Title
A Massive Increase in Roadside Woody Vegetation: Goals, Pros, and Cons

Authors
Forman, Richard T. T.
McDonald, Robert I.

Publication Date
2007-05-20

A Massive Increase in Roadside Woody Vegetation: Goals, Pros, and Cons

Richard T. T. Forman (617-495-1930, rforman@gsd.harvard.edu), PAES Professor of Landscape Ecology, Graduate School of Design, Harvard University, Cambridge, MA 02138 USA
Robert I. McDonald (617-495-1930, rmcdonald@gsd.harvard.edu), D.H. Smith Conservation Biology Research Fellow, Graduate School of Design, Harvard University, Cambridge, MA 02138 USA

Abstract: An extensive area of frequently mowed open grassy roadsides is designed for highway safety, yet paradoxically, in many locations woody vegetation of various types may make safer highways, and additionally provide diverse valuable benefits for society. Therefore our objective is to identify the goals of greatly increasing woody vegetation, consider the pros and cons, and identify the especially desirable and undesirable locations for it. Today, frequent costly roadside mowing favors many non-native species including invasives. Rare species also live on roadsides, including nearly a quarter of the U.S. federally listed threatened-and-endangered plant species with at least one roadside population. The prime goals of greatly increasing woody roadside vegetation are to: (1) increase wildlife habitat, biodiversity, and landscape connectivity; (2) increase highway safety and driver experience; and (3) decrease pollutant and peak-water-flow inputs to nearby water-bodies. The first goal has few disadvantages and also accomplishes diverse societal benefits. The second goal emerges from a modest decrease in vehicle speed in appropriate areas, plus the use of visually diverse types of roadside woody vegetation. An entrée into the travel-behavior and wildlife literature indicates that drivers drive more slowly on narrow than wide two-lane highways, and suggests that a sharp drop in wildlife/vehicle crashes appears between a posted speed limit of 90 and 70 km/hr (55 and 45 mph). The third goal enhances nearby streams, ponds, and other water bodies, mainly by significantly improving conditions in roadside ditches. Tall shrubs or natural forest/woodland are especially desirable vegetation types for >50% of the 35 situations common along road networks. Mowed grass is especially desirable on 17% of the situations, essentially the most risky driving locations. Meadow/low shrubs and small trees with herbaceous layer are intermediate in overall roadside value. We conclude that a massive increase in woody roadside vegetation offers numerous transportation, environmental, and societal benefits with minor disadvantages. Evaluation by a blue-ribbon panel of diverse experts and widespread pilot projects with research and monitoring are valuable next steps.

Background

Many nations have a very high density of roads and roadsides, yet even in the medium-road-density USA (0.75 km/km^2 or 1.2 mi/mi^2), about 1/400th of the entire land area is apparently roadside (Forman et al. 2003). This resource basically provides one major function to society, traffic safety. Intensive costly management commonly maintains roadsides as open grassy areas for driver visibility and errant vehicles. Lines of evidence are presented for an alternative strategy of using woody vegetation extensively, but carefully, in roadsides.

Woody roadside vegetation of various types offers many values for transportation, ecology, and society…ranging from increased wildlife habitat and highway safety to visual quality, aquatic-ecosystem, and carbon-sequestration benefits (Aanen et al. 1991, Forman et al. 2003, van Bohemen 2005). Shrubs and trees in distinctive combinations are no panacea, but when carefully meshed with grassy areas along highways, they offer many more opportunities and benefits than shortcomings.

Interestingly, the primary apparent shortcoming of increasing roadside woody vegetation, i.e., roadkilled animals and wildlife/vehicle crashes, seems likely to change little from the current situation, and could be significantly improved. This issue, involving wildlife populations, landscape connectivity, perceived road width, and traffic speed, will be considered in somewhat greater detail than many other important issues. In addition to evaluating the pros and cons of roadside woody vegetation, emphasis will placed on the optimal type of woody and grassy vegetation on 35 key types of situations along the highway network.

Therefore the objective of this article is to identify the major goals and evaluate the consequences of a massive increase in various types of roadside woody vegetation, while maintaining open grassy roadsides in key areas. To accomplish this, we briefly describe: (a) current species, vegetation, and management of roadsides; (b) goals of greatly increasing roadside woody vegetation; (c) the pros and cons of this development; and (d) its especially desirable and undesirable locations.

Current Vegetation, Species, and Management of Roadsides

Creating a road corridor significantly alters the environmental site conditions, perhaps most profoundly in the soil. During road construction, roadside soil tends to be homogenized, small depressions filled in, small hills levelled, large rocks removed, and the soil profile mixed horizontally and vertically (Forman et al. 2003, Forman 2004). Immediately adjacent to the road, soil is greatly compacted, reducing water infiltration and root penetration. Consequently plant diversity in roadsides is sharply reduced and one or a few species adapted to these conditions usually predominates. Specific locations however, especially in the outer roadside portion, largely escape the homogenization and compaction processes and may support relatively natural diverse vegetation.

Open grassy roadsides receive direct solar radiation which raises air and soil temperatures and lowers relative humidity. Adjacent roads and vehicles also spread various chemicals, from mineral nutrients and roadsalt to heavy metals and hydrocarbons, across the roadside. For example, road salt often increases chloride, a plant micronutrient, but can also cause sodium toxicity at high levels (Goldman and Malyj 1990). These environmental changes alter the suite of plant species that barely survive or that become competitively dominant on roadsides.

The type of road-corridor management has perhaps the greatest control on vegetation composition (Aanen et al.1991). The road shoulder may be bare earth or covered by low disturbance-tolerant plants, while the nearby roadside area may be mowed frequently, and thus largely covered by grasses and other herbaceous plants. Less frequently cleared areas may have many shrubs, and the lowest-maintenance areas in a forest/woodland climate usually have trees. The forest understory and shrubs may be cleared creating a park-like appearance, or left alone as in a natural forest/woodland. Finally, the manner of vegetation clearing, using mower, wood cutting, herbicide, or even fire, greatly affects the plant species composition (Parr and Way 1988).

Grasses and grass-like plants often predominate close to the road where these environmental alterations are most severe. The remaining vegetation of the road corridor is often more variable, with a mix of native and introduced species. The oldest and tallest vegetation allowed by the management regime dominates. Given the abundance of light along a road corridor, fast-growing shade-intolerant species are usually at a competitive advantage. Nevertheless, significant variation in plant composition along a road corridor occurs due to fine-scale variation in edge orientation, site topography, and management history (McDonald and Urban 2006).

An often-overlooked characteristic of roadsides is as habitat for rare native species. These are usually short-statured plants adapted to relatively open ecosystems like prairies or savannas, and are normally located in the outer roadside portion with less soil alteration. Surprisingly, based on the USDA PLANTS list of federally listed Threatened and Endangered (T&E) Plants for the continental USA (excluding California, which was beyond the scope of our study), 23% of these T&E plants have at least one population on roadsides. Large numbers of such rare roadside plants occur in the Southeast, particularly Florida, mirroring general patterns of plant diversity (figure 1). However the largest proportion of a state's rare species is found on roadsides in a band extending eastward and westward from the Ohio Valley. Previous to European settlement, this region largely had extensive forest and grassland patches, and today's roadsides may mimic grassland conditions for remnant rare species.

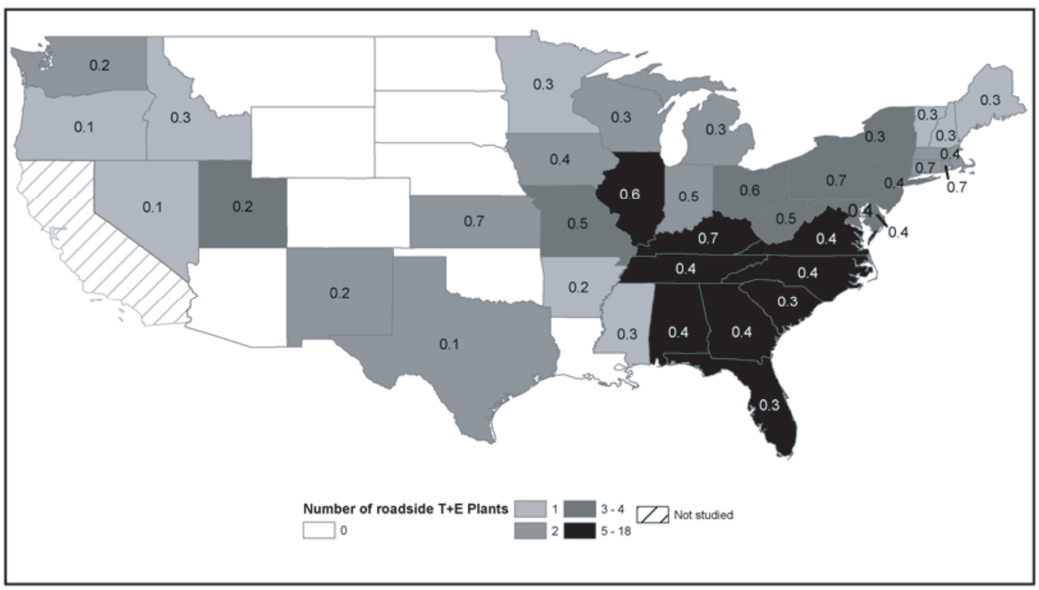

Figure 1. Federally listed Threatened and Endangered plant species in U.S. roadsides. Shading indicates the number of T&E species with at least one known population in a roadside (darker shades indicate more species). The number marked on each state indicates the proportion (ranging from 0 to 70%) of federally listed Threatened and Endangered plant species in a state that occur in a roadside. All species also occur in non-roadside locations.

Rare species and rare natural communities on roadsides are of particular conservation importance in landscapes of intensive human use, such as certain agricultural and built areas (Forman et al. 2003). Indeed, at least nine roadsides in the United Kingdom are designated as protected natural areas, and roadside management in The Netherlands especially protects rare species and natural communities on certain scarce sandy roadsides. Roadside natural areas or road reserves are widespread in Australia's intensive agricultural landscapes (Saunders and Hobbs 1991, Forman et al. 2003).

Roadsides also serve as habitat for invasive species (Harper-Lore and Wilson 2000). Non-native invasive plant species are typically fast-growing shade-intolerant herbaceous species, and thus well adapted for roadsides. Some invasive species such as kudzu (Pueraria lobata) were purposely planted for erosion control, but for most, frequent disturbance simply facilitates their establishment (Randall and Marinelli 1996). Furthermore, road corridors enhance the dispersal of invasive species (Trombulak and Frissel 2000, Forman et al. 2003). Vehicles often transport seeds along the road. Wind and wildlife also move seed along the corridor. In essence, roadsides serve as a connected corridor of suitable habitat for the spread of non-native invasive species.

Goals of Greatly Increasing Roadside Woody Vegetation

Three major ecological and transportation goals of society are achieved by greatly increasing woody vegetation on roadsides. These are a significant:

1. Increase in wildlife habitat, biodiversity, and landscape connectivity
2. Increase in highway safety and driver experience
3. Decrease in pollutant and peak-water-flow inputs to nearby water-bodies

These goals are discussed along with an evaluation list of pros and cons in the next section.

Several secondary goals are accomplished by a major increase in woody roadside vegetation. These include reduced management/maintenance costs, increased harvestable wood products, recreational benefits, and enhancement of adjoining and surrounding areas (table 1, end), as well as stormwater pollutant control in elongate shrub-lined depressions, nature and culture education, and other benefits. Together these benefits lead to a functionally and visually variegated roadside for society (Forman et al. 2003, Forman 2005).

Pros and Cons

A diverse list of advantages and disadvantages is presented as a succinct evaluation of the consequences of greatly increasing roadside woody vegetation (table 1). Rather than discussing each pro and con, certain broad themes are emphasized in considering the three major goals just articulated. This list is basically a launch-pad; each reader can add to it.

Wildlife Habitat, Biodiversity, and Landscape Connectivity

The improvement in wildlife habitat, biodiversity, and landscape connectivity (table 1) results from valuable solutions to several problems such as the following. With mowed-grass roadsides, many road/vehicle effects including chemicals, noise, and visual disturbance readily spread outward. Grassy roadsides usually have numerous non-native, mainly herbaceous, species including invasives. Shrubland is now scarce in many human-dominated landscapes. The scarcity of dead wood significantly degrades vertebrate and invertebrate biodiversity as well as forest ecosystem processes. And wide, open road/roadside strips are significant barriers or filters to crossing by many animal species, which effectively fragments habitats and the landscape. Woody roadside vegetation in forest/woodland climates provides significant benefit for all of these issues.

Highway Safety and Driver Experience

Driving a multilane highway in Europe with coppiced oaks covering both roadsides recently highlighted the importance of woody roadsides (Forman 2005). Dense stems about 6 cm in diameter and 5 m high extended right to the roadside ditches. A transportation official was asked about the dense woody cover, and she thought that it was to increase traffic safety. Almost immediately, a paradox crystallized. That was the exact opposite of the U.S. strategy of keeping roadsides open for traffic safety. She explained that research apparently shows that the perceived width of a road ahead is a key determinant of traffic speed. Drivers go more slowly with narrow visibility ahead, and speed up with wide visibility.

Table 1: Pros and cons of covering roadsides with woody vegetation. Adapted from Forman (2005)

	Wildlife Habitat, Biodiversity, and Landscape Connectivity
Pros:	Woody vegetation on roadsides adds considerable wildlife habitat and improves habitat in adjoining areas, thus increasing population sizes of numerous species.
	Disturbance-favored non-native and invasive species, which are mostly herbaceous, would decrease, though some non-native woody species would probably increase.
	Shrubland and associated species, which tend to be scarce in intensive agricultural and built areas, can be sustained.
	Dead branches and logs provide habitat and food for numerous species, and organic matter from diverse woody plants enriches the soil.
	Narrower road space between roadsides means more connectivity for wildlife movement (decreased road-barrier effect) and less habitat or landscape fragmentation.
Cons:	With more animals crossing roads and drivers going more slowly, the animal roadkill rate may change little (slight increase or decrease).
	Highway Safety and Driver Experience
Pros:	A narrower field of vision ahead means overall lower traffic speed, fewer speeders, fewer vehicle crashes per km, less severe crashes, and therefore a safer road.
	A slower-moving driver is less stressed and better able to enjoy the landscape, e.g., in rural, scenic, and tourist areas.
	Shrubs absorb/diffuse crash energy much better than does grass or large tree, so well-located abundant shrubs can reduce the human injury/fatality rate.
	Diverse types of woody vegetation reduce the monotony of grassy roadsides.
	Low-visual-quality places, such as polluted sites and strip development, are screened from drivers.
Cons:	Woody vegetation can reduce driver visibility around a curve in the road.
	Tree shade can slow snowmelt/icemelt resulting in a more hazardous road surface.
	An errant vehicle crashing into a large tree typically causes auto damage and human injury/fatality; shrubs may rupture the gasoline tank or hide the vehicle.
	More wildlife crossing narrower roads, plus drivers going more slowly, is likely to result in little change (a slight increase or decrease) in wildlife/vehicle crashes.
	Slower traffic means more time driving, e.g., commuting, to reach a destination.
	Views of diverse landscapes beyond roadsides are reduced.
	Water and Water Pollutants
Pros:	Friction along ditches due to woody vegetation decreases peak water flow (i.e., flood hazard) during high-runoff times.
	Woody vegetation evapo-transpires more water to the air than does grass, thus reducing water flow in ditches and downstream impacts.
	Roadside ditch water is shaded and cooler so nearby streams, ponds, and fish are less degraded by inputs of solar-warmed water.
	Sediment flow in ditches is reduced by shrub stems, thus limiting sedimentation and turbidity impacts on fish in streams and ponds.
	Woody vegetation limits inputs of mineral nutrients, especially phosphorus, to streams and ponds, resulting in less eutrophication.
	Woody vegetation limits the movement of chemical pollutants from roads and vehicles, including hydrocarbons and heavy metals, to streams and ponds.
Cons:	With less water runoff in shrub-lined shallow ditches, water may saturate a roadbed, causing roadbed failure and/or road surface degradation.
	In droughts or dry areas, reduced ditch-water flow could contribute to lowering nearby stream and pond levels.
	Management, Production, and Recreation
Pros:	Grass mowing and equipment-related costs should decrease.
	Natural vegetation processes replace many maintenance activities and costs.
	Wood products include firewood, fence posts, etc. extractable at frequent intervals, pulpwood at intermediate intervals, and lumber at infrequent intervals.
	Carbon is sequestered by tree production, helping to balance vehicular CO2 greenhouse gas emissions.
	Separate parallel walkways, bikeways, and greenways are partially screened from road and traffic.
	Diverse water benefits listed above lead to more fish and more successful fishermen in surrounding water-bodies fed by roadside ditches.
Cons:	Costs for controlling woody vegetation would increase.
	Adjoining and Surrounding Areas
Pros:	Species invasions of surrounding areas may decrease due to the reduced number of non-native herbaceous plants.
	Roads and traffic are visually screened from adjoining areas.
	Soil berms and noise barriers that decrease noise propagation to adjoining areas are partially hidden.
Cons:	Local business may decrease where drivers are screened from strip development.

A literature search was launched and the scattered evidence over decades and continents supported the official's thesis. An entrée into the literature, plus some particularly salient points, is useful here, though this is not a critical review (which should be done). Although research frameworks and methods in the relevant fields vary (Gale et al. 1996, Rothengatter and Huguenin 2004), seven useful points emerge. (1) On average drivers drive more slowly on narrow than wide two-lane highways (Godley et al. 2004, de Waard et al. 2004, Lewis-Evans and Charlton 2006). The difference is independent of driver's sex and driving experience (Recarte and Nunes 1996, Lewis-Evans and Charlton

2006, Conchillo et al. 2006), though younger drivers (in an age range of 18 to 53) rated wide roads as less risky (Lewis-Evans and Charlton 2006). (2) In diverse controlled studies with traffic speeds generally in the 60-120 km/hr (37-75 mph) range, the difference in drivers' speed between wide and narrow two-lane highways is roughly 5-15 km/hr (Recarte and Nunes 1996, Conchillo et al. 2006, Lewis-Evans and Charlton 2006). (3) With a posted speed limit of 80-100 km/hr, drivers on two-lane highways estimate their speed quite closely, whereas on wide multilane highways drivers underestimate their speed by nearly 10 km/hr (Conchillo et al. 2006). This may be related to decreased ability to estimate speed in the presence of parallel same-direction traffic or traffic complexity (Nunes and Recarte 2005, Conchillo et al. 2006). (4) Drivers on narrow highways drive further from the road edge, i.e., in their traffic lane but closer to the center line (van Driel et al. 2004, Lewis-Evans and Charlton 2006). (5) Drivers may not perceive the narrow highways to be narrower, though they do perceive narrow highways to be more risky and more likely to produce accidents (Wilde 1988, Lewis-Evans and Charlton 2006). This driver perception is at odds with the evidence that on wider roads vehicles travel faster and closer to the road edge, both actions placing the driver at increased accident risk. (6) Slower driving on narrow highways seems to be an inherent subjective response, rather than an objective decision based on an increase in edge information, such as noticing objects close by in the peripheral visual field of drivers (Denton 1980, Godley et al. 2004, Nunes and Recarte 2005, Lewis-Evans and Charlton 2006). (7) The research results linking slower safer driving to narrower highways seem generally consistent with traffic safety analyses of accidents (Fildes and Lee 1993, European Transport Safety Council 1995), traffic calming approaches (County Surveyors Society 1994, Burrington and Thiebach 1998), and visual and observational insights of landscape architects and planners in road/roadside projects (Appleyard et al. 1964, U.S. Department of Transportation 1997, Olin 2000, Schneider 2003, Givens 2003). Still, the overall evidence is not exhaustive and research is needed.

The lead author of this article tested his own driving speed in rural locations of Spain and Wyoming where buildings or high vegetation are close to both sides of the road. He found that the limited lateral vision ahead increased his concern for safety and resulted in his significantly reducing speed (by about 10-20 km/hr). If most other drivers also reacted this way, the result would be somewhat lower overall traffic speed (for instance, more drivers driving the legal speed limit) and fewer less-severe crashes per kilometer, effectively creating a safer road.

An extensive study of moose-vehicle collisions on two-lane highways in Sweden links wildlife/vehicle crash rates to posted traffic-speed limits (Seiler 2003). The average number of moose-vehicle collisions per 100 km of unfenced road per year was 1 at 50 km/hr, 2 at 70 km/hr, slightly >10 at 90 km/hr, and slightly <10 at 110 km/hr. The five-fold drop in wildlife/vehicle crashes from a posted speed limit of 90 to 70 km/hr (55 to 45 mph) is striking, and of planning and policy importance. Reducing traffic speed in this apparently critical range should dramatically reduce rates of roadkilled animals and wildlife/vehicle crashes. For instance, a 10-20 km/hr decrease by all vehicles should greatly improve safety, yet perhaps crash rate would decrease much more by designing roads and roadsides to especially slow down the fastest-moving vehicles.

Wildlife underpasses and overpasses are the safest way for wildlife to cross roads, but expense essentially limits them to especially critical locations for major wildlife corridors (Trocme et al. 2003, Luell et al. 2003, Forman et al. 2003, van Bohemen 2005, Clevenger and Waltho 2005). Most animal crossing from roadside to roadside presumably will always occur on the road surface. With woody roadside vegetation in many areas and an associated slight decrease in traffic speed (Table 1), the roadkill rate might slightly increase or slightly decrease. Irrespective, the increase in wildlife population sizes due to more woody roadside habitat should far outweigh any decrease in population sizes by roadkill, thus providing a net ecological gain.

The benefits to highway safety and driver experience primarily emerge from a modest decrease in vehicle speed in appropriate areas, as well as the use of visually diverse types of roadside woody vegetation (Table 1). Roadsides can become much more a key element in designing highways for safe and pleasant driving, rather than designing them for "stressed driving" and speeders. Fast-moving vehicles are not only at risk of hitting vehicles, structures, pedestrians, and wildlife, but also they consume more fossil fuel, emit more greenhouse gas, distribute more chemical pollutants along the road, and cause more traffic noise. Shortcomings of roadside woody vegetation for safety exist (Table 1), but overall, reducing vehicle speed provides major societal benefits.

Water and Water Pollutants

Finally, using roadside woody vegetation to decrease water and water-pollutant inputs to nearby water-bodies helps address flood hazard and pollution problems (table 1) (Forman et al. 2003, Forman 2004, 2007). Normally road construction significantly alters hydrology. Both the size and shape of water bodies and the blockage or acceleration of water flows tend to be noticeably changed. Most distinctive is the creation of straight roadside ditches that funnel stormwater (and snowmelt water) to downslope surface water-bodies, such as streams and ponds, creating potential flood hazards. In addition, ditch water in open roadsides carries lots of pollutants…heat from the sun, particles from road/vehicle wear, sediment from roadside erosion, mineral nutrients from roadsides, and toxic chemicals from diverse vehicle and road sources. The nearby receiving streams, ponds, aquatic ecosystems, and fish populations are therefore subject to major doses of these hydrologic and pollutant inputs flowing through open ditches. Maintaining woody vegetation adjacent to roadside ditches decreases all of the inputs, and thus helps protect surrounding water-bodies.

Especially Desirable and Undesirable Locations

Thirty-five common situations along highways are evaluated for the relative suitability of different types of roadside vegetation (table 2). Five types of vegetation are considered: (1) mowed grass, (2) meadow/low shrubs, (3) tall shrubs, (4) small trees with herb layer, and (5) forest/woodland. The highway situations selected and qualitative estimates of the suitability of vegetation are mainly based on the authors' recent observations in Massachusetts, North Carolina, Catalunya (Spain), and New South Wales (Australia).

Two-Lane Highways

For each roadside vegetation type, the number of especially desirable highway situations and the associated rationale are encapsulated as follows.

Mowed grass appears to be especially desirable in 6 of the 35 situations (17%) (table 2). These locations are the most risky or dangerous for driving, where vehicles are particularly at risk of crashes with vehicles, structures, bikers, or pedestrians. In some cases drivers are also at risk for wildlife/vehicle collisions. Mowed grass requires the highest management effort and cost.

Meadow/low shrubs is especially desirable in 11 cases (31%). Many of these highway situations represent a balance between open conditions for driver visibility and somewhat natural vegetation conditions. Some cases apply to non-forest/woodland climates.

Tall shrubs represent especially desirable vegetation in 20 of the 35 situations (57%) (table 2). Existing good visibility for a driver and the appropriateness of a lower driving speed characterize most of these cases. Tall shrubs provide good cover for almost all forest wildlife, so these locations are particularly important for wildlife crossing of highways. Dense shrubs also sometimes provide valuable soil and water benefits.

Small trees with herb layer is an especially desirable roadside type in 10 cases (28%). These highway situations generally combine relatively good driver visibility with certain forest conditions, such as shade and partial wildlife cover.

Natural forest/woodland serves as an especially desirable condition in 19 of the 35 cases (54%). Most of these highway situations have existing good visibility for drivers and are appropriate for lower-speed driving. Here tall trees are suitable next to the road. A shrub layer in the forest provides good wildlife cover, and these situations are especially important for wildlife crossing of the highway. Management effort and cost are low.

The relative frequency of desirable and undesirable vegetation types is somewhat similar among the four broad categories of Table 2...highway, local roadside conditions, local area conditions, and surrounding broad landscape conditions...which represent increasing spatial scale. Thus the benefits of, for example, natural forest/woodland or of mowed grass apply at a relatively consistent level from narrow- to broad-scale situations.

Although the vegetation patterns illustrated in table 2 refer only to one side of the two-lane highway (the driver's side), roadsides on both sides are important for certain variables and situations. For example, maintaining the same vegetation on both sides of a highway, especially tall shrubs or natural forest/woodland, facilitates wildlife crossing of the road surface. Thus roadside design and management must focus on the combination of vegetation types on opposite sides of the road. This will often require evaluating whether the same or different vegetation is optimal on both sides, such as the contrasting desirable conditions for uphill and downhill driving on the same slope (Table 2).

Highway driving involves both specific locations and long highway stretches, and all five vegetation types are found to be desirable (or undesirable) in both situations (table 2). Estimates of the relative lengths of each highway situation, plus the current vegetation characterizing those situations, would permit calculation of the amount of roadside change required to reach the optimum for the road network. Where roadside vegetation is currently mowed grass, all changes in vegetation type presumably would represent a saving in management effort and cost. More important however, are the rich benefits (Table 1) to transportation, ecology, and society.

Table 2: Especially desirable and undesirable roadside vegetation types in different highway locations. Five major types of roadside vegetation are given with their typical heights: (1) mowed grass, 0.3 m; (2) meadow/low shrubs, 1 m; (3) tall shrubs, 2.5 m; (4) small trees with herb layer, 5-15 m; and (5) natural forest/woodland with all layers, 5-30 m. + = especially desirable vegetation type; - = especially undesirable; dot = advantages and disadvantages about equal. Results refer to a natural forest/woodland climate. Maintenance intensity and cost generally decreases from mowed grass to natural forest/woodland. Roadside vegetation refers to the 10+ m zone next to the road surface alongside the driver's lane (natural vegetation is often suitable beyond that zone). Meadow/low shrubs provide cover for mid-sized wildlife. Both high shrubs and natural forest/woodland provide cover for large animals, which also are primarily involved in wildlife/vehicle crashes. Special local or site conditions of course may alter the broad-pattern results

Mowed Grass	Meadow	Tall Shrub	Small Trees	Forest Wood	
					Highway: Straight, Curves, and Hills
-	.	+	+	+	*Straight flat highway section.* Wildlife movement more likely to be detected by driver.
-	.	+	+	+	*Outside/outer curve.* Geometry means that driver faces and has good view of roadside.
+	+	-	.	-	*Inside/inner curve.* Poor driver visibility ahead.
-	-	+	.	+	*Uphill section.* Shorter vehicle avoidance/stopping distance.
-	.	+	+	+	*Hillcrest.* Reduced driver visibility ahead; short vehicle avoidance/stopping distance; hilltop/ridgetop with distinctive vegetation/animals; ridgetop is wildlife-movement corridor.
+	+	-	.	-	*Downhill section.* Long vehicle avoidance/stopping distance, especially on wet or icy surface.
					Local Roadside Conditions
-	-	.	.	+	*Behind guardrail.* No danger of crashing into large tree; poor driver visibility.
-	-	+	-	+	*Fillslope on lower side.* Diverse and deep woody roots reduce earth-slides and surface erosion; little effect on driver visibility due to lower surface and (usually) guardrail; wildlife tend to enter road slowly.
+	+	-	.	-	*Gradual cutbank on upper side.* Avoid fallen trees/branches on road; wildlife have wide view, may rapidly enter road.
-	.	+	+	-	*Steep cutbank on upper side.* Woody plants reduce surface erosion/sedimentation and rockfalls; few animals enter road; avoid fallen trees/branches on road.
-	.	+	.	-	*Equator side of east-west road in cold climate.* Trees shade road surface; ice forms readily and snow/ice melts slowly.
					Local Area Conditions
-	-	+	+	+	*Approach before road-intersection area.* Slows vehicles by creating narrowed visibility ahead for driver.
+	+	-	.	-	*Immediate area around road intersection.* Enhanced driver visibility for children, elderly persons, and vehicles crossing; relatively unsuitable location for most wildlife.
-	-	+	+	+	*Approach before edge of rural town or village.* Slows vehicles by creating narrowed visibility ahead for driver.
+	+	-	+	-	*Edge and inside of rural town or village.* Enhanced driver visibility for children, elderly persons, and vehicles.

Mowed Grass	Meadow	Tall Shrub	Small Trees	Forest Wood	**Local Area Conditions (cont.)**
-	-	+	.	+	*Before and after bridge over water/land.* Helps slow vehicles (along with guard rail and narrowed roadside), including before icy bridge surface; reduces blockage of wildlife movement along stream/river corridor.
-	.	+	.	+	*Local wildlife crossing zone.* Short (e.g., 100-1000 m) continuously marked and monitored zone for terrestrial animals of local importance to cross road.
-	-	-	.	+	*Arboreal-animal crossing zone.* Short continuously marked zone with guardrail and large trees by road; on both sides, tree branches/artificial structures connect over the road.
-	-	-	.	+	*Windbreak.* Taller vegetation reduces streamline wind velocity for a longer distance; medium-porous vegetation reduces turbulence.
-	-	-	.	+	*Snowbreak.* Wide dense bands of low-branched trees several meters upwind of road surface accumulate snow to keep surface clear; relatively close upwind high trees reduce blowing-snow on roadways.
					Surrounding Broad Landscape Conditions
-	.	+	+	+	*Park, scenic, and recreational roads.* Slower driving with major goal of seeing wildlife/viewing natural landscapes; facilitates natural wildlife movement across road.
-	-	+	.	+	*Road between nearby natural vegetation areas.* Areas between natural-vegetation patches have abundant wildlife movement and road crossing; woody vegetation reduces the road barrier or disruption effect.
-	+	-	.	-	*Road in matrix between sustainable emeralds.* Near an emerald network (large natural areas connected by major wildlife corridors for the future), need to balance tendency of wildlife to cross a less-suitable matrix separating natural patches, and the goal of encouraging wildlife to use well- located and protected wildlife corridors elsewhere.
-	-	.	-	+	*Road crossing location of a future major emerald-network wildlife corridor.* Short (e.g., 100-1000 m) continuously marked zone for key wildlife from emeralds to cross road.
+	-	-	-	-	*Existing high-roadkill-rate site not at future major emerald-network corridor location.* Reduce roadkills, wildlife/vehicle crashes, and wildlife crossing here.
-	+	-	-	-	*Road in grassland climate zone.* Woody vegetation is normally incompatible except by water sources.
-	+	+	-	-	*Road in shrubland climate zone.* Trees usually incompatible.
-	+	+	-	-	*Road in desert climate or desertified zone.* Mimic the natural vegetation of the surrounding landscape, which may vary from no vegetation to dispersed shrubs.
-	+	-	-	-	*Road in fire-prone area.* Road serves as barrier disrupting natural fire movement, but a greater problem is increased human-caused fire frequency, so highly flammable shrubs and small trees close to roads are typically undesirable.
-	+	+	-	-	*Scenic view from road.* Where roadside trees are ecologically desirable, periodic rather than continuous stretches without trees are appropriate for visual benefit.
-	-	.	+	+	*View of the road.* In a relatively natural landscape, trees are useful to obscure roads and traffic from view.

Multilane Highways

In contrast to the preceding patterns for two-lane highways, multilane highways typically have a range of different environmental effects, including: high traffic volume (density); periods of intense congestion that spread diverse pollutants, including hydrocarbons, heavy metals, and NOX (plus greenhouse gas); a wide habitat-degradation or wildlife-avoidance zone on both sides of the highway, in part due to numerous fast vehicles creating traffic noise (which may be reflected/absorbed by soil berms, sunken roadways, and/or noise-barrier structures with or without plants); and major wildlife-barrier and habitat-fragmentation effects. Woody vegetation on outer roadsides here provides important benefits, though some advantages are reduced by these environmental patterns.

Nevertheless, vegetation on the central median strip of multilane highways is particularly significant from three perspectives. (1) Headlight glare. On an inside/inner curve, drivers have good visibility of the median and have little oncoming traffic-headlight glare at night. On an outside/outer curve, drivers have poor visibility of the median and considerable headlight glare, and on straight highway sections headlight glare is significant. Tall shrubs are especially appropriate to cut headlight glare of oncoming vehicles. (2) Wildlife. Tall shrubs enhance wildlife crossing of the wide multilane highway. But setting shrubs back from the road surface enhances driver visibility, especially in the adjacent fast-traffic lanes (where vehicles have longer avoidance/stopping distances), thus helping to reduce roadkills and wildlife/vehicle crashes. Trees and branches in median strips of forest/woodland are particularly subject to windfall. (3) Water/sediment. Shrubs along a drainage ditch in the median should decrease erosion and sedimentation. Tall shrubs on the equatorward side of a drainage ditch provide shade that helps maintain cool water temperature, thus reducing degradation of nearby water-bodies and fish populations. In brief, tall shrubs are the best of the five vegetation types for most median strips of multilane highways.

Conclusion

The advantages of greatly increasing roadside woody vegetation appear to far outweigh the disadvantages. Tailoring the type of vegetation to the different situations along highways is a key to success. The prime benefits gained are wildlife/landscape connectivity, driver safety and experience, and water and pollutant improvements in nearby water bodies, yet many ancillary benefits are identified. The key challenge is to spatially arrange the vegetation types and societal benefits so that wildlife/vehicle crashes do not increase, but instead decrease. Greatly increasing roadside woody vegetation is quite consistent with the broad objectives for road ecology in serving and benefiting transportation and society (Forman 2007). Important next steps are to establish: (1) widespread monitored pilot projects and empirical research; and (2) a key council of ecology, safety, travel behavior/psychology, roadside management, and other experts to rigorously evaluate the net benefits for society, plus outline a trajectory and timetable for appropriate implementation, of this potentially wonderful transformation of our roadsides.

Biographical Sketches: Richard T. T. Forman is the PAES Professor of Landscape Ecology at Harvard University, where he teaches ecological courses in the Graduate School of Design and in Harvard College. His research and writing include landscape ecology, road ecology, changing land mosaics, land-use planning and nature conservation, urban region ecology, and, more broadly, spatially meshing nature and people on the land. He received a B.S. from Haverford College, Ph.D. from the University of Pennsylvania, honorary Doctor of Humane Letters from Miami University, and honorary Doctor of Science from Florida International University. He formerly taught at Rutgers University and the University of Wisconsin. He served as president or vice-president of three professional societies, and has received awards and honors in France, Colombia, England, Italy, China, Czech Republic, Australia, and the USA. Professor Forman has authored numerous articles, and his books include Landscape Ecology (1986), the award-winning *Land Mosaics* (1995), *Landscape Ecology Principles in Landscape Architecture* and *Land-use Planning* (1996), *Road Ecology* (2003), *Mosaico territorial para la region metropolitana de Barcelona* (2004), and *Urban Regions: Ecology and Planning Beyond the City* (2007 forthcoming).

Robert I. McDonald is a D.H. Smith Conservation Biology Research Fellow, based in the Graduate School of Design at Harvard University. His research and writing focuses on the implications of urban growth on conservation of biodiversity and ecosystem services. He received a B.S. from the University of North Carolina at Chapel Hill and a Ph.D. in ecology from Duke University. His articles cover a wide variety of topics, and have been published in journals such as *Ecology, Conservation Biology, Biological Conservation, Biological Invasions, Forest Ecology and Management, Landscape Ecology,* and *Landscape and Urban Planning*. An article, entitled "A World of the City, by the City, for the City", has been published in a recent book, *Taking Sides: Clashing views in global issues* (2007).

References

Aanen, P., W. Alberts, G. J. Bekker, H. D. van Bohemen, P. J. M. Melman, J. van der Sluijs, G. Veenbaas, H. J. Verkaar, and C. F. van de Watering. 1991. *Nature engineering and civil engineering works*. Pudoc, Wageningen, Netherlands.

Appleyard, D., K. Lynch, and J. Myer. 1964. *The View from the Road.* MIT Press, Cambridge, Massachusetts.

Burrington, S. H. and V. Thiebach. 1998. Take Back Your Streets: How to Protect Communities from Asphalt and Traffic. Conservation Law Foundation, Boston.

Clevenger, A. P. and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biological Conservation* 121: 453-464.

Conchillo, A., M. A. Recarte, L. Nunes, and T. Ruiz. 2006. Comparing speed estimations from a moving vehicle in different traffic scenarios: absence versus presence of traffic flow. *The Spanish Journal of Psychology* 9: 32-37.

County Surveyors Society (R-U). 1994. *Traffic Calming in Practice.* Landor Publishing Co., London.

de Waard, D., F. J. J. M. Steyvers, and K. A. Brookhuis. 2004. How much visual road information is needed to drive safely and comfortably? *Safety Science* 42: 639-655.

Denton, G. G. 1980. The influence of visual pattern of perceived speed. *Perception* 9: 393-402.

European Transport Safety Council. 1995. *Reducing Traffic Injuries Resulting from Excess and Inappropriate Speed.* Brussels.

Fildes, B. N. and S. J. Lee. 1993. *The Speed Review: Road Environment, Behavior, Speed Limits, Enforcement and Crashes*. Report CR 127. Federal Office of Road Safety, Canberra, Australia.

Forman, R. T. T. 2004. Road ecology's promise: what's around the bend? *Environment* 46: 8-21.

Forman, R. T. T. 2005. Roadside redesigns – woody and variegated – to help sustain nature and people. *Harvard Design Magazine* (Fall 2005/Winter 2006): 36-41.

Forman, R. T. T. 2007. Major objectives for road ecology to benefit transportation and society. In *International Conference on Ecology and Transportation 2007 Proceedings*, Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina. In press.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Island Press, Washington, D.C.

Gale, A. G., I. D. Brown, C. M. Haslegrave, and S. P. Taylor, eds. 1996. *Vision in Vehicles*, V. Elsevier, Amsterdam.

Givens, J. S. 2003. Rural rustic roads in Virginia – implementation of program guidelines and pilot projects. *Transportation Research Board* 1819: 155-165.

Godley, S. T., T. J. Triggs, and B. N. Fildes. 2004. Perceptual land width, wide perceptual road centre markings and driving speeds. *Ergonomics* 47: 237-257.

Goldman, C. R. and G. J. Malyj. 1990. *The Environmental Impact of Highway Deicing*. University of California, Davis, California.

Harper-Lore, B. L. and M. Wilson, eds. 2000. *Roadside Use of Native Plants*. Island Press, Washington, D.C.

Iuell, B., H. (G. J.) Bekker, R. Cuperus, J. Dufek, G. Fry, C. Hicks, V. Hlavac, V. Keller, C. Rosell, T. Sangwine, N. Torslow, and B. le M. Wandall. 2003. *Habitat Fragmentation due to Transportation Infrastructure: Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. COST 341. KNNV Publishers, Brussels.

Lewis-Evans, B. and S. G. Charlton. 2006. Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis and Prevention* 38: 610-617.

McDonald, R. I. and D. L. Urban. 2006. Edge effects on species composition and exotic species abundance in the North Carolina Piedmont. *Biological Invasions* 8: 1049-1060.

Nunes, L. M. and M. A. Recarte. 2005. Speed, traffic complexity, and visual performance: a study on open road. Pages 339-354 in G. Underwood, ed. *Traffic and transport psychology: Theory and application*. Elsevier, Amsterdam.

Olin, L. 2000. *Across the Open Road*. University of Pennsylvania Press, Philadelphia.

Parr, T. W. and J. M. Way. 1988. Management of roadside vegetation: the long term effects of cutting. *Journal of Applied Ecology* 25: 1073-1087.

Randall, J. M. and J. Marinelli. 1996. *Invasive Plants: Weeds of the Global Garden*. Brooklyn Botanic Garden, New York.

Recarte, M. A. and L. Nunes. 1996. Perception of speed in an automobile: estimation and production. *Journal of Experimental Psychology, Applied* 2: 291-304.

Rothengatter, T. and R. D. Huguenin, eds. 2004. *Traffic and transport psychology: Theory and applications*. Elsevier, Amsterdam.

Saunders, D. A. and R. J. Hobbs, eds. 1991. *Nature Conservation 2: The Role of Corridors*. Surrey Beatty, Chipping Norton, Australia.

Schneider, K. L. 2003. *The Paris-Lexington Road: Community-Based Planning and Context-Sensitive Highway Design*. Island Press, Washington, D.C.

Seiler, A. 2003. *The toll of the automobile: Wildlife and roads in Sweden*. Silvestria 295. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Trocme, M., S. Cahill, H. (J. G.) de Vries, H. Farrall, L. Folkeson, G. Fry, C. Hicks, and J. Peymen, eds. 2003. *Habitat fragmentation due to transportation infrastructure: The European review*. COST Action 341. European Commission, Brussels.

Trombulak, S. C. and C. A. Frissel. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18-30.

U.S. Department of Transportation. 1997. *Flexibility in Highway Design*. Report FHWA-PD-97-062. Federal Highway Administration, Washington, D.C.

Van Bohemen, H. D. 2005. *Ecological Engineering: Bridging Between Ecology and Civil Engineering: A Practical Set of Ecological Engineering Principles for Road Infrastructure and Coastal Management.* Directorate-General of Public Works and Water Management, Delft, Netherlands.

van Driel, C. J. G., R. J. Davidse, and M. F. A. M. van Maarseveen. 2004. The effects of edgeline on speed and lateral position: a meta-analysis. *Accident Analysis and Prevention* 36: 671-682.

Wilde, G. J. S. 1988. Risk homeostasis theory and traffic accidents: propositions, deductions and discussion of dissension in recent reactions. Ergonomics 3: 441-468.