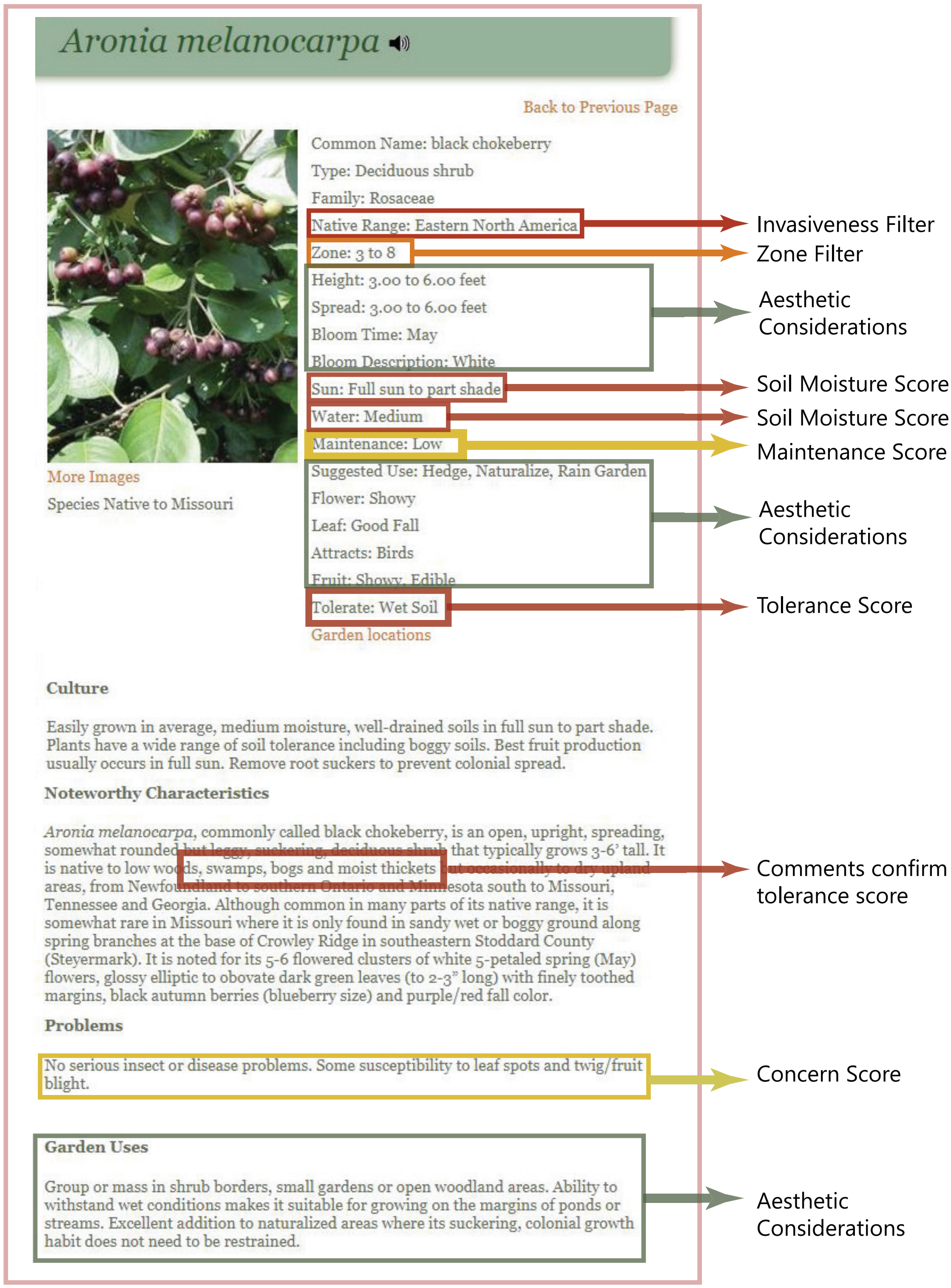


Figure 3.13: Translating Source Information to Filtering and Scoring Components.

soil conditions as more important than other, less certain, primary climate conditions (such as wind throw, snow load intensity, and precipitation increase).

Soil Moisture Score

Scoring soil moisture is an assumption based on climate change conditions. Higher temperatures in the summer combined with increased drought conditions suggest an increase in soil dryness. Using the logic of evapotranspiration, which increases in hot, sunny conditions, a score can be given for plants that tolerate compatible moisture and light conditions. For instance, a plant that requires full sun but has high water requirements (listed as “wet” or “wet to medium” in the MOBOT catalog), will require more water inputs due to evapotranspiration, and when left alone will struggle to survive. Similarly, a plant that needs dry soil and shady conditions will struggle in the winter and spring when precipitation is expected to increase. Shade conditions in this instance will further reduce the chances of evapotranspiration, potentially stressing a plant intolerant of wet conditions. Shrubs that can tolerate compatible extremes (sun and dry, shade and wet) are given the highest score while shrubs that need opposite extremes (sun and wet, shade and dry) receive a low score of 0. The scoring for this section is intentionally weighted higher than other sections because it involves two combined plant traits (Table 3.5).

Table 3.5: Basic Soil Moisture Scoring Principles

		Moisture Requirement		
Light Requirement		Dry/Dry to Medium	Medium	Wet/Wet to Medium
	Full/Full to Part Sun	2	1	0
	Part Sun	1	1	1
	Shade/Shade to Part Sun	0	1	2

Of the 76 shrubs entering the scoring portion of the flow chart, 8 were found to tolerate compatible extremes and received a score of 2. Most shrubs (64/76) fell in between extremes, receiving a score of 1. Only 4 shrub entries required opposite extremes and received a score of 0 (Figure 3.14).

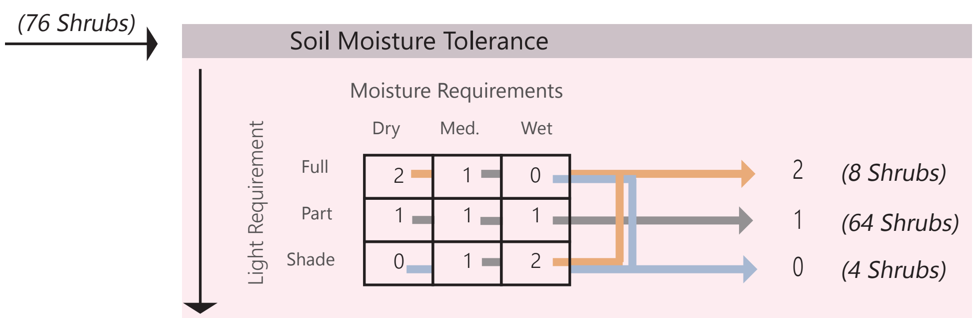


Figure 3.14: Resulting Soil Moisture Score in Flow Chart

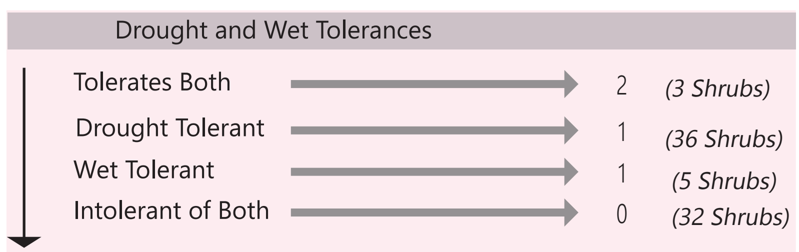
<u>Drought and Wet Tolerance Score</u>

Drought and wet tolerances were scored together as bonus points on top of the soil moisture score. Increases in drought conditions in the summer months will stress many shrub species. Shrubs that currently do not require much additional water outside of summer rain may be stressed under future conditions and require more inputs, such as irrigation, to stay alive. Drought tolerance will be an important characteristic for a shrub to have in the future. If a shrub is considered drought tolerant, it is given plus 1 point. Additionally, precipitation is expected to increase in the winter, spring, and fall months and increase in intensity. If a shrub is intolerant of standing water it will require more inputs, such as soil amendments and grading, to ensure survival. Therefore, tolerance of wet conditions, standing water, or boggy soils was given plus 1 point. Plants tolerant of both conditions received 2 points (the sum of both bonuses), and those intolerant of both conditions received 0 points (Table 3.6). The scoring is set up in this way in the flow chart to identify the exact number and identity of shrubs tolerant of zero, one, or both conditions as opposed to adding tolerances separately and risk double counting shrubs tolerant of both. Using the flow chart as a scoring device (Figure 3.15), 3 shrubs (4%) were found tolerant of both conditions, 36 shrubs (47%) were tolerant of just drought conditions, and 5 shrubs (7%) were tolerant of just wet conditions. Less than half the shrubs were intolerant of both conditions at 32 shrubs (42%).

Table 3.6: Tolerance Scoring Principles

Tolerates both drought and wet conditions	+ 2
Tolerates Drought	+ 1
Tolerates Wet	+1
Intolerant of both conditions	+0

Figure 3.15: Resulting Tolerance Score Results in Flow Chart



SCORE 2: EXTERNAL TRAIT SCORE

The external trait score provides a way to assess the potential success of a shrub apart from its intrinsic survival traits (soil moisture, drought, and wet tolerances). External traits are shrub qualities more directly related to the motivations and values of the homeowner and may improve or reduce the chance a shrub will thrive after planting. Outside of irrigation, which resolves incompatibility soil moisture or drought, high maintenance and “concerns” (insects and disease) are the traits most closely linked to homeowner input.

Maintenance

Everyone wants a low maintenance yard, and there are numerous manuals, books and blogs out there on how to go about designing a low maintenance yard, and suggestions vary across the board. Some say the answer for low maintenance is more of a stylistic choice rather than embodied in the traits of an individual plant. These groups promote planting in swathes as opposed to individual species so that the entire group can all be maintenanced at the same time and manner. Others suggest the minimalistic use of plants with a focus on shrubs, trees, and mulch as these will be less demanding than perennials, annuals, or turf grass[4].

While these tips are useful, some individual shrub species are inherently going to be more work than others depending on their growth rate, growth habit, and any byproducts of growth (seeds, fruits, shoots)[5]. The reality is that the homeowner or designer will have to choose what best suits their maintenance desires and understand that all landscapes require maintenance.

Given the limitations of this project, MOBOT declarations for maintenance were taken at face value. A shrub declared "low maintenance" (refer to Figure 3.13) by MOBOT or a secondary source is given a bonus under the assumption that lower maintenance equals less input from the homeowner to insure its health and survival. Scoring or relevance of this trait is somewhat user dependent and should be adjusted to fit the individual's willingness for maintenance. Of the 76 shrubs going through this filter, 55 (72%) received 1 point for being low maintenance. Medium maintenance shrubs (18/76) received no bonus with 0 points added, and 3 shrubs received -1 point for being high maintenance (Figure 3.16).

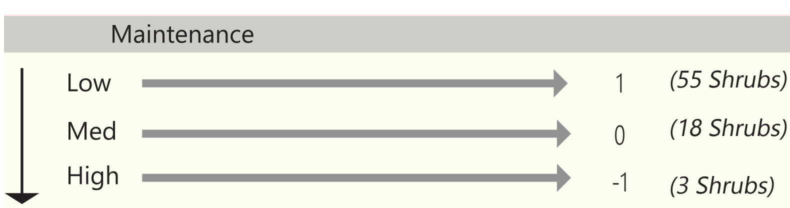


Figure 3.16: Resulting maintenance scores as represented in the flow chart.

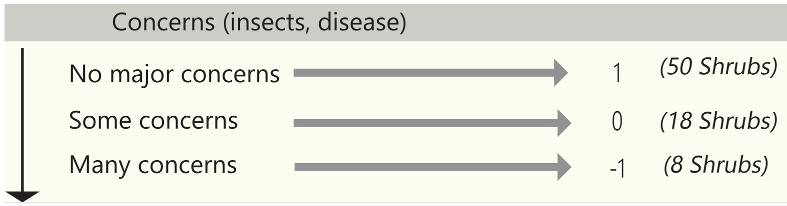
Concerns

The final part of the scoring system considers concerns, meaning susceptibility to insects and disease. As described in the Literature Review, it is suspected that climate change will result in increased damage by native and non-native pests due to warming temperatures and longer frost-free seasons. This fact is considered in this section on external traits because the reaction against insect and disease is the application of pesticides or other alternative methods. While there is some uncertainty on the persistence of current pests, if a shrub currently experiences many pest and disease issues, it may experience similar issues in the future. A shrub with many concerns received -1 points, 0 points if it had some insect and disease issues, and 1 point if there were no major concerns. Technically, a plant cannot be entirely pest free, so judgment of MOBOT information was used to set limits on what too many issues looked like (Table 3.7). Of the 76 shrubs, 50/76 had no major concerns (65%), 18/76 (24%) had some concerns, and 8/76 (11%) had major concerns (Figure 3.17).

Table 3.7: Correlation of MOBOT description to Concerns score.

Plant	**Problem Description in MOBOT**	**Score**
Myrica pennslyvanica Bayberry	"No serious insect or disease problems."	No Major Concerns = 1 point
Hamamelis x intermedia Witch Hazel	"No serious insect or disease problems. Watch for gall aphids, weevils, scale, leafroller and leafminer. Potential diseases include powdery mildew, occasional leaf spots and rots.	Some Concerns = 0 points
Syringa vulgaris Common Lilac	"Powdery mildew frequently attacks in summer...Common lilac is susceptible to a number of additional disease problems including blights, leaf spots, wilts, ring spot virus and honey fungus. Potential insect pests include scales, borers, leaf miners, thrips and caterpillars."	Many Concerns = -1 point

Figure 3.17: Resulting concern scores as represented in the flow chart.



TOTAL SCORE

The second part of the flow chart scored compatible shrubs with the goal of using a basic scoring system as another organizational tool to improve the accuracy of the previously determined groups. Of the 76 shrubs thought to be Compatible Now and/or in the Future, 20 were identified through the scoring as having traits less than desirable for climate change conditions. The two shrubs previously identified as At Risk due to their zone ranges joined the newly identified 20 in the "At Risk Under Climate Change" category for a total of 22 At Risk shrubs (Figure 3.18).

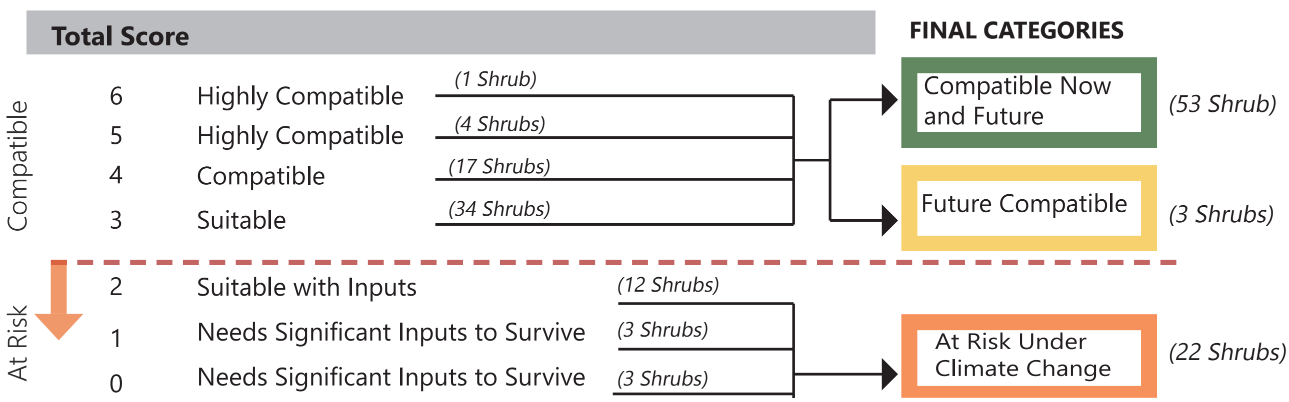


Figure 3.18: Scoring part of the flow chart with results from all scoring sub-sections. The score total section shows the re-sorting of shrubs into their previous categories. Twenty shrubs previously thought to be Compatible or Future Compatible were found to be less suitable (total score 2 or less), and thereby At Risk, due to their traits. Two shrubs previously identified At Risk due to zone range joined the 20 identified by the scoring to make a total of 22 At Risk shrubs.

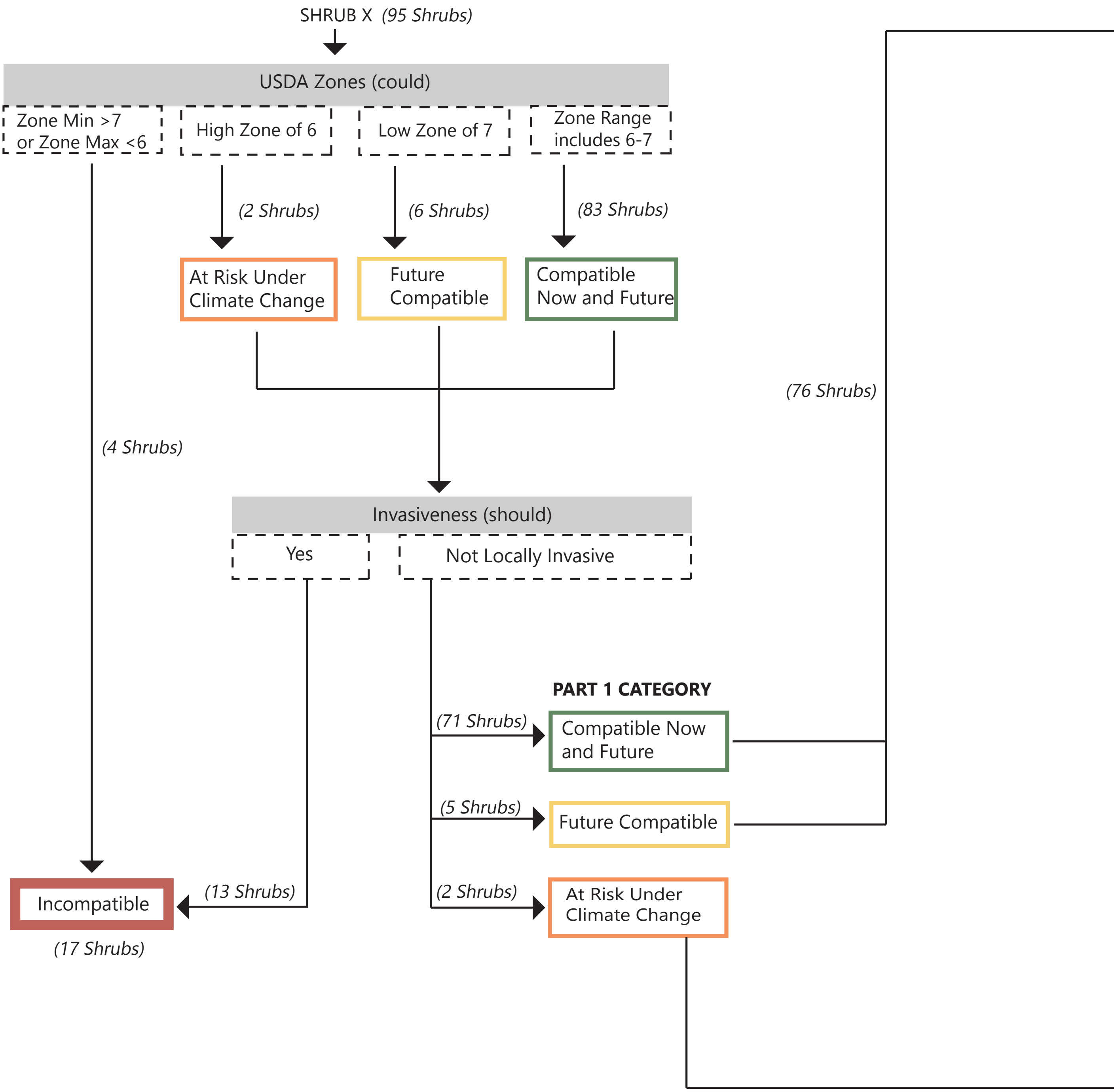
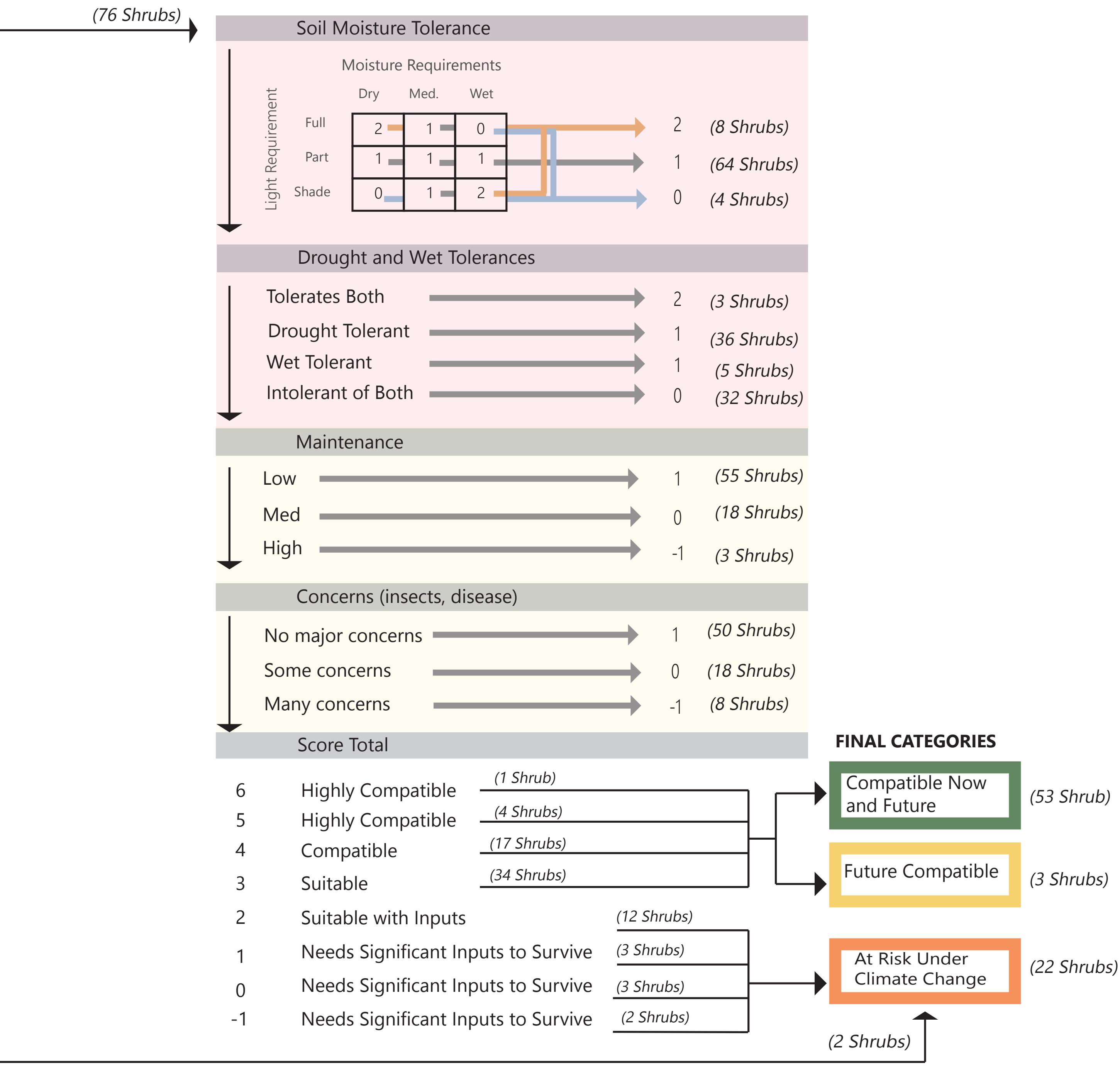


Figure 3.19: Flow Chart with Filters and Scoring Results. Pink background in the scoring section denotes the intrinsic trait sub-scores, and the yellow the external trait subscores.



(76 Shrubs)
Soil Moisture Tolerance
Moisture Requirements
Dry
Med.
Wet
Light Requirement
Full
Part
Shade
2
1
0
1
1
1
0
1
2
2 (8 Shrubs)
1 (64 Shrubs)
0 (4 Shrubs)
Drought and Wet Tolerances
Tolerates Both 2 (3 Shrubs)
Drought Tolerant 1 (36 Shrubs)
Wet Tolerant 1 (5 Shrubs)
Intolerant of Both 0 (32 Shrubs)
Maintenance
Low 1 (55 Shrubs)
Med 0 (18 Shrubs)
High -1 (3 Shrubs)
Concerns (insects, disease)
No major concerns 1 (50 Shrubs)
Some concerns 0 (18 Shrubs)
Many concerns -1 (8 Shrubs)
Score Total
6 Highly Compatible (1 Shrub)
5 Highly Compatible (4 Shrubs)
4 Compatible (17 Shrubs)
3 Suitable (34 Shrubs)
2 Suitable with Inputs (12 Shrubs)
1 Needs Significant Inputs to Survive (3 Shrubs)
0 Needs Significant Inputs to Survive (3 Shrubs)
-1 Needs Significant Inputs to Survive (2 Shrubs)
FINAL CATEGORIES
Compatible Now and Future (53 Shrub)
Future Compatible (3 Shrubs)
At Risk Under Climate Change (22 Shrubs)
(2 Shrubs)

EVALUATING TOTAL SCORE

The score total has a range between -2 to 6, although no shrub earned a value of -2, which would have meant the shrub scored a 0 intrinsic trait score and -2 external trait score. A score of 6 was achieved by 1 plant, meaning that it is highly compatible for climate change. Discerning the in-between scores was more difficult, as it is subjective where the cutoffs for "compatibility". For each score below, possible score distributions (intrinsic score + external score) will be given to clarify why a score of 3 served as the cutoff for a compatible shrub. The main reason is that a score of 3 ensures a shrub has at least one point carried over from the intrinsic trait score, whether it's from soil moisture, drought tolerance, or wet tolerance to aid in survival (Figure 3.20)

6 – Highly compatible (1 shrub). Shrubs must have earned all points (4+2) to earn a 6.

5 – Highly compatible (4 shrubs). Point possibilities: (4+1) or (3+2).

4 – Compatible (17 shrubs). Point possibilities: (4+0), (3+1), or (2+2).

3 – Suitable (34 shrubs). Point possibilities: (5-2), (4-1), (3+0), (2+1), or (1+2).

At Risk with No Inputs

2 – Suitable with inputs (12 shrubs). Point possibilities: (4-2), (3-1), (2+0), (1+1), or (0+2).

1 – Needs significant inputs (3 shrubs). Point possibilities: (3-2), (2-1), (1+0), (0+1).

0 – Needs significant inputs (3 shrubs). Point possibilities: (2-2), (1-1), or (0+0).

-1 – Needs significant inputs (2 shrubs). Point possibilities: (1-2) or (0-1).

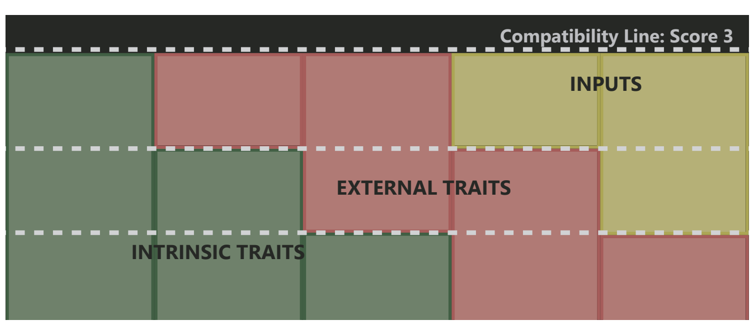


Figure 3.20: Achieving compatibility with intrinsic and external score contributions. When a shrub scores below a 3, it indicates that additional inputs will likely be required to succeed in climate change.

The scoring was separated into two sections to better understand the relationship between a shrubs intrinsic traits and external traits. However, all traits that were scored can have a reciprocal input to offset the vulnerability. For example, a shrub that has poor soil moisture compatibility will require more irrigation to survive if it needs full sun and a lot of water. Similarly, a shrub that wants little water and full shade will need inputs upfront in terms of soil amendments and good drainage to ensure its survival in wet months of winter and spring. Figure 3.21 compares the impact of the intrinsic trait score on the overall score of a shrub via this method. There is an overall positive correlation between intrinsic trait score and final score, apart from 6 shrubs whose final scores were lower than their intrinsic score.

On the other hand, a plant can be entirely compatible to the growing conditions of the region but have a weakness to insects or diseases, making it a poor choice unless pesticides are used. Maintenance to improve growing conditions and the prevention of pests are both secondary climate traits (external traits) which inputs can modify. Figure 3.22 shows all the entries organized by final score, where the contribution of each trait score is illustrated. For example, most shrubs scoring a 4 were 4s because they scored a 2 in their external trait score (2+2) as opposed to having better survival traits (higher intrinsic trait score).

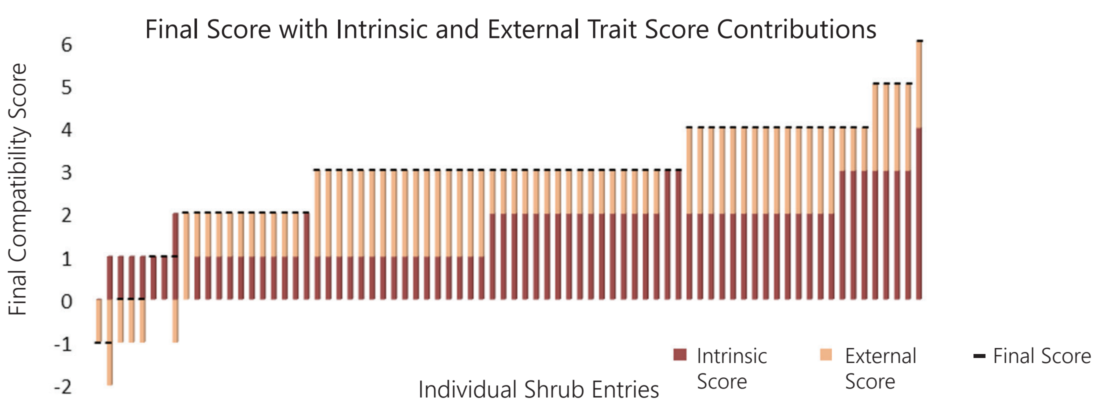


Figure 3.21: Total score with intrinsic and external score contributions. The black bar represents the final score for that shrub entry.

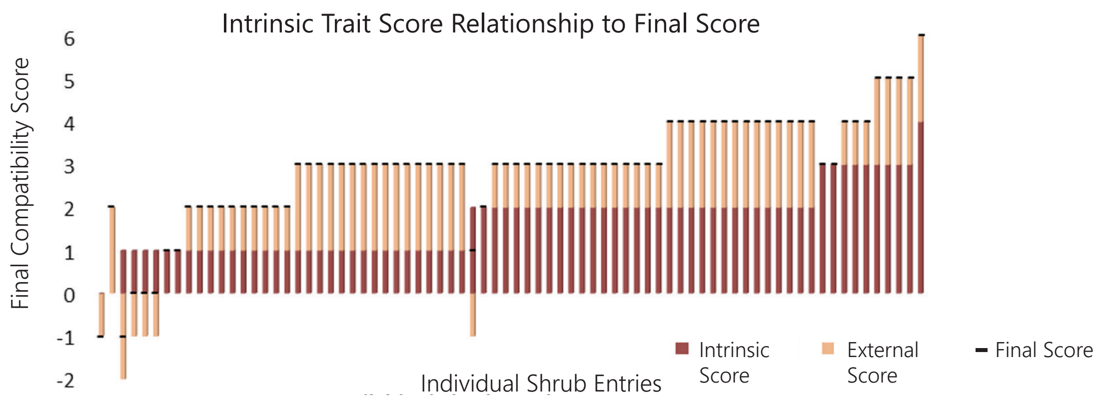


Figure 3.22: Influence of the Intrinsic Trait Score on Overall Compatibility Score.

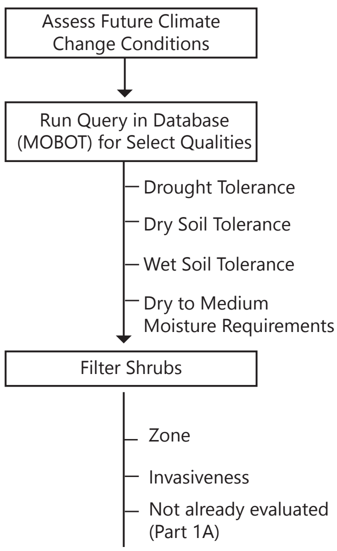
Table 3.8: Species Most Compatible to Climate Change

Common Name	Latin Name	Intrinsic Trait Score	External Trait Score	Compatibility Score
Bayberry	Myrica pensylvanica	4	2	6
Dogwood, Gray	Cornus racemosa 'Muszam'	3	2	5
Sumac, Fragrant	Rhus aromatica 'Gro-Low'	3	2	5
Bushclover	Lespedeza bicolor 'Yakushima'	3	2	5
Sumac, Dwarf	Rhus copallinum var. latifolia 'Morton' PRAIRIE FLAME	3	2	5
Ninebark	Physocarpus opulifolius	3	1	4
Chokeberry	Aronia melanocarpa	2	2	4
Sumac, Smooth	Rhus glabra	3	1	4
Sumac, Staghorn*	Rhus typhina cultivars	3	1	4
Arborvitae 'Green Giant'	Thuja occidentalis 'Green Giant'	2	2	4
Cleyera	Cleyera japonica	2	2	4
Beautyberry	Callicarpa dichotoma 'Early Amethyst'	2	2	4
Crape Myrtle, Dwarf	Lagerstroemia indica x faueri	2	2	4
Deutzia, Yuki Cherry Blossom	Deutizia 'NCDX2' Yuki Cherry Blossom	2	2	4
Dyer's Greenwood	Genista tinctoria	2	2	4
Forsythia*	Forsythia x intermedia cultivars	2	2	4
Snowberry*	Symphoricarpos x doorenbosii cultivars	2	2	4
Viburnum, Chinese Snowball	Viburnum macrocephalum	2	2	4
Spirea, Reeves	Spiraea cantoniensis	2	2	4
Bluebeard	Caryopteris x clandonensis	2	2	4
Sawara/Japanese Falsecypress 'Lemon Thread'	Chamaecyparis pisifera 'Lemon Thread'	2	2	4
Sawara/Japanese Falsecypress 'Mops'	Chamaecyparis pisifera 'Golden Mop'	2	2	4

Table 3.9: Species Most At-Risk to Climate Change

Common Name	Latin Name	Intrinsic Trait Score	External Trait Score	Compatibility Score
Gardenia*	Gardenia jasminoides cultivars	1	-2	-1
Elderberry, Black Lace	Sambucus nigra 'Eva' Black Lace	0	-1	-1
Rhododendron*	Rhododendron cultivars	1	-1	0
Camellia*	Camellia sasanqua cultivars	1	-1	0
Lilac*	Syringa vulgaris cultivars	1	-1	0
Dogwood, Red Twig	Cornus sericea 'Baileyi'	1	0	1
Holly, Japanse Compacta	Illex crenata 'Compacta'	2	-1	1
Pine, Mugo	Pinus mugo	1	0	1
Euonymus Eastern Wahoo	Euonymus atropurpureous	1	1	2
Beautyberry, American	Callicarpa americana	1	1	2
Virginia Sweetspire*	Itea virginica cultivars	0	2	2
Euonymus, Golden	Euonymus japonicus 'Aureomarginatus'	1	1	2
Common Boxwood*	Buxus sempervirens cultivars	1	1	2
Korean Boxwood*	Buxus sinca var. insularis cultivars	1	1	2
Alder Buckthorn	Rhamnus frangula 'Ron Williams' Fineline	1	1	2
Althea/Rose of Sharon*	Hibiscus syriacus cultivars	2	0	2
Bigleaf Hydrangea	Hydrangea macrophylla	1	1	2
Leyland Cypress	Cuprocyparis leylandii	1	1	2
Yew, Japanese	Taxus cuspidata 'Columnaris'	1	1	2
Euonymus Manhattan	Euonymus kiautschovica 'Manhattan'	1	1	2
American Silverberry	Elaeagnus commutata	NA	NA	NA
Spruce, Alberta Dwarf	Picea glauca 'Conica'	NA	NA	NA

PART 1B: Identify Potential Shrubs



3.4 PART 1B: GATHERING POTENTIAL SHRUBS FOR CLIMATE CHANGE

The second part of this project aims to identify shrubs that may be compatible to climate change conditions and were not currently distributed in the area. The goal of this step was to add to the palette of compatible plants and identify what groups were currently being left out of common distribution. The desired traits included:

- Dry to medium moisture requirement
- Dry soil tolerant
- Wet soil tolerant
- Drought tolerant

To generate this list, the MOBOT Database was used because of its locally oriented content, vast amount of research, and efficient search operations. The following table (Table 3.10) illustrates the results of the separate queries that were run through the database.

Table 3.10: Query Results from MOBOT

Type	**Moisture Requirement**	**Tolerance**	**Number of Shrubs**
Deciduous	Dry to medium	Dry soils	60
Deciduous	Dry to medium	Wet soils	2
Deciduous	Dry to medium	Drought	79
Broadleaf Evergreen	Dry to medium	Dry soils	32
Broadleaf Evergreen	Dry to medium	Wet soils	0
Broadleaf Evergreen	Dry to medium	Drought	40
Needled Evergreen	Dry to medium	Dry soils	4
Needled Evergreen	Dry to medium	Wet soils	0
Needled Evergreen	Dry to medium	Drought	6
Total			223 potentially compatible shrubs

The 223 potentially compatible shrubs were filtered according to zone and checked for invasive qualities under the same assumptions and method as Part 1A. Most shrubs were eliminated based on zone, and numerous same-species cultivar groups were removed because of invasiveness. Others were eliminated because they did not fit the definition of a shrub as set by this project, such as vines, grasses, and small trees. Additionally, any shrub that was previously evaluated in Part 1A were eliminated, resulting in 28 potential shrubs to use in Missouri that were not currently widely distributed (Table 3.11). Of the 28, 3 were appropriate for future use (Zone 7), and 3 were noted to die

Table 3.11: Shrubs not popularly distributed in Columbia with traits compatible for climate change

Common Name	Latin Name	Native?
Prickly Thrift	Acantholimon ulicinum	
Coastal Serviceberry	Amelanchier obovalis	Yes - eastern US
Lead Plant	Amorpha canescens	Yes
Dwarf Chapparal-Broom*	Baccharis pilularis 'Pigeon Point'	Yes - western US
Barberry	Berberis × mentorensis	hybrid cross
Barberry	Berberis × stenophylla 'Corallina Compacta'	hybrid cross
Barberry	Berberis japonica	
Three-leaf Oregon Grape*	Berberis trifoliolata	Yes- southwestern US, mexico
Rose Peashrub	Caragana rosea	
California Lilac	Ceanothus × pallidus 'Minmari' MARIE BLEU	hybrid cross
New Jersey tea	Ceanothus americanus	Yes
California Lilac*	Ceanothus 'Concha'	hybrid
Mountain Mahogany	Cercocarpus montanus	Yes - western US
Cumberland Rosemary	Conradina verticillata	Yes - southeast US
Aralia	Eleutherococcus sieboldianus 'Variegatus'	
Mint- shrub	Elsholtzia stauntonii	
English Lavender	Lavandula angustifolia 'KERLAVANGEM' SWEET ROMANCE	
Russian Sage	Perovskia atriplicifolia 'WALPPB' PEEK-A-BLUE	
Mock Orange	Philadelphus microphyllus 'June Bride'	Yes - western US
Firethorn	Pyracantha angustifolia 'Gnome'	
Chinese Sumac	Rhus chinensis	
Winged Sumac	Rhus copallinum	Yes - eastern US
Dwarf Sumac	Rhus copallinum var. latifolia	Yes - parents are native
Lavender Cotton	Santolina chamaecyparissus	
Bladdernut	Staphylea trifolia	Yes - eastern US
Wall Germander	Teucrium chamaedrys	
Blackhaw Viburnum	Viburnum prunifolium	Yes - eastern and central US
Adam's Needle	Yucca filamentosa	Yes -southern US
Spanish Dagger	Yucca gloriosa 'Variegata'	Yes -southern US

*Indicates future compatibility, with low hardiness zone of 7.

back to the ground in temperatures below zero, a circumstance likely in Missouri now.

Within this list, 16/28 (57%) are native to the United States or are hybrids with native parents. and 2/28 (7%) were cultivated crosses that have no native region, generating a total of 64% replacement shrubs that are local to the United States. This presents a strong argument that native shrubs may be more adaptive to climate change conditions when invasive non-natives are removed from the equation. Of the potential shrubs, only 3 were unable to be planted now, suggesting that looking to southern zones may be less important than extending the popularity of native shrubs in the horticultural market. The following section will use these potential plants along with results from Part 1A to discuss potential trends in climate change plant palettes.

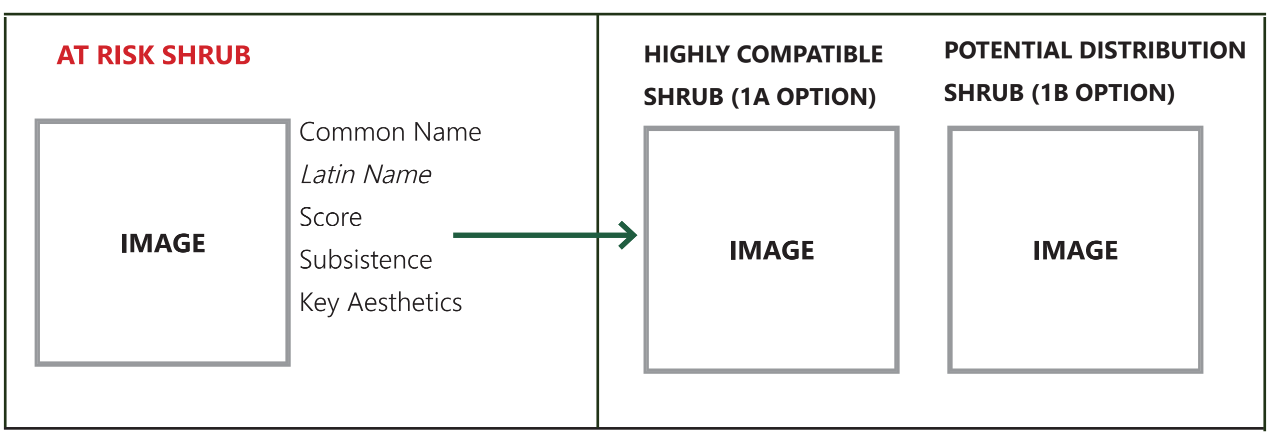
3.5 PART 2: REPLACEMENT & ALTERNATIVE DESIGN

REPLACEMENT

Part 1B of the Methods generated a list of potentially useful, climate change adapted shrubs to utilize in design. While there is uncertainty inherent in climate change and its effect on individual plants, there is a good chance that the traits these shrubs were selected for will be beneficial to their survival. Thus far, this project has generated a score for different shrub species and identified the most Compatible shrubs, the most At Risk shrubs, and underutilized, potentially useful shrubs. This section addresses possible uses and implications of this information.

It has been previously established that there are many ways to design and plan for climate change at the residential scale. The simplest way is to look at individual plants, identify struggling species, and replace them with a similar species to maintain a common aesthetic. Because the aesthetic of the typical residential landscape in the Columbia can be minimalistic (favoring turf, trees, and foundation shrubs), this is likely a popular approach by many homeowners, especially ones looking to maintain their yard similar to current practice. The 22 species declared At Risk Under Climate Change are displayed in subsequent pages with climate compatible alternatives chosen from the list of highly compatible currently supplied shrubs in Columbia, and the compatible potential shrubs currently under-supplied in Columbia. These pairing are simply options for replacement based on some of the main aesthetic attributes of the shrubs and are by no means the only option to utilize. The main aesthetic attributes were assessed visually, by observation in design, and through MOBOT description, and appear next to the At Risk Shrub. Figure 3.23 describes the layout of these pairings.

Figure 3.23: Diagrammatic simplification of the following pages. The shrubs in a shared row relate to each other, identifying the At Risk shrub (left) and two replacement options sourced from Part 1A and Part 1B results (right).



Page Spread

SHOWY FLOWERS

AT RISK SHRUBS

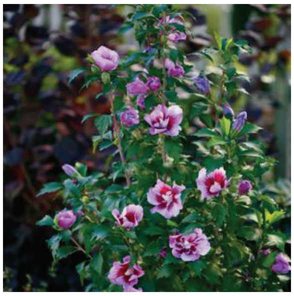


Image sourced from www.vanes-sennursery.com

Althea
Hibiscus syriacus
Score: 2
Deciduous
Naturalizing
Aesthetic: Showy pink flowers, group plantings, informal hedge.

Image sourced from www.exten-sion.uga.edu

Bigleaf Hydrangea
Hydrangea macrophylla
Deciduous
Score: 2
Aesthetic: Showy pink flower clusters, group plantings, hedge.

Image sourced from www.gardenia.net

Gardenia
Gardenia jasminoides
Evergreen
Score: -1 (*future comp.)*
Aesthetic: Showy white flower clusters, specimen, potted or indoors in Missouri.

Image sourced from www.plants-rescue.com

Common Lilac
Syringa vulgaris
Deciduous
Score: 0
Aesthetic: Showy, fragrant flowers vary in color, pollinator and bird attractor.

HIGHLY COMPATIBLE ALTERNATIVES

1A Options (Commonly avaiable)

Image sourced from www.boethingtreeland.com

Dwarf Crape Myrtle
Lagerstormea indica x faueri
Score: 4
Deciduous
Aesthetic: Tree or shrub form, attractive bark, showy pink flowers, specimen.

Image sourced from www.growers-solution.com

Chinese Snowball Viburnum
Viburnum macrocephalum
Deciduous
Score: 4
Aesthetic: Specimen, shrub borders, foundations, hedges.

Image soured from www.nurcar.com

Reeves Spirea
Spiraea cantoniensis
Deciduous
Score: 4
Aesthetic: Pollinator, massing or specimen, foundations, informal hedge.

Image sourced from www.monrovia.com

Bluebeard
Caryopteris x clandoensis
Deciduous
Score: 4
Aesthetic: Fragrant, showy flowers summer to fall, borders, massed, low hedge.

1B Options (Less Commonly Available)

Image sourced from www.amazon.com

Mint-shrub
Elsholtzia stautonii
Deciduous
Zone 4-8
Full sun, dry soils, drought, low maintenance, no major concerns.
Aesthetic: Fall flowers, shrub or perennial borders.

Image sourced from www.proven-winners.com

California Lilac
Ceanothus 'concha'
Deciduous
Zone 7-10
Western US native
Full sun, dry soils, drought, med. maintenance, no major concerns.
Aesthetic: Shrub borders, native gardens, foundations, hedge.

Image sourced from www.prairie-break.blogspot.com

Prickly thrift
Acantholimon ulicinum
Evergreen
Zone 4-8
Full sun, dry soils, drought, med. maintenance, no major concerns
Rock or alpine style gardens, showy flowers.

Image sourced from www.proven-winners.com

California Lilac
Ceanothus x pallidus 'Minmari' MARIE BLUE
Deciduous
Zone 6-9
Full sun, dry soils, drought, low mainteance, no major concerns.
Use: Hedge, showy, shrub borders, native plant gardens.

Image courtesy of Keith Johannon, www.scholar.lib.vt.edu

Rhododendron
Rhododendron sp.
Evergreen
Score: 0
Aesthetic: Showy, massing, shrub borders, shade gardens, foundation specimen, evergreen structure.

Image courtesy of Keith Johannon, www.scholar.lib.vt.edu

Sasanqua Camellia
Camellia sasanqua
Evergreen
Score: 0 (*future comp.)*
Aesthetic: Showy, hedge, mixed borders, lawn accent, hedges, espalier, bonsai, evergreen structure.

DECIDUOUS NATIVES

Image courtesy of Hugh Conlon, www.whatgrowsthere.com

Beautyberry
Callicarpa americana
Deciduous
Score: 2
Aesthetic: Winter interest, arching form, natural area borders.

Image courtesy of George Weigel, www.georgeweigel.net

Virginia Sweetspire
Itea virginica
Score: 2
Deciduous
Aesthetic: Specimen or massing, shrub borders, foundations, natural area borders.

Image sourced from www.jacksonandperkins.com

Deutzia
Deutzia 'NCDX2' Yuki Cherry Blossom
Deciduous
Score: 4
Aesthetic: Foundation plantings, shrub groups, massing, open woodland areas, or informal hedge.

Image sourced from www.monrovia.com

Golden Barberry/Rosemary Barberry
Berberis x stenophylla 'Corallina Compacta'
Evergreen
Zone 6-9
Full sun, dry soils, drought, low maintenance, no major concerns.
Aesthetic: Compact low hedge, borders, rock gardens, foundation, bonsi.

Image sourced from www.jacksonandperkins.com

Deutzia
Deutzia 'NCDX2' Yuki Cherry Blossom
Deciduous
Score: 4
Aesthetic: Foundation plantings, shrub groups, massing, open woodland areas, or informal hedge.

Image sourced from www.sunlightgardens.com

Cumberland Rosemary
Conradina verticillata
Evergreen
Zone 6-8
Southeast US native, *currently listed as Threatened by USFWS* Full sun, dry soils, drought, med. maintenance, no major concerns.
Aesthetic: Rock gardens, native plant gardens, bank stabilization.

Image sourced from www.brokenarrownursery.com

Beautyberry
Callicarpa dichotoma 'Early Amethyst'
Deciduous
Score: 4
Aesthetic: Showy fruit persists into winter, massing, hedge, borders, bird gardens.

Image courtesy of Stephanie Brundage, Lady Bird Johnson Wildflower Center.

Winged Sumac
Rhus copallinum
Deciduous
Eastern US native
Zone 4-9
Full to part shade, dry/medium water, medium maintenance, some concerns.
Aesthetic: Informal, dry naturalizing areas, woodland margins, somewhat weedy for garden use.

Image courtesy of Lake County Nursery, www.plants.pecksgreenthumb.com

Grey Dogwood
Cornus racemosa 'Muszam'
Deciduous
Score: 5
Aesthetic: Birds and butterfly attractor, rain garden, group planting near wild areas, native plant garden, trim for informal hedge.

Image sourced from www.missouribotanicalgarden.org

New Jersey Tea
Ceanothus americanus
Deciduous
Zone 4-8
Full to part sun, dry soils, drought, low maintenance, no major concerns.
Uses: Native plant gardens, ground cover, rocky slopes or banks.


Image sourced from www.www.gardens4you.ie

Common Boxwood
Buxus sempervirens
Evergreen
Score: 2
Aesthetic: Hedge, massing, formal gardens, topiary, evergreen structure.


Image sourced from www.daves-garden.com

Korean Boxwood
Buxus sinca var. insularis
Evergreen
Score: 2
Aesthetic: Hedge, massing, ground cover, borders and foundations.


Image sourced from www.mid-landhort.co.nz

Japanese Holly
Illex crenata
Evergreen
Score: 1
Aesthetic: Hedge, massing, borders, foundations.


Image sourced from www.mon-rovia.com

Euonymus Golden
Euonymus japonicus 'Aureomarginatus'
Evergreen
Score: 2
Aesthetic: Hedge, specimen, accent color, woodland margins.

Image sourced from www.exten-
sion.umass.edu

Dwarf Fragrant Sumac
Rhus aromatica 'Gro-Low'
Deciduous
Score: 5
Aesthetic: Bird and butterfly attraction, native plant gardens, informal hedges, bank stabalizations.

Image sourced from www.plant-
master.com

Dwarf Coyote Bush
Baccharis pilularis 'Pigeon Point'
Evergreen
Zone 7-10
West Coast native
Full sun, dry soils, drought, low maintenance, no major concerns.
Aesthetic: ground cover, informal evergreen hedge.

Image sourced from www.plants.
longfellowsgreenhouses.com citing
NetPS Plant Finder.

Bayberry
Myrica pensylvanica
Evergreen
Score: 6
Aesthetic: Massing, shrub borders, informal hedge.

Image sourced from www.missouri-
botanicalgarden.org

Wall Germander
Teucrium chamaedrys
Evergreen
Zone 5-9
Full sun, dry soils, drought, medium maintenance, no major concerns.
Aesthetic: Hedge, low edging plant, massing, rock gardens, herb gardens.

Image sourced from www.earth.
com/plants

Cleyera
Cleyera japonica
Evergreen
Score: 4
Aesthetic: Hedge, borders, screens, foundations.

Image sourced from www.thetreef-
arm.com

Firethorn
Pyracantha angustifolia 'Gnome'
Deciduous
Naturalizing in CA and AZ.
Zone 5-9
Full to part sun, dry soils, drought, low maintenance, some disease concerns.
Uses: Fall and winter interest, massing, borders, foundations, informal hedge, espalier.

Image courtesy of Patrick Breen,
www.landscapeplants.oregonstate.
edu

Japanese Falsecypress
Chamaecyparis pisifera 'Lemon Thread'
Evergreen
Score: 4
Aesthetic: Winter interest, color, specimen or group planting, foundation, rock gardens, screens.

Image sourced from www.brokenar-
rownursery.com

Variegated Fiveleaf Aralia
Eleutherococcus sieboldianus 'Variegatus'
Deciduous
Naturalizing on the East Coast, US.
Zone 4-9
Full/part shade, dry/medium water, drought, low maintenance, no major concerns.
Aesthetic: Shade, borders, foundation, hedge, screen.

Image courtesy of Lake County Nursery, www.plants.pecksgreen-thumb.com

Euonymus Manhattan
Euonymus kiautschovica 'Manhattan'
Semi-evergreen
Score: 2
Aesthetic: Hedge, screens, specimen or group planting, showy fragrant flowers.

NEEDLED EVERGREEN, HEDGE-ABLE

Image sourced from www.missouri-botanicalgarden.org

Leyland Cypress
Cuprocyparis leylandii
Evergreen
Score: 2
Aesthetic: Evergreen structure, hedge, screens, windbreak, winter interest.

Image sourced from www.conifer-society.org, citing Gertens Nursery, Inc.

Japanese Yew
Taxus cuspidata columnaris
Evergreen
Score: 2
Aesthetic: Evergreen structure, foundation, screen or accent, groupings, winter interest.

Image sourced from www.sixmile-nursery.com

Mugo pine
Pinus mugo
Evergreen
Score: 1
Aesthetic: Evergreen structure, rock gardens, foundations, bonsai, winter interest.

Image courtesy of Lake County Nursery, www.plants.pecksgreen-thumb.com

Grey Dogwood
Cornus racemosa 'Muszam'
Deciduous
Score: 5
Aesthetic: Birds and butterfly attractor, rain garden, group planting near wild areas, native plant garden, trim for informal hedge.

Image courtesy of Mark Brand, University of Connecticut Plant Database.

Barberry
Berberis x mentorensis
Deciduous
Zone 5-9
Full/part sun, dry soils, drought tolerant, low maintenance, some concerns.
Aesthetic: Hedge, barrier, foundation, shrub border, massing.

Image sourced from www.thujagreengiant.net

Arborvitae 'Green Giant'
Thuja occidentalis 'Green Giant'
Evergreen
Score: 4
Aesthetic: Specimen or groups, winter interest and evergreen structure, hedges or screens.

Image sourced from www.missouribotanicalgarden.org

Chinese Barberry
Berberis japonica
Evergreen
Zone 6-8
Part to full shade, dry/medium water, low maintenance, no major concerns.
Uses: Part shade areas as understory, shrub borders, foundations, screening.

Image sourced from www.thujagreengiant.net

Arborvitae 'Green Giant'
Thuja occidentalis 'Green Giant'
Evergreen
Score: 4
Aesthetic: Specimen or groups, winter interest and evergreen structure, hedges or screens.

Image courtesy of Stiki Niki, www.weedcrafter.blogspot.com

Three-leafed oregon grape-future plant
Berberis trifoliola
Evergreen
Zone 7-9
Southern US native
Full to part sun, dry soils, drought, medium maintenance, no major concerns.
Uses: Winter interest, edible, borders, foundations, stablization.

Image sourced from www.willowaynurseries.com

Japanese Falsecypress
Chamaecyparis pisifera 'Mops'
Evergreen
Score: 4
Aesthetic: Winter interest, color, specimen, shrub borders, foundation, rock gardens.

Image sourced from www.landscapeplants.oregonstate.edu

Lavender Cotton
Santolina chamaecyparissus
Evergreen
Zone 6-9
Full sun, dry soils, drought, medium maintenance, no major concern.
Aesthetic: Herb or rock gardens, dwarf hedge, ground cover, edging.

Image sourced from www.what-growsthere.com

Dwarf Alberta Spruce
Picea glauca 'Conica'
Evergreen
Score: NA (At Risk by Zone)
Aesthetic: Large shrub to medium sized tree. Formal, with cone shaped. Foundations, accent, or screen.

DECIDUOUS, SEASONAL COLOR

Image sourced from www.eatonrapidsjoe.blogspot.com

Euonymus Eastern Wahoo
Euonymus atropurpureous
Deciduous
Score: 2
Aesthetic: Woodland garden, native plant garden, informal hedge or screen, fall color, tree form.

Image sourced from www.green-sandgardens.com

Black Lace Elderberry
Sambucus nigra
Deciduous
Score: -1
Aesthetic: Aromatic, edible, wildlife, color accent, backdrop or specimen.

Image sourced from www.centre-dejardinbrossard.com

Alder buckthorn
Rhamnus frangula
Deciduous
Score: 2
Aesthetic: Semi-formal, upright nature. Foundations, borders, texture backdrop or accent, hedge, screening.

Image sourced from www.thujagreengiant.net

Arborvitae 'Green Giant'
Thuja occidentalis 'Green Giant'
Evergreen
Score: 4
Aesthetic: Specimen or groups, winter interest and evergreen structure, hedges or screens.

Image sourced from www.landscapeplants.oregonstate.edu

Lavender Cotton
Santolina chamaecyparissus
Evergreen
Zone 6-9
Full sun, dry soils, drought, medium maintenance, no major concern.
Aesthetic: Herb or rock gardens, dwarf hedge, ground cover, edging.

Image sourced from www.missouribotanicalgarden.org

Dwarf Sumac
Rhus copallinum var. latifolia 'Morton' PRAIRIE FLAME
Deciduous
Score: 5
Aesthetic: Ornamental, fall color, compact size, natural areas, massing, wild areas or woodland margins.

Image courtesy of Randy Stewart, www.rslandscapedesign.blogspot.com

Coastal Serviceberry
Amelanchier obovalis
Deciduous
Zone 5-8
Northeastern US native
Full to part sun, dry soils, drought, low maintenance, no major concerns.
Aesthetic: compact shrub or tree form, fall color, borders, native garden, edible

Image courtesy of wyomingplantcompany.com, citing Bailey Nursery.

Ninebark
Physocarpus opulifolius 'Diablo'
Deciduous
Score: 4
Aesthetic: Massing, borders, hedge, screen, native plant gardens, color varieties.

Image sourced from www.wilsonnurseries.com

Blackhaw Viburnum
Virburnum prunifolium
Deciduous
Zone 3-9
Full sun to part shade, dry soils, drought tolerant, low maintenance, no major concerns.
Aesthetic: Native, habitat, hedge, edible fruit, prune to tree form.

Image sourced from www.americanmeadows.com

Forsythia
Forsythia x intermedia
Deciduous
Score: 4
Aesthetic: groups, borders, open areas, early spring specimen, hedges.

Image sourced from www.behmerwald.com

Adam's Needle
Yucca filamentosa
Evergreen
Native to US
Zone 5-10
Full sun, dry soils, low maintenance, no major concerns.
Aesthetic: Rock gardens, dry slopes, structural form, pollinators.

Image sourced from www.vanpeltnv.com

Silverberry/Wolf Willow
Elaeagnus commutata
Deciduous
Score: NA (At Risk by Zone)
Aesthetic: Native plant garden, pruned to small tree, silvery accent plant-good seasonal color.

Image sourced from www.proven-winners.com

Red Twig Dogwood
Cornus sericea
Deciduous
Score: 2
Aesthetic: Massing or specimen, shrub border, evergreen pairing, winter interest, wildlife interest, fall color.


Image sourced from www.plant-farm.wordpress.com

Snowberry
Symphoricarpos x doorenbosii
Deciduous
Score: 4
Aesthetic: shrub borders, hedge, foundation, open woodland area, bank stablization.


Image sourced from www.brokenarrownursery.com

Variegated Fiveleaf Aralia
Eleutherococcus sieboldianus 'Variegatus'
Deciduous
Naturalizing on the East Coast
Zone 4-9
Full/part shade, dry/medium water, drought, low maintenance, no major concerns.
Aesthetic: Shade, borders, foundation, hedge, screen.


Image sourced from www.plant-farm.wordpress.com

Snowberry
Symphoricarpos x doorenbosii
Deciduous
Score: 4
Aesthetic: shrub borders, hedge, foundation, open woodland area, bank stabilization.


Image sourced from www.architecturalplants.com

Spanish Dagger
Yucca gloriosa'Variegata'
Evergreen
Southeast US native
Zone 6-10
Full sun, dry soils, drought, low maintenance, no major concerns.
Uses: Border, foundation, rock gardens, dry slopes.

VISUALIZATION OF REPLACEMENT & ALTERNATIVE DESIGN

The previous pages looked at establishing yard resilience to climate change through replacement of individual species. The replacement investigation aims to keep aesthetics and practices the same, without addressing important concerns. As discussed in the Literature Review, the aesthetic of Columbia relies heavily on the pastoral, open lawn tradition where shrubs often serve as evergreen backdrops and house foundation cover. Often, shrubs provide seasonal interest or habitat functions. The other major component to the aesthetic is the lawn, a monoculture which reduces biodiversity and climate resilience. A biodiversity approach to such aesthetics can increase resilience with the inclusion of more species.

Additionally, the identification of multiple native plants in Part 1B suggested that native plants may be under-utilized in regional design (due to low presence in the local nursery data sources) and may offer climate resilience benefits.

Three approaches to climate change design (replacement, native, and biodiversity) are worth visualizing to discuss the impacts of each on yard aesthetics. One yard, documented from a site visit in Columbia, will be used to visualize each resilience approach through a three-step process:

1. Diagram the yard's current conditions and identify shrubs (when possible), shrub form, and shrub function in the landscape.
2. Identify the At Risk shrubs.
3. Replace these species (Replacement Approach), design with native species (Native Approach), or design with native and non-native species (Biodiversity Approach).

Forms and *functions*, as alluded to in the plant replacement pages, refer to the visual qualities of shrubs. Evergreen and deciduous define the form of the plant, which is important in defining yard structure. If attempting to maintain the same "look" of the yard, shrub replacement should consider form (deciduous, broadleaf evergreen, and needled evergreen) in addition to the *function*. A function is the role a shrub plays in the yard outside of form, such as foundation cover, hedge, seasonal interest, specimen (showy/interesting), or habitat.

Possible Forms:

Deciduous
Broadleaf Evergreen
Needled Evergreen

Possible Functions (**Note, a shrub can hold more than one function, but not form*):

Foundation
Hedge
Specimen
Seasonal Interest
Native
Habitat

The generically representative yard in Figure 3.21 is used as a case study to visualize new climate change plant palettes. There appear to be 4-5 different species present, 3 of which are clearly evergreen. The shrubs in the front could be evergreen or herbaceous perennials. The dark green, hedged shrub is believed to be *Illex crenata*, a shrub determined to be at risk with high certainty. Regardless of the number of at-risk shrubs present, this yard can serve as an example for climate change design. The first design will focus on replacement of current species utilizing highly compatible shrub species from Part 1A and the not widely distributed but compatible shrubs Part 1B. Replacement was approached with the goal of fitting the current form and function of the yard.

Figure 3.24: Average Front Yard in Columbia, Missouri

<u>Diagramming Shrub Forms and Functions</u>

The first step to finding alternative plants was to diagram the current shrub functions. Figure 3.22 simplifies the landscape into plant volumes and documents the forms and functions. This process simplifies evaluation to make replacement based on form and function easier to establish.

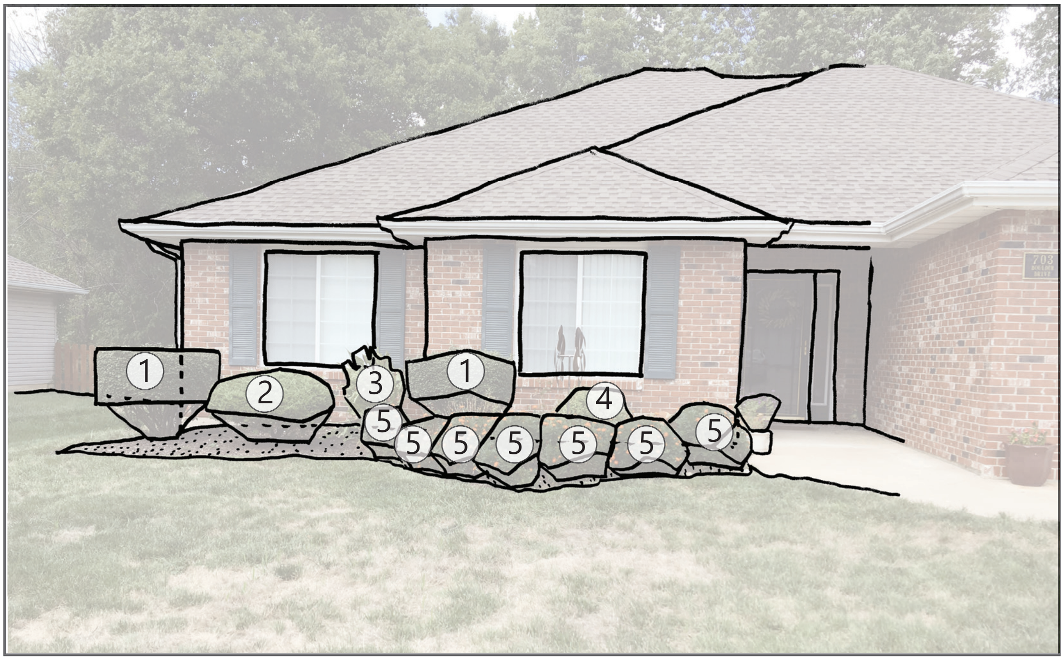


Figure 3.25: Draft Diagram of Shrub Form and Function

1. Illex crenata, *At Risk*, broadleaf evergreen, foundation, hedgeable.
2. Needled evergreen shrub, *risk unknown,* foundation, hedgeable.
3. Herbacious perennial, *risk unknown,* foundation.
4. Deciduous shrub, *risk unknown,* foundation.
5. Deciduous or perennial shrub, *risk unknown,* seasonal interest (flowers).

Through the diagramming process, one shrub species (two shrubs), *Illex crenata*, was identified as At Risk previously in Part 1A of the Methods. Other shrubs in the yard were of unknown risk or compatibility. For the purpose of aesthetic exploration, this project assumed the extreme stance that all shrubs are at risk. The following approaches to design (replacement, native, and biodiversity) are explored under this premise.

Replacement Palette:

1. Myrica Penslyvanica, *highly compatible (6)*, broadleaf evergreen, foundation, hedgeable.

2. Chameacyparis pisifera 'Mops', *highly compatible (4)*, needled evergreen, foundation, hedgeable.

3. Herbacious perennial, not replaced, risk unknown, foundation.

4. Cleyera japonica, *highly compatible (4)* broadleaf evergreen, foundation, hedgeable.

5. Conradina verticillata, broadleaf evergreen, shrub borders, native, rock gardens, seasonal interest (flowers).

6. Santolina chamaecyparissus, broadleaf evergreen, shrub borders, seasonal interest (flowers).

7. Ceanothus x pallidus 'Minmari', deciduous, seasonal interest (flowers).

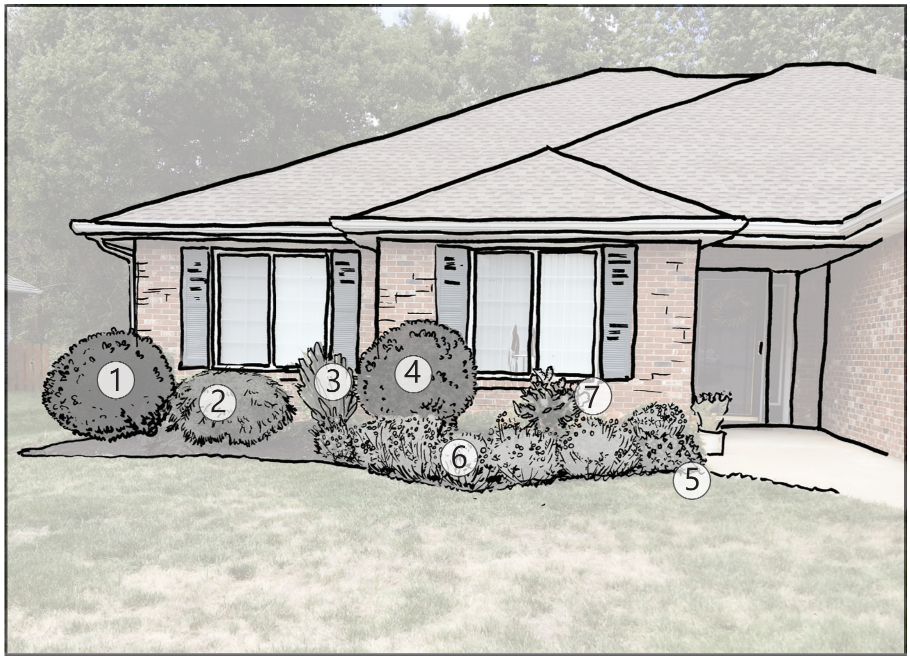


Figure 3.26: Replacement Approach

Replacement Approach

In the basic replacement design (Figure 3.23), the main design goal is to simply replace potentially at-risk species with climate compatible species. The biggest aesthetic change in this design is most likely the color palette and the absence of Illex crenata as a square hedge which mimics the form of the house. This design, however, provides additional benefits of being relatively drought tolerant while maintaining the same evergreen and foundational structure in the use of *Myrica penslyvanica*, *Chameacyparis pisifera*, and *Cleyera japonica*. Seasonal interest is provided with *Santolina chamaecyparissus* with its yellow fall flowers.

Figure 3.27: Replacement Approach, Spring Structure (May-June)

Figure 3.28: Replacement Approach, Winter Structure.

Native Palette:

1. Rhus copallinum var. latifolia 'Prairie Flame', *highly compatible (5)*, deciduous, native, seasonal interest (fall color).

2. Viburnum prunifolium, deciduous, native, small tree form, seasonal interest (fall color).

3. Cornus racemosa, deciduous, native, habitat, informal hedge.

4. Myrica Penslyvanica, *highly compatible (6)*, broadleaf evergreen, native, foundation, hedge-able.

5. Ceanothus americanus, deciduous, native, seasonal interest (spring flowers).

6. Yucca filamentosa, evergreen, native, architectural, pollinator.

7. *Schizachyrium scoparium, native ornamental grass, seasonal interest, texture.

8. Duetzia Yuki Cherry Blossom, *highly compatible (4)*, deciduous, seasonal interest (spring flowers).

9. Berberis trifoliolata, evergreen, native, edible, shrub borders.

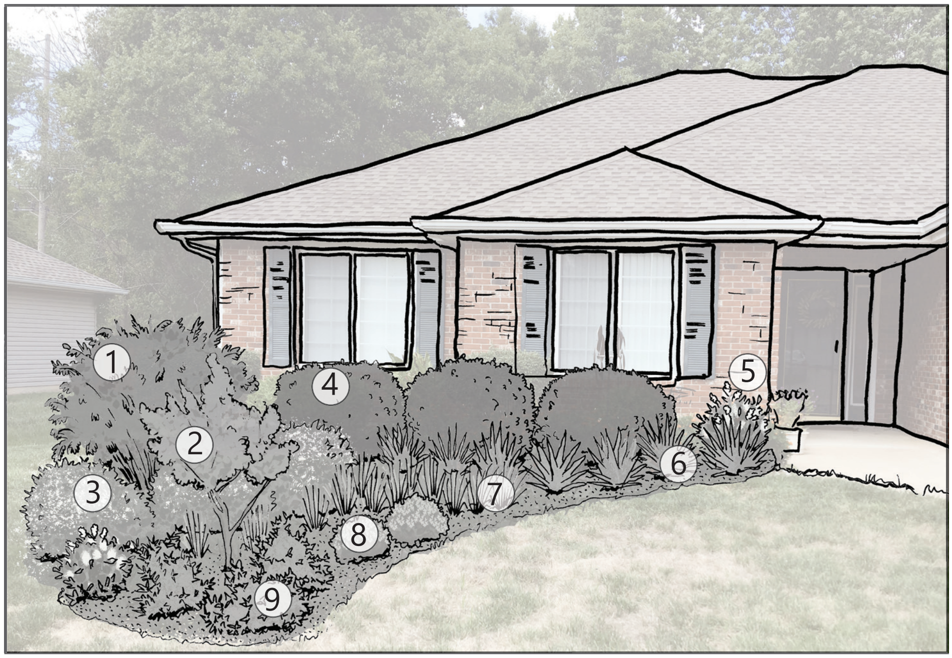


Figure 3.29: Native Approach

Native Approach

In the native design, the main goal is to design only with native plants that are compatible to climate change. The benefits behind using native plants lie in the support of native habitat, pollinators, and other insects and animals. This is a system-based design that still aims to provide the clarity and function of the original yard. Some elements of the original yard that translate into this design are formalism and simplicity, showing that designing with native plants does not have to translate into "messy" or even "naturalistic" design. The repetition of plants in a near-linear fashion, and the employment of the architectural *Yucca filamentosa* against an evergreen hedge of *Myrica penslyvanica*, along with mulch, establishes a semi-formalism. As the plants get further away from the door, the "wilder" natives with fall color and seasonal interest appear. This is both a physical and visual gradient that serves native pollinators and species as well as a homeowner desiring habitat function and simplicity. This design still fulfills the yard's original shrub function of establishing a hedge-able, evergreen foundation cover and a simple plant palette. Maintaining visibility of the yard from the windows, a homeowner concern, can be established by the use of short or hedge-able shrubs.

Figure 3.30: Native Approach, Spring Structure (May-June).

Figure 3.31: Native Approach, Winter Structure.

Biodiversity Palette:

1. Rhus copallinum var. latifolia 'Prairie Flame', *highly compatible (5)*, deciduous, native, seasonal interest (fall color).

2. Cleyera japonica, *highly compatible (4)* broadleaf evergreen, foundation, hedgeable.

3. *Schizachyrium scoparium, native ornamental grass, seasonal interest, texture.

4. Rhus aromatica 'Gro-Low', *highly compatible (5),* deciduous, native, informal hedge.

5. Symphoricarpos x doorenbosii, *highly compatible (4),* deciduous, foundation, seasonal interest (berries).

6. Myrica Penslyvanica, *highly compatible (6)*, broadleaf evergreen, foundation, hedgeable.

7. Elsholtzia stautonii, deciduous, foundation, seasonal interst (fall flowers).

8. Ceanothus americanus, deciduous, native, seasonal interest (spring flowers).

9. Amelanchier obovalis, deciduous, native, tree form, seasonal interst (fall color).

10. Ceanothus x pallidus 'Minmari', deciduous, seasonal interest (spring flowers).

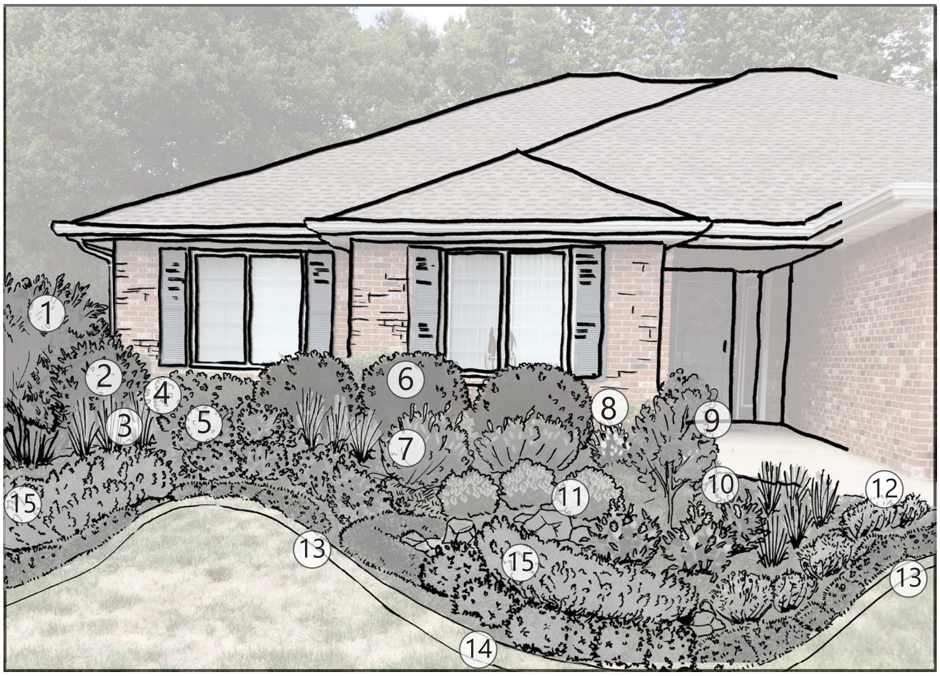


Figure 3.32: Biodiversity Approach

Biodiversity Approach

In the biodiversity design (Figure 3.24), the main goal is to design with a wide variety of plants which are compatible to climate change. The benefit of using both native plants and non-native plants is in diversifying the plant species subjected to climate change impacts. More plants will contribute to each-others resilience by shading the ground and providing some protection from wind and snow loads. An approach that maximizes biodiversity naturally deviates from the minimalism of the original yard conditions, but some overall aesthetic qualities can remain: a trio of *Myrica pensylvanica* lines the central house foundation to provide evergreen backdrop and hedging opportunities, and a plethora of seasonal interest is provided by native and non-native shrubs. A large factor of this design is a reduction of lawn space. While some is kept for functional purposes, this approach acknowledges that lawns, as a monoculture, are reduced because they are the opposite of biodiversity. Since this lawn already appeared to be struggling in the source image, perhaps the replacement of the lawn by more resilient species is a climate-wise approach.

Figure 3.33: Biodiversity Approach, Spring Structure (May-June).

11. Duetzia Yuki Cherry Blossom, *highly compatible (4),* deciduous, seasonal interest (spring flowers).

12. Santolina chamaecyparissus, broadleaf evergreen, seasonal interest (late summer flowers).

13. Acantholimon ulicinum, needled evergreen, seasonal interest (spring flowers).

14. Conradina verticillata, broadleaf evergreen, native, seasonal interest (spring flowers).

15. Baccharis pilularis 'Pigeon Point', evergreen, native, informal hedge.

Figure 3.34: Biodiversity Approach, Winter Structure.

CHAPTER 3 REFERENCES

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CHAPTER 4

DISCUSSION

4.1 INTRODUCTION

The following chapter takes a closer look at the results of the previous found in Chapter 3. Trends, implications, and conclusions of the results are discussed as well as considerations on the scoring and categorization of shrub species. The visualizations of climate change design are compared in their benefits and challenges.

4.2 SHRUB COMPATIBILITY

SCORING RESULTS

The purpose of scoring shrubs based on Missouri's climate change metrics was to see if currently marketed shrubs in the area were going to be at risk in a climate change future. Of the 95 shrub groups assessed in Part 1A (Section 3.3, Filtering and Scoring for Climate Compatibility), 22 were found to be at risk according to the method used. This number makes up 23% of shrubs sold in the area, indicating that there is a significant group of plants which may struggle in future conditions, thereby requiring more inputs. Interestingly, 22/95 shrubs were highly compatible by this scoring method, suggesting equal amounts of very hardy shrubs are available on the market. Nearly half of the shrubs scored a 3 by this method, indicating average suitability to climate change. These shrubs will probably requiring occasional inputs to survive.

QUALITIES BEHIND SHRUB COMPATIBILITY

Looking more closely at the functional qualities of the At Risk shrubs, 8 were broad leaf evergreen, 6 had particularly showy flowers, 5 were natives, 4 were conifers, 5 were popular hedge species, and 5 had seasonal color to them. Given the broad range of functions, there appears to be no group that is more vulnerable than another. However, when looking at the entire list of evaluated shrubs, there is one significant correlation. Of 16 broadleaf evergreen shrubs sourced in Columbia, 8 were found to be at risk (50%). Needled evergreen shrubs (4/16) were at risk about the same as deciduous shrubs (10/45) with 25% and 22%, respectively. Of the highly compatible shrubs (scores 4, 5, or 6), 18/24 (75%) were deciduous, 4/24 (17%) were needled evergreen, and 2/24 (8%) were broadleaf evergreen. These results, based on this scoring system, suggest that broadleaf evergreen shrubs tend to be more at risk to climate change, and deciduous shrubs tend to be more compatible. Additionally, there is a weak correlation between shrubs with showy flowers (often considered “ornamental”) and risk conditions, most likely from high maintenance and high input requirements to meet optimal flower production. Six of the 22 at risk shrubs (27%) displayed an ornamental quality.

SCORING- WHO DECIDES?

Overall, the traits that made a plant most compatible to climate change were the criteria scored favorably by the method. In this case, climate tolerances and a degree of adaptability and independence (ability to survive without many inputs) were criteria that earned higher scores. The judgment was based on the distillation of climate change data, literature, and a homeowners perspective. It would be easy to adjust the selection or weight of qualities depending on what the deciding individual believes the biggest threat of climate change to be. For instance, if concerns (insects and disease) were thought to be the biggest challenge for plants under climate change, one would give concerns a higher score weight relative to other factors. Based on literature, this project weighted soil moisture, drought, and wet tolerances (the intrinsic traits) higher than other factors, but the filtering and scoring could easily be adjusted to fit other criteria.

The intrinsic traits weighted heavier because they were presented with the most certainty in climate change research. The method could be adjusted to focus on other elements, such as low maintenance (time, fossil fuels), water consumption (irrigation), and insect/disease prevention (pesticides and fertilizers). These are all landscape goals which have a larger impact on ecosystem health and can contribute further to climate change resilience. One should modify this method based on their values for a residential yard, but in anticipation to climate change, the current focus could be an appropriate approach for the Midwest given current knowledge on climate change in the region.

4.3 TRENDS OF COMPATIBILITY

LOOKING SOUTH

Interestingly, most of the plants sourced from Part 1B (Section 3.4, Gathering Potential Shrubs for Climate Change) were not purely southern species. Only 3/28 were not yet zone hardy in Missouri (at 7 hardiness). Of over 7,500 plants in the MOBOT database, only 3 from just south of Missouri's zone were not invasive and met the search requirements for low water requirement and drought or dry soil tolerance. The other 25 species could be planted in Missouri's current climate.

As discovered in Part 1B, there was a disproportionate number of species that were either fully capable of living in Missouri now and the future (zone compatible) or completely outside of Missouri's zone range (zone incompatible) and would be greenhouse or indoor plants in Missouri. This points out that the data source is highly skewed to currently compatible species or wildly incompatible species that should only be grown indoors. While it is useful to have the local insight which was provided by Missouri Botanical Gardens, the source may be skewed in its available data. As the website proclaims, it is a database that contains "over 7,500 plants which are growing or have been grown in the Kemper Center display gardens and selected editions", which points out a data flaw. The Kemper Center display gardens contain both outdoor sections and indoor greenhouses, and it is highly probable that most shrub data is collected from plants which are winter hardy in Missouri now, or live fully in a greenhouse environment. The lack of future compatible plants (Zone 7) in current distribution makes sense because of this indoor-outdoor ambiguity. People are more willing to buy an indoor, ornamental plant or an outdoor, climate-tolerant shrub, as opposed to an average shrub which may struggle outdoors. For future research, it would be important to diversify the data sourcing or look directly at southern resources for plant assessment.

NATIVE VS. NON-NATIVE

This project chose to source popularly available local shrubs, which explains the prevalence of non-native shrubs in the data. Because of the data sourcing, it is harder to provide a definitive answer to whether homeowners should favor native plants for climate resilient design. Using data collected from Columbia's larger nurseries and department stores, 23/95 (24%) shrubs were native. Six of the 23 natives were at risk under climate change (26%), 9/23 (39%) were compatible, and 8/23 (34%) were highly compatible. Even with the small data sample, the data suggests that native plants tend to show a tendency for climate compatibility.

The query for potential shrubs from MOBOT did highlight what is currently being overlooked in the popular market. Most of these potential shrubs were less formal, more wild, and often native. In fact, 57% were native species, suggesting that there is untapped potential in native shrubs when it comes to designing a climate resilient yard.

Unlike nativity, invasiveness was a negative factor not questioned by this research. The stance was taken to respect previously established guidelines around invasive plants. In the case that the shrub was not aggressively taking over habitat or was somewhat invasive in a completely different climate, it was allowed to stay in the pool. As for any plant, it is highly recommended that the homeowner or designer research each plant thoroughly before planting. Not only is this good practice to ensuring plant survival (by meeting soil, moisture, and light requirements), but it can also raise a flag for invasive tendencies. A plant that is known to spread aggressively and is highly climate compatible may have an advantage over nearby native species in the future. These shrubs may eventually qualify as an invasive species. Since it is uncertain whether a shrub will be invasive in the future, it is necessary to do the research, be critical of the selection, and keep an eye on the habit of the shrub.

4.4 ANTICIPATING THE CLIMATE RESILIENT YARD

VISUALIZATION CONCLUSIONS

The benefit of the replacement design is its simplicity: it provides a suitable approach for many homeowners in the Midwest. Widely, the aesthetic in the Midwest and many suburban areas throughout the United States is pastoral, relying heavily on turf grass and a spattering of trees and shrubs. Replacing a few shrubs is an easy option. But does this really provide the best form of resilience? If a yard has only 6 shrubs and 2 die, then 33% of the yard’s habitat, species support, and aesthetic value has declined. Diversifying species and spatial organization allows plants to benefit from the protection and proximity of others as well as increase the probability that the entire yard will remain climate resilient.

The biodiversity approach utilizes natives and non-natives that are suited for climate change conditions. There is uncertainty whether natives or non-natives will be more successful in future conditions, so utilizing species across both groups appears to be the safest approach. Additionally, planting with native and non-native shrubs will provide resources for both generalist and native-specific pollinators. This variety allows flexibility for certain plants to die out without causing detrimental effects to yard functionality and aesthetics (Hunter, 2011).

Maximizing the biodiversity approach in a single yard can be challenging. These designs often tend toward a naturalistic aesthetic-one that aims to mimic plants in nature. Without some repetition of species, basic organization, or intentional framing of the planting area, the yard may feel “messy” or uncared for. A yard that is too messy or too far from the norm may cause contention with neighborhood codes or the neighbors themselves (Nassauer, Wang, & Dayrell, 2009). Large garden areas will require more maintenance. As the species variety increases, the amount of maintenance will increase because each plant will need separate care. Repeating species and grouping them together will make maintenance easier since the group can be handled in a similar manner. To successfully design with biodiversity as a resilience strategy for climate change, it is necessary to plan and be mindful to the species and organization of the yard.

The native approach must consider the same concerns as the biodiversity approach. A homeowner or designer must be aware of the social norms and codes in addition to their personal values when planting with natives and attempting a naturalistic design. While there are acceptations, native plants are often perceived as messier; however, as the native design approach in this document shows, this does not have to be the case. It is possible to use natives to establish an aesthetic beyond "naturalism". In the native approach design, a semi-formal aesthetic was created by using a small palette of species, utilizing the repetition of species, adding spacing between shrubs, and selecting an architectural shrub, *Yucca filamentosa.*

ANTICIPATING THE CLIMATE RESILIENT YARD

The design visualizations serve to provide options to creating a yard resilient to climate change. The basis of these designs is rooted in the utilization of compatible shrub species, supporting the hypothesis that by utilizing compatible shrub species, a yard can increase its climate resilience. Additionally, the designs further support the idea that there are certain designs which better attain the resiliency goal. As supported by the literature, a design that minimizes turfgrass monoculture and instead utilizes a diversity of species - native or non-native - will have more overall resilience to climate change factors. Given the results of this project, it is likely that the residential aesthetics in Missouri will have to change if a homeowner pursues the move toward a climate compatible, resilient yard.

It is important to consider the time line and goals of the yard. What is the desired aesthetic of the yard, and how can climate resilient design be included? Are there species that are struggling now and can be replaced with something more compatible to climate change? In most situations, it is important to stagger the time line of replacements over different years to improve stability and continue ecosystem function as opposed to a complete and immediate makeover. A shrub that is already existing and thriving in current conditions should not be replaced right away, but only when it starts to decline or require more inputs than the homeowner is willing to give. Plants are also very adaptable when they develop under harsh conditions. Favor younger plants that can still adapt to the level of inputs expected (eg. less water) versus older plants that grow up in ideal nursery or greenhouse conditions.

When considering timeline, stay up to date on climate change projections. More extreme changes in temperature and precipitation are expected by 2100 although some models and sources project large changes as early as 2050. If considering the typical lifespan of a large shrub (40-50 years), it is likely that at least one generation can grow now and survive with little stress from climate change, while a second generation of the shrub might struggle.

4.5 CONCLUSIONS

In the big picture, this project was conducted to learn more about designing for climate change at the residential scale. In order to understand design strategies, the parameters of planting palette needed to be known based on what plants were compatible to climate change in the Midwest. To narrow the scope, the project looked only at popularly available shrub species in Columbia, Missouri. These shrubs served as a test population for the filtering and scoring method. The results provided parameters on which to explore climate change designs and possible changes to front yard aesthetics in the Midwest. Evaluating other sources of shrub collection provided the knowledge that perhaps natives are an underutilized resource and may play a role in climate change design.

The biggest take-away of the process is the understanding that climate change is complex and plants are complex. Narrowing both down to a few prediction points and beneficial traits underestimates both factors. It is also difficult to score plant traits based on a database which acts as a secondary source of information. It would take raw data and years of analysis for each shrub species in this project to accurately assess its compatibility to climate change. However, for the homeowner looking to make a landscape change, protect their yard from climate uncertainty, or minimize their future inputs, this project provides a good first look at how to achieve these goals. The scoring and categorization of shrubs should be taken as guidelines with an understanding of the subjectivity behind the scores and the uncertainty of the topic in general.

The best move forward is to plant. Diversify the yard and evaluate results. See what grows with little care applied – particularly in terms of water. Replace species and try something new. Landscapes are meant to evolve with the climate and desired functionality. Consider ways front yards can not only be resilient but provide ecosystem services (Groot et al., 2002). Can a yard provide food, herbs, or materials? These uses can reduce a carbon footprint, and therefore larger impacts on the environment and climate change. Can a yard be designed with the intention of storing atmospheric carbon through the use of tree species and deeply rooted prairie grasses (Zirkle, Lal, Augustin, & Follett, 2012)? The advantage of personal property is that these types of goals are usually within reach, if desired. The hope is that the results of this project benefit future pursuits of increasing climate resilience in the residential yard and expanding our collective use of this resource.

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APPENDIX A-D

CONTENTS

APPENDIX A
CLIMATE CHANGE FIGURES

Figure 1: Mean annual temperature difference (F) projections for 2021-2099 based on differences from 1971-1999. Under high emissions scenarios (A2), Missouri's mean annual temperature is likely to increase 8-9 degrees F. Source: NOAA.

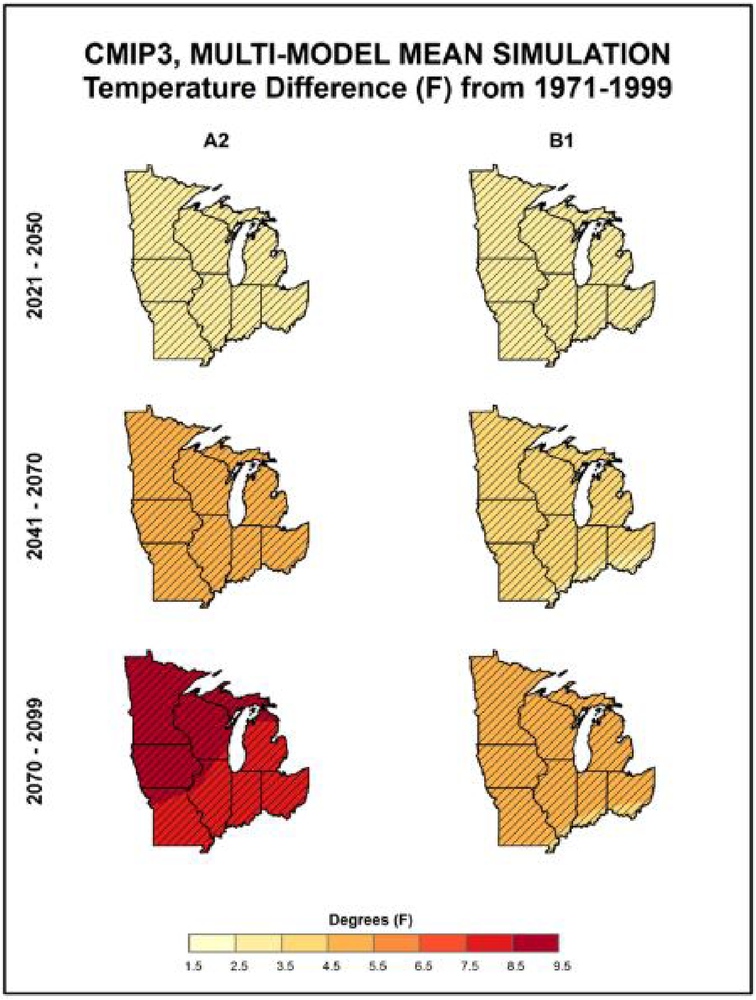


Figure 29. Simulated difference in annual mean temperature (°F) for the Midwest region, for each future time period (2021-2050, 2041-2070, and 2070-2099) with respect to the reference period of 1971-1999. These are multi-model means for the high (A2) and low (B1) emissions scenarios from the 14 (B1) or 15 (A2) CMIP3 global climate simulations. Color with hatching (category 3) indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change (see text). Grid boxes whose centers are over the Great Lakes or outside the 8-state region are masked out. Temperature changes increase throughout the 21st century, more rapidly for the high emissions scenario.

Figure 1: Projected number of consecutive days in a year with temperatures over 95 degrees F. Based on 1980-2000 data and high emissions models (A2), the number of days is likely to increase by 18 days from currently 10-15 consecutive days with extreme heat. This will lead to possibly 25-35 consecutive days experiencing extreme heat in Missouri in 2070. Source: NOAA.

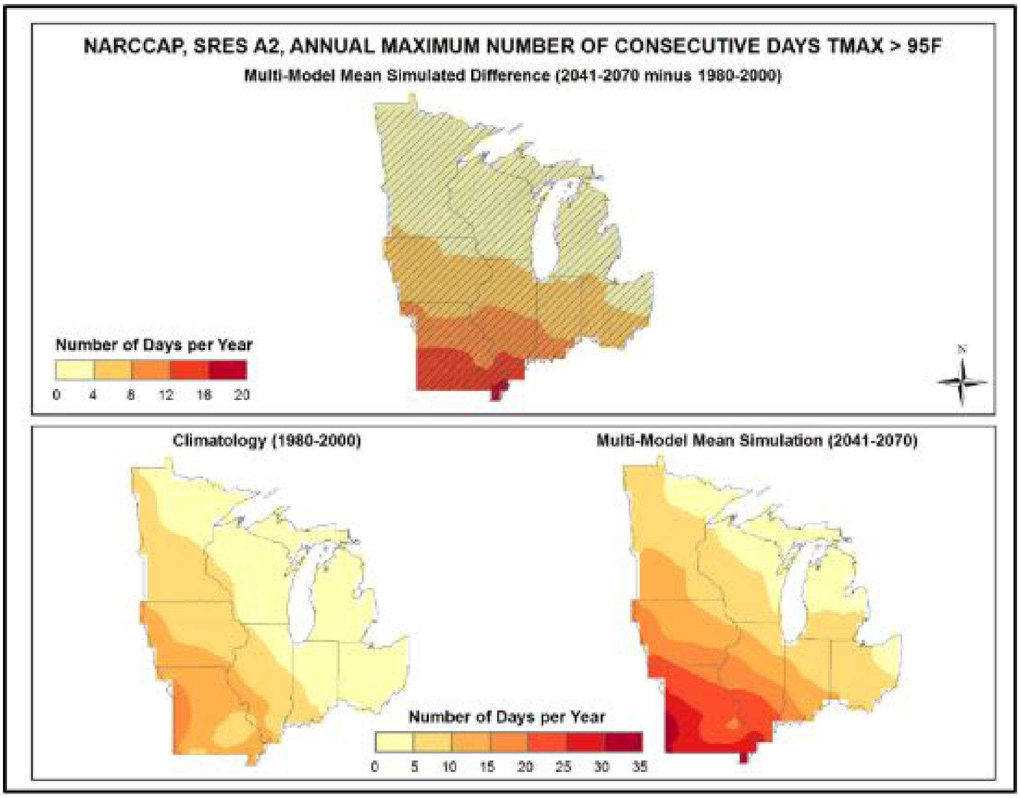


Figure 36. Simulated difference in the mean annual maximum number of consecutive days with a maximum temperature greater than 95°F (T_{max} > 95°F) for the Midwest region, for the 2041-2070 time period with respect to the reference period of 1980-2000 (top). Color with hatching (category 3) indicates that more than 50% of the models show a statistically significant change in the number of consecutive days, and more than 67% agree on the sign of the change (see text). Mean annual maximum number of consecutive days with T_{max} > 95°F for the 1980-2000 reference period (bottom left). Simulated mean annual maximum number of consecutive days with T_{max} > 95°F for the 2041-2070 future time period (bottom right). These are multi-model means from 8 NARCCAP regional climate simulations for the high (A2) emissions scenario. Grid boxes whose centers are over the Great Lakes or outside the 8-state region are masked out. The changes are upward everywhere. Increases are largest in the south and decrease northward, in a pattern similar to the present-day climatology.

Figure 3: Observed decadal mean precipitation change (deviations from the 1901-1960 average %) for the Midwestern U.S. for winter (top left), spring (top right), summer (bottom left), and fall (bottom right). Grey lines indicate 20th and 21st c. simulations from 15 CMIP3 models for the high (A2) emissions scenario. Source: NOAA.

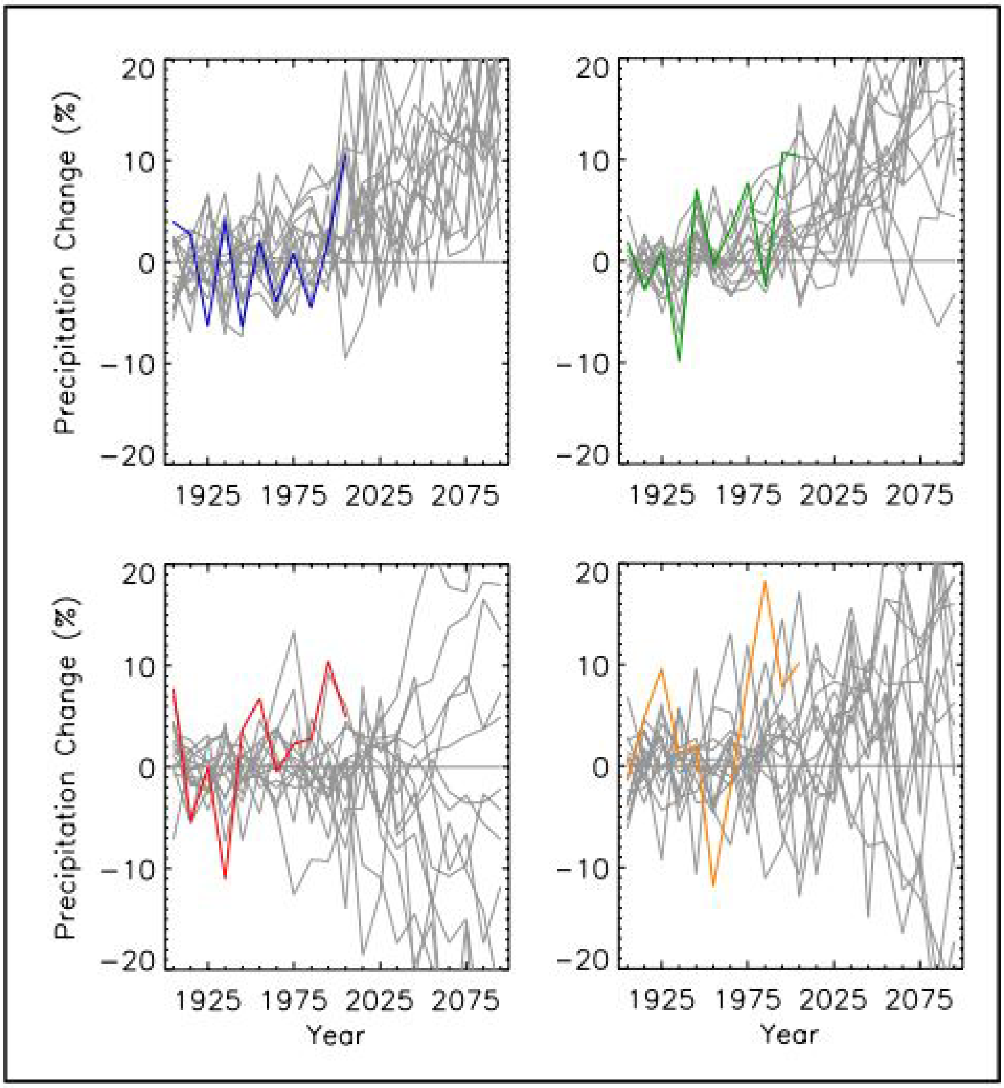
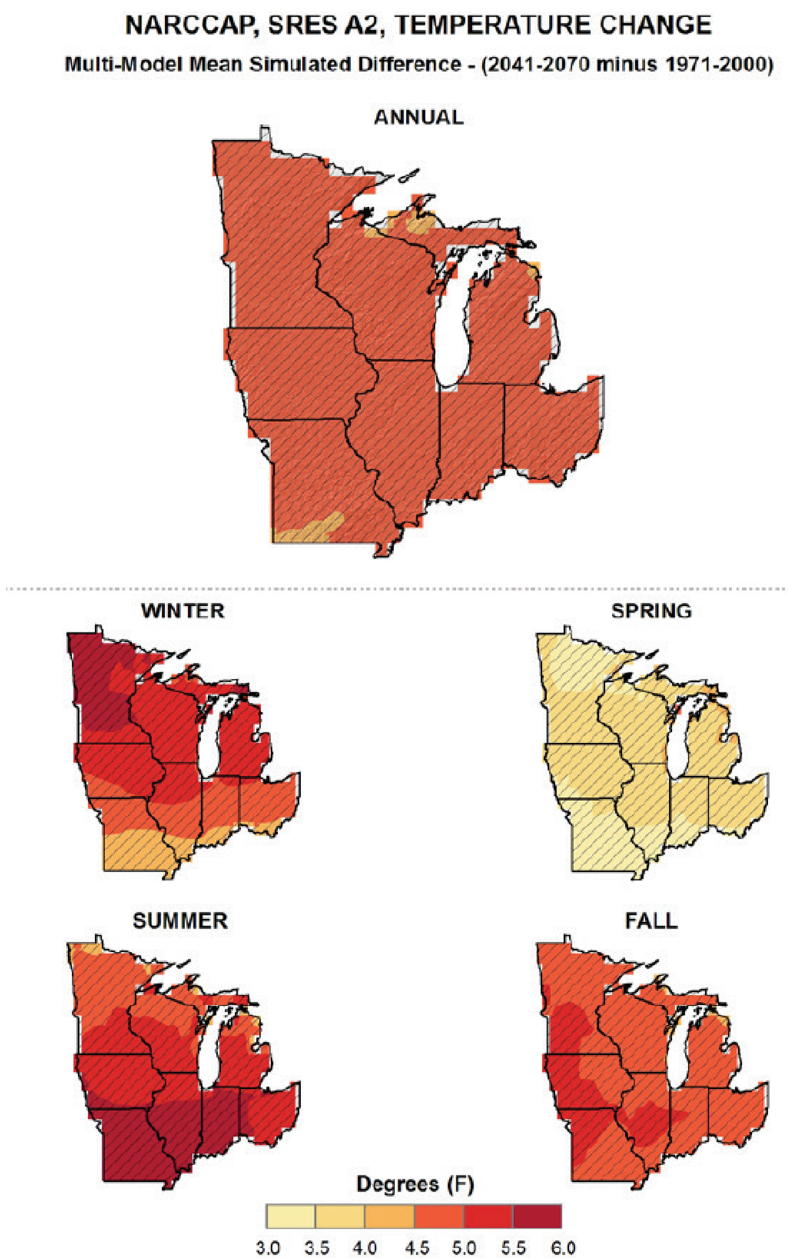


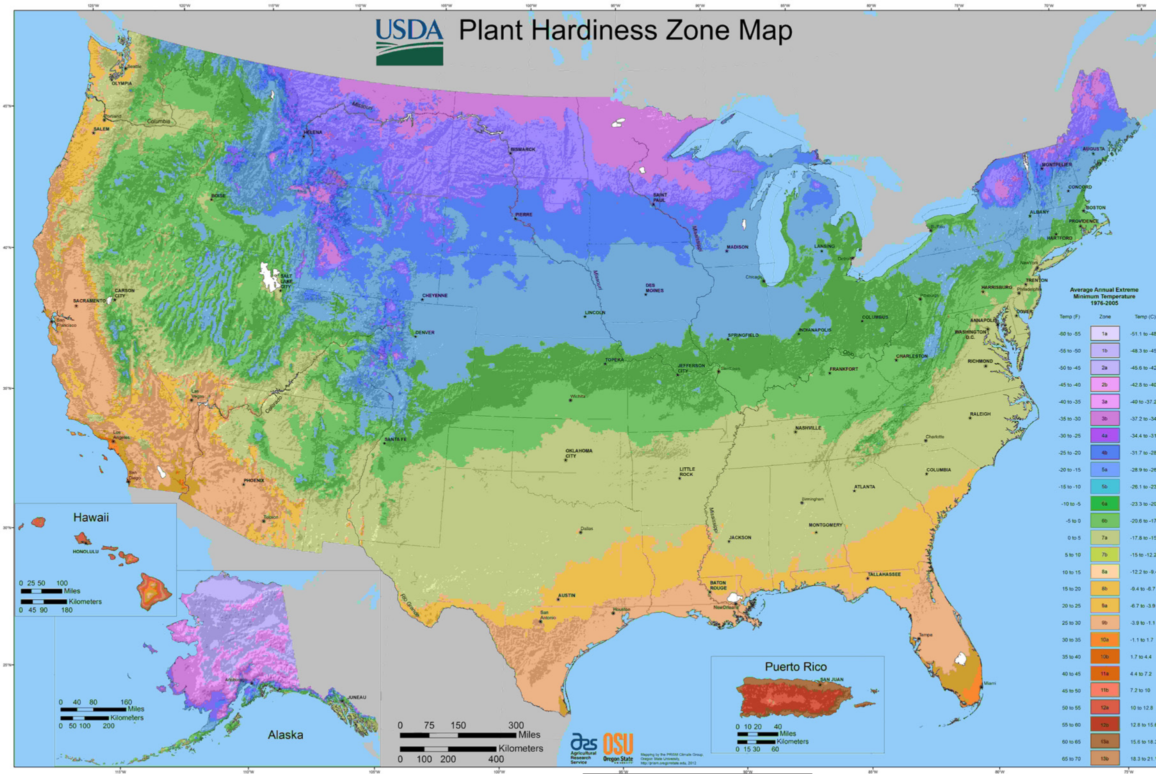
Figure 49. Observed decadal mean precipitation change (deviations from the 1901-1960 average, %) for the Midwest U.S. for winter (top left, blue line), spring (top right, green line), summer (bottom left red line), and fall (bottom right, orange line). Based on a new gridded version of COOP data from the National Climatic Data Center, the CDDv2 data set (R. Vose, personal communication, July 27, 2012). Gray lines indicate 20th and 21st century simulations from 15 CMIP3 models, for the high (A2) emissions scenario. Observed seasonal precipitation variations are within model simulations for all seasons.

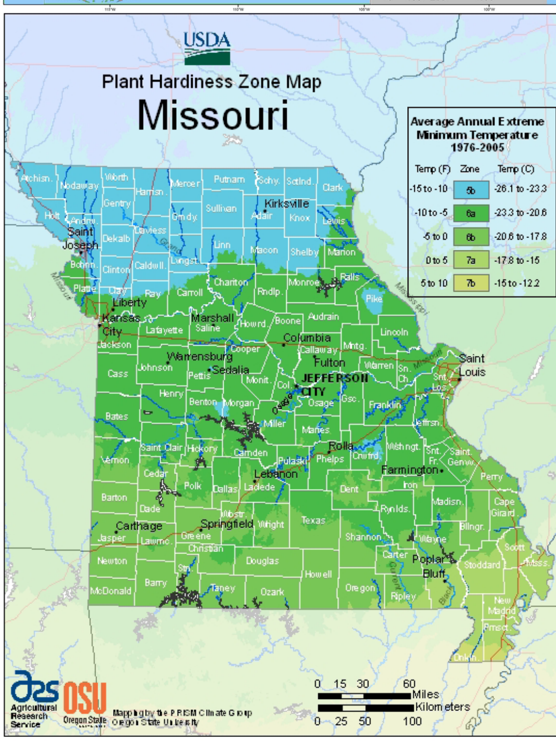
Figure 4: Projected annual (top) and seasonal temperature changes in the Midwest under high emission scenarios (A2). Missouri is projected to experience slight increases in spring and winter temperatures (about 3-4 degree F average increase) whereas summer and fall are likely to experience greater changes (4.5-6 degrees F) Source: NOAA.



APPENDIX B

USDA HARDINESS ZONES





Average Annual Extreme Minimum Temperature 1976-2005

Temp (F)	Zone	Temp (C)
-15 to -10	5b	-26.1 to -23.3
-10 to -5	6a	-23.3 to -20.6
-5 to 0	6b	-20.6 to -17.8
0 to 5	7a	-17.8 to -15
5 to 10	7b	-15 to -12.2

Figure 1 (above): USDA Hardiness Zones of the U.S. Source: US Department of Agriculture.

Figure 2 (left): USDA Hardiness Zones of Missouri. Columbia's zone is currently 6A, -10°F to -5°F. Missouri has USDA zones ranging from 5b to 7b in the bootheel. Source: US Department of Agriculture.

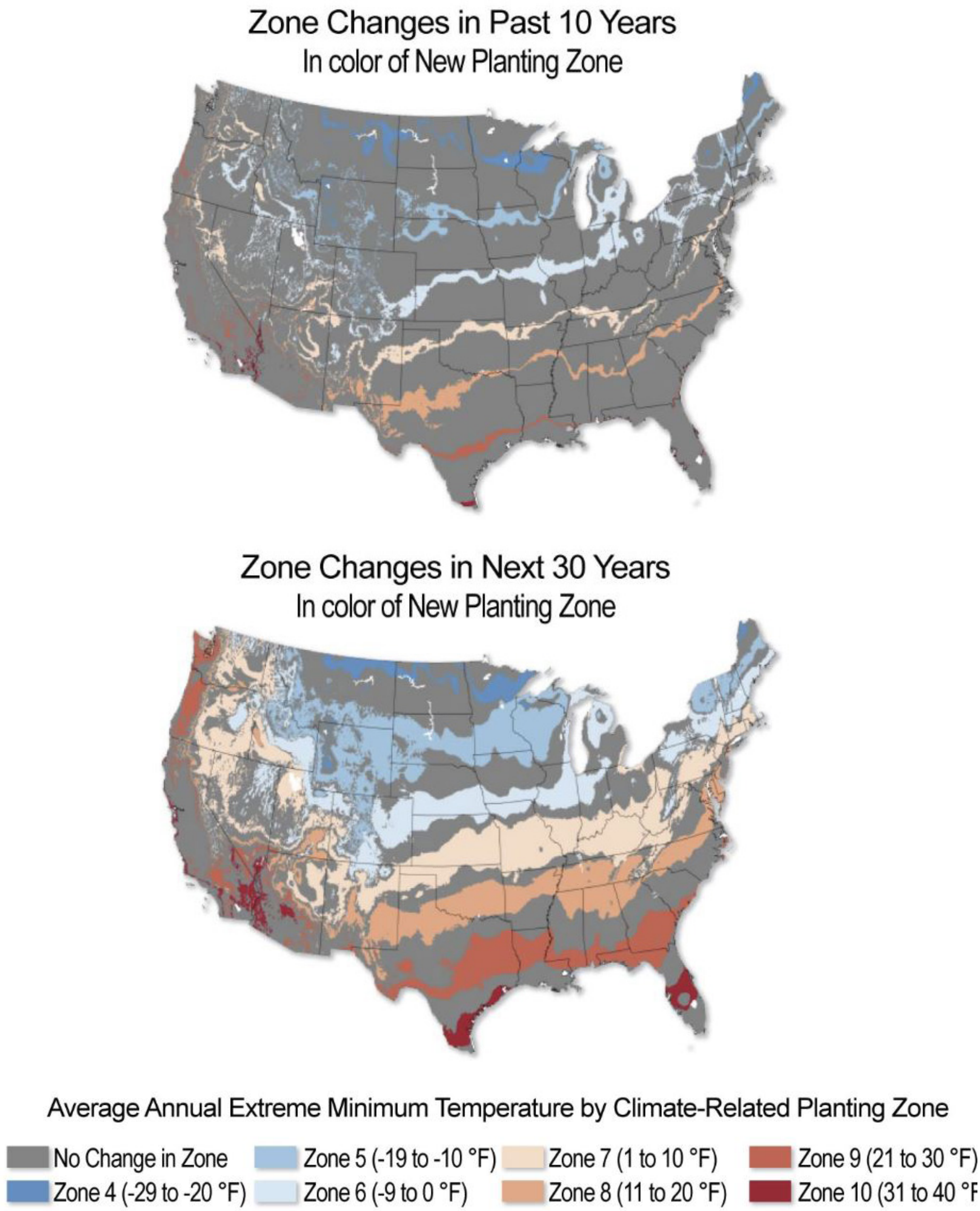


Figure 3: Potential USDA zone changes in the next 30 years due to climate change. Source: The National Climate Assessment.

APPENDIX C: SHRUB INDEX

0. GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Da
*Abelia x grandiflora**	ABELIA, KALEIDOSCOPE	*Abelia x grandiflora 'Kaleidocscope'*	X					Y
	ABELIA, RASPBERRY	*Abelia x grandiflora 'Raspberry'*	X					N
*Aronia melanocarpa**	CHOKEBERRY, AUT. MAGIC	*Aronia melanocarpa 'Autumn Magic'*	X					Y
	CHOKEBERRY, VIKING	*Aronia melanocarpa 'Viking'*	X					Y
*Berberis thunbergii**	BARBERRY, CONCORDE	*Berberis thunbergii 'Concord'*	X					N
	BARBERRY, CRIMSON PYGMY	*Berberis thunbergii 'Crimson Pygmy'*	X					N
	BARBERRY, ORANGE ROCKET	*Berberis thunbergii 'Orange Rocket'*	X					N
*Buddleja davidii**	BUTTERFLY BUSH	*Buddleja davidii*		X				Y
	BUTTERFLY BUSH, BLUE CHIP	*Buddleja davidii 'Blue Chip Junior'*					X	Y
	BUTTERFLY BUSH, BL. HEAVEN	*Buddleja davidii 'Blue Heaven'*	X					N
	BUTTERFLY BUSH, BLUEBERRY	*Buddleja davidii 'Blueberry'*	X					N
	BUTTERFLY BUSH, MS MOLLY	*Buddleja davidii 'Ms. Molly'*	X					N
	BUTTERFLY BUSH, MS. VIOLET	*Buddleja davidii 'Ms. Violet'*					X	N
	BUTTERFLY BUSH, PEACH COB	*Buddleja davidii 'Peach Cob'*	X					N
	BUTTERFLY BUSH, PSCHODELIC SKY	*Buddleja davidii 'PIIBD=III First Edition Psychec*	X					Y
	BUTTERFLY BUSH, PINK MICRO CHIP	*Buddleja davidii 'Pink Micro Chip'*					X	N
	BUTTERFLY BUSH, PURPLE HAZE	*Buddleja davidii 'Purple Haze'*	X					N
	BUTTERFLY BUSH, TUTI FRUTI	*Buddleja davidii 'Tuti Fruti'*	X					N
	BOXWOOD, GREEN MOUNTAIN	*Buxus 'Green Mountain'*	X					Y
*Buxus sempervirens**	BOXWOOD, COMMON	*Buxus sempervirens*		X	X			N
	BOXWOOD, 3-TIERED	*Buxus sempervirens '3-Tiered'*	X					N
	BOXWOOD, DEE RUNK	*Buxus sempervirens 'Dee Runk'*	X					N
	BOXWOOD, COLUMNAR	*Buxus sempervirens 'Fastigiata'*	X					N
	BOXWOOD, GRAHAM BLANDY	*Buxus sempervirens 'Graham Blandy'*	X					N
	BOXWOOD, GREEN VELVET	*Buxus sempervirens 'Green Velvet'*	X					Y
	BOXWOOD, NEWPORT BLUE	*Buxus sempervirens 'Newport Blue'*	X					N
	BOXWOOD, VARDER VALLEY	*Buxus sempervirens 'Varder Valley'*	X					Y
*Buxus sinica var. insularis**	BOXWOOD, WINTER GEM	*Buxus sinica var. insularis 'Winter Gem'*	X					Y
*Callicarpa americana**	BEAUTYBERRY, AMERICAN	*Callicarpa americana*	X				X	Y
	BEAUTYBERRY, PURPLE PEARL	*Callicarpa americana 'Purple Pearl'*	X					N
	BEAUTYBERRY, SNOW STORM	*Callicarpa americana 'Snow Storm'*	X					N
Callicarpa bodinieri var. giraldii	BEAUTYBERRY, PROFUSION	*Callicarpa bodinieri var. giraldii*	X					Y
Callicarpa dichotoma 'Early Amethest	BEAUTYBERRY, EARLY AMTH.	*Callicarpa dichotoma 'Early Amethest'*	X					Y
*Calycanthus raulstonii**	SWEETSHRUB, HART. WINE	*Calycanthus raulstonii 'Hartlage Wine'*	X					Y
	SWEETSHRUB, VENUS	*Calycanthus 'Venus'*	X					Y
*Camellia sasanqua**	CAMELLIA SASANQUA	*Camellia sasanqua*				X	X	Y
	CAMELLIA, JESSICA'S RUFFLES	*Camellia sasanqua 'Jessica's Ruffles'*						N
	CAMELLIA, OCTOBER MAGIC	*Camellia sasanqua 'October Magic'*						N
	CAMELLIA, OCTOBER MAGIC ORCHID	*Camellia sasanqua 'October Magic Orchid'*						N
	CAMELLIA, PINK STELLA	*Camellia sasanqua 'Pink Stella'*						N
	CAMELLIA, SHI SHI GASHRIA	*Camellia sasanqua 'Shi Shi Gashria'*						N
	CAMELLIA, YULTIDE	*Camellia sasanqua 'Yultide'*						N
Caryopteris x clandonensis 'Sapphire :	BLUEBEARD, SAPPHIRE SURF	*Caryopteris x clandonensis 'Sapphire Surf'*	X					Y
Cephalotaxus harringtonia 'Duke Garı	PLUM YEW, DUKE	*Cephalotaxus harringtonia 'Duke Gardens'*	X					Y
	QUINCE, CAMEO	*Chaenomeles 'Cameo'*	X					Y
	QUINCE, ORANGE STORM	*Chaenomeles 'Orange Storm'*	X					Y
	QUINCE, TEXAS SCARLET	*Chaenomeles 'Scarlet'*	X					Y
	QUINCE, SCARLET STORM	*Chaenomeles 'Scarlet Storm'*	X					Y
*Chaenomeles speciosa**	QUINCE, PINK STORM	*Chaenomeles speciosa*	X					Y

Figure 1: Entire list of shrubs collected from the distribution 4 sources in Columbia. Common name, latin name, data origin, and presence of MOBOT data is listed, as well as indication of shrub cultivar groups (*). 242 entries were condensed to 95 groups.

0. GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Data
Chamaecyparis pisifera 'Mops'	JAPANESE FALSECYPRESS, MOPS	*Chamaecyparis pisifera 'Golden Mop'*	X					Y
Chamaecyparis pisifera 'Lemon Threa	JAPANESE FALSECYPRESS, LEMONTHREAD	*Chamaecyparis pisifera 'Lemon Thread'*	X					Y
	JAPANESE FALSECYPRESS, MINIMA	*Chamaecyparis pisifera 'Minima'*	X					N
*Cleyera japonica**	CLEYERA, BRONZE BEAUTY	*Cleyera japonica 'Bronze Beauty'*				X	X	N
	CLEYERA, LEANN	*Cleyera japonica 'Leann'*						N
Cornus alba 'Baton Rouge'	DOGWOOD, BATON ROUGE	*Cornus alba 'Baton Rouge'*	X					Y
Cornus racemosa 'Muszam'	DOGWOOD, MUSKINGUM	*Cornus racemosa 'Muszam'*	X					Y
Cornus sericea 'Baileyi'	DOGWOOD, BAILEYI RED	*Cornus sericea 'Baileyi'*	X		X			Y
*Cotinus obovatus**	SMOKEBUSH, ROYAL PURPLE	*Cotinus obovatus 'Royal Purple'*	X					Y
	SMOKE TREE	*Cotinus obovatus 'Velvet Cloak'*			X			Y
	SMOKE TREE, VELVET CLOAK	*Cotinus obovatus 'Velvet Cloak'*	X					Y
Cupressus leyandii	LEYLAND CYPRESS	*Cupressus leyandii*				X		N
Deutizia gracilis	DEUTZIA, CHAR. PEARLS	*Deutizia gracilis 'Duncan' CHARDONNAY PEAR*	X					Y
Deutizia 'NCDX2' Yuki Cherry Blossom	DEUTZIA, YUKI CHERRY	*Deutizia 'NCDX2' Yuki Cherry Blossom*					X	Y
Elaeagnus communata	AMERICAN SILVERBERRY	*Elaeagnus communata*				X		N
Elaeagnus x Ebbingei	EBBINGE'S SILVERBERRY/ OLEASTER	*Elaeagnus x Ebbingei*					X	Y
*Euonymus alatus**	BURNING BUSH, DWARF	*Euonymus alatus 'Compactus'*	X	X	X			Y
	BURNING BUSH, LIL' MOSES	*Euonymus alatus 'Odom' LITTLE MOSES*	X					Y
	BURNING BUSH, RUDY HAAG	*Euonymus alatus 'Rudy Haag'*	X					Y
Euonymus atropurpureous	EUONYMUS, EASTERN WAHOO	*Euonymus atropurpureous*	X					Y
Euonymus fortunei	WINTERCREEPER, GOLDSPLASH	*Euonymus fortunei 'Gold Splash'*					X	Y
Euonymus japonicus 'Aureomarginatu	EUONYMUS, GOLDEN	*Euonymus japonicus 'Aureomarginatus'*				X		Y
Euonymus kiautschovica 'Manhattan'	EUONYMUS, MANHATTAN	*Euonymus kiautschovica 'Manhattan'*	X					Y
*Forsythia x intermedia**	FORSYTHIA, GOLD TIDE	*Forsythia 'Courtasol' GOLD TIDE*	X					Y
	FORSYTHIA, SHOW OFF	*Forsythia x intermedia 'Mindor' SHOW OFF*	X					Y
	FORSYTHIA, SPRING GLORY	*Forsythia x intermedia 'Spring Glory'*	X					N
*Fothergilla gardenii **	FOTHERGILLA, DWARF	*Fothergilla gardenii*	X					Y
	FORTHERGILLA, MT. AIRY	*Fothergilla gardenii 'Mt Airy'*	X					Y
*Gardenia jasminoides**	GARDENIA	*Gardenia jasminoides*				X		Y
	GARDENIA, AUGUST BEAUTY	*Gardenia jasminoides 'August Beauty'*	X					N
	GARDENIA, BEAUTY	*Gardenia jasminoides 'Beauty'*	X					N
	GARDENIA, FROST PROOF	*Gardenia jasminoides 'Frost Proof'*	X					N
	GARDENIA, JUBILATION	*Gardenia jasminoides 'Jubilation'*	X					N
	GARDENIA, RADICANS DWARF	*Gardenia jasminoides 'Radicans Dwarf'*	X					N
	GARDENIA, SCENTAMAZING	*Gardenia jasminoides 'ScentAmazing'*	X					N
Genista tinctoria	LYDIA, DYERS GREENWEED	*Genista tinctoria*	X					N
*Hamamelis x intermedia**	WITCHHAZEL, ANGELLY	*Hamamelis x intermedia 'Angelly'*	X					Y
	WITCHHAZEL, ARNOLDS PROM	*Hamamelis x intermedia 'Arnolds Prom'*	X					Y
	WITCHHAZEL, DIANE	*Hamamelis x intermedia 'Diane'*	X					Y
	WITCHHAZEL, JELENA	*Hamamelis x intermedia 'Jelena'*	X					Y
	WITCHHAZEL, SUNBURST	*Hamamelis x intermedia 'Sunburst'*	X					Y
*Hibiscus syriacus**	ALTHEA	*Hibiscus syriacus*		X				Y
	ALTHEA TREE FORM	*Hibiscus syriacus*	X	X				N
	ALTHEA, APHRODITE	*Hibiscus syriacus 'Aphrodite'*	X					N
	ALTHEA, AZURRI BLUE SATIN	*Hibiscus syriacus 'Azurri Blue Satin'*	X				X	Y
	ALTHEA, BLUE CHIFFON	*Hibiscus syriacus 'Blue Chiffon'*	X				X	N
	ALTHEA, LAVENDER CHIFFON	*Hibiscus syriacus 'Lavender Chiffon'*	X					Y
	HYBISCUS, LIL' KIM	*Hibiscus syriacus 'Lil Kim'*	X					Y
	ALTHEA MINERVA	*Hibiscus syriacus 'Minerva'*	X					Y
	ALTHEA, PURPLE PILLAR	*Hibiscus syriacus 'Purple Pillar'*	X				X	N
	ALTHEA, SUGAR TIP	*Hibiscus syriacus 'Sugar Tip'*	X					Y

GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Data
Hydrangea macrophylla	HYDRANGEA, BIGLEAF	*Hydrangea macrophylla*		X				Y
Hydrangea quercifolia	HYDRANGEA, OAKLEAF	*Hydrangea quercifolia*			X			Y
Hypericum calycinum	ST. JOHNS WORT, GOLDEN RULE	*Hypericum calycinum 'Golden Rule'*	X					Y
*Ilex crenata**	HOLLY, JAPANESE COMPACTA	*Ilex crenata 'Compacta'*				X		Y
	HOLLY, JAPANESE SKY PENCIL	*Ilex crenata 'Sky Pencil'*				X	X	Y
Ilex x meserveae 'Hachfee'	HOLLY, CASTLE SPIRE BLUE	*Ilex x meserveae 'Hachfee'*					X	N
Illex cornuta 'Dwarf Burford'	HOLLY, DWARF BURFORD	*Illex cornuta 'Dwarf Burford'*				X	X	Y
	HOLLY , SOFT TOUCH	*Illex crenata 'Soft Touch'*				X		N
*Itea virginica**	ITEA, HENRYS GARNET	*Itea virginica 'Henry's Garnet'*	X					Y
	ITEA, LITTLE HENRY	*Itea virginica 'Little Henry'*	X					Y
	ITEA, MERLOT	*Itea virginica 'Merlot'*	X					N
Ixora coccinea	IXORA BUSH	*Ixora coccinea*				X		Y
Juniperus chinensis	JUNIPER, CHINESE	*Juniperus chinensis*				X		
Juniperus conferta 'Blue Pacific'	JUNIPER, SHORE	*Juniperus conferta 'Blue Pacific'*					X	
	JUNIPER, HUGHES	*Juniperus horizontalis 'Hughs'*	X					N
Juniperus horizontalis 'Wiltonii'	JUNIPER, CREEPING, BLUE RUG	*Juniperus horizontalis 'Wiltonii'*	X		X			Y
	JUNIPER, CALGARY CARPET	*Juniperus sabina 'Monna'*	X					N
Juniperus sabina 'Skandia'	JUNIPER, SKANDIA	*Juniperus sabina 'Skandia'*	X					Y
	JUNIPER, GREY GUARDIAN	*Juniperus virginiana 'Greguard'*	X					N
Juniperus virginiana 'Grey Owl'	JUNIPER, EASTERN, GREY OWL	*Juniperus virginiana 'Grey Owl'*	X					Y
*Juniperus x pfitzeriana**	JUNIPER, DAUBS FROSTED	*Juniperus x pfitzeriana 'Daub's Frosted'*	X					Y
	JUNIPER, SAYBROOK GOLD	*Juniperus x pfitzeriana 'Saybrook Gold'*	X					Y
	JUNIPER, SEA GREEN	*Juniperus x pfitzeriana 'Sea Green'*	X					Y
Lagerstormea indica	CRAPEMYRTLE, DYNAMITE	*Lagerstormea indica 'Dynamite'*	X					Y
	CR. MYRTLE, PR. SERIES	*Lagerstormea indica 'Princess'*	X					N
Lagerstormea indica x fauriei	CRAPEMYRTLE (INDICA X FAURIEI)	*Lagerstormea var. indica x fauriei*		X				N
	CRAPEMYRTLE, HOPI	*Lagerstromea indica 'Hopi'*	X					Y
	CRAPEMYRTLE, PINK VELOUR	*Lagerstromea indica 'Pink Velour'*	X					Y
	CRAPEMYRTLE, POCOMOKE	*Lagerstromea indica 'Pocomoke'*	X					Y
	CRAPEMYRTLE, RED ROCKET	*Lagerstromea indica 'Red Rocket'*	X					N
	CRAPEMYRTLE, TONTO	*Lagerstromea indica 'Tonto'*	X					Y
	CRAPEMYRTLE, VICTOR DWF	*Lagerstromea indica 'Victor Dwarf'*	X					Y
	CRAPEMYRTLE, ZUNI	*Lagerstromea indica 'Zuni'*	X					Y
Lespedeza bicolor 'Yakushima'	BUSHCLOVER, YAKUSHIMA	*Lespedeza bicolor 'Yakushima'*	X					Y
Lespeszdia thunbergii	BUSHCLOVER, GEMPEI	*Lespeszdia thunbergii 'Gempei'*	X					N
	BUSHCLOVER, GIBRALTER	*Lespeszdia thunbergii 'Gibralter'*	X					Y
Ligurstrum 'Vicaryi'	PRIVET, GOLDEN TICKET	*Ligurstrum 'Vicaryi'*	X				X	N
Ligustrum japonicum	LIGUSTRUM RECURVIFOLIA, CURLY LEAF	*Ligustrum japonicum 'Recurvifolia'*				X	X	N
Lonicera periclymenum	HONEY SUCKLE, SENSATION	*Lonicera periclymenum 'Sensation'*					X	Y
Loropetalum chinense f. rubrum	LOROPETALUM, CAROLINA MIDNIGHT	*Loropetalum chinense f. rubrum 'Carolina Midnight'*				X		N
Loropetalum chinense	LOROPETALUM, PURPLE DIAMOND SEMI-DWARF	*Loropetalum chinense 'Purple Diamond'*				X	X	N
	LOROPETALUM, PURPLE PIXIE	*Loropetalum chinense 'Purple Pixie'*				X	X	N
	LOROPETALUM, RUBY	*Loropetalum chinense 'Ruby'*				X		N
Lycium chinense	GOJI BERRY, SWEET LIFE	*Lycium chinense or Lycium barbarum*					X	Y
Myrica pensylvanica	BAYBERRY, BOBBEE	*Myrica pensylvanica BOBBEE*	X					Y
*Nandina domestica**	NANDINA, GULF STREAM	*Nandina domestica 'Gulf Stream'*	X		X			N
	NANDINA, MOYERS RED	*Nandina domestica 'Moyers Red'*	X					N
*Physocarpus opulifolius**	NINEBARK	*Physocarpus opulifolius*		X	X			Y
	NINEBARK, AMBER JUBILEE	*Physocarpus opulifolius 'Amber Jubilee'*	X					Y

GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Data
	NINEBARK, CENTER GLOW	*Physocarpus opulifolius 'Center Glow'*	X					Y
	NINEBARK, LITTLE DEVIL	*Physocarpus opulifolius 'Little Devil'*	X					N
	NINEBARK, SUMMER WINE	*Physocarpus opulifolius 'Summer Wine'*	X					Y
Picea glauca 'Conica'	SPRUCE, DWARF ALBERTA	*Picea glauca 'Conica'*	X		X		X	N
Picea pungens	SPRUCE, GLOBE BLUE	*Picea pungens 'Globe'*	X					Y
Pinus mugo	PINE, MUGO	*Pinus mugo*	X		X			Y
Pittosporum tobira 'Variegatum'	PITTOSPORUM, VARIGATED	*Pittosporum tobira 'Variegatum'*				X		Y
Prunus laurocerasus	ENGLISH LAUREL, OTTO	*Prunus laurocerasus 'Otto Luyken'*	X					Y
	ENGLISH LAUREL, SKIP	*Prunus laurocerasus ''Schipkaensis''*	X					N
Rhamnus frangula 'Ron Williams' FINI	ALDER BUCKTHORN, FINELINE	*Rhamnus frangula 'Ron Williams' FINE LINE*	X				X	Y
*Rhaphiolepis indica**	INDIAN HAWTHORN, ELEANOR TABOR	*Rhaphiolepis indica 'Eleanor Tabor'*				X		N
	INDIAN HAWTHORN, SNOW WHITE	*Rhaphiolepis indica 'Snow White'*				X		Y
*Rhododendron sp**	AZALEA	*Rhododendron*		X				Y
	AZALEA, BLOOM-A-THON	*Rhododendron BLOOM-A-THON*	X					N
*Rhododendron sp**	RHODODENDRON CAPISTRANO	*Rhododendron 'Capistrano'*	X					Y
	RHODODENDRON CAT ALBUM	*Rhododendron 'Catawbiense Album'*	X					Y
	RHODODENDRON ROSEUM ELEGANS	*Rhododendron catawbiense 'Roseum Elegans'*	X					Y
	AZALEA, ENCORE	*Rhododendron ENCORE*	X	X		X	X	Y
	AZALEA, GIBRALTER	*Rhododendron 'Gibralter'*	X					Y
	AZALEA, GIRARD CAROLINE	*Rhododendron 'Girard Caroline'*	X					N
	AZALEA, GIRARD CHRISTINE	*Rhododendron 'Girard Christine'*	X					N
	AZALEA, GIRARD CRIMSON	*Rhododendron 'Girard Crimson'*	X					Y
	AZALEA, GIRARD HOT SHOT	*Rhododendron 'Girard Hot Spot'*	X					Y
	AZALEA, GIRARD WHITE	*Rhododendron 'Girard White'*	X					N
	RHODODENDRON NOVA ZEMBLA	*Rhododendron 'Nova Zembla'*	X					Y
	RHODODENDRON OLGA	*Rhododendron 'Olga Mezitt'*	X					N
	RHODODENDRON PJM COMPACT	*Rhododendron x 'PJM'*	X					Y
Rhus aromatica 'Gro-low'	SUMAC, GRO-LOW FRAG.	*Rhus aromatica 'Gro-low'*	X					Y
Rhus copallinum var. latifolia 'Morton	SUMAC, PRAIRIE FLAME	*Rhus copallinum var. latifolia 'Morton' PRAIRIE*	X					Y
Rhus glabra	SUMAC, SMOOTH	*Rhus glabra*	X					Y
Rhus typhina	SUMAC, STAGHORN	*Rhus typhina*	X					Y
Rosa sp.	ROSE, ABRAHAM DARBY TEA	***Rosa 'Abraham Darby Tea'***	X					N
	ROSE, CAREFREE DIANA	***Rosa 'Carefree Diana'***	X					Y
	ROSE, CHRYSLER IMPERIAL TEA	***Rosa 'Chrysler Imperial Tea'***	X					N
	ROSE, CROCUS ROSE TEA	***Rosa 'Crocus Rose Tea'***	X					N
	ROSE, DOUBLE KNOCKOUT	***Rosa 'Double Knockout'***	X	X				N
	ROSE, DRIFT APRICOT	***Rosa 'Drift Apricot'***	X					N
	ROSE, DRIFT CORAL	***Rosa 'Drift Coral'***	X					N
	ROSE, DRIFT PEACH	***Rosa 'Drift Peach'***	X					N
	ROSE, DRIFT PINK	***Rosa 'Drift Pink'***	X					N
	ROSE, DRIFT POPCORN	***Rosa 'Drift Popcorn'***	X					N
	ROSE, DRIFT RED	***Rosa 'Drift Red'***	X					N
	ROSE, DRIFT SWEET	***Rosa 'Drift Sweet'***	X					N
	ROSE, FIGHT. TEMERAIRE TEA	***Rosa 'Fighting Temeraire Tea'***	X					N
	ROSE, FJ GOOTENDORST	***Rosa 'FJ Gootendorst'***	X					N
	ROSE, FRAU DAGMAR	***Rosa 'Frau Dagmar'***	X					N
	ROSE, HOME RUN	***Rosa 'Home Run'***	X					N
	ROSE, JOHN F. KENNEDY TEA	***Rosa 'John F. Kennedy Tea'***	X					N
	ROSE, KNOCKOUT RED	***Rosa 'Knockout Red'***	X					Y
	ROSE, KNOCKOUT SUNNY	***Rosa 'Knockout Sunny'***	X					N
	ROSE, LICHFIELD ANGEL TEA	***Rosa 'Lichfield Angel Tea'***	X					N

. GROUP	0. NAME	LATIN NAME	ROST	CMSE	OBS	WAL	HD	MOBOT Data
	ROSE, MUNSTEAD WOOD TEA	***Rosa 'Munstead Wood Tea'***	X					N
	ROSE, PEACE TEA	***Rosa 'Peach Tea'***	X					N
	ROSE, TEASING GEORGIA TEA	***Rosa 'Teasing Georgia Tea'***	X					N
	ROSE, WHITEOUT	***Rosa 'Whiteout'***	X					N
Sambucus nigra 'Eva' Black Lace	ELDERBERRY, BLACK LACE	*Sambucus nigra 'Eva' Black Lace*					X	Y
Spiraea betulifolia	SPIREA, TOR	*Spiraea betulifolia 'Tor'*	X					Y
Spiraea cantoniensis	SPIREA, REEVES BRIDAL WREATH	*Spiraea cantoniensis*		X		X	X	N
Spiraea japonica	SPIREA, DOUBLEPLAY CANDY CORN	*Spiraea japonica 'Double Play Candy Corn'*					X	N
	SPIREA, SUNDROP	*Spiraea 'Sundrop'*	X					N
	SPIREA, DOUBLEPLAY GOLD	*Spiraea 'Double Play Gold'*	X					Y
	SPIREA, DP BING BANG	*Spiraea 'Double Play Big Bang'*	X					N
	SPIREA, GOLDFLAME Dense	*Spiraea japonica 'Goldflame'*	X		X			Y
	SPIREA, GOLDMOUND	*Spiraea japonica 'Goldmound'*	X					Y
	SPIREA, LITTLE PRINCESS	*Spiraea japonica 'Little Princess'*	X					Y
	SPIREA, MAGIC CARPET	*Spiraea japonica 'Walbuma'*	X					Y
	SNOWBERRY, CANDY	*Symphoricarpos x doorenbosii 'Candy'*	X					N
*Symphoricarpos x doorenbosii**	SNOWBERRY, SWEET	*Symphoricarpos x doorenbosii 'Sweet'*	X					N
	LILAC, DWARF KOREAN	*Syringa meyeri 'Palibin'*	X					N
	LILAC, MINUET	*Syringa 'Minuet'*	X					N
Syringa 'Penda' BLOOMERANG	LILAC. BLOOMERANG	*Syringa 'Penda' BLOOMERANG*	X				X	Y
*Syringa pubescens subsp. Patula**	LILAC, MISS KIM	*Syringa pubescens subsp. patula 'Miss Kim'*	X	X				Y
	LILAC, SWEET TREAT	*Syringa pubescens subsp. patula 'Sweet Treat'*	X					N
*Syringa vulgaris**	LILAC, COMMON PURPLE	*Syringa vulgaris*	X		X			Y
	LILAC, COMMON WHITE	*Syringa vulgaris*	X					N
	LILAC, SENSATION	*Syringa vulgaris 'Sensation'*	X					Y
Tamarix ramosissima	TAMARISK, SUMMER GLOW	*Tamarix ramosissima 'Summer Glow'*	X					Y
Taxus cuspidata 'Capitata'	YEW, CAPITATA	*Taxus cuspidata 'Capitata'*	X					Y
Taxus x media 'Densiformis'	YEW, DENSI	*Taxus x media 'Densiformis'*	X					Y
*Thuja occidentalis**	EASTERN ARBORVITAE, MAGIC MOMENT	*Thuja occidentalis ' Magic Moment'*					X	Y
	EASTERN ARBORVITAE, BOWLING BALL	*Thuja occidentalis 'Bowling Ball'*	X		X			Y
	EASTERN ARBORVITAE, EMERALD GREEN	*Thuja occidentalis 'Emerald Green'*				X		Y
	EASTERN ARBORVIITAE, GOLD	*Thuja occidentalis 'Gold'*					X	Y
Thuja occidentalis 'Green Giant'	EASTERN ARBORVITAE, GREEN GIANT	*Thuja occidentalis 'Green Giant'*				X		Y
	EASTERN ARBORVITAE, HETZ MID	*Thuja occidentalis 'Hetz Midget'*	X					Y
Viburnum macrocephalum	VIBURNUM, CHINESE SNOWBALL	*Viburnum macrocephalum*				X	X	
Viburnum nudum	VIBURNUM NUDUM (SNOWBALL)	*Viburnum nudum*		X		X		Y
*Vitex agnus-castus**	CHASE TREE, SHOAL CREEK	*Vitex agnus-castus 'Shoal Creek'*	X					Y
	CHASE TREE, SILVER SPIRE	*Vitex agnus-castus 'Silver Spire'*	X					N
*Weigela florida**	WEIGELA	*Weigela florida*		X				Y
	WEIGELA, WINE AND ROSES	*Weigela florida 'Alexandra' WINE AND ROSES*	X					Y
	WEIGELA, BURGANDY FIRE	*Weigela florida 'Burgandy Fire'*	X					N
	WEIGELA, WINGS OF FIRE	*Weigela florida 'Wings of Fire'*	X					N

APPENDIX D
SHRUB SCORES

Figure 1: Filter Results from 95 shrub entries. Latin name, subsistence, and zone range are documented. The last three columns indicated whether, based on the criteria explained in Chapter 3, the shrub passed the Zone Filter and Invasiveness Filter. Data companion to Figure 3.10.

0.LATIN NAME	SUSTENANCE	ZONE	1. Zone Filter	2. Invasive or spreading	2. Inv. Filter
Taxus cuspidata 'Columnaris'	Evergreen	4,5,6,7	C	A bit on the east coast- consi	C
Euonymus fortunei 'Canadale Gold'	Evergreen	5,6,7,8	C	Highly locally invasive, speadi	N
Lespedeza thunbergii	Deciduous	4,5,6,7,8	C	mildly	N
Illex crenata 'Compacta'	evergreen	5,6,7,8	C	mildly in the northwest	C
Illex cornuta 'Dwarf Burford'	evergreen	7,8,9	F	mildly to the south	N
Abelia x grandiflora	Deciduous in MO	(5),6,7,8,9	C	No	C
Aronia melanocarpa	Deciduous	3,4,5,6,7,8	C	No	C
Buxus sempervirens cultivars	Evergreen	5,6,7,8	C	No	C
Buxus sinca var. insularis cultivars	Evergreen	4,5,6,7,8,9	C	No	C
Callicarpa americana	Deciduous	6,7,8,9,10	C	No	C
Callicarpa bodinieri var. giraldii 'Profusion'	Deciduous	6,7,8	C	No	C
Callicarpa dichotoma 'Early Amethyst'	Deciduous	5,6,7,8	C	No	C
Calycanthus cultivars	Deciduous	5,6,7,8,9	C	No	C
Caryopteris x clandonensis	Deciduous, (total die	5,6,7,8,9	C	No	C
Cephalotaxus harringtonia	Evergreen	6,7,8,9	C	No	C
Chaenomeles speciosa cultivars	Deciduous	(4),5,6,7,8,9	C	No	C
Chamaecyparis pisifera 'Golden Mop'	Evergreen	5,6,7	C	No	C
Chamaecyparis pisifera 'Lemon Thread'	Evergreen	4,5,6,7,8	C	No	C
Cleyera japonica	Evergreen	6,7,8,9	C	No	C
Cornus alba 'Baton Rouge'	Deciduous	3,4,5,6,7,8	C	No	C
Cornus racemosa 'Muszam'	Deciduous	4,5,6,7,8	C	No	C
Cornus sericea 'Baileyi'	Deciduous	3,4,5,6,7,8	C	No	C
Cotinus obovatus cultivars	Deciduous	4,5,6,7,8	C	No	C
Cuprocyparis leylandii	Evergreen	6,7,8,9,10	C	No	C
Deutizia gracilis cultivars	Deciduous	5,6,7,8	C	No	C
Deutizia 'NCDX2' Yuki Cherry Blossom	Deciduous	5,6,7,8	C	No	C
Euonymus atropurpureous	Deciduous	3,4,5,6,7	C	No	C
Euonymus japonicus 'Aureomarginatus'	Evergreen	6,7,8,9	C	No	C
Euonymus kiautschovica 'Manhattan'	Semi-evergreen to d	5,6,7,8	C	No	C
Forsythia x intermedia cultivars	Deciduous	5,6,7,8	C	No	C
Fothergilla gardenii cultivars	Deciduous	5,6,7,8	C	No	C
Genista tinctoria	Deciduous	4,5,6,7	C	No	C
Hamamelis x intermedia cultivars	Deciduous	5,6,7,8 (9)	C	No	C
Hydrangea macrophylla	Deciduous	5,6,7,8,9,10,11	C	No	C
Hydrangea quercifolia	Deciduous	5,6,7,8,9	C	No	C
Illex x meserveae 'Hachfee' CASTLE SPIRE	evergreen	5,6,7	C	No	C
Itea virginica cultivars	deciduous	5,6,7,8,9	C	No	C
Juniperus chinensis	Evergreen	4,5,6,7,8,9	C	No	C
Juniperus conferta 'Blue Pacific'	Evergreen	6,7,8,9	C	No	C
Juniperus horizontalis 'Wiltonii'	Evergreen	3,4,5,6,7,8,9	C	No	C
Juniperus sabina 'Skandia'	Evergreen	3,4,5,6,7	C	No	C
Juniperus x pfitzeriana cultivars	Evergreen	4,5,6,7,8,9	C	No	C
Lagerstroemia indica x faueri	Deciduous	6,7,8,9	C	No	C
Lespedeza bicolor 'Yakushima'	Deciduous	4,5,6,7,8	C	No	C
Ligustrum 'Vicaryi'	Evergreen	5,6,7,8	C	No	C
Lycium chinense	Deciduous	6,7,8	C	No	C
Myrica pennsylvanica	Evergreen	3,4,5,6, 7	C	No	C
Physocarpus opulifolius	Deciduous	2,3,4,5,6,7,8	C	No	C
Picea pungens cultivars	Evergreen	3,4,5,6,7	C	No	C
Pinus mugo	Evergreen	2,3,4,5,6,7	C	No	C
Rhamnus frangula 'Ron Williams' Fineline	Deciduous	3,4,5,6,7	C	No	C

C = COMPATIBLE
F = FUTURE COMPATIBLE
N = INCOMPATIBLE
R = At Risk

Rhododendron cultivars	Evergreen	(4),5,6,7,8	C	No	C
Rhododendron cultivars	Evergreen	5,6,7,8	C	No	C
Rhus aromatica 'Gro-Low'	deciduous	3,4,5,6,7,8,9	C	No	C
Rhus copallinum var. latifolia 'Morton' PRAI	deciduous	4,5,6,7,8,9	C	No	C
Rhus glabra	deciduous	3,4,5,6,7,8,9	C	No	C
Rhus typhina cultivars	deciduous	3,4,5,6,7,8	C	No	C
Rosa sp. cultivars	Deciduous	(4),5,6,7,8,9	C	No	C
Sambucus nigra 'Eva' Black Lace	Deciduous	4,5,6,7	C	No	C
Spiraea betulifolia	deciduous	4,5,6,7,8	C	No	C
Spiraea cantoniensis	deciduous	5,6,7,8	C	No	C
Symphoricarpos x doorenbosii cultivars	Deciduous	3,4,5,6,7	C	No	C
Syringa 'Penda' Bloomerang	Deciduous	4,5,6,7	C	No	C
Syringa pubescens, subsp. patula	Deciduous	3,4,5,6,7,8	C	No	C
Taxus x media 'Densiformis'	Evergreen	4,5,6,7	C	No	C
Thuja occidentalis cultivars	Evergreen	2,3,4,5,6,7	C	No	C
Thuja occidentalis 'Green Giant'	Evergreen	5,6,7,8	C	No	C
Viburnum macrocephalum	Deciduous	6,7,8,9	C	No	C
Viburnum nudum	Deciduous	5,6,7,8,9	C	No	C
Weigela florida cultivars	Deciduous	4,5,6,7,8	C	No	C
Camellia sasanqua cultivars	Evergreen	7,8,9	F	No	F
Elaeagnus x Ebbingei	Evergreen	7,8,9	F	No	F
Gardenia jasminoides cultivars	Evergreen	7,8,9	F	No	F
Loropetalum chinense cultivars	Evergreen	7,8,9	F	No	F
Loropetalum chinense f. rubrum cultivars	Evergreen	7,8,9,10	F	No	F
Ixora coccinea	evergreen	9,10,11	N	No	_
Pittosporum tobira 'Variegatum'	Houseplant - evergre	9,10	N	No	_
Rhaphiolepis indica cultivars	evergreen	8,9,10	N	No	_
Elaeagnus commutata	deciduous	2,3,4,5,6	R	No	R
Picea glauca 'Conica'	Evergreen	3,4,5,6	R	No	R
Lonicera periclymenum	Deciduous	5,6,7,8,9	C	Naturalizing in north and PNV	N
Hypericum calycinum	Deciduous	5,6,7,8,9	C	Naturalizing in west coast	C
Hibiscus syriacus cultivars	Deciduous	5,6,7,8	C	SE US, couple counties in MO	C
Syringa vulgaris cultivars	Deciduous	3,4,5,6,7	C	somewhat	C
Lagerstomea indica*	Deciduous	6,7,8,9	C	somewhat in south	N
Vitex agnus-castus var.	Deciduous	6,7,8,9	C	somewhat in south. Placed or	N
Euonymus alatus cultivars	Deciduous	4,5,6,7,(8)	C	Yes	N
Spiraea japonica	deciduous	4,5,6,7,8	C	Yes in east	N
Ligustrum japonicum	Evergreen	8,9,10	N	Yes in south	_
Prunus laurocerasus	Evergreen	6,7,8	C	Yes somewhat	C
Tamarix ramosissima	Deciduous	3,4,5,6,7,8	C	Yes- west southwest and boo	N
Buddleja davidii cultivars	Deciduous/semi-herl	5,6,7,8,9	C	Yes, cultivar dep	N
Berberis thunbergii cultivars	Deciduous	(4)5,6,7,8	C	Yes, cultivar dep. Spread by b	N
Nandina domestica cultivars	semi-evergreen, deci	6,7,8,9	C	yes in south	N
Juniperus virginiana 'Grey Owl'	Evergreen	2,3,4,5,6,7,8,9	C	Yes-on east coast (native but	N

C = COMPATIBLE
F = FUTURE COMPATIBLE
N = INCOMPATIBLE
R = At Risk

native?	COMMON NAME	LATIN NAME	SUBSISTENCE	ZONE	Filter1 (Z)	Filter2 (Inv)	Score1 (SMS)	Score2 (+Dt, Wt)	Intrinsic Score	Score3 (Maint)	Score4 (Concerns)	External Score	Total Score	Final Category
	Gardenia*	Gardenia jasminoides cultivars	Broadleaf Evergreen	7,8,9	F	F	1	0	1	-1	-1	-2	-1	At Risk
	Elderberry, Black Lace	Sambucus nigra 'Eva' Black Lace	Deciduous	4,5,6,7	C	C	0	0	0	-1	0	-1	-1	At Risk
	Rhododendron*	Rhododendron cultivars	Broadleaf Evergreen	(4),5,6,7,8	C	C	1	0	1	0	-1	-1	0	At Risk
	Camellia*	Camellia sasanqua cultivars	Broadleaf Evergreen	7,8,9	F	F	1	0	1	0	-1	-1	0	At Risk
	Lilac*	Syringa vulgaris cultivars	Deciduous	3,4,5,6,7	C	C	1	0	1	0	-1	-1	0	At Risk
Y	Dogwood, Red Twig	Cornus sericea 'Baileyi'	Deciduous	3,4,5,6,7,8	C	C	0	1	1	1	-1	0	1	At Risk
	Holly, Japanse Compacta	Illex crenata 'Compacta'	Broadleaf Evergreen	5,6,7,8	C	C	1	1	2	0	-1	-1	1	At Risk
	Pine, Mugo	Pinus mugo	Needled Evergreen	2,3,4,5,6,7	C	C	1	0	1	1	-1	0	1	At Risk
Y	Euonymus Eastern Wahoo	Euonymus atropurpureous	Deciduous	3,4,5,6,7	C	C	1	0	1	1	0	1	2	At Risk
Y	Beautyberry, American	Callicarpa americana	Deciduous	6,7,8,9,10	C	C	1	0	1	0	1	1	2	At Risk
Y	Virginia Sweetspire*	Itea virginica cultivars	deciduous	5,6,7,8,9	C	C	0	0	0	1	1	2	2	At Risk
	Euonymus, Golden	Euonymus japonicus 'Aureomarginatus'	Broadleaf Evergreen	6,7,8,9	C	C	1	0	1	1	0	1	2	At Risk
	Common Boxwood*	Buxus sempervirens cultivars	Broadleaf Evergreen	5,6,7,8	C	C	1	0	1	0	1	1	2	At Risk
	Korean Boxwood*	Buxus sinca var. insularis cultivars	Broadleaf Evergreen	4,5,6,7,8,9	C	C	1	0	1	0	1	1	2	At Risk
	Alder Buckthorn	Rhamnus frangula 'Ron Williams' Fineline	Deciduous	3,4,5,6,7	C	C	1	0	1	1	0	1	2	At Risk
	Althea/Rose of Sharon*	Hibiscus syriacus cultivars	Deciduous	5,6,7,8	C	C	1	1	2	0	0	0	2	At Risk
	Bigleaf Hydrangea	Hydrangea macrophylla	Deciduous	5,6,7,8,9,10,11	C	C	1	0	1	0	1	1	2	At Risk
	Leyland Cypress	Cuprocyparis leylandii	Needled Evergreen	6,7,8,9,10	C	C	1	0	1	0	1	1	2	At Risk
	Yew, Japanese	Taxus cuspidata 'Columnaris'	Needled Evergreen	4,5,6,7	C	C	1	0	1	1	0	1	2	At Risk
	Euonymus Manhattan	Euonymus kiautschovica 'Manhattan'	Semi-evergreen to d	5,6,7,8	C	C	1	0	1	1	0	1	2	At Risk
Y	American Silverberry	Elaeagnus commutata	Deciduous	2,3,4,5,6	R	NA	NA	NA	NA	NA	NA	NA	NA	At Risk
Y	Spruce, Alberta Dwarf	Picea glauca 'Conica'	Needled Evergreen	3,4,5,6	R	NA	NA	NA	NA	NA	NA	NA	NA	At Risk
Y	Dogwood, Tartarian	Cornus alba 'Baton Rouge'	Deciduous	3,4,5,6,7,8	C	C	1	2	3	1	-1	0	3	Compatible
Y	Oak-leaf Hydrangea	Hydrangea quercifolia	Deciduous	5,6,7,8,9	C	C	1	0	1	1	1	2	3	Compatible
Y	Smoke Tree*	Cotinus obovatus cultivars	Deciduous	4,5,6,7,8	C	C	1	1	2	0	1	1	3	Compatible
Y	Smooth Witherod	Viburnum nudum	Deciduous	5,6,7,8,9	C	C	0	1	1	1	1	2	3	Compatible
Y	Sweetshrub*	Calycanthus cultivars	Deciduous	5,6,7,8,9	C	C	1	0	1	1	1	2	3	Compatible
Y	Fothergilla*	Fothergilla gardenii cultivars	Deciduous	5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
Y	Juniper, Creeping	Juniperus horizontalis 'Wiltonii'	Needled Evergreen	3,4,5,6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible
Y	Spruce, Colorado Blue	Picea pungens cultivars	Needled Evergreen	3,4,5,6,7	C	C	1	1	2	1	0	1	3	Compatible
	Holly, Castle Spire Blue	Illex x meserveae 'Hachfee' CASTLE SPIRE	Broadleaf Evergreen	5,6,7	C	C	1	1	2	1	0	1	3	Compatible
	Azalea*	Rhododendron cultivars	Broadleaf Evergreen	5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	English Laurel	Prunus laurocerasus	Broadleaf Evergreen	6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Privet, Goldern	Ligustrum 'Vicaryi'	Broadleaf Evergreen	5,6,7,8	C	C	2	1	3	-1	1	0	3	Compatible
	Quince*	Chaenomeles speciosa cultivars	Deciduous	(4),5,6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible
	St. Johns Wort	Hypericum calycinum	Deciduous	5,6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible
	Witchhazel*	Hamamelis x intermedia cultivars	Deciduous	5,6,7,8 (9)	C	C	1	1	2	1	0	1	3	Compatible
	Beautyberry, Bodinier	Callicarpa bodinieri var. giraldii 'Profusion'	Deciduous	6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Deutzia*	Deutizia gracilis cultivars	Deciduous	5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Goji Berry/ Sweet Lifeberry	Lycium chinense	Deciduous	6,7,8	C	C	1	1	2	0	1	1	3	Compatible
	Lilac, Manchurian	Syringa pubescens, subsp. patula	Deciduous	3,4,5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Rose*	Rosa sp. cultivars	Deciduous	(4),5,6,7,8,9	C	C	1	1	2	0	1	1	3	Compatible
	Spirea	Spiraea betulifolia	deciduous	4,5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Weigela*	Weigela florida cultivars	Deciduous	4,5,6,7,8	C	C	1	0	1	1	1	2	3	Compatible
	Lilac, Bloomerang	Syringa 'Penda' Bloomerang	Deciduous	4,5,6,7	C	C	1	0	1	1	1	2	3	Compatible
	Glossy Abelia	Abelia x grandiflora	Deciduous in MO	(5),6,7,8,9	C	C	1	0	1	1	1	2	3	Compatible
	Juniper, Chinese	Juniperus chinensis	Needled Evergreen	4,5,6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible

Figure 2: Filter and Scoring Results of all 76 shrubs assessed in this project, organized by final compatibility scores. This does not include those eliminated in the Filters due to zone or invasiveness.

	Juniper, Pfitzfer*	Juniperus x pfitzeriana cultivars	Needled Evergreen	4,5,6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible
	Juniper, Shore	Juniperus conferta 'Blue Pacific'	Needled Evergreen	6,7,8,9	C	C	1	1	2	1	0	1	3	Compatible
	Juniper, Skandia	Juniperus sabina 'Skandia'	Needled Evergreen	3,4,5,6,7	C	C	1	1	2	1	0	1	3	Compatible
	Arborvitae*	Thuja occidentalis cultivars	Needled Evergreen	2,3,4,5,6,7	C	C	1	0	1	1	1	2	3	Compatible
	Yew	Taxus x media 'Densiformis'	Needled Evergreen	4,5,6,7	C	C	1	1	2	1	0	1	3	Compatible
	Yew, Plum	Cephalotaxus harringtonia	Needled Evergreen	6,7,8,9	C	C	1	1	2	0	1	1	3	Compatible
Y	Ninebark	Physocarpus opulifolius	Deciduous	2,3,4,5,6,7,8	C	C	2	1	3	0	1	1	4	Compatible
Y	Chokeberry	Aronia melanocarpa	Deciduous	3,4,5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
Y	Sumac, Smooth	Rhus glabra	Deciduous	3,4,5,6,7,8,9	C	C	2	1	3	0	1	1	4	Compatible
Y	Sumac, Staghorn*	Rhus typhina cultivars	Deciduous	3,4,5,6,7,8	C	C	2	1	3	0	1	1	4	Compatible
Y	Arborvitae 'Green Giant'	Thuja occidentalis 'Green Giant'	Needled Evergreen	5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Cleyera	Cleyera japonica	Broadleaf Evergreen	6,7,8,9	C	C	1	1	2	1	1	2	4	Compatible
	Beautyberry	Callicarpa dichotoma 'Early Amethyst'	Deciduous	5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Crape Myrtle, Dwarf	Lagerstroemia indica x faueri	Deciduous	6,7,8,9	C	C	1	1	2	1	1	2	4	Compatible
	Deutzia, Yuki Cherry Blossom	Deutizia 'NCDX2' Yuki Cherry Blossom	Deciduous	5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Dyer's Greenwood	Genista tinctoria	Deciduous	4,5,6,7	C	C	1	1	2	1	1	2	4	Compatible
	Forsythia*	Forsythia x intermedia cultivars	Deciduous	5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Snowberry*	Symphoricarpos x doorenbosii cultivars	Deciduous	3,4,5,6,7	C	C	1	1	2	1	1	2	4	Compatible
	Viburnum, Chinese Snowball	Viburnum macrocephalum	Deciduous	6,7,8,9	C	C	1	1	2	1	1	2	4	Compatible
	Spirea, Reeves	Spiraea cantoniensis	Deciduous	5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Bluebeard	Caryopteris x clandonensis	Deciduous, (total die	5,6,7,8,9	C	C	1	1	2	1	1	2	4	Compatible
	Sawara/Japanese Falsecypress 'Lem	Chamaecyparis pisifera 'Lemon Thread'	Needled Evergreen	4,5,6,7,8	C	C	1	1	2	1	1	2	4	Compatible
	Sawara/Japanese Falsecypress 'Mo	Chamaecyparis pisifera 'Golden Mop'	Needled Evergreen	5,6,7	C	C	1	1	2	1	1	2	4	Compatible
Y	Dogwood, Gray	Cornus racemosa 'Muszam'	Deciduous	4,5,6,7,8	C	C	1	2	3	1	1	2	5	Compatible
Y	Sumac, Fragrant	Rhus aromatica 'Gro-Low'	Deciduous	3,4,5,6,7,8,9	C	C	2	1	3	1	1	2	5	Compatible
	Bushclover	Lespedeza bicolor 'Yakushima'	Deciduous	4,5,6,7,8	C	C	2	1	3	1	1	2	5	Compatible
	Sumac, Dwarf	Rhus copallinum var. latifolia 'Morton' PRAIRIE FLAME	Deciduous	4,5,6,7,8,9	C	C	2	1	3	1	1	2	5	Compatible
Y	Bayberry	Myrica pennsylvanica	Broadleaf Evergreen	3,4,5,6, 7	C	C	2	2	4	1	1	2	6	Compatible
	Loropetalum*	Loropetalum chinense cultivars	Broadleaf Evergreen	7,8,9	F	F	1	0	1	1	1	2	3	Future Compatible
	Loropetalum*	Loropetalum chinense f. rubrum cultivars	Broadleaf Evergreen	7,8,9,10	F	F	1	0	1	1	1	2	3	Future Compatible
	Ebbinge's Silverberry/ Oleaster	Elaeagnus x Ebbingei	Broadleaf Evergreen	7,8,9	F	F	1	1	2	0	1	1	3	Future Compatible