Cultivating Capacity in the Northeast's Native Seed and Plant Supply Chain

by

Eve B. Allen

BA in Ecology, Botany, and Anthropology
Hampshire College,
Amherst, Massachusetts, 2015

SUBMITTED TO THE DEPARTMENT OF URBAN STUDIES AND PLANNING
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER IN CITY PLANNING
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

MAY 2022

Author____
Department of Urban Studies and Planning
May 19, 2022

Certified by ____
Alan M. Berger
Professor of Landscape Architecture and Urban Design
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by____
Cesar McDowell
Professor of the Practice
Chair, M.C.P. Committee
Department of Urban Studies and Planning

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ABSTRACT

The United States Northeast is turning to nature to prepare for climate change and mitigate the economic, societal, and environmental challenges caused by urbanization and industrialization. Cities and suburbs across the megalopolis are replanting forests, softening coastlines, restoring wetlands, harnessing plants and microbes to remediate brownfield sites, and planting native vegetation on rooftops and old elevated railway lines. These activities spanning from the micro-scale (e.g., street tree plantings) to the macro-scale (e.g., coastal restoration) require seeds and plant propagules. This physical living material forms the foundation of both natural and constructed landscapes. Vegetation plays a critical role in providing an array of regulating, provisioning, and cultural ecosystem services that greatly benefit urban regions. However, largely missing from the discourse is how the chronic commercial shortage, or even unavailability, of most native plant species as seeds or nursery materials constrain efforts to reestablish biodiverse self-sustaining populations, assemblages, and communities that improve ecosystem functioning, support pollinators and wildlife, and are durable enough to withstand the impacts of climate change.

This thesis research uses a mixed-method multi-level case study approach to understand the structure of the social network— government agencies, academic institutions, nonprofit organizations, private companies, and local citizens — as a first step in understanding viable pathways to strengthen the Northeast’s native seed and plant material supply chain, which is a prerequisite for achieving the multiple objectives of current and future restorative activities.

Thesis Supervisor: Alan M. Berger
Title: Professor of Landscape Architecture and Urban Design

ACKNOWLEDGEMENTS

I would like to extend my gratitude to my advisor, Alan Berger, for all of the generous advice and constructive feedback that he has offered me throughout my time at MIT, especially during researching and writing this thesis. I am deeply indebted to the EcoHealth Network, for seeing the value in this research and deciding to sponsor it by providing me with a year and a half long internship. I would also like to express my profound appreciation to James Aronson and Adam Cross, my readers from the EcoHealth Network, whose invaluable mentorship has helped me grow as a researcher and writer. Finally, I want to thank my close friends, family members, and my partner, whose love, support, and counsel have formed a foundation that has allowed me to pursue all of life's golden threads.

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CHAPTER 1: DESCRIBING AND DEFINING RESTORATIVE ACTIVITIES

In 2021, the United Nations declared the Decade on Ecosystem Restoration to highlight the need for worldwide cooperation to prevent and halt further deterioration and accelerate the restoration of 350 million hectares of land, freshwater, and seascapes by 2030. The realization of this commitment, supported by more than eighty countries, could potentially generate at least USD 9 trillion in net benefits and sequester 13-26 gigatons of greenhouse gases (GHS) from the atmosphere over the next decade (United Nations Environment Programme, 2020).

The Society for Ecological Restoration (SER) defines ecological restoration "as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER Primer 2004). Globally ecological restoration, and the continuum of restoration activities recognized in the SER Standards Version 2 (Gann 2019) translates into a vast array of on-the-ground activities: countries are deconstructing dams to reconnect the hydrological flows of major rivers and recuperate water storage capacity; cities are constructing massive green belts around their urban cores to improve the health of wildlife and people; botanists and ecologists are experimenting with wielding fire to recover thousands of hectares of grassland that lie dormant underneath forests; local municipalities are constructing artificial wetlands to absorb water from more frequent flood events; farmers in tropical lands are interspersing a variety of shrubs and trees with their coffee and chocolate plants to break up monocultures; landscape architects are designing ecologically enhanced breakwaters to buffer storm surges and 'sponge' gardens to soak up pollution; and local residents are ditching turfgrass and instead planting an assortment of native flowers to attract pollinators.

These efforts to mend and enhance impaired ecosystems fall into a "family of restorative activities" (Aronson et al. 2017) within a landscape perspective or context for planning, implementation, and management of this kind of work. The essence of this framework is rooted in the acknowledgment that the immense and interlinked challenges of our current moment beckon us to widen our perspective on how we go about assisting the recovery of degraded, damaged, and destroyed ecosystems. Pervasive fragmentation and alteration of habitats, climate change, and biodiversity loss necessitate a range of approaches—from the basic remediation or reclamation of polluted sites and rehabilitation of semi-natural ecosystems to the full recovery of structure, function, and composition of natural systems (Aronson et al. 2017).

Policymakers, practitioners, and scientists use a number of terms — 'nature-based solutions,' 'green infrastructure,' 'urban greening,' 'ecological engineering,' 'landscape infrastructure, 'ecosystem restoration' — to describe the myriad activities within the "family." Often, they will use these terms interchangeably (Matsler et al. 2021). Although authors of various literature reviews have tried to define and describe these terms to more precisely distinguish the differences among them, a large amount of "conceptual fuzziness" still exists (Koc et al. 2017; Wang and Banzhaf 2018; Matsler et al. 2021). Ultimately the terminology, descriptions, metrics, and goals differ based on the basis of differing disciplinary and geographic filters and contexts (Matsler et al. 2021). However, there are a number of elements that all of these activities share in common.

Fundamental to the core of all of these activities an aim to 1) repair ecosystem composition, structure, and functionality by through the use of improving vegetation, soils, microorganisms, sediments, hydrology, and other landscape features; to 2) generate a wide range of ecosystem services (including provisioning services (e.g., food, fiber, fodder, medicines),supporting (e.g., soil formation and nutrient cycling that supports sustainable forestry and farming, *inter alia*), regulating (e.g., flood protection, heat reduction, water filtration), and cultural (e.g., public health, sense of place, educational).

The origin of the concepts that underlie restorative activities can be traced back to the fields of spatial planning and conservation, which emerged in the mid to late 19th Century (Grêt-Regamey et al. 2021). Grêt-Regamey et al. (2021) explain that today these activities are embedded in the contemporary practices of habitat creation and restoration and ecological networks and draw restoration ecology, geographic information systems (GIS), landscape ecology, architecture, urban planning, engineering, conservation biology, geomorphology, hydrology, soil science, and economics.

Nearly all of these activities emphasize people and the critical role that healthy ecosystems in improving human health and wellbeing (Reid 2019). Scientists, practitioners, and policymakers universally promote these activities for their multi-functionality or the ability to simultaneously provide multiple social, environmental, and economic benefits (Hansen and Pauleit 2014). Moreover, these activities can occur over a wide range of spatial (e.g., street tree plantings to coastline restoration) and temporal (e.g., month-long bioretention pond project to multi-year river restoration project) scales.

1.2 Growing global investments in restorative activities

It is challenging to quantify and comprehend the myriad ways that humans have altered the immense diversity of terrestrial and aquatic ecosystems. However, globally, we dammed over 75% of the world’s major rivers (Grill et al. 2019); eradicated forests in 25 countries, and reduced forest cover to 10% in another 29; removed, filled and polluted over 85% of wetlands (Davidson 2014); and replaced of 1.0–3.4 million km2 of rocky reefs, sandy beaches, mudflats, and mangroves with seawalls, breakwalls, wharves, and other engineered structures (Floerl et al. 2021).

In 2021, the United Nations published the report *State of Finance for Nature*, which found that currently, our world invests $113 billion annually in protecting and restoring nature. 86% of that spending is done by the public sector, primarily domestic governments, while private companies make up the remainder of the investments. However, the authors of the report estimate that investments will need to triple by 2030 and quadruple by 2050, equating to a cumulative total investment of $8.1 trillion, if we are to meet various climate change, biodiversity, and land degradation targets (United Nations Environmental Programme, 2021).

In 2021, the US federal government approved a $ 1.4 billion Investment in Ecosystem Restoration and Resilience. The provision included in the Infrastructure Law makes a "critical investment in the resilience and restoration of America's lands, including funding for stewardship contracts, ecosystem restoration projects, invasive species detection and prevention, and native vegetation restoration efforts." The investments include $100 million to address invasive species and $400 million for states, Tribes, and territories to participate in a wide range of restorative activities (US Department of the Interior, 2022).

Across the US Northeast, state and local governments, private companies, nonprofit organizations, and citizen groups are working to restore ecological functionality as part of a multi-pronged approach to adapt to a changing climate. Sizeable investments via climate and green bonds, federal grants, and the allocation of taxpayers' dollars are helping towns, cities, counties, and states across the region carry out a wide range of activities.

The National Ocean and Atmospheric Administration (NOAA) and the National Fish and Wildlife Foundation (NFWF) are helping to fund coastal restoration projects across the Northeast aimed at assisting communities in mitigating the impact of floods and storms while enhancing fish and wildlife habitat (NFWF, 2022). Examples of funded projects since 2018 include $752,799 to restore seven miles of coastal dunes along New York City's Atlantic shoreline; $850,000 to restore 147 acres of degraded salt marsh in Mastic Beach, NY; $982,103 to restore 30 acres of degraded saltmarsh habitat in Charlestown, Rhode Island; $4,600,000 to re-introduce tidal hydrology and plant marsh vegetation in Fairhaven, MA; and $11,916,152 to create a living shoreline and protect and create new marsh habitat at the mouth of Maurice River in NJ (NFWF, 2022).

State-level programs are also directing money towards restorative activities. For example, in Massachusetts, since 2017, the state has invested $65 million in climate change resiliency through the Municipal Vulnerability Preparedness Program, which provides cities and towns with the funding and technical support to develop strategies to mitigate impacts like SLR, inland flooding, storms, and temperature extremes (Mass Gov, 2021). The majority of the funded project types include restoring wetlands and floodplains to reduce flooding; implementing green infrastructure to manage stormwater; and planting trees to mitigate the urban heat island effect (Mass Gov, 2021).

In New York, the fiscal year 2023 Budget proposal includes a $4.2 billion environmental bond act to support climate change mitigation and adaptation efforts through investments in "clean water, clean air, and green jobs." If passed, the state would allocate a record $400 million within the budget to safeguard and restore critical environmental habitats, rehabilitate recreational lands, clean up brownfield sites, and promote sustainable agriculture (New York State, 2022).

Cities and metropolitan areas are investing in activities like green infrastructure to absorb and purify stormwater, reduce urban heat island effect, and reinforce hard infrastructure to protect against sea-level rise (SLR). For example, in early 2022, the New York City Department of Environmental Protection (DEP) launched a $53 million contract with the engineering firm Arcadis to work with private property owners across the city's five boroughs to install green infrastructure to manage stormwater better and improve the health of local waterways (City of New York, 2021). In 2021, The City of Boston selected firms to develop an Urban Forestry Plan, which will invest $500,000 over the next 20 years to protect and expand the city's urban tree canopy by 2,000 trees planted each year (City of Boston, 2020).

These activities that span from micro-scale (e.g., street tree plantings) to the macro-scale (e.g., coastal restoration) require seeds and different forms of containerized plant material. This physical living material forms the foundation of both natural and constructed landscapes, and plays a critical role in providing an array of regulating, provisioning, and cultural ecosystem services that greatly benefit urban regions. The growing investments in restorative activities in the Northeast is increasing the demand for quality native seed and plant material supplies. It is essential that practitioners are equipped with the resources they need to ensure that activity outcomes are successful.

1.3 The need for seed and plant material

While ecosystems can naturally regenerate after destruction and disaster, nearly all of the activities mentioned above have a vegetation component and require some quantity of seed and or plant propagules (e.g., tree saplings). Moreover, practitioners may need to accelerate ecosystem recovery or have specific goals like improving water filtration, pollination services, or poor soils. This is especially true in urban areas with highly degraded and compacted soils. Additionally, human activities may have altered seed dispersal mechanisms to the point that natural vegetation regeneration processes become insufficient (Bossuyt and Honnay 2008).

For larger landscape-scale projects, the volume of plant material required is considerable. For example, Madrid is embarking on an urban forestry project that will involve planting over 500,000 tree saplings on a 75-kilometer ring around the city (EuroNews, 2021). In the United States (US), a study by American Forests found that cities nationwide will need to plant 522 million trees to address gaps in tree cover inequity (American Forests, 2022). Farigione et al. (2021) carried out a study to estimate how many additional tree saplings nursery growers would need to produce in order to reforest 26 million hectares of natural and agricultural lands by 2040 across the US. The authors found that this effort would require nurseries to produce 1.7 billion tree seedlings in addition to the 1.3 billion seedlings that are already produced each year (Ibid). For grassland restoration, land managers in Minnesota used more than 500,000 kg (1,100,000 lb) of seed to restore 9000 hectares of northern tallgrass prairies (Harrison et al. 2020). In southeastern Australia, 2000 kg (4400 pounds lb) of seed was needed to restore 2800 hectares (km2) of degraded land. In Massachusetts, the restoration of wetlands, streams, and sandplain grasslands can require between 5,000 and 50,000 native plants and seeds per project (Personal Communication, 2022). When restorative activities reach hundreds to thousands of hectares by means of one large-scale project or many small-scale projects, nursery growers will need to produce hundreds of thousands of kilograms of seeds and billions of propagules.

Researchers and practitioners recognize that supply chain shortfalls exist for projects ranging from neighborhood to landscape-scale. The demand for plant material now and in the future cannot be met solely by sourcing seed and cuttings of plants from wild populations, which stresses already fragmented native ecosystems (Broadhurst 2015 A; Broadhurst et al. 2015 B; Tischew et al. 2011). Therefore, it is ethical, practical, and often more economical to bring species into horticultural production to multiply seeds and create various forms of propagated planting stock.

Those who form the user community have noted that there is a limited selection of species for various habitat types; poor commercial availability of plant and seed material containing genetically appropriate ecotypes; plant labels frequently omitting or misrepresenting genetic origin, misidentifying species, or indicating straight species or local ecotype even though the product itself is a cultivar; and lack of adequate quantities of seed and plant propagules for larger-scale activities (Tangren and Toth 2020).

Those who collect seed and propagate plant material for restorative activities, the producer community, are often biased toward a few core species that germinate easily, grow reliably, and meet the anticipated market demand (Personal communication, 2021, 2022). According to Broadhurst et al. (2016), these "workhorse" species cost-effectively deliver environmental outcomes, but they constitute a fraction of the plant diversity required to reconstruct resilient ecosystems. Thousands of species remain outside of horticultural production even though they are key elements of plant communities that practitioners are restoring. Moreover, plant biodiversity, widely framed as a target for conservation action, has not yet been fully appreciated by policymakers and practitioners for climate stabilizing effects (Mori et al., 2021). Forests rich in species diversity absorb and sequester more carbon than species-poor forests, like monocultural tree plantations (Liang et al. 2017). However, beyond ensuring that our constructed landscapes have sufficient species diversity, practitioners should also look for seed and plant material that is genetically appropriate or has sufficient intraspecific diversity.

1.4 The need for genetically appropriate seed and plant material

Increasingly research is showing how plant genetic diversity or the variation between members of the same species in plant populations is not only crucial for long-term evolutionary adaptation and biogeographical shifts in the face of climate and other global changes but also for ecosystem functioning (Kettenring et al. 2014; Naeem et al. 2009). Several compelling studies demonstrate how genetic diversity underpins a plant population's ability to establish rapidly, resist invasion, recover from episodic herbivory and extreme weather events, and adapt to climate change (Reusch et al. 2005; Rice et al. 2003; Crutsinger et al. 2008).

Environments are highly heterogenous in both time and space. To deal with unfavorable conditions plant species either escape through migration or acclimate in situ. In nature we see that plant populations are comprised of dozens to thousands of individuals. Each plant can exhibit slightly different traits from the others, including germination rates, size, age, the timing of flowering and setting seeds, tolerance to heat, cold, and extreme weather events, resistance to disease and pests, etc. This variation is known as intraspecific diversity.

Both genetic and environmental factors cause the variability that exists among members of the same species. However, if that variation is heritable, then it has a genetic basis and serves as the raw material on which natural selection operates to solve problems and bring novelty into the world (Fisher 1930). If that variation is induced by environmental factors alone, we can attribute it to phenotypic plasticity, or the capacity of a genotype to express different phenotypes in response to different environmental conditions (Bradshaw 1965).

Genetic diversity can have favorable ecological consequences at the population, community, and ecosystem levels, and in some cases, the effects are comparable in magnitude to the impact of species diversity (Espeland et al. 2017). In this time of rapid environmental change, landscape architects, urban planners, restoration ecologists, ecosystem engineers, and others who construct, enhance, and maintain restoration activities should consider sourcing and using plant material that has sufficient genetic variation.

1.5 Supply Chains and Social Networks

Overcoming the shortfalls stated above requires strengthening seed and plant material supply chains. A supply chain is the entire system of people, resources, information, and activities that help transform raw materials into a final product or service that will be consumed by end-users (Whichmann and Kaufmann 2016; Carter et al 2015; Bellamy et al., 2014). In the context of restorative activities, the seed and plant material supply chain encompasses everything from *in situ* conservation of plant genetic resources, to the collection of seed material, and all of the associated pathways—germination, cultivation, harvesting, processing, cleaning, storage—required to multiply seed material and produce commercially viable quantities of both seed and planting stock for end users. Seed and plant material supply chains are unique because living genetic resources such as seeds or the tissues of plants are a public resource that public and private for-profit and non-for-profit companies and organizations transform into commodities. Once commercially produced seed and other forms of vegetative material find its way back into ecosystems it becomes a public good again. Not many other products follow a similar trajectory.

The research underlying this thesis draws on literature from the fields of supply chain management (SCM) and social network analysis (SNA). Supply chain management is a field of research and practice that is focused on understanding how to better integrate key processes and manage multiple relationships across supply chains (Lambert and Cooper 2000). Social network analysis is a domain of scientific investigation that studies and describes emergent properties and patterns of social systems (Newman 2010; Barabási 2016). The conceptual and methodological approaches associated with SNA allow for an in-depth investigation of the structural characteristics and the complex relationships that are embedded within a supply chain, that could not be easily understood with traditional research methods (Kim et al. 2011).

Researchers are increasingly adopting a network paradigm in SCM research as evidenced by a growing number of publications in the last twenty years (Wichmann and Kaufmann 2016). The approach has been utilized to study a number of phenomena such including project governance, risk management, learning and knowledge transfer, and collaboration (Wichmann and Kaufmann 2016). However, to date, there are no studies that employ SNA to elucidate the structural characteristics and relational complexity of seed and plant material supply chains.

Although SNA has numerous advantages over traditional research methods for analyzing supply chains, it may not be effective as a standalone method. Researchers have demonstrated that networks are constantly in flux and dramatic shifts in patterns can occur even after a brief interval (Cross and Parker 2004). One limitation of SNA is that without additional or continued data collection, the results of an analysis may only offer a snapshot of the supply chain in focus in a particular moment in time. While this is important for capturing fundamental information on the structure of the supply chain and patterns of the social network, it may be insufficient when it comes to explaining more contextual or specific processes related to the management of that supply chain. Therefore, as other researchers have found (Prell et al. 2009), supplementing SNA with qualitative methods allows for a more thorough and complete study. This research uses a mixed method approach also analyzes qualitative data from semi-structured interviews to more fully understand the social network that underpins the Northeast's seed and plant supply chain.

The application of SNA to SCM in the context of preparing for operational challenges associated with restorative activities merits further examination. The ability to analyze and describe the network of actors—government agencies, academic institutions, nonprofit organizations, private companies, and local citizens—who are engaged in plant material supply chains is a first step in understanding how to optimize processes to ensure that there are adequate supplies of seed and propagules to meet current and future demand.

1.6 Research case study and aims

This research looks at the US Northeast because supply chains in this region are still generally inadequate to meet both the current and future demands for seed and plant material to successfully carry out the activities stated above (National Academies of Sciences, Engineering, and Medicine 2020; Tangren and Toth 2020; Personal Communication 2021, 2022).

According to an interim report *An Assessment of the Needs for Native Seeds and the Capacity for Their Supply published by the* US National Academies of Sciences and Medicine in 2020, the strongest and most functional seed and plant material supply chains exist in the US exist in the western states, where the federal government manages a large percent of the land, in some states up to 40%. The report outlines how the eastern US is constrained by several factors. For example, there are only few institutions and state-level programs in eastern US that are actively working on generating a supply of genetically appropriate plant materials for restoration activities. Beyond those efforts, seed collection, processing, and production of genetically appropriate planting stock is carried out on a short-term or individual project basis. The commercial plant nurseries that carry plant material for restorative activities frequently produce material that is marketed for use over broad geographical areas. Another issue the report mentions is that eastern US has no large public or private seed warehouses. This means that region does not have adequate supplies of material on hand for next large-scale natural disaster. Because of the humid climate, seed warehousing is more challenging than in the dry and arid western states. Another issue affecting the region is that Midwestern vendors have captured the majority of the native seed market in the eastern US. In 2018, the Mid-Atlantic Regional Seed Bank (MARSB) and the University of Maryland surveyed the native plant and seed user community in the eastern US. They received 760 responses and found that, on average, buyers purchase native seeds from vendors who are 418 miles away (Tangren and Toth 2020).

An additional motivation for centering my research in the Northeast is that I have had an internship with a nonprofit organization called the EcoHealth Network that is headquartered in Boston, MA, and works at the intersection of human health and well-being and ecological restoration. The organization has a focus on connecting long-term ecological restoration projects and programs, so that they may learn from each other, share scientific efforts, identify key knowledge gaps, and dramatically increase awareness of the enormous benefits of ecological restoration among the public and policymakers.

This thesis research has two main goals:

(1) Identify and improve understanding about the types restorative activities that are taking place in the US Northeast. I ask several sub-questions to fulfill the goal stated above: Who is engaging in restorative activities? What types of activities are being carried out, and by who? In which ecosystem types do activities take place? At what geographical scale do these interventions take place? Who are the primary actors engaged in the supply chain? Which actors are part of the user community? In which step(s) of the restoration process are they engaged? Which actors are part of the producer community? In which step(s) are they engaged in the seed and propagule production process?

(2) Improve understanding about the social structure of the seed and plant material supply chain in the Northeast. I ask the following sub-questions: How is the social network at large structured? How is the network divided into subgroups? Who are the most critical players in the network? How does the network's social structure affect its function? What are some of the underlying obstacles that constrain the supply chain from adequately providing plant material to meet the demand of current and future restoration activities?

1.7 Overview of remaining chapters

In *Chapter 2: The Emergence of Seed and Plant Material Supply Chains*, I review the literature on issues related to the limitations of seed and plant materials for restorative activities. I chronologically cover the emergence of how researchers have applied the concept of a 'supply chain' to describe and solve these issues and the gaps that exist within this approach. I then review literature from the fields of supply chain management and social network analysis and describe how a study that draws from these domains can help fill those gaps.

In *Chapter 3: Case Study and Methods,* I introduce my multi-level case study area and detail my methodological approach to collecting and analyzing quantitative and qualitative data through a survey questionnaire, semi-structured interviews, and focus groups.

In *Chapter 4: Social Actors and Restorative Activities*, I present the results of the first portion of the survey questionnaire that revealed the diversity of actor types that are engaged in supply chain processes and information about what restorative activity types they are involved in; what types of ecosystems they work on; what geographical scales they work at; and what key steps of the activity process they are engaged in.

In *Chapter 5: The Supply Chain Network,* I build on the findings in Chapter 4 by introducing the results of the social network analysis, which allowed me to gain a deeper understanding of the how the emergent relationships between the diversity of actors form the structure of the supply chain and affects its function.

In *Chapter 6: Reflections and Next Steps*, I discuss what I have learned from carrying out this thesis research and recommend a series of 'next steps' that actors in the US Northeast could take to strengthen the seed and plant material supply chain. Additionally, I offer a brief description of the limitations of this thesis research and potential areas that researchers should prioritize for future investigation. Finally, I conclude with a discussion about why ameliorating widescale land, freshwater, and sea degradation is as imperative as keeping fossil fuels in the ground and drawing down legacy carbon. To which cultivating capacity in seed and plant supply chains is essential.

CHAPTER 2: THE EMERGENCE OF SEED AND PLANT MATERIAL SUPPLY CHAINS

Limited supplies of seed and vegetative material suitable for propagation, acquired either within the in situ soil-borne seed bank, proximate remnant ecosystems of the same type, or else commercial outlets, have been a major concern of practitioners in nearly every ecosystem type where restoration activities take place (Bakker and Berendse 1999; Holl et al. 2000; Mortlock 2000; USDI & USDA 2002; Walker et al. 2004; Broadhurst et al. 2008; Hölzel et al. 2012; Broadhurst et al. 2015a; Nevill et al. 2018). For example, in North American cities and towns, lack of tree stock that is tolerant to stressors like compacted soil, salinity, and air pollution has constrained urban forestry activities (Gamstetter and Gulik 1988,1996). Limited tree stock continues to hinder urban forestry activities in many cities across the country (Personal Communication, 2021, 2022). Inadequate supplies of seeds and containerized plant material (e.g., plugs, saplings) continue to present as a critical bottleneck to advancing both current and future restorative activities globally (Nevill et al. 2018).

The international community began to address these issues around seed and plant limitations starting in the early 2000s. There have been a number of responses including the publication of articles and technical reports over the past decade aimed at improving seed, collection, production, and harvesting practices (Broadhurst et al. 2008; Merritt and Dixon 2011; Brancalion et al. 2012; Kiehl et al. 2014; Nevill et al. 2016); the development of national-level assessments and strategies to improve the availability of native plant materials (Oldfield and Olwell 2015; White et al. 2018); creation of regional seed cooperatives, associations, and community-based networks to facilitate the coordination of tasks associated with the collection and multiplication of seed and plant materials among diverse stakeholders (Urzedo et al. 2021; Schmidt et al. 2019).

2.1 'Supply Chain' Framing

The increase in number and scale of restorative activities around the world, combined with the growing recognition that practitioners need to reduce pressures on naturally occurring plant populations and the high costs associated with wildland seed collection, has amplified the necessity of multiplying seed and plants in agricultural settings to produce adequate volumes of material for restoration activities (Merritt and Dixon 2011; Broadhurst et al. 2015a; Nevill et al. 2016 and 2018; Cross et al. 2020). Accordingly, researchers have used the conceptual framing of a 'supply chain' to describe the interrelated stages of seed and plant material production systems. Broadhurst et al. (2015a). appear to be the first to use the term 'supply chain' in this context; unfortunately, they did not offer a clear definition or description of what a supply chain consists of in the complex context of native seed and plant material production for restoration work.

Similarly, while not focused on material production in agricultural settings, Merritt et al. (2016) present a 'chain-of-seed-use' model to describe how the stages of seed handling practices from wildland collections to restoration sites should be viewed "not in isolation, but rather as a continual journey, with the effectiveness of the previous step impacting the success of the next" (p. 39). A number of publications subsequently mention the term 'supply chain' in the context of discussing either the hurdles with large-scale ecological restoration (Menz et al. 2013); techniques to improve native seed germination for grassland restoration (Pedrini et al. 2019); or assessing the gaps in seed and plant production and distribution systems in South and Central American countries (Atkinson et al. 2018; Moreira da Silva et al. 2019). However, like Broadhurst et al. (2015), these publications do not offer a definition of a supply chain or provide any references to literature that does.

2.2 Increasing the resolution on supply chain steps, stages, components, and flows

Since 2019, there have been several publications including articles, planning documents, a special issue in an academic journal, and a technical report that begin to describe the stages, steps, and associated components, inputs, outputs, and information and resource flows of seed and plant material supply chains. For example, León-Lobos et al. (2018) outlines the key steps in seed and plant material production systems and corresponding hurdles and strategies to overcome supply bottlenecks in Chile. In 2019, the Tallgrass Prairie Center in Iowa published a report about their annual stakeholder meeting where a participants developed a conceptual model of the native seed supply chain to describe interconnections and unmet needs for coordination and communication (Fisher-Walter 2019). In 2020, Society for Ecological Restoration published a special issue in the journal Restoration Ecology entitled International Standards for the Use of Native Seeds in Ecological Restoration. The special issue comprised of a series of overview articles that examine each key stage in the native seed supply chain and a final synthesis article that details practical tools and standards for improving the reliability of each of those stages (Cross et al. 2020). The same year, the US National Academies of Sciences and Medicine released the interim report An Assessment of the Needs for Native Seeds and the Capacity for Their Supply that presents the findings of an "exploration into the complex system by which seeds of native plants are produced and used in the United States" (p.*ix*) and dedicates a chapter to describing the components and flows of the supply chain.

While the aforementioned publications greatly increase the resolution on the key stages, steps, and components required to multiply seed and plant material in agricultural settings, they also share two main shortcomings: 1) they do not draw from the field of supply chain management (SCM) literature; and 2) they depict production systems as a series of linear steps or as a circular 'chain' of unidirectionally connected activities. Not a single publication reviewed in which in this thesis uses the term 'supply chain' or references any literature from the long-standing field of SCM that emerged from Industrial Engineering and Operations Research in the late 1980s Oliver and Webber 1982. SCM has many subdisciplines and has developed theoretical, methodological, and representational approaches for understanding how to improve the transformation of raw materials into final products (Davis 1993; Lambert and Cooper 2000; Croxton et al. 2001). And while there are a series of a key steps that different actors must perform related to the commercial production of seed and plant materials, the conceptual understanding of a supply chain as a series of unidirectionally connected steps or stages is limited in scope and significantly misrepresents the complexity of what it takes to transform raw materials into goods. Supply chains are characterized by bi-directional flows and interorganizational coordination of multi-tiered activities across sectors and scales in often non-linear steps (Lamming et al. 2000; Burgress et al. 2006).

It is critical to address these gaps because the demand to quickly and effectively establish and strengthen seed and plant material supply chains to meet the goals of current and future restorative activities is burgeoning. Moreover, resources for planning, implementation, and coordination are always limited and the lack of a comprehensive and nuanced picture of what it takes to produce adequate supplies of seed and plant materials could potentially hinder or dilute global restoration efforts in the future.

2.3 Adopting a network paradigm

The emergence of SCM has generated a wellspring of research across many disciplines. Chen and Paulraj (2004) reviewed and synthesized the large, and often fragmented, body of knowledge and then developed their own conceptualization of an SMC framework, which is underscored by the premise that a supply chain is composed of "a network of interdependent relationships developed and fostered through strategic collaboration with the goal of deriving mutual benefits" (Chan and Paulraj 2004, p.147). Other researchers have posited a re-conceptualization of supply chains away from simple linear systems with a few strong linkages towards more complex adaptive systems with many entities and interactions (Bradbury 2002; Pathak et al., 2007; Li et al., 2010). Hearnshaw and Wilson (2011) explain how the adoption of a network paradigm facilitate this re-conceptualization while neither oversimplify nor capturing every detail of a supply chain system. Carter, Rogers, and Choi (2015), in developing a theory of supply chains, also incorporates a network perspective to re-cast supply chains as consisting of nodes and links.

In the context of this research, the framing of the supply chain as a network of relationships provides solid foundation to carry out more effective analyses about how to improve performance and maintain resilience in the face of unpredictable circumstances (e.g., species die offs, natural disasters, policy shifts, etc.) (Hearnshaw and Wilson, 2013). This framing is more successful at capturing inherent system complexities such as the interplay between linear and non-linear steps; interrelations and interdependencies among multisectoral actors; and how inputs and outputs flow across multiple scales (Surana et al. 2005).

One method considered particularly useful for modeling and managing supply chain systems is social network analysis (SNA) because of its strength in identifying and analyzing embedded relational dynamics (Pathak et al. 2007; Borgatti 2009; Kim et al. 2009). With a history of more than 70 years, SNA is a domain of scientific investigation that has distinct conceptual, methodical, and representational approaches for visualizing and analyzing a network's social connectivity. The main tenants of SNA include that all actors in a network are interdependent rather than independent; the linkages among those actors' channels information, resources, and materials and therefore the linkages become a unit of analysis; the structure of the relations or ties among actors both constrains and facilitates flows of information, resources, and materials; and the emergent patterns of the relations among the actors defines the structure of the network which affects its function (Wetherell 1998; Surana et al. 2005; Saffer et al. 2018).

The metrics in the SNA toolbox are particularly useful for mapping out relational patterns between the producers, users, and beneficiaries of native seed and plant materials. For example, it is possible to identify the positions of actors within the network who are the most well connected and therefore may be able to influence others or define the key outputs of the supply chain. Locating these actors or sub groups of actors is important for understanding which actors in the network act as a nexus point or 'central connector' or a 'bottleneck,' either facilitating or constraining the exchange of information and resources (Wichmann and Kaufmann 2016). Such insights are useful for strengthening supply chain processes because the structure of the social network affects innovation output, and how quickly and effectively novel information and knowledge can flow among actors to generate new ideas, optimize practices, or provide costs savings (Bellamy et al. 2014; Pryke 2017). Recasting supply chain steps, stages, components, and flows as embedded within a network of interconnected social relationships is a first step in illuminating viable pathways to enhance seed and plant material production systems.

To date, there are no studies that apply SNA to better understanding how the interrelationships between actors — government agencies, academic institutions, nonprofit organizations, private companies, and local citizens —affect the structure and function and seed and plant material supply chains. Therefore, a major contribution of this research will be to 1) understand the wide range of multi-sectoral actors that have stakes in strengthening seed and plant material supply chains; and 2) analyze the relationships between those actors to reveal important insights about the inherent supply chain complexities such as the interplay between linear and non-linear steps; interdependencies among multidisciplinary and multisectoral actors; and how inputs and outputs flow across multiple temporal and spatial scales.

CHAPTER 3: CASE STUDY AND METHODS

I use a mixed-method multi-level case study approach to illustrate how a social network analysis approach can be applied to study seed and plant material supply chains. While, I consider four geographical levels, due to the time constraints of this project being a 2-semester thesis research project, it was not feasible to collect and analyze data on all the actors who are engaged in the network at level of the US Northeast. Therefore, I focused this thesis research on the level of the greater Boston region in order to collect and analyze more granular data on the diversity of types actors who are engaged in supply chain processes and the social network that those actors form.

3.1 Case Study

This case study considers four hierarchically nested levels: US Northeast region; Ecoregion 59; Massachusetts State; and the greater Boston region. Taking a multi-scalar approach was helpful for better capturing the social and ecological interlinkages that underpin the structure of the seed and plant supply chain (Galaz et al. 2008). In this section, I offer descriptions of each of these four levels in fact is the right word I think, not scales and an explanation as to why the inclusion of each level was important for this study.

US Northeast

The boundaries of the Northeast region of the US are variously defined. I refer to the delineation made by the U.S. Global Change Research Program (USGCRP), in which the Northeast includes the thirteen states of West Virginia, Virginia, Maryland, Delaware, Pennsylvania, New Jersey, New York, Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine (USGCRP, 2018). However, from an ecological, biogeographical, and human geography perspective, the Northeast region extends into parts of southeastern Canada, in the Provinces of Ontario, Quebec, and Nova Scotia. Here, I focus on the US Northeast, or NE for short.

The urbanized portion of the region, known as the Northeast megalopolis, contains a string of cities—Boston, Providence, Hartford, New York, Philadelphia, Baltimore and Washington D.C. —woven together by expansive and expanding suburban zones (Gottmann 1961). 56 million people call this urbanized corridor home, making it the most densely populated region in the US (Yaro et al. 2018). The area is also the world's greatest economic zone with a $3.6 trillion megaregional economy (Ghosh, 2018). Beyond the clusters of skyscrapers, sprawling housing developments, and networks of highways, there are extensive areas of contiguous forests and agricultural lands (Yaro et al. 2018).

The inclusion of the entire Northeast was important to my research for understanding how broad patterns of land-cover modification and climate change impacts are driving investments in restorative activities. For example, the federal government of the US models and interprets climate change impacts at the regional level (USGCRP, 2018), as sea-level rise and flood and extreme heat events extend across political boundaries. Additionally, any efforts to strengthen seed and plant supply chains require a comprehensive regional strategy to prevent an uncoordinated patchwork of duplicative efforts and real or perceived competition for resources and - for producers - access to markets.

In the Northeast, ecological degradation correlated to the legacies of settlement patterns and ongoing development increase the vulnerabilities of cities and towns to SLR, coastal storms, and extreme rainfall and heat events increasingly common in this 'climate change era' (USGCRP, 2018). Moreover, anthropogenic climate change further exacerbates and accelerates threats to ecosystems, especially those already in peril.

Glaciers and icesheets melting thousands of miles away will continue to alter the Northeast's low-lying coastal areas. Scientists predict up to 1ft of SLR by 2050—an increase that equals the total amount measured over the past century (Sweet et al. 2022). Higher sea levels amplify the impacts of storm surge and extend its impact further inland, as evidenced by the aftermath of Superstorm Sandy in 2012 (Yin et al. 2013). Coastal ecosystems like salt marshes, dunes, and seagrass meadows have the natural capacity to attenuate wave height, reduce storm surge, and accumulate and stabilize sediments which help slow erosion and sea-level rise (Hobbie and Grimm 2020). However, collateral damage from development like storm-water runoff and pollution from sewers, along with the direct effects due to clearing and transformation for building and transport infrastructure contribute to ongoing transformation and degradation of thousands of acres of coastal habitats each year (MAPC, 2018).

The dominant trend over the past 30 years in the Northeast has been towards increased rainfall intensity, with those increases exceeding all other regions of the contiguous United States (USGCRP, 2018). Since 1996, the region has experienced a 53% increase in extreme precipitation events (Huang et al. 2021). The deleterious effects of pluvial flooding are exacerbated by the impervious surfaces of the built environment. Roads, sidewalks, parking lots, and buildings prevent infiltration and when combined with dense urban drainage networks can lead to high volumes of runoff. When runoff is not properly absorbed it contributes to combined sewer overflows (CFOs), damages important infrastructure, releases pollutants and sediment into rivers, and destroys valuable aquatic and riparian habitats (Strokal et al. 2021).

Studies suggest that the Northeast will experience more than twice the number of days each year with temperatures over 90 degrees F by the year 2030 (USGCRP, 2018). Northeastern cities, with an abundance of asphalt and concrete, frequently have higher day and nighttime temperatures than surrounding areas due to the urban heat island effect (USGCRP, 2018). More frequent and longer heatwaves are a public health concern because of associated heat-related mortality (see Table 3.1).

Drivers of Ecological Degradation

Ecosystem Type	Key Pressures
Marine	Intensive Removal of Marine Resources, Shipping, Pollution
Salt Marshes	Habitat alteration and destruction caused by coastal development, sea level rise, Pollution, Contamination
Mudflats	Navigational Dredging, Pollution
Seagrass/Eelgrass	Pollution, Nutrient loading
Kelp Beds	Storm events, Rising Temperatures
Coastlines	Storm Events, Sea Level Rise, Erosion
Estuaries	Nutrient Loading, Pollution
Tidal Wetlands	Development Pressure, Pollution/Nutrient Loading
Freshwater Wetlands	Drainage and conversion to other uses, Chemical Contamination, Increased Nutrient Inputs, Eutrophication, Sediment Deposition from Air- and Water-Borne Sources, Invasive Species
Grasslands	Conversion to other uses (e.g., agricultural fields, landfills), invasive species, fire suppression
Forests	Conversion To Development (Specifically Urban Sprawl), Timber Harvesting

Table 3.1: Drivers of ecological degradation in the US Northeast.

Level III Ecoregion 59-The Northeast Coastal Zone

Level III Ecoregion 59, the Northeast Coastal Zone, covers the highly urbanized coastal areas of eight states of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, and New Jersey. Ecoregions are areas of land defined by natural features rather than political or administrative boundaries (Bailey 2014) Ecologists delineated the boundary of The Northeast Coastal Zone by analyzing patterns of geology, landforms, soils, vegetation, climate, hydrology, and wildlife (Omernik 1987, 1995).

The inclusion of Level III Ecoregion was important because it is a sub-regional ecological scale that actors use to guide the collection, production, and movement of seed and plant material for restorative activities (Bower et al. 2014). Federal and state agencies are increasingly requiring the use of locally adapted or genetically appropriate native seed and plant materials to mitigate maladaptation and enhance restoration outcomes. (Plant Conservation Alliance 2015). Scientists perform genetic analyses or common garden studies to reveal a species seed transfer zone. Seed transfer zones are geographically delineated areas where a species can be transferred minimal risk of maladaptation (Bower et al. 2014). However, this data is lacking for most native species because it is be time consuming and costly to perform such studies and analyses. Therefore, ecologists and botanists have encouraged the use the Level III ecoregion as a proxy to help guide seed and plant collection and movement of plant materials for restoration (Bower et al. 2014). According to Bowers et al. (2014) research on local adaptation in plant populations suggests that transfer between widely separated or nonadjacent ecoregions can result in maladaptation.

Massachusetts State

Massachusetts, covering an area of 10,565 sq mi and home to 7,029,917 people is the third most densely populated state in the Northeast (US Census, 2020). The state is bordered by Connecticut and Rhode Island to the south, New York to the west, Vermont and New Hampshire to the north, and the Atlantic Ocean to the east. The eastern portion of the state is highly urbanized and is home to the Greater Boston area, which is the fourth largest metropolitan center in the Northeast (US Census, 2020).

The incorporation a state-level scale important because it represents the unit of government that has the authority to set policy that affects natural resource management and coordinate the activities of local government. State-level political boundaries also impact how funding from the federal government is allocated towards activities like habitat conservation and restoration. Additionally, the Massachusetts state often acts as the liaison between broader regional contexts (e.g., The North East, the entire United States, and the global setting) and more local scales (e.g., cities and towns).

The Greater Boston region

The greater Boston region consists of 101 administrative cities and towns. The Metropolitan Area Planning Council (MAPC) further delineates the cities and into four basic community types: Inner Core; Regional Urban Centers; Maturing Suburbs; and Developing Suburbs (MAPC, 2018). Direct oversight and coordination of the 101 cities and towns is largely lacking because there is no regional government body with executive powers. Although there is no formal mesoscale governance, a few government bodies do operate above the local scales. These include the City of Boston and the City of Cambridge (Kitchin and Moore-Cherry 2021).

In context of this thesis research, it was not feasible to collect and analyze data on the entire social network of actors who are engaged in supply chain and restorative activities at the regional-scale. Therefore, the greater Boston region provides a more appropriate scale for the time limitations of this thesis project, to gather more granular data on the diversity of types actors who are engaged in supply chain processes and the social network that those actors form.

3.2 Methods

Database development

I gathered information on the network of actors that comprise the user and producer communities of the plant material supply chain. Additionally, I collected information on actors that who are not explicitly a user or producer but have unique assets that could be leveraged to strengthen the existing supply chain and advance restoration goals (e.g., botanic gardens, herbaria, arboreta, academic intuitions, research labs, etc.). Although my data collection was centered on actors who work in the greater Boston region, I also gathered information on actors that work at all scales aforementioned. For example, I included nonprofit organizations that works to conserve and restore ecosystems outside of the metropolitan area but are still important for supplying water to Boston and plant nurseries that sell products to practitioners who work across the region.

I started the search with a selection of key words (e.g., 'native plant nursery', 'native seeds company', 'ecotypic plant material', 'native plants,' 'restoration ecology', 'ecological restoration', 'wetland restoration', 'watershed restoration', 'coastal restoration', etc., and 'Boston') and then snowballed from there. I also found several directories including the Massachusetts Nursery Landscape and Nursery Professionals; National Reforestation, Nurseries, and Genetic Resources (RNGR); Environmental Business Council New England, Inc.; Massachusetts Association of Conservation Commissions (MACC), which provided information on actors who are engaged in the seed and plant material supply chain. Additionally, I reviewed the mass.gov website and included all the departments working on natural resource management, habitat conservation and restoration, agriculture, and horticulture.

Survey

After drawing up a list of 158 actors who are engaged supply chain processes (see Appendix A), I then developed and sent a survey to selected individuals (e.g., executive directors, presidents, heads of sales, etc.) from those private companies, academic universities, government agencies, and nonprofit organizations. I administered the online survey from April to June 2021. I recruited participants by email, phone, or both, and made a minimum of three contact attempts.

I designed the survey to elicit information about how actors are involved in supply chain processes and restorative activities and how these actors are engaged with each other. The survey that was divided into two parts: 1) general context questions; and 2) network questions. In Part I of the survey, I asked participants to answer questions about what types of activities they worked on; what ecosystem types they worked in; at which scale(s) the impact of their work is most felt; what step(s) of the ecological restoration process they are engaged in; and what assets, resources, or capacities their company, organization, or agency could or potentially could contribute to activities.

In Part II of the survey, I asked participants to describe their level of connection and collaboration between where they work the other companies, agencies, and organizations in our list using a 4-point scale. To describe their level of collaboration I asked them to use 0 for not at all (i.e., My place of work does not collaborate with that agency, organization, or company); 1 for yes, in the past but not likely again (i.e., My place of work has collaborated with that agency, organization, or company in the past, but it is unlikely that collaboration will happen with them again in the foreseeable future); 2 for yes, in the past and would do so again (i.e., My place of work has collaborated with that agency, organization, or company in the past and would collaborate with them again if given the opportunity); and 3 for yes currently (i.e., My organization is currently collaborating or regularly collaborates with that agency, organization, or company).

Social Network Analysis

I used social network metrics to analyze the data I collected in Part II of the survey. As mentioned in Chapter 1, increasingly researchers are using social network analysis (SNA) to understand, design, and manage supply chains (Bellamy and Basole, 2013). A basic network is formed from a series of nodes and linkages. In the context of this research, the nodes represent the actors and the linkages between those actors based on how well they know one another and how frequently they collaborate. I removed entries where respondents rated their level of collaboration as "0. Not at all" (i.e., My place of work does not collaborate that agency, organization, or company), therefore, the edges analyzed represent collaboration between actors that has happened in the past, may happen in the future, or happens on a regular basis. I then used the open-source software tool Gephi 0.9.3 to analyze and visual the network. The embedded statistical toolkit allowed me to calculate network metrics including degree centrality, betweenness centrality, eigenvector centrality, modularity, and network density. I explain these metrics in more detail below, however it was important to use a combination of metrics to understand how the structure of the social network and how it impacts the function of the supply chain.

Betweenness centrality is a metric that captures which nodes are most influential and important for facilitating flows of information and resources from one part of the network to another (Golbeck 2015). In the context of supply chain management, actors who have high betweenness centrality scores are important because they stand between different parts of a network and serve as "connecter[s] among different nodes in the network" (Giuffre 2013 pg. 121). Within the context of seed and plant material supply chains, betweenness centrality is an import metric for identifying who has the greatest ability to disseminate new information, provide access to external resources, help initiate or support collective action, and foster trust among previous unconnected groups (Bodin and Crona 2009).

Eigenvector centrality is a metric that is helpful for identifying influential nodes in a network. An actor with a few connections could have a high eigenvector centrality score if those few connections were to actors who are well-connected to other actors in the network (Golbeck

2013. For example, scores are assigned by counting both the number and the quality of network connections so that a node with few ties to other central nodes may outrank one with a larger number of less central nodes (Newman 2008). Within supply chains, eigenvector centrality reveals which actors might have more power within the network to influence the behavior and action of other actors.

Modularity metrics calculates the strength of division of a network into clusters of nodes to understand the behavior of and interrelationship between subgroups. Networks with high modularity contain cohesive subgroups of densely connected nodes that have few connections to nodes in other subgroups. I used the measurement of modularity to help reveal patterns of collaboration between agencies, academic institutions, nonprofits, and private companies. Additionally, modularity helped me understand where fragmentation occurs or where silos exist in the network and information and resources are not being transferred among subgroups. In the context of understanding the supply chain, community detection is useful because it "can reveal functional groups and the gaps between them" (Cross 2009: p. 312). Additionally, understanding subgroup formation can provide insight into if collaboration happens based on interest, background, or ecosystem type.

Semi-structured interviews

I also conducted semi-structured interviews with 26 survey participants. These individuals represented a subset of actors from government agencies, private companies, and nonprofits and hold positions as supply chain end users, producers, and intermediaries. I conducted interviews from May to December 2021. I recruited interview participants by email and followed up a maximum of two times.

The purpose of holding the interviews was to elicit more information about the key inputs, outputs, and processes that support the supply chain's functioning; the underlying obstacles that constrain the supply chain from adequately providing plant material to meet the demand of current and future restoration activities; and what types of resources, expertise, and capacities are embedded within the larger social network that could be better leveraged to strengthen the supply chain.

I developed sets of open-ended questions (Appendix C) for different categories of actors (e.g., urban planners, restoration ecologists, horticulturists or those working in the commercial nursery trade, those working at nonprofit organizations; those working at government agencies, etc.,). Additionally, my questions addressed opportunities and constraints around collaboration with other companies, agencies, and organizations. Interviews ranged from 25 minutes to 1.5 hours. I recorded and transcribed interviews when participants granted me permission. I coded and transcribed interviews and notes from unrecorded interviews to identify emergent themes.

Roundtable discussions

In March 2022, I co-hosted two virtual roundtable discussions with a PhD student John Capanelli from the University of Connecticut. A total of 22 individuals from different sectors of the supply chain—policy makers, urban planners, nursery growers, botanists, farmers, native plant educators, restoration ecologists—joined the two meetings. These roundtables operated like focus groups and allowed me to 1) introduce preliminary findings from this research; 2) facilitate a discussion with participants to understand how the identified constraints affect their position of the supply chain and how they might overcome barriers through forming closer ties or network connections with other stakeholders; and 3) receive feedback on a series of proposed next steps that could address the collective regional needs related to strengthening the seed and plant material supply chain.

CHAPTER 4: SOCIAL ACTORS AND RESTORATIVE ACTIVITIES

4.1 Who is engaged in restorative activities and supply chain processes?

I identified 158 actors (Appendix A) who represent a sample of the types of entities who have stakes (albeit to different degrees) in strengthening native seed and plant material supply chains and advancing restorative activities, including actors who were not directly engaged in supply chain processes or restorative activities but have unique expertise and resources that could be leveraged to advance restoration outcomes and strengthen the supply chain. Identified actors comprised private companies, government agencies, nonprofit organizations, academic institutions, and citizens groups, and were organized into three broad categories: producers (n=38), end users (n=27), and intermediaries (n=58). While it was helpful to organize actors into these coarse groupings for a general analysis of the primary position of actors along the supply chain, it is important to note that actors frequently inhabited multiple categories simultaneously, or changed their position over time. I found 35 actors that were either 'end user-intermediary,' 'end user-producer,' or 'producer-intermediary.' For example, I found several landscape design and contracting companies who occupy both end user and producer positions, because of their decision to cultivate their own vegetation stock due to limited commercial availability of native seed and plant material. In the following paragraphs, I offer my own descriptions of producers, end users, and intermediaries and provide examples of the types of actors located in the Northeast who fall under each of these categories.

Producers

I defined producers as actors who play a key role in any of the key steps related to the collection, storage, propagation, or distribution of native plant materials. In the Northeast, producers are mostly private companies and some nongovernmental organizations (NGOs). I identified 36 native plant material suppliers (i.e., wholesale and retail plant nurseries and seed suppliers) who sell seed and plant material to end users carrying out activities across the Northeast. This list is not exhaustive and includes some companies that are located outside of the region. For example, Ernst Conservation Seed and North Creek Nursery in Northwestern and Southeastern Pennsylvania respectively, and Prairie Moon Nursery in Southeast Minnesota. I included these companies after interviewing end users who told me that they often purchased seed from companies since no wholesale seed suppliers exist in the Northeast.

I also identified two NGOs that produced native seed and plant materials. These include the Northeast Organic Farming Association's (NOFA) Connecticut Chapter, supporting the Ecotype Project which helped to catalyze a farmer-led seed collective—Eco59—that is working to collect and multiply the seeds of regionally appropriate wildflowers for pollinator habitat restoration, and The Native Plant Trust, previously known as the New England Wildflower Association. This organization has historically focused on rare plant conservation, but also operate the nursery Nasami Farms that supplies home gardeners and small landscape design companies with native plants. Over the last decade, The Native Plant Trust has also periodically participated in the collection and banking of seed of species for ecosystem restoration. In 2015, the Department of the Interior awarded the Bureau of Land Management a $3.5 million grant through the Hurricane Sandy Supplemental Mitigation Fund for seed collection in coastal habitats from Virginia to Maine (Haidet and Olwell 2015). The Native Plant Trust partnered with the Bureau of Land Management to collect 850 accessions of roughly 300 native taxa from coastal and riparian habitats from Rhode Island to Maine. The collections have been used by a variety of end users for Hurricane Sandy remediation and restoration projects. However, the seed collected by the Native Plant Trust was not multiplied by horticulturists, rather it was cleaned, stored, and banked until it could be used by restoration practitioners.

End Users

A wide range of actors fall under the end user category. I defined end users as any actor who plays key role in the planning, design, implementation, or monitoring and maintenance of restorative activities or are the beneficiaries of those activities. The authors of the interim report *An Assessment of the Need for Native Seeds and the Capacity for Their Supply* (2020) provide details about the various types of end users that have a need for native seed and plant material (National Academies of Sciences, Engineering, and Medicine 2020). For example, academic institutions might have sustainability initiatives that require native species be planted on their grounds; nonprofit organizations often manage land for conservation purposes; and local governments (counties, municipalities, and states) regularly need to procure seed and plant material for a variety of reasons including ecosystem rehabilitation after hurricanes, floods, and fires, to maintain roadside plantings, creation of green infrastructure (e.g., bioretention ponds), and to improve wildlife habitat.

In the Northeast, I identified examples of end users that fit both my definition and the descriptions offered by the interim report. I found 16 academic institutions (e.g., university departments, labs, field labs); 29 government agencies (i.e., local municipality, state, and federal); 21 private for-profit companies that offer consulting, design, or contracting services; 5 watershed associations and coalitions; and 38 nonprofit organizations. I further organized the nonprofit organizations into several sub-categories based on the focus and scope of their work. These include 21 organizations that undertake landscape protection, conservation, and restoration; 11 organizations that work on landscape architecture, horticulture, or arboriculture; 2 organizations that work on indigenous land stewardship; 4 organizations that work on urban greenspace management; 2 organizations that work on environmental justice; and 2 organizations that work on soil and regenerative agriculture.

Intermediaries

In the context of this research, I define an intermediary as any actor that supports, or could support, the activities of two or more actors who are engaged in supply chain processes or in the planning, design, implementation, or monitoring and maintenance of restorative activities. I borrowed the concept from Howells (2006) who coined the term 'innovation intermediaries' after investigating the role of organizations who help spur innovation in different sectors.

According to Howells (2006), an 'innovation intermediary' act as an agent or broker between two or more parties and can perform diverse roles such as demand forecasting, gathering and synthesizing information, helping combine or exchange the knowledge or resources of two or more parties, engaging in regulation and arbitration services, or facilitating collaboration or networking.

I identified 9 herbaria, arboreta, and botanic gardens; 22 nonprofit organizations; and 9 governmental agencies. These actors have access to expertise, information, equipment, technology, financial resources, and advocacy or education campaigns that they could feed into the supply chain or restorative activities to strengthen and advance outcomes. For example, Massachusetts State has a Wetland and Waterways Program, which regulates activities in wetland areas and maintains various guidelines and other forms of technical assistance. Although this actor is not directly engaged producing wetland vegetation stock or restoring wetlands, their activities, such as the development of target and priority species lists of wetland species, supports other state departments like the Division of Ecological Restoration, private companies, and local municipalities who actively working on restoring or monitoring wetlands. Another example of potential intermediary is the Sustainable Solutions Lab at UMass Boston, which is an applied research center working at the intersection of climate and equity. This actor may produce analyses that help direct and secure funding for restorative activities in low-income communities.

4.2 What types of activities do they engage in?

84 of 158 of the actors responded to the survey (53% response rate). Response rate varied among the various sub-categories: 14 of 16 academic institutions (87%); 19 of 29 government agencies (65%); 6 of 9 herbaria, arboreta, and botanic gardens (67%); 9 of 21 private for-profit consult, design, and build companies (43%); 25 of 44 of nonprofit organizations (57%); 9 of 36 native plant material suppliers (25%); and 1 of 5 watershed coalitions and associations (20%).

Individuals from five agencies, institutions, companies, and organizations explicitly declined because they felt the survey did not relate to their work. Notable examples who said their work did not relate to native plant material supply chains, ecological restoration, or restorative activities were the Massachusetts Department of Public Health; City of Boston's Department of Environmental Protection; and Massachusetts Invasive Plant Advisory Group. Four retail native plant suppliers responded that they did not have time to respond to the survey. I administered the survey from April to June, which one individual from a wholesale plant nursery noted was the busiest time of the year for their industry.

What types of activities are they engaged in?
48% of the respondents are engaged in ecological restoration; while 47% reported they work on other activities. Respondents left comments about the types of 'other' activities they work on beyond the multiple-choice questions options, these included: academic research (4),

education or training (8), climate change resilience and mitigation (2), seed banking, cultivation, and plant production (4), habitat conservation (5), civil engineering (2), sustainable food systems (1), pollinator gardens (1) and botanic garden management (3). Almost half (44%) of respondents see themselves engaged in nature-based solution activities; while 35% responded they work on green infrastructure. 22% of the respondents are engaged in regenerative agriculture, while 20% work on remediation projects. Just 13% of respondents reported that they work on rewilding activities.

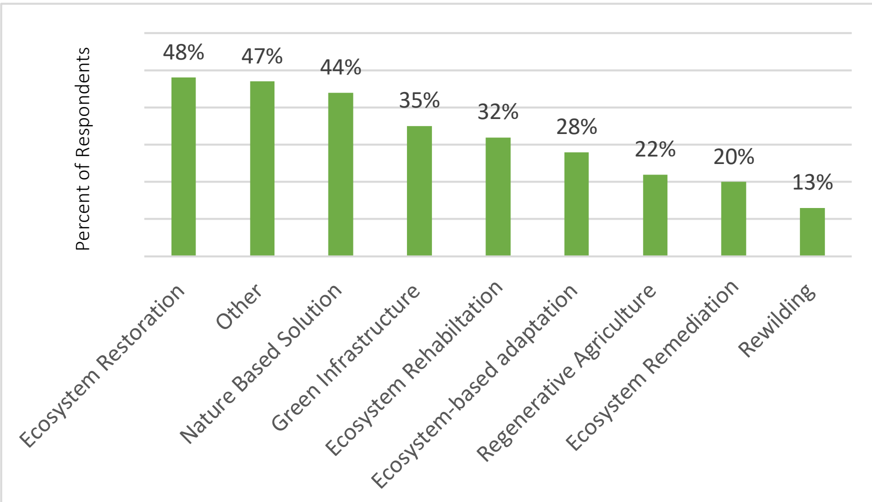


Figure 4:1 Percentage of respondents engaged in different restorative activity types.

Which ecosystem types do they predominately work on restoring?

More than half of the respondents (54%) work on restoring wetland ecosystem types. There was nearly an equal percent of respondents that work on forest (36%) and coastal ecosystems (34%). 22% of the respondents work grassland; 9% on riparian, and 5% on agricultural ecosystems. 17% of the respondents indicated they work on 'other' and left comments on what they work on which included responses like 'shrublands, barrens, old field habitats', 'private property/residence', 'pollinator habitats', 'headwaters, brooks, ponds, lakes', and 'reducing suburban fragmentation'. 40% of the respondents reported that they work on urban and peri-urban ecosystems, which could encompass any of the other ecosystem types listed.

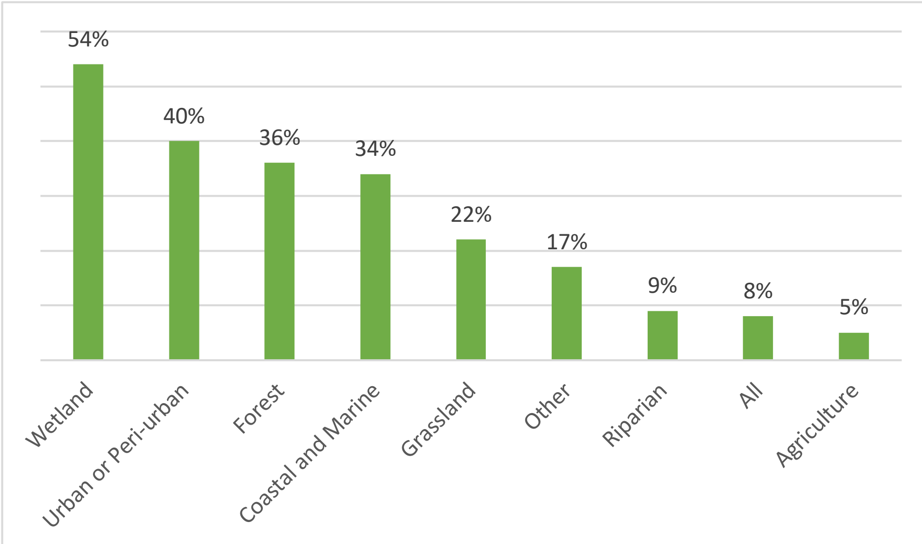


Figure 4:2: Percentage of respondents that work in different ecosystem types.

At which geographical scales do their interventions take place?

The impact of the actors' interventions largely takes place at the neighborhood (45%), local municipal (45%), or metropolitan (42%) scales. 25% percent of respondents work at the state level; and less than a quarter work at Northeast (23%); national (23%); and global (15%) scales. 32% of respondents work at the scale of a watershed and included the names of the watersheds in the write in box included 'Ipswich', 'Cape Cod Bays', 'Sudbury, Assabet, Concord River Watershed', 'Narragansett Bay', 'Mill River Watershed', and 6 respondents wrote in that they work on watersheds across Massachusetts state. 13% of respondents reported that they work at the scale 'other' and the answers included 'Midwest', 'Coastal State from Maine to North Carolina', and 'eastern Asia.'

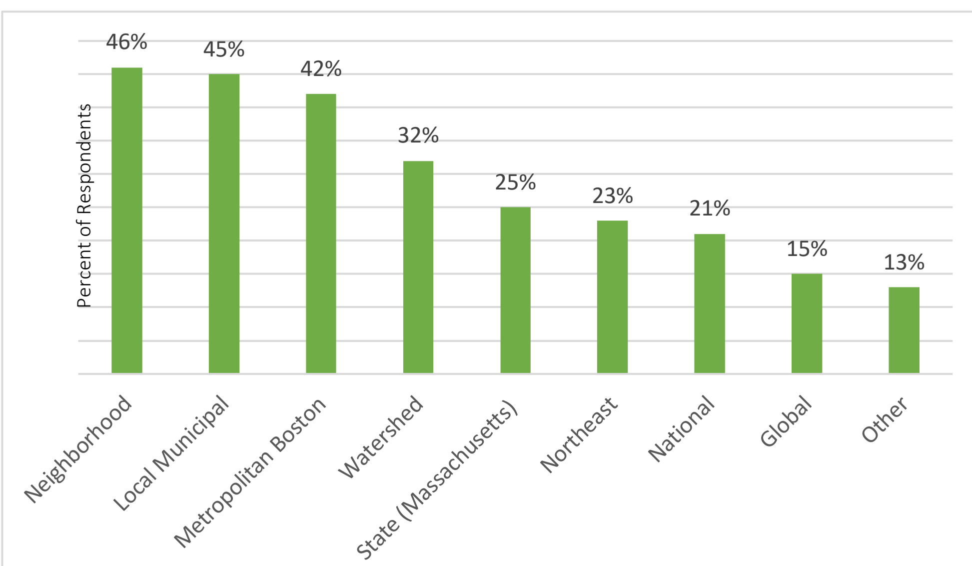


Figure 4:3: Percentage of respondents that work at different geographical scales.

At which steps does their work take place?
54% of the respondents reported that they are engaged in the planning step of restorative activities and 50% reported they are engaged in knowledge generation. 48% of the respondents are engaged in design; and 44% work on the implementation and monitoring and maintenance. Just over a quarter (26%) of the respondents are directly engaged in material production; while 22% work on regulation. 19% of the respondents reported that they are engaged in 'other' steps and two individuals wrote in the comments that these include the 'sharing of information with regulatory agencies', and 'plant selection and release to commercial growers.' 16% of the respondents reported that this question was not applicable to their company, organization, institution, or agency.

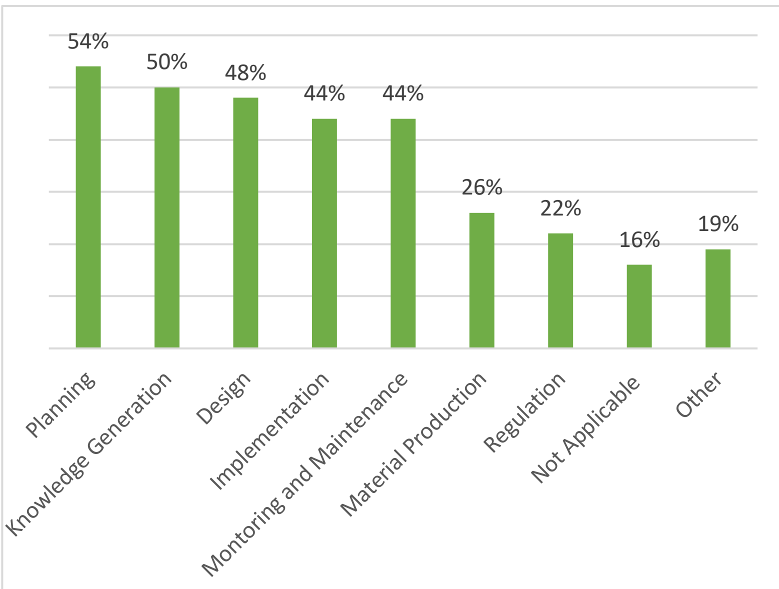


Figure 4:4: Percentage of respondents engaged in different steps of the restorative activity process.

CHAPTER 5: THE SUPPLY CHAIN NETWORK

The survey was designed to solicit information about how frequently actors in the network have interacted (i.e., collaboration). As mentioned in Chapter 2, one advantage of coupling a study of the supply chain with a network perspective is that it allows researchers to consider different units of analysis (Hearnshaw and Wilson 2013). Taking this approach allowed me to examine the structure of the study area's native seed and plant network at three different levels: 1) the entire network; 2) at the meso-scale or where subgroup formation happens; and 3) at micro-scale or where individual actors are positioned.

5.1 The Social Network

The network at-large

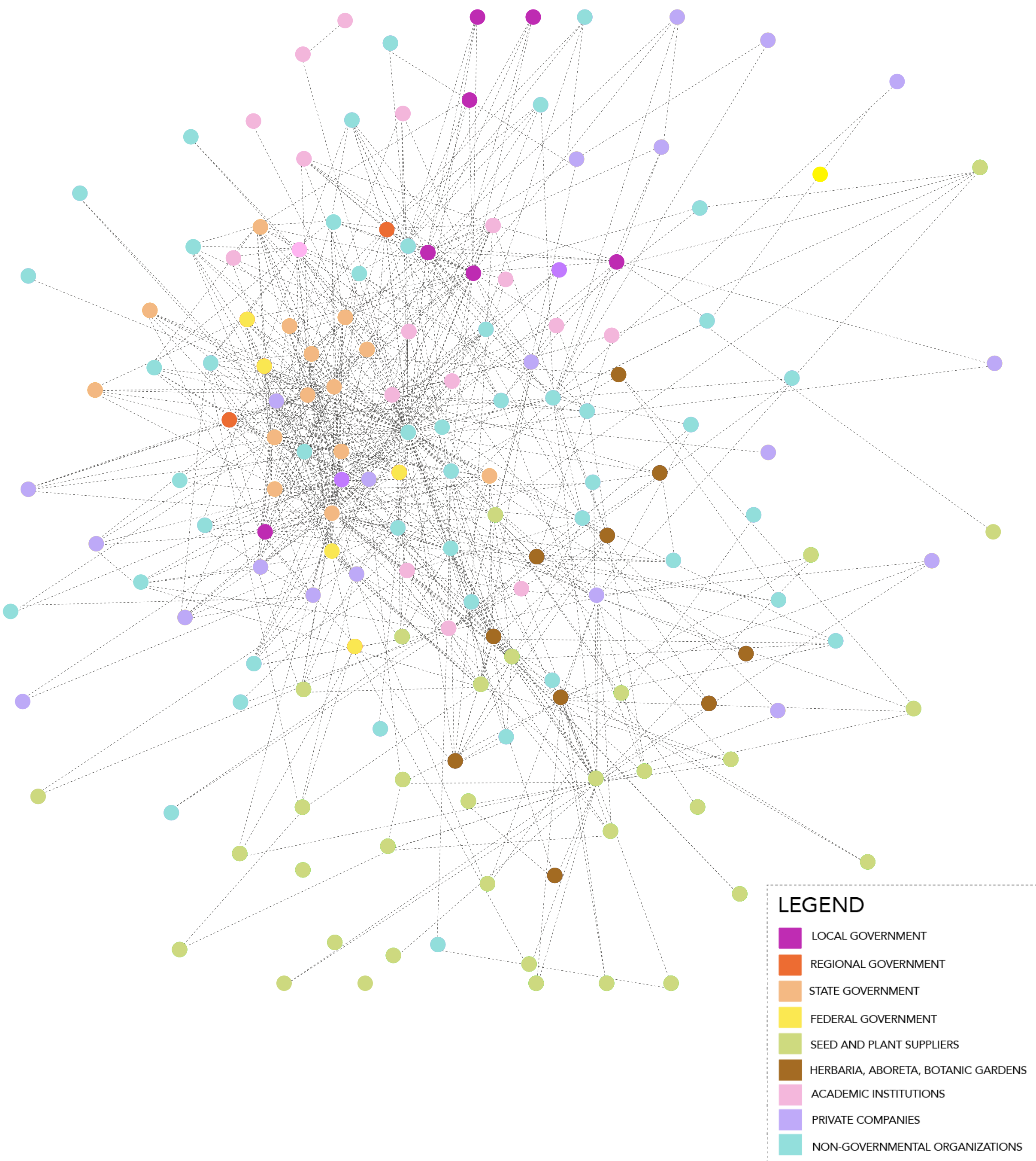
Because collaboration is an exchange of two actors working together, the 84 actors that responded to the survey helped to populate data for the 74 actors who did not respond. As entries where respondents rated their level of collaboration as "0. Not at all" were removed from analyses, the edges analyzed represent collaboration between actors that has happened in the past, may happen in the future, or happens on a regular basis. The network contained 2,196 edges or links between the 158 actors. Figure 5.1 shows the structure of the entire social network.

The network has a core–periphery structure. The core of the network consists primarily of state, regional, and federal government agencies, academic institutions, and private for-profit design, consult, and build companies, while the periphery of the network is made up smaller, less densely connected subgroups of plant nurseries, botanic gardens, arboreta, and herbaria, and a smaller number of design, consult, and build companies. Nonprofit organizations are dispersed evenly throughout the network and are located in the core and at the periphery, and comprise the majority of the network's interstitial space. In the core, the nonprofit organizations are primarily those who work on landscape protection, conservation, and restoration, while those at the periphery include NGOs that work on indigenous land stewardship.

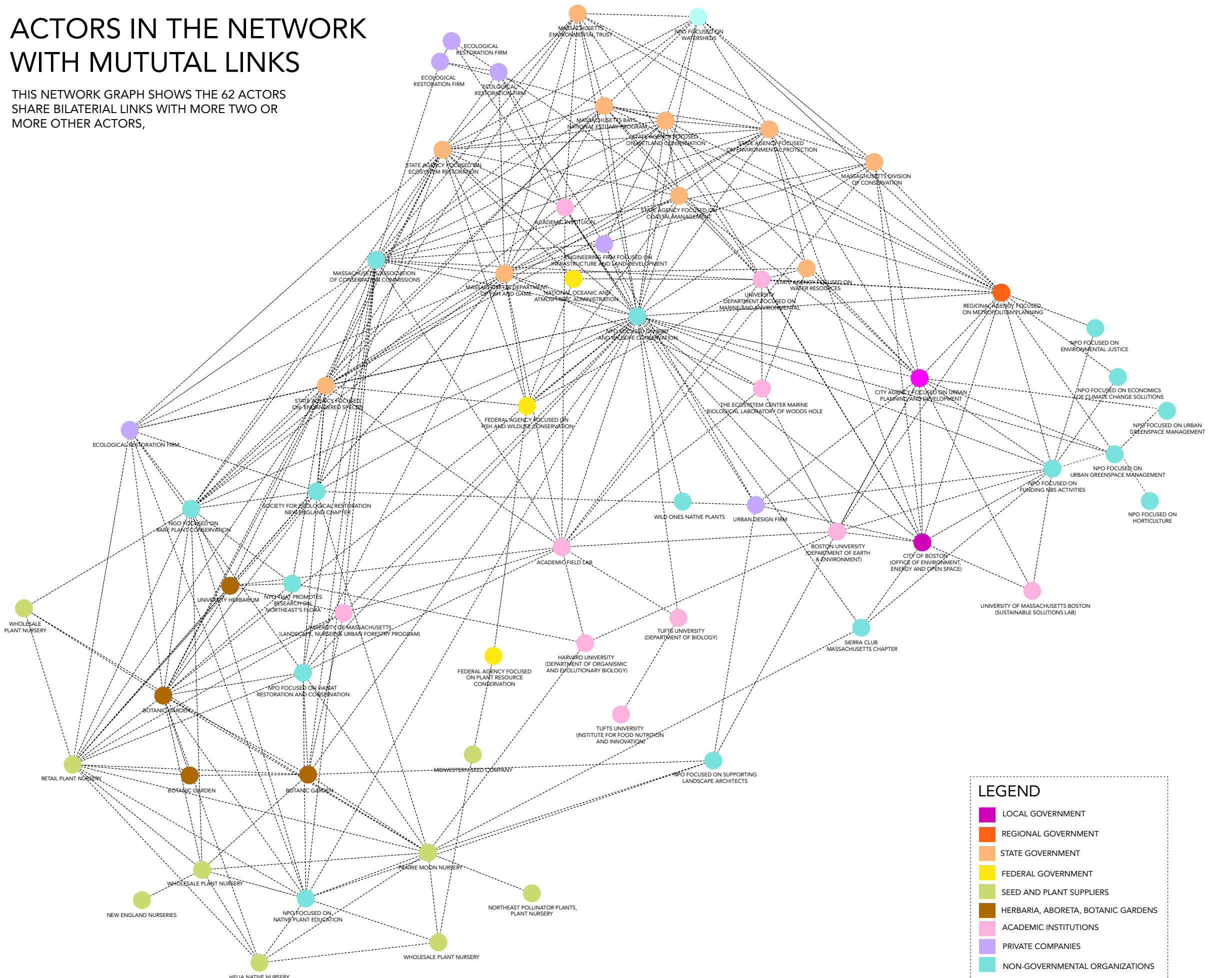
Although the edges indicate that collaboration exists between actors, I also wanted to understand if any two actors shared the same perception about how often collaboration happens between them. After filtering the data for mutual edges of the same strength, I found that 542 of 2,196 or 25% of the edges flowed bidirectionally at same strength between 62 actors. One limitation of receiving a 53% survey response rate is that the number of mutual links at the same strength in the network could be significantly higher. However, this number still provides a useful snapshot of where high levels of reciprocity exist in the network. Fig 5.2 shows a graph with actors in the network that have mutual links at the same weight.

ALL ACTORS IN THE SOCIAL NETWORK

This network graph shows the patterns of connectivity between 158 actors who comprise end-users, producers, and intermediary positions in the US Northeast's Native Seed and plant material supply chain.



(Figure 5.1. Network graph of 158 actors by type in social network)



(Figure 5.2: Network graph that shows all actors in the network that have bi-directional links at the same strength).

Network subgroups

Analyzing the structure at a sub-network or meso-scale helped identify clusters of subgroups formed by emergent relationships between individual actors. I found that the network can be divided into 7 subgroups based on the density and sparseness of edges between actors (see Appendix D). Reviewing the list actors in each subgroup revealed that geographic location, research and practice areas were the primary drivers of cohesion. For example, in subgroup #1, 5 of 8 actor in this subgroup were located or worked primarily in western MA. Whereas, in subgroup #2, the majority of the 19 actors are engaged in activities related to the protection, conservation, and restoration of aquatic ecosystem types (e.g., wetland, riparian, estuaries, and coastal and marine habitats). For example, 3 of 5 of the included watershed associations and coalitions from the entire survey, state-level agencies like the MA Bays National Estuary Program, Wetland and Waterways Program, and Office of Coastal Zone Management, and Northeastern University's Department of Marine and Environmental Science fall within this subgroup. In subgroup #4, both geographic location and content area influence subgroup formation as most of the actors are based in the greater Boston area and have a focus on urban green space management, environmental justice, climate change mitigation, urban planning, and landscape architecture. For example, actors like the Emerald Necklace Conservancy, Green Roots, Boston Food Forest Coalition, Urban Canopy Works, City of Boston Parks and Recreation, and the Boston Planning and Development Agency fall within this subgroup.

Only 3 of 7 subgroups had actors that fall under the producer category. The 3 subgroups with wholesale and retail plant nurseries also included of herbaria, botanic gardens, and arboreta, private ecological restoration and landscape design and architecture firms. Some of these subgroups also included academic institutions, although to a lesser extent. The academic institutions in subgroups with plant nurseries and seed companies had departments that serve as either agricultural research extensions or field labs. Additionally, these groups did not have many government agencies NPOs. For example, the 17 actors in subgroup #4 included 2 government agency, 3 NPOS, 6 private consulting, design, build firms, and 6 plant nurseries.

Intermediaries and Influencers

At the micro-scale several actors occupy critical positions in the network due to their ability to facilitate or restrict exchange or shape the behavior of other actors. Eigenvector Centrality helps to capture which actors are most influential in the network because they are connected to other actors, who are themselves, also well-connected (Borgatti, 2005). Table 5.1 lists the top ten actors in the network that have the most wide-reaching influence in the network. These actors include 3 NGOs working on landscape protection, conservation, and restoration; 6 state-level government agencies working on issues of environmental protection, ecosystem restoration, coastal management, and endangered species; and 1 federal-level government agency that works on habitat conservation.

Betweenness Centrality represents an index of brokerage or the ability to act as a bridge or intermediary between individuals and subgroups (Golbeck 2015). This metric is calculated by measuring the number of times an actor lies on the shortest path between other actors. Table 5.2 lists the top ten actors that have the highest levels of betweenness centrality, and therefore act as nexus points in the network. This reveals that these actors may have a greater ability than other actors to control flows of inputs like information and resources because they stand between different parts of a network and as nexus points between different nodes in the network" (Giuffre 2013).

List of top 10 actors who act as intermediaries		Actor Type
1	Mass Audubon	NGO
2	Prairie Moon Nursery in Winona, MN	Plant Nursery
3	Garden in the Woods	Herbarium/Arboretum/Botanic Garden
4	Native Plant Trust	Nonprofit Organization
5	Massachusetts Association of Conservation Commissions (MACC)	Nonprofit Organization
6	Boston Planning and Development Agency	Local Government
7	Boston University (Department of Earth & Environment)	Academic Institution
8	University of Massachusetts	Academic Institution
9	Metropolitan Area Planning Council	Regional Government
10	Native Plant Trust's Nasami Farm	Plant Nursery

(Table 5.1 list of top List of top 10 actors with most ability to act as brokers)

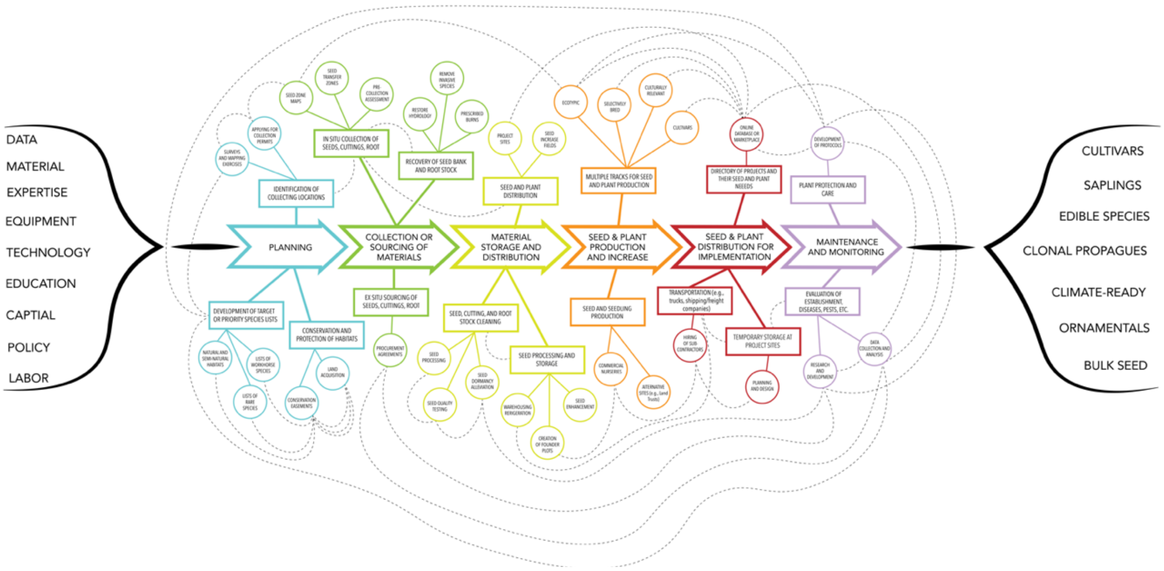
List of top 10 actors with the most influence in the network

List of top 10 actors with the most influence in the network		Actor Type
1	Trustees of the Reservation	NGO
2	Mass Audubon	NGO
3	The Nature Conservancy MA Chapter	NGO
4	Massachusetts Department of Environmental Protection	State Government
5	Massachusetts Department of Fish and Game	State Government
6	Massachusetts Department of Conservation and Recreation	State Government
7	U.S. Fish and Wildlife Service	Federal Government
8	Massachusetts Division of Ecological Restoration	State Government
9	Natural Heritage & Endangered Species Program	State Government
10	Massachusetts Office of Coastal Zone Management (CZM)	State Government

(Table 5.2: list of top List of top 10 actors with the most influence in the network).

5.2 Network Insights

The key supply chain stages or steps include planning; collection or sourcing of materials; material storage and distribution for production; seed and plant production and increase; seed and plant distribution for implementation; and monitoring and maintenance (León-Lobos et al. 2018; Fisher-Walter 2019; Cross et al. 2020). Interviews with producers, end users, and intermediaries confirmed that these stages are interconnected and form the foundation of the supply chain in the Northeast. However, the data from interviews, combined with the results of social network analysis, revealed important insights about inherent supply chain complexities such as the interdependencies among multidisciplinary and multisectoral actors; how inputs and outputs flow across multiple temporal and spatial scales; and how there is an interplay between linear and non-linear steps (See Figure 5.3). The diagram does not include every input, output, flow, and required step or activity, however, it does aim to more effectively capture the system of inputs, stages, activities, and bi-directional and non-linear flows required to transform the living genetic resources contained in seeds and tissues of plants into commodities (e.g., bulk seed, plugs, saplings, etc.,) for restorative activities.



(Figure 5.3: Diagram that shows inherent supply chain complexities).

Multi-tiered steps

Embedded within each key stage or step are a multitude of secondary, tertiary, and quaternary activities each that require different type of expertise, inputs, and planning horizons. For example, there is a common misperception that supply chains begin where raw materials originate. In the case of native seed and plant material supply chains, the raw materials—seed, cuttings, root stock—come from local, wild populations (National Academies of Sciences, Engineering, and Medicine 2020). However, the supply chain does not start in areas where wild plants naturally occur, rather there are various multi-tiered activities that precede the collection and sourcing of 'raw materials' to bring into production systems. End users, producers, and intermediaries, either in collaboration or independently, might develop target or priority species lists to guide collection efforts; conduct surveys or mapping exercises to identify suitable areas to collect materials; and submit applications to obtain collection permits. Additionally, actors must conserve and protect habitats that harbor plant germplasm either through easements or land acquisition from government agencies at federal, state, and local levels. Each of the key supply chain stages or steps is connected to numerous requisite ancillary activities.

Working across sectors and disciplines

The matrix of network relationships revealed how multidisciplinary and multisectoral engagements provide the foundation for the entire supply chain to function. For example, private for-profit companies like plant nurseries and seed companies are adept at activities related to multiplying and transporting seed and producing saplings, plugs, and other forms of containerized vegetative material. While, these actors, on an ad hoc basis, collect seed, cuttings, and rootstock from naturally occurring plant populations to bring into their horticultural production systems, their selection of species is often influenced by what they are able to easily and reliably germinate, propagate, and sell. Public sector actors like government agencies, working in collaboration with academic institutions and NPOS, are often better equipped to carry out the multi-tiered activities related to the collection, processing, and mid- to long-term storage of greater diversity of plant taxa due to their combined expertise (e.g., knowledge of botany and taxonomy, species distribution maps) and access to resources (e.g., volunteer labor, graduate students, gene bank facilitates, grant funding).

Seed and plant material supply chains are unique because living genetic resources such as seeds or the tissues of plants are a public resource that public and private for-profit and non-for-profit companies and organizations transform into commodities. Once commercially produced seed and other forms of vegetative material find its way back into ecosystems it becomes a public good again.

Working across scales

The structure of the social network revealed how ties of collaboration among private companies, NPOs, academic institutions, and government agencies provides the means for actors to work across varying spatial and temporal scales. Producers, intermediaries, and end-users contend with international standards or guidelines (e.g., collecting protocols), federal-level strategies (e.g., US National Seed Strategy), regionally-led planning projects (e.g., Hudson-Raritan Estuary Comprehensive Restoration Plan), state-level policies (e.g., Wetlands Protection Act Regulations) and local municipal initiatives (e.g., Climate Ready Boston). For example, in the network there were a lot of close and dense connections among federal and state-level agencies and NPOs, and then again between NPOs, state-level agencies, and private companies who are working at neighborhood and local municipality scales. This indicates, that state-level agencies and NPOs play an important role in the network as a liaison between regional contexts (e.g., The North East, the entire United States, and the global setting) and more local scales (e.g., cities and towns). NPOs and state-level agencies are also the actors in the network who have the most influence.

Seed and plant material supply chains also function across varying timescales. The planning horizons of farmers, horticulturists, and other producers are longer than the duration of most restorative activities, but shorter than the project timescales of government agencies and NPOs. For example, the design, planning, and construction phases of a coastline restoration project may be as short as 1-2 years, where live plant production could take up to 3 years, and bulk seed production 5-12 years (Personal communication, 2021, 2022).

The interplay between linearity and non-linearity

The conceptualization of the supply chain comprises a network of social actors performing multi-tiered activities across different sectors, disciplines, spatial scales, and time horizons provides a basis for understanding how nonlinear interactions are part of the system. Within supply chain management, nonlinearity refers to the idea that changes in inputs may not be proportionally related to changes in outputs (Surana et al., 2005). Within the context of native seed and plant supply chains, nonlinear dynamics affect each key stage or step. For example, the development of target and priority species is fundamental to improving the commercial availability of seed and plant materials because it helps consumers and producers focus on the same subset of species versus the thousands that are native to the region (Tangren and Toth 2020). However, developing these lists which could target and priority species for ecoregion level IV and lower habitat classifications, generalizable ecosystem types (e.g., inland wetland, saltmarsh, upland grassland), and a variety of urban contexts (e.g., rooftop pollinator garden, bioswale, front lawn alternatives, highway and roadside plantings, climate-adapted urban street trees) is a multidimensional nonlinear process. It requires that inputs of data from monitoring and maintenance and on-going research and development activities flows in reverse to inform earlier stages and steps.

5.3 Supply Chain Constraints

Semi-structured interviews revealed how the inability of the supply chain to adequately support current and future restorative activities in the Northeast is symptomatic of deeper underlying and interlinked issues. The analysis of qualitative data collected from semi-structured interviews revealed how there are a number of barriers that constrain the supply chain’s functioning. I organized these barriers into the five categories: economic, infrastructural, informational, logistical, and environmental. While such categorization has been helpful for analyzing and understanding the multiple forces that constrain the system, in practice, the delineation between the different categories is not always clear.

Economic

The majority of interviewees either explicitly mentioned or implied that economic barriers are present at nearly every stage of the supply chain. In both of the roundtable discussions, the participants prioritized economic barriers as the primary constraint that that they face. For example, nursery growers expressed how they are unwilling to bear the costs associated with seed cultivation for reasons that include market volatility and a lack of information or technical support to create a viable businesses plan. For example, a director of sales at a large wholesale plant nursery in New Jersey described how uncertain demand constrains their already well-established business:

Our biggest constraint, is that we aren't given enough time, or we don't see the demand. We don't have renewable business. We have to base our production on the averages of what we've sold in past years. We really don't have an idea of what the demand will be one year to the next. For example, *Chamaecyparis thyoides* [Atlantic White Cedar] is a perfect example. One year we can sell 30,000 and the next year 0, and it's a living plant and has a short shelf life. This year we had demand for 100,000, and when two years went by and you had no demand, and then you get a request for 100,00 with any notice its challenging.

A multi-generational farmer Connecticut, explained what prevents his nursery business from entering into seed farming:

> I don't have the information to create a business plan. It's hard to get a straight answer about how many pounds of seed you could produce per 1,000 or 10,000 square feet for whatever different species you would want to grow. I could look at what the market will bear for price because there are people selling seed in other places. I just don't know how large of a plot I would need to produce let's say 100lbs of a certain species. Without those metrics, I can't make a calculated decision.

From the demand side the financial resources for carrying out projects like ecosystem restoration or rehabilitation are often limited. An environmental horticulturist, explained how he has witnessed an increase the amount of land trust organizations that are planning restorative activities like converting agricultural fields into meadows. He explained how many of these organizations do not have the budget for buying locally produced ecotypic seed material:

> Oftentimes, these organizations are barely scraping by, from a budgetary point of view. To tell them they need to expect to pay five times as much to do the work is something that most of them are not willing to hear.

While small-scale regional seed companies and collectives like the Wild Seed Company, in Maine and EcoType 59 in Connecticut (CT) are starting to sprout up, their customer base is primarily home owners and small-scale landscape design firms. A restoration practitioner explained that beyond these two businesses, it is incredibly challenging to find seed that is actually native to the Northeast at scale. They stated:

> It's wonderful for the homeowner, but when you're starting to talk about a 20-acre meadow, you can't be ripping open 3000 individual packets of seed. We need companies who are focused on turning one seed into thousands of seed, and I don't know any in the area who's currently doing that.

This restoration practitioner's sentiments were shared by other interviewees who expressed that they simply cannot find adequate quantities of seed that is cultivated in the region and has local ecotypes. The majority of market share of seed purchases has been captured by larger Midwestern suppliers. In the Midwest, land is cheap and plentiful. Companies like Ernst Conservation Seed have thousands of acres that they use to cultivate seed and they also have equipment that mechanizes the seed harvesting and cleaning processes which allows them to maximize their profits.

Overall, the commercial availability of seed material that originates and is cultivated in the Northeast is heavily influenced by the cost of production coupled with uncertain demand. On the supply side, prospective growers or those already within in agricultural and horticultural industries experience high costs to start a new business or expand an existing one. Although the costs of production will vary by the species propagated and how easily those species can be grown in an agronomic setting, how long it takes for them to reach seed-bearing age, how much seed they yield, and how time-intensive it is to collect their seed, there still are capital investments that suppliers must bear including the costs of land, labor, equipment, and other inputs need for productions (e.g., fertilizers, irrigation, storage facilitates).

Infrastructural

The region lacks public sector gene banks dedicated to mid- to long-term storage, seed cleaning facilities, and seed warehouses that are capable of storing significant quantities of bulk seed. While, botanic gardens in the region have the capacity to store seeds, there are only two gene banks in the region that focus on storage of native plant materials for restorative activities. These are the Native Plant Trust's headquarters in Framingham, MA and the Mid-Atlantic Regional Seedbank (MARSB) which is located in Staten Island, NY, is part of the New York City Department of Parks and Recreation, and works closely with Seeds of Success (SOS).

Seed and plant production and increase is also constrained by expensive and limited land in the Northeast. Many interviews commented how would be incredibly costly and challenging to find thousands of acres where seeds could be cultivated and harvested with mechanical equipment. One interview expressed that "land is not plentiful and cheap like it is in the Midwest."

Logistical

Logistical obstacles are present across supply chain and manifest at junctions where actors from different sectors carry out non-linear activities. My interviews revealed that organizational and planning challenges predominantly affect activities associated with the 'production and increase' and the 'distribution for implementation' stages. It is common that seed and plant production and restorative activity project timelines are highly disjointed. For example, a U.S. Army Corps of Engineers employee that manages ecosystem restoration projects explained how its challenging to develop contractual agreements with producers so that they have enough notice to begin producing the huge number of seed and plant materials required for large scale projects. The interviewee elaborated:

> Often growers want to know how many projects are in the pipeline and how many plants those projects will need, and if it possible to lock down an agreement and pay years in advance for specific plants to be grown. However, we don't get the funds for the construction [the phase where seed and plant materials are procured] until we go a through a feasibility analysis, and get the budget approved for the engineering and design and planning phases.

This example illustrates how the inability to provide growers with enough lead time and associated financial commitments prevents project and production timelines from more optimally synching. Other interviewees mentioned the same issue. End users who work on the planning and design phases (e.g., restoration ecologists, landscape architects) usually develop the project's planting plan. However, that plan will then go out to bid to a construction company who will then be responsible for procuring the seed and plant material.

Informational

A lack of scientific and technical information affects multiple stages of the supply chain. For example, the planning, collection and sourcing stages, and implementation stages are stifled by the fact that region lacks authority target or priority species to guide conservation, collecting, and restorative efforts. According to Toth and Tangren (2020), 95% of their survey respondents want better availability of technical information, and 65% of the respondents indicated that target or priority species lists are the most desired type of document. My interviews with a range of end users, producers, and intermediaries support Toth and Tangren's findings. However, the interviews also revealed what types of species lists exist in the region and how these are not wholly sufficient for strengthening the aforementioned supply chain stages.

From the end user side, target or priority species list are desired to help guide planting plans for a range of activities from urban forestry management to coastal restoration. I spoke with a field operations coordinator at one of Boston's urban green space management organizations who manages tree planting projects. The interviewee explained how she would like to use more native trees but feels somewhat limited because the City of Boston is focused on character preservation. They explained that any public planting project in the City of Boston must go through a design review with the Boston Landmarks Commission, which has an have a list of accepted species. Additionally, there is an Olmstead approved planting list which dictates which species can be planted in the portions of the park system.

The interviewee explained that refining these species lists can challenging because the experts and consultants that have the power to change these lists come from different backgrounds and have differing opinions on what should be planted where. For example, some will select species for its historic preservation value, although those species are not native, whereas others might choose a species for its ability to support wildlife or its disease and pest resistance. Overall, there is less attention if any on ensuring that the species on these lists have local ecotypes. The interviewee explained that having technical guidance in the form of an urban forestry recommended species list would be extremely helpful:

> Next year, I will start a parkway tree planting program. I have to go out and assess the dead trees and the conditions of the ones that are still living. I wish there was guidance on a systematic way to undertake successional planting. I would love to know which native species are the best to replace a large tree for all the urban forestry reasons – carbon sequestration, storm water retention, shade, character preservation, and resistance to pests and diseases.

A wetland restoration practitioner in MA explained they also needs more information about best practices for specifying not just species but also additional levels of detail about where the seed and plant material should ideally originate from. However, a plant sciences professor from a university in Rhode Island, shared that the lack of scientific information about the genetic structure of the many of the native plant populations in the Northeast, limits scientists and practitioners from understanding the true geographical extent of populations which in turn can limit the development of guidelines for conservation and collection activities. The interviewee continued, "and unfortunately there is little to no grant funding that will support this kind of research."

The lack of target and priority species lists also impact farmers, horticulturists, and other nursery professionals who also need reliable information about what species end users will want to purchase. A farmer from a seed growing collective in CT, explained that farmers are excited to engage in growing seed but they need a ranked priority list of the species and ecosystems that would be most useful to end users. They elaborated:

> It is hard for the farmers to understand what are the critical species to work on next. We have 20 species in production now, but we are eager to pick the next 20 species for production. That is where some organization and clarity among stakeholders would be helpful for us to figure out what the demand will be.

There are a number of considerations that underpin the decision making of seed companies and plant nurseries like how widely the species is distributed; how fecund the species is; if the species will support pollinators; if it showy; or if it easy to grow. For example, I spoke with a horticulturist who works at one of the primary suppliers of native seed materials in the Northeast, although the company and its operations are located outside of the region. The interviewee confirmed that the growing demand for ecotypic plant material in the Northeast has spurred the company to consider planning "plant hunting" expeditions in the Northeast. When I asked the interviewee how they prioritize what to collect, they directed me to the Biota of North America Program's website and asked me to look up the distribution ranges of two species in the bergamot family Monarda fistulosa and M. didyma. The first species, M. Fitulosa had a broad distribution across most of the Northeast, whereas M. didyma range was restricted to Vermont. They then rhetorically asked:

> So, if you had to prioritize which species to collect, what would you choose? You don't want to be stuck with a situation where you've grown something and produced an excess and can't sell it to all of New England.

They continued to explain how aesthetics is another factor that drives decision making about what to collect. They shared an instructive story about two related flower species *Oenothera perennis* and *O. fruticosa*. *O. fruticosa* would be prioritized because it has larger blossoms and would sell more easily than its relative *O. perennis* with smaller blossoms. However, they also explained that the flower with smaller blossoms has a smaller corella and therefore is a more optimal flower to plant for attracting lady bugs, since they can more easily reach the nectar.

Beyond developing guidance on which species should be targeted or prioritized for activities, there is also a lack of collated ancillary information about optimal seed harvest timing, the best approach for maintaining genetic diversity for the species based internationally accepted protocols; how to clean and store seed; how to germinate and propagate species; and how to take care of species throughout their life cycle. For example, seed handlers may inadvertently lose genetic diversity if they discard lighter and smaller seeds during the cleaning process. Nursery growing conditions also expose plants to novel environments. Stress is not as severe and heterogenous as in nature because growers can control factors like light, temperature, fertilization, irrigation, pests, and diseases. Nursery conditions inevitably impose artificial selection on plants, affecting genetic diversity and adaptation within a few generations. In other cases, the loss of diversity may be more intentional. For example, growers might select larger, more uniform, or faster-germinating plants and cull the others that do not meet these criteria (Espeland et al. 2017).

Environmental

Ecoregion 59, like many other areas in the Northeast are heavily urbanized or have a long land use history of agriculture or industrial use that has resulted in extensive habitat loss and fragmentation. This ultimately constrains the 'collection and storage' phase of the supply chain, as habitat fragmentation threatens the foundation of current and future wild seed collection. Seed storage is also somewhat constrained by the humid climate and seasonal variability of the Northeast (Interim Report, 2020), as it is more cost prohibitive to build large climate-controlled warehouses to store bulk seed than other regions of the U.S., like the West where the temperature does not fluctuate as much and environmental conditions are more arid.

Climate change will also continue to exert pressure on the supply chain. For example, more frequent and extreme weather can damage fields of native plant crops and delay seed collection. Several practitioners that I spoke with expressed that they are unsure if planting native species with local ecotypes is even the correct approach under climate change. For example, one restoration ecologist explained how there has been a push in the horticulture industry to produce plant material with hyper local genotypes, even though, some people question if there is a strong empirical basis behind this trend. The interviewee remarked:

> What does native mean in a changing climate? Many species are moving northwards that people are calling invasive species. At what point should we call these species native? Also, I am not sure if planting local ecotypes is always the best approach. For example, the distribution of Red Maple runs from Florida to Canada, and sure it doesn't make a lot of sense to plant a Florida genotype in Massachusetts, but with climate change it could make sense to plant a Virginia ecotype. We just don't have enough information.

The interviewee ended our call by saying "we have more questions than answers, but with climate change we need to make some decisions now." An outreach program coordinator for a native plant educational organization explained that their working group recently discussed what is legitimately a native plant and should climate change need to be taken into account when sourcing seed or plant material. The interviewee went on to say: "are you going to look within a narrow boundary like an ecotype region… or do you want to take into account climate change."

CHAPTER 6: REFLECTIONS AND NEXT STEPS

In this chapter, I offer a prescriptive reflection. I discuss what I have learned from carrying out this thesis research. I then introduce 6 'next' steps that actors in the Northeast could take to address supply chain shortcomings and the barriers outlined in Chapter 5, Section 3. Additionally, I review the limitations of this thesis research and highlight areas that researchers and practitioners should prioritize for future investigation.

6.1 Key Learnings

This thesis research has allowed me to understand how the strongest interrelationships occur among government agencies, academic institutions, and private firms that work on environmental engineering, landscape design, habitat restoration, and urban planning and design. Nonprofit organizations occupy the interstitial parts of the network, and plant nurseries, seed companies, botanic gardens, herbaria, and arboreta are located on the periphery. Due to the density and strength of connections among the actors who comprise the 'core' of the network, and that these actors are also the most well connected and influential in the network, they should be engaged in any formal actions to improve supply chain processes like the series of 'next steps' that I will introduce in the following section.

However, efforts to strengthen the seed and plant supply cannot be siloed into one approach. Instead, the well-connected actors must continuously reinforce the relationships with actors throughout the network to work across sectors, disciplinary areas, jurisdictional boundaries, and ecological scales more effectively. This will help build supply chain strength and maintain resilience. For example, nonprofit organizations that work on indigenous land stewardship and environmental justice had weak connections to the network's core and other actors who occupy 'central' positions. Strengthening ties to these groups could help improve social, environmental, and ecological outcomes for indigenous people, people of color, immigrants, people with lower incomes, and others who have faced a legacy of systemic injustices.

Equally important is that actors forge new linkages with actors inside and outside the preexisting social network. For example, the Massachusetts Department of Public Health was one of the actors who declined to participate in the survey because the director expressed that they are "not involved in ecological restoration." However, network data collected from other actors revealed that the Massachusetts Department of Public Health was one of the actors located on the network's periphery. Due to the critical role that open spaces, recreational landscapes, and restored ecosystems play in improving public health and wellbeing, it is a missed opportunity that those working at a state-level public health department are not more well-integrated into the network.

However, my biggest takeaway from this thesis research is that adopting a network paradigm is an essential first step to understanding the inputs, outputs, structure, components, stages, and flows of seed and plant material supply chains in the US Northeast and beyond. This framing is more advantageous than a conceptual model that posits supply chains as simple linear systems with a few strong unidirectional linkages. Without adopting a fundamentally different framework for analyzing and addressing relevant issues, we risk coming to the wrong conclusions and then implementing the wrong solutions to optimize supply chain performance to meet the demand of current and future restorative activity goals.

6.2 Next Steps

There are numerous 'next steps' that actors can take to strengthen the supply chain. However, during the roundtable discussions, the conversation generated among 22 individuals from different sectors of the supply chain—policymakers, urban planners, nursery growers, botanists, farmers, native plant educators, and restoration ecologists—revealed which actions should be prioritized to work on first. The results of this thesis research also reaffirmed that these next steps merit further attention.

Target or priority species list

There is a need for actors to develop authoritative target and priority species tailored to the diversity of restorative activities taking place in the region. Actors can assemble species lists for ecoregion level IV, lower habitat classifications, and different broad ecosystem types (e.g., inland wetland, saltmarsh, upland grassland, etc.), by drawing information from published scientific literature, unpublished survey data and reports, herbarium specimen records, and consultation with regional experts. There is also a need to generate target species lists for various urban contexts, including rooftop pollinator gardens, brownfield remediation projects, artificial wetland/bioswales, front lawn alternatives, and highway and roadside plantings climate-adapted urban street trees. These lists are also valuable to urban planners and landscape architects because they also provide guidance about which species scientists predict to perform well under a changing climate. This is a fundamental step to improving the commercial availability of seed and plant material because, as Tangren and Toth (2020) point out, it allows producers and end-users to focus on the same subset of species versus the thousands native to the region.

Regional Seed and Plant Material Needs Directory

In addition to target and priority species lists, producers in the region need information about the volumes of material required for restorative activities. An online regional directory system would be beneficial for logging activities and characterizing the potential demand for native plant materials in the context of resiliency planning. Another benefit of a regional directory is that it could provide a conduit for producers and end-users to establish contract grow and supply agreements more effectively. End-users can work with producers earlier in the design and planning phases of a product to pre-order seed and plant material that meets project specifications, budgetary constraints, and deadlines. This would also provide producers with financial security, which helps mitigate economic risk.

Regional Lobby Organization:

With all of the growing investments in restorative activities throughout the region, a portion of those funds should help subsidize the cost of activities critical to strengthening the supply chain but do not return an investment (e.g., research and development). Creating a formalized lobbying group could help bring together conservation organizations, government agencies, farmers, and other stakeholders to lobby state governments to direct a portion of resiliency funding toward activities to strengthen supply chain processes. In addition, a group could also more effectively coordinate policy around such issues as seed quality regulations.

Regional quasi-governmental organization:

In addition to creating a regional directory of needs, it would also be critical that the end-users that require the largest volumes of plant material (e.g., state departments of environmental protection (DEEPs)) exchange information and better coordinate their efforts. For example, the regional state DEEPs could form a coalition similar to the New England Transportation Consortium (NETC), which pools the research funds for all six New England state DOTs. Such coordination becomes important once seed zones are created, which will traverse state political boundaries. In addition, this group could better communicate their collective needs to native seed and plant material producers.

More roundtables, working groups, and workshops to bring end-users, intermediaries, and producers together:

There is a need for more roundtables, working groups, and workshops to improve communication among policymakers, researchers, conservation planners, large seed consumers, and native seed and plant producers. Such forums could provide the opportunity for supply chain actors to identify and discuss relevant issues like emerging restoration needs (e.g., increased need for coastal vegetation); market trends (e.g., more demand for bulk seed over containerized plant material); and seed quality testing methods and standards (e.g., development of certification program). However, there is also a need for more focused meetings with representatives from similar stakeholder groups to share knowledge and build consensus about best practices and protocols for carrying out the various multi-tiered activities associated with each key stage of the supply chain. For example, there will be a need for botanic gardens, farmers, and nursery professionals to share information about seed production protocols for species that are hard to germinate and cultivate in agricultural settings to increase supply and reduce costs.

A Regional Supply Chain Strategy Plan:

All of the 'next steps' mentioned above would be ideally be integrated into a regional strategy plan, which is why the development of this plan should be prioritized first. Drawing inspiration from the US National Seed Strategy, a regional strategy plan would offer a comprehensive roadmap for strengthening native seed and plant material supply chains in the Northeast. For example, the document would include various immediate, short-term, and long-range practice, science, and advocacy objectives. In addition, each objective would have ancillary information that outlines: 1) which agencies, companies, and organizations should be engaged; 2) what data sources, methodologies, expertise, resources, and capacities need to be leveraged; and 3) what sequential "action" steps should be taken. Formal efforts to strengthen seed and plant supply chains will require regional interstate coordination, as it will be more effective than leaving matters to individual states. There is 'strength in numbers,' and a regional approach can resolve individual state policymakers to support efforts to bolster seed and plant supply chain activities. Moreover, shared environmental goals across the region warrant strengthening regional interstate collaboration.

6.3 Limitations

Several factors limited this thesis research. First, due to time constraints, I was only able to collect granular data on actor types at the scale of the greater Boston region. Above this level, the incorporation of actors who represented different supply chain sectors was reduced to agencies, organizations, private companies, and institutions primarily located within Massachusetts. For example, I did not include state-level agencies or academic institutions from other Northeastern states. Although, the insights that I have gathered from analyzing the patterns of connectivity in the social network studied (e.g., which actor types are most influential, general network structure, etc.) could be extrapolated to the level of the US Northeast and even other regions, it would be important for other researchers who are interested in using a social network analysis approach to study supply chains to collect more robust network data.

Another potential constraint of this thesis research was that I collected data about how frequently actors collaborated through a survey, which relied on individuals' subjective judgment to determine on a scale from 0 to 3 how often their organization, agency, institution, company, etc. works with others actors in the list. It is possible that some survey participants might not be fully aware of the ties between their place of work and other actors in the social network. Therefore, patterns of connectivity between actors may not always be accurate.

As I mentioned in Chapter 1, social captures a static snapshot of a network at a particular time. While, I was able to supplement my analysis with qualitative data collected from semi-structured interviews, if I had more time, I would have liked to organize more interviews with a broader range of individuals to more fully understand the dynamics of the network.

6.4 Areas for future consideration and investigation

This thesis research illuminated several research areas that merit further consideration and investigation. First, it is critical to include various areas of expertise in any future seed and plant supply chain investigations. For example, those interested in carrying out studies to understand how to strengthen seed and plant material supply chains should consider drawing from the field of supply chain management or consulting with supply chain management experts. Similarly, it would be beneficial to include individuals with knowledge of economics and business management. While federal and state governments should continue to invest in and subsidize activities related to strengthening seed and plant supply chains, research also needs to be carried out to make seed and plant material production a more economically viable business endeavor. Since the seed and plant material production falls under the agricultural sector, there will always be inherent risks (e.g., weather, pests, diseases). Therefore, researchers could investigate how a cooperative business model could be a viable approach for strengthening seed and plant supply chains while generating new economic opportunities for historically marginalized communities.

While seed and plant material supply chain shortcomings are an issue in many regions worldwide, some groups have made significant inroads to overcome many of the constraints that the US Northeast is facing. For example, The Great Basin Native Plant Project, the Nevada Native Seed Partnership, The Southwest Seed Partnership in the US West, and the Xingu Seeds Network in the Brazilian Amazon have been formed to increase the availability of native plant materials for restoring degraded lands. It would be incredibly valuable for researchers to systematically review these precedent partnerships and associations and synthesize information about their management structure, how information is generated and disseminated within their networks, how they successfully bring different supply chain sectors together, etc.

Additionally, researchers who are interested in native seed and plant material supply chains might consider carrying out more investigations on other types of agricultural supply chains to understand if embedded within these systems are practices, protocols, techniques, forms of equipment, formalized procurement agreements, etc., that could be transferred to improve the processes related to native seed and plant material supply chains. For example, it could be highly beneficial for researchers to study edible crop seed companies that operate in the region, like High Mowing Seeds located in Vermont and Fedco and Jonny's Selected Seeds in Maine.

6.5 Concluding Thoughts

We attribute our environmental problems to excess carbon dioxide in our atmosphere, and this is reflected in our current climate policy. Equally important are strategies to restore and revive our planet's imperiled ecosystems. To successfully advance the replanting of forests, rehabilitation of wetlands, softening of coastlines, and all of the other myriad activities underway or planned for the future, it is imperative to secure adequate supplies of native plant species as seeds or nursery materials. This will allow us to reestablish biodiverse self-sustaining populations that improve ecosystem functioning, support pollinators and wildlife, and are durable enough to withstand the impacts of climate change.

Limited supplies of seed and vegetative plant material have been a major concern for practitioners in nearly every ecosystem type where restorative activities occur. Increasingly, researchers and practitioners are applying the conceptual framing of a 'supply chain' to understand the key stages, inputs, flows, and components involved with producing commercially viable quantities of seed and plant material for end-users. However, this conceptual framing treats the seed and plant supply chain as a series of unidirectionally connected steps or stages, significantly limiting its scope.

This multi-level case study of the US Northeast showed that we must adopt a network paradigm to build and strengthen seed and plant material supply chains. The first step is to identify the full range of actors involved in restorative activities in a given region. Then, by understanding how these actors are connected, we can more effectively analyze inherent system complexities like the interplay between linear and non-linear steps; interdependencies among multisectoral actors; and how inputs and outputs flow across multiple scales. Finally, this information provides the basis for developing plans to enhance communication, coordination, and collaboration among various supply chain actors.

The advantage of embracing and building off this framework is that it will provide us with a more robust conceptual foundation to generate solutions to optimize supply chain performance, which will allow us to better meet the burgeoning demand for restorative activity goals in the US Northeast and beyond.

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APPENDICES

Appendix A: List of actors in the database

#	NAME	TYPE
1	Boston University (Department of Earth & Environment)	Academic Institution
2	Harvard University (Graduate School of Design)	Academic Institution
3	Harvard University (Department of Organismic and Evolutionary Biology)	Academic Institution
4	MIT (Media Lab) (Living Observatory, Inc.)	Academic Institution
5	MIT (The Department of Earth, Atmospheric and Planetary Sciences)	Academic Institution
6	Northeastern University (Department of Marine and Environmental Sciences)	Academic Institution
7	Tufts University (Department of Biology)	Academic Institution
8	Tufts University (Institute of the Environment)	Academic Institution
9	Tufts University (Institute for Food Nutrition and Innovation at the Friedman School)	Academic Institution
10	University of Massachusetts Boston (Department of Ecology and Conservation)	Academic Institution
11	University of Massachusetts Boston (Sustainable Solutions Lab)	Academic Institution
12	University of Massachusetts (Landscape, Nursery & Urban Forestry Program)	Academic Institution

13	University of Massachusetts (Amherst Soil Testing Lab)	Academic Institution
14	Harvard Forest	Academic Institution
15	The Ecosystem Center Marine Biological Laboratory of Woods Hole	Academic Institution
16	Army Corps of Engineers (New England District)	Regional Government Agency
17	Boston Planning and Development Agency	Local Government Agency
18	City of Boston (Office of Environment, Energy and Open Space)	Local Government Agency
19	City of Boston Water and Sewer Commission	Local Government Agency
20	City of Boston (Boston Parks and Recreation)	Local Government Agency
21	City of Boston (Department of Environmental Protection)	Local Government Agency
22	City of Boston (Department of Neighborhood Development)	Local Government Agency
23	City of Boston (Public Health Commission)	Local Government Agency
24	Massachusetts Department of Agricultural Resources (MDAR)	State Government Agency
25	Massachusetts Department of Conservation and Recreation	State Government Agency
26	Massachusetts Office of Coastal Zone Management (CZM)	State Government Agency
27	Natural Heritage & Endangered Species Program	State Government Agency
28	Massachusetts Department of Environmental Protection	State Government Agency

29	Massachusetts Department of Fish and Game [or Division of Fisheries and Wildlife?]	State Government Agency
30	Massachusetts Department of Public Health	State Government Agency
31	Massachusetts Division of Conservation	State Government Agency
32	Massachusetts Bays National Estuary Program (MassBays)	State Government Agency
33	Massachusetts Environmental Trust (MET)	State Government Agency
34	Massachusetts Natural Resource Damages Program (NRD)	State Government Agency
35	Massachusetts Water Resources Authority (MWRA)	State Government Agency
36	Massachusetts Wetland and Waterways Program	State Government Agency
37	Massachusetts Division of Ecological Restoration	State Government Agency
38	Metropolitan Area Planning Council	Regional Government Agency
39	National Oceanic and Atmospheric Administration (NOAA) Restoration Center	Federal Government Agency
40	USDA National Resources Conservation Services (National Offices?)	Federal Government Agency
41	The National Fish and Wildlife Foundation (NFWF)	Federal Government Agency
42	U.S. Fish and Wildlife Service	Federal Government Agency
43	Restoring Roots Cooperative	Private- For Profit Consulting, Design, and Build Firm
44	Applied Ecological Services	Private- For Profit Consulting, Design, and Build Firm
45	BSC Group	Private- For Profit Consulting, Design, and Build Firm

46	EcoTec Inc	Private- For Profit Consulting, Design, and Build Firm
47	Essex Horticulture	Private- For Profit Consulting, Design, and Build Firm
48	Harrison McPhee	Private- For Profit Consulting, Design, and Build Firm
49	Inter.fluve	Private- For Profit Consulting, Design, and Build Firm
50	Lucas Environmental LLC	Private- For Profit Consulting, Design, and Build Firm
51	Parterre Ecological	Private- For Profit Consulting, Design, and Build Firm
52	Sasaki Design Firm	Private- For Profit Consulting, Design, and Build Firm
53	Stephen Stimson Associates Landscape Architects, Inc	Private- For Profit Consulting, Design, and Build Firm
54	SumCo Eco-Contracting, Inc.	Private- For Profit Consulting, Design, and Build Firm
55	Polatin Ecological Services, LLC and or Land Stewardship, Inc.	Private- For Profit Consulting, Design, and Build Firm
56	Crawford Land Management	Private- For Profit Consulting, Design, and Build Firm
57	Wilkinson Ecological Design, Inc.	Private- For Profit Consulting, Design, and Build Firm
58	Environmental Consulting & Restoration	Private- For Profit Consulting, Design, and Build Firm
59	Stross Landscape Urbanism	Private- For Profit Consulting, Design, and Build Firm
60	Urban Canopy Works	Private- For Profit Consulting, Design, and Build Firm
61	Agency Landscape + Planning	Private- For Profit Consulting, Design, and Build Firm
62	Arnold Arboretum of Harvard University	Herbarium/Arboretum/Botanic Garden

63	Harvard University Herbaria & Libraries	Herbarium/Arboretum/Botanic Garden
64	University of Massachusetts Herbarium	Herbarium/Arboretum/Botanic Garden
65	Wellesley College Botanic Gardens	Herbarium/Arboretum/Botanic Garden
66	The Botanic Garden of Smith College	Herbarium/Arboretum/Botanic Garden
67	Berkshire Botanical Garden	Herbarium/Arboretum/Botanic Garden
68	Garden in the Woods (of the Native Plant Trust)	Herbarium/Arboretum/Botanic Garden
69	Mount Auburn Cemetery	Herbarium/Arboretum/Botanic Garden
70	Tower Hill Botanic Garden	Herbarium/Arboretum/Botanic Garden
71	Boston Society of Landscape Architects on behalf of Toby from Wolf Landscape Architecture	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
72	Massachusetts Arborists Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
73	Massachusetts Association of Landscape Professionals	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
74	Massachusetts Nursery and Landscape Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
75	New England Nursery Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
76	Indigenous Resources Collaborative (IRC)	Nonprofit Organization-Indigenous
77	Native Land Conservancy	Nonprofit Organization-Indigenous
78	Mass Audubon	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
79	Applied Economics Clinic	Nonprofit Organization- Climate, Energy, and Economics
80	Barr Foundation	Nonprofit Organization- Climate, Energy, and Economics

81	Mothers Out Front	Nonprofit Organization- Environmental Justice
82	Emerald Necklace Conservancy	Nonprofit Organization- Urban Green Space Management
83	Boston Food Forest Coalition	Nonprofit Organization- Soil and Regenerative Agriculture
84	Fenway Garden Society (FGS)	Nonprofit Organization- Urban Green Space Management
85	Franklin Park Coalition	Nonprofit Organization- Urban Green Space Management
86	Friends of the Public Garden	Nonprofit Organization- Urban Green Space Management
87	Green Roots, Inc	Nonprofit Organization- Environmental Justice
88	Grow Native Massachusetts	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
89	Massachusetts Association of Conservation Commissions (MACC)	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
90	Massachusetts Invasive Plant Advisory Group	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
91	Massachusetts Land Trust Coalition	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
92	Native Plant Trust (Previously New England Wild Flower)	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
93	New England Forestry Foundation	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
94	Norcross Wildlife Foundation	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
95	Northeast Organic Farming Association Massachusetts Chapter	Nonprofit Organization- Soil and Regenerative Agriculture

96	Society for Ecological Restoration New England Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
97	Sierra Club Massachusetts Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
98	Soil And Water Conservation Society Southern New England Chapter	Nonprofit Organization- Soil and Regenerative Agriculture
99	The Quabbin-to-Cardigan Partnership	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
100	Trustees of the Reservation	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
101	Wild Ones Native Plants, Natural Landscapes Mass Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
102	Wildlands and Woodlands-The Regional Conservation Partnership (RCP) Network	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
103	The Nature Conservancy MA Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
104	American Public Garden Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
105	Consortium of Northeastern Herbaria	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
106	Massachusetts Horticultural Society	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
107	New England Botanical Club (NEBC)	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture
108	Select Horticulture Premium Plant Material in Lancaster, MA (Plant Nursery)	Plant Nursery - Wholesale

109	Hillside Nursery in Ashfield, MA (Specialty Plant Nursery)	Plant Nursery - Retail
110	City Natives in Mattapan, MA (Retail Plant Nursery)	Plant Nursery - Retail
111	Earth Tones Native Plants in Woodbury, CT (Specialty Plant Nursery)	Plant Nursery - Retail
112	Kohl Gardens in Wendall, MA (Specialty Plant Nursery)	Plant Nursery - Retail
113	Northeast Pollinator Plants in Fairfax, VT (Northeast Pollinator Plants)	Plant Nursery - Retail
114	Colonial Seed in Windsor, CT (Seed & Plug Supplier)	Plant Nursery - Retail
115	Prairie Moon Nursery in Winona, MN (Seed & Plug Supplier)	Plant Nursery - Retail
116	Toadshade Wildflower Farm in Frenchtown, NJ (Seed & Plug Supplier)	Plant Nursery - Retail
117	Charbrook Nursery in Princeton, MA (Specialty Plant Nursery)	Plant Nursery - Retail
118	Dale Tree Movers and Tree Farm in Cape Cod, MA (Tree farm)	Plant Nursery - Wholesale
119	Ernst Conservation Seeds in Meadville, PA (Seed & Plug Supplier)	Plant Nursery - Wholesale
120	New England Nurseries in Bedford, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale
121	North Creek Nursery in Landenberg, PA (Seed & Plug Supplier)	Plant Nursery - Wholesale
122	Pineland Nursery in Columbus, NJ (Wholesale Plant Nursery)	Plant Nursery - Wholesale
123	Weston Nurseries Inc in Hopkinton, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale

124	Whalen Nursery Inc. in Great Barrington, MA. (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale
125	Allandale Farm in Brookline, MA (Retail Garden Center)	Plant Nursery - Wholesale
126	Amherst Nurseries in Amherst, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
127	Andrew's Greenhouse in Amherst, MA (Garden Center and Plant Nursery)	Plant Nursery - Wholesale
128	Bigelow Nurseries in Northbrook, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
129	Cavicchio Nurseries in Sudbury, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
130	Helia Native Nursery in Stockbridge, MA (Specialty Plant Nursery)	Plant Nursery - Wholesale
131	Native Plant Trust's Nasami Farm (Retail and Specialty Plant Nursery)	Plant Nursery - Wholesale
132	New England Wetland Plants Inc. in Hadley, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
133	Site One Landscape Supply in West Springfield, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
134	Spillane's Nursery in Middleboro, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
135	Sudbury Nurseries West, LLC. In Gill, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
136	Sylvan Nursery Inc in Westport, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale
137	TripleBrook Farms in Southampton, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale

138	Wanczyk Evergreen Nursery in Hadley, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale
139	New Moon Nursery in Woodstown, NJ (Wholesale Plant Nursery)	Plant Nursery - Wholesale
140	Pierson Nurseries in Dayton, ME (Wholesale Plant Nursery)	Plant Nursery - Wholesale
141	Planter's Choice in Newtown and Watertown, CT (Wholesale Plant Nursery)	Plant Nursery - Wholesale
142	Rhody Native in Kingston, RI Now Rhode Island Natural History Survey (Wholesale Plant Nursery)	Plant Nursery - Wholesale
143	Van Berkum Nursery in Deerfield, NH (Wholesale Plant Nursery)	Plant Nursery - Wholesale
144	Charles River Watershed Association	Watershed Association/Coalition
145	Massachusetts Watershed Coalition	Watershed Association/Coalition
146	Mystic River Watershed Association	Watershed Association/Coalition
147	Nashua River Watershed Association	Watershed Association/Coalition
148	Neponset River Watershed Association	Watershed Association/Coalition
149	Conway School of Landscape Architecture	Academic Institution
150	Broad Brook Coalition	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
151	GZA GeoEnvironmental	Private- For Profit Consulting, Design, and Build Firm
152	Salem Sound Coast Watch	Nonprofit Organization- Landscape Protection, Conservation, and Restoration

153	Mill River Greenway Initiative	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
154	BioDiversity for a Livable Climate	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
155	EcoTypic Seed Project of NOFA CT	Nonprofit Organization- Landscape Protection, Conservation, and Restoration
156	City of Northampton Planning	Local Government Agency
157	USDA National Resources Conservation Services (Cape May Plant Materials Center)	Federal Government Agency
158	Mary May Binney Wakefield Arboretum	Nonprofit Organization- Herbarium/Arboretum/Botanic Garden

Appendix B: Survey Questionnaire

SURVEY PART I	
1. What company, organization, or agency do you work for?	'Short answer text'
2. What is your position or job title?	'Short answer text'
3. Which type of restorative activity does your company, organization, or agency predominantly undertake? Please choose all that apply or select 'I. other' if you feel this question doesn't relate to your work.	Multiple Answer(s): A. Ecological Restoration; B. Ecological rehabilitation; C. Ecological remediation; D. Nature-based solutions; E. Ecosystem-based adaptation; F. Green infrastructure; G. Agriculture (urban and/or regenerative); H. Rewilding; I. Other (Please describe in 'Other box').
4. At which level(s) best describes where you work or where the impact of your work is most felt? Please choose all that apply.	Multiple Answer(s): A. Neighborhood; B. Local municipality; C. greater Boston region; D. Watershed-scale (Please write which water in the 'Other Box') E. Massachusetts State; F. Northeast; G. National Level; H. Global; I. Other (Please describe in 'Other Box')
5. Which ecosystem type(s) do you predominantly work on restoring? Please choose all that apply or select 'G. non-	Multiple Answer(s): A. Forest; B. Wetland; C. Coastal and/or Marine; D. Grassland; E.

applicable' if you feel this question doesn't relate to your work.	Urban or Peri-urban; F. All; G. Non-applicable (Please describe in 'Other box')
6. Which step(s) of ecological restoration best describe where your work takes place? Please choose all that apply or select 'I. Non-applicable' if you feel this question doesn't relate to your work.	Multiple Answer(s): A. Planning; B. Material Production; C. Design; D. Implementation; E. Monitoring and Maintenance; F. Knowledge Generation; G. Regulation; H. Non-Applicable; I. Other (Please describe in 'Other box')
SURVEY PART II	
1. How would you describe the level of collaboration that takes place between your place of work and the following organizations, agencies, and companies? By collaboration we mean working together to design, plan, implement or monitor ecological restoration activities or share knowledge, resources, materials. "Included in this part of the survey was a list of all 158 actors. Participants used check boxes labeled '0,' '1,' '2,' and '3' adjacent to each name in the list to denote the strength of the tie between them and all other actors in the database based on collaboration.	Please respond using either: 0. Not at All (i.e., My place of work does not collaborate that agency, organization, or company). 1. Yes, in the past but not likely again (i.e., My place of work has collaborated with that agency, organization, or company in the past, but it is unlikely that collaboration will happen with them again in the foreseeable future). 2. Yes, in the past and would do so again (i.e., My place of work has collaborated with that agency, organization, or company in the past and would collaborate with them again if given the opportunity). 3. Yes, currently (i.e., My organization is currently collaborating or regularly collaborates with that agency, organization, or company).

Appendix C: Examples of semi-structured interview questions

Ecological Restoration Practitioners/ Environmental Consulting Firms

1. What are the main ecosystem or habitat types that you work on restoring? (e.g., floodplain forest, wetland, coastal, grassland/meadow, etc.) Do you ever work on any urban or peri-urban restoration projects, if so which ones?

2. How do you determine the assemblage of species that you will reintroduce to a restoration site? Is your selection of species based off of looking at a reference ecosystem? Or are there any standards and guidelines or lists that you try to follow?

   Possible follow up questions if they replied that they used a reference ecosystem:

   a. What reference ecosystem did you use?
   b. What proportion (can be a guestimate) of the species from the reference ecosystem were available to source from local (MA state) nurseries? What proportion of the species came from out of state nurseries? Which states?
   c. Were there any species that were not at all available in any plant nurseries (both local and out of state)? If so, did you have to collect seed from wild populations yourself or did you omit that species from the project?

3. What proportion of the revegetation is done by broadcast seeding or planting?

4. For ecological restoration projects that have a revegetation component, what is the average size or ranges of size of the area where new vegetation will be introduced? (size in sq. feet or kilometers or hectares or acres) (e.g., 100's or 1000's of acres)

5. For a project of X-Size (based on what they mentioned), what would be the quantity of seeds, seedlings, or saplings would you need to procure?

6. Where do source the majority of your native plant material from? Do you ever have to source plant material out of state? If so, which states do you source from?

7. What are the key drivers that influence your decision making around provenance and where plant material is sourced from? (e.g., climate proofing, regulation, cost, availability?)

8. Do the nurseries provide any information on the plant material's provenance? Are you able to specify when you place an order that you want plant material with local ecotypes?

9. Are you able to procure every species that you need and in the appropriate quantities?

10. If you need plant material of a certain species that isn't available in a nursery, where would you find that material? Would you collect seed yourself?

11. Do you ever feel like ecological restoration projects are designed around plant material availability?

12. Have you ever worked with nurseries to contract grow plant material for certain projects?

13. Do you have any species lists from restoration project design documents that you could share with me?

14. From your perspective, what are the strong and the weak links in the native plant supply chain?

Plant Nurseries

1. What portion of what you propagate is for ecological restoration projects? What types of quantities of seeds, seedlings, or saplings do you supply to ecological restoration projects?

2. What types of plant material do you specialize in producing? (e.g., trees, grasses, coastal plants, wetland plants, ornamental, street trees).

3. What is the origin of your plant material? (e.g., where do you get your seeds, cuttings, seedlings?) Do you communicate details on provenance to your customers? Why or why not?

4. If you wanted to incorporate a new species into production, where would you get seed or cuttings from or how would you start growing the plants?

5. Do you propagate plant material with local ecotypes? Why or why not?

6. Does climate change influence what you decide to grow?

7. Have you experienced increased demand for certain species for ER projects or increased demand to propagate a more diverse range of species for ER projects?

8. If you wanted to increase the number of different native plant species, how would you figure out which plant species to grow? Would you talk to restoration ecologists? Or speak with another type of expert? Or review any standards or guidelines?

9. Have you ever collaborated with the USDA, SER, or any botanic gardens, herbaria, or arboreta? If so, what are the outcomes of such collaborations?

10. Do you ever work with any other native plant nurseries in your local area or region? Why or why not?

11. What are the main constraints you face propagating and selling native plant material for ecological restoration projects? (e.g., are operational costs prohibitive, lack of technology, lack of infrastructure?)

12. 11.Would you consider expanding or scaling up your operation so that you could meet potential future increased demand for native plant material for ER projects? Why or why not? What do you think would be the greatest challenge to scaling up your operation?

13. Can you share your inventory lists with me of all the species that you currently have in production with associated quantities?

14. How does your knowledge of trends about the industry affect your decision making today?

15. Beyond your two primary customers, who else do you sell plant material to?

16. What the impediments or barrier to increasing production of both plugs and seed? (e.g., technology, equipment, information, financial resources, price of our land).

17. Would you ever consider contract growing, why or why not?

18. Do you have protocols for maintaining genetic variation? If so, what are they?

19. How has your understanding of the native plant sector changed? Do you find yourself reaching out to different entities that previously would not have been on your radar? If you have, who are they and what has the nature of the relationships? What are the qualities in other potential partners that you find either impede or help forge tighter connections?

Botanic Gardens and Herbaria/Arboreta

1. What is the proportion of the species in your collection are native to the Northeast?

2. Have you ever worked or collaborated on any ecological restoration projects? If so, who did you work and on which projects? What did that collaboration look like? What were the opportunities and constraints of that collaboration?

3. Have you noticed or experienced the objectives of botanic gardens/herbaria/arboreta becoming more focused on the science or practice of restoration? If YES, then follow up with “What do you think are the key drivers influencing this shift?” If NO, then follow up with “In your opinion, why do you think that is?”

4. Are you familiar with the work of Botanic Gardens Conservation International?

5. What are the primary assets that you think your botanic gardens/herbaria/arboreta could contribute to ecological restoration projects in the Greater Boston Region, MA, or the greater New England region?

6. Has your organization ever worked with or supplied plant material to any commercial nurseries? If so, which ones? What was the purpose of doing so?

7. If your organization wanted to incorporate a new selection of native species into its collection to advance conservation efforts, how easy or challenging would it be to do that?

8. Does your organization currently have the capacity (e.g., expertise, knowledge, infrastructure, land availability, etc.) to undertake projects around local native plant conservation? If not, which resources and types of capacities would need to be increased to do so?

Academic-Field Lab or Program

1. Have you ever worked or collaborated on any ecological restoration projects? If so, who did you work and on which projects? What did that collaboration look like? What were the opportunities and constraints of that collaboration?

2. What areas or systems does your lab or program focus on? (e.g., forestry, agriculture, urban, coastal systems).

3. Are the majority of your research directives with or for those working in various industries or the government? Depending on their reply, follow up with "Which industries?" Or "How does it support the government? Which level of government?"

4. Who is funding research on ecological restoration research and adjacent directives like native plant conservation, soil remediation, urban biodiversity, environmental justice, etc.?

5. Depending on their reply, follow up with "What are the donors main funding priorities? (e.g., climate change adaptation, conservation, public health, soil health)

Nonprofit Organizations

1. Have you ever worked or collaborated on any ecological restoration projects? If so, who did you work and on which projects? What did that collaboration look like? What were the opportunities and constraints of that collaboration?

Watershed Association/Coalitions

1. How much does water quality, water supply, or water-related disaster risk issues influence your decision making around ecological restoration activities?

2. When you work on ecological restoration activities do you collaborate with any external consultants, agencies, or organizations? If so, on which activities? And what do those collaborations look like? What are the opportunities and constraints of those collaborations?

3. How do you determine the assemblage of species that you will reintroduce to a restoration site? Is your selection of species based off of looking at a reference ecosystem? Or are there any standards and guidelines or lists that you try to follow?

4. Where do source the majority of your native plant material from? Do you ever have to source plant material out of state? If so, which states do you source from?

5. What are the key drivers that influence your decision making around provenance and where plant material is sourced from? (e.g., climate proofing, regulation, cost, availability?)

6. Do the nurseries provide any information on the plant material's provenance? Are you able to specify when you place an order that you want plant material with local ecotypes?

7. Are you able to procure every species that you need and in the appropriate quantities?

8. If you need plant material of a certain species that isn't available in a nursery, where would you find that material? Would you collect seed yourself?

9. Have you ever worked with nurseries to contract grow plant material for certain projects?

Appendix D: List of actors by subgroups

NAME	TYPE	SUBGROUP
Massachusetts Department of Agricultural Resources (MDAR)	State Government Agency	1
Massachusetts Department of Conservation and Recreation	State Government Agency	1
Massachusetts Division of Conservation	State Government Agency	1
Amherst Nurseries in Amherst, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	1
Andrew's Greenhouse in Amherst, MA (Garden Center and Plant Nursery)	Plant Nursery - Wholesale	1
TripleBrook Farms in Southampton, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale	1
Conway School of Landscape Architecture	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	1
City of Northampton Planning	Federal Government Agency	1
Northeastern University (Department of Marine and Environmental Sciences)	Academic Institution	2
University of Massachusetts Boston (Department of Ecology and Conservation)	Academic Institution	2
Army Corps of Engineers (New England District)	Local Government Agency	2
Massachusetts Office of Coastal Zone Management (CZM)	State Government Agency	2
Massachusetts Department of Environmental Protection	State Government Agency	2
Massachusetts Department of Fish and Game [or Division of Fisheries and Wildlife?]	State Government Agency	2
Massachusetts Department of Public Health	State Government Agency	2

Massachusetts Bays National Estuary Program (MassBays)	State Government Agency	2
Massachusetts Environmental Trust (MET)	State Government Agency	2
Massachusetts Natural Resource Damages Program (NRD)	State Government Agency	2
Massachusetts Water Resources Authority (MWRA)	State Government Agency	2
Massachusetts Wetland and Waterways Program	State Government Agency	2
Massachusetts Division of Ecological Restoration	Regional Government Agency	2
National Oceanic and Atmospheric Administration (NOAA) Restoration Center	Federal Government Agency	2
Massachusetts Watershed Coalition	Watershed Association/Coalition	2
Nashua River Watershed Association	Watershed Association/Coalition	2
Neponset River Watershed Association	Academic Institution	2
GZA GeoEnvironmental	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	2
Salem Sound Coast Watch	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	2
Boston University (Department of Earth & Environment)	Academic Institution	3
Harvard University (Graduate School of Design)	Academic Institution	3
University of Massachusetts Boston (Sustainable Solutions Lab)	Academic Institution	3
Boston Planning and Development Agency	Local Government Agency	3
City of Boston (Office of Environment, Energy and Open Space)	Local Government Agency	3
City of Boston Water and Sewer Commission	Local Government Agency	3

City of Boston (Boston Parks and Recreation)	Local Government Agency	3
City of Boston (Department of Environmental Protection)	Local Government Agency	3
City of Boston (Department of Neighborhood Development)	Local Government Agency	3
City of Boston (Public Health Commission)	State Government Agency	3
Metropolitan Area Planning Council	Federal Government Agency	3
Sasaki Design Firm	Private- For Profit Consulting, Design, and Build Firm	3
Stross Landscape Urbanism	Private- For Profit Consulting, Design, and Build Firm	3
Urban Canopy Works	Private- For Profit Consulting, Design, and Build Firm	3
Agency Landscape + Planning	Herbarium/Arboretum/Botanic Garden	3
Applied Economics Clinic	Nonprofit Organization- Climate, Energy, and Economics	3
Barr Foundation	Nonprofit Organization- Environmental Justice	3
Mothers Out Front	Nonprofit Organization- Urban Green Space Management	3
Emerald Necklace Conservancy	Nonprofit Organization- Soil and Regenerative Agriculture	3
Boston Food Forest Coalition	Nonprofit Organization- Urban Green Space Management	3
Fenway Garden Society (FGS)	Nonprofit Organization- Urban Green Space Management	3
Franklin Park Coalition	Nonprofit Organization- Urban Green Space Management	3
Green Roots, Inc	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	3
Sierra Club Massachusetts Chapter	Nonprofit Organization- Soil and Regenerative Agriculture	3
Charles River Watershed Association	Watershed Association/Coalition	3

Mystic River Watershed Association	Watershed Association/Coalition	3
BioDiversity for a Livable Climate	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	3
USDA National Resources Conservation Services (National Offices?)	Federal Government Agency	4
Applied Ecological Services	Private- For Profit Consulting, Design, and Build Firm	4
BSC Group	Private- For Profit Consulting, Design, and Build Firm	4
EcoTec Inc	Private- For Profit Consulting, Design, and Build Firm	4
Inter.fluve	Private- For Profit Consulting, Design, and Build Firm	4
Stephen Stimson Associates Landscape Architects, Inc	Private- For Profit Consulting, Design, and Build Firm	4
SumCo Eco-Contracting, Inc.	Private- For Profit Consulting, Design, and Build Firm	4
Native Land Conservancy	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	4
Massachusetts Association of Conservation Commissions (MACC)	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	4
Soil And Water Conservation Society Southern New England Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	4
Colonial Seed in Windsor, CT (Seed & Plug Supplier)	Plant Nursery - Retail	4
Toadshade Wildflower Farm in Frenchtown, NJ (Seed & Plug Supplier)	Plant Nursery - Retail	4
Ernst Conservation Seeds in Meadville, PA (Seed & Plug Supplier)	Plant Nursery - Wholesale	4
Pineland Nursery in Columbus, NJ (Wholesale Plant Nursery)	Plant Nursery - Wholesale	4

New England Wetland Plants Inc. in Hadley, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	4
Pierson Nurseries in Dayton, ME (Wholesale Plant Nursery)	Plant Nursery - Wholesale	4
USDA National Resources Conservation Services (Cape May Plant Materials Center)	Nonprofit Organization- Herbarium/Arboretum/Botanic Garden	4
MIT (Media Lab) (Living Observatory, Inc.)	Academic Institution	5
Tufts University (Department of Biology)	Academic Institution	5
Tufts University (Institute of the Environment)	Academic Institution	5
Tufts University (Institute for Food Nutrition and Innovation at the Friedman School)	Academic Institution	5
The Ecosystem Center Marine Biological Laboratory of Woods Hole	Regional Government Agency	5
The National Fish and Wildlife Foundation (NFWF)	Federal Government Agency	5
U.S. Fish and Wildlife Service	Private- For Profit Consulting, Design, and Build Firm	5
Mass Audubon	Nonprofit Organization- Climate, Energy, and Economics	5
New England Forestry Foundation	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	5
The Quabbin-to-Cardigan Partnership	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	5
Trustees of the Reservation	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	5
Wildlands and Woodlands-The Regional Conservation Partnership (RCP) Network	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	5
Harvard University (Department of Organismic and Evolutionary Biology)	Academic Institution	6

MIT (The Department of Earth, Atmospheric and Planetary Sciences)	Academic Institution	6
Harvard Forest	Academic Institution	6
Natural Heritage & Endangered Species Program	State Government Agency	6
Polatin Ecological Services, LLC and or Land Stewardship, Inc.	Private- For Profit Consulting, Design, and Build Firm	6
Wilkinson Ecological Design, Inc.	Private- For Profit Consulting, Design, and Build Firm	6
Environmental Consulting & Restoration	Private- For Profit Consulting, Design, and Build Firm	6
Arnold Arboretum of Harvard University	Herbarium/Arboretum/Botanic Garden	6
Harvard University Herbaria & Libraries	Herbarium/Arboretum/Botanic Garden	6
University of Massachusetts Herbarium	Herbarium/Arboretum/Botanic Garden	6
The Botanic Garden of Smith College	Herbarium/Arboretum/Botanic Garden	6
Garden in the Woods (of the Native Plant Trust)	Herbarium/Arboretum/Botanic Garden	6
Indigenous Resources Collaborative (IRC)	Nonprofit Organization-Indigenous	6
Massachusetts Invasive Plant Advisory Group	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6
Massachusetts Land Trust Coalition	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6
Native Plant Trust (Previously New England Wild Flower)	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6
Norcross Wildlife Foundation	Nonprofit Organization- Soil and Regenerative Agriculture	6
Northeast Organic Farming Association Massachusetts Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6

Society for Ecological Restoration New England Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6
The Nature Conservancy MA Chapter	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	6
American Public Garden Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	6
Consortium of Northeastern Herbaria	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	6
New England Botanical Club (NEBC)	Plant Nursery - Wholesale	6
Hillside Nursery in Ashfield, MA (Specialty Plant Nursery)	Plant Nursery - Retail	6
Kohl Gardens in Wendall, MA (Specialty Plant Nursery)	Plant Nursery - Retail	6
Native Plant Trust's Nasami Farm (Retail and Specialty Plant Nursery)	Plant Nursery - Wholesale	6
Wanczyk Evergreen Nursery in Hadley, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale	6
Planter's Choice in Newtown and Watertown, CT (Wholesale Plant Nursery)	Plant Nursery - Wholesale	6
Rhody Native in Kingston, RI Now Rhode Island Natural History Survey (Wholesale Plant Nursery)	Plant Nursery - Wholesale	6
Broad Brook Coalition	Private- For Profit Consulting, Design, and Build Firm	6
Mill River Greenway Initiative	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	6
EcoTypic Seed Project of NOFA CT	Local Government Agency	6
		6
University of Massachusetts (Landscape, Nursery & Urban Forestry Program)	Academic Institution	7

University of Massachusetts (Amherst Soil Testing Lab)	Academic Institution	7
Restoring Roots Cooperative	Private- For Profit Consulting, Design, and Build Firm	7
Essex Horticulture	Private- For Profit Consulting, Design, and Build Firm	7
Harrison McPhee	Private- For Profit Consulting, Design, and Build Firm	7
Lucas Environmental LLC	Private- For Profit Consulting, Design, and Build Firm	7
Parterre Ecological	Private- For Profit Consulting, Design, and Build Firm	7
Crawford Land Management	Private- For Profit Consulting, Design, and Build Firm	7
Wellesley College Botanic Gardens	Herbarium/Arboretum/Botanic Garden	7
Berkshire Botanical Garden	Herbarium/Arboretum/Botanic Garden	7
Mount Auburn Cemetery	Herbarium/Arboretum/Botanic Garden	7
Tower Hill Botanic Garden	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
Boston Society of Landscape Architects on behalf of Toby from Wolf Landscape Architecture	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
Massachusetts Arborists Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
Massachusetts Association of Landscape Professionals	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
Massachusetts Nursery and Landscape Association	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
New England Nursery Association	Nonprofit Organization-Indigenous	7

Friends of the Public Garden	Nonprofit Organization- Environmental Justice	7
Grow Native Massachusetts	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	7
Wild Ones Native Plants, Natural Landscapes Mass Chapter	Nonprofit Organization- Landscape Protection, Conservation, and Restoration	7
Massachusetts Horticultural Society	Nonprofit Association-Landscape Architecture/Horticulture/Arboriculture	7
Select Horticulture Premium Plant Material in Lancaster, MA (Plant Nursery)	Plant Nursery - Retail	7
City Natives in Mattapan, MA (Retail Plant Nursery)	Plant Nursery - Retail	7
Earth Tones Native Plants in Woodbury, CT (Specialty Plant Nursery)	Plant Nursery - Retail	7
Northeast Pollinator Plants in Fairfax, VT (Northeast Pollinator Plants)	Plant Nursery - Retail	7
Prairie Moon Nursery in Winona, MN (Seed & Plug Supplier)	Plant Nursery - Retail	7
Charbrook Nursery in Princeton, MA (Specialty Plant Nursery)	Plant Nursery - Wholesale	7
Dale Tree Movers and Tree Farm in Cape Cod, MA (Tree farm)	Plant Nursery - Wholesale	7
New England Nurseries in Bedford, MA (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
North Creek Nursery in Landenberg, PA (Seed & Plug Supplier)	Plant Nursery - Wholesale	7
Weston Nurseries Inc in Hopkinton, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Whalen Nursery Inc. in Great Barrington, MA. (Retail and Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Allandale Farm in Brookline, MA (Retail Garden Center)	Plant Nursery - Wholesale	7

Bigelow Nurseries in Northbrook, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Cavicchio Nurseries in Sudbury, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Helia Native Nursery in Stockbridge, MA (Specialty Plant Nursery)	Plant Nursery - Wholesale	7
Site One Landscape Supply in West Springfield, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Spillane's Nursery in Middleboro, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Sudbury Nurseries West, LLC. In Gill, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Sylvan Nursery Inc in Westport, MA (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
New Moon Nursery in Woodstown, NJ (Wholesale Plant Nursery)	Plant Nursery - Wholesale	7
Van Berkum Nursery in Deerfield, NH (Wholesale Plant Nursery)	Watershed Association/Coalition	7
Mary May Binney Wakefield Arboretum	Nonprofit-Herbarium/Arboretum/Botanic Garden	7