Ecological Impacts of Roads in the Greater Grand Canyon: An Annotated Bibliography

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EXECUTIVE SUMMARY

Introduction

Roads are created by and for travel. For thousands of years they have facilitated the exchange of goods, information and services. Today we use roads to commute to and from work, to visit family and friends, and even to access some of our most special natural places. It is nearly impossible to carry out our daily activities without the use of roads. In many cases, roads are more than travel routes, they are medians for the exchange of culture; important webs that help knit together our modern society.

Recently, however, people have become more aware of some undesirable changes that roads and vehicles bring. One of the greatest impacts of roads is their effect on the ecology of natural landscapes. In many areas where few paved roads exist a maze of developed and undeveloped roads has seriously altered the function of ecological systems. Roads have changed the composition of vegetation, the dispersal and movement of animals and the flow of water and nutrients. The cumulative impacts of these changes across vast landscapes are difficult to measure, but undoubtedly critical in the long-term.

Managers of public lands in northern Arizona are constantly challenged with the need to provide access to our splendid natural places, while at the same time ensuring that these places are kept healthy and intact for future generations. Road management on our public lands is a pivotal part of this challenge. The purpose of the following annotated bibliography is to facilitate better integration of scientific information into road management decision-making processes across northern Arizona.

Focused research on the ecological impacts of roads has been a fairly recent phenomenon. Many aspects of roads' specific, general, and landscape-scale effects have yet to be described. Nevertheless, current research does provide valuable information to assist in developing a more ecologically sustainable road management system in the Greater Grand Canyon region. More than 6000 publications describing the effects of roads now exist and are located in many different journals as well as other formats (eg. conference abstracts, dissertations and agency reports). The following annotated bibliography is the result of a thorough information search about road impacts specific to the Greater Grand Canyon region. It contains a list of over 200 articles from a broad array of sources describing specific, general, direct, indirect, and cumulative impacts of roads and their impacts on biotic and abiotic systems. The bibliography also includes limited information on management considerations and public attitudes related to roads and road management.

Methods

We reviewed five bibliographies containing more than 2000 articles and conducted more than 30 searches in nine on-line scientific databases to produce the 226 articles cited in the annotated bibliography. Two criteria directed the selection of a majority of the studies in this compilation: 1) A focus on road impacts to plant and animal species with current and/or historic distribution in

northern Arizona; 2) A focus on impacts of roads to abiotic systems of northern Arizona (and similar systems).

Five bibliographies were used to search for citations, including *End of the Road* compiled by the Natural Resources Defense Council[1], two bibliographies compiled by the Arizona Game and Fish Department[2], one bibliography compiled by the U.S. Fish and Wildlife Service[3], and one compiled by the U. S. Forest Service[4]. The following on-line databases provided the remaining articles in the bibliography: Biological and Agricultural Index, Biological Sciences, Biology Digest, Conference Papers Index, Environmental Sciences and Pollution Management, General Science Abstracts, GEOBASE, Plant Science, ScienceDirect, and Zoological Record.

We omitted certain articles because they were observational in nature, conducted by potentially biased organizations, or used outdated study methods. Species-specific subcategories were limited to 15-20 articles (usually those most relevant to northern Arizona) - thus some articles describing impacts on well-studied species (ie deer, elk, and some bird species) were not included. Because very little research has been conducted on road-caused impacts to amphibian, reptile, and fish species occurring in the northern Arizona region, information describing impacts to those species was derived from sources focusing on species occurring outside of the region. These articles are intended to provide insight into how roads *might* affect the species in our region. More than 90% of the articles in the bibliography focused on species and ecosystems of North America. A few exceptions include Roth and Marr (1988), Mech and Merrill (1976), and Mark (1976), whose studies offer insight into more broadly-defined ecological effects of roads. Because this bibliography is specific to roads and road travel, articles related to the impacts of snowmobiles, motorboats, aircraft and other motorized forms of transportation were not included.

The articles comprising the annotated bibliography are organized into four main categories: 1) biotic impacts; 2) abiotic impacts; 3) general reviews; and 4) indirect impacts. *Biotic Impacts* includes articles focused on the study of specific organisms, such as mammals, birds, fish, and plants. Articles are arranged under species-specific subcategories. Articles related to plants are organized into three subcategories: 1) general impacts; 2) soil compaction; and 3) exotic species. The second section, *Abiotic Impacts*, includes articles describing the impacts of roads on abiotic portions of ecosystems. Studies are organized under two subcategories: 1) waterflow; and 2) erosion/sedimentation.

Articles in the section *General Reviews* contain information on habitat fragmentation, biological effects of roads and their edge habitats, and biological effects of off-road vehicles, traffic noise,

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[1] Natural Resources Defense Council. 1999. End of the Road: the adverse ecological impacts of roads and logging: a compilation of independently reviewed research. December 1999.

[2] Brahmdstedt J, and Barsch B. 1993. Roads and Wildlife: and annotated bibliography. Region II Arizona Game and Fish Department (May). Barsch, B, R.A. McBride, R. Miller. 1998. recreational impacts on wildlife and wild lands: an annotated bibliography. Arizona Game and Fish Department Region II (March).

[3] USFWS. 1983. Nonconsmptive outdoor recreation: an annotated bibliography of human-wildlife interactions. US department of the Interior Fish and Wildlife Service. Special Scientific report-wildlife No. 252. Washington, D.C.

[4] USFS. 1980. Impact of back-country recreationists on wildlife: an annotated bibliography. US Department of Agriculture Forest Service. General technical report INT-84. Intermountain Forest and Range Experimental Station. compiled by Catherine H. Ream (June).

and road-caused pollution. Articles focusing on public attitudes towards roads and road management are also included as well as literature reviews describing general effects of roads. *Indirect Impacts* covers such topics as road-caused game poaching and animal harassment - both often the result of access provided by roads. Also included are articles on the effects of exotic species, soil compaction, the importance of mychorrhizae and soil organisms, and sedimentation. Lastly, we have referenced other annotated bibliographies that deal with roads and off-road travel to turn to for additional research needs.

This annotated bibliography is intended to be representative of the scientific information available on roads in northern Arizona - but it is not a comprehensive collection. The articles represent a range of study approaches and research-sponsoring organizations. When studies were not available on a specific species present in northern Arizona, or did not meet other criteria, the best available information was used. The following literature review highlights basic trends present in the included articles.

Literature Review

General effects of roads

Trombulak and Frisell (2000) identified seven general effects of roads. Some of these include modified animal behavior, such as altered reproductive rates and displacement, changes in physical geography, such as changes in surface runoff, erosion and sedimentation which effect aquatic and terrestrial animals, changes in populations due to direct kills, the spread of exotic species and increases in human ecological impacts. The seven general effects are very similar to the ecological impacts identified by Foreman and Alexander (1998).

Effects of roads can be immediate and localized or long-term and geographically widespread. Foreman (2000) concluded that 1% of the United States is covered by roads and as much as 20% of natural areas are affected directly by roads. Roads negatively impact a wide-variety of species but these impacts may not be noticed for eight to thirty years after the road has been built (Findlay and Bourdages 2000, Findlay and Houlahan 1997). In the long-term, roads tend to favor and discourage different species, which can lead to a change in species compositions of forest ecosystems (Foreman and Alexander 1998).

Intricately connected to roads are the vehicles that travel them. Noise from vehicles has been shown to disturb wildlife, leading to relocation of wildlife populations (U.S. EPA 1971). Vehicles that travel off-road have different and often times more severe impacts on the surrounding environment. Impacts of off-road vehicles in fragile desert ecosystems were noticed and documented as early as the 1970's (Hoover 1973, Mace 1974). Declines in biodiversity were the most obvious effects of off-road travel. The causes of these declines ranged from inadvertent wildlife harassment to direct impacts on vegetation (Bury et al. 1977). Stebbins (1974) noted that soil compaction and erosion from vehicular travel were also affecting plant and animal populations. Recently, Lovich and Bainbridge (1999) concluded that many of these changes occur with a minimal number of vehicle passes and may not be naturally restored for hundreds of years.

Roads often facilitate the dispersal of exotic species. Forcella and Harvey (1983) surveyed exotic species in Montana and related their abundance to frequency of road use. Parendes and Jones (2000) describe similar results, showing a higher abundance of exotic species along high and low use roads than abandoned roads. Many species such as spotted knapweed not only take advantage of the disturbed ground found alongside roadways, but are also dispersed by tires, mud and crevices in the undercarriage of vehicles (Marcus et al. 1998). Roads also affect the distribution and occurrence of insect species such as gypsy moths and tent caterpillars (Bellinger et al., Roland 1993).

Effects of roads on individual species

While the effects of roads and vehicles are wide-ranging, many of the scientific studies conducted have dealt with their effects on single populations. The effects of roads on wildlife range from extremely detrimental to neutral to beneficial. For instance, Boyd and Pletschner (1999) discovered that wolves tended to disperse away from heavily used roads and that human-caused wolf mortality was highest near roads. However, wolves do benefit from certain kinds of roads. For example, there is a tendency for wolves to use seldom-traveled roads as hunting corridors (Thurber et al. 1994, James and Smith 2000). Similar outcomes were identified in studies on black bear, mountain lion and bobcats (Hayden and Meslow 1999, VanDyke et al. 1996).

Ungulates also have varying levels of tolerance to roads. For example, bighorn sheep are extremely sensitive to displacement due to roads (DeForge 1972, Bear and Jones 1973, Jorgensen 1974). While elk and deer can adapt fairly well to busy highways, roads with slow moving traffic caused displacement and changes in range use (Burbridge and Neff 1976, Gruell et al. 1976, Edge and Marcum 1991).

While larger animals tend to be displaced by roads, smaller animals tend to suffer different effects. Because smaller animals are less noticeable and slower-moving, direct kills from motorized vehicles are extremely common. For example, kills of desert tortoises and rattlesnakes by motorized vehicles are significant (Bury 1978, Berish 1998). In addition, smaller roads block movement of small animals more easily and populations are more easily cut off from each other (herpetofauna- DeMaynadier and Hunter 2000, DeMaynadier and Hunter 1995; small rodents- Oxley, et al. 1974, Wilkins 1982).

Birds are often used as indicators of ecological health due to the prominence of population records. Many studies have linked declines in bird populations to habitat fragmentation caused by roads (Keyser et al, 1997, Jones, et al. 2000, Boren 1999). Roads displace certain species of birds while attracting others (Kuitunen et al. 1998). For example, raptors may benefit from roads as they provide good hunting habitat (Dijak and Thompson 2000).

The effects of roads on aquatic species are often overlooked because they are less direct. The range and available habitat for fish is often reduced by road crossings and culverts required by roads, creating a type of stream fragmentation (Warren and Pardew, 1998). Additionally, roads tend to increase erosion and stream sedimentation. Frequently, this directly affects fish growth

and hatching success (Eaglin and Hubert 1993, Newcombe and Jensen 1996). Often the macroinvertebrates that fish feed upon decrease in response to sedimentation. The decrease in food supply results in decreases in fish populations (Furniss et al. 1991 and Alexander and Hansen 1986).

Some effects of roads such as soil compaction, changes in composition due to imported road surfaces, disturbed ground, and exhaust emissions and dustings greatly affect soil organisms. Haskell (2000) examined the occurrence of macroinvertebrates essential to soil nutrition processes and found them to decrease in areas adjacent to roads. Mychorrhizae and other soil organisms eliminated through soil compaction are essential for protection against pathogens, and nutrient and water uptake (Amaranthus et al. 1994). Changes at the soil community level are extremely important because they cause changes in essential processes that can propagate throughout an ecosystem, eventually altering other animal and plant communities. For example, changes in soil compaction, composition and soil flora and fauna have been shown to contribute to the alteration of plant communities alongside roads (Angold 1997, Sharifi et al. 1999, Adams 1982).

Effects of roads on abiotic functioning of ecosystems

As noted above, roads can significantly affect abiotic processes in ecosystems. Roads can cause changes to soil structure, aridity, erosion, and hydrology. Road construction often results in an increase in surface water flows that can lead to erosion of soil surfaces (Harr et al. 1975, Jones et al. 2000, Jones and Grant 1996). Alterations in surface flow can cause the formation of new drainages, as well as diversions and changes to the hydrology of water basins (Wemple et al. 1996). The increases in peak flows can also cause landslides (Montgomery, 1994). Finally, the pollutants left by vehicles on roads can be moved by surface flows into aquatic systems and neighboring terrestrial systems (Boxall and Maltby, 1997).

Increases in erosion are well-documented around forest roads (Egan 1999, Reid and Dunne 1984, Swift 1984). In some instances roads are the cause of major erosion events such as landslides and debris flows in forests (Amaranthus et al. 1985, McCashion and Rice, 1983). Additionally, increases in erosion due to roads increase sedimentation in streams (Bilby et al. 1989). It is not unlikely that these changes in hydrology are contributing to changes in species composition and riparian habitat. Swanson et al. (1989) found that roads in the Pacific Northwest affected downslope and upslope species, and Ryan and Grant (1991) used remote sensing techniques to identify changes in riparian vegetation linked with roads.

Public Attitudes and Management Considerations

The widespread effect of roads on ecosystems as well as the more localized impacts of roads on individual species has led to more active management of roads in many places. Lugo and Gucinski (2000) suggest approaching roads as ecological systems in order to better assess their roles in the make-up of landscapes. Swift and Burns (1999) discuss road closures, road redesigns and reconstruction of road systems in their article published in the Journal of Forestry.

Public attitudes and perceptions towards roads are also changing and this may be a leading factor in changing management towards roads. Roads are no longer viewed as harmless parts of the ecosystems in which they reside. Their effects and costs are being better understood and many of the previous attitudes towards roads are being reconsidered. Bengston and Fan (1999) categorized the major beliefs associated with roads (through analysis of 4,000 on-line news stories), finding that roads as recreation access providers was closely followed in importance by roads as agents of ecological damage.

Conclusion

Assessing the ecological impacts of roads is difficult. We do know that roads have the capacity to change species compositions through both displacement and mortality of native species and introduction of exotic species. They can change physical processes through increasing erosion, sedimentation and run-off. Roads can also facilitate recreation activities where interactions between humans and wildlife take place creating the potential for intentional and unintentional resource impacts. We know many things about the real and potential impacts of roads. Nevertheless, many of roads' most dramatic and far-reaching impacts probably have yet to be observed, studied or even considered.

Effects of roads are complex and varied, benefiting certain disturbance-tolerant species and doing irreparable damage to many other species and ecological processes. The impacts of roads and vehicles in natural places can and do go far beyond the physical area directly affected by each road. These impacts caused by roads and vehicles are altering almost all ecosystems at amazing rates and levels.

It is critical that land managers incorporate the best available scientific information describing the ecological impacts of roads when making access management decisions. While this information does not comprehensively describe our region, it is a substantial body of literature that can begin to facilitate ecologically sustainable access management planning. Ecologically sustainable access management is of paramount importance if we take a reasoned and responsible look at road proliferation trends, known and potential road impact patterns, and ecological values threatened by roads in this region, into the next century.