



Inventory of Nature-Based Solutions for Climate Change in Massachusetts

Index

1. Introduction
 - 1.1 Nature-Based Solutions
 - 1.2 Threats to Massachusetts
2. Catalog
 - 2.1. Sustainable Forestry
 - 2.2. Sustainable Agriculture
 - 2.3. Aquatic Environments
 - 2.4. Urban Spaces
3. Global Nature-Based Solutions
4. References

1

Introduction

Contents

1.1 Nature-based Solutions

1.2 Threats to Massachusetts

1.1 Nature-Based Solutions

Nature-based solutions (NbS) are actions addressing key societal challenges through the protection, sustainable management, and restoration of both natural and modified ecosystems, benefiting both biodiversity and human wellbeing (IUCN, 2020). These challenges include things such as food security, climate change, water security, human health, disaster risk, social and economic development. This definition is quite broad and covers a wide range of ecosystem approaches that can be further categorized into various types of infrastructure. On one side of the spectrum is natural infrastructure, which focuses on the restoration and conservation of primarily natural ecosystems. On the other side is engineered infrastructure, which focuses on primarily engineered ecosystem approaches such as permeable pavement. In between the two are semi-cultivated and cultivated infrastructure, with the former being closer to natural infrastructure than the latter. Semi-cultivated infrastructure includes projects such as living shorelines and constructed wetlands, while cultivated infrastructure includes things like bioswales and rooftop gardens. Regardless of distinction, all nature-based solutions currently have significant, but underutilized potential to help address our planet's dual climate and biodiversity crisis. The following nature-based solutions have already been implemented in Massachusetts, and Seaside encourages the implementation of additional projects in the state.

1.2 Threats to Massachusetts

The state of Massachusetts is an important coastal state on the Eastern Seaboard and has a variety of both aquatic and terrestrial ecosystems that are affected by climate change. One major consequence that Massachusetts experiences is heightened storm risks. With the ice caps melting due to increased temperatures, there is more water in circulation in the oceans. These increased global temperatures also result in faster evaporation rates that cause precipitation to occur more frequently and at a greater extent. All storms— blizzards, hurricanes, even the average thunderstorm— will be intensified. Massachusetts and other northeastern states are expected to see intense blizzards with high levels of snow and more destructive hurricanes. These intense thunderstorms, in combination with sea level rise, will also lead to inland and coastal flooding, which will affect many of the state's ports and coastal developments. The loss of wetlands, already exacerbated from human development, is also expected to increase. This removes an important line of defense against coastal flooding. Finally, faster evaporation rates will also affect drinking water in towns that rely on local wells and groundwater due to a slower rate of water table recharge.

In addition, Massachusetts will face extremes of temperature, both hot and cold, in response to climate change. Urban areas will be especially affected due to the urban heat island effect which occurs when natural land cover is replaced with dense concentrations of pavement, buildings, and other surfaces that absorb and retain heat (EPA). Rising temperatures in the state will have a number of negative impacts: increased populations of pests like black legged ticks, increased exposure to allergens due to a longer growing season, intensification of air pollutants such as ground level

ozone, a potential decrease in viable crops, reduced milk and product yields from heat stress on livestock, oxygen depletion in lakes and ponds, changes in traditional fisheries, an increase in drought risk during the warmer months, and many more unforeseen events.

Consequently, adopting nature-based solutions for the various ecosystems found within the state would be immensely beneficial in combating these threats. There are already many in place in the state, ranging from urban to rural to coastal areas. Many of these solutions focus on sequestering carbon and increasing biodiversity. Carbon capture is effective in reducing and hopefully reversing the effects of climate change because increased atmospheric carbon is the leading cause of global rising temperatures. Nature-based solutions in the form of constructed wetlands and sustainable forestry or agriculture are great solutions to carbon sequestration, as well as reducing energy needs in urban spaces. Flood risk mitigation is also found in many nature based solutions described below and is significant for combating climate threats in Massachusetts as about 26% of the state is at risk of being affected by flooding in the next 30 years (MA Flood Factor n.d.)

2

Catalog

Contents

- 2.1 Sustainable Forestry
- 2.2 Sustainable Agriculture
- 2.3 Aquatic Environments
- 2.4 Urban Spaces

2.1 Sustainable Forestry

Forests make up 62-64% of land cover, or about 3.1 million acres, in Massachusetts, making sustainable forestry incredibly important to the state (UMass Amherst 2022). The primary forest types that constitute Massachusetts include Northern Hardwoods; Oak and Hickory; White and Red Pines; Oak and Pine; Elm, Ash, and Maple; and a few others and are found all throughout the state but are concentrated in the western region. The eastern region of the state is more developed and has many major cities and ports, which accounts for the fact that forest cover is not as concentrated there. These forests are filled with various wildlife ranging from deer and the occasional moose to beavers, otters, hares, foxes, raccoons, and chipmunks to wild turkeys and pheasants. Additionally, forests along the coasts are an important habitat for wildlife like herons, gulls, kingfishers, and warblers (Encyclopedia Britannica 2022).

In response to a history of potentially unsustainable forestry practices, policies and plans have been implemented throughout all levels of government in Massachusetts in order to facilitate more environmentally friendly practices. Forest stewardships programs and other nature based solutions are being encouraged and some even financially incentivized.

One very resourceful and effective solution to mitigate effects of climate change like temperature increase and flooding is the use of agroforestry. At UMass's Permaculture Garden in Amherst, agroforestry is employed in the form of shade layering. This creates multiple niches using the different amounts of sunlight available at different elevations in a single ecosystem. This is done by planting tree species that require different amounts of sunlight so that the shade created by the trees accommodates the species less dependent on sunlight (Delle 2014). This solution mitigates flooding by increasing soil diversity, which also results in increased absorption and retention of carbon from the atmosphere. Shade layering also provides food and shelter to a great variety of species since it creates many niches and allows for a diverse group of plants to thrive in one plot of land.

This solution also saves money and reduces greenhouse gas emissions because the food UMass produces is then used in their own dining hall and does not require further transportation. However, there are multiple things that need to be considered with agroforestry. It is critical that non-native species are not used in agroforestry, because they could disrupt the natural environment and outcompete native species. Agroforestry also requires land use, therefore, location as well as land clearing or conversion must also be considered. It is incredibly important that these projects are carefully planned in order to avoid any potential negative consequences.

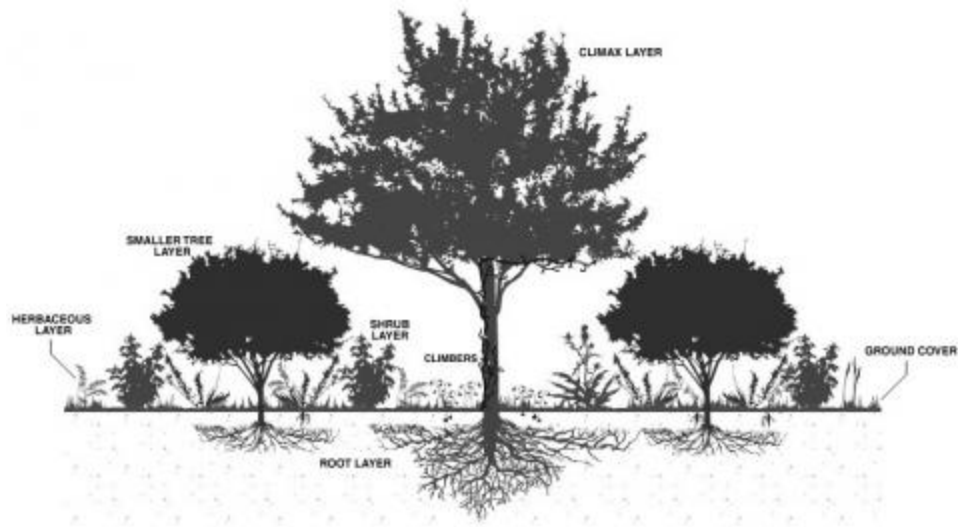


Image Source: <https://umassdining.com/blog/sustainability/agroforestry-umass-amherst>

Alley cropping is another nature-based solution that mitigates threats such as coastal flooding and rising temperatures. Alley cropping is a form of agroforestry where trees and occasionally shrubs are planted in rows between crops. These alleys provide numerous benefits to the crops and the land itself. This method is being tested at the Stockbridge Agricultural Learning Center in Massachusetts and it hopes to teach students a new approach to farming that could also benefit the climate (Stockbridge School of Agriculture 2022). This solution offers many benefits to its surrounding ecosystem: it reduces land degradation, improves biodiversity, reduces soil erosion, increases water filtration, adds organic carbon to soil, and improves crop health. Trees that are planted can protect against wind, insects, and extreme temperatures while also increasing pollination and creating habitats for various species at different niches. Trees can act as windbreaks in the case of extreme storms caused by climate change, they can act as a barrier against pests for other crops, and they can also mitigate the effects of flooding which can reduce land degradation and wetland loss near vulnerable coastal areas (AgriFarming 2020).

One drawback, however, is that alley cropping can be more labor intensive than a traditional farm and can make it difficult to use certain equipment, thereby creating an obstacle to crop cultivation. Thus, it is important to make design considerations with obstacles and conditions of the land in mind before implementing alley cropping.



Trees are an undeniably important factor in combating climate change and nature-based solutions like the Forest Stewardship Plan can play a big role in mitigating its effects. This project, overseen by the Massachusetts Woodlands Institute, focuses on the education and development of forest management plans for individual landowners. The basic function is to help landowners create management plans to achieve a specific goal they may have for the land such as environmental consciousness, outdoor recreation, working woodlands, or wildlife stewardship. Land owners can connect with the private lands Service Forester District Map, fill out a Forester Stewardship Cost Share Application, and then work with a private consulting forester to choose a goal (Commonwealth, 2022).

Depending on the goal the landowner is trying to achieve, the benefits to the surrounding ecosystem can vary. The environmentally conscious goal is beneficial because it increases forest resiliency, minimizes damage from forest pests, protects water quality, sequesters and stores carbon to mitigate climate change, and suppresses or eradicates invasive plants. These goals can be met by planting trees along waterways to protect water quality or planting mixed species stands. The Wildlife stewardship goal is beneficial because it enhances both terrestrial and aquatic habitats for wildlife and promotes diversity of plant species. Finally, the working woodlands goal is beneficial because it enhances the quality and quantity of forest products and practices agroforestry, which helps mitigate various effects of climate change (Commonwealth, 2022).

Economically, some forest management plants can help lower property taxes, thereby acting as an incentive for landowners to take part in the program. One such example is that of Jan Storm and Bill Millington in Cummington, Massachusetts who wanted to maintain their forest's health and live a "close to net zero" lifestyle. They are pictured here below.



Image Source: <https://www.mass.gov/doc/caring-for-your-woods-setting-goals/download>

Massachusetts is vulnerable to coastal and inland flooding, heat waves, and extreme storm events, however, a riparian forest buffer is a promising nature-based solution to combat these events. It is a form of agroforestry that is usually located near a stream or river, and they have already been implemented across the United States, including in the state of Massachusetts at the Merrimack River Watershed. Its basic function is to mitigate the effects of land use on a neighboring body of water, but it has additional benefits as well. Before implementation, a specialized design plan must be created based on the specific goals and conditions of the land. The area closest to the body of water should be developed with native shrubs and trees to stabilize the bank and prevent erosion. The function of this first zone is to shade the stream and moderate water temperatures, filter material that moves through the buffer, and reduce the velocity of flood water. Further out from the body of water, fast growing trees and shrubs that are resistant to periodic flooding should be planted. Other species can also be grown in this area to increase sources of profit. The function of this second zone is to provide infiltration and store and breakdown nonpoint source pollutants. Finally, the farthest zone from the body of water should be developed with crops and grazing lands where native grasses and forbs will also be permitted to grow. The function of this last zone is to filter sediments and uptake nutrients and chemicals (University of Missouri Center for Agroforestry 2005).

This form of agroforestry benefits the surrounding ecosystem by protecting water quality, improving aquatic habitat, reducing runoff, and providing a diverse source of food and shelter for an equally diverse number of species. In addition, the trees grown by the bank of the water help create a buffer against flooding and other climate change related changes in weather conditions like previously mentioned intensification of storms. Simultaneously, riparian forest buffers also have many economic benefits to encourage its implementation. For example, the three zones can all offer different economic opportunities and bring profit at different times of the year depending on the growing seasons of the diverse vegetation planted. It should be known, however, that maintaining this buffer can be very intense and hard to implement in heavily developed areas. Before implementing a buffer, landowners need to assess the stream bed and bank, consider what kind of vegetation naturally grows near the bank, and the width that their buffer will need to be.



Image Source: https://www.chesapeakebay.net/news/blog/forest_buffer_plantings_make_progress_fall_short_of_annual_target

Monoculture farms and intensive livestock farming are two major causes of greenhouse gas emissions. Therefore, nature-based solutions in the form of agroforestry like silvopastoralism are good ways to combat climate change and decrease GHG emissions when compared to traditional monoculture farms. One example of this silvopasture technique is found in Sunderland, Massachusetts along the Connecticut River at Jono Neiger's Farm (Hanes 2019). It operates by having trees, grasses, ground cover plants, weeds, and chickens all occupying the same plot of land. This benefits the surrounding ecosystem because the diverse plant life increases soil health and productivity which helps increase absorption of carbon from the atmosphere. In addition, this type of farming does not require nitrogen fertilizers to help grass which decreases the amount of chemicals in the soil. Moreover, this technique of farming allows for healthier soil than a monoculture farm, which means the soil can support more plant life that can subsequently store more carbon from the atmosphere. Less livestock also leads to a decrease in greenhouse gas emissions.

Silvopastoralism entails less intensive livestock farming which also leads to a decrease in GHG emissions and requires little to no land conversion to support grazing practices. On top of that, the farm rotates livestock through different enclosures which allows the soil to maintain its nutrients and health and absorb atmospheric carbon. This type of farm is thus more humane in terms of raising livestock and more organic because fertilizers are not used or used very minimally. Just as importantly, this nature-based solution allows farmers to create cooler microclimates by employing the trees and other vegetation. This reduces the heat stress put on animals that can affect milk yields and can also prevent wildfires caused by rising temperatures. Some local and state governments have been setting up financial incentives for farmers who choose to implement climate friendly farming practices such as silvopasture.



Image Source: <https://www.csmonitor.com/Environment/2019/1114/From-chickens-to-chestnuts-Where-farmers-work-the-old-fashioned-way>

2.2 Sustainable Agriculture

Small and family oriented farm culture is prevalent in Massachusetts agriculture, containing 7,241 farms on 491,653 acres. The state's agriculture industry employs about 26,000 people and produces an annual market value of over \$475 million in agricultural goods. Massachusetts ranks 5th in the nation for direct market sales with over \$100 million, and ranks 3^d in the nation for direct market sales per farm at \$55,384. Massachusetts' most valuable crops include greenhouse and nursery commodities, cranberries, sweet corn, and apples.

Nature-based solutions are being implemented state-wide to encourage sustainable agriculture. New England Biochar, a company located in Eastham, Massachusetts, repurposes local biomass as charcoal, also known as "biochar." The founder originally created it to supercharge the weak and sandy soil of his little organic farm on Cape Cod, and now it is now available for purchase for farms in the surrounding areas. Biochar is produced through the process of pyrolysis, which is the heating of biomass without oxygen. For the purpose of agriculture, its basic function is to improve soil fertility, increase nutrients, reduce irrigation, increase crop yield, and reduce tillage (Agricultural Resources Facts and Statistics). Biochar greatly benefits its surrounding ecosystem by its lightweight and porous nature, which serves as a habitat for many beneficial soil microorganisms that are known to promote soil and plant health. Biochar also sequesters about 50% of source carbon, and the production of biochar through pyrolysis actually creates a renewable energy source that can be distributed through local power plants and used in rural areas where energy is a limited resource (New England Biochar).

Utilizing this resource increases soil resilience and minimizes or diminishes the need for tilling which aids in storing both carbon and water. Water is not stored in dry, brittle soil, so enhancing it through healthy soils heavily reduces the use of irrigation. For farms to adapt to climate change, it is vital that the soil is of high quality to continue producing high crop yields and minimizing the use of water as droughts become more frequent.



[Carrots grown without Biochar]



[Carrots grown with Biochar]

Image Source: <https://newenglandbiochar.com/gallery>

Enhancing soil resilience through the natural increase of fertility and nutrients produces more nutrient dense foods and higher crop yields which generates revenue for the farmer. In comparison, artificially produced high crop yields from fertilizers and pesticides produces food that is low in nutrients and increases the risk of consuming hazardous chemicals. Therefore, by opting for naturally derived yields, the crops will be more nutritionally dense without any additional chemicals. There is a risk that using biochar in the soil can lead to an excess absorption of water and nutrients, which can cause crop yields to decline. However, it is unlikely and the use of biochar in soil is still considered to be an effective nature-based solution for climate change.



Image source: <https://newenglandbiochar.com/gallery/>

Black Earth Compost, located in eastern Massachusetts and Rhode Island, collects food scraps and processes them into nutrient rich compost. By returning the compost back into the growth cycle of local gardens and farms, the company has created a circular system of zero waste. To increase their sustainability, they have created a system to purchase their compost April-May in order to plot a resource and energy efficient course through each neighborhood to drop off the compost (Black Earth Compost).

The compost encourages water retention which helps to reduce erosion and runoff as well as establish vegetation. It also improves downstream water quality by retaining pollutants such as herbicides and pesticides, and the nutrient-rich soil created by compost provides a healthy habitat for microorganisms. Composting food scraps prevents wasted food from going into the landfill where it will eventually release methane into the atmosphere. Going from this traditional linear system to a circular system is key to adapting to climate change. Additionally, compost aids in producing nutrient-dense foods that are filled with vitamins and minerals essential for a healthy life. Through their community-oriented service, Black Earth Compost is increasing access to healthier foods which is incredibly beneficial to the health of local residents.

Composting is an effective nature-based solution as it is essential in minimizing food waste that would otherwise end up in the landfills and release huge amounts of methane. It is also important because it provides multiple environmental benefits while also promoting a healthy lifestyle for the community.



Image Source: <https://www.facebook.com/blackearthcompost>

Cover crops are close-growing crops that provide soil and seeding protection and improve soil quality between seasons. They improve structure and also provide insulation to the soil, allowing it to stay cool in summer and warm in winter (Dyer, 2021). Cover crops also provide an organic way of reducing diseases and pests in the soil, thus reducing the use of pesticides, and can be used as food for grazing livestock. Additionally, they reduce tilling and provide a habitat for wildlife such as insects and pollinators. Alprilla Farm, located in Essex, Massachusetts, utilizes cover crops on their farm to reduce tillage, increase microbiomes, and sequester carbon dioxide from the atmosphere (Alprilla Farm).

Cover crops help to mitigate climate change through the ability to capture and filter carbon dioxide from the atmosphere. Traditionally, soil is tilled which makes the land unable to filter carbon dioxide. With the absence of plants during tilling season, carbon dioxide levels are at their highest until the planted crops begin to grow and the levels begin to decrease again. However, with cover crops, tilling is reduced which increases carbon sequestration throughout the year.

Similarly to compost, cover crops increase soil fertility and nutrients which increases crop yields. This makes it an economically beneficial solution for the farmer, and it is beneficial to human health since it increases the nutrient density in food.

There are few potential issues of utilizing cover crops for farming which include the additional costs created through the planting and killing of cover crops, increased disease and pest risk. These crops are also typically planted when time and labor is most limited. However, when implemented, cover crops are both economically and environmentally advantageous, making it an effective nature-based solution.



Image Source: facebook.com/Aprilla-Farm

Cover crops can also be used to produce green manure. Green manure is created when the cover crops are plowed into the soil, and it reduces the need for animal manure or manmade chemicals. Intervale Community Farm located in Burlington, Vermont, has utilized this method to increase soil fertility and ecosystem resilience as they begin to adapt to periodic flooding (Intervale Community Farm).

Green manure improves the growth environment of cover crops and promotes sustainable high-yield crops by increasing soil quality, balancing soil nutrients and enhancing soil water storage capacity. It provides a habitat for organisms like frogs and beetles that are natural predators of pests. Green manure also supports earthworms and other beneficial microbes and soil organisms.

The use of cover crops helps to mitigate climate change by enhancing the amount of carbon sequestration from the plants, and the green manure increases soil resilience that will help to withstand floods and act as irrigation control. Together, they create a healthier, more nutritious soil that can yield organic food for the consumer, while also increasing the resilience of crops and providing a higher yield and revenue for the farmer. Green manure and cover crops carry the risk of using the majority of water resources, rather than conserving it, if moisture is limited from the beginning (Intervale Community Farm). Therefore, they must be carefully implemented in areas with sufficient water supplies. When done properly, green manure and cover crops aid in sequestering carbon from the air as well as creating a more resilient, organic farm that can better adapt to changes in the climate while also supporting economic and social sustainability.



Image source: facebook.com/intervalecommunityfarm

Fenway Farms, located in Boston, Massachusetts, sits above third base at Fenway Park and covers 5,000 square feet. Previously an underutilized black rubber membrane roof, the space has been converted into a much more productive rooftop farm with an estimated 6,000 lbs of produce harvested annually (Fenway Farms). This is a massive improvement, as cities are often lacking in green spaces and abundant in concrete. The conversion of an empty, hot roof into an urban farm reduces surface and air temperature, and it improves air and water quality since the plants act as a filter, greatly benefiting its surrounding ecosystem (Fenway Farms).

The farm has improved air and water quality for the neighborhood, conserved energy for the Red Sox front offices, and provided 4,000 lbs. of organic produce each year for hungry fans at the EMC Club and in the ballpark (Fenway Farms). The leftover produce is donated to the community group Lovin' Spoonfuls, creating a circular system and limiting waste. This urban farm is a very effective nature-based solution and is also such a great opportunity for people in the city to learn more about climate change and the importance of urban gardens.



Image source: greencitygrowers.com/fenway-farms/

Another amazing project located in Boston is run by the Boston Food Forest Coalition, a group of neighbors working to transform vacant lots into locally-run, public, edible parks protected by their land trust (Boston Food Forest). This network of parks protects local green space and prioritizes neighborhoods where there is inequitable access to parkland and its critical benefits. Each park holds a diverse arrangement of plants that attempts to mimic the ecosystems and patterns found in nature and are inspired by permaculture (Boston Food Forest). The food forest benefits the surrounding ecosystem by growing perennials which act as a habitat for pollinators and other organisms, increases plant diversity and density, and promotes an urban tree canopy (Boston Food Forest). Additionally, the increase of vegetation aids in carbon sequestration and increases biodiversity, both of which are essential in mitigating climate change. Due to the urban setting of these farms, it is important for such projects to monitor both the soil and water to ensure there is no risk of contamination in the produced food.

The Boston Food Forest is an effective solution for climate change. Although it does not have a dramatic impact through carbon sequestration or cause a large decrease in industrial agricultural production, it does reduce urban hotspots and connects people in urban areas to where their food comes from, hopefully creating more conscious consumers. Finally, it provides an important green space in a metropolitan environment which is not only beneficial to the wildlife in Boston, but also to the people living there as well.

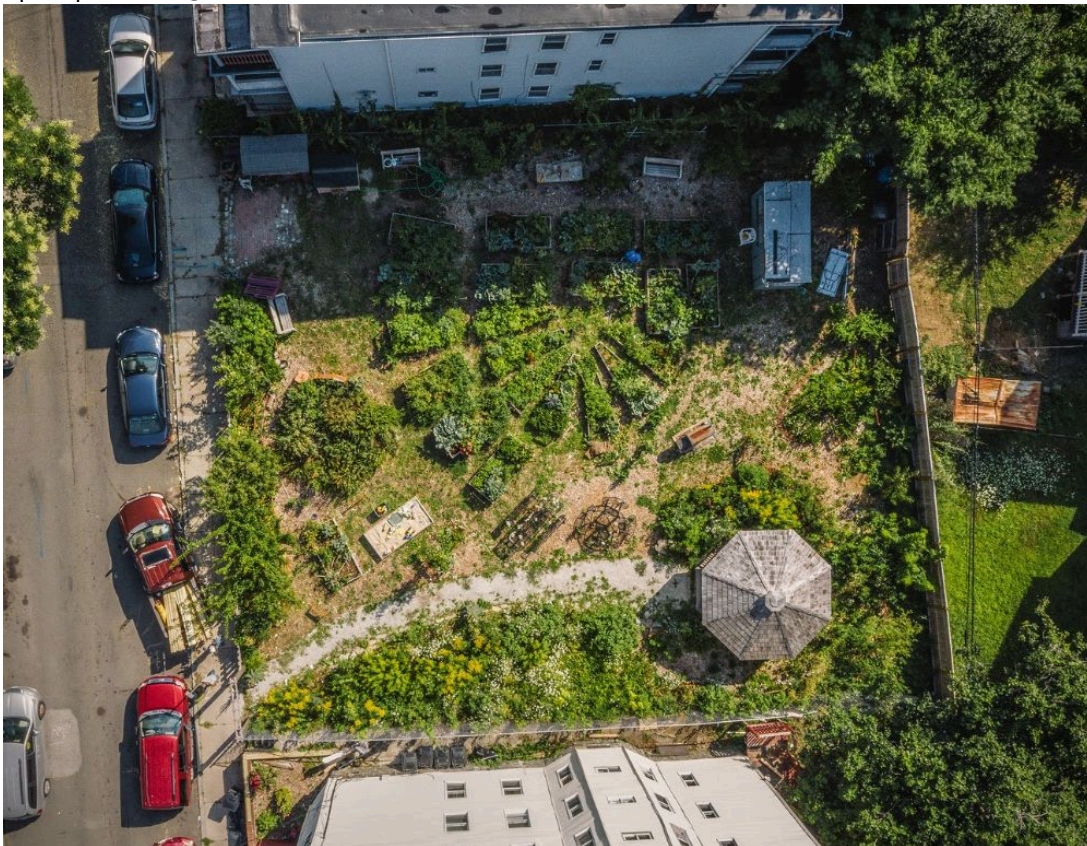


Image source: facebook.com/bostonfoodforest

Another important type of garden is a pollinator garden. The Mary Prentiss Inn located in Cambridge, Massachusetts, has planted a large pollinator garden on the property that guests get to enjoy. The garden is layered with an array of nectar-rich perennials and annuals that bloom spring through fall, thus creating a habitat for many important pollinators like bees by supplying food in the form of pollen and nectar. It has become a mecca for neighborhood pollinators and seed-seeking songbirds in an otherwise urban area, which are often lacking in native pollinating plants. This pushes out the organisms who feed off them, so planting a garden of this size in the city helps to maintain the natural biodiversity. The changing climate also impacts pollinators by shifting the seasons, which weakens the plant populations that pollinators depend on. Implementing more of these gardens helps to create more environments for these pollinators who are naturally losing their habitats. Pollinators are incredibly important to the environment and also agriculture, as they help flowering plants such as flowers, fruits, and even crops reproduce. Also, having diverse plant life helps to filter out carbon dioxide and lower air temperatures.

From a social standpoint, pollinator gardens are pleasant to look at, therefore beautifying any property and increasing its worth. From an economic standpoint, pollinator products like honey are vital for food supplies and also have medicinal properties. Without bees and the honey they produce, the world could be a very different place. Similar to urban farms, singular pollinator gardens might not yield a significant carbon drawdown, but they do provide a vital ecosystem in an urban setting. There are often not enough green spaces in urban areas, so the intentional gardening of pollinating plants is important to keeping these species happy and thriving.



Image source: monarchbutterflyfilm.com/2017/08/05/cambridges-mary-prentiss-inn-urban-pollinator-garden/

In the largest freshwater ecological restoration ever attempted in the Northeast, Tidmarsh Farms has been converted into a wildlife sanctuary and wetland preserve. Located in Plymouth, Massachusetts, the land was originally farmed for cranberries, which involved regular sand applications onto the native peat. The sand layer was approximately 2 feet deep and interspersed with relatively impermeable layers of leaf drop, thereby separating the platform from the water table. The farming also used extensive pesticides and fertilizers (*Tidmarsh Farms*). All of these landscape manipulations resulted in a loss of wetlands and a loss in stream and wetland function. The restoration involved removing the dams and flow control structures, building a sinuous stream channel, placing more than 3000 pieces of large wood for habitat, roughening the bog surface for increased habitat complexity, replacing an undersized culvert, and building a wildlife-friendly bridge (*Tidmarsh Farms*).

Tidmarsh is now a mosaic of habitats including ponds, cold-water streams, red maple and Atlantic white cedar swamps, grasslands, and pine-oak forest (*Restoration at Tidmarsh*). Through microtopography, the rewilding of this ecosystem created a habitat for pollinators and insects, as well as the diversification of plants, increasing biodiversity. This was done using a “pit and mound” design which encouraged diversification of flora and fauna, and made the habitat more resilient to climate change. They have already seen native plants emerging and attracting a wide variety of insect, reptile, and bird species that have not previously been seen for many decades. The removal of the dams, water control structures, and sediment, as well as the culvert installation helped to reconnect the hydrology in the Beaver Dam Brook watershed. This helps to connect the headwaters of the brook with the ocean for migrating fish such as river herring, brook trout, and American eel (*Tidmarsh Farms Wetland Restoration*).

This is an effective nature-based solution for the restoration of old farms where the land is no longer useful for its original intended purpose. Restoring the land to its natural state builds resilience to climate change through biodiversity conservation and restoration. It also greatly benefits the surrounding community by creating cleaner water and supporting migrating fish, which is an important part of the food supply and economy in Massachusetts.



Image source: livingobservatory.org/properties-3

2.3 Aquatic Environments

Massachusetts contains a myriad of diverse aquatic ecosystems mainly due to its geographic location next to the Atlantic Ocean. These ecosystems include but are not limited to bays, sounds, lakes, estuaries, and rivers. Thanks to the diversity among these aquatic ecosystems, aquatic ecosystems as a whole in Massachusetts are very biodiverse and provide Massachusetts with a lot of ecosystem products and services, such as fish to eat. A famous aquatic ecosystem in Massachusetts is Cape Cod, which is famous for their seafood production as well as a great place to enjoy recreational activities such as boating. Fisheries are estimated to produce around \$600 million annually for Massachusetts according to the Division of Marine Fisheries in Massachusetts as well as provide food for millions of Massachusetts residents. However, more recently, the Division of Marine Fisheries in Massachusetts has reported that fisheries lost roughly \$255 million in annual revenue thanks to the pandemic which is concerning given the importance of fisheries to Massachusetts. As the pandemic conditions continue to lighten, the total revenue of fisheries as well as output is projected to increase to pre-pandemic levels.



Image Source: <https://geology.com/lakes-rivers-water/massachusetts.shtml>

One of the largest nature-based solutions in the state is the Great Marsh Project. The Great Marsh is the largest contiguous salt marsh in New England and borders five coastal towns: Gloucester, Essex, Ipswich, Newbury, and Rowley (*Great Marsh ACEC*). It is a diverse ecosystem of barrier beaches, dunes, and bodies of water and it provides many economic and ecological benefits. This project focuses on dune nourishment, native vegetation planting, salt marsh habitat restoration, and sediment transport modeling. It also aims to repair the remnants of ditching – an agricultural practice that disrupts the natural tidal flow and drainage of the marsh. It is essential to maintain the health of this ecosystem, because it is an incredibly important habitat for many types of animals including large migratory fish such as alewives and smelt and rare birds like the seaside sparrow and the least tern (*Great Marsh ACEC*). The area is used for fishing, shellfishing, tourism and recreation. It also provides critical protection for people and property by acting as a natural buffer to storms and sea level rise. Marsh environments also capture and store carbon from the atmosphere which helps combat climate change. The main drawback with these restoration projects is typically the cost, as it can be expensive and difficult to support long-term projects such as this one. However, this project specifically has received multiple grants including \$1 million from the North American Wetlands Conservation Act (*Trustees*), and the benefits of restoring ecosystems like the Great Marsh far outweigh the costs.



Image Source: <https://www.8tgm.org/>

The city of Gloucester is home to another restoration project: one that focused on restoring Little River from an old concrete fish ladder and lagoon system back into a natural river stream. The project involved day-lighting portions of buried waterway, restoring sensitive coastal wetlands, and replacing the old concrete ladder with a naturalized cobblestone and boulder-based stream bottom which creates pooled areas for the fish. They also planted significant amounts of salt marsh, riparian, and upland vegetation (Horgan, 2016).

Returning the river to its natural state increases the biodiversity and resiliency of the ecosystem by providing a habitat for wildlife such as alewife, smelt, and glass eels. Little River also contains important migratory fish as well as a spawning habitat for diadromous fish (Horgan, 2016). Therefore, increasing the health of Little River not only makes the stream, but also the surrounding ponds and the ocean healthier. This is beneficial to the fisheries which in turn support the economy and identity of Gloucester as a fishing community. Beyond fishing, this solution also addresses coastal flooding, erosion, and sea level impacts. Additionally, the river also provides important services such as clean drinking water and recreational opportunities.

The project was initially expected to cost about \$550,000 but actually came in under budget. It was funded through a variety of grants with the largest being the \$400,000 Coastal Resiliency Grant from the Coastal Zone Management (Horgan, 2016). One of the biggest challenges with restoration projects is that scientists are often unaware of how an ecosystem will recover. It is possible that the habitat will never return to its original function and quality. However, with Little River and many other restoration projects, they can and will make significant recoveries which are greatly beneficial to the environment and worth the cost.



Image from: www.gloucestercommunitydevelopment.wordpress.com

Lakes are an integral part of nature and serve a myriad of purposes. Lakes not only increase biodiversity by acting as a habitat for many organisms, but also provide other benefits such as storm and flood protection. Lake restoration is a process in which previously uninhabitable or extremely unhealthy lakes, usually due to eutrophication, are made habitable once more. Lakes are not only aesthetically pleasing, but they also have a lot of recreational value, such as swimming and fishing. Additionally, storm intensity is predicted to increase with climate change, which makes the storm protection very valuable.

One of the main issues plaguing lakes is eutrophication which occurs when there are high nitrogen and/or phosphorus levels in the lake, mainly due to agricultural runoff. This causes an extreme amount of vegetation to form at the surface of the lake such as an algal bloom. When the algae die, they are decomposed through aerobic respiration which leads to decreased oxygen levels in the lake. These oxygen minimum zones make it difficult for organisms to survive. Lake restoration is effective at combating eutrophication, however it is no simple task. According to Søndergaard et. al, many organisms have to be removed from the previously eutrophic lake in order to prevent eutrophication from recurring. This is due to the elevated nutrient levels within the tissues of said organisms. Once they die or are consumed by another organism, the nutrients will cycle back into the ecosystem. An example of a successful restoration is Fawn Lake, which is located in Massachusetts. Fawn Lake was suffering from eutrophication but it underwent lake restoration and now it is an extremely more healthy environment.

Overall, lake restoration is a very effective nature-based solution for both water management and adapting to climate change, however, not only does it require a lot of effort, but it also can be very pricey, especially if you are dealing with a larger lake such as one of the Great Lakes.

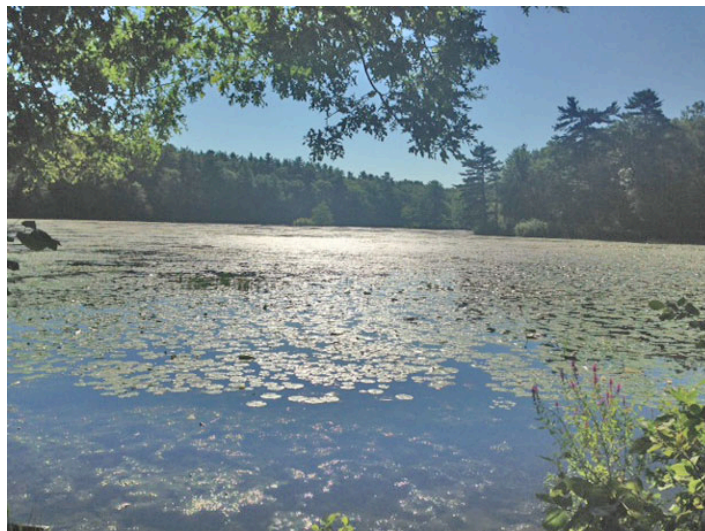


Image Source: <https://www.thebedfordcitizen.org/2018/06/fawn-lake-restoration-project-update/>

Rainwater Harvesting is quite a simplistic, yet effective way to conserve water and limit the amount of polluted runoff from reaching streams. Rainwater Harvesting is the process in which water from storms is collected from an impervious surface and stored for usage at a later date. A major advantage of this NBS is the fact that it can operate in more urban areas as the storage vessel is underground. Rainwater harvesting can be done in a myriad of ways, ranging from small to large scale. A common example is a roof with gutters that connects to a storage vessel that is later collected and treated for usage. A huge advantage of this NBS is how simplistic it is, meaning it can be implemented almost anywhere without the need of a professional to set it up for smaller scale environments. Additionally, rainwater harvesting is hypothesized to be a great tool in adapting to climate change (Pandey 2003).

The main downside of rainwater harvesting however is the need for regular maintenance, as the storage vessels will need to be emptied before the next storm in order to function properly. This isn't a major issue for smaller scale harvesting however it will require a decent amount of effort for larger scale harvesting. In addition to the environmental benefits caused from preventing a portion of storm runoff, rainwater harvesting can be used for municipal usage as well as educational purposes. Overall, this NBS is great in that it is simplistic, cheap, flexible, and effective for usage in a variety of settings.

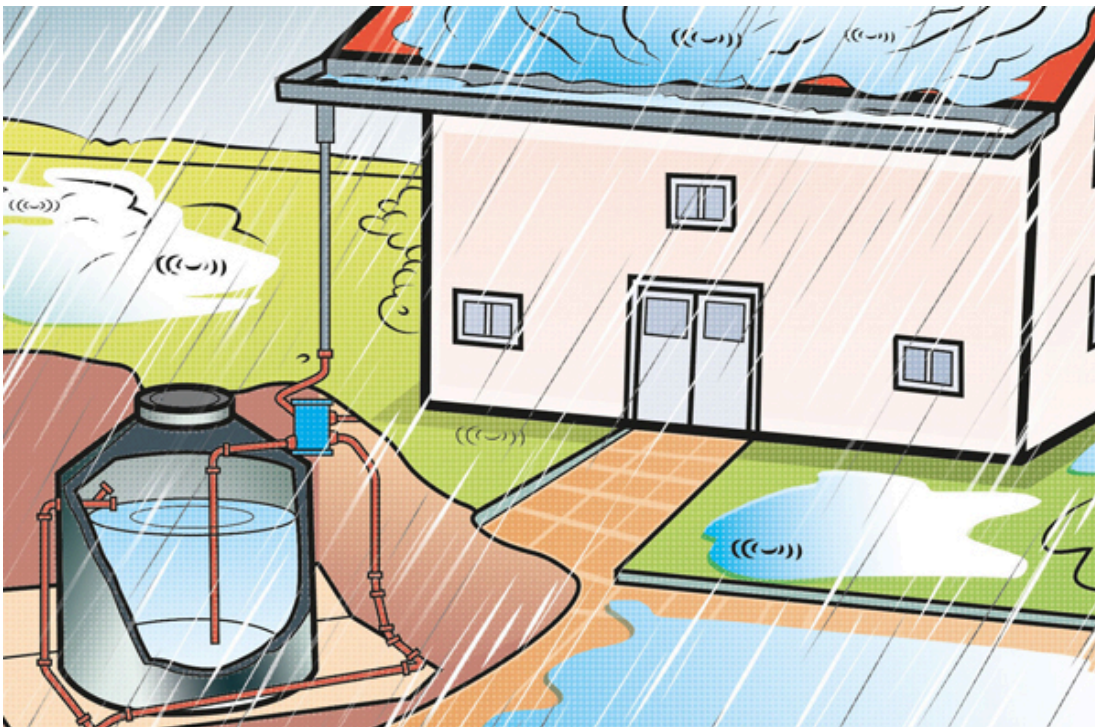


Image Source: <https://www.constrofacilitator.com/rainwater-harvesting-advantages-types-and-methods/>

Wetlands are one of the most crucial but also most sensitive ecosystems on the Earth. Wetlands provide many benefits, including but not limited to storm protection, carbon sequestration, and being a very biodiverse habitat. Constructed wetlands are made to mimic natural wetlands so that society can receive the same benefits that natural wetlands provide. An example of a constructed wetland is the one located next to Long Lake in Littleton, Massachusetts (see image below). Its primary purpose is to capture and filter stormwater before it reaches Long Lake. It operates by implementing wetland vegetation, soils, and other microbial processes to try and mimic an actual wetland. These biotic factors help improve water quality as well as reduce stormflow and the resulting damages.



Image Source: www.kleinfelder.com

Another example is Wellington Park along Mill Brook in Arlington, Massachusetts. The park has undergone a massive revitalization effort over the past several years. A multi-partner effort removed invasive plants and chain link fences and replaced them with a constructed wetland that absorbs flooding from Mill Brook and provides wildlife habitat. They also introduced a boardwalk, natural play area, accessible walkways, educational signage, and native plantings to the park (*Mill Brook and Wellington Park*, 2020). These improvements increase the ecological quality of the riparian edge, increase biodiversity, and provide an educational and recreational space for the community. Future plans include constructing a rain garden as well as hopefully extending the park into a longer linear corridor along the brook.

The main downside to this nature-based solution however is how expensive the upfront cost is. It is estimated that for one acre of constructed wetland, one would have to approximately pay as low as \$39,000 and as high as \$82,000 depending on the area

in which the constructed wetland is going to be located (CRWA). In addition to the upfront cost, regular maintenance is required in order to ensure the conditions of the constructed wetland are maintained. For the Mill Brook project, funding was provided by the Arlington Community Preservation Act (CPA), the Community Development Block Grant, Judy Record Foundation, and the Massachusetts Municipal Vulnerability Preparedness Program.

Overall, constructed wetlands are a superb way to not only limit stormwater, but also act as a great source of carbon sequestration and a habitat for many organisms. The main concern is the price, but if funding can be secured, the constructed wetland will prove to be very useful in providing the world with the aforementioned benefits.

Retention and detention ponds (also known as retention/detention basins) are great nature-based solutions when it comes to water management. These ponds are artificially made in order to provide both the environment as well as humanity with many benefits. Retention and detention ponds both manage stormwater runoff as well as increase biodiversity and provide temperature regulation to the surrounding area. Retention ponds use storm drains to divert stormwater runoff away from other bodies of water and into the retention pond. Retention ponds have a constant body of water while its counterpart, the detention pond, does not. Detention ponds use the landscape to divert stormwater runoff into an empty area to also prevent stormwater runoff from reaching other bodies of water. This is helpful because stormwater runoff is often heavily polluted and can cause phenomena such as eutrophication to occur thanks to the excess nutrients the runoff picks up.



Image Source: www.megamanual.geosyntec.com

While these nature-based solutions do provide society with many helpful benefits, they do have some downsides. Both types of ponds require large amounts of land in order to function properly, which can take away from already existing habitat. Detention ponds specifically can become a mosquito breeding ground thanks to the moist environment, which can cause property value to decrease. Retention ponds however tend to increase the surrounding property value, which makes this the more preferred option for those trying to implement a pond on their property. The downside however is that retention ponds are pricier upfront in comparison to detention ponds. Detention ponds do however sequester carbon, which is important when considering climate change.

Overall, retention and detention ponds are two distinct nature-based solutions despite being quite similar in nature that each have their advantages and disadvantages. Depending on the setting, one type of pond may be more preferable than the other while in a completely different setting the inverse may be true. Both do however provide an excellent job managing stormwater runoff which is the main threat to many aquatic environments.

While some cultivated nature-based solutions are very beneficial, like retention and detention basins, other solutions involve removing man made inventions that are no longer beneficial to their surrounding environments. An example of this is the removal of the River Street Dam in the city of Acton. The dam was originally built in the 1800s and provided hydropower for early industrialization. However, now, the dam is structurally unstable and poses a hazard to residents living downstream if the dam were to fail (Laidler, 2021). This is especially dangerous since extreme weather events and flooding are only expected to increase due to climate change. By getting rid of the dam, the goal is to restore the natural movement of fish, water, sediment, and nutrients to the downstream Fort Pond Brook which will increase the resiliency of that ecosystem. Once the dam is removed, the town also plans to build a small park which will allow the public to learn about the human and natural history of the brook. The removal of the dam not only protects public safety, but also supports biodiversity, and economically benefits fisheries. The city of Acton will use its \$75,000 grant allotted by the state through a program that supports local initiatives to address failing dams, seawalls, and levees as well as \$25,000 of its own funds (Laidler, 2021).



Image Source: www.bostonglobe.com

As a coastal state, Massachusetts' shorelines are an important connectivity to a major part of the state's identity and livelihood—the ocean. On the coast of Salem, a living shoreline project restored 800 linear feet of salt marsh at Collins Cove with 15,000 salt marsh plants. The project used a volunteer effort to restore the vegetation on the barrier beaches and dunes, and once established, the roots and the organic material buildup will help stabilize the shoreline (Warren, 2021). This buffers incoming wave energy and flood impacts as well as prevents erosion. It also helps filter stormwater runoff, sequester carbon, and promotes the biodiversity of both aquatic and terrestrial species. More specifically, it provides an important nursing habitat for finfish which are both commercially and recreationally important to the region. This is a great example of how natural solutions can be cheaper and in many cases more effective than simply building infrastructure. The project was a partnership between the city of Salem, Salem Sound Coastwatch, Massachusetts Office of Coastal Zone Management, and The Nature Conservancy (Warren, 2021).

Projects like these are great, because they offer an opportunity for people to come together and work to help their community. As mentioned, Collins Cove was restored by volunteers which not only makes the project more cost effective but also leads to community engagement and learning. Educating others and getting more people involved in environmental work should always be a major goal.



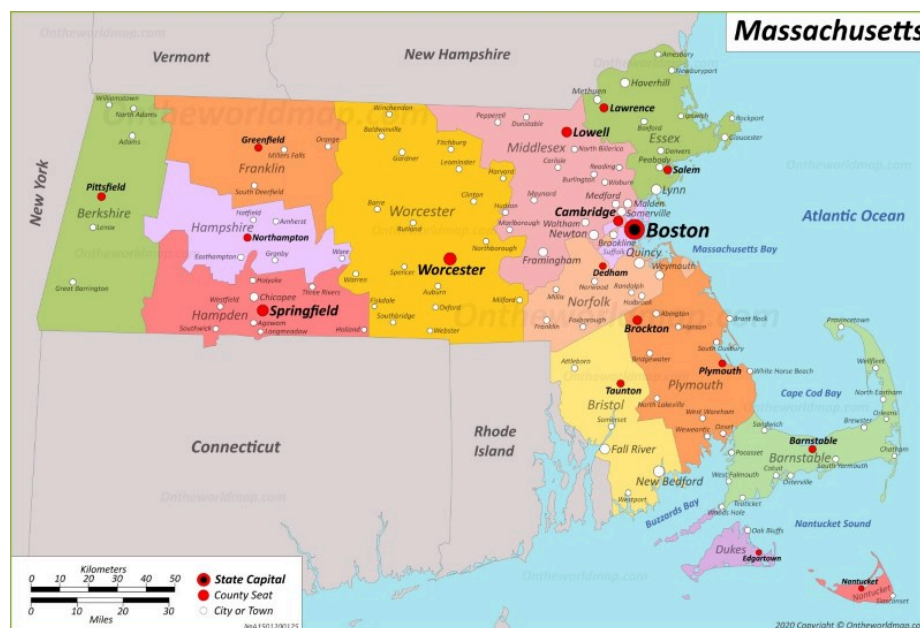
Image Source: www.nature.org

2.4 Urban Spaces

Massachusetts is one of the original thirteen states, located in the northeastern corner of the country. Its major cities include Boston, Worcester, Springfield, and Cambridge. Boston is by far its largest city, with a population of 694,295, a density of 14,363.1 people per square mile, and a total of 301,702 housing units (Boston Planning and Development Agency Research Division). Worcester, in comparison, has a population of 185,421 with a density of 4,963.1 people per square mile.

The state has a historically strong bond with its fishing and manufacturing industry because of its poor agricultural yields. While the fishing industry still remains strong to this day, manufacturing has faltered since the days when Francis Cabot Lowell built the first American power loom in Waltham in 1814. Now, the high-technology and service sector are Massachusetts' powerhouse, particularly in the close relationship between technology and communication (Britannica), as well as Massachusetts' world-renowned universities such as Harvard University, Massachusetts Institute of Technology, Boston University, and Boston College.

Massachusetts' early settlement patterns were along the seacoast at first, but expanded to settlements along the Connecticut River in the western side of the state. Many of its most popular tourist destinations are the long-established seaside cities, such as Plymouth, Duxbury, Gloucester, and Cape Ann. Waterways have historically been important parts of Massachusetts, with the Connecticut and Merrimack River (as well as the now retired Middlesex Canal) (Britannica). Even in a post-automobile society, Boston ranks impressively on public transportation, with its 113 bus lines, twelve rail lines, three subway lines, and five light rail lines (Ortegren). Many urban spaces in Massachusetts are also pushing for more solutions for environmental problems that are commonly found in cities.



Source: <https://ontheworldmap.com/usa/state/massachusetts/> Map of Massachusetts Metropolitan Area

Urban gardens are specially designed to survive the challenging and space-deficient conditions typically found in urban environments, making them valuable in space conservation. By increasing vegetation cover, urban gardens help limit rising temperatures and turn a previously urban area into a habitat for small wildlife. With enough space, gardens can also be used for urban agriculture which produces fresh food for the surrounding community and helps improve food security. They can also increase the surrounding air quality.

One example of an urban garden with a more artistic focus is the Everett Earthworks Sculptural Garden which was created by artist Carolyn Lewenberg. The center of the sculpture is “a visual representation of what happens when a drop of water hits the surface of water, and the paths and garden beds of the piece represent the rippling of the water that flows outwards in concentric circles” (Un, 2020). Everett high school students created sculptural mural panels for the garden shed, and the hope for the piece was to create community-engaging art and promote innovative thinking.

The main concern with urban gardens is the need for space in an already crowded area. However, these gardens are space efficient and can be placed almost anywhere. For example, the Everett garden was installed on under-utilized public land which meant the garden was an addition, not a disturbance, to the community. In general, urban gardens are an efficient option for implementing nature-based solutions into urban areas. They provide environmental, economical, and recreational benefits and can be easily introduced on both an individual and community level.



Image from: www.mapc.org

Green roofs are a simple, yet effective nature-based solution which can be implemented in many areas, some of which are not attainable by other nature-based solutions. Green roofs are most commonly used in urban areas, but can also be used in more rural areas as well. They are a permanent rooftop planting system with live plants that are designed to retain precipitation and reduce runoff. When rain falls, it is taken up by roots of the plants and eventually released through evapotranspiration.

Green roofs are economically beneficial because they reduce energy demand by lowering heating and cooling costs. In reducing energy demand, the roofs also decrease carbon emissions, and the plants also remove pollutants and sequester carbon from the air (*Green Roofs*). Additionally, green roofs can be used to grow herbs, flowers and vegetables which can increase biodiversity by supporting small wildlife like insects, pollinators, and birds. They are also aesthetically pleasing, produce a green space for people to enjoy, and reduce the urban heat island effect. Some examples of buildings with green roofs include Boston City Hall, the Graduate Residences at Harvard University, and Cambridge Center in Kendall Square (*Green Roofs*).

The construction costs for a green roof vary from \$10-\$25 per square foot which can be more expensive than traditional materials, however, they typically last longer than traditional roofs when cared for properly. Overall, green roofs are an excellent nature-based solution when they can be implemented.



Image Source: <https://www.arrowstreet.com/portfolio/green-roof-study/>

In the town of Arlington, two bioretention basins were installed at the intersection of Herbert and Egerton Road. Bioretention basins, which utilize native plant species, help to collect stormwater and reduce runoff into aquatic environments. These specific basins reduce runoff into Alewife Brook. Runoff is the leading cause of pollution in urban streams, and Alewife Brook is often impacted by nutrient contamination (*Arlington and MRWS, 2019*). These basins are a good nature-based solution because they improve water quality in the stream, which is an important habitat for river herring, and they help to replenish groundwater. All of this aids in maintaining healthy and productive habitats and provides the community with clean swimming and recreational opportunities, thereby protecting public health. They also reduce flood risks and beautify the streets.

The Town of Arlington partnered with the Mystic River Watershed Association to design and construct the basins as well as other infiltration trenches, and the entire project was funded by a \$135,000 grant given by the Office of Coastal Zone Management (CZM) Coastal Pollutant Remediation Grant Program (*Arlington and MRWS, 2019*). Installing bioretention basins requires careful design: the streets must be wide enough, must have adequate runoff, must use native vegetation, and should not disrupt traffic (River, 2018). Despite the necessary planning, these basins are relatively simple and are extremely beneficial to the surrounding environment.



Image from: mysticriver.org

Urban environments are densely populated areas that experience the urban heat island effect, subsequently creating a very hot microclimate during some parts of the year. This can cause intensification of air pollution, increase exposure to allergens, and strain water resources. In response, one nature based solution that Massachusetts implemented in cities like Salem, Springfield and Worcester was the Urban Canopy Project. The project's goal is to inspire people to plant and maintain trees in an urban environment where tree populations might be lacking and where greenhouse gas emissions are highest. It is run by Greening the Gateway Cities Program and they partner with home and business owners interested in planting trees on their land to aid them in the design process. They provide consultations to ensure the design utilizes the most suitable species and locations in order to maximize the benefits (Greening the Gateway Cities 2020).

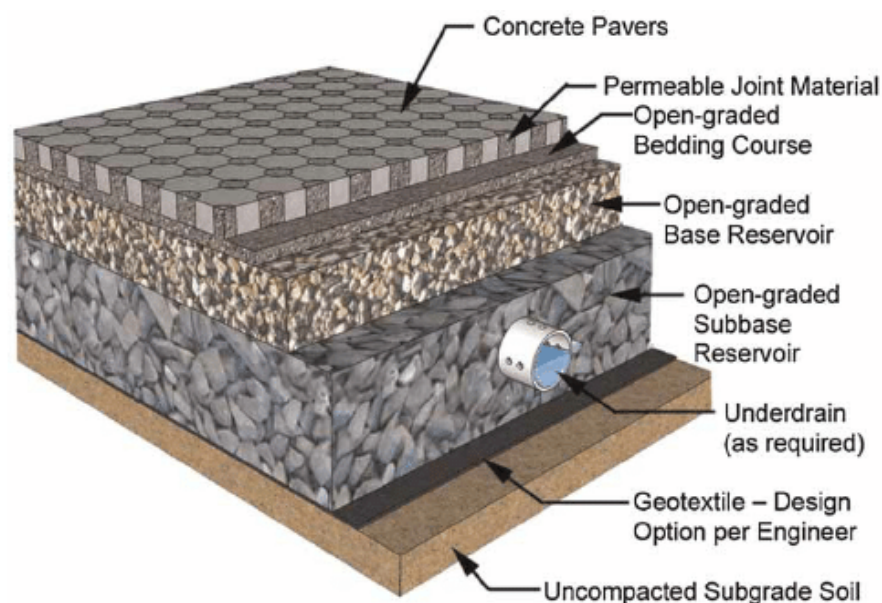
This solution is beneficial because trees can filter the air, reduce noise pollution by absorbing sounds, create habitats for many organisms, and can lower surface temperatures. They provide shade to help create a cooler microclimate and also store carbon. In addition, this solution also has economic benefits. More trees makes areas more visually appealing and increases property values. Implementing this solution also requires labor, which can spur job opportunities that can benefit the economy. Plus, trees buffer extremes in temperature and can take the stress off of heating and cooling systems thereby saving people money. To be eligible to take part in this plan, patrons must agree to a two year watering commitment to ensure the success of the program. Foresters also conduct year round site visits to keep up with progress and address any problems.



image source:<https://chesapeaketrees.net/2020/11/17/baltimore-tree-trust-doing-more-together/>

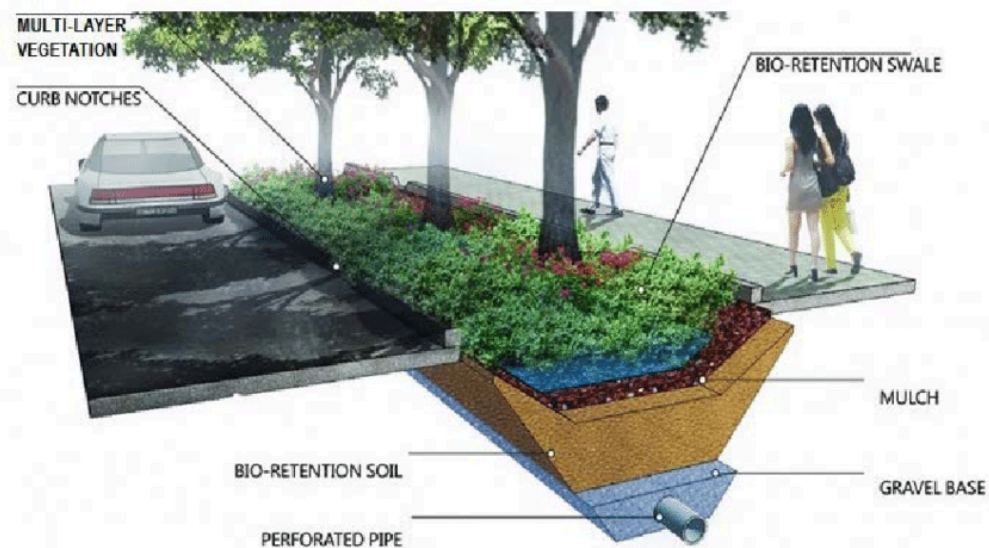
Permeable pavement is a nature-based solution that focuses on mitigating stormwater runoff by absorbing leftover water slowly into its many layers. This allows the water to be retained so that it can be used by soil and vegetation rather than evaporating and exacerbating the urban heat island effect. It also naturally filters out pollutants such as sediments and bacteria, and it cools the temperature of urban runoff which decreases stress on river and lake environments. Overall, permeable pavement can reduce discharge rates by as much as 70-80%. However, permeable pavement is prone to clogging, due to the pores inside, which can require aggressive maintenance with jet washing or vacuum street sweepers. Construction must also take into account that permeable pavement is susceptible to frost heaving and cannot compact underlying parent soils.

One example of permeable pavement is in the city of Saint Paul, Minnesota, where they have constructed two way, off street bike trails along portions of their most popular street using porous asphalt. So far, Saint Paul's bike trails have seen great success and have elevated the Twin Cities' reputation as a bike-friendly city. Permeable pavement was also installed in the Silver Lake Beach parking lot in Wilmington, Massachusetts. This project incorporated three low-impact development (LID) practices: permeable paving materials, bioretention cells and vegetated water quality swales (*Commonwealth of Massachusetts: Demonstration 3*). Before the installation, the lake's quality had previously been decreasing from nutrients, sediments, and bacteria entering its waters from runoff. The beach had to be closed repeatedly in the years prior to this project due to high bacteria counts. Approximately half of the lot was repaved using permeable pavement which helped reduce the runoff, improved the health of the lake, and increased groundwater recharge and quality. This was a great improvement for the ecosystem but also for commerce and recreation as well.



Cross-section of a certain type of permeable pavement (Source)

Sidewalk bioswales are channels of vegetation and soil that are designed to capture and convey water by allowing it to slowly infiltrate the ground. They are easily placed in small or large sites where rainwater gathers. In comparison to traditional materials like cement, bioswales allow water to percolate through the soil which reduces stormwater runoff and decreases the stress on sewage infrastructure. According to research done by the ASLA (American Society of Landscape Architects), a 4-meter bioswale can reduce 25% of the total rainfall runoff in that area. Hence, bioswales are a useful nature-based solution that reduces the stress on our sewer infrastructure. By filtering the water through vegetation and soil, bioswales also act as a natural filtration system, removing pollutants that would have otherwise gone into sewer infrastructure and possibly natural environments. Bioswales also encourage planting vegetation which is aesthetically pleasing to many people living in urban areas. Plants in bioswales also undergo transpiration quite regularly, helping to mitigate the urban island heat effect.



Uploaded by Milena Dinic Brankovic on [this website](#)

The economic benefits of bioswales are that they can be installed once and do not need much maintenance afterwards. They are inexpensive to install in comparison to other large scale projects and are relatively non-invasive on surroundings. The average person, for example, will never notice a bioswale unless they are looking for them or if they are installed improperly. Without ample research and preparation, bioswales can be highly invasive and disruptive to the environment and people's surroundings. It is important that bioswales are constructed to native plants that are suited to their specific conditions. Otherwise, invasive species could take over which would create an environmental problem instead of fixing one. Additionally, it would be a waste of resources if plants were not suited to survive in their environment. New York City, for example, requires drought and flood-tolerant, as well as low-maintenance plants. We must also be careful to not use too much compost to fertilize bioswale soil, since excess chemicals might absorb into the groundwater.

Overall, bioswales are an excellent method of mitigating groundwater runoff and putting less stress on our sewer infrastructure. They improve water efficiency by restoring water back to where it naturally should be: in soil and vegetation. If implemented thoughtfully, bioswales can be a wonderful addition to any environmentally-friendly city.



Source: <https://inhabitat.com/hundreds-of-water-absorbing-bioswales-coming-to-queens-sidewalks/>

Wildlife crossings are bridges or underpasses constructed around highways and roadways that allow safe passage for wildlife. While they are often pictured as huge overarching structures, wildlife bridges can also be smaller crossings appearing at calculated intervals. Examples of successful wildlife crossings include the Snoqualmie Pass bridge over the I-90 in Seattle, Florida State Route 46 underpass, and twenty-four crossings, mostly underpasses, in Banff National Park in Canada. Automobile infrastructure cuts through many stretches of land, causing wildlife habitats to become increasingly more disturbed. Wildlife crossings serve to mitigate the effects of roadways by connecting key animal habitats to each other again.



Wildlife bridge in Banff National Park (Source: [The Guardian](#))

It is estimated that around twelve percent of North American's mammal wildlife die in road collisions (Vox). Costing an average of \$8,190 per crash, wildlife collisions are estimated to cost the United States \$8 billion every year (National Geographic). Roads also block animals from reaching other communities which leads to less diverse populations and increases the stress on these populations. This can have dire results such as inbred animals or population extinction from starvation. Wildlife crossings are estimated to mitigate this problem by decreasing collisions by as much as 85-90% in some areas, saving endangered populations such as maned wolves, brown hyenas, and leopards (Vox). It would also drastically decrease the money spent on collisions, making it a worthwhile investment for humans as well.

However, cost and maintenance have made it difficult to sell wildlife crossings as a bipartisan necessity. Further research is still needed to understand which kind of crossing, overpass or underpass, thin or wide, flat or curvy, and which species of vegetation should be implemented. The Infrastructure Investment and Jobs Act,

passed in November of 2021, will use fiber-reinforced polymer (FRP) to construct crossings that are much cheaper and lighter than concrete ones, which will hopefully lead to construction of more wildlife bridges.



Wildlife bridge construction in progress (Source: WSP)

Green highways are highways working towards being more environmentally friendly. This can be achieved by turning stormwater runoff ponds into amphibian habitats, like in France, naturalizing roadsides into prairie corridors and nesting grounds, like in the Midwest, preventing invasive plants from spreading alongside roads, and putting systems in place to alert drivers of endangered animal sightings nearby. All of these plans are helpful to the environment separately, but work even better together. Overall, making our highways more environmentally friendly helps to prevent the loss of natural spaces and species. Certain animals, such as ground-nesting birds like quails or pheasants, use the spaces next to highways as their primary habitat because many countries are so developed in both urban and rural areas.



Example of green highway project | Source: <https://www.sustainablehighways.org/779/77/massdot-assessing-challenges-and-opportunities-of-planning-for-sustainability-in-roadway-projects.html>

Green highway plans differ from state to state, making it more difficult to track the progress of each plan. The NYSDOT, for example, has been implementing a plan near the Adirondacks on Route 73 for more tree planting, snow clearing, trail improvements, and protecting endangered species such as the Seaside Goldenrod. It is currently unknown how much these projects have cost, but it is assumed from reports that beautifying highways is relatively cheap compared to most projects. Many states are interested in beautifying their highways as well, since 76% of Americans commute by car (Brookings). However, it is important that these projects are well thought out and designed in order not to waste time, resources or money. The goal for environmentalism is to be *proactive*, however reactive solutions can still be beneficial as well.



Example of highway beautification process | Source:
https://www.sustainablehighways.dot.gov/FHWA_Sustainability_Activities_June2014.aspx

3

Global Nature-Based Solutions

3.1. Global Solutions

Forests are one of the most crucial ecosystems across the world due to the wide range of benefits they provide. Not only do they act as a habitat for many species and provide society with many products, but they also are a major sink for carbon, which is important for mitigating climate change. In addition to conserving current forests, reforestation as well as afforestation allows society to increase the amount of total benefits gained from forests. Forests not only provide a lot of environmental benefits, but they also provide economic and recreational benefits in the form of products derived from forests such as lumber and activities such as camping, respectively.



Image Source: <https://towardsdatascience.com/understanding-random-forest-58381e0602d2>

A downside to this NBS is that not every area is suitable for a forest ecosystem. Certain areas do not contain soil with sufficient nutrients or do not receive enough rainfall to support a forest ecosystem, such as many desert environments. Additionally, reforestation and afforestation take a considerable amount of time, as trees need a lot of time to grow as well as time for wildlife to move in and adapt to the environment.

However, a Japanese method of afforestation known as the Miyawaki Method might be the key to overcoming these difficulties. Created by Doctor Akira Miyawaki, it involves using 15-100 strictly local, indigenous species and planting them very densely, with various layers of vegetation, e.g. understory, shrub, tree, and overstory trees, planted side by side (Nagri, 2019). This creates a micro-forest that mimics the complexity of a native forest, but it can be planted as small as 1000 square feet, causing the plants to compete for space, light, and water, thereby accelerating their growth. This methodology creates native urban forest ecosystems 10 times faster and supports 20 times more biodiversity than letting a forest recover on its own (Nagri, 2019). These micro-forests buffer against flooding and erosion, help balance water

cycles to fight drought conditions and sequester carbon. They also cool their surrounding areas by mitigating the urban heat island effect and provide aesthetically pleasing green spaces. They help improve air quality, and there is even hope that they can remediate soil and prevent contamination (City of Cambridge, 2021). The forests are also supposed to be self-managing and require little maintenance after two years which makes them cost effective. In September 2021, the first Miyawaki Forest in the Northeast US was planted at Danehy Park in North Cambridge. It was planted by over 100 volunteers, and the city hopes the forest will continue to encourage the same sense of community and provide a natural space for residents to gather (City of Cambridge, 2021).

Overall, forests are one of the most important ecosystems and nature-based solutions on the planet, as they help to fight climate change and support biodiversity.

In Barcelona, the Trees Master Plan was introduced as a response to the lack of trees. The plan is essentially a way to introduce more trees in an urban environment. Its main goal is to maintain a healthy and biodiverse woodland to improve green corridors and combat the urban heat island effect. The overall solution is broken down into individual projects: street trees, green corridors, peri-urban forests, hybrid dunes, and urban gardens.

Aptly named, the street trees line the streets of urban areas while green corridors help create connectivity between green areas. The peri-urban forest is similar to a national park, and hybrid dunes are semi-fixed dunes on heavily used urban beaches. Finally, urban gardens provide pockets of greenery in otherwise urban areas. Each project contributes its own benefits to the ecosystem and aids in adapting to climate change. Street trees improve connections between ecosystems and provide homes to many small organisms in an urban environment while also sequestering carbon, limiting rising temperatures, reducing urban heat, and reducing water runoff. Green corridors create an ecological connection between fragmented ecosystems that can allow different species to interact, which can help lower risks of species extinction and increase resiliency. They also enable stormwater retention and infiltration and reduce chances of combined sewer overflows. Peri-urban forests maintain large ecosystems for many species while also contributing to air pollution removal and urban cooling. Hybrid dunes create ecosystems in heavily visited beaches that will allow species to live undisrupted while also protecting against flooding and sea level rise. Finally, urban gardens can increase soil fertility and biodiversity, create ecosystems, and increase pollination. Consequently, the Trees Master Plan has many benefits against the effects of climate change. This plan also has many economic benefits and will increase the overall attractiveness of the city. This plan can be transferred and recreated all over the world, including the urban environments of Massachusetts (Barcelona: Nature-based Solutions (NBS) Enhancing Resilience to Climate Change 2022).

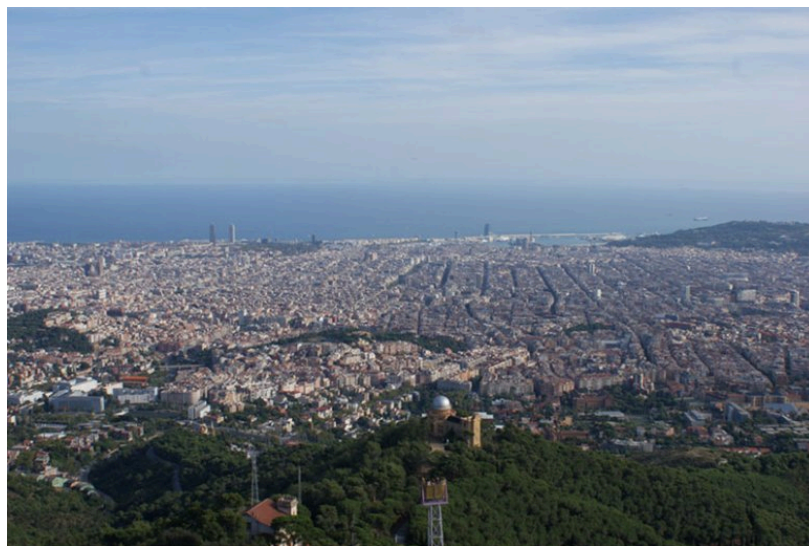


image source: <https://una.city/nbs/barcelona/tree-master-plan>

Coastal Ecosystems are one of the most important ecosystems in the world as they serve a wide variety of purposes. Benefits of coastal ecosystems include but are not limited to storm damage mitigation, carbon sequestration, and a major habitat for many species according to Seddon et. al.. Some examples of important coastal ecosystems include mangrove swamps, salt marshes, and wetlands. These ecosystems are incredibly fragile, and while they are heavily protected in many places, not every country recognizes their importance. A project in Nigeria has been experimenting with the use of GIS and remote sensing applications to monitor and protect its coastal ecosystems. According to Twumasi & Merem, the continued growth of environmental problems in the 21st century has created a need for new design approaches for monitoring coastal ecosystems remotely. Remote monitoring is both more accurate as well as more efficient than the traditional methods of monitoring. Rising technology will be integral to protecting coastal ecosystems across the globe.

It was previously thought that habitat size was the major contributor to ecosystem service productivity in coastal ecosystems, however newer studies have shown that the relationship between habitat size and ecosystem services is rarely linear (Barbier et. al., 2021). Additionally, other factors such as climate change, human development, and chemical pollution have degraded coastal ecosystems ability to produce their ecosystem services that society so desperately needs. Countries will need to work together to monitor and preserve coastal ecosystems.

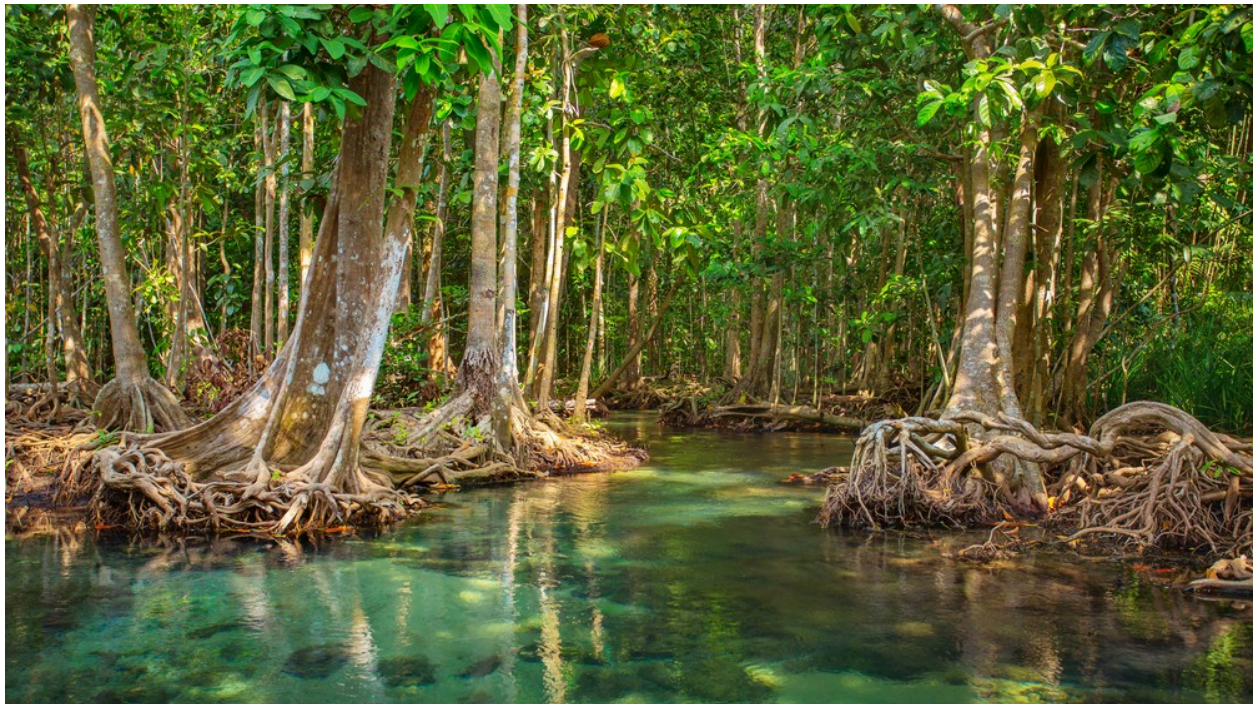


Image Source: <https://worldtraveltourismcouncil.medium.com/surprised-by-mangroves-b21b44604f14>

One of the most concerning aspects of climate change is sea level rise caused by global warming. Sea level rise is expected to leave many habited regions inundated in coming years. One nature based solution that could be used to combat this is green infrastructure in the form of constructed wetlands. This nature based solution is a form of coastal management located in Gorla Maggiore, Italy. Its basic function is to replace traditional infrastructure in treating sewage overflow and finding new methods of water management with green infrastructure. The fundamental components of the solution are a “pollutant removal area with a grid, a sedimentation tank, and 4 vertical subsurface flow constructed wetlands” (Connecting Nature 2020). Constructed wetlands have many benefits including increasing biodiversity, buffering floods, pollution retention, carbon storage, and creating a cooler microclimate. Flood buffering can be especially important in regions below sea level, but also in events where flooding can lead to sewage overflow and lead to a series of other public health safety issues. Carbon storage is another important mitigation effect of constructed wetlands because they are very productive ecosystems.

Its economic benefits also add to its allure. Constructed wetlands can be cheaper than traditional gray infrastructure and there are less costs associated with the decrease in damage caused by flooding and sewage overflow. It can also create recreational opportunities, like it did when they implemented it in Italy. They created walking and cycling paths through the wetlands, which allows for resident engagement that can raise awareness about the benefits of constructed wetlands and why we need them in the first place. Even better, however, is that this nature based solution can be implemented all over the world.



Image Source: <https://connectingnature.eu/oppla-case-study/17252>

An experimental study at the Plymouth Marine Laboratory in the UK tested the ability of mussels to clean microplastics from the ocean with their natural filtration system. Mussels get their food by filtering seawater, sieving out plankton and other nutritious particles and flushing out unwanted particles from their digestive systems. The experiments showed that a cluster of 300 mussels (5 kg) could filter out over 250,000 microplastics per hour. Most importantly, the concentrations of microplastics encountered in marine environments are unlikely to cause the mussels any harm.

This nature-based solution has obvious benefits of filtering microplastics from marine ecosystems, and this helps to protect other species who are harmed by microplastics in the ocean. The experiments conducted showed that a cluster of 300 mussels could filter out over 250,000 microplastics per hour. Cleaning microplastics out of the ocean saves lives of carbon sequestering mammals and organisms, as well as mussels being able to sequester large amounts of carbon as well (PML trials pioneering nature-based solution for the marine plastic crisis, 2021).

Cleaner oceans help to protect human health as well since microplastics are often taken up by marine organisms and accumulate through the food chain. The production of microplastic filtering mussels can also provide more job opportunities and increase carbon sequestration, as well as creating a mussel bed habitat for other organisms. Thus, mussels are an effective nature-based solution for the health of the oceans and climate change as a whole (PML trials, 2021).



Image source: <https://www.pml.ac.uk>

In England and Wales, a citizen science group and non profit organization, "Project Seagrass", is using seagrass meadows to help restore the ocean into a healthy and thriving ecosystem. Seagrass meadows provide a number of important ecosystem services: they are nurseries for young fish that support about 20% of the world's largest 25 fisheries, they sequester carbon about 35% faster than tropical forests, they reduce coastal erosion, and they are unique, biodiverse ecosystems (Project Seagrass). Seagrass provides food, shelter, and nursery for many marine organisms. Many communities around the world also depend on seagrass meadows for food security. Reversing the loss of this habitat will aid in regaining this vital ecosystem for those organisms. Restoration involves filling burlap bags with seed, which are then attached to strings anchored to the seabed.

This nonprofit advocates for citizen science to increase awareness and participation in seagrass conservation which leads to more information and data being gathered on the topic. They have a tool that regular citizens can use to help monitor seagrass meadows globally, and they aim to provide education on the importance of seagrass for ecosystem service provision. Hopefully, this will inspire larger restoration projects in other parts of the UK and maybe one day in Massachusetts.

4

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