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The Ecological Effects of Roads

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The Forest Service and other public agencies will claim that road closures, revegetation, and other restorative measures are too expensive to be implemented on a broad scale. But much of the approximately $400 million of taxpayers' money squandered annually by the Forest Service on below-cost timber sales goes to road-building. Road maintenance is also expensive. Virtually all of this money could be channelled into road closures and associated habitat restoration. This work would be labor-intensive, and providing income to the many laid off loggers, timber sale planners, and road engineers - for noble jobs, rather than jobs of destruction! likewise, the huge budgets of federal, state, and county highway departments could be directed to road closures and revegetation, as well as viaducts and underpasses to minimize roadkill on roads kept open.

We cannot expect our public agencies to shift to a more enlightened roads policy without a fight. A lot of people make a lot of money designing and building roads, and exploiting the resources to which roads lead. Nor can we expect the slothful, ignorant populace to give up what they see as the benefits of roads (fast transportation, easy access to recreational areas, scenery without a sweat, etc) for the sake of bears and toads. Education of the public, the politicians, and our fellow environmentalists about the multiple and far-reaching impacts of roads is critical. As Aldo Leopold noted, "recreational development is a job not of building roads into lovely country, but of building receptivity into the still unlovely human mind" The greatest near-term need is direct action in defense of existing roadless areas, and to close roads where they are causing the most problems for native biodiversity.

Despite heightened recognition (by informed people) of the harmful effects of roads, road density continues to increase in the US and other countries. Federal, state, and local transportation departments devote huge budgets to construction and upgrading of roads. Multinational lending institutions, such as the World Bank, finance roads into pristine rainforest, which usher in a flood of settlers who destroy both the rainforest and the indigenous cultures. Public land-managing agencies build thousands of miles of roads each year to support their resource extraction activities, at a net cost to the taxpayer. The US Forest Service alone plans to build or reconstruct almost 600,000 miles of roads in the next 50 years. Most public agencies disregard the ecological impacts of roads, and attempt to justify timber roads as benefiting recreation and wildlife management. Even when a land manager recognizes the desirability of closing roads, he or she usually contends that such closures would be unacceptable to the public.

This article will review some ecological effects of roads, with emphasis on impacts to wildlife (broadly defined). My concern is with all roads, from primitive logging roads to four-lane highways. Although the effects of different types of roads vary, virtually all are bad, and the net effect of all roads is nothing short of catastrophic. The technical literature that pertains to this topic is vast, and an entire book would be needed to summarize it adequately. Consider this only an introduction, or an "executive summary" of a massive tragedy.

Direct effects, such as flattened fauna, are easy to see. In contrast, many indirect effects of roads are cumulative and involve changes in community structure and ecological processes that are not well understood. Yet, these long-term effects signal a deterioration in ecosystems that far surpasses in importance the visual and olfactory insult to us of a bloated deer by the roadside.

The above statement notwithstanding, roadkill can have a significant impact on wildlife populations. The Humane Society of the US and the Urban Wildlife Research Centre have arrived at a conservative figure of one million animals killed each day on highways in the United States. When I-75 was completed through a major deer wintering area in northern Michigan, deer road mortality increased by 500%. In Pennsylvania, 26,180 deer and 90 bears were killed by vehicles in 1985. These statistics do not account for animals that crawl off the road to die after being hit. Also, roadkill statistics are invariably biased toward mammals, against reptiles, amphibians, and probably birds, and do not include invertebrates at all (who wants to count the insects smashed on windshields and grills?).

Vehicles on high-speed highways pose the greatest threat to wildlife. Unpaved roads, particularly when "unimproved", are less dangerous. Roadkill usually increases with volume of traffic. In one Texas study, however, mortality was greatest on roads with intermediate volumes, presumably because higher-volume roads had wider rights-of-way that allowed better visibility for animals and drivers alike. Increases in traffic volume do result in more collisions on any given road, and in our profligate society more people means more cars on virtually every road.

Florida is a rapidly developing state with more than 1000 new human residents each day and over 50 million tourists annually. Primary and interstate highway mileage has increased by 4.6 miles per day for the last 50 years. Hence it is no surprise that roadkills are the leading known cause of death for all large mammals except White-tailed Deer.

Roadkills of Florida Black Bear, a subspecies listed as threatened by the state, have been rising sharply in recent years, from 2-3 per year in the 1970s to 44 in 1989. Many of the bears are killed on roads through public lands, in particular the Ocala National Forest. Seventeen Florida Panthers, one of the most endangered subspecies of mammals in the world, are known to have been killed on roads since 1972. Since 1981, 65% of documented Florida Panther deaths have been roadkills, and the population of

A priority system for determining which roads should be closed first is necessary to guide conservation actions toward the most deserving targets. The Grizzly Bear Compendium (Lefranc et al. 1987, pp.145-46) specifies which kinds of roads should be closed on public lands to protect Grizzlies: Access roads should be closed after harvesting and restocking, temporary roads and landings should be obliterated, collector roads and loop roads should be closed in most instances, local roads should be closed within one season after use, and seismic trails and roads should be closed after operations have ceased. Bear biologist Chuck Jonkel has long recommended an aggressive road closure program on public lands. Public education on the rationale for closures, and strong law enforcement, must accompany road closure programs if they are to be effective. The Grizzly bear Compendium recommends that road use restrictions, such as seasonal closures of roads in areas used only seasonally by bears, be placed on roads that cannot be permanently closed.

In a series of publications, I have recommended that large core areas of public lands be managed as roadless "wilderness recovery areas" (a concept attributable to Dave Foreman). Buffer zones surrounding these core areas would have limited access for recreation and other "multiple-use" activities consistent with preservation of the core preserves. Buffer zones also would insulate the core areas from the intensive uses of the humanized landscape. These large preserve complexes would be connected by broad corridors of natural habitat to form a regional network.

As Keith Hammer has documented, however, road closures that appear on paper may not function as such on the ground. Keith found that 38% of the putative road closures on the Flathead National Forest in Montana would not bar passenger vehicles. The road miles behind the ineffective barriers represented 44% of the roads reported by the Forest Service as being closed to all motorized vehicles year-round. Gates, earthen berms, and other structures are not usually effective in restricting road use. This is especially true in more open-structured habitats, such as Longleaf Pine and Ponderosa Pine forests, where motorists can easily drive around barriers. It may be that the only effective road closures are those where the road is "ripped" and revegetated.

alarm. When assured by highway and wildlife officials that the new interstate would include fences and underpass for Panthers, making it much less dangerous than the infamous Panther-smashing Alligator Alley which it would replace many conservationists (including the Florida Audubon Society and the Sierra Club) came out in support of the new road.

How effective will these underpasses be in allowing for movement of Panthers and other wildlife? Eighty-four bridges are being constructed on the 49 miles of new I-75 in Collier county, 46 of them designed solely for wildlife movement. Each of these "wildlife crossings" consists of three 40-foot spans, for a total length of 120 feet with 8 feet of vertical clearance. Much of the 120 feet will be under water, however, at least in the wet season. There is no guarantee that these crossings will be functional for Panthers and other large mammals. Even Thomas Barry, the project manager for the Florida Department of Transportation, admits that the ideal solution would have been to build a viaduct (elevated highway) across the entire stretch, but that this solution was deemed too expensive. As advocated by Florida Earth First!, the "ideal solution" would be to close Alligator Alley and all other roads in the Everglades - Big Cypress bioregion, and to allow no new roads. The desirability of this solution became more evident when we learned that the new I-75 will include recreational access sites for ORVs, as recommended by the Florida Game and Fresh Water Fish Commission.

The Preferred Alternative

In evaluating various mitigation options for road-wildlife problems, it must be remembered that each is a compromise, addresses only a subset of the multiple ecological impacts of roads, and is far less satisfactory than outright road closure and obliteration. The serious conservationist recognizes that mitigation options should be applied only to roads already constructed, and which will be difficult to close in the near future (i.e., major highways). In such cases, construction of viaducts over important wildlife movement corridors (as documented by roadkills) and other critical natural areas should be vigorously pursued. Amphibian tunnels and other smaller underpasses also should be constructed where needed. But the bottom line is that no new roads should be built, and most existing roads - especially on public lands - should be closed and obliterated. This is the preferred alternative!

only about twenty individuals is unlikely to be able to sustain this pressure. An average of 41 Key Deer, a species listed as Endangered by the US Fish and Wildlife Service, were killed on roads yearly from 1980 through 1986, and 57 were killed in 1987. Roadkill is also the leading cause of mortality for the American Crocodile, also an Endangered species, in south Florida. The Florida Scrub Jay, a Threatened species, has been found to suffer considerable mortality from collision with vehicles, and researchers have concluded that these birds cannot maintain stable populations along roads with considerable high-speed traffic.

Snakes are particularly vulnerable to roadkill, as the warm asphalt attracts them; yet their carcasses are seldom tallied. Herpetologists have noted dramatic declines of snakes in Paynes Prairie State Preserve near Gainesville, Florida, which is crossed by two four-lane highways. This preserve was once legendary for its diversity and density of snakes, but no more. Similarly, a study of south Florida herpetofauna by Wilson and Porras attributed declines in many snakes to the increasing road traffic in that region.

Roadkill is a classic death-trap phenomenon. Animals are attracted to roads for a variety of reasons, often to their demise. Snakes and other ectotherms go there to bask, some birds use roadside gravel to aid their digestion of seeds, mammals go to eat de-icing salts, deer and other browsing herbivores are attracted to the dense vegetation of roadside edge, rodents proliferate in the artificial grasslands of road verges, and many large mammals find roads to be efficient travelways. Songbirds come to dustbathe on dirt roads, where they are vulnerable to vehicles as well as predators. Vultures, Crows, Coyotes, Raccoons, and other scavengers seek out roadkills, often to become roadkills themselves.

Road Aversion and other Behavioural Modifications

Not all animals are attracted to roads. Some have learned that roads bring unpleasant things, such as people with guns. Species that show road aversion exhibit decreasing densities toward roads. Various studies report that Turkey, White-tailed Deer, Mule Deer, Elk, Mountain Lions, Grizzly Bear, and Black Bear avoid roads. When these animals are disturbed by vehicles, they waste valuable energy in flight. Other studies show conflicting results, which usually can be explained by differences in road use. Certain bird species also have been found to avoid roads, or the forest edges associated with roads. In the Netherlands, researchers found some bird species to be displaced up to 2000 meters from busy highways.

The American Elk is one of the best-studied species with respect to road aversion. Elk avoidance of roads is clearly a learned response (they do not avoid natural edges), and is related to traffic volume and hunting pressure. In western Montana, Jack Lyon found that Elk avoid areas within 1/4 - 1/2 mile of roads, depending on traffic, road quality, and the density of cover near the road. According to work by Jack Thomas in Oregon, a road density of one mile per square mile of land results in a 25% reduction in habitat use by Elk; two miles of road per square mile can cut Elk habitat use by half. As road density increases to six miles of road per square mile, Elk and Mule Deer habitat use falls to zero. Elk in some areas have learned that roads are dangerous only in the hunting season, and do not show road aversion in other seasons. Other studies suggest that Elk avoid open roads, but not closed roads. Where hunting pressure is high however, even closed roads may be avoided because so many hunters walk them.

Grizzly Bears also may be displaced by roads. In British Columbia, Grizzlies were found to avoid areas within 1/2 mile of roads. A study in the Cabinet Mountains of northwestern Montana determined that the mean distance of Grizzly radio-telemetry signals from open roads (2467 m) was significantly greater than the mean distance from closed roads (740 m). Other studies have found that Grizzlies avoid areas near roads, especially by day, even when preferred habitat and forage are located there. This is particularly alarming, because in Yellowstone National Park, which has the second largest Grizzly population in the lower 48, roads and developments are situated in the most productive Grizzly Bear habitat Natural movements of Grizzly Bears may also be deflected by roads, as Chuck Jonkel has documented in Montana. In other cases, however, Grizzlies may use roads as travelways, particularly when they find off-road travel difficult due to dense brush or logging slash. Grizzlies have also learned to exploit the hastened growth of forage plants near roads in spring. Similarly, the abundance of soft mast such as Pokeberry and Blackberry along road edges attracts Appalachian Black

expanses of unsuitable habitat. The management of "roadside verges" for fauna and flora has a long history in Britain, as reviewed by J.M.Way in 1977.

Undoubtedly, mitigation measures, if implemented intelligently, can reduce the harmful effects of roads on wildlife. A 1982 report by Leedy and Adams, for the US Department of Transportation and Fish and Wildlife Service, summarizes a variety of design and construction options to mitigate the effects of roads. For reducing roadkills, a combination of fencing and underpasses has proven effective in many instances. Tunnels under roads were used as early as 1958 in the United Kingdom to reduce roadkill of badgers and have been used in several countries to reduce roadkill of amphibians (many frogs toads, and salamanders migrate to their breeding ponds on wet spring nights). Toad tunnels were constructed as early as 1969 in Switzerland, and have been built throughout much of the United Kingdom, West Germany, the Netherlands, and other countries under the auspices of the Fauna and Flora Preservation Society and Herpetofauna Consultants international. A private firm, ACO Polymer products Limited even specializes in the design and production of amphibian tunnel and fencing systems (see Defenders 10-89).

In Colorado, underpasses and deer-proof fencing were constructed on I-70, to channel movement of Mule Deer along a major migratory route, and have proved fairly successful. D.F. Reed and co-workers, however, found that many individual deer were reluctant to use a narrow underpass (3 meters wide and high, and 30 meters long), and recommended that underpasses be significantly wider. Biologists in various Western states are experimenting with one-way gates that keep most deer off the highway but allow deer that get into the highway ROW to escape. In southeastern Australia, Mansergh and Scott constructed a funnel-shaped rocky corridor and two tunnels of .9 X 1.2 meters each beneath a road that bisected the breeding area of the rare Mountain Pygmy-possum (the only marsupial hibernator known). The design proved very successful in restoring natural movement and breeding behavior of the Pygmy-possums. One of the more controversial applications of the underpass strategy has been in south Florida, for the sake of the Florida Panther. As noted above, roadkill is the leading known cause of death for this subspecies. Thus, when an extension of I-75 through the Everglades-Big Cypress Swamp was proposed, conservationists reacted with are ignited along roadsides, the net effect of roads on this habitat has been to stop the spread of fires that once covered areas the size of several counties. Those roadside fires that do ignite are mostly winter burns, which are less effective in controlling shrub invasion. As shrubs, oaks, and other hardwoods overtake this ecosystem, they shade out the herbaceous plants upon which the herbivorous Gopher Tortoise depends.

The net, cumulative effect of roads is to diminish the native diversity of ecosystems everywhere. Habitats in many different places around the would are invaded by virtually the same set of cosmopolitan weeds. Regions gradually are homogenized - they lose their "character". Every place of similar climate begins to look the same and most ecosystems are incomplete and missing the apex of the food chain. The end result is an impoverishment of global biodiversity.

What Can Be Done?

Mitigation

The traditional response of public agencies to road - wildlife conflicts, in those rare instances when they do respond, is "mitigation," i.e., build the road but design it so as to minimize its impacts. For example, barren roadsides can be planted and stabilized by wire netting in order to reduce erosion, landslides, and sedimentation of streams. Stream culverts can be designed to minimize disruption of flow and bed morphology. New roads can be located, and existing roads relocated, outside of critical wildlife habitats (such as moist meadows, shrub fields, riparian zones, and other Grizzly Bear feeding areas). Speed bumps and warning signs can be installed to slow down motorists and reduce roadkill. Reflective mirrors along roadsides and hood-mounted ultrasonic whistles are devices intended to warn animals of approaching death-machines, but are still of unproven benefit.

Road rights-of-way can be managed to maximize their potential as native wildlife habitat and dispersal corridors. If wide swaths of old-growth longleaf Pines are maintained along highway ROWs in the Southeast for example, they may serve to connect isolated Red-cockaded Woodpecker populations. Such corridors were recommended by a committee of the American Ornithologists' Union. Some evidence suggests that Red-cockaded Woodpeckers may indeed disperse along such corridors, but not across long

Bears in summer. Any advantages associated with roads for either bear species are outweighed by the increase in sometimes fatal (usually for the bear, unfortunately) encounters with humans.

Wild animals can become habituated to roads. Thirty years ago, for example, bears in Yellowstone, the Great Smokies, and other parks often sat along the roadsides and picnic areas waiting for handouts from tourists. When parks disallowed handouts and relocated habituated hears, the attraction subsided. In any area where animals are exposed to frequent human activity, habituation can be expected. This is not necessarily a desirable response, however. Although animals that are attracted to roads and vehicles do not waste energy reserves in flight response, some of them become aggressive toward people. Aggressive behavior of habituated animals has been noted in bears, Mule Deer, Elk, Bighorn Sheep, Bison, and other species. Conflicts occur most often when humans approach animals closely in order to feed or photograph them. A few years ago in the Smoky Mountains, a bear reportedly chomped on a baby's face when a parent held it close for a kissing photo - the baby's cheek had been smeared with honey. Such encounters usually result in relocation or killing of the "problem" animals, though the real problem is human stupidity. Studies of Grizzly Bears in Montana and British Columbia have found that bears habituated to human activity especially moving vehicles, are more vulnerable to legal and illegal shooting.

Fragmentation and Isolation of Populations

Some species of animals simply refuse to cross barriers as wide as a road. For these species, a road effectively cuts the population in half. A network of roads fragments the population further. The remaining small populations are then vulnerable to all the problems associated with rarity: genetic deterioration from inbreeding and random drift in gene frequencies, environmental catastrophes, fluctuations in habitat conditions, and demographic stochasticity (i.e., chance variation in age and sex ratios). Thus, roads contribute to what many conservation biologists consider the major threat to biological diversity: habitat fragmentation. Such fragmentation may be especially ominous in the face of rapid climate change. If organisms are prevented from migrating to track shifting climatic conditions, and cannot adapt quickly enough because of limited genetic variation, then extinction is inevitable.

In one of the first studies on habitat isolation by roads, D.J. Oxley and co-workers in southeastern Ontario and Quebec found that small forest mammals such as the Eastern Chipmunk, Grey Squirrel, and White-footed Mouse rarely ventured onto road surfaces when the distance between forest margins (road clearance) exceeded 20 meters. The authors suggested that divided highways with a clearance of 90 meters or more maybe as effective barriers to the dispersal of small mammals as water bodies twice as wide. Earlier work in Africa had shown that tortoises, and young Ostrich, Wart hogs, and African Elephants, had difficulty crossing roads with steep embankments. In Germany, Mader found that several species of woodland carabid beetles and two species of forest-dwelling mice rarely or never crossed two-lane roads. Even a small, unpaved forest road closed to public traffic constituted a barrier. All of these animals were physically capable of crossing roads but appeared to be psychologically constrained from venturing into such openings. In Ontario, Merriam and co-workers found that narrow gravel roads were "quantitative barriers" to White-footed Mice in forest fragments; many fewer mice crossed roads than moved an equal distance in the forest alongside roads.

expect that the barrier effect of roads would be less severe in more open habitats, where the contrast between the road and adjoining habitat is less. Yet, a study by Garland and Bradley of the effects of a four-lane highway on rodents in the Mojave Desert found that rodents almost never crossed the road. Of eight species captured, marked, and recaptured, only an adult male Antelope Ground Squirrel crossed the entire highway. No roadkills were observed, suggesting that few rodents ever ventured onto the highway.

Animals far more mobile than rodents and beetles may hesitate to cross roads. In the Southern Appalachians, Brody and Pelton found that radio-collared Black Bears almost never crossed an interstate highway. In general, the frequency at which bears crossed roads varied inversely with traffic volume. Bears appeared to react to increasing road densities by shifting their home ranges to areas of lower road density. The power of flight may not override the barrier effect of roads for some bird spe-

heavy browsing, many warblers and other forest songbirds undergo serious declines. With Wolves gone, opportunistic medium-sized mammals ("mesopredators") such as Opossums and Raccoons increase in abundance and feed on the eggs and nestlings of songbirds, many of which nest on or near the ground, further depressing their numbers. Brown-headed Cowbirds parasitize these beleaguered songbirds within 200 meters or so of road edges. Cutting of snags for firewood along the roadsides decimates cavity-nesting bird populations. Populations of insect pests now cycle with greater amplitude, resulting in massive defoliation. The roads also bring in developers, who create new residential complexes, and still more roads. Roadside pollutants from increased traffic levels poison the food chain. The original forest ecosystem has been irretrievably destroyed.

This scenario is fictitious, but every part of it has been documented somewhere. Because many of the animal species most sensitive to roads are large predators, we can expect a cascade of secondary extinctions when these species are eliminated or greatly reduced. Recent research confirms that top predators are often "keystone species", upon which the diversity of a large part of the community depends. When top predators are eliminated, such as through roadkill or because of increased access to hunters, opportunistic mesopredators increase in abundance, leading to declines of many songbirds and ground-dwelling reptiles and amphibians. In the tropics, predator removal can lead to an increased abundance of mammals that eat large-seeded plants, which in turn may result in changes in plant community composition and diversity (see John Terborgh's article, "The Big Things that Run the World", reprinted in Earth First!, 8-89).

Other keystone species may be similarly vulnerable to roads. The Gopher Tortoise of the southeastern US, for example, digs burrows up to 30 feet long and 15 feet deep. By a recent count, 362 species of commensal invertebrates and vertebrates have been found in its burrows, and many of them can live nowhere else. Yet, the slow-moving Gopher Tortoise is extremely vulnerable to roadkill on the busy highways of this high growth region. Roads also provide access to developers and poachers, the tortoise's biggest enemies. But the effects of roads on Gopher Tortoises can be more subtle. Good Gopher Tortoise habitat is longleaf Pine-Wiregrass, which requires frequent summer fires to maintain its open structure. Although, as discussed above, many fires

)almetto) communities. It is a curious contradiction that the US orest service often justifies high road densities as necessary to)rovide fire control, when in fact most fires begin along roads.

)f the disturbances promoted by road access, perhaps the most levastating is development. Highways introduce pressures for :ommercial development of nearby land. Highway interchanges nevitably become nodes of ugly commercialism. Arterial streets encourage commercial strip development, and new rural and suburban roads bring in commercial, industrial, and residential development. Internationally funded road-building in Third World countries introduces hordes of immigrants, who quickly cut and burn the native forest. In Brazilian Amazonia, Philip Fearnside reported that road development funded by the World Bank facilitates the entry of settlers whose land claims (established by clearing the forest) justify building more roads. Thus, roads and deforestation interact in a positive feedback relationship. Roads bring settlement and development, which in turn call for more roads.

CUMULATIVE EFFECTS

So far, this article has discussed effects of roads mostly in isolation from one another. Indeed, almost all research on road problems has looked at one factor at a time, be it lead pollution, roadkill, edge effects, or access. In real ecosystems, however, these factors interact in complex ways, with long-term effects at several levels of biological organization.

To illustrate the complexity of possible impacts, consider this scenario: A network of roads is built into prime Grey Wolf habitat in northern hardwoods forest. Hunters flock into the area, depressing the Wolf population. Some Wolves are killed by vehicles. Eventually, the Wolf becomes extinct in this region. In the absence of Wolf predation, and with the abundance of brushy roadside edge habitat, the White-tailed Deer population explodes. Fires started by humans along roadsides create even more deer habitat. Hunters and vehicles take some deer, but they cannot keep up. The burgeoning deer population overbrowses the forest eliminating regeneration of favored Eastern Hemlock, Arbor Vitae, Canada Yew, and a number of rare herbaceous plants. As a result, the floristic composition and vegetation structure of the forest gradually change. With reduced understory density due to

cies. Many tropical forest birds are known to be averse to crossing water gaps no wider than a highway. Further research is needed to determine if these species react to road clearings as they do to water gaps.

Thus, populations of many animal species divided by a heavily traveled road may be just as isolated from one another as if they were separated by many miles of barren urban or agricultural land. Larry Harris and Peter Gallagher, writing in a recent Defenders of Wildlife publication on habitat corridors ("Preserving Communities & Corridors" available from Defenders, 1244 19th St. NW, Washington, DC 20036; $10 each), put the road fragmentation problem into proper perspective:

"Consider this triple jeopardy: At the same time that development reduces the total amount of habitat, squeezing remaining wildlife into smaller and more isolated patches, the high-speed traffic of larger and wider highways eliminates more and more of the remaining populations."

To the extent that various plant species depend on road-averse animals for dispersal, roads fragment plant populations as well.

POLLUTION

Pollution from roads begins with construction. An immediate impact is noise from construction equipment, and noise remains a problem along highways with heavy traffic. Animals respond to noise pollution by altering activity patterns, and with an increase in heart rate and production of stress hormones. Sometimes animals become habituated to increased noise levels, and apparently resume normal activity. But birds and other wildlife that communicate by auditory signals may be at a disadvantage near roads. Highway noise can also disrupt territory establishment and defense. A study by Andrew Barrass found that toads and tree frogs showed abnormal reproductive behavior in response to highway noise.

Vehicles emit a variety of pollutants, including heavy metals, carbon dioxide, and carbon monoxide, all of which may have serious cumulative effects. Combustion of gasoline containing tetraethyl lead, and wear of tires containing lead oxide, result in lead contamination of roadsides. Although unleaded gasoline now purchase of Pinhook Swamp and its transfer to the Forest Service. Experimenters testing the feasibility of Panther reintroduction in this area released 5 neutered and radio-collared Texas Cougars, a subspecies closely related to F.c. coryi, into this habitat. Within a month, one cat died of unknown causes. Two more cats were killed by hunts soon thereafter. The final two cats discovered livestock (a goat pasture and an exotic game reserve), and were removed from the wild. This setback in the Panther reintroduction program demonstrates that even one of the wildest areas in the Southeast is still far too human-accessible for Panthers to survive. Except for the wettest part of the Okefenokee Swamp, the poorest Panther habitat, the area is riddled with roads and swarming with gun-toting "Crackers" and their hounds.

Other large mammals that suffer from road access include Cougars (western version of F.c.) and Grizzly Bears. A radio-telemetry study in Arizona and Utah, by Van Dyke and co-workers, found that Cougars avoided roads (especially paved and improved dirt roads) whenever possible, and established home ranges in areas with the lowest road densities. In southeastern British Columbia, McLellan and Mace found that a disproportionate amount of Grizzly Bear mortality occurred near roads. Of 11 known deaths, 7 bears were definitely shot and another 3 were probably shot from roads. Dood and co-workers found that 32% of all hunting mortality and 48% of all non-hunting mortality of Grizzlies in Montana occurred within one mile of a road. Knick and Kasworm recently found that illegal shooting was the primary cause of death for Grizzlies in the Selkirk and Cabinet-Yaak ecosystems, and concluded that the ability of regions to maintain viable populations of Grizzly Bears is related to road density and human access.

Road access imperils Black Bears, too. In the Southern Appalachians, Mike Pelton has estimated that bears cannot maintain viable populations when road density exceeds .8 miles of road per square mile. Later studies found that the situation is more complicated, and is related to traffic volume and other road use factors. The primary effect of roads on bears in the Southern Appalachians is to expose them to increased hunting. Hunting with the aid of trained hounds is the major source of mortality for bears in this region, including within National Parks and other sanctuaries, and is encouraged by the trade in bear gall bladders

and end up as roadkills or at least get a dose of the salt's toxic additives, including cyanide compounds. Drainage of salt-laden water from roads into aquatic ecosystems may stimulate growth of blue-green algae; the chloride concentration of major water bodies near urban areas has been found to increase by as much as 500%. Furthermore, sodium and calcium ion exchange with mercury releases toxic mercury into these Systems. The cyanide ions from rust-inhibiting additives are extremely toxic to fish.

In many rural areas, waste oil from crankcases is sprayed onto unpaved roads for dust control. A 1974 study estimated that some 100 million gallons of waste oil are sprayed on dirt roads in the US each year. Only about 1% of this oil remains in the top inch of a road surface. Much of it reaches water bodies, where it coats the surface, limiting oxygen exchange and sunlight penetration and having toxic effects on aquatic organisms.

Impacts on Terrestrial Habitats

The impacts of roads on terrestrial ecosystems include direct habitat loss; facilitated invasion of weeds, pests, and pathogens, many of which are exotic (alien); and a variety of edge effects. Roads themselves essentially preempt wildlife habitat. A 1974 report by the Council on Environmental Quality estimated that one mile of interstate highway consumes up to 48 acres of habitat. Logging roads result in the clearing of about 50 acres for each square mile of commercial forest (i.e., 10 acres are deforested for every mile of road, and each square mile of forest averages 5 miles of road). Road construction also kills animals and plants directly, and may limit long-term site productivity of roadsides by exposing low nutrient subsoils, reducing soil water holding capacity, and compacting surface materials. It also makes slopes more vulnerable to landslides and erosion, which in turn remove additional terrestrial wildlife habitat and degrade aquatic habitats.

Some species thrive on roadsides, but most of these are weedy species. In the Great Basin, rabbit brush is usually more abundant and vigorous along hard-surfaced roads than anywhere else, because it takes advantage of the runoff water channeled to the shoulders, Although certainly attractive, the common rabbit brush species are in no danger of decline, as they invade disturbed areas such as abandoned farmsteads and fence rows, and are considered an indicator of overgrazing. In the Mojave Desert, Creosote Bush is another abundant species that opportunistically exploits the increased moisture levels along roadsides.

Many of the weedy plants that dominate and disperse along roadsides are exotics. In some cases, these species spread from roadsides into adjacent native communities. In much of the west, Spotted Knapweed has become a serious agricultural pest. This Eurasian weed invades native communities from roadsides, as does the noxious Tansy Ragwort. In Florida, a state plagued by exotic plants, one of the biggest offenders is Brazilian Pepper. This tall, fast-growing shrub readily colonizes roadside habitats. When soil in adjacent native habitats is disturbed by off-road vehicles, Brazilian Pepper invades. Invasion by Brazilian Pepper and other roadside exotics is becoming a serious problem in the Atlantic coastal scrubs of south Florida, communities endemic to Florida and containing many rare species. Another invasive exotic, Melaleuca, is expanding from roadsides and dominating south Florida wetlands. In southwest Oregon and northwest California, an apparently introduced root-rot fungus is spreading from logging roads and eliminating populations of the endemic Port Orford Cedar.

Opportunistic animal species also may benefit from roads. Grassland rodents, for example, sometimes extend their ranges by dispersing along highway verges. In 1941, L.M. Huey documented a range extension of pocket gophers along a new road in the arid Southwest. Meadow voles have been found to colonize new areas by dispersing along the grassy rights-of-way (ROWs) of interstate highways. Roads also facilitate dispersal of prairie dogs. In 1983, Adams and Geis reported that more species of rodents may be found in highway ROWs than in adjacent habitats, though several species avoid ROW habitat. Birds associated with grassland or edge habitat, such as the European Starling, Brewer's and Red-winged Blackbirds, Brown-headed Cowbird, Indigo Bunting, White-throated Sparrow, Song Sparrow, and Killdeer, all have been found to increase in abundance near roads. Cliff and Barn Swallows, Starlings, House Sparrows, and Rock Doves (the latter three are exotic species in North America) often nest and roost in highway bridges. Many species of birds and mammals feed on roadkill carrion.

was the best predictor of Grey Wolf habitat suitability. As road density increased in the study area, the Wolf population declined. Wolves failed to survive when road densities exceeded .93 mile per square mile (.58 km per square km). Similar studies in Michigan and Ontario by Jensen and co-workers, and in Minnesota by Mech and co-workers, found a virtually identical threshold level for the occurrence of Wolves. Roads themselves do not deter Wolves. In fact, Wolves often use roads for easy travel or to prey on the edge-adapted White-tailed Deer. But roads provide access to people who shoot, snare, trap, or otherwise harass wolves. David Mech found that over half of all known Wolf mortality was caused by humans, despite the "protection" of the Endangered Species Act.

Many other large mammal species have been found to decline with increasing road access. The Florida Panther once ranged throughout the Southeast, from South Carolina through southern Tennessee into Arkansas, Louisiana and extreme eastern Texas. It is now restricted to south Florida, an area of poor deer and Panther habitat, but the last large roadless area available in its range. Problems associated with roads - roadkill, development, and illegal shooting - are now driving it to extinction. A population viability analysis has determined an 85% probability of extinction in 25 years, and a mean time to extinction of 20 years. Proposed management interventions still yield 75% to 99% probabilities of extinction within 100 years.

Recently, Seminole Chief James Billie shot a Panther with a shotgun from his pickup truck in the Big Cypress Swamp, ate it, and claimed this murder was a native religious ritual. Billie eventually won his case, not on religious grounds, but because taxonomists could not prove beyond all reasonable doubt that the skull found in Billie's possession was that of a Florida Panther, Felis concolor subspecies coryi (the various subspecies of Cougar differ little from one another in morphology).

Biologists agree that the only hope for the Panther is reestablishment of populations elsewhere within its historic range. But is there anywhere with low enough road density to be safe? The best opportunity seems to be the 1.2 million acres in and around Okefenokee National Wildlife Refuge in southern Georgia and Osceola National Forest in north Florida, recently connected by cient to maintain oxygen supply. Fine sediments may cement spawning gravels, impeding the construction of redds. Increases in fine sediments also reduce the availability of oxygen to eggs and increase embryo mortality. Stowell and co-workers reported that deposition of 25% fine sediments in spawning rubble or gravel reduces fry emergence by 50%. Sedimentation also has negative effects on the invertebrate food supply of many fish. Furthermore, destruction of riparian vegetation by road construction results in higher water temperatures, which reduces dissolved oxygen concentrations and increases fish oxygen demands (a "double whammy"). If the fishing public was adequately informed of the negative effects of roads on fisheries, perhaps all but the laziest would demand that most roads on public lands be closed and revegetated!

Indirect Effects

Access

The most insidious of all effects of roads is the access they provide to humans and their tools of destruction. Let's face it, the vast majority of humans do not know how to behave in natural environments. Fearful of experiencing Nature on its own terms, they bring along their chainsaws, ATVs, guns, dogs and ghetto blasters. They harass virtually every creature they meet, and leave their mark on every place they visit. The more inaccessible we can keep our remaining wild areas to these cretins, the safer and healthier these areas will be. Those humans who respect the land are willing to walk long distances. If this is an "elitist" attitude, so be it; the health of the land demands restrictions on human access and behavior.

Many animal species decline with increasing road density precisely because roads bring humans with guns. For many large mammals, road aversion is not related to any intrinsic qualities of the road, but rather to their learned association of roads with danger. In other Cases, mammals may continue to use roads because they provide convenient travelways or food supply, but are unable to maintain populations where road densities are high because of the mortality they suffer from legal or illegal hunting, or roadkill.

An historical study by Richard Thiel in northern Wisconsin, supplemented by modern radio-telemetry, showed that road density

Some people claim that increases in grassland, edge, and other opportunistic species near roads constitute a benefit of roads. But increased density near roads may not be favorable for the animals involved, if the road exposes them to higher mortality from heavy metal poisoning or collision with vehicles. In this sense, a road can be an "ecological trap" and a "mortality sink" for animal populations. Furthermore, the species that may benefit from roads are primarily those that tolerate or even thrive on human disturbance of natural landscapes, and therefore do not need attention from conservationists (except occasional control). Many of these weedy species are exotic, and have detrimental effects on native species.

Edge effects, once considered favorable for wildlife because many game species (e.g., White-tailed Deer, Eastern Cottontail, Northern Bobwhite) are edge-adapted, are now seen as one of the most harmful consequences of habitat fragmentation. Especially when it cuts through an intact forest, a road introduces a long swath of edge habitat. Forest edge is not a line, but rather a zone of influence that varies in width depending on what is measured. Changes in microclimate, increased blowdowns, and other impacts on vegetation may extend 2-3 tree-heights into a closed-canopy forest. Shade-intolerant plants, many of them exotic weeds, colonize the edge and gradually invade openings in the forest interior. Dan Janzen found weedy plant species invading treefall gaps in a Costa Rican forest up to 5 kilometers from the forest edge. Changes in vegetation structure and composition from edge effects can be more persistent than effects of clearcutting, from which at least some forest types will eventually recover, if left alone.

The Brown-headed Cowbird, originally abundant in the Great Plains but now throughout most of North America because of forest fragmentation, is known to penetrate forests at least 200 meters from edge. The cowbird is a brood parasite that lays its eggs in the nests of other bird species and can significantly reduce the reproductive success of its hosts. Forest birds, most of which did not evolve with the cowbird and are not well adapted to its parasitism, may show serious declines in areas where cowbirds have become common. In addition, many opportunistic nest predators, such as jays, crows, Raccoons, and Opossums, are common in roadside environments (partially because of supplemental food in the form of carrion) and often concentrate their predatory activities near edges. Increases in nest predation from these opportunists can extend up to 600 meters from an edge) as shown by David Wilcove using artificial nest experiments.

A narrow logging road with no maintained verge would not be expected to generate substantial edge effects, particularly if surrounded by a tall forest canopy. In this sense, the road would not differ much from hiking trail (even trails create some edge effects, however, such as invasion of weedy plants caused by pant-legs dispersal). As forest roads are "improved," road clearance increases and allows more penetration of sunlight and wind. Edge species are then attracted to these openings. Two-lane roads with maintained rights-of-way and all interstate highways are lined by edge habitat. A forest criss-crossed by improved roads may be largely edge habitat, and its value for conservation of native flora and fauna diminished accordingly.

Impacts on Hydrology and Aquatic Habitats

Road construction alters the hydrology of watersheds through changes in water quantity and quality, stream channel morphology, and ground water levels. Paved roads increase the amount of impervious surface in a watershed, resulting in substantial increases in peak runoff and storm discharges. That usually means flooding downstream. Reduced evapo-transpiration within road rights-of-way may also result in increased runoff and streamflows. However, increases in streamflows in forested watersheds are not usually significant unless 15% or more of the forest cover is removed by road construction and associated activities such as logging. When a road bed is raised above the surrounding land surface, as is normally the case, it will act as a dam and alter surface sheet flow patterns, restricting the amount of water reaching downstream areas. Mike Duever and co-workers found this to be a significant problem in the Big Cypress Everglades ecosystem of South Florida. Ditches dug for road drainage often drain adjacent wetlands as well. The US Fish and Wildlife Service, in 1962, estimated that 99,292 acres of wetlands in western Minnesota had been drained as a result of highway construction. This drainage occurred at a rate of 2.33, 2.62, and 4.10 acres of wetland per mile of road for state and federal, county, and township highways, respectively.

Roads concentrate surface water flows, which in turn increases erosion. Megahan and Kidd, in 1972, found that erosion from logging roads in Idaho was 220 times greater than erosion from undisturbed sites. Logging roads used by more than 16 trucks per day may produce 130 times more sediment than do roads used only by passenger cars. Incision of a slope by roadcuts in mountainous areas may intercept subsurface flow zones, converting subsurface flow to surface flow and increasing streamflow rates. Water tables are almost always lowered in the vicinity of a road.

Where a road crosses a stream, engineers usually divert, channelize, or otherwise alter the stream. Culverts and bridges alter flow patterns and can restrict a passage of fish. Channelization removes natural diverse substrate materials, increases sediment loads, creates a shifting bed load inimical to bottom-dwelling organisms, simplifies current patterns, lowers the stream channel and drains adjacent wetlands, reduces the stability of banks, and exacerbates downstream flooding.

The impacts of roads on fish and fisheries have long concerned biologists. Increased erosion of terrestrial surfaces almost inevitably results in increased sedimentation of streams and other water bodies. Even the best designed roads produce sediment, and unpaved roads continue to produce sediment for as long as they remain unvegetated. A divided highway requiring exposure of 10 to 35 acres per mile during construction produces as much as 3000 tons of sediment per mile. In a study of the Scott Run Basin in Virginia, Guy and Ferguson found that highway construction contributed 85% of the sediment within the basin. The yield was 10 times that normally expected from cultivated land, 200 times that from grasslands, and 2000 times that from forest land. Studies in northwestern California show that about 40% of total sediment is derived from roads and 60% from logged areas. Much of the sedimentation associated with roads occurs during mass movements (i.e., landslides) rather than chronic surface erosion. Roads dramatically increase the frequency of landslides and debris flows. Studies in Oregon have found that roads trigger up to 130 times more debris torrents than intact forest.

Increased sediment loads in streams have been implicated in fish declines in many areas. A 1959 study on a Montana stream, reported by Leedy in 1975, found a 94% reduction in numbers and weight in large game fish due to sedimentation from roads. Salmonids are especially vulnerable to sedimentation because they lay their eggs in gravel and small rubble with water flow suffi-