Chapter 1

Green infrastructure: Considering nature before and during development

Decision makers today face the common challenge of determining the effects of development on the natural landscape within the context of profound and rapid change. Land development is a daily occurrence, but it often results in the loss of natural, life-sustaining resources that has consequences—not just for wildlife, but for drinking water, recreation, quality of life, and health. Even public safety is affected by the floods and fires that follow when land is disturbed or paved. Scientific evidence points to climate change, resulting in more severe weather events and rising sea levels that shift shorelines inland, causing habitat loss when artificial structures or paved surfaces create impediments to that movement. Sea level rise requires advance planning to accommodate these changes. When a landscape is denuded of trees and its natural waterways are impeded, changes to hydrology, air quality, fisheries, and water supply result. A clear example occurred in southeastern Texas in 2017, when Hurricane Harvey caused about $160 billion in damage, becoming the most expensive natural disaster in US history to date, according to AccuWeather.[1] The storm's severity resulted partly from increased temperatures in the Gulf of Mexico that caused the system to absorb record volumes of water. The water had nowhere to go, partly because of massive alterations to the landscape from paving and rechanneling of streams and marshes.

If communities want to become more resilient and learn to adapt to a changing climate, then we must discover—as Ian McHarg said back in 1969—how to *design with nature*.[2] This book shows how to design with nature by mapping, conserving, and restoring our most highly valued landscapes. This work will allow communities to become more resilient and understand the tremendous ecosystem services that our natural world provides.

Thanks to new analytical tools, we can measure, evaluate, and map our natural world more rapidly and widely than ever before. By identifying and integrating a network of critical landscapes, communities can protect the places and resources that help people, wildlife, and economies thrive. A key avenue to push that change in perspective is to begin to see our natural world as our *green infrastructure (GI)*.

Green infrastructure comprises the natural assets we see around us: trees, parks, streams, lakes, forests, and rivers. They form a natural system of interconnected ecological processes that protect our native species and provide human beings with many things essential to life: clean water, clean air, healthy lifestyles, and significant economic benefits. GI planning is not just about conserving our wildlife; it also seriously affects a community's social and economic health in ways that will be discussed throughout this book.

What is green infrastructure?

The science of green infrastructure provides a framework for sustainable growth and conservation, including such factors as:

- **Protection of the Environment:** Green infrastructure protects the health and diversity of wildlife and maintains natural systems that deliver critical, life-sustaining services.
- **Contributing to a thriving economy:** Green infrastructure benefits property values, lowers health care costs, boosts tourism, and helps communities make smarter investments in grey infrastructure.
- **An enhanced quality of life:** Green infrastructure ensures people can connect with nature; have access to clean air and water; and live healthier, happier lives.

As a science, GI planning uses maps and other analysis and legal tools to plan for land development and conservation consistent with natural environmental patterns and the needs of developmental change. As such, GI planning becomes an invaluable way to promote both smart growth and smart conservation. Many communities already employ GI planning to improve their economies by using their natural assets to attract tourists, recreationists, and businesses to a healthful, attractive, and functional environment.

GI planning is also about protecting wildlands and wild places, even if no one ever visits them. Consider the vast populations of the western US that receive much of their water for drinking and agriculture from mountains and glaciers many hundreds of miles upslope. Wild places also need protection and consideration, even if they have no evident utility in our daily lives. Much as Aldo Leopold – the father of wildlife management in the US – promoted the land ethic in the 20th century, we encourage consideration for the natural values that our landscapes give us daily, both seen and unseen, known and unknown, in every planning decision.

The GI approach envisions decision makers and the public collaborating to preserve and link open spaces, watersheds, wildlife, habitats, parks, and other natural areas that enrich and sustain a community's quality of life, economy, and sense of place. This is a change from how planning has been practiced traditionally in the 20th century in the US and across the globe. Beginning planning with an assessment of natural resources and ecosystems as a first step rather than trying to provide open space and mitigate development after development plans have been put in place has resulted in the dysfunctional ecologies seen today. The flooding in Houston, noted earlier, and the tremendous fires in California in 2018 are a direct result of both climate change *and* poor planning that have not accounted for landscape connectivity and functionality. GI planning is a strategic approach that reorders traditional planning approaches by prioritizing the environment that sustains and enriches our lives first before development plans are made. Geographic information systems (GIS) users offer critical support for this work by mapping those critical environmental resources, such as groundwater recharge areas or fire-risk or flood-prone areas, and prioritizing their protection or avoidance. This book combines the skills and knowledge needed by GIS users with the tools and approaches of GI modeling and mapping to support the growing movement to conserve our world's GI.

> *Conservation means development as much as it does protection. I recognize the right and duty of this generation to develop and use the natural resources of our land; but I do not recognize the right to waste them, or to rob, by wasteful use, the generations that come after us.*
>
> Theodore Roosevelt, speech at Osawatomie, Kansas, August 31, 1910[3]

Canyon De Chelly National Monument, Arizona, protects both the natural and cultural landscape. Credit: Green Infrastructure Center Inc.

Why we need a new way to plan

Despite growing awareness of the significance of preserving our natural environment and a proliferation of new tools, planning with natural features and functions in mind is not yet widespread. We still develop in ways that disrupt natural systems. Sprawl-patterned development continues to consume natural landscapes, disconnecting wildlife corridors, causing excessive storm runoff and water pollution, marring scenic vistas, impacting historic and archeological sites, and paving over once productive aquifers, preventing their vital recharge.

> ***Ecologists from across the globe estimated that humans have already transformed about 43 percent of the ice-free land surface of the planet, leaving the world's ecology at risk of collapse.***[4]

We need houses but often "grow" them, instead of food, on our best agricultural soils. We need clean water but often cover the tops of recharge zones with roads and parking lots. We must change our thinking to see our natural elements as part of our infrastructure and plan for development in ways that minimize land disturbance and maximize natural resource conservation. When we begin to think of nature as our GI because it provides us with our clean water and air, food and healthy lifestyle, and shaded homes and scenic vistas, we can intentionally develop infrastructure to foster conservation and safeguard natural elements that sustain and benefit us. In short, if we want healthy, economically vibrant communities, then we need healthy, vibrant landscapes too.

Species at risk

Despite many conservation victories, across America the natural landscapes and species that depend on them are increasingly isolated and put at risk. Endangered Species International estimates the number of endangered species for North America at more than 1,261, with many more species threatened or at risk.[5] As habitats become increasingly fragmented by roads, subdivisions, mines, and pipelines, biodiversity is put at risk when animals cannot reach new areas to take advantage of water or food or to find mates.

First, we must harness all the tools at our disposal to evaluate, map, and plan for our connected natural landscapes and resilient ecosystems within the context of sensibly planned growth and development. Fortunately, we now have the data and analytical tools to map large landscapes more accurately than ever before. Geographic information systems can integrate multiple datasets to craft a more sophisticated, detailed, and nuanced understanding of the natural landscape.

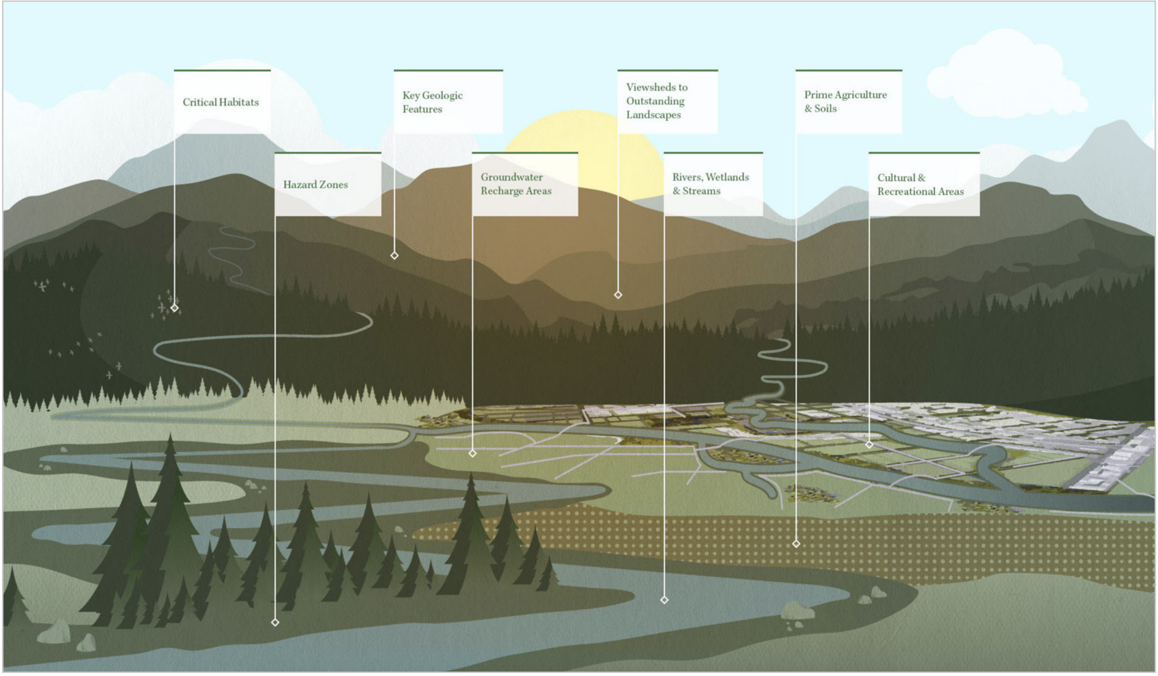
This book describes these new mapping tools and methods for GI planning that utilize the vast amounts of data now available. GIS analysts can access these data to organize and prioritize that information effectively and rapidly, saving time and money. These methods involve sophisticated modeling that turns scalable data into highly useful information directed to specific planning goals and projects. This book describes how to apply a GIS model for natural resource conservation, laying out the processes involved and explaining how these tools allow planners and decision makers to protect and foster a connected, resilient, and biologically diverse landscape in which both wildlife and humans can prosper. However, before beginning this journey of landscape conservation modeling, some context is needed.

Although still a relatively young country, the US has protected a great deal of land from development. With more than 400 national park areas, 560 national wildlife refuges, and nearly 250 million acres of other public lands managed by the US Department of the Interior, Americans have a wealth of publicly held resources supporting their natural assets and cultural treasures. And that doesn't include the thousands of state and local parks. Yet, because natural habitats don't end at park boundaries, both wildlife and humans require connections across the *entire* landscape. The growing demands of development can cause conflicts at these boundaries.

Using maps

Maps are a vital tool used extensively in GI planning. Maps enable planners to identify areas of natural resources and tag them with various criteria, as well as attach values to those criteria. The extent of specific natural resources, the balance of overall environmental assets, and their relationship to a range of overlays, such as leisure facilities, endangered species, future developments, the road and rail network, water recharge and supply sources, enable planners to identify both opportunities and potential problems.

Maps also are invaluable because they get the public involved. Highly visual maps can be printed and used in displays to identify public concerns, evaluate priorities, and help decision makers visualize issues at multiple scales. A local landscape can be seen within wider county, state, regional, national, and even international contexts. Maps can identify wildlife migration routes and nationally or regionally endangered species, show how roads fit within a regional network, and mark the location of a business park relative to a wider economic network.



GI maps help communities grow smarter. They identify natural assets that allow communities to grow richer, healthier, and more responsibly while preserving valuable natural areas if they consider and identify the valuable green landscapes they wish to protect and connect. Credit: Esri.

A healthy landscape means a healthy community

People depend on a healthy landscape to sustain their very existence. Thoughtful, long-term planning intended to sustain the ecological services that nature provides clearly enhances a healthful community. Not planning for nature's benefits can have consequences. For example, a county in Virginia slated future housing developments to occur on its best agricultural soils, while designating areas with poor soils as the agricultural zone. Doing so put its food security at risk and foreclosed on its agricultural future. Why did this happen? Local planners did not use soil data to create maps that would have informed their decisions about where to locate future developments or agricultural uses. These problems are preventable. A healthy food supply for people and abundant habitat for wildlife can be maintained, side by side. But it requires good data and maps to inform planning decisions.

Undeveloped landscapes are not just important for food. People also need to access nature to remain healthy. Indeed, many studies show the importance of green spaces for both *mental* and *physical* health. Just being able to see green spaces can reduce illness and stress. In fact, one study found that employees without views of green spaces reported 23 percent more incidences of illness.[6] Hospital patients studied by Dr. Roger S. Ulrich at the Center for Health Systems & Design at Texas A&M University found that having views of nature led to faster recovery for patients. Patients experiencing views of nature had "shorter post-operative stays, fewer negative comments from nurses, took less pain medication and experienced mostly minor post-operative complications."[7] Many hospitals are beginning to provide rooms facing on green scenery or having photographs of nature on the walls; some hospitals are adding trails around their grounds. Most urban hospitals do not own the landscapes providing those views, so they depend on local planners and developers to maintain the green spaces that help their patients heal faster.

A vibrant tourist industry requires a vibrant natural landscape

Heritage tourism is another way that nature pays us back. Heritage tourists spend, on average, about 2.5 times more than other types of tourists. And these types of tourists often desire access to both culture and nature. In Nelson and Albemarle counties in Virginia, the Brew Ridge Trail follows the ridges and valleys that cross the piedmont of the Blue Ridge Mountains. The trail offers hiking and local craft beers within a natural landscape that is increasingly seen as the key factor in a strongly reviving tourist industry that also boasts wineries, bed and breakfast establishments, and destination weddings.

Similarly, in Colorado, the Brew Trail offers an interactive map that allows visitors to locate their brews and views and plan outings as part of an integrated leisure activity. These beer and nature lovers spend money on outdoor gear, local arts and crafts, hotel rooms, restaurants, and gas, as well as enjoying scenery and participating in outdoor and cultural activities.

Clean water requires a clean watershed

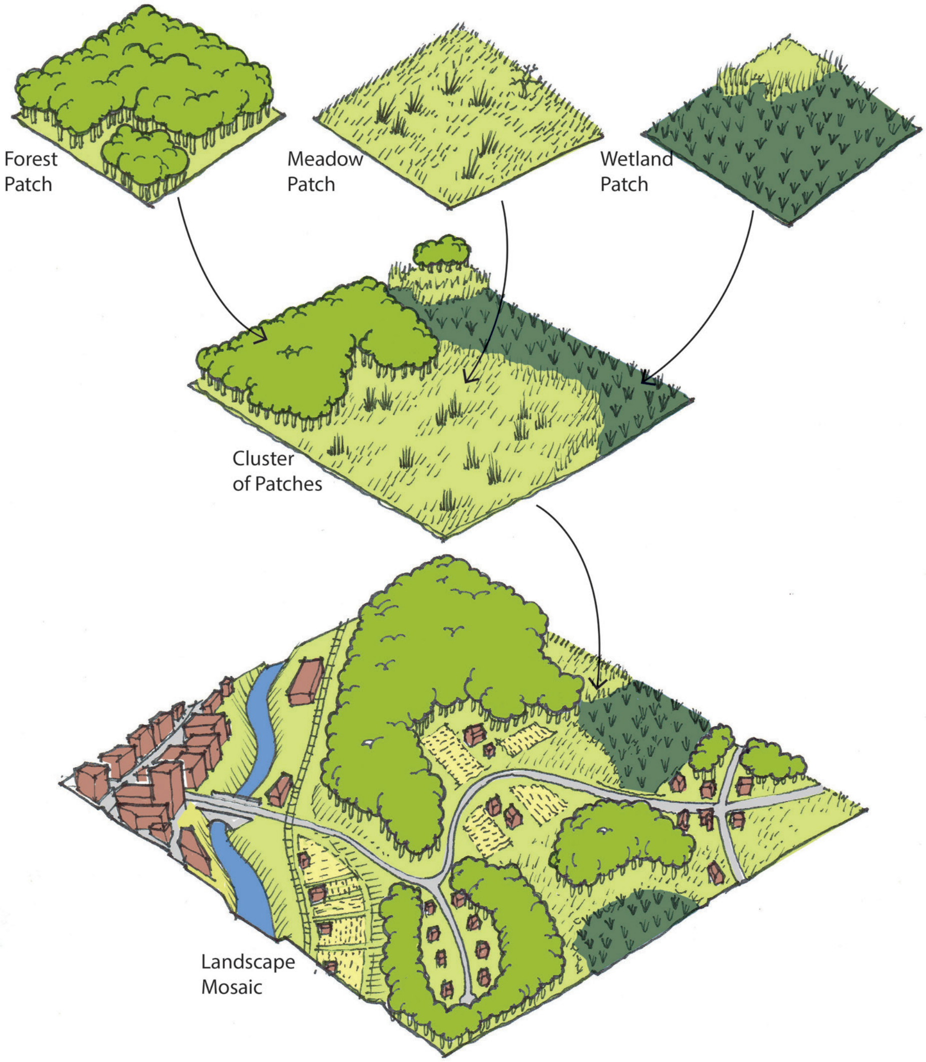
Beyond natural beauty, clean water is perhaps the most recognizable human value associated with landscape conservation. Protecting just 20 percent more forested land can reduce drinking water treatment costs by 10 percent, because water arrives cleaner to reservoirs or river intakes.[8] However, protecting clean water often requires interjurisdictional cooperation, because watersheds tend not to observe political boundaries. Rivers usually wander across multiple counties and through many urban areas, passing sewage treatment plants, factories, and storm water outlets. For example, Ulster County, New York, contains the upper Adirondack watersheds that supply the drinking water demanded by New York City's five boroughs. Healthy water that did not have to utilize expensive filtration systems because it is so clean is made possible by Ulster County's abundant forests, which have been protected for many years.

The focus of this book—GI planning—arises from a multitude of researchers who have studied how landscapes function and why connectivity is critical for creating resilient communities. For readers less familiar with how these theories arose, Appendix A reviews a brief history of the seminal work that led to the current status of the field and to the creation of the national GI model for the US hosted by Esri.

Key terminology in GI network design

Different disciplines use distinct and unique terms to refer to intact habitats. In landscape architecture, the term *patches* is often used to refer to a distinct habitat type. Scottish botanist and plant ecologist Alex Watt presented his theory of *patch dynamics* in his 1947 address to the British Ecological Society in which he suggested that plant species within bounded communities are distributed in *patches* that form mosaics across a landscape.[9] Patches can be described as distinct areas of similar types of habitat that differ significantly from adjacent landscapes and are often dependent on delicate climate factors or a specific underlying geology and hydrology.

Ecosystems can be thought of as a mosaic of patches. A grassland or mountain range is obviously a mosaic of many patches. A relatively intact and local forestland can also be considered a complex mosaic of patches, because it may also contain open, nonforested areas and wetlands. Patch size, shape, duration, and boundaries are mutable and of varying sizes and sensitivities to change. Disturbances such as wind, floods, and fire can irrevocably disrupt their communities. Although these disruptions can create openings in the habitat for new species, the distribution of the original species that utilized the disturbed area can be irreparably changed. For example, a blowdown in a forested area may become a meadow and provide forage areas for edge species, such as butterflies and birds, while displacing other species that reply on dense forest cover.



Mosaic is a term used to describe the pattern of patches, corridors, and boundaries with a matrix that forms an entire landscape. Credit: Green Infrastructure Center Inc.

Habitat fragmentation

Habitat fragmentation is the breaking up of natural landscapes into smaller and more disconnected pieces. Fragmentation leads to species loss and decline when damages to one area cannot be overcome by repopulation as organisms migrate to a new habitat. Similarly, areas where species have been lost are less likely to be recolonized when they become greatly isolated.

Conservation of the sage grouse

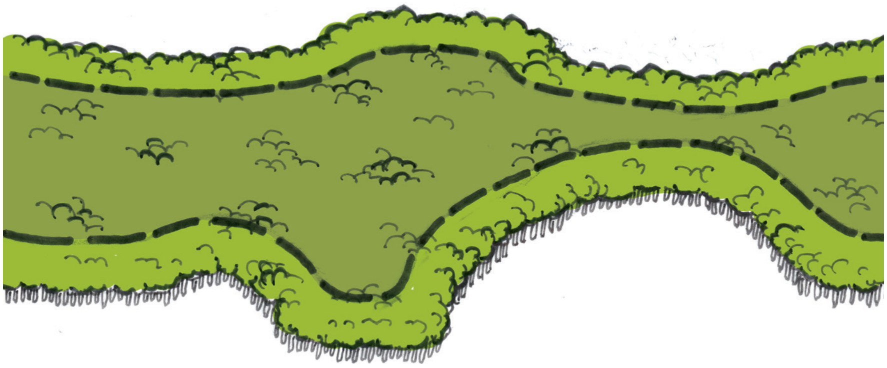
Although most land in the US is privately owned, concerted conservation efforts that involve multiple landowners across large landscapes can make a significant difference to land preservation, especially when it comes to species with a large but generally endangered range. For example, in the US, the greater sage grouse has recently been removed from its protected listing under the Endangered Species Act (ESA). According to former US Secretary of the Interior Sally Jewell, the determination that the greater sage grouse does not require ESA protection is "proof that we can conserve sage grouse habitat across the West while we encourage sustainable economic development."[10]

Thanks to coordinated restoration efforts, which have overcome fragmentation of habitat, sage grouse populations are now rebounding in the US. Image courtesy of Alan D. Wilson.

Habitat corridors

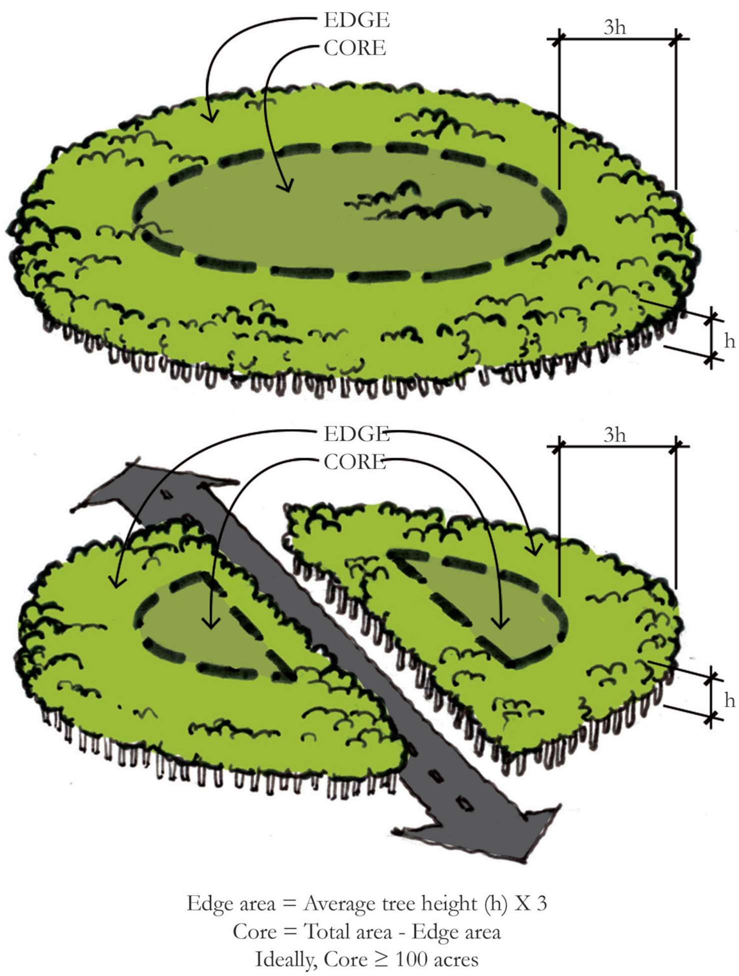
Central to the health and populations of animals and plants is the degree of connectivity between patches. Connectivity of natural habitats supports species movement by providing cover and forage area, as well as opportunities to reproduce and increase genetic diversity, thus contributing to species' viability over the long term. Corridors—vegetated linear areas of similar habitat types that differ from adjacent landscapes—allow sheltered passage from one patch to another, as well as forage and habitat. How well species can utilize corridors for movement depends in part on the individual species and on the habitat quality of the corridor itself.

Note: Corridors, and other technical terms of GI planning, are dealt with in more detail in chapter 2, "Modeling the natural landscape."



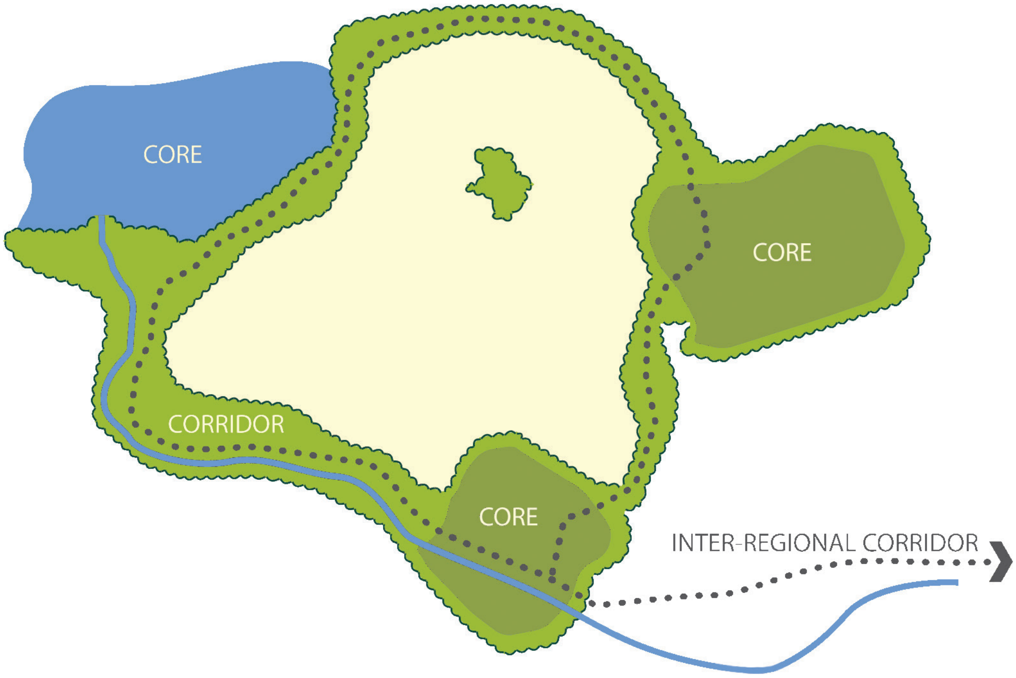
A corridor is primarily a linear pathway that connects habitat patches and is wide enough to allow for species to travel safely. Credit: Green Infrastructure Center Inc.

Planners often use the term *core* to refer to an intact landscape that is large enough to support a multitude of native species. The terms *core* and *patch* are often used synonymously. Cores are connected by corridors that provide pathways for species to move across the landscape.



Habitat cores are measured by subtracting the edge and then determining if enough interior habitat remains to support a multitude of species.
Credit: Green Infrastructure Center Inc.

Cores (patches) and corridors have become key principles in the framework of connected landscapes. The term *core* comes from the work of the Biosphere Conference, which dealt with the utilization and preservation of genetic resources. In 1970, the United Nations Educational, Scientific and Cultural Organization (UNESCO) General Conference proposed a worldwide network of biosphere reserves to ensure genetic material is preserved across the globe. The conference also launched the Man and Biosphere (MAB) Program.[11] Each participating country had to designate specific biosphere reserves that would conserve key species and provide areas for research. They included criteria and guidelines for these reserves, particularly the importance of having core areas protected by buffer zones.[12]



A GI network is composed of habitat cores and connecting corridors that support the biodiversity of both flora and fauna. Credit: Green Infrastructure Center Inc.

The UNESCO conference decided that a core needed to be large enough to meet the habitat needs of any species of concern in situ, whereas the buffer should be large enough to support some uses and provide space for research stations. In the design of biosphere reserves, cores (interior areas) are "securely protected sites for conserving biodiversity."[13] Cores can be considered as similar to patches, but they are also large enough to support more than one species and are surrounded by buffer zones and linked by corridors.

***A GI network** is an interconnected landscape of prioritized cores and connecting corridors.*

Examples of biospheres in the US are the Everglades and Dry Tortugas, both in Florida, and the northern Mojave Desert, which encompasses four different management units of government land, including Death Valley National Park, Joshua Tree National Park, Anza-Borrego Desert State Park, and the Santa Rosa and San Jacinto Mountains National Monument.

Managing key biosphere ecosystems across multiple land ownerships presents challenges. For example, for a long time, the Dana Biosphere Reserve in Jordan faced challenges because of poaching, as its previous uses included subsistence hunting by local people over many centuries. The problem was solved only when local hunters were trained as nature guides, and today they protect the wildlife rather than eat it. Other joint management areas, such as the Changbai Mountains bordering China and North Korea, face challenges related to managing species across borders of countries that lack relationships stable enough to facilitate shared conservation planning.

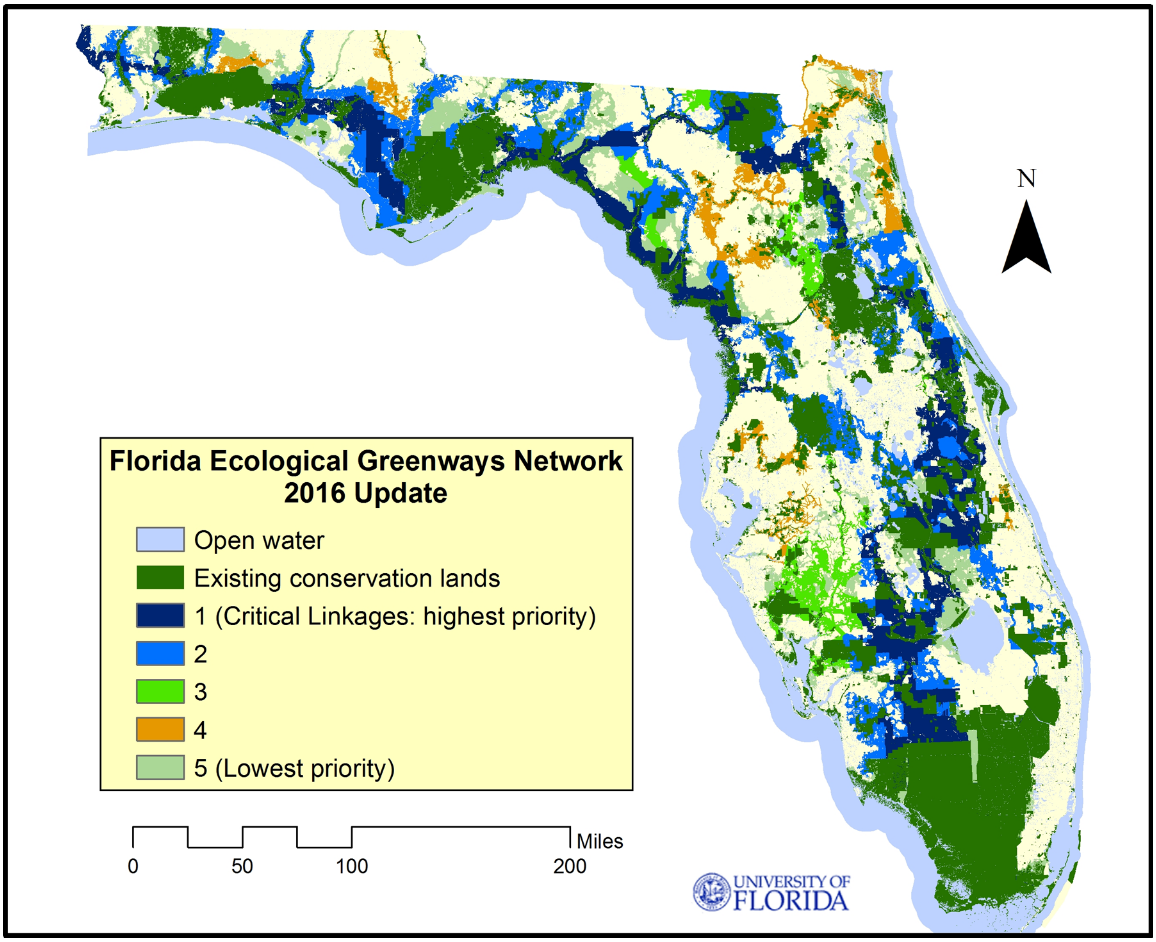
The Dana Biosphere Reserve in the Hashemite Kingdom of Jordan supports many rare and endangered species within 320 square kilometers along the face of the Great Rift Valley. It encompasses four different biogeographical zones: Mediterranean, Irano-Turanian, Saharo-Arabian, and Sudanian. Credit: Green Infrastructure Center Inc.

Corridors provide a way for wildlife to cross the landscape and increase potential connectivity between habitat patches, which allows for greater movement and intermingling of populations. This intermingling, in turn, allows for greater genetic diversity, as well as for repopulation of previously disturbed areas. The role of corridors for providing connectivity has increasingly been recognized, as has the understanding that the corridors themselves provide habitat.

GI modeling in the US

The very idea to call systems of habitat cores and connecting corridors "green infrastructure" can trace its origins to the Florida Greenways Commission. The focus on connecting green resources followed work focusing on important natural areas in Florida led by The Nature Conservancy, as well as advocacy and planning by the Conservation Fund and 1000 Friends of Florida. The commission studied the Loxahatchee River and nearby conservation lands in southeast Florida as a connected landscape that represented some of the most pristine habitat remaining in that rapidly developing part of Florida. Based on this work, in 1991, 1000 Friends of Florida and their partners advocated for a statewide green network covering the entire state. As a result, Governor Lawton Chiles appointed the Greenways Commission for that purpose. Its 1994 report proposed a linked habitat network, using Reed F. Noss's recommended state-wide design as a foundation for a network of core preserves, buffer zones, and corridors.[14]

The report also laid out the Greenway Commission's vision of the state's natural resources as infrastructure: "The Commission's vision for Florida represents a new way of looking at con-servation, an approach that emphasizes the interconnectedness of both our natural systems and our common goals and recognizes that the state's 'GI' is just as important to conserve and manage as our built infrastructure."[15] A team at the University of Florida created a network of cores and corridors resulting in the Florida Ecological Network design.[16] For more on this model, see chapter 2.



Florida Ecological Greenways Network. Credit: Tom Hoctor, Ph.D., Director, Center for Landscape Conservation and Planning, University of Florida.

Similar to Florida, Maryland's GreenPrint Program originated with an emphasis on greenways. The Maryland Greenways Commission was established in 1991; its purpose was to create a statewide network of greenways that would provide natural pathways for wildlife movement and trails for recreation and alternative transportation routes. The assessment was based on Florida's ecological network approach.

In 1997, the Maryland Department of Natural Resources provided Baltimore County with a grant to develop a county model of GI. In 1999, during his inaugural address, Maryland governor Parris Glendening called for the state to plan carefully for its forests, woodlands, streams, and rivers as integral parts of Maryland's GI. He explained that this GI was just as important as the state's roads and bridges.[17]

In 2000, the Maryland Department of Natural Resources used the prototype developed for Baltimore to create a state GI network of hubs and corridors, which today is called the Maryland GreenPrint, of which only 25 percent of those lands are protected. To better guide conservation of these lands, the GreenPrint map depicts Targeted Ecological Areas (TEAs), lands and watersheds of high ecological value identified as conservation priorities by the Maryland Department of Natural Resources. It also displays priorities for the state's land conservation programs: Program Open Space, the Maryland Agricultural Land Preservation Foundation, the Maryland Environmental Trust, and the Rural Legacy Program. GreenPrint helps these programs integrate their priorities and helps to steer land acquisitions for Program Open Space. The TEAs were first developed in 2008 and then updated in 2011.

Since the development of the Florida and Maryland models, statewide GIS-based GI models have been built by state agencies for Virginia, California, Colorado, and Montana. The Green Infrastructure Center built statewide models for New York, Arkansas, and South Carolina. The Conservation Fund built a statewide model for West Virginia and has also built many regional models. In 2006, the Conservation Fund further popularized the concept in its book *Green Infrastructure*, which describes GI as "a strategically planned and managed network of wilderness, parks, greenways, conservation easements, and working lands."[18] Other groups, such as The Trust for Public Land, The Wilderness Society, Defenders of Wildlife, and The Nature Conservancy (which founded a conservation modeling firm, NatureServe), as well as many universities and local groups, are conducting GI planning while developing new models, tools, and methods to do this work.

Most statewide models, and the national Esri model, were constructed using land cover at a 30-meter resolution. However, local governments have also created higher resolution models at the 1-meter scale to allow for more detailed assessments at the local level.

The risk of isolating populations of species

Isolated populations are most at risk of depredation or extinction. If a disease affects a species, causing it to decline or disappear, isolated areas are less likely to be recolonized. Also, such smaller habitat areas cannot support abundant species.

For example, although American brown bears (*Ursus arctos*), also commonly referred to as grizzly bears, are abundant in Yellowstone National Park, they occupy less than 2 percent of their former range. Bighorn sheep (*Ovis canadensis*) are endangered and have declined from an estimated population of 1.5 million to 2 million to only 70,000 today. Some species, far less noticeable, such as the Karner blue butterfly (*Lycaeides melissa samuelis*), are also declining. Unlike large megafauna, small insects may not capture our attention as readily, and yet they form a vital part of the ecosystem as pollinators, thereby indirectly contributing to the beauty of the world's landscapes and feeding the world.

Bighorn sheep (*Ovis canadensis*) populations, although eliminated from Washington, Oregon, Texas, North Dakota, South Dakota, Nebraska, and part of Mexico in the 1920s, are now rebounding in areas where they had been reintroduced. Credit: Image courtesy Alan D. Wilson.

In the US, sprawl—wasteful patterns of land development that place people in areas farther from built areas and cities—creates landscapes that require more road building, causing loss of wildlife habitat and reducing agricultural lands. Part of this destruction is driven by a lack of consideration for the natural resources that are being lost.

In late 2015, the Green Infrastructure Center partnered with Esri to create a national model of cores using the script Green Infrastructure Center had created for its South Carolina GI model. Esri has since developed online apps to help users visualize different priorities for GI networks. As part of this process, Esri convened a technical committee made up of representatives from Green Infrastructure Center, NatureServe, the Conservation Fund, The Trust for Public Land, and Conservation Science Partners, all of whom reviewed the model. In several cases, surrogate data were needed because not all the data that a state model might supply were available nationally. The types of data used to create the national model are covered in chapter 4, whereas chapter 5 includes tips for creating customized GI models at the user's desired scale.

The national GI model for the US provides, for the first time, a countrywide model that can be used for conservation planning at the county, region, state, and national levels. However, to refine the model for local use, users should add more data. The national GI model is available for download at the state scale; data can then be clipped to the user's area of interest, such as a county, region, or watershed. The online apps that come with the model are especially useful to help users test quick snapshots of an area or for goal setting. Chapter 2 provides the description of the model and its component parts.

Green infrastructure planning around the world

Key foundational principles for GI mapping and planning originated from different countries. The early work of visionaries and scientists such as Alexander von Humboldt and landscape designers such as Calvert Vaux played a significant role. See Appendix A for more on the foundational work that led to GI planning.

In some countries, GI plans arise entirely from the grassroots, led by nongovernmental organizations. In 2010, the Tenth Meeting of the Conference of the Parties to the Convention on Biological Diversity held in Japan set the stage for the Strategic Plan for Biodiversity 2011–2020. In 2015, the Ecological Society of Japan, the largest membership-based conservation organization in the country, sent a delegation to the US to study GI planning. They hoped to address the increasing habitat fragmentation in their multi-island nation and protect the country's rich natural assets.

Ecological Society of Japan leaders and Green Infrastructure Center staff study the GI network along Virginia's Blue Ridge Mountains. Credit: Green Infrastructure Center Inc.

Meanwhile, efforts in Central America have focused on the conservation needs of particular species. One such project was the Jaguar Corridor Initiative. Partners, including the US-based Wildlife Conservation Society and various Central American groups, started the project in 1990 to link jaguar populations from northern Argentina to Mexico. In many cases, protecting the habitat of one animal that serves as an umbrella species also protects many more species. The Jaguar Corridor Initiative identified 44 corridors that were threatened by human uses, and one specific area in Costa Rica, the Barbilla-Destierro Biological Corridor, was determined to be particularly important to preserving the jaguar's genetic diversity.

In European Union (EU) countries, national governments are driving forces in motivating GI planning and public-private partnerships are forming to map and plan for GI across the EU.

In 1993, the EU created the Convention on Biological Diversity (CBD), with three main objectives:

- Conservation of biological diversity
- Sustainable use of the components of biological diversity
- Fair and equitable sharing of the benefits arising out of the utilization of genetic resources

In 2006, the European Centre for Nature Conservation published the *National Ecological Networks of European Countries Map*. As part of its Europe 2020 strategy, the EU created a plan to reverse biodiversity loss and move toward a resource-efficient, green economy.[19] More recently, the CBD developed the 20 Aichi Biodiversity Targets, of which Strategic Goal C is "to improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity," whereas Target 17 is especially relevant to GI, as it calls for each signatory country to have an effective, participatory, and updated national biodiversity strategy and action plan. The principles also recommend that planning take place across country boundaries to ensure the survival and health of endangered or at-risk species. The vision is that "by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people."[20]

The European Commission's (EC) biodiversity strategy recognizes the impacts of land fragmentation, finding that nearly 30 percent of the EU territory is moderately to highly fragmented. In Target 2 of its protocol, the EC recommends maintaining and enhancing ecosystem services and restoring degraded ecosystems by incorporating GI in spatial planning.[21]

A 2016 review of national ecosystem assessments compiled for the EU showed that many assessments were developed to meet the goals of the EC's biodiversity strategy. The assessments focused primarily on ecosystem services values, such as providing clean water, although some of the assessments also regarded biodiversity as a value in and of itself. Of those, Portugal, the United Kingdom, Spain, and Flanders conducted the most comprehensive studies. The United Kingdom, Flanders, Norway, and the Netherlands also addressed cross-border ecosystem services.[22] Some countries put greater emphasis on stakeholder engagement than others.

Researchers have recommended the EU focus on standardization of data collection, indicators, and methods to assess biodiversity and ecosystem services. This focus is especially important, given the many ecosystems that span multiple national boundaries, such as the Pyrenees between France and Spain; the Alps between Switzerland, Austria, France, and Italy; and the Carpathians between Hungary and Romania.

Several researchers have proposed a pan-European Green Infrastructure Network that would overlay quantified ecosystem services for specific landscapes with identified core habitats and wildlife corridors.[23] They mapped a large region of Europe for its capacity to regulate air quality, water flows, erosion protection, coastal protection, crop pollination, soil protection, water purification, and climate. These topical overlay maps could be combined to find areas satisfying the greatest number of ecosystem services. They also modeled essential cores using the Landsat Vegetation Continuous Fields tree cover layer from the Global Land Cover Facility to locate core habitats of at least 50 percent forest density and 500 square kilometers in size. Some countries showed extensive areas of core habitats for large mammals (approximately half of Estonia, Slovenia, Latvia, and Austria), whereas others, such as Cyprus and Denmark, had none.[24] The authors acknowledge that their academic endeavor did not engage governments in vetting the priorities but does show the potential that GI maps offer the EU.

Another driver for on-the-ground conservation work in Western and Central Europe is provided by the goals of the EC's Natura 2000 initiative. As part of this initiative, the EU committed to providing support and a legal framework for the preservation of national habitat networks. Natura 2000 is a network of core breeding and resting sites for rare and threatened species and for some rare natural habitat types. Stretching across all 28 EU countries, including land and aquatic resources, it aims to ensure the long-term survival of the region's most valuable and threatened species and habitats.[25] A more inclusive, multistakeholder effort has been implemented to meet Natura 2000's goals for a European greenbelt. This effort is discussed further in chapter 8.

Esri's national GI model creates a key tool for land planning in the US. By providing the analysis and location for large intact habitat cores across the country, the national GI model provides a critical starting point for geographers, planners, landscape ecologists, and architects to develop their own conservation plans. However, the Esri model is just the beginning. It is intended for GIS analysts to download the model, update or add data, change priorities, or uncover new relationships that inform conservation planning. Chapter 2 provides more information on the scientific underpinnings of the US national GI model; chapter 3 discusses the essential process for establishing goals. Chapters 4 through 8 then describe how to obtain the right data and utilize the model, create maps, identify risks, discover opportunities, and, most important, implement plans.

Notes

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