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DIVERSE PRODUCTIVE ROADSIDES: ECOLOGICALLY INTEGRATING AGRICULTURE INTO OUR HIGHWAY SYSTEM

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ABSTRACT

The extensive under-used area of roadsides along public highways could readily provide valuable environmental, economic, and cultural benefits for society. Furthermore, local food sources are an increasing priority as energy and environmental costs of long-distance transport increase. This article highlights the central goals and principles for introducing food production in roadsides. Seven types of roadside cultivation are considered: market vegetables, grain, fodder, orchard, biofuel, compost, and livestock. Principles important for incorporating food production into roadsides include: location relative to adjacent land uses; wildlife movement and biodiversity; site topography and hydrology; and arrangement of crops based on roadside pollutant concentrations. Potential problems and their solutions are examined, such as: a swale and remediation system for stormwater and aerial pollutants; a banded vegetation pattern with inedible crops close to the road and edible crops farther from the road; and strategically locating trees to narrow the perceived highway width for enhanced driver safety. Major benefits of roadside production include providing additional farmland for farmers, vegetation design that facilitates wildlife movement and reduces the effects of habitat fragmentation, a cultural symbol of productivity in a highly visible landscape, local food for markets and eateries, carbon sequestration, and multi-use right-of-way biodiversity and landscape management. A case study uses the goals and principles pinpointed to outline a specific design strategy for inserting diverse agriculture along 30km of highway (MA I-495) outside Boston, Massachusetts (USA). Now, widespread designs and pilot projects are needed to initiate the next generation of our roadsides, where public appreciation for local food production, multiple uses of infrastructure, and the landscape's wildlife heritage become the norm.
Keywords: Right-of-way; cultivation; landscape; wildlife; culture.

RESUMO

PRODUÇÃO DIVERSIFICADA NO ENTORNO DE RODOVIAS: INTEGRAÇÃO ECOLÓGICA DA AGRICULTURA NO SISTEMA RODOVIÁRIO. A extensa área subutilizada do entorno de rodovias públicas podem facilmente fornecer valiosos benefícios ambientais, econômicos e culturais para a sociedade. Além disso, fontes locais de alimentos são prioridades crescentes devido ao aumento dos custos energéticos e ambientais do transporte de longa distância. Este artigo destaca os objetivos centrais e os princípios da introdução da produção de alimentos no entorno de rodovias. Sete tipos de cultivos no entorno de estradas são considerados: vegetais para alimentação, grãos, forragem, frutas, biocombustíveis, composto e pecuária. Princípios importantes para a incorporação da produção de alimentos no entorno de estradas incluem: localização em relação ao uso das terras adjacentes; movimento da vida selvagem e biodiversidade; topografia e hidrologia local; e a combinação de culturas com base nas concentrações de poluentes no entorno das estradas. Possíveis problemas e suas soluções são examinados, tais como: um sistema de valas e filtragem para águas pluviais e poluentes aéreos; um padrão de vegetação em faixas com culturas de produtos não comestíveis perto da estrada e culturas de produtos comestíveis mais longe da estrada; e o posicionamento estratégico de árvores para estreitar a largura percebida da estrada pelos motoristas, aumentando a sua segurança. Os principais benefícios da produção no entorno de estradas incluem o fornecimento de terra adicional aos agricultores, uma

estrutura de vegetação que facilita o movimento dos animais selvagens e reduz os efeitos da fragmentação do habitat, um símbolo cultural de produtividade em uma paisagem amplamente visível, alimentos produzidos localmente para mercados e restaurantes, o sequestro de carbono, e o múltiplo uso do direito de passagem pela biodiversidade e gestão da paisagem. Um estudo de caso utiliza as metas e princípios salientados para delinear uma estratégia de abordagem específica para a inserção da agricultura diversificada ao longo de 30km de estrada (MA I-495), próxima de Boston, Massachusetts (USA). Agora, a ampliação de desenhos e projetos-piloto é necessária para introduzir a nossa próxima geração de estradas, onde tornem-se regras a apreciação pública da produção local de alimentos, os usos múltiplos da infraestrutura e a manutenção da paisagem selvagem.
Palavras-chave: Direito de passagem; cultivo; paisagem; vida selvagem; cultura.

RESUMEN

PRODUCTIVIDAD DIVERSIFICADA A LOS COSTADOS DE LA CARRETERAS: INTEGRACIÓN ECOLÓGICA DE LA AGRICULTURA EN EL SISTEMA DE RUTAS. La extensa área de rutas subutilizada a lo largo de las carreteras públicas podría proporcionar fácilmente valiosos beneficios ambientales, económicos y culturales para la sociedad. Además, las fuentes locales de alimentos son una prioridad cada vez mayor debido al incremento de los costos energéticos y ambientales del transporte a gran distancia. Este artículo destaca los objetivos centrales y los principios de la producción de alimentos a los costados de las carreteras. Se consideraron siete tipos de cultivos en el entorno de las carreteras: verduras frescas, granos, forrajes, árboles frutales, biocombustibles, abono y ganado. Los principios fundamentales para la producción de alimentos a los costados de la carretera incluyen: la ubicación en relación con el uso del suelo adyacente; el movimiento de la fauna silvestre y la biodiversidad; la topografía e hidrología local y la disposición de los cultivos en base a las concentraciones de contaminantes en la carretera. Se examinaron los potenciales problemas y sus soluciones, tales como: un sistema de drenaje y filtros para las aguas pluviales y los contaminantes aéreos; un patrón de bandas de vegetación con cultivos no comestibles cercanos a la carretera y cultivos comestibles alejados de las carreteras y árboles ubicados estratégicamente para reducir el ancho percibido de la ruta a fin de promover la seguridad de los conductores. Los principales beneficios de la producción a los costados de la carretera incluyen el suministro de tierras de cultivos adicionales para los agricultores, un diseño de vegetación que facilita el movimiento de la fauna y reduce los efectos de la fragmentación de hábitat, un símbolo cultural de productividad en un paisaje altamente visible, alimentos locales para los mercados y restaurantes, captura de carbono, y un uso variado del derecho de vía por la biodiversidad y para la gestión del paisaje. Un estudio de caso utiliza los objetivos y principios señalados para delinear una estrategia de diseño específica para lograr la inserción de la agricultura diversificada a lo largo de 30km de carretera (MA I-495), en las afueras de Boston, Massachusetts (USA). Ahora, son necesarios diseños generales y proyectos pilotos para iniciar la próxima generación de nuestras rutas, en donde el reconocimiento público por la producción de alimentos locales, los usos múltiples de la infraestructura y la conservación del paisaje silvestre sea la norma.
Palabras clave: Derecho de vía; cultivo; paisaje; fauna silvestre; cultura.

INTRODUCTION

The cultivation of local food sources grows increasingly critical, due to the rising cost and environmental impact of the long-distance transport of agricultural produce. Rapidly expanding urban populations place great pressure on rural food sources as well as the transportation network that services urban demand for agricultural products. While urban agriculture initiatives (ex. The Food Project in Boston or The Vertical Farm Project, developed by D. Despommier of Columbia University) provide promising sources for food production in and near cities, the vast network of roadsides linking urban and rural landscapes offers a largely unexplored opportunity for expanding local food production.

Over 6.2 million km (3.9 million miles) of road permeate the United States. While only 1.2% of these roads are federal interstate highways, they carry approximately 23% of all travel. These interstate highways include over 130,000km (80,000 miles) of roadsides and up to 65,000km (40,000 miles) of median strips (Forman *et al.* 2003). Contiguous stretches of open roadside may extend for only tens of meters or for several kilometers. Despite their scale in the American landscape, highways are one of the least considered public spaces – even as their expanse positions them as one of the most visible and experienced landscapes, a ubiquitous background that molds our perception. The Federal interstate highway system opened up the American landscape for people to travel over great distances, an important step in the cultural history of the United States. Jack Kerouac's iconic novel, On The Road, embodies the cultural significance of the highway as a symbol of exploration and self-determination.

This paper examines the productive capacity and cultural implications of repurposing this marginal and often degraded landscape for eight types of production: market vegetables, grain, fodder, orchard, biofuel, compost, coppicing, and livestock grazing. The objective of this paper is to consider the central goals and principles for the introduction of extensive agriculture in U.S. roadsides. In order to do this, solutions for anticipated problems are also articulated, including concerns about: roadside pollutants, adjacent landscape conditions, water management, bioremediation potential, biodiversity, and transportation safety. While this paper specifically focuses on the interstate highway system in the United States, it presents a framework for inserting agriculture in any roadside. A design case study along interstate highway 495 in Massachusetts illustrates how the established principles and goals could be applied.

Roadside agriculture is only one way to redesign the roadside; other productive uses of the roadside could surely be explored (van Bohemen 2004). Indeed, 'variegated roadsides' as a sequence of semi-natural systems providing diverse societal benefits, may be the big-picture objective (Forman *et al.* 2003, Forman & McDonald 2007). As one of the most visible public spaces, roadsides function as an expression of cultural attitudes toward the land. For example, in addition to designing for safe and efficient transportation, since the 1930s, U.S. roadside management goals have gradually changed from "our nation's front yards" to beautification with flowers to environmental sensitivity or ecological enhancement (Forman *et al.* 2003). A failure to value these spaces for their potential to be productive or expressive places is also a failure to communicate aspirations for the future of this shared landscape.

ROADSIDE PRODUCTION AND CULTURE

Engaging the roadside for productive purposes is not new. In diverse parts of the world, livestock grazing is a conspicuous part of roadside management. In Europe, for example in the Netherlands, some multi-lane highway roadsides are grazed or used to produce hay for livestock (Aanen *et al.* 1991, Bekker *et al.* 1995). In many developing countries, roadside grazing is an informal practice, particularly where open grassland is limited; in Accra, Ghana, livestock grazing occurs along roads within the city and along those extending out into the peri-urban and suburban zones. In The United States, federal and state roadside management regimes rarely include grazing, even in landscapes where pastureland is abundant, though exceptions exist (Gere 1977, Forman *et al.* 2003). Roadsides in the United States are predominately managed in a uniform fashion to keep vegetation low for driver visibility, road clearance, and errant vehicles. Inserting cropland and fenced pastureland into the roadside offers an opportunity to maintain a low vegetation typology consistent with driver safety while also offering productive possibilities.

Crops in the roadside may be cultivated for multiple purposes. These include market crops or grain for human consumption, forage for livestock grazing *in situ*, hay or fodder for livestock consumption *ex situ*, crops for biofuel production, orchards for fruit production, and vegetation for compost used in the agricultural process. The determination of which crops to plant largely depends on the environmental conditions of the roadside. Standards for heavy metal concentrations in crops for human consumption, fodder, and compost restrict planting for these purposes based on specific site conditions. Figure 1 illustrates the sectional implication of these conditions on the appropriate location of roadside products; market vegetables and fruits are only grown at measured acceptable pollutant levels, while non-edible crops

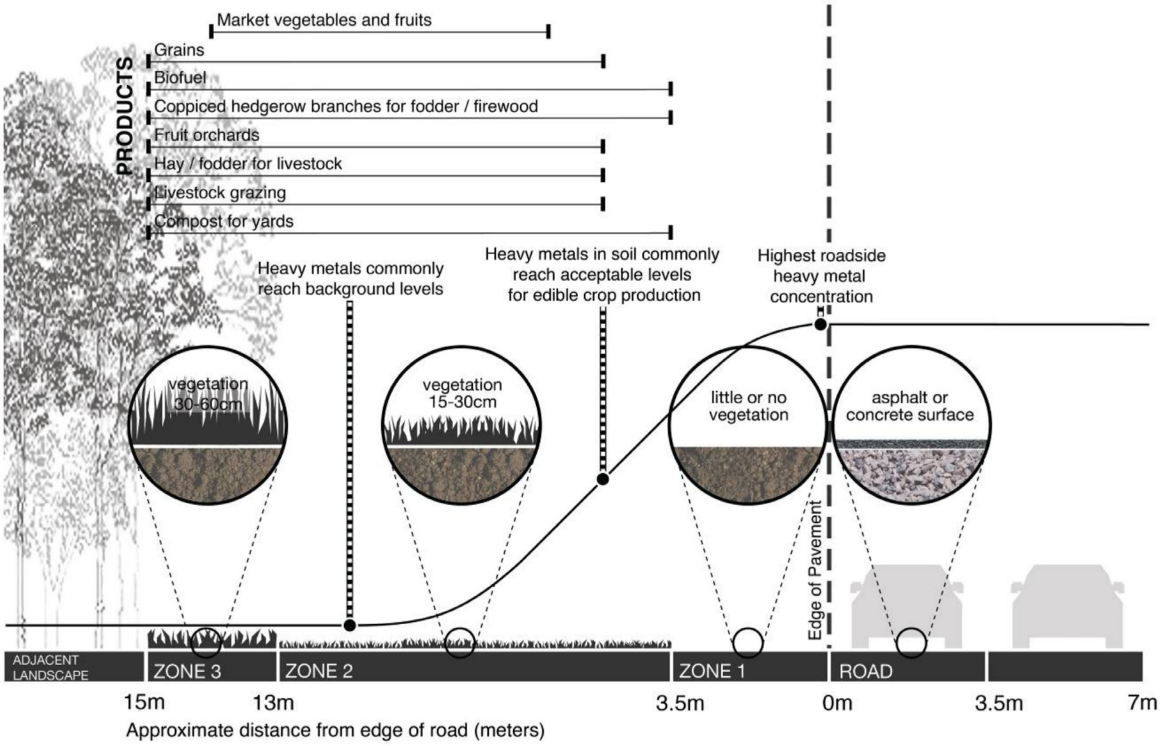

Figure 1. A schematic diagram of typical roadside vegetation design relative to pollutant levels along a U. S. highway and opportunities for introducing roadside production.

such as biofuels or coppiced hedgerows are grown within areas of higher pollutant levels. Testing of soils and an assessment of potential bioaccumulation of metals in crops planted in a particular site should occur before undertaking a large-scale agricultural intervention. Studies show that roadside heavy metal levels in the U.S. are usually within an acceptable range for crops used for fodder or compost. However, crops for human consumption require lower pollutant levels, so some roadside locations would be unsuitable, and soil and plants for this purpose would require more frequent testing to make sure that heavy metals and other pollutants remain at acceptable levels (Ministerie van Verkeer en Waterstaat 1999).

Although conditions for fruits, vegetables, and legumes are the most restrictive in limits of heavy metal concentrations in soil and plants, they offer the most profitable planting strategy per acre. These products also most directly address the effort to increase local sources of food since, unlike crops that need to be processed such as wheat, barley, or rye, fruits and vegetables can be transported directly to market in suburban or urban centers. In addition to requiring more regular testing to ensure consumer safety, fruits and vegetables also require more water, nutrients, and pest and weed control. Thus an appropriate composting regime for maintaining soil fertility and limiting pests and weeds through organic means, as well as an irrigation infrastructure usually must be developed. These requirements could be accomplished by integrating the planting area with a swale system to remediate and channel stormwater for fruit and vegetable cultivation. Farmer access to fruit and vegetable plots would be critical, suggesting that roadside agriculture would be most successful near to or adjacent to existing cropland.

Even as food shortages persist, crops are being diverted for biofuel production, despite the still inefficient production of these fuels from major food staples such as corn and wheat (Biello 2008, Crutzen *et al.* 2008). The use of these marginal landscape strips for the cultivation of biofuel crops would be a powerful solution to the current diversion of food crops for this purpose; this is a particularly critical issue in developing countries that experience chronic food shortages (Pimentel & Patzek 2005, Peskett *et* *al.* 2007). In a striated or mixed planting scheme, biofuel crops could be located closest to the road, where higher levels of heavy metal accumulation occur and non-edible crops are ideal. A benefit of cultivating crops for biofuel is the absence or scarcity of restrictions on the levels of heavy metals that may accumulate in the crops. Using the roadside for biofuel production, especially portions where heavy metal concentrations are too high to support crops for human consumption, would help alleviate pressure on food supplies. As the development of new energy sources remains a critical issue, using the roadside for fuel production links these crops into the network of road transport for local processing and distribution. Indeed, cultivating energy along a transportation system is particularly appropriate.

ROADSIDE POLLUTANTS

A wide range of chemicals from vehicles, road surfaces, and roadside management is deposited in roadsides. These include heavy metals, road salt (used to melt the ice after snowstorm), petroleum, hydrocarbons, pesticides, and fertilizers (Ministerie van Verkeer en Waterstaat 1999, Forman *et al.* 2003). While road salt and fertilizers largely determine what kind of vegetation will thrive in the roadside, heavy metals that accumulate in soils and plant tissues are the prime determinant of the safety of roadside crops for human or livestock consumption. Heavy metal particles are spread through aerial deposition as well as from stormwater runoff over asphalt or concrete pavement, carrying oil, gasoline, and the wear of automobile engines, brakes, and tires. The most abundant heavy metals spread by vehicular deposition include lead, cadmium, nickel, zinc, chromium, and copper. These heavy metals accumulate in roadside soils and in the biomass of plants grown in that soil. The concentration of these metals in plants determines their appropriateness for human consumption, fodder for pasture animals used for meat or dairy products, and compost. Although there is limited research on the uptake of heavy metals in roadside vegetation, many studies focus on the concentration of heavy metals in roadside soils, which indirectly indicate planting conditions that would support production of food crops with safe heavy metal concentrations (Lagerwerff & Specht 1970, Francek 1997, Carlosena 1999, Yang *et al.* 2002, Luilo & Othman 2003, Haal 2004, Koleli 2004, Grigalaviciene *et al.* 2005, Hooda *et al.* 2007, Kalavrouziotis *et al.* 2007, Li *et al.* 2007, Woodard *et al.* 2007, Bakirdere 2008, Suthar 2008).

The uptake of heavy metals by plants involves multiple factors, including the physiological preference of plants to accumulate particular metals, the presence of other metals in soil, and the pH of the soil (Ramakrishnaiah & Somashekar 2002). Due to the aerial deposition of heavy metals along the roadside, washing the leaves of plants before measuring heavy metal content or eating a plant markedly decreases concentrations (Li *et al.* 2007). Concentrations of heavy metals in the roadside decrease with increasing distance from the road and vehicular traffic, and also decrease with increasing soil depth. While some studies have shown that the distribution of certain heavy metals can extend up to 76m (250ft) from the edge of pavement, these results largely refer to Pb in areas where leaded gasoline use in vehicles was still prevalent (Fakayode & Olu-Owolabi 2003). Most studies show a sharp drop in all heavy metal concentrations approximately 4.5m (15ft) from the edge of pavement (Lagerwerff & Specht 1970, Francek 1997, Fakayode & Olu-Owolabi 2003, Forman *et al.* 2003, Haal 2004, Woodard *et al.* 2007, Bakridere 2008). The concentration of heavy metals in roadside soils increases with increasing traffic volume; however, increasing traffic volume does not correlate with an increase in the horizontal distance of roadside heavy metal distribution. Nevertheless, increased concentrations based on heavier traffic volume do indicate that the spread of metals through the hydrologic network of a particular site may be greater in roadsides next to heavily trafficked roads (Wu *et al.* 1998, Bean *et al.* 2007, Kayhanian *et al.* 2008).

The presence of lead in the roadside should be noted in particular, due to its demonstrated association with developmental disorders in children. In developed nations, where de-leaded gasoline has been the required standard since the 1990s, lead has significantly dropped in roadsides. However, in many developing countries, leaded gasoline is still used, which increases the contamination of roadside soils with Pb and its related risks for food grown in these soils (Fakayode & Olu-Owolabi 2003, Nabulo *et al.* 2006).

Besides heavy metal concentrations in roadsides, the structural quality of roadside soils is a concern for roadside agriculture. Road construction, usually involving a cut or fill in order to level the road to create an appropriate roadbed for laying asphalt or concrete, is extremely disruptive to soils. The soil horizon is destroyed, leaving a relatively homogenous composition that lacks a fertile organic top layer. Amending soil and stabilizing soil through compost, to be discussed later, is one method for preparing soil for agriculture. Incorporating nitrogen-fixing crop species into the rotation is another way to enhance and preserve the fertility of roadside soils. The variability of study results on the concentration and horizontal extent of roadside heavy metals emphasizes the importance of examining the specific traffic, soil, and hydrologic conditions of a roadside where the introduction of agriculture is considered.

WATER MANAGEMENT AND BIOREMEDIATION

Roads are typically designed to move water off the road surface as fast as possible, in order to promote driver safety during storms and to ensure the longevity of the asphalt surface and roadbed. Roads are slightly ridged down their centers, and water sheets off to either side into ditches cut into the roadside. The water may then flow to check dams that slow the movement of water in sections. Ultimately, the water is channeled above ground or through pipes into nearby water bodies, where heavy metals, road salt, and other transportation-related chemicals degrade aquatic ecosystems and fish populations (Kaighn & Yu 2007, Li *et al.* 2008).

The insertion of agriculture into the roadside is an opportunity to reconfigure the current roadside water management system to bioremediate heavy metals from roadside soils, use the cleaner water to irrigate crops, and decrease erosion through planting (U.S. Department of Transportation 1995). This planting strategy may also be targeted towards increasing wildlife habitat, as illustrated in Figure 2. The design of a roadside system to remediate and reuse rainwater for irrigation requires a quantification of rainfall and storage in a particular site, as well as an assessment of the temporal or seasonal availability of this water. In some climates and locations water for irrigation generated by precipitation may be insufficient and need to be supplemented.

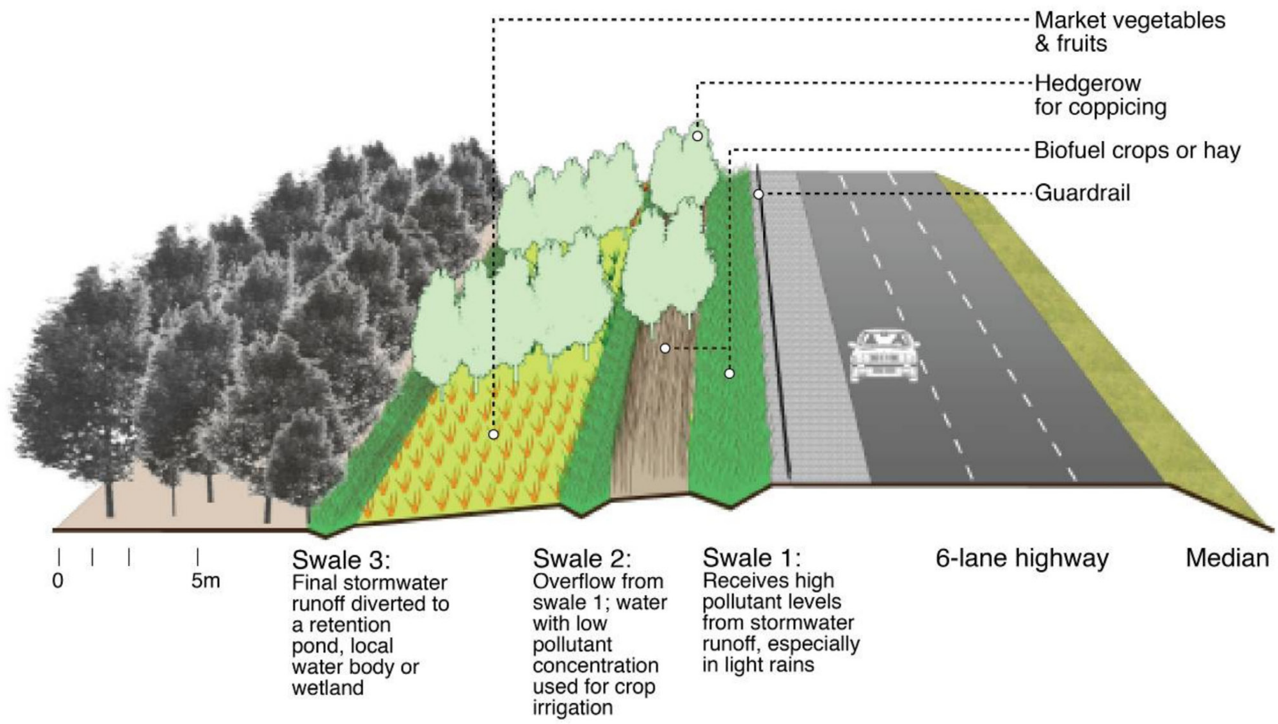

Figure 2. Design of roadside swales for water flow, crops, and augmented wildlife habitat.

The goal of a bioremediation process is to naturally filter the water so that when it does reenter the local hydrological system, it contains fewer pollutants (Lind & Karro 1995, Backstrom 2003, Zanders 2005, Barrett *et al.* 2006, McDonald *et al.* 2007). Certain plants, especially grasses (for exemple rye, wheat, switchgrass), are known to remediate heavy metals common in roadsides. These species would be strategically planted in roadside swales, which, at the onset of a storm catch the first flush of water from the road entering the roadside. Pollutant concentrations are highest in the first flush and progressively decrease with time, so the initial filtration through a grassed swale would have the greatest cleansing effect. This filtered water could then be channeled to irrigate crops in the roadside. The quality of the water then running off of these crops would depend largely on design and management. If manure or industrial fertilizers are used, significant amounts of nitrogen and phosphorous would likely cause eutrophication of local water bodies. Additionally, hedgerows, orchards, and adjacent trees shade the final swale, thus minimizing sun-heated ditch water, which inhibits cool-water fish, such as trout and salmon, in nearby streams and ponds.

However, an alternative would be organic management of roadside crops through the use of compost. Many states are increasing the use of compost in their roadside management regime, successfully reusing municipal and industrial organic waste that would otherwise enter landfills (Armstrong 2007, Larimore 2007, Persyn *et al.* 2007). Expanding the use of compost in the roadside reuses this waste material (potentially producing an economic value for it); correctly processed compost also provides a management system for roadside agriculture that maintains acceptable nutrient (for exemple nitrogen, phosphorus) levels for stormwater runoff into nearby waterbodies.

ADJACENT LANDSCAPES: CONDITIONS FOR AGRICULTURAL PRODUCTION

In addition to the inputs and impacts of the road, the landscape on the other side of a roadside also influences the roadside condition and the appropriateness of cultivating crops. Roads slice through a mosaic of land uses and natural ecosystems. These are in corridor, small patch, and large patch forms, each contributing potential effects on the roadside environment. Effects range in their intensity from high to low, and may include deer, coyote or other wildlife populations, various seeds, stormwater, or fire- and wind-blown nutrients. Thus some roadside stretches are ideal and some inappropriate for agriculture based on the advantages and arrangement of the surrounding landscape.

Natural areas such as forests or wetlands are likely to be a source of native animals and plants entering the roadside. Crops or pastureland in roadsides could attract wildlife populations, such as rodents or birds that feed on crops; forests or wetlands might also increase local biodiversity or provide pollinators necessary for cultivation. Developed landscapes, including residential, commercial, and industrial uses, may contribute non-native plant seeds, airborne heavy metals, and a diversity of other chemicals from roads, machinery, and smokestacks. For example, a residential edge generates materials associated with adults, children, and domestic animals. An industrial or commercial edge generates possible air pollutants and water pollutants.

Other landscapes include golf courses or agricultural fields, from which nitrogen and phosphorus used in fertilizers may enter the roadside through aerial deposition and runoff. For water-transported chemicals, the impact of each of these landscapes depends largely on their topographical and hydrological relationship to the roadside. For example, if a golf course is sloped away from the roadside, runoff across the fertilized turf will not increase levels of nitrogen and phosphorus in the roadside. Preponderant wind direction and the prevalence of particles on surfaces largely determine the amount of wind-transported chemicals on roadsides. A successful roadside agriculture intervention will require communication and coordination with the owners or representatives of adjacent landscapes.

WILDLIFE AND BIODIVERSITY

At present wildlife populations, from frogs and butterflies to birds and mammals, are significantly reduced by highways in four major ways (Forman *et al.* 2003): (1) habitat loss (area of road and roadside); (2) habitat degradation (adjoining area affected by traffic noise, pollutants, altered microclimate, etc.); (3) road-kill (mortality of animals hit by vehicles); and (4) the barrier or filter effect (road and roadsides inhibiting the crossing by wildlife). Productive roadsides offer both pros and cons for wildlife.

Compared to typical wide grassy roadsides along highways, the diverse productive plantings for roadsides provide several significant wildlife benefits. Figure 3 illustrates potential impacts on habitat and wildlife movement associated with roadside production. Roadside habitat diversity greatly increases, for example, with wet ditches, woody plants, different meadow patches, and diverse crop plantings. On average, the area of useful wildlife habitat increases. The amount and diversity of wildlife food resources also greatly increase. Channeling wildlife across roads using woody plants at specific locations decreases the barrier/filter effect, with a resulting expected increase in gene flow and population sizes. Birds and terrestrial animals tend to follow a line of hedgerow trees, even with no shrub cover, across an open roadside to the other side of the road, especially if they see similar vegetation ahead.

On the other hand, some increase in road-kill may be expected from increasing the connectivity for wildlife across roads with traffic. The road-kill rate, however, can be lowered, for exemple, by reducing excess vehicle speeds using perceptual highway narrowing (see transportation and safety section below), signage, and road surface changes, as often done for school or hospital zones. Large mammal and vehicle collisions on two-lane roads in Sweden dropped from a very high to very low rate when the posted traffic safe-speed limit was ≤80kph (≤50mph) (Seiler 2003, Forman & Sperling 2011). Thus on balance, the benefits of productive roadsides seem to far outweigh the disadvantages for wildlife populations.

The quality of roadside soil and water conditions has powerful consequences for what plants will live there and the associated wildlife that will be able to thrive. Invasive species often thrive in the roadside, based on extreme conditions of fertility and organic matter in soils, fluctuating hydrologic conditions, and repeated disturbance due to traffic and roadside management. Invasive species often establish in roadsides and spread along roads (Harper-Lore & Wilson 1999, Von der Lippe & Kowarik 2007, 2008). This may cause a decrease in plant biodiversity that also decreases the variety of wildlife and pollinators that depend on a diverse plant community.

Planting selected crops in the roadside could contribute to higher native biodiversity. For example, if the roadside is cultivated for particular crops such as market vegetables, the weeding and

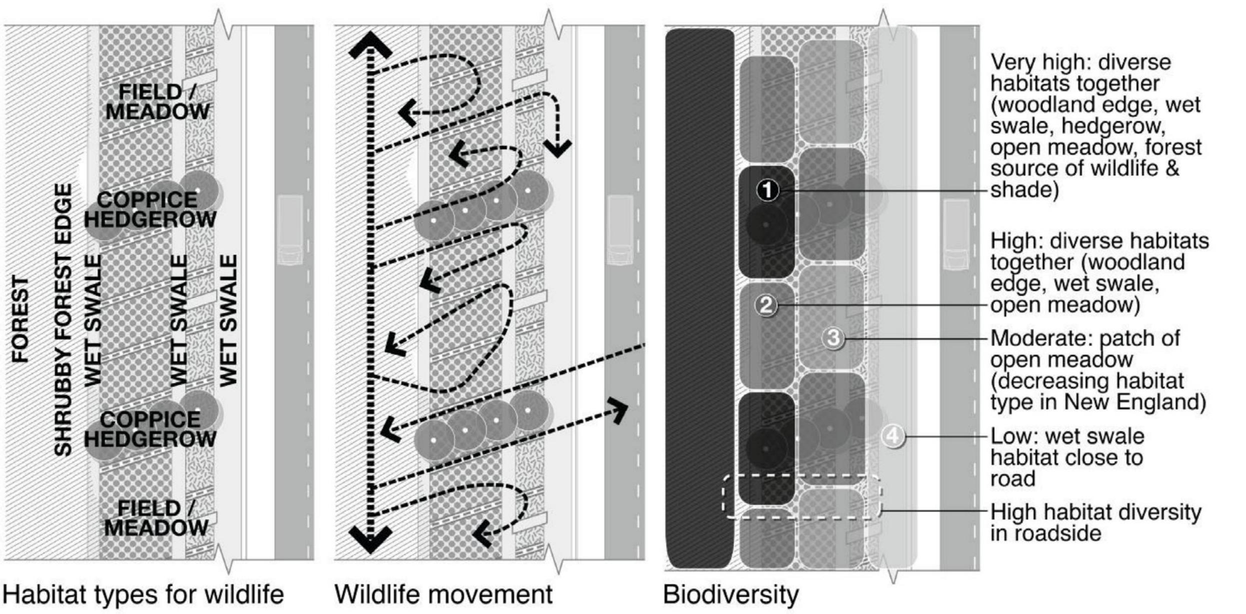

Figure 3. Potential impact of roadside production on wildlife habitat, wildlife movement, and roadside biodiversity

nutrient management of soils could decrease the establishment of large populations of invasive species. The insertion of these agricultural plots in roadsides could interrupt the spread of invasive species into adjacent landscapes; as well as the unchecked spread of invasive species along the long, continuous corridors of the highway roadside network. Grazing animals have also been shown to decrease invasive populations, as noted by the resurgence of these communities when grazing activities are discontinued (Popay 1996). Strategic planting could provide a variety of habitats that support both common and uncommon wildlife, as shown in Figure 4.

LANDSCAPE COMPONENT INCREASED IN ROADSIDE	UNCOMMON WILDLIFE FAVORED	COMMON WILDLIFE FAVORED
Stormwater ditch/swale	Fowler's toad, spotted turtle, king rail	Gray treefrog, wood turtle, raccoon*
Pond/wetland/biofilter	Fowler's toad, spotted turtle, black duck*	Gray treefrog, mallard*
Shrubby edge/strip/patch	Eastern kingbird, yellow-billed cuckoo, loggerhead shrike, willow flycatcher, coyote*	Brown thrasher, yellow warbler, chestnut-sided warbler, indigo bunting, rufous-sided towhee, song sparrow, ring-necked pheasant, white-footed mouse*, woodchuck*
Tree row	Northern oriole, orchard oriole, saw-whet owl	Wood pewee, warbling vireo, red-tailed hawk*, white-footed mouse*
Fence	Eastern bluebird, northern shrike*	
Farmer access road	Vesper sparrow	American kestrel*, bobcat
Vegetables/low fruits		Eastern cottontail*, meadow vole*, woodchuck*
Fruit trees/shrubs/vines	Eastern bluebird*	Meadow vole*
Biofuel woody/herb crops	Coyote*	
Meadow/hayfield/fodder	Grasshopper sparrow*, henslow's sparrow*	Goldfinch*, bobolink*, meadow vole*, eastern cottontail*
Grain/corn		
Compost	Grasshopper sparrow*	
Remediation plants/crops	Golden-winged warbler*	
Livestock pasture		Killdeer*, goldfinch*, white-footed mouse*, eastern cottontail*, meadow vole*

Figure 4. Potential common and uncommon wildlife increased in the northeastern USA roadside. Species from DeGraaf & Rudis 1983; * = authors' addition.

TRANSPORTATION AND SAFETY

The insertion of agriculture in the roadside involves a major consideration: the physical safety of drivers and farmers. Highway roadsides in the United States are typically cleared and managed up to 14m from the edge of pavement to accommodate errant vehicles (Forman *et al.* 2003). The management of this landscape has changed over the past several years; frequent mowing of these strips has begun to be replaced by once or twice-yearly mowing, which is shown to increase the biodiversity of this grass landscape, while still controlling the growth of woody plants. This mowing regimen also increases the competitive advantage of native plant species over invasive exotics (Aanen *et al.* 1991).

The insertion of agriculture in the roadside does not change its open design as a safety goal for driver visibility and precaution for errant drivers. However, an additional layer of trees that could act as hedgerows to protect crops for various reasons, from wind, aerial deposition, etc., would require a new understanding of how the roadside enhances the safety of drivers. Studies have shown that the perceived width of the road ahead of a driver directly relates to driving speed; as the width seems to increase, so does driving speed (Godley *et al.* 2004, Lewis-Evans 2006). Increasing the woody vegetation in the roadside offers a design opportunity for slowing traffic, particularly on long, straight stretches of highway where a lack of peripheral vegetation may contribute to the kind of monotonous driving experience that promotes accidents (Forman & McDonald 2007). Guardrails along roadside stretches with woody vegetation allow for this narrower perceived road width, while still preventing errant vehicles from hitting trees.

Safety considerations for roadside production would protect farmers and fenced grazing animals along the roadside from errant vehicles. Precautions could include guardrails, prominent signs, and bright clothing, as currently practiced for roadside maintenance crews. Studies of driver attention and anger show that designed roadside landscapes slow and calm drivers. This beneficial result of activating the roadside through agriculture could be an increase in driver attention, lowering the risk not only to farmers or grazing animals in the roadside but also to drivers themselves (Denton 1980, Cackowski & Nasar 2003, Moka *et al.* 2006). Fencing and/or guardrails would keep farm animals off the road surface, which would be safer than the occasional case of farmers tying animals to stakes to graze roadside vegetation. Figure 5 illustrates a possible roadside design, incorporating angled hedgerows that narrow the perceived road width, while also providing directed views for wildlife that move along hedgerow edges towards oncoming cars. Strategic spacing and placement of trees within an agricultural planting scheme would provide the safety benefits of woody vegetation along the road, while maintaining large open swaths of crops or grassland that are appropriate for both productive and safety purposes.

Several effects of carefully integrating hedgerows into a roadside agriculture scheme emerge. (A) Drivers reduce vehicle speed based on a narrower perceived road width (speed is a key factor in most crashes; always drive a safe speed, consistent with changing conditions); fewer vehicle crashes per kilometer means a safer road. (B) Drivers still have good views of wildlife ready to cross the road as lower branches of hedgerow trees nearest to the road are pruned and shrubs are absent under these trees. (C) Even though the hedgerow trees close to the road have no shrub cover, birds and terrestrial animals tend to follow the line of woody vegetation across an open roadside, especially if they see the corresponding hedgerow on the other side of the road. Wildlife crossing-zone signage could be used within 1.5km (1 mile) of hedgerow and agricultural plantings, similar to that for school zones. (D) Strong streamline-airflow crosswinds can be a hazard to drivers. Hedgerows parallel to the predominant wind have negligible effects. An obliquely oriented hedgerow could bend and accelerate streamline airflow across a road. However, maintaining gaps in the hedgerow tree canopy and shrub layers creates local turbulence that reduces streamline airflow and associated hazard to drivers. (E) In snow country the hedgerows can be designed to minimize snow accumulation and shading on a road surface. Tree height, distance between trees, and relative openness or density of vegetation layers are readily designed for these and other goals (Brandle *et al.* 1988, Forman *et al.* 2003).

Safety and ecology must be integrated in a productive roadside design to assure and ideally improve human safety, as well as augment wildlife habitats and biodiversity. Incorporating hedgerows into a roadside design increases the variety of wildlife habitats; the resulting accommodation of both common and uncommon flora and fauna increases roadside biodiversity.

ROADSIDE MAINTENANCE

Altering the roadside management regime of a public highway is not a simple proposition. Major considerations include cost, safety for drivers and maintenance crews, function (for exemple, conveyance of water), and appearance. Highway roadside regimes are typically funded by the state or federal government and emphasize low cost solutions for the long-term integrity of the road and maximum safety. Roadside agriculture offers an opportunity to transform conventional maintenance regimes into productive landscape management programs that integrate public and private interests.

Productive roadsides could raise the cost of maintenance. For example, agricultural production requires more human labor, planting and fencing materials, and monitoring than a conventional mowing routine. However, the sale of these crops could offset the cost or even result in a net profit. In particular, adjacency to existing agricultural uses would provide access to necessary infrastructure and expertise. Cooperation between public and private entities on roadside production projects will require clear guidelines for the approval of roadside management regimes and rigorous monitoring

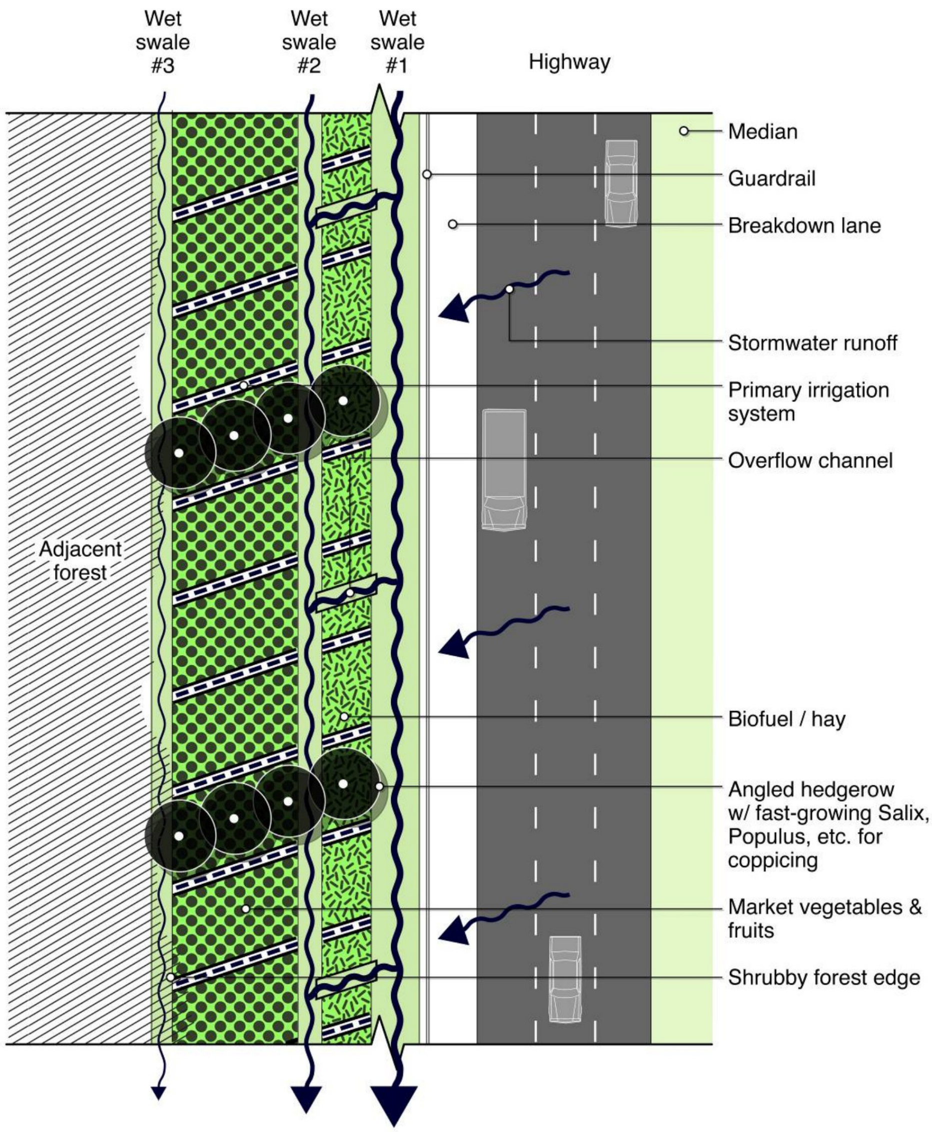

Figure 5. Possible roadside production design incorporating angled hedgerows.

programs for ensuring that adequate precautions are made for the integrity of the road and roadside, and the safety of drivers and workers.

MASSACHUSETTS (USA) CASE STUDY

In order to test the potential of inserting agriculture into the roadside, we designed an intervention along a 32km (20 miles) stretch of Interstate 495 in Massachusetts, north of its intersection with I-90 in Hopkinton and south of its intersection with Route 2 in Littleton. I-495 is an outer-ring highway approximately 48km (30 miles) from Boston, intersected by eight radial highways. This is a 6-lane highway, which includes paved shoulders and managed roadsides that range in width from 4.5 to 15m (15 to 50ft); the wide medians and large patches of land left by on- and off-ramps at highway exchanges are certainly viable for use as cropland or pastureland, but they are not included in this study. The total area of asphalt pavement for this 32km (20 miles) stretch of I-495 is 102ha (255 acres). The state owned and maintained roadside along this stretch includes 48ha (120 acres) of mowed grassland, much of it edged by forest.

Figure 6 outlines opportunities and constraints for introducing cropland and pastureland into these 48ha (120 acres) of managed roadside. Multiple roadside conditions were analyzed, including: local and regional hydrology, adjacent land uses, topography, soil conditions, and road curvature.

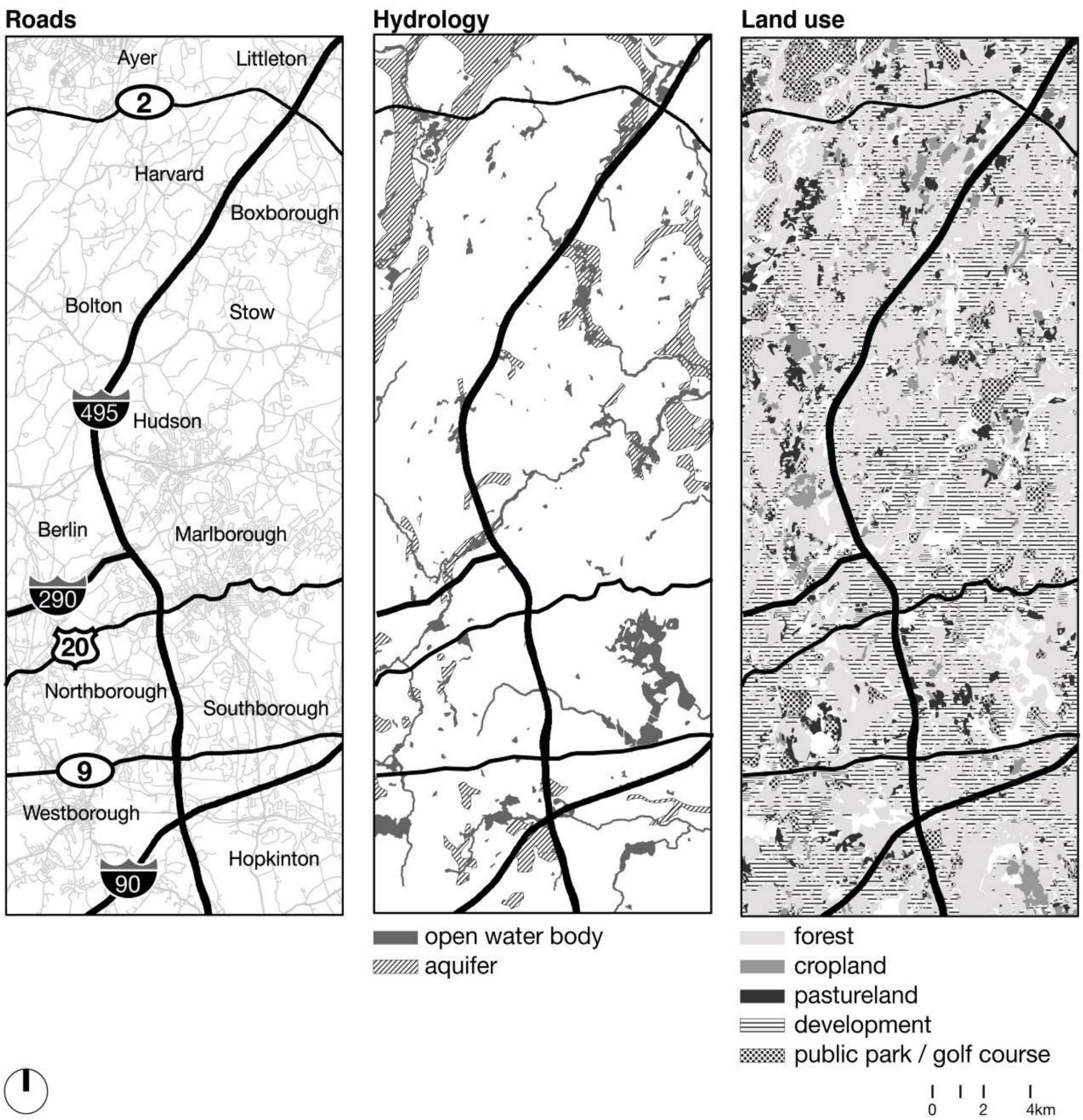

Figure 6. Existing conditions around the I-495 roadside in Massachusetts.

Cropland and pastureland exist in patches near this section of I-495; however, most of the open space along this roadside consists of forest and occasional development. In Massachusetts, a steady increase in residential development and decrease in agricultural activity over the last half century have diminished grassland habitats, as old fields succeeded into forests. Although suitable farmland soils are commonly present, grassland has become an increasingly rare habitat, particularly for certain birds and small mammals. Efforts to encourage farmers to preserve existing cropland and farmland include a Chapter 61 state program in Massachusetts, which offers tax incentives to farmers who guarantee that they will maintain their farmland. Opening up new patches of cropland and pastureland in roadsides that are currently forest is an opportunity to expand this habitat type.

Of the 48ha (120 acres) of roadside along this stretch, approximately 50 acres offer especially good opportunities for inserting agriculture, as shown in Figure 7. The following points clarify design guidelines to direct the planting and water management of a roadside agriculture scheme. (A) Grass vegetation selected to remediate heavy metals is planted in single or multiple swales (linear depressions), parallel and close to the road surface. The first flush of stormwater from the road is caught and filtered in these swales to provide clean irrigation water for crops further from the road. (B) Grass crops that may be used for biofuel or hay for local livestock are planted adjacent to the roadside; these plants may also absorb heavy metals in runoff as well as aerial deposition from the road. (C) High-profit market vegetables and fruits are planted furthest from the road where soil is fertile and least contaminated, and can be managed by local farmers. (D) Crops for biofuel, hay, or livestock grazing are planted where soil is less fertile or is moderately contaminated. Figure 8 illustrates several options for applying these concepts in the roadside of I-495.

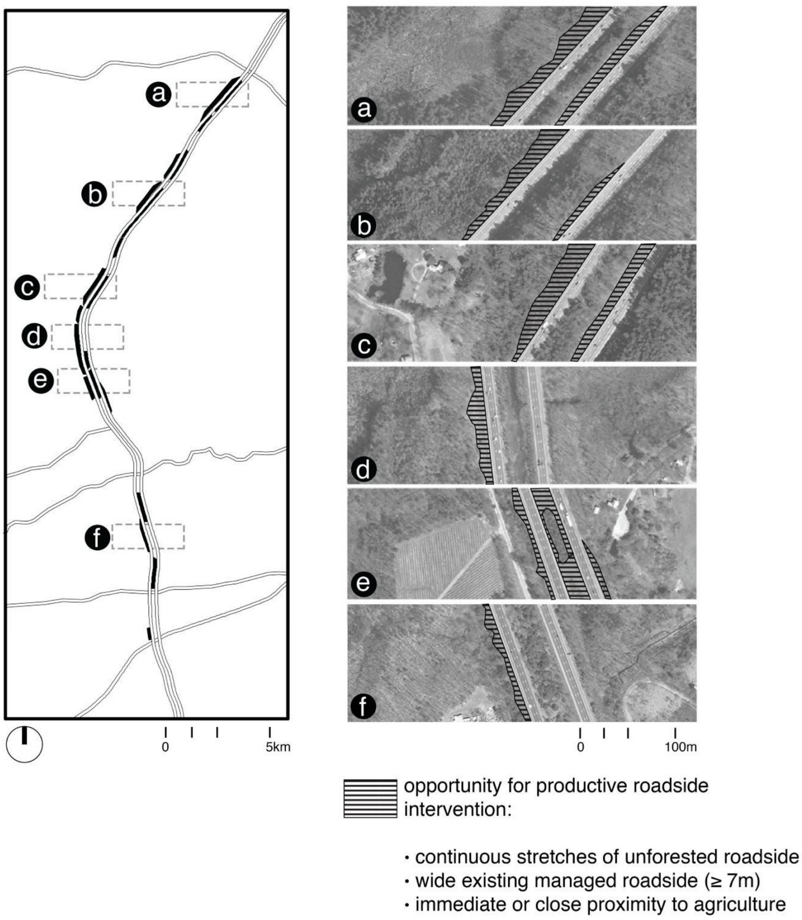

Figure 7. Opportunities for inserting agriculture in the roadside of I-495 west of Boston. Dark bands along the 20-mile stretch of highway identify 120 acres that are especially suitable for roadside agriculture.

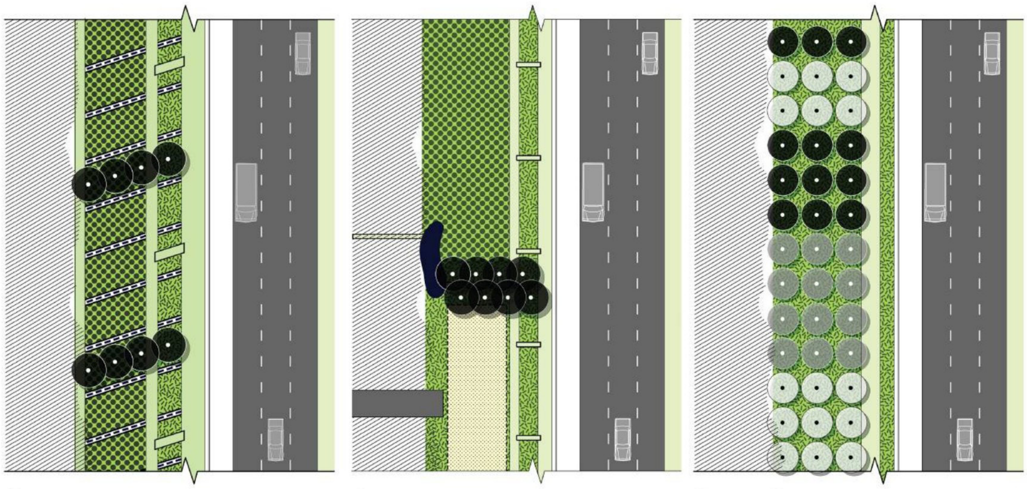

Figure 8. Roadside production options for MA I-495.

From the roadside site of cultivation, crops are transported for local processing or, in the case of fruits and vegetables, directly at low cost into Boston through the adjacent road network. Thus the design for this stretch of highway would include crops for livestock, biofuel, and human consumption. A wide range of crops presently cultivated in Massachusetts is available to provide these valuable products in roadsides for society. This case study highlights opportunities for transportation and agriculture in the particular topographical and environmental conditions of Massachusetts. Yet, based on the goals and principles presented in this paper, many iterations of roadside agriculture insertions tailored to different climates and sites should be developed. A wide range of possible components and simplified organizational strategies is available for roadside agriculture schemes, as illustrated in Figure 9. The implementation of these, based on specific site conditions and local agricultural practice, offers a rich array of options for initiating the next generation of American roadsides.

CONCLUSION

Managing the extensive network of roads is an enormous service to society, which uses and depends on transportation daily. The task is complex and efficiency critical. Inserting agriculture into the roadside requires an understanding and an alteration of both the existing roadside condition and the management system. The inclusion of partners in this process – the local farmers who would profit from productively managing key strips of roadside and the federal, state, and local transportation departments – is intended to ease the burden of management, while proposing a system that is productive and ensures that roadsides remain safe for drivers. The proposal of a productive roadside also reveals an opportunity for visually enhancing the driving experience, using diverse agricultural cultivation or other means. The application presented in this paper is only one example; future research and testing through pilot projects should be undertaken to further evaluate how extensive agriculture could be introduced into the U.S. highway system and provide so many benefits to society.

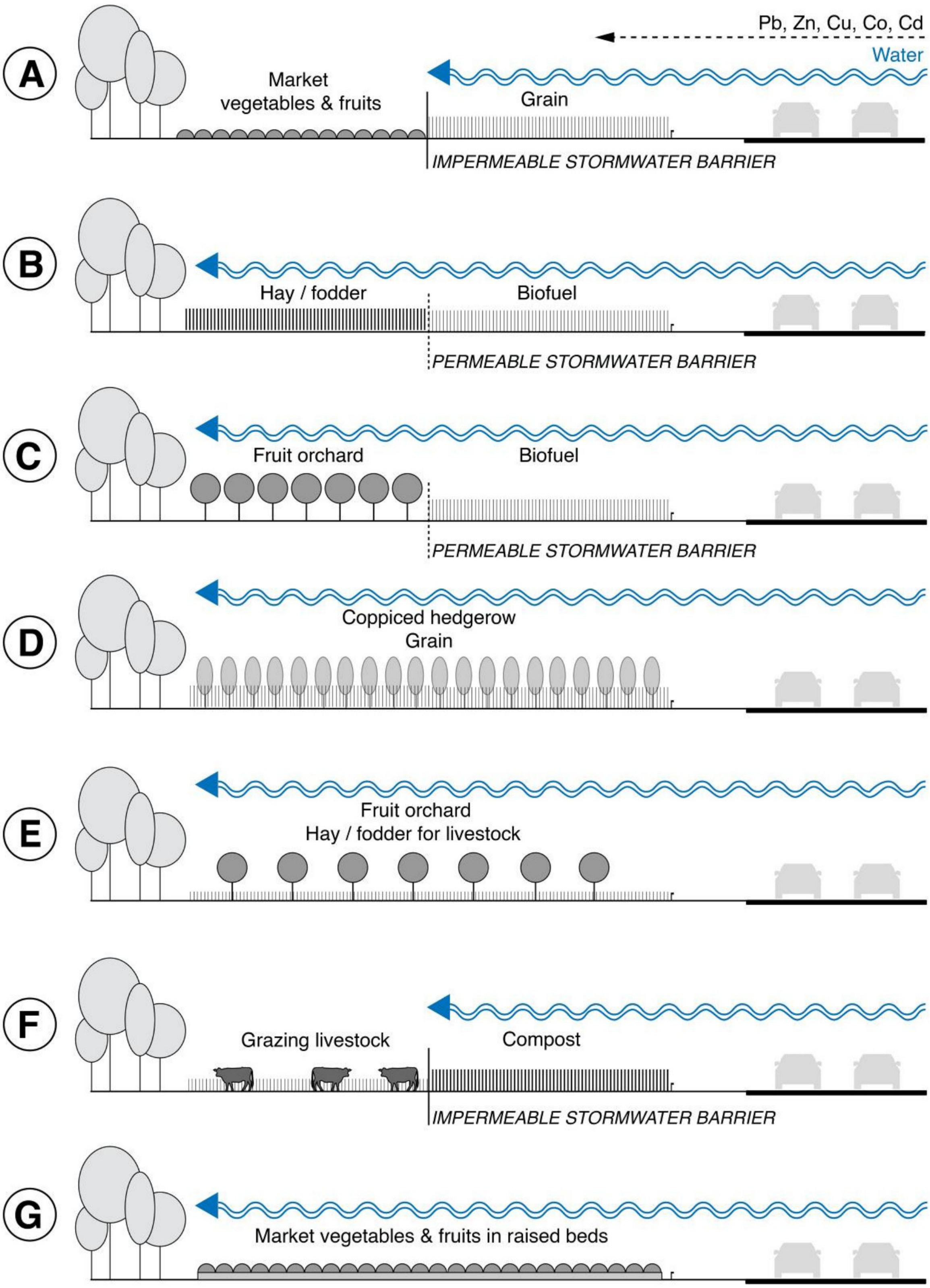

Figure 9. Potential roadside configurations for diverse site conditions and planting options.

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