WATER RESOURCES IMPACT

INCORPORATING AQUATIC ECOLOGY INTO DECISIONS ON PRIORITIZATION OF ROAD DECOMMISSIONING

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INTRODUCTION

Roads provide increased access to lands rich in natural resources and beauty, but they can also damage those lands and the ecological values therein. In particular, much interest has been focused on the hydrologic and geomorphic changes in roaded watersheds and their effects on aquatic ecosystems (Lee *et al.*, 1997; Dunham and Rieman, 1999; also see papers in Luce and Wemple, 2001). As a consequence, most public land management agencies and some private forest land managers are closing and rehabilitating roaded areas to restore forest productivity and improve watershed function.

The decision to decommission or to retain a road is complex and often controversial and involves many issues, including aquatic ecosystem health. While some controversy may be inevitable, managers and specialists given the task of selecting roads to decommission need scientific, ecologically-based criteria to guide their decisions. Existing guidance, however, is limited primarily to descriptions – and occasionally models – of how roads alter stream hydrology, geomorphology, and ecology. Little guidance exists on the effectiveness of road decommissioning and alternative treatments. Coherent strategies for road system management and closure that consider potentially conflicting objectives and opportunities in multiple use and ecological management would be useful (Rieman *et al.*, 2000).

Setting priorities for road closure and decommissioning is not a new practice, and a variety of strategies have been used. While watershed restoration may be a primary motivation, other strategies may emerge where, for example, wildlife or recreation concerns predominate. The most common priority is the 'problem' roads that yield substantial mass wasting or severe surface erosion. Such roads represent a small fraction of most road systems, and many such roads have already been decommissioned. Some proponents of road decommissioning strongly favor prioritizing streamside roads that directly contribute surface erosion, constrain the channel, and reduce shading. Others note that roads in the riparian corridor often have lower gradients than midslope roads and drain to more stable ground so they may represent less of a potential problem. Yet others support a strategy that would reduce road density by decommissioning as much of the road system as financially, practically, and politically feasible. Dead-end ridgetop and short spur roads supporting management of individual stands and recently constructed roads are common targets. In some cases, sediment modeling has been used to support prioritization for road closures and decommissioning. This is often in response to the goal of managing basin-wide sediment yields to be within prescribed limits, such as those prescribed by state's criteria and the Federal Clean Water Act.

Surface erosion from forest roads affects the fine sediment budget and may impose a chronic condition of sediment inputs to streams directly affecting the stream substrate and the health of aquatic life

Despite the obvious rationale for managing and closing roads, there is no common framework for prioritizing management alternatives. Evaluating and prioritizing alternative road management strategies will be difficult, given the diverse nature of watersheds, aquatic ecosystems, and specific effects of roads. However, we believe there are some fundamental principles that can inform a more thoughtful strategy, including the following:

1. Not all ecosystems are of equal importance or value.
2. Not all roads are equal in their physical effects.
3. Not all similar physical effects have equal ecological consequences.
4, Not all road effects can be repaired or mitigated to equal degrees.

In the remainder of this paper, we explore these ideas in more detail.

NOT ALL WATERSHEDS, STREAMS, OR HABITATS ARE OF EQUAL ECOLOGICAL SIGNIFICANCE

Conservation of biological diversity and ecological integrity has become a cornerstone of public land management. A fundamental approach for management has been to prioritize some areas for conservation and restoration because of their disproportionate contribution to biological diversity or ecological process and function.

Biological diversity is an important concept viewed as the representation of the variation in living organisms and the physical and biological complexes in which they occur. The richness of biological elements, such as number of species, is an important component of diversity. There is growing recognition, however, that diversity also includes within-species variation as represented by genes, distinct life histories, life stages, or even behavioral types, as well as the structural and functional characteristics of whole communities and ecosystems (Franklin, 1993).

An important point in this understanding is that the physical environment and the processes that create and maintain habitats for aquatic organisms represent a template for the maintenance and evolution of biological diversity at all scales of organization. Different types of streams and distinct habitats within streams can support different types of species, genetically different populations, and distinct life history forms or life stages within a species or population. To conserve ecological diversity, process, and function, it will be necessary to conserve a mosaic of watersheds, streams, and habitats within streams that represent the range of possibilities. For example, conserving a population of bull trout (*Salvelinus confluentus*) will require the conservation of spawning, rearing, and overwintering habitats and the stream corridors connecting them. All of these elements may be found within a kilometer of stream or scattered across a larger network of streams (Dunham and Rieman, 1999). Conserving populations of all native species may require representation of the higher elevation cold-water habitats required by some, as well as the lower elevation alluvial channels required by others.

Representation of diverse environments is important, but it is also important that some redundancy exists in any particular type (Rieman and Dunham, 2000). Because natural disturbances like fires and floods will alter landscapes and habitats whether humans manage them or not, ultimately, all habitats and populations are vulnerable to change (Benda *et al.*, 1998). If critical types of habitats, streams, and watersheds are replicated in space, the risk of all being degraded or lost in any single event is reduced. If some are particularly productive or large, they may survive most disturbances and serve as important sources for recolonization and gene flow to other areas as they recover (Rieman and Dunham, 2000).

An example may serve to illustrate how redundancy may be useful. Using an erosion model based on the R1-R4 method (Ketcheson *et al.*, 1999), calibrated to the coast range using data from Luce and Black (1999), we estimated the average annual sediment yield from surface erosion off of road segments in a basin and routed it to the stream. The resulting stream map shows that within this basin there is only one stream that has nearly no road sediment over much of its length (Figure 1) although there is quite a bit of variability among streams. The map of roads shows disturbance over most of the watershed, explaining why most of the streams show disturbance from roads. In naturally functioning watersheds, there may be a mosaic of conditions, owing to the patchy nature of natural disturbance and recovery (e.g., Benda *et al.*, 1998). Thus, from the perspective of fish habitat, natural systems are generally not disturbed uniformly in one place or time. In natural systems, some places are suitable for some species at some times, and many species may have evolved to exploit this variability (Rieman and Dunham, 2000). Large-scale homogenization of landscapes through management activities involving roads may explain, in part, the relatively uniform declines of many environmentally sensitive species, such as salmonids (e.g., Lee *et al.*, 1997) over large areas. A major challenge to management is to better understand and mimic natural processes and patterns to support species that depend on a diverse natural environment.

In general, management and roading of most lands has not occurred in a random pattern. Roading and

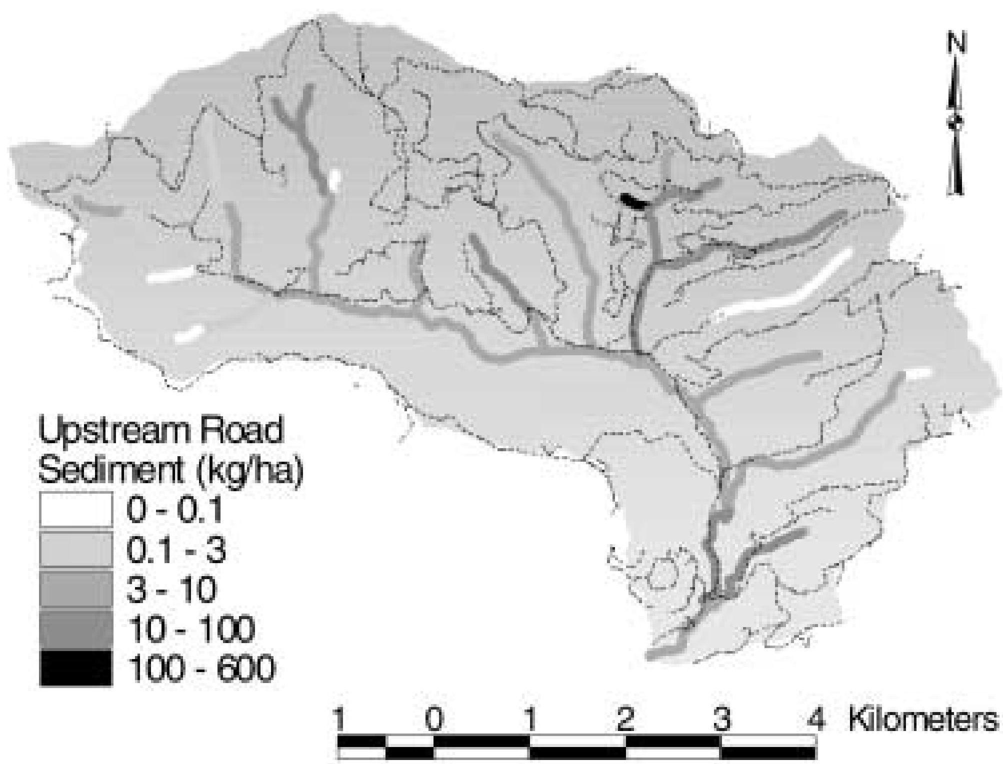

Figure 1. Stream Network of Order 2 and Higher Showing Modeled Sediment Load Derived From Roads Per Unit of Stream Contributing Area. Streams with less contribution from fine sediment are in lighter shades. Fine dashed lines are roads, which are distributed over almost all of the subwatersheds of the basin. Stream colors are generally darker where road densities are higher, and the undisturbed stream segment in the northeast side of the basin is undisturbed because the two ridgetop roads flanking it drain to other areas.

intensive land use, for example, often first occurred in lower elevation, relatively flat areas that were more productive and easier to access. These are also the areas more often held in private ownership. As demand for timber increased in the 1950s and 1960s, steeper, higher elevation lands were entered. In cases where higher elevation lands were entered, effects of disturbance may propagate in a downstream direction to further affect lower elevation streams. As a result, watersheds, streams, and habitats found in higher elevation, steeper, and colder sites are often in better condition than those at lower elevations. Thus, the ecological significance of restoration activities may be much greater in low elevation streams that are not well represented in the distribution of habitat types.

An important goal for managers intent on conserving biological diversity will be to conserve or restore a network of habitats. That network should represent as much of the historic distribution of conditions as possible, should be spatially diverse, and should contain multiple examples of representative habitat with some that are as productive as possible at any point in time. Because strong environmental gradients exist across streams, watersheds, and whole river basins the representation of biological diversity will require the representation of habitats that span those gradients. Some environments may be poorly represented or may be disproportionately important in the scheme of conserving ecological process and biological diversity, so it will be important to prioritize restoration activities that hold the greatest ecological significance.

NOT ALL ROADS ARE EQUAL IN THEIR PHYSICAL EFFECTS

Roads affect watershed function and fish ecology through numerous mechanisms, such as water flow, sediment delivery and transport, stream connectivity, and stream temperature (Jones *et al.*, 2000; Luce and Wemple, 2001). Scientists looking at large scale physical variables relating to fish abundance have noted that increased road density yields lower fish abundance (Lee *et al.*, 1997) or occurrence (Dunham and Rieman, 1999). This evidence supports a strategy of reducing road mileage in heavily roaded basins, and restricting development of new roads in unroaded areas.

A growing body of evidence suggests that all roads are not equal when it comes to increased sediment delivery and erosion. As an example, we applied the same erosion model described earlier and we estimated the average annual sediment yield from surface erosion in 18 small basins (6th code HUC basins between 16 and 26 km^2). The results suggest that road density correlates poorly to sediment yield from surface erosion (Figure 2). The apparent outlier had high sediment yield and delivery from a single poorly constructed road segment. One implication is that a strategy aimed at reducing road miles alone may not reduce sedimentation in streams. This is a general lesson that probably applies to other processes as well.

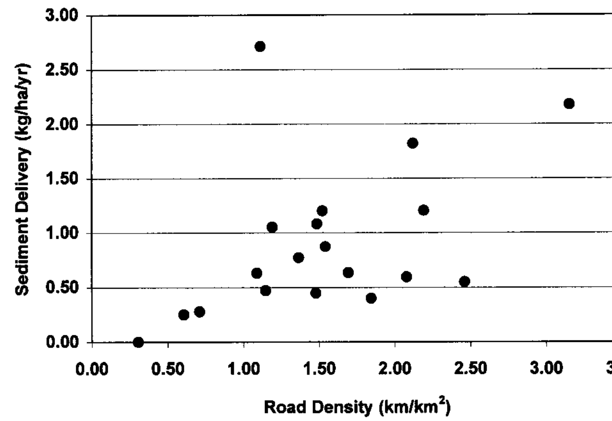

Figure 2. Relationship Between Sediment Delivery Predicted by a Surface Erosion Model and the Road Density in 19 Sixth Code HUC Basins (average about 16 km^2 each) in the Oregon Coast Range.

Surface erosion from forest roads affects the fine sediment budget and may impose a chronic condition of sediment inputs to streams directly affecting the stream substrate and the health of aquatic life. Surface erosion contributions to streams are affected by erosion processes on the road itself and by the fraction delivered. Sediment production is controlled primarily by the road slope, road length, and condition of the surface as expressed by soil texture, road surfacing, or vegetation cover. Traffic and road maintenance have strong effects on the surface condition (Reid and Dunne, 1984; Luce and Black, 1999). Following maintenance or cessation of traffic, reduction of erosion rates can be rapid, potentially reducing erosion rates to very small values (Megahan, 1974; Reid and Dunne, 1984). Factors controlling sediment delivery include distance from the stream, the volume of sediment and water exiting the drainage feature, and sediment texture (Megahan and Ketcheson, 1996). As a consequence, ridgetop roads rarely have substantial surface erosion contribution.

Mass wasting through gullies and landslides can be initiated by road drainage on steep hillslopes. Greater contributing lengths of road and steeper drainage slopes lead to greater probabilities of initiating gullies and landslides (e.g., Montgomery, 1994). Landslides also occur less frequently from a given road over time because there are a limited number of locations where failures can occur, which become exhausted over time, and because road engineers gradually repair problem sites as they become apparent.

Stream crossing culverts are related to a number of difficult problems on roads. Blockages of stream crossing culverts causing diversion over or along the road are risk factors for mass wasting, with undersized, unprotected culverts being at greatest risk (Furniss *et al.*, 1997.). Improperly designed stream crossings can also be barriers to fish migration.

Some evidence exists that roads increase peak flows of more common floods (Jones and Grant, 1996; Thomas and Megahan, 1998). Interception of subsurface flow by forest roads has been suggested as a mechanism for increased peak flows in roaded basins. Subsurface flow interception may also alter the timing of runoff within a season. It is not clear which roads most strongly affect basin wide hydrology. Theoretically, those with the greatest opportunity to intercept flows and those yielding the greatest shortening of flowpaths would pose the greatest risks (Wemple, 1998). Such combinations are most likely to occur on midslope roads.

Where roads are close to streams they affect the stream more directly. Roads in riparian zones prevent growth of dense stands of trees shading streams, and roads that travel long distances along stream channels would be more likely to yield a measurable effect on stream temperature. Roads are sometimes placed partially in an existing stream channel. Riprap is placed to prevent erosion of the road fill, and the channel form is dramatically changed. Access to streams allows fishing and the possible introduction of pathogens and competing species.

NOT ALL SIMILAR PHYSICAL EFFECTS HAVE EQUAL ECOLOGICAL CONSEQUENCE

Clearly the effects of roads may vary with physical and biological conditions and the physical location in question. Our intent is not to provide an analysis of all the possible interactions, but to point out that context is important. Specific biological effects of sediment in streams have been reviewed elsewhere (Waters, 1995). In referring to "context," we refer to the process of considering specific effects of roads in relation to the spatial and temporal dynamics of physical habitats relative to the biological requirements of a species. Biological requirements may be considered at the level of individual fish, populations, collections of populations in a basin, or in relation to life stage (Rieman and Dunham, 2000). For example, important questions related to context might include (1) "How are different life stages affected by the particular physical change?" (2) "Which life stages are most important to population growth?" and (3) "Where are habitats used by sensitive life stages relative to the road under consideration?" These types of considerations separate more thoughtful prioritization strategies from those that seek to reduce one aspect of road impacts across a basin (e.g., reduce overall sediment loading).

The issue of "context" is probably best illustrated with examples. For many fishes, the effects of fine sediment can vary by life stage. Fine sediment can smother embryos and young juveniles rearing in the substrate, and reduce feeding or abrade gills in older juveniles and adults. If survival of young juveniles (including eggs and developing embryos) is believed to be the most important factor limiting population growth, then roads contributing fine sediment to spawning and rearing habitats may constitute a greater ecological risk than roads contributing fine sediment to habitats used for migration.

To carry the above example further, consider the effects of ridgetop roads on a species that spawns in headwater streams. Ridgetop roads are generally more benign, but because they drain to headwater streams, they may directly threaten the integrity of spawning and rearing habitats. Because the effects of roads on sediment may be cumulative, effects of roads in up-slope areas may be especially important for species that spawn downstream of particularly damaging roads but not for those spawning in habitats found predominantly above the influence of the roads. Roads along stream bottoms most directly affect stream segments that may be degraded through other upstream disturbances, so removal of those roads alone, without consideration of the upstream disturbances, may yield less benefit than removing roads from a basin with few other sources of risk or chronic disturbance. In addition, some fish may only use these lower stream segments for migration between higher quality segments. Road crossings that act as barriers to movements low in a watershed might isolate an entire population or eliminate a sizeable area of habitat for a migratory species. Crossings higher in the basin might eliminate a proportionally smaller area of habitat. Roads that access particularly small or vulnerable populations, might significantly increase the threat of local extinction while access associated with healthier populations would not be an issue. These examples highlight the importance of context, in addition to the more conventional views of sediment on stream ecosystems.

NOT ALL ROAD EFFECTS CAN BE REPAIRED OR MITIGATED TO EQUAL DEGREES

Mitigation of road effects ranges in scope from allowing time and nature to take their course to aggressively removing roads and evidence of their existence. Because the success of treatments depends on many factors. including the skill in the design and implementation of some projects, there is little guidance on the effectiveness of some treatments in a general way. We can, however, gain some insight from several investigations.

Surface erosion is a common concern addressed in watershed restoration projects. Techniques to reduce erosion include: application of surfacing or mulch and seed, ripping the road surface, and recontouring the road (pull back fill and place on road to restore original hillslope shape). Vegetation regrowth, and surface armoring can be very effective in reducing surface erosion over just a few years (Megahan, 1974). A small fraction of roads do not recover and produce sediment at sustained high levels over many years. Long, steep, ditchlines and poorly revegetated cutslopes are two characteristics observed to contribute to this behavior. Time, good road surfacing, reduced traffic, and selective ditch maintenance combined with focused effort to revegetate problem cutslopes and shorten long ditchlines can lead to low surface erosion production from open forest roads. Outsloping and frequent drainage can reduce delivery to streams.

Ripping can be partially effective in increasing infiltration into the road tread, reducing runoff and erosion. Conditions improve enough through ripping that runoff generation would be rare, but capacities are not restored to natural conditions (Luce, 1997). After ripping, runoff can occur during high intensity events or during sustained water input that would saturate the ripped layer. Frequent cross drainage would be wise to prevent effects associated with concentration of flows along the ripping furrows. Recompaction and sealing of the ripped surface are two processes leading to reductions in infiltration capacity after ripping. Some ripped roads recompact to densities approaching the original road surface. Substantial improvement may be realized with soil amendments encouraging the development of soil structure. Recontouring suffers from some of same drawbacks as ripping and rills sometimes form in the steep fills.

Risks associated with concentration of flow, like mass wasting, gullies, and increased peak flow can be greatly reduced by ripping or recontouring. The material is still lacking in strength and structure until trees are reestablished, and while there is a reduced risk of uncompacted fill failure it is not completely removed, particularly in lower slope positions (Madej, 2001). If roads are kept open, inventories of road drainage, combined with empirical analysis, can find threshold combinations of segment length and drainage slope yielding gullies and landslides (e.g., Montgomery, 1994) leading to information that can aid in the design of roads with lower risk of initiating erosion. Frequent drainage is once again helpful. Given that there is little control or ability to maintain areas after recontouring or ripping, a well-designed, open, and maintained road may sometimes represent less risk for mass wasting.

For stream encroachment and culvert problems, removal of the road and offending culverts is effective. Culvert replacement and protection from debris combined with increased monitoring and maintenance is a more expensive approach that still retains some risks.

Reestablishing streamside vegetation where there is a streamside road is greatly facilitated by ripping or recontouring the road, as more area is allowed for planting. The problems of recompaction and reduced infiltration in ripped or recontoured roads can lead to poor soil productivity. The nearly complete lack of organic material might be important too. Addressing soil productivity issues for decommissioned roads is important in addressing their effects on stream temperature. Vigorous tall vegetation provides the best shade. If soil productivity is impaired, restoration of vigorous tall vegetation may be delayed or nonexistent. Soil amendments are used in mine reclamation because of the poor tilth and nutrient status of these soils, and amendments may be a promising approach to restoring productivity in decommissioned roads.

TOWARD A MORE THOUGHTFUL STRATEGY

A comprehensive strategy would attempt to generate the greatest ecological benefits with the least fiscal and social cost. So the questions should be: (1) where are the highest priorities ecologically; (2) within those, where are the most damaging roads; and (3) within those, which ones can we effectively decommission or mitigate?

Thus, from an ecological perspective, prioritization of road management alternatives may be viewed as a nested hierarchy of decisions with at least three levels. At the first level, application of this strategy would require a prioritization of available habitats for potential use. This would be a search for which areas would be most critical to the conservation of species, metapopulations, or other critical elements of ecological diversity. Conceptually we want to build a network of high quality diverse habitats with multiple examples of representative habitat. A key for the prioritization process is to rank the available restoration areas, recognizing that social or fiscal constraints may require selection of an alternative.

At the second level of prioritization, we seek out the roads that impose the greatest limitations on habitat quality and connectivity. This requires examining the physical effects of the roads and determining which effects from which roads constitute ecological hazards. This should produce a set of goals for each segment of road within a basin, such as reducing surface erosion, or removing migration blockage. Again, some ranking is needed with the realization that some minimal set of roads may need to be rehabilitated to make any effort in the area worthwhile.

At the third level of prioritization we consider which of the roads can be effectively decommissioned or otherwise mitigated. In this part of the strategy, the physical, financial, and social constraints must be reconciled. If migration blockage is a problem; social constraints prevent culvert removal; and financial constraints do not allow culvert replacement and maintenance, then there may be little we can effectively do for the problem that road represents. If the road is not critical to the overall plan for that area, then prioritization resumes at the second level. If it is critical, a lesser choice of an area to rehabilitate may be a better choice because the restoration may have a greater likelihood of success. Within some region a clear definition of the ecological priorities and possible physical solutions may allow for negotiation or partnership with affected publics to reduce social and fiscal constraints.

This strategy combines the four principles cited at the beginning of the paper with considerations of other factors, like cost and social acceptability. Consideration of a combination of biological and physical processes at site and basin scale, along with an understanding of capabilities in mitigation and decommissioning practices. provides a firm scientific foundation for decisions about forest road decommissioning. When we understand what would be most beneficial to the systems we are managing, it is easier to turn to our publics and show them the choices and tradeoffs.

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