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The Nature of Roads

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Abstract

Recognizing paved roads in the U.S. as an intersection between humans and other living things can contribute to new ways of relating to the world around us. While engineering capabilities can accomplish feats that increase the possibilities for human connectivity, human transportation also affects the movement and lives of many other organisms. A multispecies approach to understanding roads considers humans as one of many component parts of the ecosystems we occupy—as animals entangled with and interdependent on other beings, each seeking solutions for survival. Ultimately, I am curious how a multispecies exploration of paved roads in the U.S. could influence change in the way humans design transportation systems and share space with other species. By comparing human movement to the movement of other organisms, humans may learn better ways to move ourselves and remember to see ourselves as animal actors within the ecosystem.

There are multiple indications that a close examination of American road infrastructure is a timely endeavor. While the cost of materials and labor makes large scale change to the built environment challenging, three factors that contribute to change are currently coalescing. I argue that deteriorating infrastructure coupled with recent ecological discoveries and new developments in technology present the conditions for a major change in the American landscape.

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Introduction

From October through April, before poison ivy takes over my preferred route, my walk to work starts where my street dead ends at a sewer easement through a bamboo forest. A few oaks, sweetgums, maples, and pines struggle against the tangled tug of wisteria vines in a sea of smooth, green bamboo stalks. This path intersects with Campus Drive, a private serpentine road with a sidewalk alongside it that links the east and west campuses of Duke University. The sidewalk is wide and flat, dappled with shadows cast by oak trees populated by sloppy squirrel nests that rest in the elderly elbows of their branches. Sycamores line a stream that sometimes bubbles with moving water and sometimes brews with stagnant algae, depending on the recent weather. As I walk, bicycles, scooters, buses, cars and service vehicles pass by on the road; joggers make their way around me on the sidewalk.

There is evidence of other travelers as well. Slug trails glisten on the cement. I can make out deer and raccoon tracks pressed into the mud near the stream. I hear the shriek of hawks as they scout from above. One afternoon, a black snake draped like a trapeze artist from a branch over the sidewalk. Sometimes I see foxes dart through the trees. In the winter, praying mantis egg cases and the dangling pouches of silkworm cocoons bulge on bare branches. Tree snags hide barred owls that call out at dusk, waiting to swoop silently through the dark after fluttering bats.

For all of the things I can observe by moving at a walking pace, countless multitudes remain unseen. I wonder how we all move with and around each other on this and other corridors of asphalt, where there are points of harmony or conflict, and also where, despite

proximity, there is complete disconnect. This diverse multispecies community was created by design. Campus Drive was designed by the Olmsted Brothers, the landscape design firm created by John Charles Olmsted and Frederick Law Olmsted, Jr. to carry on the work of their late father, landscape designer Frederick Law Olmsted. The Olmsted family was known for designing public parks and other landscapes that incorporate elements of nature as components of the built environment. The Olmsted Brothers' design firm was responsible for the roads, quads, and pedestrian paths added to the Duke University campus in 1924 (www.nps.gov/frla/learn/historyculture/college-campuses.htm). My passing observations of Campus Drive hint at the way road design affects the experience of a variety of organisms--of those who use the road and those who are affected by their adjacent existence.

Roads move us through the world and in so doing, require us to negotiate space with each other and other living things. In this paper, I set out to investigate a series of telescoping questions that are, at their core, about moving through a multispecies world as humans. As humans, what is the spectrum of what is visible and invisible in the world around us? How can this change when we observe carefully or use new information to direct our attention? What remains fundamentally imperceptible? How do these observations influence the way humans create and inhabit the built environment?

In the United States, roads are practically everywhere. Raymond Watts of the US Geological Survey claims that the farthest point from a road in the contiguous U.S. is 22 miles (Watts et al., 2007, p. 736). This vast connective circuitry is made up of ribbons of asphalt that streak through and across the country, a network of lines that connects one point to the next, from farm field to forest, through cities and suburbs, along overpasses twisting above

interstates and bridges arcing over waterways, cinching through mountain switchbacks and dusty desert straightaways, until just about all of the points on a map--the places that contain human activity--are connected. Measuring over four million miles, the United States surpasses all other countries with the length of its roads (US Dep't of Transportation, 2016) and this national network supports 250 million vehicles (Paul, 2016, p. 6). Historian I.B. Holley exalts the system of paved highways criss-crossing the U.S. as "the greatest highway system the world has ever known" (2008, p. ix). This system is the result of collaboration between human engineers, scientists, contractors, politicians, and citizens interacting with earth materials and the landscape that holds them, which includes sunlight, water, wind, and the many species of non-human living things.

In this paper, I consider what paved roads in the United States can reveal about human relationships with other living things. I propose that recognizing paved roads in the U.S. as an intersection between humans and other living things can contribute to new ways of relating to the world around us. While engineering capabilities can accomplish feats that increase the possibilities for human connectivity, human transportation also affects the movement of many other organisms.

In this exercise, I will incorporate work from a variety of disciplines. Historians offer insight into the factors that contribute to current road design and use. Psychologists study the cognitive processes that take place in humans during transportation. Landscape scholars study roads as a part of the everyday landscape. Transportation and mobilities research focuses on ways that roads connect humans to each other as well as to economic and recreational resources. Engineers figure out how to design roads that will support transportation needs.

Road ecologists focus on the effects of roads on nonhuman organisms and propose engineering solutions that offer compromises. I will use multispecies ethnography emerging from anthropology as a way to consider the ways the experiences of various species are intertwined.

Paved roads are a marker of the built environment, seemingly a clear dividing line between humans and the natural world, but roads interact with the natural world and the natural world interacts with roads. To further complicate matters, understandings of the very idea of nature are shifting. A multispecies approach to understanding roads offers a perspective that considers humans as a component part of the ecosystems we occupy, as animals entangled with and interdependent on other beings, each seeking solutions for survival. Additionally, this view also includes other living things as a part of the built environment. Ultimately, I am curious how a multispecies exploration of paved roads in the U.S. could influence change in the way humans design transportation systems and share space with other species.

The idea of multispecies consideration comes from anthropology, specifically the work of Donna Haraway. In her book *Staying with the Trouble*, Haraway dismisses the concept of dividing lines and “bounded individualism,” instead encouraging a perspective that views the fate of all species as bound together in systems with blurred boundaries in between (2016, p. 5). By taking Haraway’s posthumanist approach, the conventional categories of humans and nature, nature and culture, and the built environment and natural environment as distinct and opposing constructs lose their meaning (Aisher and Damodaran, 2016). A number of other scholars join Haraway in questioning the idea of nature as separate from humans. In *Ecology Without Nature*, Timothy Morton argues that nature is an unnecessary distinction, a dated concept with roots in Romanticism that represents the opposite of humans, an object humans

damage, and an aesthetic (2009, p. 18-22). Ultimately, Morton acknowledges that nature and culture may persist as “an ideological feature of the way the world operates” (2009, p. 23). Ingrid Leman Stefanovic and Stephen Bede Scharper address the natureculture dualism as editors of the book, *The Natural City* (2012). Stefanovic and Scharper argue that “green” technologies can only go as far as the values and attitudes that drive policy decisions will let them. The complexity of nature and the way that humans fit within it is hard to observe and therefore hard to grasp. Multispecies anthropologist Eduardo Kohn suggests that we can begin to recognize and revise “the ways in which we have treated humans as exceptional—and thus as fundamentally separate from the rest of the world—by developing a more robust analytic for understanding human relations to nonhuman beings” (2013, p. 7).

Language has not quite caught up with this evolving understanding. Proposals for new terms like natureculture (Latimer and Miele, 2009) and enviro-organism (Adams, 2016) attempt to use language to recognize these blurred lines. Some conservationists promote the idea of assigning monetary values to ecosystem services (Hausman, 2016). While this practice emphasizes human dependence on nature, it commodifies nature by translating natural elements and systems into the language of human economics. In this paper, I will continue to refer to non-human aspects of the living world as parts of nature, but will also do my best to clarify when I am referring either to elements of nature beyond or including humans.

Chapter One begins with the way road ecologists document the complex relationships between humans and other species of living things that revolve around roads. Not only are roads a threat to the plants and animals living in the path of a road, but many living things, including humans, are affected by their proximity to roads. Automotive vehicles contribute to

air pollution, impermeable pavement reroutes rainfall and roads result in habitat fragmentation for plants and animals (Forman et al., 2003). These accumulating effects don't always seem immediately consequential to humans, which affects transportation decision making. Road ecologists study the consequences of roads, warning that the hazards roads pose to nonhuman species and ecological systems will be ultimately harmful to humans.

Road ecology also focuses on mitigating these conflicts through research, better road design, and regulation. Richard Forman, a founder of the field of road ecology, writes optimistically that the current system of roads was designed before ecology began to reveal how considerations such as road location, construction methods, and vehicle use are critical to ecosystem health, but now that we understand the problems, we can begin to correct design flaws (2012, p. xi). Other road ecologists think that ecosystems will not likely be able to fully recover from the unexpected environmental damage caused by the transportation system (Trombulak and Frissell, 2000). Others argue that it isn't possible to change the current layout in any drastic ways (Lewis, 1979) since decisions to place new roads and repair existing roads are determined by other aspects of built environment (Nat'l Research Council, 2005). The existing network of roads is trapped in place by buildings and other parameters of the human-built landscape.

The factors and variables that go into road building are complex. From the time of European colonization, America entered into a complex and fraught relationship between human movement and the other inhabitants of the land. History provides a lens to understand the origins of the current system and **Chapter Two** surveys the history of paved roads in the U.S.

Chapter Three explores the experience of human movement on paved roads and the cultural, social, and emotional inputs. The speed of automotive travel changes the way humans are able to experience our surroundings. Roads are a place designed to be experienced in motion, a place that suspends the perception of time and boundaries of space that apply when we are fixed in place (Li, 2003, p. 42). Roads are a liminal place, a margin in which human identity shifts from the selves we embody at a standstill.

Chapter Four considers animal movement and ways that it can inform better human transportation design. By comparing human movement to movement of other organisms, humans may learn better ways to move ourselves and remember to see ourselves as animal actors within the ecosystem. This encourages transportation planners and policy makers to begin basing decisions on long term interests and reflects a shift from thinking about nature as a resource for materials (Williams, 2002) to nature as a habitat that sustains all life, including humans.

Chapter Five uses The Bonner Bridge in the Outer Banks of North Carolina as a case study of an infrastructure project that considers multiple objectives in its design. I will conclude with solutions and ways that seeing humans as part of ecosystem can help in transportation design, emphasizing that success will require the same caliber of collaboration that occurred at the advent of asphalt paving.

There are multiple indications that a close examination of American road infrastructure is a timely endeavor. While the cost of materials and labor makes large scale change to the built environment challenging (Lewis, 1979, p. 15), a number of factors that contribute to change are currently coalescing. The failing state of American infrastructure requires attention (Petroski,

2016), while road ecology is revealing the interconnections between living things, and new technologies are offering innovative design strategies. These three factors indicate readiness for a cultural shift that will change the physical landscape. Through my examination of paved roads in the U.S., I argue that deteriorating infrastructure coupled with recent ecological discoveries and new developments in technology present the conditions for a major change in the landscape of American infrastructure.

Chapter One: Road Ecology

In eight of the eastern United States, a small, unassuming shrub with waxy, evergreen leaves the size of a thumb nail grows in isolated patches. Box huckleberry (*Gaylussacia brachycera*) is easy to overlook. With low-lying branches that hover close to the ground, it spreads out under the shade of trees in emerald clumps that can cover many forested acres (see Fig. 1). Despite box huckleberry's tendency to spread in its location, it is actually quite a rare plant. In Pennsylvania, one of the states where box huckleberry has been found, it is officially designated as critically imperiled, and globally, its conservation status is listed as vulnerable (Nicholson, 2011, p. 15). This is partly due to the fact that box huckleberry produces berries with sterile seeds, which means that it only grows by cloning its roots (Pooler et al., 2008, p. 68). While clonal colonies comprising a single plant can blanket acres, research shows that there is no genetic variation within each isolated population, threatening the plant's long term viability (Nicholson, 2011, p. 13). Since each patch is only one plant, there are only as many individuals as sites where it is found, resulting in its rarity.

Fig. 1 Box huckleberry, *Gaylussacia brachycera* in the Hugo L. Blomquist Garden of Native Plants, Sarah P. Duke Gardens, Durham, NC. Photo by author.



The first scientist to notice box huckleberry was French botanist Andre Michaux, who found it in Virginia in 1796 and published a paper in 1803 that misidentified it as a blueberry (Nicholson, 2011, p. 13). During the early 1800s, several other stands were found in West

Virginia and Pennsylvania. Frederick Coville was the first to warn that the box huckleberry could be imperiled. In his 1919 article, "The Threatened Extinction of the Box Huckleberry, *Gaylussacia brachycera*," Coville was also the first to suggest that each stand was a single plant, shooting up new growth from its rhizomes at an average rate of six inches per year (p. 32). The sole population he was able to locate was in Pennsylvania, and he observed that it was confined in place by a road on one side, cultivated fields on two sides and a small brook on the other. Coville knew that growth in the direction of the road and fields would be impossible, but the fact that the plants were only growing on one side of the brook led Coville to hypothesize that it only grows through its rhizomes, as seeds could have easily spread across the narrow brook (p. 31). If this was true, then it made sense that the entire patch was a single clonal community. Coville calculated the age of the eight-acre patch by dividing its total size by its average rate of growth, estimating it to be at least 1,200 years old (p. 32). In 1920, an even larger patch was found, covering 100 acres. According to Coville's formula, it would be 13,000 years old, though one researcher points out that the natural history of the area makes that seem unlikely--the forest that shelters it is only estimated to be 8,000 years old (Nicholson, 2011, p. 15). While it may not be quite as old Coville's method of calculation would suggest, box huckleberry is still considered to be among the most ancient plants in the eastern United States (Pooler et al., 2008, p. 73).

The story of box huckleberry is intertwined with the history of roads. Maurice Brooks professor emeritus of biology at West Virginia University, remembers how in the early 1900s, newly available Model-T cars and freshly paved roads allowed botanists to explore previously isolated areas and discover new plants (1986, p. 233). By the mid-1930s, the Skyline Drive in

Virginia connected to the Blue Ridge Parkway in North Carolina, providing hundreds of miles of paved highways by which to explore the plant communities of the Blue Ridge Mountains. As a biology professor in southern Appalachia, Brooks participated in the expansion of research and recreation that was made possible by these new roads and trails. Scores of botanists drove in to study the biodiversity of the southeast at regional universities and local researchers such as Brooks were happy to host them. It was a time of botanical discovery and rediscovery.

While people have been undoubtedly identifying, harvesting and consuming box huckleberries for a long time in the few places it grows, common use often evades record. No scientists had documented any box huckleberries in West Virginia in over a hundred years. Brooks recounts a story of how a local Presbyterian minister, Fred W. Gray, rediscovered box huckleberry when someone in his congregation baked a pie filled with its berries for a church meeting (p. 235). To the person who baked the pie, the plant had never been lost. When the minister, who happened to also be an amateur botanist, polled his community about the plant, they pointed him to over 75 locations where he found it growing. New roads, combined with the local knowledge of Gray's congregants, allowed him to easily access these populations. This story is a reminder that expertise lies in a diversity of communities and highlights the importance of sharing knowledge across disciplines and ways of thinking.

In telling stories that connect roads to botanical exploration, Maurice Brooks celebrates the way new systems of transportation allowed for the discovery and rediscovery of plants such as box huckleberry in West Virginia. The Pennsylvania populations, however, did not fare so well when it comes to roads. In the 1960s, US Route 22/322 was realigned through Perry County, Pennsylvania, home to the oldest and largest colony of box huckleberry ever

discovered, and the new route paved over a huge portion of this 100-acre stand (Nicholson, 2011, p. 15). US Route 22/322 hugs the winding Juniata River through Perry County, and its path was likely chosen to be direct and cost efficient. It's hard to know whether the box huckleberry patch could have been avoided with better planning.

In 1970, the National Environmental Policy Act (NEPA) began to require all construction projects using federal funds to complete an environmental impact study (Forman et al., 2003, p. 6). This means that road builders must assess whether endangered plants or animals live in the path of planned roads. If rare or threatened species of plants are discovered, plant rescue teams can swoop in to save the plants in harm's way, or alternate routes can be considered. Had this policy been enacted a decade sooner, perhaps it could have altered the fate of the box huckleberry in Pennsylvania. The story of the box huckleberry and the way roads assisted both in its rediscovery in West Virginia and nudged it toward demise in Pennsylvania demonstrates the complex ways that roads interact with plants.

Roads create a harsh environment for living things, but some plants survive right up to the edge of the asphalt. The plants that live closest to the roadside have to be tough. The technical term is *disturbance tolerant*, which means they can survive or even benefit from interferences like mowing, exposure to chemicals and particulate matter, and soil compaction from the weight of vehicles riding on the shoulder (Forman et al., 2003, p. 78). Grasses are particularly well suited for this environment, as their growing cells are located at the base of their stem (Forman et al., 2003, p. 78). This means that for grass, the slice of a lawnmower blade stimulates growth, whereas other flowering plants grow from the tip of their stems and are wounded when cut.

Plants

Richard Forman, widely recognized as a founder of road ecology, studies the geographic distribution of roads and the ways they interact with plants, animals and water systems. In 2000, Forman and Robert Deblinger conducted an ecological study of a suburban highway in Massachusetts. They selected a 25 kilometer stretch of a four lane highway and looked at the way the road interacted with wetlands, plants and animals including moose, deer, amphibians, and birds. They found that the effects of the road extended over 100 meters for each of the twenty ecological factors they measured, and in some cases, the effects of the road extended as far as 800 meters from the road (Forman and Deblinger, 2000). They found that roads changed the way streams and wetlands drain, they noticed that road salt had entered surface water, and they saw that exotic plants intentionally planted along roadsides had spread into wooded areas up to 120 meters from the highway. Moose, deer and birds were affected through collision with vehicles. Habitat and movement patterns had changed for moose, deer, birds, and amphibians. In their conclusion, Forman and Deblinger acknowledge the engineering prowess of roads but encourage transportation planners to consider ways to mitigate the ecological problems they create, creating solutions that allow for biodiversity and human mobility.

One of the harmful effects of roads seems, at first glance, invisible. In the early 1900s, emissions from horse-drawn vehicles consisted of piles of manure dotting the roadway. During the transition to horseless carriages, an early term for cars, the lack of physical manure was celebrated (Petroski, 2016, p. 10). No one anticipated how the invisible emissions from an exhaust pipe would end up polluting the air, and air pollution can become visible by examining

the plant communities surrounding a road. In Raleigh, North Carolina, Gary Perlmutter searches for lichen growing near highways to assess air quality. Perlmutter looks for scaly patches on tree trunks or delicate green frills decorating the tips of branches higher up. Lichen, which is a symbiosis between an algae and a fungus, is also a bioindicator, which means its presence or absence is a measure of environmental health (Perlmutter et al., 2017). Excess nitrogen ends up in water, soil and air from fossil fuel use in agriculture, industry and transportation (The Good Verge Guide, 2016). The amount of nitrogen in the air determines which species of lichen can survive. Different species of lichen have varying pollution tolerance levels. While some can adapt to thrive in areas with increased atmospheric nitrogen, others cannot. In polluted areas, Perlmutter found an increase in species that can tolerate pollution and a decrease in intolerant species, resulting in less species diversity overall. Excess nitrogen is changing plant communities worldwide, reports the organization PlantLife, resulting in a loss of species richness, a decline in overall biodiversity, and dominance by the species that can adapt to tolerate these harsh conditions (The Good Verge Guide, 2016).

A number of chemicals end up in the air, water and soil near roadsides. Vehicles contribute harmful ozone molecules to the air (Trombulak and Frissell, 2000). A number of heavy metals from gasoline additives end up in soil and water, including aluminum, iron, cadmium, copper, manganese, titanium, nickel, zinc, and boron (Trombulak and Frissell, 2000). Even dust that is spread by passing traffic can injure plants by coating their leaves which blocks access to sunlight for photosynthesis as well as inhibits respiration and transpiration (Farmer, 1993).

Air pollution has also been shown to encourage certain plants. Carbon dioxide is another greenhouse gas associated with transportation. Since the 1950s, there has been a 22% increase in carbon dioxide and the current atmospheric amount is expected to double in the next hundred years (IPCC, 2001). The increase of atmospheric carbon dioxide concentration predicts negative consequences on function of earth systems, including unpredictable weather patterns, increasing global temperatures, and rising sea levels (Crutzen and Stoermer, 2000). Researchers have recognized the potential public health hazards due to decreasing air and water quality, including the spread of diseases from an increase in pathogens (Ziska et al., 2007, p. 288). Despite the catastrophic indications for human health, climate change is still considered a controversial policy issue. Recent studies have shown that plants will likely benefit from increases in carbon dioxide, as carbon dioxide is a required ingredient in photosynthesis (Ziska et al., 2007, p. 288).

While plants are useful to humans, even essential for human survival, there also plants that pose public health risks. Poison ivy is one example. Ziska et al. performed an experiment to test field observations suggesting that poison ivy may benefit from increased levels of carbon dioxide in the atmosphere. This 2007 study confirms that increases in carbon dioxide in the air can correspond with changes in the biomass and total urushiol content of poison ivy. The experiment consisted of exposing poison ivy plants to increasing levels of carbon dioxide over eight months that correspond to predictions for atmospheric increase following current trends. They found that when poison ivy was exposed to more carbon dioxide, it grew bigger, heavier leaves and longer roots (Ziska et al., 2007). It also grew faster. Bigger leaves mean that the

plants had higher urushiol content, which is the compound that causes mild to severe contact dermatitis for most humans, posing a public health risk (Ziska et al., 2007).

In 1970, another environmental policy was enacted in the US that had an effect on roads and plants. The Clean Air Act reduced air pollution from vehicles by requiring the use of unleaded gasoline (Forman et al., 2003, p. 6). These regulations made a huge difference in air quality, but additional problems continue to emerge. The use of new chemical pollutants coupled with a surge in additional vehicles on the roads continue to produce atmospheric chemicals and runoff. Individual vehicles pollute less, but more vehicles collectively result in more air pollution. Air pollution from vehicle exhaust continues to have an effect on vegetation. The field of road ecology documents ways that roads affect plants and the way plants also affect roads.

When it rains, the falling water drops collect atmospheric pollution before hitting paved roads and parking lots. Groundwater aquifers get depleted when rainfall can't infiltrate the ground, causing changes to hydrologic systems. On Long Island, for example, there is so much paved land that rainfall is rerouted into the ocean rather than allowing it to percolate underground and recharge groundwater aquifers (Ehrlich and Ehrlich, 2008, p. 214). Over the long term, this risks limiting the availability of clean water and increasing the occurrence of droughts.

As water hits and slides off impermeable paved surfaces, it picks up additional pollutants and flows into waterways. Runoff from roads is a major contributor to water pollution. Plants have the ability to provide a valuable service in mitigating the effects of this pollution. Plants provide a filtration system by slowing down the flow of water and absorbing

chemicals and heavy metals that are present. Research shows that a strip of plants along the roadside, called a vegetated filter strip, can allow stormwater to infiltrate the soil and plants can filter out pollutants (Bloorchian et al., 2016). Not all plants are equally beneficial, however, and soil types matter. An experiment conducted in Illinois showed that native prairie grasses were more effective than turf grass at slowing runoff and filtering pollutants (Bloorchian et al., 2016).

Roadside environments have increased levels of heavy metals, salts, organic molecules, ozone, and nutrients and these types of contaminants are found in the tissue of plants growing as far as 200 meters away from a road (Trombulak and Frissell, 2000). Exposure to these pollutants can change plant communities. Cattails and common reed grass are salt tolerant (Nat'l Research Council, 2005, p. 5). Ecologists Steven Brady and Jonathan Richardson observe that red fescue (*Festuca rubra*), a common roadside grass, has developed a higher tolerance to lead pollution through the process of natural selection (2017, p. 5). Roadsides can be advantageous to certain plants and can even be an important vestige habitat for native plants. Bushy bluestem (*Andropogon glomeratus*) is one example of a native grass that thrives along the roadside in certain areas of Durham, North Carolina. Ecologists have observed that roadsides are dominated by many common plants with little variety (Forman et al., 2003, p. 79). The abundance of bushy bluestem supports this observation. This is likely due to that fact that plants growing along the roadside have to take hold quickly and competitively.

The process of road construction scrapes and compacts soil, creating an edge habitat with abundant sunlight and bare soil. Opportunistic wind-blown seeds try to take hold in this surface. Bare soil suffers from erosion and young plants are in danger of getting washed away

by rain until their roots grow big enough to hold the soil in place. Roads alter the physical landscape by changing soil density, temperature, soil moisture content, light levels, and water flow (Trombulak and Frissell, 2000). These are all variables that affect plant growth. Often road construction wipes out existing plant communities, but even when nearby plants are spared, the disruption of root systems and soil compaction during construction can harm remaining vegetation. In some instances, these consequences can be delayed, so that trees and vegetation suddenly die months or even years after road construction is complete (Nat'l Research Council, 2005, p. 7).

To avoid erosion after construction, the plants that grow along roadsides are often planted there. In some cases, plants intentionally placed along the roadside to improve aesthetics or control erosion turn out to be invasive. Roads can assist in dispersal of invasive plant and animal species. Researchers who observed fire ants building mounds along road edges in South Carolina concluded that the invasive ants prefer edge habitats (Stiles and Jones, 1998). A study of invasive plants along Oregon roadsides concluded that availability of sunlight, the level of disturbance, and the linear habitat of the road were conducive to invasive plant dispersal (Parendes and Jones, 2000).

In the southern United States, kudzu (*Pueraria thunbergiana*) is a classic example of an exotic species that thrives along the roadside. Kudzu is a vine that twines tightly around any surface it can grasp with its tendrils. As it grows, it chokes the structures supporting it, swallowing whole trees and houses in a blanket of green, ultimately crushing them under its weight. Not only does it pose a hazard to trees and property, kudzu contributes to air pollution by storing atmospheric nitrogen that is released as nitric oxide into the air, a greenhouse gas

and precursor to ozone (Hickman et al., 2010). In 1876, kudzu was brought from Japan to the US and promoted as an ornamental plant and a forage crop (Swearingen et al., 2010, p. 111). From the 1930s to the 1940s, over one million acres of kudzu were planted in the southeast as erosion control (Swearingen et al., 2010, p. 112). The deleterious effects were entirely unanticipated. In 1998, US Congress officially declared kudzu a noxious weed (Swearingen et al., 2010, p. 112).

PlantLife, an organization that advocates for plant diversity in the UK, publishes a guide to recommended roadside plants called *The Good Verge Guide*. This guide points out that a whopping 97% of prairie ecosystems in the UK have largely disappeared, subsumed by the built environment, agriculture, and forests. (The Good Verge Guide, 2016, p. 4). Roads are the closest habitat remaining for surviving prairie wildflowers and grasses to grow. In the North Carolina piedmont, areas of open prairie were common before European settlers turned their livestock loose to graze on pasture and stopped fire as a natural manager of the prairie ecosystem. These practices greatly altered the landscape and allowed hardwood forests or pastures to replace prairies.

One of the few remaining places where prairie plants continue to grow naturally are along roadsides, and these plant communities partner with animal wildlife. Road ecologist Richard Forman describes a feedback loop between plants and animals along the roadside, in which seeds attract birds and other fruit-eating animals who assist plants in spreading seeds, which grows more plants, which attracts more animals (Forman et al., 2003, p. 80). Some roadside plants are a key part of animal diets. Similar to gas and service stations along the interstate, roadside milkweed stands serve as way stations for monarchs to lay their eggs as

they migrate. While milkweed is the only host plant larval monarchs can eat, other plants along the road feed various birds, insects and other animals as they travel.

In the UK, bird's-foot trefoil (*Lotus corniculatus*) is eaten by more than 130 species of invertebrate (The Good Verge Guide, 2016, p. 4). Bird's foot trefoil is a legume, a relative of peanuts and lentils. It grows 2-3 feet tall, and each cluster of its delicate, brilliant yellow blossoms looks like a miniature version of a tea cup carnival ride. The USDA lists bird's foot trefoil as a control for wind and water erosion along roadsides, another service plants provide. It can survive saline soils, which are a result of runoff from de-icing salt applied to roads in snowy climates. The USDA also warns that in some areas, bird's foot trefoil can become invasive. According to the Minnesota Department of Natural Resources, birdsfoot trefoil is an invasive plant that outcompetes other vegetation and is problematic on roadsides. Bird's foot trefoil is a reminder that plants behave differently outside their endemic areas.

In a roadside study in central Israel, researchers Eliav Rotholz and Yael Mandelik observed increased plant species richness along the road edge and surrounding landscape, but disturbance-associated species made up for most of the species composition while there was a decrease in rare and endemic species (2013). Rotholz and Mandelik caution that the low proportion of species identified as high priority for conservation decrease the value of the road edge habitat to biodiversity conservation. Ultimately, road edges were associated with increased rates of predation, parasitism, and offspring mortality, suggesting that they have a negative overall effect on the conservation of plants and small animals in the area (Rotholz and Mandelik, 2013).

Animals

The existence of a road takes on different meanings for the many species whose lives are changed, down to the genetic level, by their proximity to paved roads and their ability to utilize or avoid them. Roads divide habitat and block animal movement. Roads fragment and isolate populations, affect population by disrupting breeding patterns, limiting gene flow, and preventing migration to nesting sites, mating locations, or food sources (Nat'l Research Council, 2005, p. 5). Traffic noise interferes with mating calls and the ability to perceive predators. In cities, squirrels seem to rely more on sign language, using their tails to communicate more than the vocalizations they use in quieter settings (Partan et al., 2010). Artificial lighting along roads can disrupt nocturnal behavior by tricking animals into thinking it is daytime (Andrews et al., 2007). Cars pose a huge threat to animals, putting them at risk of becoming roadkill. Reptiles are attracted to the heat of road surfaces for thermoregulation, increasing their risk of being hit by a car (Andrews et al., 2007). In some areas, vehicle-related mortality threatens endangered species like Florida panthers and grizzly bears (Nat'l Research Council, 2005, p. 7). Deicing salt has been seen to attract moose to the roadside (Fraser and Thomas, 1982). Roadkill can also attract scavengers, which puts additional animals at greater risk of vehicle mortality.

Roads and many species of animals have a conflicting relationship. Some of the ways in which roads disrupt animal habitat and behavior seem obvious, but sometimes the effects of roads on animals are surprising. Steen and Gibbs conducted a study comparing the effect of roads on painted turtles and snapping turtles in central New York compared a variety of wetland habitats in low and high road density areas (2004). They found that in areas with high road density there were more male than female turtles in both species. They hypothesized that

the sex ratio was affected by higher female mortality, because annual migration to lay eggs puts them in greater danger of getting hit by cars. They note that turtle populations are particularly threatened by the loss of sexually mature individuals, as it takes years for most turtle species to reach sexual maturity (Steen and Gibbs, 2004).

Ecologists Charles Brown and Mary Bomberger Brown were the first to notice that cliff swallows (*Petrochelidon pyrrhonota*) living near roads have evolved shorter wings. A shorter wingspan allows them to increase their vertical rise during take-off, reducing their likelihood of being struck by a car. Cliff swallows live together in groups and commonly attach their neighborhoods of mud nests to the vertical walls under bridges, below overpasses, and in culverts that pass underneath roads. Approximately 80 million birds are hit by cars each year in the United States (Erickson, 2005). Due to the proximity of the cliff swallow's common habitat to roads it could be expected that they would suffer from the same fate. Brown and Brown observed cliff swallow behavior over 30 years, collecting a variety of data from multiple sites. Over the years, they noticed a decrease in roadkill. When they measured the wings of the birds that had been hit by cars, they found that their wings were up to six millimeters longer than those of the surviving population (Brown and Brown, 2013). They noted other possible contributors to this morphological change could be weather or changes in insect prey, and mentioned that the reduction in road kill could also be related to learned behavior of more safely navigating near roads.

Amphibians like frogs breed in roadside habitats and their thin, absorbent skin makes them susceptible to chemical contamination from runoff, which commonly includes herbicides, petroleum, chloride from de-icing salt, and heavy metals (Andrews et al., 2007). Additionally,

some amphibians are so delicate that the high pressure air wave made by a passing car moving faster than 20 mph can kill them without making any contact (Holden, 2002). Dietrich Hummel, a professor of aerodynamics at the University of Braunschweig in Germany, was the first to notice toads who had fallen victim to this particularly gruesome end. Hummel identifies pressure shock as the cause of death when he observes otherwise intact toad bodies with the inner organs forced out through their mouths (Holden, 2002).

Ecologists Steven Brady and Jonathan Richardson document additional evolutionary changes that have been stimulated by human roads, and they have found that some species are adapting to the conditions adjacent to roads. For example, while road salt used to prevent icy conditions in the winter can be harmful to amphibians such as wood frogs (*Rana sylvatica*), spotted salamanders (*Ambystoma maculatum*) are adapting to survive around higher salt concentrations (Brady and Richardson, 2017, p. 5). Researchers have noticed what may be another adaptive evolutionary change near roads in frog mating calls. Females of some frog species associate low pitched mating calls with fitness, but traffic noise reduces the distance a low-pitched frog call can travel (Parris et al., 2009). Communities of male southern brown tree frogs (*Litoria ewingii*) living near roads have been heard adjusting their mating calls to a higher frequency to be heard over the noise of traffic, prioritizing audibility over attractiveness (Parris et al., 2009). Sound barriers between roads and vernal breeding pools have been proposed as a solution, but this could result in further fragmentation of migrating animals. Sound buffering dense vegetation is another recommendation that may have more benefits than drawbacks.

While roads pose many dangers and risks, they also provide important habitat for a number of plants and animals. Many animals, including insects, birds and mammals, rely on

roadside habitat as a source of food or shelter (Parris and Schneider, 2009). Living, eating or mating near a road is a gamble for any animal. A location that meets certain aspects of an animal's survival needs but is not ultimately beneficial is called an ecological trap, explain researchers Leslie Ries and William Fagan (2003). Ries and Fagan study habitat edges along places like rivers and roads. In a 2003 study, they described a potential ecological trap for a species of praying mantis in Arizona that lays its egg cases in a river edge habitat where it experiences higher incidence of predation by birds.

Humans may have set their own ecological trap by building roads that disrupt so many other living things and systems. Road ecology shows that roads decrease biodiversity. Ecologists Anne and Paul Ehrlich call biodiversity "the populations and species that are working parts of human life-support systems" (2008, p. 214). The species of animals that are seemingly disconnected from each other and from humans--the frogs that aren't heard by their mates, the turtles that can't migrate to lay their nests, and the moose that are killed by passing vehicles--are being affected by human patterns of movement in ways that were never imagined when our current transportation system was designed.

Numerous studies have documented additional ways the effects of roads extend far beyond the edge of the pavement for many species. This is called the road effect zone (Forman, 2000). Forman calculates that while roads take up 1% of land surface area in the United States, roads affect up to 20% of total U.S. surface area (2000). This demonstrates how the cumulative effects of humans can change earth systems in resounding ways. These unexpected ways in which roads have altered other species and systems also indicate that solutions may not be able to entirely reverse these effects. Nonetheless, road ecology looks for ways to design roads

that are “elegantly embedded” within the landscape in a multispecies friendly way (Forman et al., 2003, p. 399). The ability to apply any lessons learned from the scientific field of road ecology will require developing a collaborative partnership with the people-focused transportation community.

Chapter Two: History of Paved Roads

In his book *The Road Taken*, engineer Henry Petroski argues that the national system of roads and bridges is in critical distress due to its age (2016). The idea of a unified national transportation network took almost a hundred years to realize. In 1919, long before smoothly paved roads stretched across the country, a young Lieutenant Colonel by the name of Dwight D. Eisenhower traveled from Washington, D.C. to San Francisco as part of a U.S. military convoy determined to test military mobility while showing off the Army's Motor Transport Corps' new fleet of defense vehicles. The convoy plodded along at 5 miles an hour, constrained by the poor condition of dirt roads and wooden bridges they encountered, finally reaching their destination after 62 days of travel. When Eisenhower later became president in 1953, his experience with the convoy compelled him to secure federal funding for what became the National System of Interstate and Defense Highways (Petroski, 2016, p. 42-49). While Eisenhower is often credited with creating the interstate system, its development began decades earlier and another six presidents came and went from the oval office before the first full length of interstate was completed in 1986. The entire system was completed in 1990 (Nat'l Research Council, 2005, p. 40), and by the time the last leg was completed, earlier stretches were already in urgent need of repair. The choices about how to repair this aging infrastructure will determine the future of transportation, similar to the way the past hundred years have been shaped by Henry Ford's invention of the Model T and the discovery of asphalt as a road surface.

When functioning properly for humans, roads are a utility that fade into the landscape. "To the average citizen, infrastructure is neither seen nor heard until it flashes or makes the news," writes Petroski (2016, p. 6). In February 2017, this was the case for residents of several

counties in northern California who had to evacuate due to a failing dam that threatened to flood the surrounding area. CNN reported that traffic was immobilized for up to 4.5 hours (Park and McLaughlin, 2017). Another example occurred in early October of 2016, when Hurricane Matthew swept up the east coast of the United States, bringing with it the usual havoc of a hurricane. Wind forced its way through homes, uprooted trees, and rain water poured down more quickly than the ground was able to absorb it. From Florida to North Carolina, lines marking lanes buckled as roads washed out, mixing dark layers of asphalt with the packed red clay underneath (see Fig. 2). Unexpected events such as these examples challenge the capacity and stability of local roads, but gridlock also occurs across the country during rush hour at daily intervals as regular as the tides.

Petroski's claim about systems gaining visibility through dysfunction also applies to the earth systems and living components of the environments we live in. The ecological destruction caused by roads only becomes visible once the system has been designed and the damage has begun. Systemic change is complicated not only by cost of investment and available space, but also by the fact that humans have formed emotional attachments to vehicles and expectations for travel. Ecologist Timothy Morton supports this idea when he writes that "Coming up with a new worldview means dealing with how humans experience their place in the world," (2007, p. 2).

Fig. 2. Road washed out in Wake Forest, NC after Hurricane Matthew, October 2016. Photo by Ashlie White.



For humans, roads are an expected component of the ordinary landscape. Early proponents of studying ordinary landscape include geographer D.W. Meinig. Meinig describes landscape as an aggregate of history and use when he writes that “Every landscape is a code, and its study may be undertaken as a deciphering of meaning, of the cultural and social significance of ordinary but diagnostic features” (1979, p. 6). Meinig’s ideas on landscape interpretation were influenced by the work of naturalist May Theilgaard Watts, who suggested ways to look for clues that reveal human history in the landscape in her book *Reading the Landscape of America* (1979). For example, Watts wrote about how observing groves of thick-barked bur oaks in the prairies of Illinois tells a story of how Native Americans used fire to maintain the prairie ecosystem, a form of natural resource management that later evaded the observations of European colonists. While Watts focused her writing primarily on forest ecosystems, Meinig applied her principles of observation to the way the built environment can also reveal stories from the past. Meinig made sure to point out that is visible does not tell the whole story, but rather reveals patterns of the past in details such as the basic geometrical layout of public and private property (1979, p. 43).

History and geography provide the template for the current system of roads combined with local and regional influences on development. In 1915, historian Seymour Dunbar authored a comprehensive book over a thousand pages in length called *A History of Travel in America*. In his preface, Dunbar explained that the act of simply looking at remaining relics from the past is not nearly as important as looking to history to understand how and why things exist the way they do (p. vii). The disconnect between “old conditions and new ideas,” writes Dunbar, can only be bridged if we learn from past mistakes (p. viii).

The total length of roads in the US has less than doubled since 1900, but the vehicle capacity has multiplied (Nat'l Research Council, 2005, p. 38). The challenge of predicting future needs coupled with the plodding pace of road development, from design to construction, means that by the time roads are built, the end product is headed toward obsolescence. Despite the regular maintenance required by modern roads, human roads can be a persistent feature on the land. There are roads still in use today that date back hundreds and sometimes thousands of years. For example, the Appian Way in Italy was built almost 2,000 year ago to transport military troops and supplies from Rome to southern Italy and some of the portions outside of Rome are still driven on today (Petroski, 2016, p. 30). The top stone layer was called *pavimentum*, which is the origin of the word pavement, but the discovery of the asphalt pavement that is still used today was thousands of years away.

Hundreds of years before the use of asphalt as a road surface was discovered in Europe, Europeans traveled to America over water. In 1584 and 1587, ships sent from England on behalf of Queen Elizabeth I arrived in the New World (www.outerbanks.com/elizabeth-ii.html). Roanoke Inlet along the Outer Banks of North Carolina allowed the exploring English vessels to access Roanoke Island. Attempts at establishing settlements ultimately failed at this location, but this first point of contact between English settlers and the New World set in motion a monumental change in the landscape and established a relationship between humans and the natural world that persists in the transportation infrastructure of the United States today.

English settlers used boats to travel to the New World, but they brought horses for overland transportation, as well as other livestock. Europeans and their domesticated animals shaped the American landscape in several ways. In *Creatures of Empire*, Virginia DeJohn

Anderson describes the different relationships between wild animals, domesticated animals, European colonists and Native Americans (2004). In retelling this history with an emphasis on animals, Anderson describes how Europeans and indigenous Americans related with animals and nature in different ways. These different views of natural world resulted in vastly different ways of constructing the built environment. In the first chapter of her book, Anderson explains how Native Americans did not distinguish between natural and supernatural worlds. Rather, they included nature within spirituality and saw animals as spiritual beings. This view didn't fit within the monotheistic religious view of European settlers. Neither of these distinct ways of understanding the world translated into the other, ultimately resulting in tragic conflicts between the two communities.

Anderson argues that livestock determined the landscape of colonial America because settlers needed water and open pastures to graze their animals. They divided land into chunks of private property and built fences to contain livestock, which were also intended to keep out wild animals. Native Americans, in contrast, hunted wild animals that moved freely. These two ways of relating to natural resources result in drastically different physical landscapes, and the myth that Native American subsistence practices did not change the landscape persists. When Europeans first began exploring the eastern U.S., they encountered oak forests cleared of underbrush but did not understand this landscape was a result of careful management by indigenous people. It is now understood that Native Americans managed the landscape by regularly burning the forest to encourage certain plants and discourage others, allowing clear passage for travel, hunting and farming (Moor, 2016, p. 170). Within two decades of European colonization, however, this open forest savannah ecosystem had been transformed, due in part

to different European land management practices but also in large part to another catastrophic consequence of the differing relationships with animals between colonists and Native Americans--disease.

European domesticated animals changed the American landscape by introducing new diseases. Europeans had developed resistance to zoonotic diseases by living in proximity with domesticated animals over hundreds of years, but exposure to these new diseases ravaged indigenous populations. As the number of European colonists increased, Native American populations declined. By the time large numbers of Europeans were regularly immigrating to America, nearly 90% of the indigenous people had died (Moor, 2016, p. 169). The physical environment changed quickly as a result of fewer indigenous people practicing natural resource management.

Vehicles determine the appearance and structure of a path. Over land, Native Americans traveled by foot. Historian Seymour Dunbar explains that the Native American trails were 12-18 inches wide and worn up to a foot deep in areas of heavy travel (1915, p. 19). The Cherokee made narrow paths along ridgelines that followed game trails, which were good for foot travel but too steep for the horses Europeans used as vehicles (Moor, 2016, p. 168). Even when Europeans traveled by foot, they followed these same footpaths but their different footwear changed the appearance of the trail. Dunbar quotes 19th century author Nathaniel Hawthorne, who observed how "The forest track trodden by the hob-nailed shoes of these sturdy Englishmen has now a distinctness which it never could have acquired from the light tread of a hundred times as many moccasins" (Dunbar, 1915, p. 20). In comparing the visible differences between the ways Europeans and Native Americans left their mark on the

landscape, Hawthorne describes the way the firm steps of the English imposed “a decided line along which human interests have begun to hold their career” (Dunbar, 1915, p. 20). Dunbar notes here that Hawthorne’s definition of “human” refers specifically to white Europeans, an indication of the conflict between the two communities.

Geographer Denis Cosgrove suggests that when investigating reasons for the appearance of the human inhabited landscape, the first place to start is to examine the way humans use the land (1984). He explains that the transition to capitalism in Europe resulted in a new way of relating with land and environmental resources (Cosgrove, 1984, p. 5). Capitalism used the land as a commodity and colonists brought this market economy with them to America. Colonial farms took a very different approach to growing crops as compared to indigenous ways of managing plants. Colonists carved the land into private parcels and established routes between properties to move to buy and sell goods. The way colonists cleared land for agricultural space and roads to connect them supports Cosgrove’s claim that “changes in the way that humans organize to produce their material lives quite obviously result from and give rise to changes in relationships with their physical surroundings” (1984, p. 5). Ultimately, the transition to the system of capitalism in America resulted in “the subjugation of the whole continent of North America to European modes of material production, its inclusion within the European agricultural economy, the wholesale exploitation of its natural resources and wildlife, timber and mineral deposits, its integration by canal and railroads and its colonization by farmhouses, towns and cities” (Cosgrove, 1984, p. 5). The new colonial landscape took the place of the indigenous landscape, further obscuring it from view.

The current road system in the US, in many places, can be traced back to the patterns of movement of the Native Americans and animals that preceded European colonists. Geographer A.B. Hulbert attributes the location of many early roads, railways and canals to trailblazing buffalo (Moor, 2016, p. 144). Before European settlers arrived in the United States, Native Americans, who traveled over land on foot, primarily followed paths made by browsing buffalo (Petroski, 2016, p. 28). Some of these foot paths can still be found, even where forests have filled in around them. In other places, the footpaths became widened and then paved to form the basis for the current configuration of roads. Lamar Marshall, a historian who maps Cherokee footpaths, believes that 85% of historic Native American trails have been paved over by modern roads (Moor, 2016, p. 161). Seymour Dunbar supports this with his observation that “Practically the whole present-day system of travel and transportation in America east of the Mississippi River, including many turnpikes, is based upon, or follows, the system of forest paths established by the Indians hundreds of years ago” (1915, p. 19). Robert Moor suggests that the network of Native American footpaths “is arguably the grandest buried cultural artifact in the whole world,” and “a system of knowledge...entombed in asphalt” (Moor, 2016, p. 162). The current network of roads in the United States tells a story of colonialism by what remains invisible, particularly where the location of a modern road obscures the history of indigenous culture.

The Everyday Landscape

Where people go, roads follow, and where roads go, people follow. By the 1750s, Europeans were settling into America. They gradually moved inland, changing the landscape as

they went. They traveled on horses and horse-drawn vehicles, which needed a wide surface to support them. As settlers and pioneers continued westward to colonize indigenous land across the United States, the network of roads spread. The construction of wider, more durable thoroughfares is one of many ways that the arrival of Europeans and domesticated animals changed the American landscape.

The National Land Survey of 1785 established the Northwest Territory, which corresponds to what is considered the Midwest today (Jackson, 1979, p. 158). This landscape was laid out in a grid made up of straight roads and fence lines. Railroads became another mode of transportation for people and goods. Landscape scholar J.B. Jackson describes the way “towns grew in a grid pattern in a matter of months, only to vanish in weeks when a railroad line was built elsewhere” (Jackson, 1979, p. 160). This is comparable to cities today that wither when new highway bypasses are built and reroute traffic away from established businesses. But where new roads go, business follows. In 1951, Massachusetts Route 128 was designed to ring the outskirts of Boston. During design and construction, it was criticized as “the road to nowhere,” but the new road ultimately attracted a thriving economy as businesses popped up and demonstrated the economic development potential of the interstate system (Petroski, 2016, p. 49). Researchers Lichter and Fuguitt conducted a study on the economic impact of living near an interstate and in their findings they describe what they call the “interstate effect,” suggesting that the areas surrounding highways are zones of opportunity for commerce and employment (1980).

In 1979, geographer Peirce Lewis wrote about using the everyday landscape to understand the culture in which it is situated. He writes that the human-built environment

“provides strong evidence of the kind of people we are, and were, and are in the process of becoming” (Lewis, 1979, p. 15). When ordinary landscape is interpreted as a reflection of culture, it is important to consider not only what is visible but also what has been covered and obscured. Lewis also explains that the investment of resources in developing the landscape creates resistance to change, but change is possible under certain conditions. Due to the inconvenience, cost and effort needed to change the landscape, Lewis concludes that any large scale change in the appearance of the landscape likely coincides with a major cultural change taking place (Lewis, p. 15).

The landscape changes caused by the arrival of European colonists supports Lewis’ conclusion. Another example of a landscape change caused by cultural change took place in the 1960s and 70s. As individual car use increased, more people began commuting from homes in the suburbs to work in the city. The hub and spoke pattern of highways around cities was designed to accommodate this cultural shift (Nat’l Research Council, 2005, p. 51). A third example took place in the 1970s, highways were designed to cut across cities nationwide as part of urban renewal, a veiled term for discriminatory urban planning policies that had a devastating effect on low-income areas and communities of color (www.learnnc.org/lp/editions/nchist-recent/6242). This happened in Durham, North Carolina, where the construction of Highway 147 cut through large swaths of historically African American business and residential areas, including culturally important structures such as churches and entertainment venues (see Appendix A). Promises to fund relocating homes and businesses never materialized. Residents of the Crest Street community, originally included in

the route of the new highway, successfully opposed the plan and the highway was rerouted around the neighborhood.

Marxist geographer Don Mitchell takes issue with Lewis' claim that landscape is primarily something that reveals culture. Instead, he places the emphasis on landscape as a product of human action, what he describes as "a physical intervention into the world" (Mitchell, 2008, p. 34). Urban historian Dolores Hayden describes sociologist Henry Lefebvre's similar view of landscape as the production of space, which he sees as a way to meet social and economic needs (Hayden, 1995, p. 19). Within the market economy of capitalism, everything is produced as a commodity to maximize profits, including landscapes, Mitchell explains (2008, p. 34). D.W. Meinig agrees, observing that as long as land is a form of capital, the visible landscape will reflect this value (Meinig, 1979, p. 42). According to this view, the social benefit of roads follow their economic function, and aesthetic considerations are not a priority. While Lewis also explains landscapes in terms of their costs, he describes commodities as the ingredients of a landscape rather than a product of the landscape itself. "In trying to unravel the meaning of contemporary landscapes and what they have to 'say' about us as Americans," Lewis writes, "history matters" (1979, p. 22). Lewis is emphasizing that humans inherit our habits and our landscapes from the past. Understanding the historical context will help us to interpret and better design current landscapes. Many aspects of the history of paved roads in the US supports the idea that capitalism is a formative force on the landscape.

The Discovery of Asphalt and the Shift to Horseless Carriages

By the 19th century in the United States, roads had defined a space for movement. Historian Henry Petroski describes how horses and horse-drawn vehicles required a road surface that could hold up to horse hooves and wagon wheels (2016, p. 37). Roads were hard on horses and the wheels of horse-drawn wagons, and many experiments were aimed at identifying a better road surface. The ideal road would also need to drain water, require limited upkeep, be long lasting, be quiet under the strike of horseshoes, be easy to keep clean, limit dust, and use affordable materials and labor. Road builders experimented with methods to mixed results. Gravel roads were labor intensive because the gravel was crushed by hand, its irregular size made for an uneven surface, and it produced a lot of dust. Plus, gravel surfaces trapped wagon wheels in muddy ruts and required frequent repair. Granite slabs were long lasting but slippery when wet, collected horse manure in cracks, were loud under horseshoes, and they shocked the shin bones of horses and the nerves of their riders. Cobblestones were uneven and caused horses to lose their footing. In the 1870s, some cities tried using brick, which in addition to being slippery and loud, was also brittle. Wood blocks, which rotted after a few years, were slippery when wet and absorbed horse urine, inviting disease to travel over this unsanitary surface. Citizens were involved in the search for a better road surface. In 1868, R. Ogden Doremus and John Torrey published a letter in the *New York Times* to encourage the use of wood slabs pressure treated with creosote, which made them impermeable to moisture and resisted rotting (1868).

Meanwhile, in England, John Loudon McAdam developed a method of road construction that became known as the macadam road and was popular in Western Europe and the United

States. McAdam's method called for a 10 inch layer of uniformly sized gravel that rose 3-4 inches above grade, and he invented a gauge to ensure that each piece of gravel was the right size (Holley, 2003, p. 1). The macadam road was better draining than previous methods, and didn't require multiple layers of stone slabs underneath. By the early 1900s, almost half of US roads and main roads in Western Europe were gravel or macadam (Petroski, 2016, p. 33). The high cost and time it took to hand crush gravel led to the invention of the steam-driven mechanical stone crusher in 1832 by Eli Whitney Blake, but even with this increase in efficiency, gravel roads still required extensive upkeep under heavy use of horse drawn vehicles (Holley, 2003, p. 1). While macadam roads were an improvement over previous materials, there were still challenges with this method. Similar to previous gravel methods, macadam roads were dusty in dry conditions, muddy in wet and required frequent repairs ("The Great Public Question," March 16, 1868). Furthermore, macadam roads were no match for the increasing popularity of the automobile.

A solution was found when a Swiss engineer discovered that bitumen, a component of asphalt, could be used as a road surface. "As cars were each year built heavier and faster, their effect upon the highways became a matter of grave moment, until now road builders are agreed that the automobile, combined with other traffic, bids fair to practically destroy the roads already built," read an article in a 1909 issue of Good Roads magazine promoting bitumen as the latest ingredient in the best road surfaces ("Bitumens and Their Use in Paving and Road Making," p. 231). Bitumen, explains the article, is a naturally occurring hydrocarbon that appears in many forms--from liquid to solid, in different concentrations depending on where it is mined which affects its melting point--but agreed upon by engineers to be any hydrocarbon

soluble in cold carbon bisulfide (“Bitumens and Their Use in Paving and Road Making,” p. 231).

Bitumen is essentially made of ancient, decomposed and fossilized plant matter.

The use of asphalt as a surface for roads was discovered by accident. It was first found in Switzerland in 1721 in a deposit of rock asphalt, which is a combination of sand, stone and bitumen (Holley, 2003, p. 3). Bitumen has a tarry consistency, and when it was discovered it was used primarily as an adhesive and a sealant (Petroski, 2016, p. 37). In 1849, a Swiss engineer who was working in the asphalt quarry observed that in places where pieces of asphalt fell out of the quarry carts and were compacted by the cart wheels, the gravel path took on a particularly smooth surface. He conducted an experiment by coating a macadam road with asphalt and compacting it with a horse-drawn roller. It was a success, and in 1854, the first road paved with asphalt was constructed in Paris (“Bitumens and Their Use in Paving and Road Making,” p. 232).

Asphalt paving was an improvement on most previous methods. It was quieter, easy on horse’s legs, lasted longer, and it could be swept mechanically which led to better sanitation. Property owners in the U.S. were in charge of the portion of the road that fronted their property, which meant they had to agree on a surface and come up with the funds (Holley, 2003, p. 3). Since wheels rolled more smoothly over asphalt, drivers preferred to use paved roads, which resulted in heavier traffic, and many neighborhoods opted to keep traffic away by not paving their road. This was not the case along Fifth Ave, one of the ritzier streets of New York City. Eager to keep up with trends in Europe, and tired of dusty roads, the residents of Fifth Ave clamored to adopt the latest asphalt technology (Petroski, 2016, p. 37-38).

In 1869, when Fifth Avenue became the first road in the United States to be paved with asphalt, the excitement was short-lived. This latest road building material, as seen on the smooth streets of Paris and Geneva, had promised to be an improvement over earlier techniques. Asphalt paving was heralded as a solution to previous challenges; however, the 1869 attempt to apply asphalt to Fifth Avenue was seen as a failure. The process of applying the asphalt covered the houses along Fifth Avenue in dust and once complete, the asphalt seemed to slip off the subsurface of the granite blocks underneath, needing constant repair and causing residents to wonder if removing it altogether would be cheaper than maintaining it (Holley, 2003, p. 3).

Criticism of New York City's roads, often featuring complaints about Fifth Avenue, were a fixture in *The New York Times* during the latter half of the 19th century. It seems that roads were a matter on many minds. Frequent letters to the editor presented opinions ranging from specific technical recommendations for road surfaces to objections over the political corruption preventing the latest engineering technologies from being successfully applied. In one letter to the editor written by "several taxpayers" on November 24, 1869, they refer to the Fifth Avenue paving project as "a cheat and a swindle" that resulted in "spending so much money for a pavement of no earthly use" ("Concrete Pavement"). Another letter complains that "a ride in the saddle for a mule through Fifth avenue is an operation attended with some risk," citing concerns over dust, noise, and poor sanitation, but ultimately faulting political incompetence for these conditions as "it is entirely within the reach of modern engineering skill to give us such streets as we ought to have" ("Can We Have Good Pavements?," Nov 21, 1873). An article entitled "The Poulitce Pavement on Fifth-Avenue" similarly describes the new pavement as an

“unmitigated nuisance,” “intolerable,” and “totally lacking in the important quality of durability” before going on to accuse corrupt city politicians of awarding contracts to asphalt companies in which they had invested, lining their own pockets while costing taxpayers three dollars per square yard (November 7, 1869).

The specific frustrations expressed by these city residents over the state of their streets stem from a desire to experience and shape their physical world in a way that is conducive to health, aesthetics, mobility, and cost. Political corruption in NYC interfered with the technical ability to produce satisfactory streets and highlights social, political and economic parameters on shaping space. “If some means are not taken to prevent this intolerable annoyance on the avenue, its reputation both as a drive, a promenade, and a residence will sink to a very low ebb,” wrote the newspaper’s editor (“Good Pavements,” October 9, 1869). This description of Fifth Avenue identifies it as a place with multiple functions and meanings, with various attachments and definitions depending on a person’s relationship to the road.

Asphalt refers broadly to bitumen combined with other minerals in various quantities, resulting in different properties that made uniform application impossible and confounded all but the most experienced contractors. Historian I.B. Holley points out that herein lies the challenge of uniting theory and practice as different kinds of knowledge. The failure of early paving attempts is a result of a conflict between the theory of scientists who understand the chemical composition of asphalt and the practice of contractors who need to build a road with it (Holley, 2003, p. 1). A solution arrived in 1890, when the University of Pennsylvania, Case School of Applied Science, Harvard and MIT became the first schools to offer courses on asphalt paving to contractors and engineers (Holley, 2003, p. 10). A 2015 paper in *The International*

Journal of Pavement Engineering and Asphalt Technology acknowledge that there are still a number of challenges in pavement design. The authors identify the layer thickness, asphalt stiffness and subgrade stiffness as the three most important considerations (Dalla Valle and Thom, 2015). Additionally, the unknown variables of use and climate make it hard to predict the longevity of pavement.

As contractors in the U.S. became more familiar with applying asphalt, more and more roads in cities were paved. Rural areas were left out of advances in pavement technology, leaving a disconnect between cities and rural areas. Recreational bicyclists were the first to campaign widely for better rural roads. The League of American Wheelmen was formed in 1880 to promote recreational bicycling and lobby for improved country roads (Holley, 2003, p. 10). In 1892, they began circulating a journal called *Good Roads* that chronicled the latest road-building equipment and technologies, lobbied for government funding of better roads, accounted, with photographic evidence, the travails of travelers who had to abandon their wagons in the mud, and for good measure, a page of jokes called “Borrowed Wit” in each issue. New car owners were also eager to spin their wheels outside the city, but the argument that gained the most political traction for paving rural roads was the need to connect the goods of rural farmers with the consumers in the urban market (Altgeld, 1892). This reinforces the role of capitalism in shaping landscape.

The state of roads became a platform for hopeful politicians trying to unseat the incumbent candidates who tried to appease their constituents with promises of reform. John Peter Altgeld, elected governor of Illinois in 1893, centered his campaign on committing state support for improving rural roads. Altgeld contributed an article to the December 1892 issue of

Good Roads called "Good Roads for Illinois," in which he wrote, "We have astounded the world in the building of great cities, great railroads, great shops and great factories; we have built up a splendid agriculture, and have pushed the development of our wonderful resources, and the attention as well as the energies of the people have been directed toward these ends; but we find that nothing has been done toward the making of highways that shall be passable the year round" (1892, p. 300). He goes on to describe the way water drains toward the middle of the roads instead of off the edges, which results in farmers getting stuck in the mud 9 out of 12 months of the year. Citing railroads built by the state, he promised to find state funding for a highway that would span the width of Illinois and he proposed two alternate methods for building such a highway. The cheapest method, he suggested, would be to build a macadam road by digging up clay along the road bed and heating it in place into brick-like chunks the size of gravel. It is unclear whether this method had been tested anywhere at that point or since. The second method he described was for a more traditional macadam road made of crushed stone sourced from state quarries, which engineers estimated would have cost \$2,500-\$3,000 per mile in labor costs. To make the second method more cost effective, Altgeld suggested engaging "a very large proportion" of convicts serving time in the state penitentiary to crush the stone (1892, p. 303). This suggestion reveals that the source of materials and labor were both important considerations and limiting factors for road improvement.

These considerations also reflect cultural values that are a source of uncomfortable history not visible in the landscape. Historian Alex Lichtenstein describes how well into the early 1900s, many states in the south enforced a labor tax, requiring all able-bodied men to provide a week's worth of road labor as part of their civic duty (1993). The poor condition of roads under

this conscripted labor system contributed to support for penal labor as a suitable replacement. When this shift took place, with it came the requirement that localities consult with professional engineers. Roads improved, but the forced labor conditions for convicts were reminiscent of slavery and torture.

The history of source material for paved roads is another story of exploitation. Other than the Swiss quarry, the only other source of bitumen suitable for road building yet discovered in the early 20th century was a 115-acre lake inside an old volcano in Trinidad. This source provided 90% of asphalt used worldwide between 1875-1900 and was extracted and transported by rail (Holley, 2003, p. 4). The discovery of sandstone with high bitumen content near a rail line in Utah encouraged miners to explore for more, which was found on Uncompahgre and Uintah Native American reservations. The land was temporarily leased for mining by the North American Asphalt Company, and was ultimately seized from the indigenous tribes by rival asphalt prospectors after they petitioned the Secretary of the Interior (Holley, 2003, p. 6). By 1915, a variety of less expensive tars had been identified to replace costly bitumen in road building (Holley, Blacktop, 16). According to Bill Cunningham, the author of a series of outdoor recreational guide books, the current Uintah lands remain one of the most remote and roadless regions nationwide.

More than one hundred years later, asphalt continues to be the dominant road surface, with concrete used as the only other common alternative. Of the over 4 million miles of roads in the US, 2.3 million miles are paved (Nat'l Research Council, 2005, p. 42). Different techniques and machines have been developed to apply asphalt with more consistency. One of the biggest innovations is asphalt recycling. When roads need to be resurfaced as part of regular

maintenance, over 99% of the asphalt that is removed can be reused (Nat'l Asphalt Pavement Association, 2014).

Chapter Three: Human Movement

The priorities at the turn of the 20th century America were centered on progress, individualism and building capital. The use of cars for transportation is an outcome of those ideals, cementing expectations of mobility and speed in consumer culture (Sheller, 2004, p. 228). There was no sense of finite natural resources, only excitement at discovering new materials to engineer in innovative ways. Before 1904 only 4% of roads were paved (Nat'l Research Council, 2005, p. 38). Within just a few years, new road paving techniques provided a smoother surface for horse-drawn wagons and the availability of horseless carriages, an early term for cars, became more widespread. From an environmental perspective, the invisible exhaust of motorized vehicles was seen as a reprieve from the physical pollution of horse manure (Petroski, 2016, p. 10).

Cars and other motor vehicles provided a new way to experience space, and the world became smaller through connection. Cars allowed humans to move faster and farther while carrying more cargo. Faster travel changed the perception of space and time--space shrinks and time expands. Traveling at a higher speed meant getting places more quickly, and it also allowed access to new places that had been previously beyond reach. However, there were dangers to these new methods of moving, and the pace of change and innovation was faster than regulations could be implemented. Every new driver getting behind the wheel was simultaneously faced with learning how to operate a car while also learning to navigate around immobile obstacles, pedestrians, other new drivers, and other vehicles moving at a variety of speeds. Many accidents took place during this time.

Pedestrians weren't used to calculating the speed of a motor vehicle compared to the more familiar velocity of a horse, and cars couldn't slow down quickly enough for pedestrians crossing the street. A 1913 article in *The New York Times* shows that over the three-year period between 1910 and 1913, the number of fatalities caused by wagons and streetcars decreased, while there was an increase in pedestrian fatalities due to automobiles. The number of pedestrians killed by cars went from 112 in 1910 to 221 in 1913. For comparison, in 2013, 156 pedestrians were killed by cars in New York City (Gray, 2014).

Pedestrians learning to safely cross the street bring to mind the behavior of a squirrel, a common victim of roadkill. Ecologist David Steen supposes that part of the reason cars are such frequent predators of squirrels is because squirrels can't conceive of the way cars move. On his blog, Steen explains how suddenly changing direction of travel is a squirrel's mechanism to avoid predation, hoping that by repeatedly changing their path, they'll confuse their predator or lose them in zig-zag pursuit (www.livingalongsidewildlife.com/2011/04/). Instead, the way squirrels dart in and out of the way of an oncoming car increases their likelihood of being hit.

There are a number of cognitive processes at work that help humans navigate space and avoid obstacles. Once these processes have been learned, humans become so accustomed to the cultural and spatial rules of familiar space that it is easy to overlook the work going on behind the cerebral scene that keep us from bumping into the people and objects in our surroundings. Proprioception is the sense of one's body relative to other objects, an awareness of space and the boundaries of our body that allows us to control our limbs without directly observing them (Ropper et al., 2009). Proprioception is what keeps us from bumping into door jams as we pass through them or swinging our arms into anything or anyone when we walk. It

allows us to reach for and grasp nearby objects without looking directly at them or type without looking at the keyboard and see words appear on the screen.

Humans can extend the sense of proprioception beyond the body to include common tools such a hammer, a pen or a baseball bat. Through use, these tools can become a mechanical extension of the biological system of the body (Plettenberg, 2002). In 1974, medical researcher David Simpson described this phenomenon as extended physiological proprioception in his book *The Control of Upper-Extremity Prostheses and Orthoses*. Simpson's research, inspired by his own experience with temporary paralysis due to a shrapnel wound inflicted during World War II, focused on developing prostheses for children born with limb abnormalities caused by prenatal use of the drug thalidomide in the 1950s and 60s (protomag.com/articles/the-brain-extended). Simpson designed prostheses that interacted with the patient's shoulder joints to communicate with the central nervous system and improve the patient's sense of proprioception.

There are limits, however, to the sense boundaries we can extend beyond our own body. In a 2002 presentation at the Myoelectric Controls Symposium, Dick Plettenburg, a professor of design and engineering at the Delft University of Technology in the Netherlands, notes that 20-40% of prosthetics go completely unused and 40-60% of users do not wear them regularly during daily tasks. Plettenberg suggests that prosthetics still rely too heavily on visual cues to function and need to find better ways to incorporate Simpson's concept of extended physiological proprioception. Since Plettenberg's suggestion in 2002, studies have successfully used electrical stimulation of the brain and nervous system to mimic the sense of touch for people who experience paralysis or use prosthetics. Researchers are currently experimenting

with new ways to stimulate the somatosensory cortex, the area of the brain that controls proprioception. Current research in experimental medicine focuses on the development of new neural interfaces to reintroduce the sense of proprioception for patients with prosthetics (Tomlinson and Miller, 2016).

Geographer Mimi Sheller observes the way cars become an extension of the human body, similar to prosthetics. When we get inside a car, our body fuses with the vehicle and a new set of mental rules applies. This is the experience of extended physiological perception described by Simpson. Together, a driver and a car form a new unit, an “automobilized body” that extends our senses beyond the boundaries of our own body (Sheller, 2004, p. 228).

Proprioception is one of a number of coordinated skills used while driving. In 1963, army psychologist Marvin J. Herbert conducted a study at the army’s Yuma Desert Test Station in Arizona to identify and evaluate the complex psychomotor skills employed while driving. Herbert identified five basic skill factors that can be used to test driving ability: multi-limb coordination, spatial orientation, proprioception, response orientation, and reaction time. Another interesting aspect of this experiment is the location. The desert location was chosen partly because of the expanse of available space, but also because the hard surface of desert soil required minimal expense or effort to prepare as a surface for driving. Herbert describes the simplicity with which the experimental driving courses were prepared using a grader, a bulldozer, and a sprinkler (1963, p. 365). This is an example of the physical parameters the landscape enforces on the built environment.

While proprioception regulates our ability to sense the space and boundaries between people and objects, learning how to move around other humans is also governed by cultural

expectations. In 1962, cultural anthropologist Edward Hall coined the term “proxemics” to describe the nonverbal negotiation between people that establishes what is considered an appropriate distance to maintain between each other. Hall proposed that the proximity between people ultimately determines the scale of the built environment, from individual buildings to cities (1963).

Learning how to move around each other in cars also requires cultural input. People have been shown to pay less attention when performing familiar tasks in familiar places. Learning a new skill takes total focus, but once a skill is learned, it can be practiced with little effort. Samuel Charlton and Nicola Starkey write about the way this applies to driving. With enough experience, driving becomes automatic, requiring less vigilance to the point of feeling mindless. In 1963, G.W. Williams proposed the term “highway hypnosis” to refer to the split between conscious and subconscious awareness that allows people to enter a trancelike state while driving. Williams thought this could be an explanation for accidents that took place while drivers were in a daze induced by monotony and fatigue. When experienced drivers are in a familiar space, they can experience inattention blindness, selectively looking for new relevant information while overlooking changes to the familiar landscape (Charlton and Starkey, 2013). One experiment tested drivers over 5 days on a driving course that included a variety of traffic signs, and many drivers failed to notice on the last day when a right of way sign changed to a yield (Martens and Fox, 2007). I.D. Brown referred to this as “driving without awareness” and investigates whether this plays a role in reducing reaction time (1994).

Through driving practice, learning the meaning of traffic signals, and becoming accustomed to navigating familiar places, it is easy to forget all of the essential information that

must be processed to stay safe in a car. Knowing which side of the road to occupy, which lines indicate a passing zone, how to keep a safe distance from other vehicles, when to use a turn signal, and how to calculate stopping time at various speeds—all of the cues that drivers follow to stay safe—are learned. Geographer Nigel Thrift argues that, even after more than one hundred years of driving history, moving in cars is a very different way to experience space that humans still haven't fully reckoned with. Thrift writes that “the experience of driving is sinking in to our ‘technological unconscious’ and producing a phenomenology that we increasingly take for granted but which in fact is historically novel” (Thrift, 2004, p. 41). All of the cultural input that helps humans learn how to navigate available space safely is part of an evolving proxemics for the road.

A complex system of standards and signals has been developed over time, often through trial and error, to regulate driving. In the early 1900s, Henry Ford's Model T made cars affordable to a large number of Americans and car ownership skyrocketed (Petroski, 2016, p. 68). In 1915, 400,000 vehicles were sold for \$440 each (Forman et al., 2003, p. 26). Advances in paving techniques expanded the network of paved roads. Excitement over the dazzling innovations that were allowing people to move in new ways began to fray as limitations and challenges became evident. As cars gained popularity, the rush of new cars onto the roads resulted in gridlock traffic jams and frequent accidents. There was a need for regulations to control the movement of cars around each other.

The frequency of collisions between pedestrians and vehicular traffic in the early 1900s needed to be addressed. An editorial article called “Looking Forward” in a 1912 issue of *Cassier's Engineering Monthly* forecast a solution to this growing conflict over sharing road

space that dismissed the idea of policy solutions. The author saw no need for either mode of travel to compromise, writing that “any attempt to limit the speed and freedom of the motor vehicle means the retardation of progress and the perpetuation of inconvenience. At the same time, anything which debars the foot passenger from the entire freedom to traverse the highway in comfort and safety cannot be considered” (July 1912, p. 68). Rather than developing regulations to safely share space, the solution was to isolate “power propelled” vehicles from pedestrians, limiting their ability to encounter one another by building separate paths on different levels. This proposal indicates the zeitgeist of enthusiasm for progress, disinterest in regulatory legislation, and a confidence in engineering.

As a network of roads designed to support motorized traffic spread through cities, roads continued to serve a variety of modes and speeds of transport. This conflicted with their potential as a commodity. One solution was to segregate different speeds of traffic. A 1913 article in *Cassier's* laid out a hypothetical vision for a five storied street. It included a detailed drawing of “the city street of the future,” depicting separate levels for foot traffic, cars, and public transportation. “The real difficulty lies, not with the provision in cities of a highway for the car, but with the maintenance of a clear roadway, so that the full advantages of the speed of the motor car may be realized without danger to the foot-passer,” read the article (“A Five Storied Street,” June 1913, p. 57). The article promised that this design could increase the efficiency of business traffic by 25 percent, an indicator not only of changing expectations for human mobility but also of a growing understanding of the economic potential of roads.

The following issue of *Cassier's* published a real plan to ameliorate traffic congestions in Detroit by separating pedestrians and vehicles at Washington Boulevard. This double decker

road design promised to eliminate the “nerve wracking mental tension” pedestrians and vehicles faced while trying to avoid each other (“The Proposed Washington Ways at Detroit,” 1913, p. 165). Other multi-level roadways built in reality include the Embarcadero Freeway in San Francisco, which was built as a double decker highway for motor vehicles, rather than a way for motor vehicles to share space with pedestrians. The Embarcadero impacted city residents by cutting off low income neighborhoods from access to the water, a reminder that roads do not always meet human connectivity needs. Roads that are intended to increase access end up having the opposite effect. The controversial Embarcadero was damaged in an earthquake and finally removed in 1989 (Petroski, 2016). Researchers have documented a number of additional environmental justice issues related to roads, including ways that low-income areas are disproportionately isolated and exposed to increased stormwater flooding, noise, and poor air quality (Strasburg, 2003).

Chapter Four: Animal Movement

Humans are not alone in their ability to alter the landscape for transportation. All animals are defined by the ability to move through space to meet survival needs. Some animals don't move much in their lifetime while others cover great distances. Adult sponges stay fixed in one oceanic spot after exhausting all of their movement during the larval stage of their life cycle (Mariani et al., 2006). In urban areas, most mice stay within a hundred feet of their birthplace and raccoons travel up to half a mile in search of food (Bradley, 2015). Honeybees can forage up to six miles from their hive in search of nectar (Beekman and Ratnieks, 2000). Wandering glider dragonflies (*Pantala flavescens*) have been documented crossing the Indian Ocean, a distance of up to 2,485 miles (May, 2013).

Some animals make their own path to travel. Snails secrete their own mucus path that helps them to glide forward smoothly on a single foot and leaves a silvery trail behind (Lai et al., 2010). Some marine gastropods, like mud snails, follow each other's slime trails over the ocean floor, whereas limpets follow their own slime like breadcrumbs back to their home (Moor, 2016, p. 61). Elephants make and maintain networks of paths that cover hundreds of miles, altering the landscape by uprooting trees that grow in their paths and spreading the seeds of their favorite fruits along their routes (Blake et al., 2009, p. 460). Ants lay down pheromones, blazing a trail for other ants to follow (Fourcassié et al., 2010). Other animals leave a trail behind, like deer snapping branches as they bound through woods and Galapagos tortoises that crush vegetation under their heavy feet.

Some animals make use of existing paths. In the book *On Trails*, Robert Moor describes the way trails that form over time operate "as a form of external memory and collective

intelligence,” a sort of space that allows animals to mindlessly follow and trust that it will lead somewhere meaningful (p. 93). Ecologists Stephen Trombulak and Christopher Frissell review several ways that roads can change animal movement (2000). Trombulak and Frissell describe the way some animals learn to navigate roads and even prefer traveling in open linear space to wooded areas, as in the case of caribou in Alaska who use roads in places that correspond with the direction of their migration. On the other hand, the land snail (*Arianta arbustorum*) will go out of their way to avoid crossing a road. Sheep prefer to eat varieties of plants that grow along the open space of edge habitat (Moor, 2016). Coyotes travel into cities and suburbs on human roads by learning to navigate traffic (Heimbuch, n.d.).

But in order to follow a trail, animals need to know where to go, what signs to read and signals to follow. Some animals, such as pigeons, are thought to navigate through landmark recognition, making mental maps that they repeatedly follow. Researchers hypothesize that they retrace identical routes even when more efficient routes are available because it takes less energy to memorize and process two dimensional images of the landscape below (Meade et al., 2005). Animals use instincts and learned behavior to create and navigate paths. Humans, on the other hand, need regulations to negotiate space with other vehicles. As more and more people began driving cars in the early 20th century, all of the systems and symbols to guide them were yet to be developed. Cars allowed people to move beyond familiar places, and there was a greater need for street signs instead of landmarks to navigate.

Humans need utilitarian design to be able to use roads in safe and functional ways. In his book *The Road Taken*, historian Henry Petroski recounts a number of stories about how and when various signals were developed. He notes that stop lines were painted at intersections in

Portsmouth, VA in 1907 and crosswalks for pedestrians were introduced in New York City in 1911. A two-lane stone road in Mexico City that dates back at least 500 years has a stripe of different colored stones down the midline to demarcate the center, a feature that didn't occur to Americans until there were so many accidents between oncoming cars around curves that resulted from vehicles not staying in their lanes. The first centerline on a paved road in the U.S. was painted in Michigan in 1917 around a particularly sharp curve where a number of accidents had occurred (Petroski, 2016, p. 56-75).

Design is adjusted through use to become more functional, as some of the decisions seem arbitrary until tested. For example, should stop signs be red or yellow? What color should centerlines be and how thick? In 1932, a federal Joint Committee on Uniform Traffic Control Devices was formed to develop the Manual on Uniform Traffic Control Devices (MUTCD) to determine standard traffic control guidelines for all 50 states. Petroski explains that many states had already started using white centerlines by that time, but Oregon preferred to use yellow lines because they were more easily visible under snow. The 1958 edition of the MUTCD required the centerlines of all state, U.S. and interstate highways to be changed to white so that markings would be standard across the country. Oregon was forced to change all state highway centerlines to white, or lose \$300 million in federal funding. After much grumbling from public officials in Oregon, they capitulated, only to have the 1971 edition of the MUTCD revise the standard to require that all centerlines separating opposite directions of traffic be yellow. That remains the standard today (Petroski, 2016, p. 59).

Signals, signs, and lane markings are intended to keep cars on the road, but the meanings have to be learned. In early trials of traffic light signals, the colors weren't standard

between cities and there were misunderstandings about what each of the colors meant. In 1930, the standard for color positions was established, with red on top and green on the bottom, to the great benefit of colorblind drivers (Petroski, 2016, p. 75).

Many animals also have signals that they follow to keep them on track. For example, rats use an olfactory signal to mark their paths. Jason Munshi-South is an urban ecologist in New York City, and he studies the animals that have come to coexist with humans in cities (Bradley, 2015). There are over two million rats living in New York City and the common name for the particular species is Norway rats or brown rats. These rats establish routes to food sources, and as they walk, they stay close to the walls of buildings, feeling along with their whiskers and shying away from the exposure of open spaces. As they rub against the wall, rats secrete sebum, an oil that transfers from their fur as they travel, creating a marker that functions similar to lines on a human road. Rats follow the scent the sebum leaves behind, but if enough rats travel the same route, an oily line becomes visible to the human eye. While rats rely on their sense of smell to follow their route, humans primarily sense road signals through sight. There are several exceptions of signals that add an auditory sensory dimension for humans, including rumblestrips that signal an upcoming stopping point, raised bumps along road edges, and horns in individual vehicles.

Traffic Lights, Traffic Circles, and Ants

As car sales continued to skyrocket in the early half of the 20th century, engineers and policy makers stayed busy dreaming up solutions to the various problems. Petroski explains that Fifth Avenue in New York City was the site of several traffic control experiments that

ultimately led to a debate over traffic lights and traffic circles. At intersections, there was no system to determine who had the right of way and cars frequently collided. When turning left, drivers commonly cut corners to increase the angle of their turning arc, crossing the centerline and crashing into oncoming cars. To prevent accidents caused by cutting the corner when turning left, city planners installed posts to keep drivers in their lane at intersections.

At first, the towers in the center of the road held police officers manually controlling signals, and these later developed into traffic lights. Before the towers were added, traveling 1.25 miles along a particularly crowded stretch of Fifth Ave took 42 minutes. The addition of the towers reduced the travel time to 9 minutes (Petroski, 2016, p. 72). Initially, the lights used what was called a continuous block system in which every signal along the same road changed simultaneously. This meant that all the cars sped forward together, trying to make it through as many green lights until all the lights turned red. Petroski describes how American businessman William Phelps Eno was distressed by the way cars clumped up at the red lights, leaving great gaps of open road ahead and behind while all the cars waited for the signal to change (2016, p. 76). Eno wanted to have the entire road surface covered in steadily moving vehicles. He came up with the idea to use roundabouts to improve traffic flow and his design for Columbus Circle was built in 1905.

It turns out that Eno's vision for Fifth Avenue is very similar to the way ants move as a group. Ant movement is the focus of a number of studies on traffic flow. Ants use stigmergy, depositing pheromones from an abdominal gland to build chemical scent trails that signal to other ants (Fourcassié et al., 2010). The pheromone trails of leafcutter or seed harvesting ants,

which spend a long time collecting large amounts of food from the same location, can end up turning into a visible trail from prolonged travel over the same route (Fourcassié et al., 2010).

Not only did animals provide the original layout and clear the way for many modern roads, studying the movement of the certain animals may have application for human vehicular movement. Ants are among the few animals that travel back and forth along the same route, similar to the way humans travel bi-directionally along roads. Ants have been observed to move efficiently en masse, and researchers study ant traffic flow to look for improvements that could be applied to human traffic flow.

Many animals travel together in the same direction, but there is a more limited number of animals known to travel close to another but in opposite directions. Other bi-directional animals include ants, social caterpillars, termites, and stingless bees (Fourcassié et al., 2010). While humans travel in separate lanes going opposite directions, ants such as wood ants, army ants and African driver ants use a three lane road: the ants returning to the nest with heavy food travel more slowly in the center lane, while outbound foragers form higher speed lanes on either side (Peters et al., 2006, p. 3). Fourcassié et al. observe that this three lane system likely serves to protect the ants in the middle carrying food from attacks from competitors. Additionally, because traveling along a three-lane road results in more stable and symmetrical pheromone application, the path is less likely to shift (Fourcassié et al., 2010).

Other ant species do not move in differentiated lanes, bumping into each other as they move, traveling the shortest path between food source and nest. Collision slows travel but the energy costs of construction and potential physical obstacles to laying down new routes are both barriers to making wider trails (Fourcassié et al., 2010). These energy cost considerations

are very similar to the parameters that limit human road construction. For ants, there is an additional benefit to traveling in large communities. The strength of pheromones is reinforced by higher ant traffic volume, which disincentivizes widening paths or adding alternative routes (Peters et al, 2006, p. 4). Rerouting through collision also provides an opportunity to communicate which can be compared to human road signs that alert drivers to emerging changes in road conditions.

Researchers discover similarities and also note differences, with application for improving human transportation design. Ants move on many levels, horizontal and vertical, above and below ground, mixing bits of geological layers as they tunnel. Peters et al. note that human and ant roads share the high energy cost of adding alternative routes, as well as space constraints. One big difference is that the goal of ants is to get the most food back to their nest in the shortest time, with the least energy expended and stationary end points on both ends (Peters et al., 2006, p. 13). Humans, instead, originate from different locations and travel to various destinations. Comparing ants and humans is still relevant, argue Peters et al., who conducted a mathematical modeling experiment to determine the factors that would cause a variety of ant species to divert their route trajectory and expend the extra energy needed to make an alternate path (2006). When alternate routes for humans are available, mathematical modeling based on ant movement could help develop a system for optimal re-routing during congested traffic situations, resulting in algorithms that reroute humans onto less crowded roads.

Another difference is that human traffic rules are imposed externally and design is reinforced through familiarity, while ants act collectively as a self-organized biological adaptive

system (Fourcassié et al., 2010). When early human drivers were left to their own devices, operating as individuals without signals or regulations, the whole group was dysfunctional. The traffic towers along Fifth Avenue centralized control, directing the flow and attempting to maintain steady movement of the whole group, similar to the way ants move together.

While ants benefit from their cooperative movement, there is also a danger in leaderless cooperation. If the pheromone trail is broken, ants become disoriented and can't always find their way back to their home (Moor, 2016, p. 68). A comparable scenario for humans could be when lanes markings lose visibility in the rain, making it hard to stay within the lanes. Ants can also get trapped in a circle, blindly retracing the same path over and over. If they don't break off to find food or shelter, they could die. Traffic jams sometimes feel similarly interminable, or a glitch in a GPS navigation system that directs its user repeatedly in a circle.

Other species also use vehicles to travel. When the female jewel wasp is ready to lay an egg, she injects a neurotoxin into a cockroach's brain that takes control of its movement. Under the wasp's control, the cockroach carries the wasp underground, where the wasp lays an egg inside the immobilized cockroach (Gal and Libersat, 2010). Remoras attach to sharks. Researchers at the Biotechnology and Biological Sciences Research Council are studying how spiders can ride wind currents for hundreds of miles on a single strand of their silk (2006). Fire ants can survive flooding by making a waterproof raft out of their own bodies that can stay afloat for days (Mlot et al., 2011).

Learning from other animals about ways to move around each other serves as a reminder that humans are also animals moving within ecosystems. As such, it is unrealistic and impossible to imagine causing no harmful ecological effects, but harm can certainly be

mitigated. It is important to remember that other animals disrupt ecosystems and alter the landscape. For example, beavers are known as “ecosystem engineers” for their ability to restore wetland areas and contribute to increasing the species diversity of birds (Nummi and Holopainen, 2014). Ecologist Stephen Blake researches several animals who trample vegetation and disperse seeds along their preferred routes, making networks of paths lined with gardens of their favorite fruits. This includes tortoises in the Galapagos (Blake, 2012) and elephants in the Congo (Blake, 2009). This argument is not meant to excuse humans from limiting ecological disruption, but rather to encourage humans to see ourselves as animals within the ecosystem. This serves as a reminder that we are subject to the same ecological forces we disrupt and are ultimately threatened by the potential cascade effect of lost biodiversity.

Chapter Five: Mediating Multiple Objectives

The Case of The Bonner Bridge

Near the site of first English contact with the New World, arguments about shaping the landscape according to human desires for mobility are still taking place today. The Bonner Bridge is a road project on the Outer Banks of North Carolina in which multiple transportation objectives between people, plants and animals have been in conflict for decades. This project is an opportunity to apply lessons from road ecology.

The Outer Banks is a chain of barrier islands separated from the North Carolina mainland coast by an estuary. Rivers feed freshwater into this brackish boundary, where it meets and swirls with saltwater pushed in twice a day by the tides. From the Virginia state line south to Cape Lookout, six inlets gape open to regulate the flow of water between the intersecting rivers and ocean (Mallinson et al., 2008, p. 5). Inlets also offer passage to commercial and recreational vessels traveling between land and sea.

Inlets open and close as part of a dynamic system of managing water flow. Inlets balance the back and forth flow of water, releasing river floodwaters outward when necessary and buffering the mainland from excess water blown in during ocean storms. Some inlets are long term, while some form temporarily to accommodate a rush of storm water and then close up. While there are currently six active inlets, a team of geologists from East Carolina University used ground penetrating radar to detect the makeup of underground sediment and map the location of inlets over time (Mallinson et al., 2008). This research has been able to document more than 30 inlets that have opened and closed over hundreds of years. Like roads, waterways

are also commodities. In addition to inlets that open and close naturally as a part of storm systems, the Army Corps of Engineers has also opened and closed inlets to maintain navigable channels that allow commercial fishing vessels direct access between the ocean and coastal communities (Mallinson et al., 2008, p. 12).

The flexibility of the inlet system protects the shoreline by regulating water systems, but also presents a challenge to the static nature of human infrastructure. The Outer Banks is slowly drifting inland over time, due to the fact that the waves of saltwater that move through an inlet also carry sand from the oceanside to deposit on the inland side. As sand is added to on the inland side of an island, the roots of marsh plants hold the sand in place and stabilize the island (Pompe, 2012, p. 7). The sand builds up, moving slowly from the oceanside inward until eventually the entire body of land has shifted. This means that the land is moving underneath roads and bridges. At various points along the Outer Banks, strips of old road are visible under sandy stretches of beach and chunks of pavement can be seen tumbling in ocean froth.

Roanoke Inlet, the passageway that allowed the English colonists through to Roanoke Island, closed naturally in 1811. Roanoke Island is currently tucked inside the narrow outer strip of shifting sands, cut off from the Atlantic Ocean. While the first English colonists did not succeed in settling there, the Outer Banks are now home to a number of plants, people and animals, and also host to a seasonal influx of tourists who are drawn to the beach for the summer. Water complicates mobility, and many of the towns on the Outer Banks that are divided by water are accessible only by boat. Bridges reach out like arms on either side of Roanoke Island to connect tourists and residents with the NC mainland to the west and the Outer Banks to the east.

In 1846, a hurricane opened Oregon Inlet between Bodie Island and Pea Island, to the south of where Roanoke Inlet had been. In the 1950s, a ferry began transporting 2,000 residents across Oregon Inlet each day, but according to the Outer Banks tourism website, high operating costs and long lines that delayed travel time encouraged the NC Department of Transportation to make a \$4 million dollar investment in a bridge (www.outerbanks.com/herbert-c-bonner-bridge.html). The Herbert C. Bonner Bridge opened in 1963 with a planned 30-year lifespan. The bridge increased traffic to the island, and 151 miles of road were paved to increase access for residents and seasonal tourists along the rest of the Outer Banks. The resulting road, NC 12, remains the sole road that connects Hatteras and Ocracoke Island to mainland North Carolina and the Bonner Bridge is an integral part of this connection.

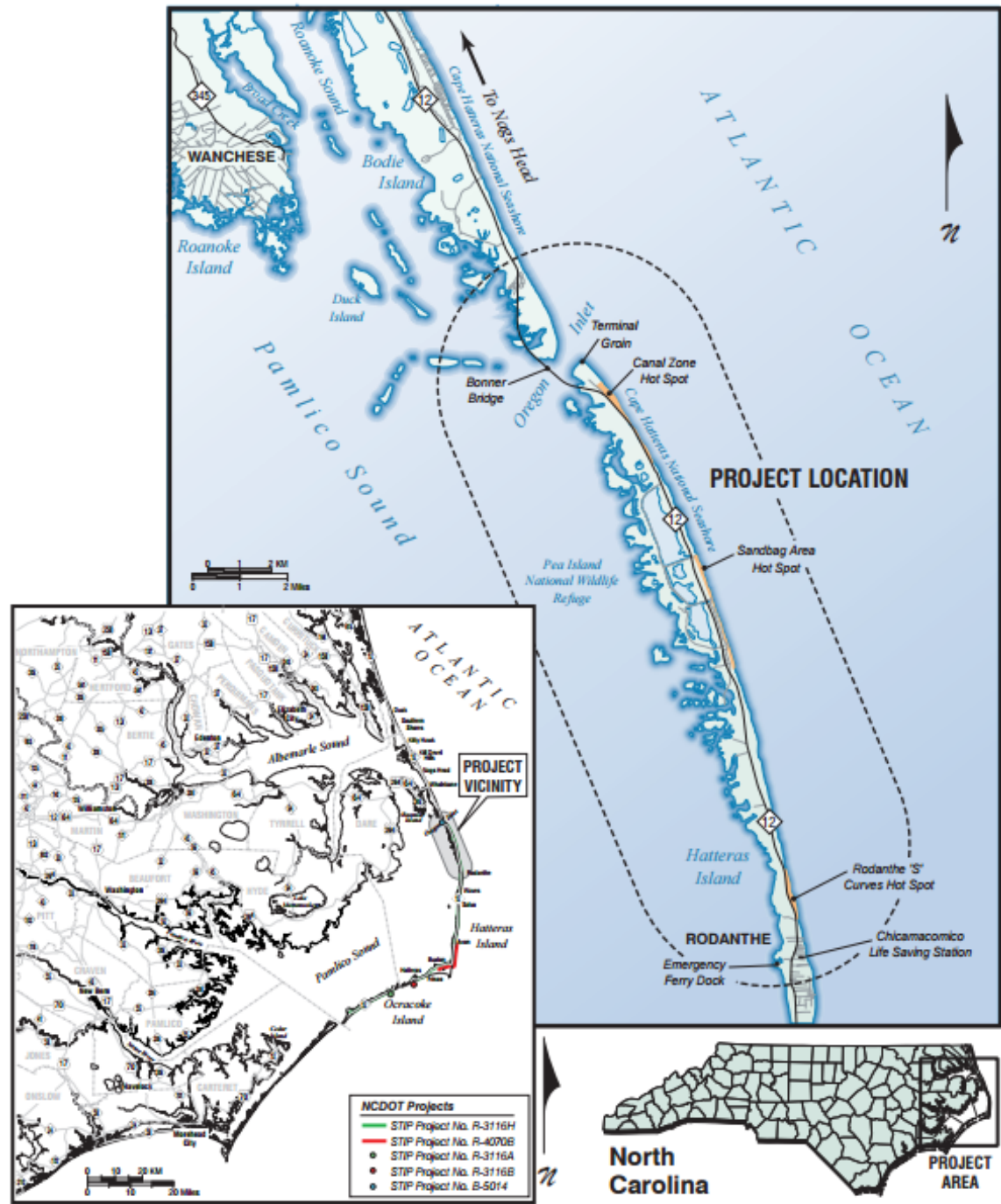
Geological studies show that from 1846 to 1989, Oregon Inlet moved 2 miles south (Mallinson et al., 2008, p. 9). The challenges of this changing landscape result in a nexus of adversarial human and nonhuman relationships, which according to the team of geologists from ECU, end up “often pitting management policies and local interests against natural coastal dynamics” (Mallinson et al., 2008, p. 9). Oregon Inlet has been dredged multiple times to maintain boat access. Heavy equipment along the shore regularly undertakes the Sisyphean task of piling sandbags to replace the shifting coastline. Rocks are inserted where sand has eroded under bridge pilings, similar to the way a shim stabilizes a wobbly table leg.

As the bridge approached the end of its lifespan, the NCDOT began planning for a replacement in 1990. Expectations for mobility clashed with new awareness of the ecological effects of road construction. Decades of legal opposition delayed the replacement. The NCDOT

dedicates a page of their website to explaining the history of the bridge and the status of the replacement project. The webpage explains that most recently, lawsuits by the Southern Environmental Law Center on behalf of the Defenders of Wildlife and the National Wildlife Refuge Association were filed in 2011 and 2013, accusing the NCDOT of violating the National Environmental Policy Act of 1969 by segmenting aspects of the project into separate projects (Defenders of Wildlife v. NCDOT, 2015, p. 1).

A settlement was reached in 2015 and construction began in March 2016, with plans to complete the new bridge by 2019 (see fig. 3). Environmental groups still continue to express concerns over damaging Pea Island Wildlife Refuge south of Oregon Inlet, but the plan was chosen out of eight alternatives because it is expected to cause the least overall harm. The new bridge will be 3.5 miles long, and will preserve additional sensitive areas of the Pea Island Refuge. It will require coastal monitoring for ongoing environmental impact, which include tracking geomorphological changes and tracking species of concern. The species that may be impacted by the new bridge include the nesting sites of piping plover, leatherback sea turtles, green sea turtles and loggerhead sea turtles and the habitat of seabeach amaranth (NCDOT Record of Decision, 2010, p. 23). Resulting in an interesting amalgamation between the built and natural environment, the old bridge will be disassembled and left in pieces underwater to become an artificial reef (NCDOT Record of Decision, 2010, p. 25).

Fig. 3. Project Location Map for the NCDOT Herbert C. Bonner Bridge Replacement Project in the Outer Banks, NC. From <https://www.ncdot.gov/projects/bonnerbridgereplace/download/ROD.pdf>



PROJECT LOCATION MAP Figure 1

Another proposed solution to replace Bonner Bridge included bypassing the Pea Island Refuge altogether by creating a 17-mile long causeway in the sound. The team of ECU geologists agreed that “from a long-term financial, management, and scientific perspective, this latter option is more viable but it conflicts strongly with local and shorter-term interests” (Mallinson et al., 2008, p. 10). The economic parameters and the length of construction time exert high pressure on decision making, but are not likely to result in the most ecologically sound option. This highlights the importance of factoring in multiple objectives, especially when they involve multispecies conflicts.

One pair of geologists proposes that geoscientists who approve infrastructure projects be required to take multiple objectives into account. At the 2016 International Geological Congress (IGC), an event held annually to share the latest geological research, geologists Ellis and Bohle proposed that geoscientists be required to take an ethical oath. In the abstract for the presentation they delivered at the IGC, they wrote that “Tackling anthropogenic global change involves scientific, technical, economic and other social concerns that require professional handling of ethical issues, which go well beyond the integrity of research or 'sound' engineering works” (Ellis and Bohle, 2016). Similar to the Hippocratic oath that doctors take, Ellis and Bohle suggested that geoscientists should be ethically required to consider not only what is possible to engineer, but what is ecologically sound. This would possibly give more weight to long term interests in transportation planning.

The Bonner Bridge project in North Carolina’s Outer Banks is an example of a road project that highlights the contentious relationship between transportation planners and environmentalists, as well as the historical context that has resulted in current human

expectations for mobility. When the options for assessing the need for a new or improved road are constrained within the opposing categories of support or resistance, it is easy to dismiss environmentalists as adversaries of mobility and road builders as heedlessly destructive. Roads as a solution to human mobility needs do pose an ecological challenge, but there is another approach to the problem. By looking at roads as a point of multispecies contact, instead of seeing the conflicts that arise as the inevitable collateral damage of being alive, new ways of framing the relationship can emerge that blur boundaries between individuals and expand the planning process to a systems perspective.

Conclusion: Proposals for Multispecies Existence Around Roads

“If we want to change the landscape in important ways we shall have to change the ideas that have created and sustained what we see. And the landscape so vividly reflects really fundamental ideas that such change requires far-reaching alterations in the social system”

-Meinig, “The Beholding Eye,” 1979, p. 42, in *The Interpretation of Ordinary Landscapes*

Roads create ecological disturbances and destruction at multiple levels, a fact too easily dismissed as the unfortunate trade-off for the convenience of vehicular travel. In the introduction to *Road Ecology*, Thomas Deen, former executive director of the Transportation Research Board of the National Academy of Sciences, asserts that roads and the economic activity they support inherently conflict with environmental health (2003, p. xi). While human roads have often been a site of contention between environmentalists and transportation designers, removing the boundaries between categories offers the potential to reevaluate these adversarial relationships. Others are more optimistic that solutions that mediate multiple objectives can be reached.

Road design must consider social and environmental justice in addition to scientific, political and economic factors, balancing the duration of construction with the cost and predicted lifespan of the project to assess the best overall utility of a plan. Road placement is one of the most important considerations in the attempt to minimize damage to wildlife (Andrews, et al., 2007). In the journal *Transport*, Brauers and a team of researchers wrote that an increase in the number of drivers worldwide requires road expansion on all scales from highways down to arterial and local roads (2008). To assess the best plans for adding or widening existing roads in a way that mediates human needs and the needs of other non-

human species prioritizing needs, the researchers advocate for using a metric called multi-objective analysis as a useful tool to identify the best alternative (Brauers, et al., 2008).

However, road ecologists argue that expanding highways is a mistake, that more road space will result in more drivers and it makes more sense to move toward eliminating roads from the current system (Forman, et al., 2003, p. 396). This challenges the desire for human connectivity.

Integration of environmental and transportation goals is possible, especially when the transportation planning process effectively incorporates a diversity of knowledge and expertise. However, streamlining may not initially meet all objectives. For example, eliminating mowing practices along the roadside to increase available habitat for plants and animals could also result in eliminating DOT jobs, which could be negatively perceived by humans. This is where collaboration from policy makers is needed to increase regulation. Many solutions to problems exist, but are disincentivized by the market economy. The regulations that were introduced during the early days of driving to make roads safer provide supporting evidence for the necessity of regulation. Similar to the way new rules and design features were needed to prevent accidents, regulation and design is required to limit ecological destruction.

Claudia Berg, a development researcher for The World Bank, writes that policy makers have three considerations when it comes to solving transportation issues: they can repair existing roads and invest in new infrastructure, encourage greater use of public transportation by implementing taxes on gasoline or subsidizing public transit, and they can regulate vehicle fuel efficiency (2015). Berg notes that policy makers benefit from high visibility infrastructure projects even though increasing or widening roads in high density areas will often result in additional use and more, rather than less, congestion. Some cities attempt to control

congestion through tolls or taxes. For example, crossing the Bay Bridge westbound from Oakland into San Francisco costs \$6 per car, while crossing back eastbound is free (baybridgeinfo.org/tolling-information, 2017). London charges for access to the city center. Mexico City determines which cars are allowed downtown based on license plate numbers. Few other cities have implemented such policies. Fuel subsidies reduce the cost of gas so that the social and environmental cost is not reflected in the consumer price.

Road ecologists are imagining solutions that will require the collaborative support of engineers, government officials, and the general public. Successful collaborations will not only be multi-agency between citizens, policy makers, scientists and engineers, but will also need to work with other species. There are several examples of multispecies transportation design projects from art activism projects that blend art and science in efforts to democratize data and decentralize authority. In 2007, Sarah Bergmann started an ongoing project called Pollinator Pathway, a one mile by twelve foot corridor of pollinator-friendly front yard gardens in Seattle (<http://www.pollinatorpathway.com/>). Bergmann works with residents of homes along the mile-long corridor who commit to following specific guidelines to each maintain a pollinator friendly garden in their front yards, forming a partnership between Bergmann, the home residents, the plants and the traveling pollinators. Pollinator insects, birds and other animals are attracted to the provided food source and travel along the linear path Bergmann designed for them, making it a collaborative, multispecies transportation design project.

The air pollution that results from roads has been the focus of another project that combines art and science. Stephen Glassman's Urban Air project, which took place in 2014 in Los Angeles, explores interactions between natural elements and the built urban landscape

(urbanair.is/about-urban-air/). Glassman devised a design to transform billboard stands in Los Angeles into tiny gardens planted with bamboo and embedded with atmospheric sensors that measure air pollution. Both projects re-envision the relationships of humans, plants and animals around roads as points of contact between the natural and built environments. The artists use existing infrastructure, available resources and multispecies partnerships to investigate challenges and design solutions.

There are a number of other specific recommendations. Habitat fragmentation due to roads has a large ecological effect on a variety of species, and many road ecologists promote designing corridors that connect plant and animal habitat over, under and around roads. Timon McPhearson, professor of urban ecology at the New School, studies how to connect plant and animal habitat and he shares that a corridor could be as little as a strip of grass between trees along the sidewalk or open pipes underground with a little soil in them (Bradley, 2015). Corridors can also take the form of rope bridges over a road and can involve fences that direct wildlife to safe crossing areas. Not only do these allow for movement between habitat areas, but they also have the potential to decrease the incidence of roadkill. There is some question about how effective these connective corridors can be, and to what extent they encourage movement for various species. Gilbert-Norton et al. reviewed 78 experiments to evaluate the effectiveness of wildlife corridors, and they found that areas with corridors did result in movement between habitat areas, especially for invertebrates, plants, and non-avian vertebrates (2015). These findings indicate that maintaining habitat connectivity needs to be an important consideration in road design.

Road ecologists have also suggested ways to mitigate the effects of noise by building berms with dense vegetation and reducing noise by improving vehicle aerodynamics and maintaining smoother road surfaces (Forman et al., 2003, p. 396). Additionally, consolidating traffic on fewer main roads would create larger roadless regions and cleaner fuel would reduce greenhouse gases. There are also ideas for individual drivers. A team of three engineers at the University of Southampton in the U.K. developed a way to encourage lower fuel consumption by causing the accelerator pedal to vibrate as way to alert drivers when they could be coasting (McIlroy, et al., 2017). But part of the problem with the current system is that it promotes individualism.

In urban areas, there are different possibilities for new transportation systems. Plans for communal driverless vehicles that move at a constant speed and follow the pattern of road lines are reminiscent of ant chemoreception. Public transportation systems also work in urban areas, but these systems are not feasible for connectivity in rural areas.

The current system of roads have incurred damage on humans, as well as a variety of other species and earth systems, which is a compelling argument for change. But the unforeseen and exponential nature of documented ecological consequences also make it likely that no solution can mitigate past or future damage. New ecological understanding spins concern for other species back into a concern for humans by showing the ways humans and other species are interdependent, in some cases related by degrees of separation in newly revealed and unforeseen ways.

Petroski's claim that road infrastructure is broken indicates that this is a good time to incorporate lessons from road ecology, but it is also important to think broadly in an

interdisciplinary way, beyond solutions to individual problems that arise, but ways to reimagine the entire system in a less anthropocentric way. Comparing people to animals serves as a reminder that we are animals. Our human habitat is a part of the ecosystem; the built environment is nested within natural systems. We are not the only animals who build destructive roads or change ecosystems, which is a reminder that the goal is not to eliminate harm. It is impossible for roads to be harmless. As author Robert Moor observes, “Sheep, humans, elephants, ants: each of us alters the world in our passage. ... The question we should ask ourselves is not whether we should shape the earth, but how” (Moor, 2016, p. 131).

The human body has even been studied to improve human transportation efficiency. As the Director for Global Strategy of UPS Healthcare Logistics, Wanis Kabbaj is responsible for creating a system for transporting medical materials worldwide, so it makes sense that he spends time thinking about the way blood carries oxygen along vascular pathways as a housekeeper for human health. He studies the vascular system to search for ways to improve traffic flow, citing the efficiency of blood vessels in transporting their cargo (Kabbaj, 2017). The urban planner, Jane Jacobs, similarly compares roads and sidewalks to human arteries (1993, p. 37). In an interview about his research on ways to measure roadless regions, Raymond Watts of the U.S. Geological Survey in Ft. Collins, Colorado calls roads “the circulatory system of our culture” (Thompson, 2007). By using the human body to mirror the vast system we have created to move ourselves and our things, we can begin to also see ourselves within this much larger system that also holds cockroach riding jewel wasps and frogs in vernal pools fed by rainfall. This is a reminder that until we reframe the problem, no specific solutions will create fundamental change.

Appendix A

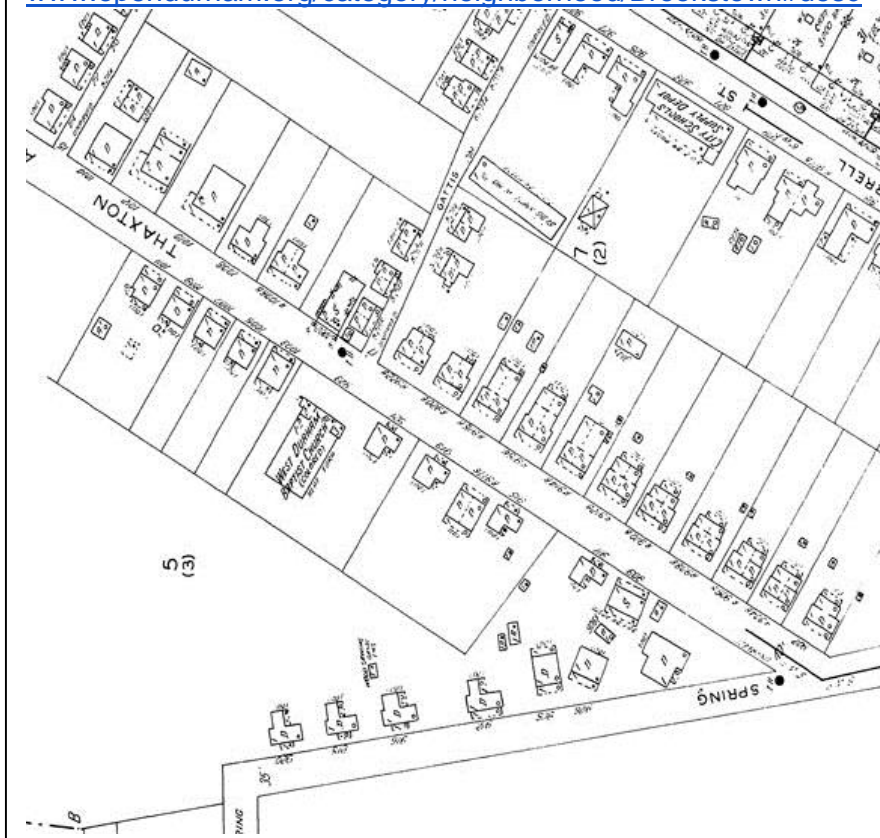
Image of Highway 147 in Durham, NC noting former site of Thaxton Ave and West Durham Baptist Church. From

www.opendurham.org/category/neighborhood/Brookstown#desc



Historic map showing Thaxton Ave in Brookstown, a neighborhood in Durham, NC that was paved over by Highway 147. From

www.opendurham.org/category/neighborhood/Brookstown#desc



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