



Measure Development Summary

Roads

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Revision History

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Background and Justification

Roads and associated activities can profoundly impact a broad range of physical, ecological, and social attributes important to parks. Comprehensive reviews have documented extensive direct and indirect impacts of roads on both terrestrial and aquatic environments (Spellerberg 1998, Ercelawan 1999, Trombulak and Frissell 2000, Forman et al. 2003), the effects of which may be undetectable in some taxa for decades (Findlay and Bourdages 2000). Even in areas where human population densities are relatively low and landscapes are perceived as natural, the impacts of roads are pervasive (Saunders et al. 2002) and may extend hundreds to thousands of meters from the roadside (Forman 2000, Forman and Deblinger 2000, Forman et al. 2002).

Physically altering the landscape, roads result in the direct loss of habitat, fragmentation of the remaining habitat (Carr et al. 2002), altered landscape structure (Saunders et al. 2002), increased influence of edge effects (Carr et al. 2002), and disruption of hydrological processes (Jones et al. 2000, Trombulak and Frissell 2000). In fact, Noss (1993) argues that roads may be the single most destructive element in the process of habitat fragmentation.

Wildlife populations are further impacted directly by increasing mortality of organisms from vehicles (e.g., Fahrig et al. 1995), modifying behavioral patterns such as home ranges and migrations (e.g., Reijnen et al. 1996, Forman et al. 2002), and imposing physical barriers which limit or prevent access to resources (Trombulak and Frissell 2000, Forman et al. 2003, Jaeger et al. 2005), limit gene flow and subdivide and isolate populations (e.g., Gerlach and Musolf 2000, Keller and Largiader 2003). Separation of complementary habitats (e.g., breeding and feeding) can be particularly detrimental (e.g., Pope et al. 2000). Mortality from vehicle collisions can have significant effects on wildlife populations, particularly for smaller organisms. For example, in studying four amphibian species, Hels and Buchwald (2001) found that the probability of getting killed ranged from 0.34 to 0.61 when crossing a low to moderately traveled road (3200 vehicles/day) and from 0.89 to 0.98 when crossing a busy road (>15,000 vehicles/day). Their results indicate that about 10% of the adult populations of these species were killed annually by traffic in their study area.

Many times, even in 'pristine' protected areas, wildlife populations are affected by several, if not all, of these direct impacts resulting in the highest risk of mortality in areas of high road density (e.g., grizzly bears - Boyce et al. 2001, Johnson et al. 2005). For example, research on grizzly bears in Yellowstone National Park indicates that the effects of roads and associated development are disproportionately high on adult females and subadults resulting in higher mortality and lower productivity (Mattson et al. 1987). Similarly, in Banff and Yoho National Parks (Alberta, Canada), where grizzly bears are protected from hunting, as much as 100% of known adult grizzly bear mortalities occurred within 500m of roads or 200m of high use trails (Benn and Herrero 2002).

Indirect effects of roads can be as important, or more so, than direct effects. Roads have been associated with an increased incidence of fire ignitions (Cardille et al. 2001,

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DellaSala and Frost 2001, Brown et al. 2004) and higher probability of large fires in the upper Midwest (Cardille et al. 2001, but see Dickson et al. 2006). Roads are also associated with an increased occurrence of invasive species (Trombulak and Frissell 2000) with improved roads having a greater proportion of exotic species occurrence and cover than unimproved (4WD) roads (Gelbard and Belnap 2003). Wildlife may experience increased legal hunting pressure and poaching (Trombulak and Frissell 2000) and chronic disturbance from human activity such as recreation (Thurber et al. 1994, Reijnen et al. 1996). More recent studies have identified other indirect species-specific effects such as impacts of salt runoff on amphibians (Karraker et al. 2008).

Estimating trends with road data is notoriously difficult because changes could have resulted from construction of new roads, or simply from an update of the map and mapping techniques that improved coverage. In addition, comparisons of different map sources have proved problematic (Hawbaker and Radeloff 2004) as scale and completeness of the data differ. These problems are exacerbated in areas where remotely sensed data is less reliable; for example to detect small roads under dense and tall tree canopies. Despite the considerable issues associated with using spatial road data, the impacts of roads are so pervasive and important that they must be addressed either as a core metric, input to additional analyses, or both.

For example, road data are needed to estimate and evaluate landscape metrics such as patch size and fragmentation (Riitters et al. 2004).

Monitoring Questions and Objectives

Information on roads is useful from local to national scales. Thus, monitoring questions are stated in a general form, recognizing that refinements are necessary to clarify the desired objectives, the area of analysis, and suitable comparisons. General questions include:

- What is the density of roads (km/km²) in parks and adjacent areas?
- How do these density values compare to densities thought to affect wildlife or other resources?
- How far are park resources from the nearest roads?
- What percent of the park and surrounding lands are roadless?

Anticipated Inferences and Uses

- Provide information necessary to estimate the amount of area without roads.
- Provide basis for estimating changes road density over time.
- Serve as base data for estimating travel times.
- Reveal opportunities for cooperative management, conservation, and education.
- Provide context for evaluating landscape pattern among regions of the country.

Metrics

Road Density

Road density, measured as the average total road length (km) per unit of area of landscape (km²), is perhaps the most common and convenient overall measure of the amount of road in an area (Forman et al. 2003). Road density must be estimated for a given area and therefore, is sensitive to the area over which it is calculated. Refined values based on road type (e.g., primary and secondary roads versus rural, 4WD roads) may provide additional insights.

Various thresholds of road densities have been reported as important for wildlife. Gibbs and Shriver (2002) suggest that areas with road densities >1km/km² and with traffic volumes of >100 vehicles/lane/day, typical of the eastern and central US, may jeopardize population persistence of some land turtles. Similar high road density (>1.5km/km²) resulted in male-biased sex ratios in painted and snapping turtles, potentially indicating incipient changes in turtle populations (Steen and Gibbs 2004). For wolves in the Great Lakes region (Mladenoff et al. 1999) and mountain lions in Utah (Forman and Alexander 1998), populations appear to thrive only where road density is less than 0.6 km/km². Wolf packs were most likely to occur in areas with <0.23 km/km², nearly all wolves occurred in areas with <0.45 km/km², and no wolf pack territory was bisected by a major highway (Mladenoff et al. 1999).

Distance to Roads

Distance to the nearest road is a simple measure of potential road impacts that is easily understood and can be estimated for a point. Refined values based on road type (e.g., primary and secondary roads versus rural, 4WD roads) may provide additional insights.

Recent reviews suggest that most road impacts occur within 1000m of roads (Forman et al. 2003) however, various distances, also referred to as the depth-of-edge influence and road-effect zones, have been identified as important depending on the species and population characteristic of interest, ecosystem, season, time of day, road width, road surface, proximity to water, and traffic density. For example, in Canada national parks where grizzly bears are protected from hunting, as much as 100% of known adult grizzly bear mortalities occurred within 500m of roads or 200m of high use trails (Benn and Herrero 2002). In Massachusetts, presence and breeding of grassland birds was decreased within 1200m of heavy traffic areas (multilane highway - >30,000 vehicles/day) and within 700m of moderately heavy traffic areas (two-lane highway - 15,000-30,000 vehicles/day). Moderate traffic (8000-15,000 vehicles/day) had no effect on bird presence but reduced regular breeding for 400m from a road (Forman et al. 2002). For macroinvertebrate soil fauna, however, even relatively narrow, lightly travel roads through continuous forest have significant impacts up to 100m away (Haskell 2000).

Effective Mesh Size

Network form, or the spatial arrangement of roads, may be a better measure of potential impacts of roads by determining the relative size, shape, and arrangement of enclosed patches (Forman et al 2003). Mesh size, the area or diameter of patches enclosed within a road network, is inversely related to road density and focuses on the enclosed habitat fragments.

Effective mesh size has been shown to be a useful measure for monitoring landscape fragmentation (Jaeger 2000, Jaeger et al. 2008) and has been applied in a variety of landscapes (e.g., Padoa-Schioppa et al. 2006, Moser et al. 2007). The effective mesh size is related to the probability of two random points in a region being connected, i.e., not separated by barriers such as roads, railroads, or other features depending on the criteria selected (Jaeger 2000, Jaeger et al. 2008). This measure explicitly addresses the movement of individuals between habitat patches in the landscape and can be interpreted as the average size of the area that an animal placed randomly in the landscape would be able to access without crossing barriers (Girvetz et al. 2007).

The calculation of effective mesh size requires specification of the landscape elements that cause fragmentation (e.g., roads, railroads) and definition of the scale over which fragmentation will be determined (e.g., counties, ecoregions).

Issues and Assumptions

Analyses of road data require acknowledgment of several inherent issues and assumptions including the following:

- Difficult to map consistently over broad areas.
- Continually out of date.
- The described process does not account for land units smaller than the MMU of either of the input datasets and is valid only at the point in time that the data were acquired. In addition, as with all spatial analyses, inaccuracies in the input data will multiply in the output.
- Calculating the proportion of area in any manner is always a function of the sampling unit being measured (e.g., county, biome, grid cell size) and must be interpreted within that context.

Data Descriptions

Data Description

Road data are available at several spatial scales from multiple sources. Those consistently available at regional and national scales include:

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- ESRI Data & Maps 9.3
- US Census TIGER Line Files
- Tele Atlas (formerly GDT)

ESRI Data & Maps 9.3

ESRI Data & Maps is an annual set of map data that is bundled with the ArcGIS software products (current version is 9.3). Among these is the StreetMap North America dataset which includes 2003 Tele Atlas streets for North America as well as current Tele Atlas North America base data. There are 27 datasets, of which 25 contain both U.S. and Canada data, and two contain only U.S. data. The datasets include detailed streets, streets with a reduced feature and attribute set for cartographic display, highway exits, street and highway maneuvers, states and provinces, counties and county boundaries, postal areas and points, highways, major roads, interstate highways, railroads, city areas and points, water features, institutions, large area landmarks, parks, recreation areas, retail centers, airports, and transportation terminals. Twelve of the datasets have multiple feature classes that provide several levels of generalization for displaying the data at different scales.

These data are available from ESRI with the purchase of ArcGIS software.

U.S. Census TIGER Line Files

The TIGER/Line shapefiles are extracts containing selected geographic and cartographic information from the Census Bureau's MAF/TIGER[®] (Master Address File / Topologically Integrated Geographic Encoding and Referencing) database. The MAF/TIGER database was developed at the Census Bureau to support a variety of geographic programs and operations including functions such as mapping, geocoding, and geographic reference files that are used in decennial and economic censuses and sample survey programs. Spatial data for geographic features such as roads, railroads, rivers, and lakes, as well as legal and statistical geographic areas are included in the product. Other information about these features, such as the name, the type of feature, address ranges, and the geographic relationship to other features, also are included.

These data were originally derived from the USGS 1:100,000 scale Digital Line Graphs (DLG), USGS 1:24,000 scale quadrangles, and geographic base files from the 1980 Census. Updates from the 1990 and 2000 Census have since been incorporated. In addition, the Census Bureau began a multi-year project called the MAF/TIGER Accuracy Improvement Project (MTAIP) in 2002 to realign and update street features. This project was completed in 2008 and the most current data are now available (as of Dec 8, 2008). As part of this project, the horizontal spatial accuracy of the data were verified and 95 percent of the time, the distance between sample control points and the corresponding street centerline does not exceed 7.6 meters (about 25 ft). Ongoing updates will be reflected in subsequent releases of the TIGER/Line shapefiles over the next two years.

These data are freely available from the US Census Bureau web page at <http://www.census.gov/geo/www/tiger/>.

Tele Atlas (previously Geographic Data Technology), Dynamap and Multinet

The Tele Atlas Dynamap and MultNet products are comprehensive databases of street, address, census, and postal data for the United States and other countries. They include millions of miles of addressed streets and an extensive list of feature attributes. Tele Atlas' street products are often acknowledged as the industry-best source and are typically the source data used in in-car and portable navigation systems.

These data are available from Tele Atlas (<http://www.teleatlas.com/>) for a cost, depending on the coverage area, number of users, data format, type of use, and type of license.

Data Dimensions (spatial, temporal, thematic)

ESRI Data & Maps 9.3

- Available for all 50 states, Canada and Mexico
- Scales vary (1:24,000-1:100,000)
- Based on the 2003 Tele Atlas streets
- Available from <http://esri.com> with purchase of ArcGIS products

U.S. Census TIGER Line Files

- Available for all 50 states
- Scales vary (1:24,000-1:100,000)
- Most recent update released Dec 8, 2008
- Available for free from <http://www.census.gov/geo/www/tiger/>

Tele Atlas

- Available for all 50 states, Canada and Mexico
- Scales vary (1:24,000-1:100,000)
- Numerous associated attributes and addresses
- Updates released quarterly
- Available for cost from <http://www.teleatlas.com/>

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