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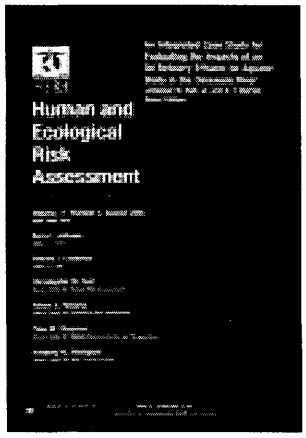

Human and Ecological Risk Assessment: An International Journal

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bher20

A Pilot Application of Regional Scale Risk Assessment to the Forestry Management of the Upper Grande Ronde Watershed, Oregon

Suzanne M. Anderson [a] & Wayne G. Landis [a]

[a] Institute of Environmental Toxicology, Huxley College of the Environment, Western Washington University, Bellingham, WA, USA

Accepted author version posted online: 30 May 2012. Version of record first published: 12 Jul 2012

To cite this article: Suzanne M. Anderson & Wayne G. Landis (2012): A Pilot Application of Regional Scale Risk Assessment to the Forestry Management of the Upper Grande Ronde Watershed, Oregon, Human and Ecological Risk Assessment: An International Journal, 18:4, 705-732

To link to this article: http://dx.doi.org/10.1080/10807039.2012.688696

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Human and Ecological Risk Assessment, 18: 705–732, 2012
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ISSN: 1080-7039 print / 1549-7860 online
DOI: 10.1080/10807039.2012.688696

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RISK ASSESSMENT ARTICLES

A Pilot Application of Regional Scale Risk Assessment to the Forestry Management of the Upper Grande Ronde Watershed, Oregon

Suzanne M. Anderson and Wayne G. Landis
Institute of Environmental Toxicology, Huxley College of the Environment, Western Washington University, Bellingham, WA, USA

ABSTRACT

An issue in forestry management has been the integration of a variety of different information into a threat analysis or risk assessment. In this instance, regional scale risk assessment was applied to the Upper Grande Ronde watershed in eastern Oregon to examine the potential of risk assessment for use in the management of broad landscapes. The site was a focus of study for the U.S. Forest Service through the Interior Northwest Landscape Analysis System (INLAS) project. In the study, a range of stressors, habitats, and endpoints were identified from previous studies in the watershed, and endpoints were determined from meeting with the primary stakeholder, the U.S. Forest Service. These endpoints were focused around the historic range of variability (HRV) defined for the area. The relative risk model (RRM) incorporating a Monte Carlo analysis was used as the analysis tool. The risk model output showed the HRV fire regime was the endpoint most at risk. The results of this analysis were compared to the Wallowa-Whitman National Forest prioritization of watershed restoration analysis. The RRM demonstrated similar results but with a better accounting for uncertainty. From this trial the RRM has proven to be a potential management tool for forestry management.

Key Words: regional risk assessment, relative risk model, forestry management, Interior Northwest Landscape Analysis System.

INTRODUCTION

Ecological risk assessment has found relatively few applications outside that of managing chemicals (Landis 2009). This is in spite of its intrinsic cause–effect

Received 15 February 2011; revised manuscript accepted 24 May 2011.
Address correspondence to Wayne G. Landis, Institute of Environmental Toxicology, Huxley College of the Environment, Western Washington University, 516 High St., ES518, MS9480, Bellingham, WA 98225-9180, USA. E-mail: wayne.landis@wwu.edu

modeling and its applicability to the management of invasive species, aquaculture, land use change, and watersheds. It is possible to broaden the use of risk assessment and especially regional risk assessment. The assumption in regional risk assessment is that there are multiple stressors working upon multiple endpoints in a variety of environments. The relative risk model (Landis and Wiegers 1997, 2005) has demonstrated its usefulness in a number of regional scenarios (Landis 2009).

This study is a demonstration of the use of regional risk assessment and specifically of the application of the relative risk model to a large-scale terrestrial ecosystem as a proof of concept for the U.S. Forest Service. The relative risk model (RRM) has been applied in various aquatic and watershed settings in previous risk assessments (Obery and Landis 2002; Hart-Hayes and Landis 2004; Colnar and Landis 2007). In this study, the RRM has been applied to the Upper Grande Ronde watershed in eastern Oregon, an area included in the Interior Northwest Analysis System (INLAS) studies conducted by the U.S. Forest Service (USFS).

The INLAS project began following the conclusion of the Interior Columbia Basin Ecosystem Management Project (ICBEMP). The ICBEMP was a project to create an ecosystem management strategy for large-scale forest ecosystems and applications on varying spatial and temporal scales were being explored (Barbour *et al.* 2004, 2007). Goals of the INLAS project included: enhancement of analytical tools to project succession and disturbance dynamics across large landscapes, and application of tools to predict changes in ecological and socioeconomic systems under various forest policy or management options on all land ownerships. From the INLAS project, data were collected and compiled and models were constructed, including state and transition models as well as alternative approaches.

The state and transition modeling research that had been previously conducted in the area by the USFS has been used to integrate conifer succession and disturbance, forest management, fluvial processes, herbivory, and invasive plants (Hemstrom *et al.* 2004). These models break the landscape into a variety of states and simulate change in landscape condition by using transition probabilities (Barbour *et al.* 2004). The state and transition model can prove useful for the study of disturbances, management activities and vegetation growth, but the models are not especially useful for finding solutions to meet management objectives (Hemstrom *et al.* 2004). These models have been applied and utilized together to describe and assess INLAS for the risks of fire, insects, and disease and ungulate herbivory. Throughout the study there was an identified interest to model the net synergistic effects of fire, invasive plants, insects, and herbivores within the INLAS area (Hemstrom *et al.* 2004). The application of the relative risk model to this area is a new modeling approach for the Forest Service and a chance to apply the RRM to a terrestrial setting. Multiple stressors and endpoints as well as uncertainty can be incorporated into the model to better understand the relationships within the area. The RRM is being tested within the INLAS study area to verify its usefulness as a modeling approach for large-scale forested and terrestrial regions.

Ecological Risk Assessment at a Regional Scale

Ecological risk assessment is a process that evaluates the probability of adverse effects to endpoints as the result of an exposure to one or more stressors (USEPA

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1998). The process organizes and evaluates data and uncertainty to understand and predict relationships between stressors and ecological endpoints. The methods for performing an ecological risk assessment are outlined in the *Guidelines for Ecological Risk Assessment* (USEPA 1998). Most traditional risk assessments are comprised of three phases; problem formulation, effects analysis, and risk characterization. The effects analysis and risk characterization phases can vary greatly among studies. Typically risks are calculated using information from single stressor-endpoint effects; this approach requires large amounts of specific data for each defined pathway. When such data are not available, extrapolation can lead to very high uncertainty. Another disadvantage of the typical method is that the risk assessor is unable to combine the effects of numerous stressors on a number of various endpoints.

Regional ecological risk assessments have demonstrated the ability to quantify risks in multiple geographical areas with a number of stressors, habitats, and endpoints (Landis and Wiegers 2007). The approach allows a regional risk assessment to evaluate landscapes at the scale necessary to manage an extensive landscape such as INLAS.

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Relative Risk Method

The RRM was developed by Landis and Wiegers (1997; Wiegers *et al.* 1998; Landis and Wiegers 2005). Risk assessments usually investigate the interaction of three components: stressors released in the environment, receptors living in the environment, and receptor response to stressors. At a regional level, the three components of risk assessment are altered. Sources become groups of stressors, habitats locations with groups of receptors, and responses are integrated to become impacts (Figure 1) (Landis and Wiegers 1997). Various studies (Wiegers *et al.* 1998; Obery and Landis 2002; Hart Hayes and Landis 2004; Colnar and Landis 2007) have effectively utilized the RRM at regional scales.

The most detailed description of how the RRM currently is applied, including the approaches toward ranking, the derivation of filters, risk calculation, and the application of Monte Carlo can be found in Colnar and Landis (2007). Although Colnar and Landis are calculating the risk due to an invasive species, the fundamental are very similar. With the RRM, risks can be calculated when multiple sources of stressors

Based on Landis and Wiegers 1997, 2005.

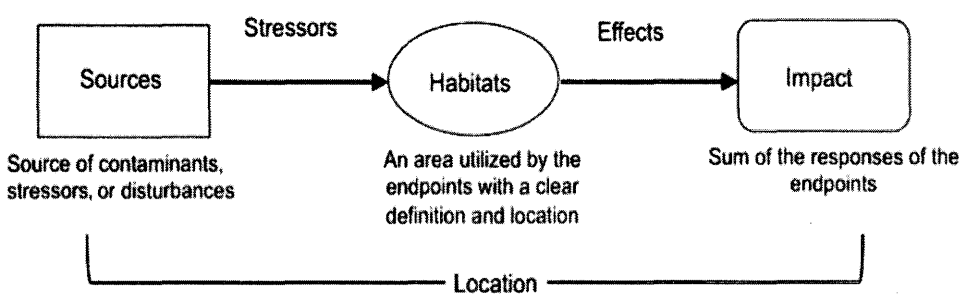

Figure 1. Diagram of the fundamental RRM conceptual model for regional risk assessment.

are present and when many pathways between sources, habitats and endpoints exist. The calculated risks are relative to each other within a particular study. Uncertainty is also explicit and specified for each of the parameters. The RRM can also be used to generate hypotheses about impacts to risk regions, and these hypotheses can be tested in the field.

Study Objectives

Main objectives of this study are: (1) use the risk assessment methodology of the RRM to organize data to allow the estimation of the effects of multiple stressors within the INLAS area, (2) consolidate the information derived from the study into a clear risk assessment framework format to present to decision-makers and stakeholders, and (3) provide a tool to assist decision-makers and managers in prioritizing management efforts and future research direction. The results of the study will provide managers with a tool to apply in other terrestrial areas with multiple stressors and multiple endpoints of concern.

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STUDY SITE AND RISK ASSESSMENT

Study Area—Interior Northwest Landscape Analysis System (INLAS): Upper Grande Ronde Watershed

The Interior Northwest Landscape Analysis System (INLAS) study area, which is comprised of the Upper Grande Ronde river watershed, encompasses 178,000 hectares of forest and rangeland in the eastern Blue Mountains near La Grande, Oregon (Figure 2). Most of this land (123,000 hectares) is in the Wallowa-Whitman National Forest, La Grande Ranger District and managed by the U.S. Forest Service (USFS). The remaining lands are non-industrial private, a holding managed by Forest Capital Partners, LLC (53, 550 ha), lands managed by the Bureau of Indian

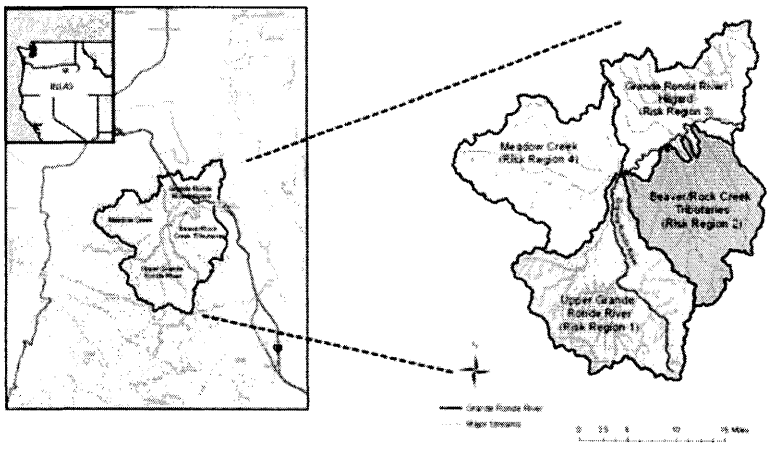

Figure 2. Map of the location of the Upper Grande Ronde watershed and INLAS study site.

Affairs (BIA) as Tribes of the Umatilla land (1373 ha), or lands managed by the state of Oregon (885 ha) (Barbour *et al.* 2004).

INLAS is comprised of four 5th order Hydrologic Unit Code (HUC) watershed areas, Meadow Creek, Grande Ronde River/Hilgard, Beaver/Rock Creek Tributaries, and the Upper Grande Ronde River (Figure 1). The Grande Ronde River runs north through the drainages and then east to eventually flow into the Snake River. Elevations in the area range from 360 to 2100 m.

These four watershed regions contain a variety of habitats and land uses. Three types of forest lands are present; warm-dry, cool-moist, and cold. These types are determined by tree species composition, which varies by topography, climate, and parent material. Also within the watersheds are grasslands, riparian and aquatic habitat (Barbour *et al.* 2004).

The area has been heavily managed and altered by humans, especially following European settlement. North American Indians commonly burned lands to clear undergrowth and promote growth of desirable crops for centuries before Europeans arrived (Hessburg and Agee 2003). Trappers were the first wave of European activity in the 1820s and were followed by pioneers along the Oregon Trail in the 1840s and 1850s. In the 1860s, pioneers began to settle the Upper Grande Ronde region and sawmills were opened. The timber harvest began to impact the area immediately, with dams blocking fish migration and railroads being built. Extensive cattle and sheep grazing and land conversion to agriculture have also impacted the area (Gildemeister 1998).

The initial land use has had residual influence over vegetation cover as well as fire and insect impacts in the area. The area has been managed by the USFS since 1908, when three forest reserves were combined to create the Wallowa National Forest. Since 1954, the Wallowa National Forest and Whitman National Forest have been managed together, creating the Wallowa-Whitman National Forest; within which the INLAS study area is located.

Regional Risk Assessment

Risk assessment was conducted using the RRM (Landis and Wiegers 1997, 2005). The three parts that comprise the risk assessment are problem formulation, analysis, and risk characterization.

Problem formulation

During problem formulation, a conceptual model is constructed based on information about the study area and the components of sources, stressors, habitats and assessment endpoints. The conceptual model shows all pathways of potential exposure and effects between all these components.

Description of risk regions

The study area was divided into four risk regions (Figure 2), based on HUC5 watersheds. The watersheds are Meadow Creek (MC), Grande Ronde River/Hilgard (GRH), Beaver/Rock Creek Tributaries (BRC), and Upper Grande Ronde (UGR)

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River. Each of these watersheds drains into the Grande Ronde River, and the Upper Grande Watershed is a HUC4 sub-basin. The risk regions contain similar land cover and land uses, and sources and endpoints occur throughout the study area.

Description of sources of stressors

Anthropogenic sources—Anthropogenic sources for this study were determined by land ownership and zoning. These sources include USFS timber/grazing land, private timber/grazing land, USFS old growth land, state timber/grazing land, and BIA lands. We determined the locations by geographical information systems (GIS) data maps available from the state of Oregon. All land was broken down by ownership, which determines how the area is managed and which stressors may be present or contained under management guidelines.

Non-anthropogenic sources—The non-anthropogenic source examined in this study is rainfall. Data on rainfall were readily available for the area from GIS data and were used as a climate factor to represent impacts on the study area that are unrelated to human activity. Rainfall is important to wildfire and insect patterns; drought conditions create dry fuel loads that increase the risk of large, hot wildfires or contribute to conditions that may lead to insect outbreaks. The amount of rainfall within an area can also determine management strategies, as well as affect grazing location and impact. Rainfall conditions vary throughout time and throughout the region, having a dynamic effect on the area.

Description of stressors

In the Forest Service literature, the "stressors" referred to in this study might typically be referred to as disturbances. In this study, the four stressors; forest management, grazing, insects, and wildfire; have individual impacts, as well as important interactions. The relationships between the sources and the stressors are also complicated.

Forest management—Forest management includes fire suppression as well as thinning, selective harvest, prescribed burning, and all fuel reduction practices done to maintain and re-establish fire regimes that have been altered by humans (Johnson and Peterson 2005). Present conditions may vary significantly from historical conditions, making the re-establishment of the historic fire regime impossible (Kerns *et al.* 2006). Timber removal for economic purposes is also a forest management practice, as well as any other human influence, such as agriculture or urban and rural development. These management activities can be done by the USFS, the state of Oregon, or other landowners within the area.

The management of forests can affect the natural succession of the trees and can move stands away from the desired composition. With this deviation, insect populations and natural fire regimes can be changed from historic patterns. Impacts on water quality by the input of sediments and alteration of nutrient input in the streams can also occur, as well as the introduction of non-native plant species into the ecosystem (Upper Grande Ronde WQMP 2000). The management of the forest also affects the availability of forest resources and output of forest products.

Grazing—Grazing by cattle, sheep, and elk also impacts water quality as animals trample riparian vegetation and walk through streams and rivers (Upper Grande

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Ronde WQMP 2000). Grazers are also responsible for the compacting of soils and reduction of plant cover leading to increased runoff and erosion (Belsky and Blumenthal 1997). Fire suppression and grazing may also increase tree densities, fuel loadings, and the possibility of crown fires (Wisdom *et al.* 2006). Shade-tolerant trees that are not fire resistant move in after grazing and timber removal, changing the natural fire regime (Barbour *et al.* 2004, 2007). The alteration of the habitat affects insect populations and host availability, changing natural insect levels. Grazing also affects forest resource availability, by limiting future grazing areas or impacting land that could be used by native grazers. Non-native plants can be introduced by grazing cattle and sheep through feed containing seeds of non-native plants or on the animal themselves, stuck on the hair or fur, or within the gut (Harrod 2001; Parks *et al.* 2005).

Insects and wildfire—The insect stressor refers to infestations above predicted outbreak or background levels, and the wildfire stressor refers to fires uncharacteristic of the natural fire regime for the specific habitat. The background insect levels or natural fire regime levels take the size, frequency, severity, and seasonality of the disturbance into account. These changes can occur as a result of forest management practices such as fire suppression and selective harvest (POWR 2002), but wildfire and insects are also a natural part of the disturbance regime. The application of the risk assessment process to wildfires has been suggested in previous studies (Fairbrother and Turnley 2005). Fire is an important natural disturbance in the region, but uncharacteristically large or severe fires are becoming more common due at least in part to land use changes. This type of fire impacts all the habitats within a region including riparian and aquatic areas.

Consecutive years of low rainfall also create ideal conditions for insect outbreak by making the trees more susceptible to infestation (Candau and Fleming 2005). Fire exclusion can also increase susceptibility to insect outbreaks by increasing the presence and density of shade-tolerant trees favored as hosts for insects (Torgersen 2001). Two of the most important defoliators in the area are western spruce budworm, *Choristoneura occidentalis* and Douglas-fir tussock moth, *Orgyia pseudotsugata.* Other important insect species in the area include Douglas-fir beetle, *Dendroctonus pseudotsugae*; mountain pine beetle, *Dendroctonus ponderosae* and western pine beetle, *Dendroctonus brevicomis.*

Description of endpoints

The endpoints for this study were selected based on input from the U.S. Forest Service (USFS) with information from previous work in the study area. No meeting was conducted in the area with stakeholders besides the USFS, which is the primary landowner and manager within the upper Grande Ronde watershed. Areas of concern include the historic range of variability for fire, insects, anadromous fish, and invasive species and forest resources such as timber, grazing, hunting, fishing, and recreation.

Historic range of variability (HRV)— Historic range of variability is the ideal ecosystem state for an area, based on a state of the landscape at some determined period of time. For the INLAS area, the HRV is determined as the state of the forest pre-European settlement. The HRV includes the species composition as well as

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disturbance regime and fragmentation index (Hann *et al.* 2003). For the Upper Grande Ronde watershed, the HRV includes disturbances such as fire and insects. The fire regime differs depending on forest type and topography (Agee 2003; Hessburg *et al.* 2000; Hessburg and Agee 2003). HRV can be difficult to determine, and re-establishing it may be difficult owing to changes in climate and current forest conditions. HRV is a stakeholder value for the USFS, and a prescribed goal for Forest Service management from a policy standpoint (Hann *et al.* 2003; Dillon *et al.* 2005), and because of this, applies to many of the endpoints in this study.

HRV anadromous fish—The Upper Grande Ronde watershed streams are home to threatened species such as Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*). The Forest Service is not responsible for managing these populations, but is responsible for managing the stream habitat and habitat surrounding the streams that support fish populations. The management of this habitat can influence stream temperature and nutrient input, both of which are important factors for fish populations. The HRV for the anadromous fish would be an increase toward numbers seen in data from previous decades (Upper Grande Ronde WQMP 2000; Whitney 2000; Rieman *et al.* 2003; Wantanabe *et al.* 2005; Ebersole *et al.* 2003).

HRV fire regime—The fire regime of the Upper Grande Ronde watershed varies depending on forest cover type, topography, and microclimate (Hann and Bunnell 2001; Hann and Strohm 2003; Ager *et al.* 2003). Current conditions prevent the historic fire regime from being re-established. Selective harvest and fire suppression have changed the species composition and fuel loadings of the area. For example, warm-dry forests are historically composed of ponderosa pine (*Pinus ponderosa*), Western larch (*Larix occidentalis*), and Douglas-fir (*Pseudotsuga menziesii*) as well as other conifers in an open, parkland-type setting (Tiedemann *et al.* 2000). These ecosystems experienced frequent, low-intensity fires that reduced undergrowth and prevented the growth of shade-tolerant species. After European settlement, the practice of suppressing fires prevented the frequent underburns that were an important disturbance to maintain the system. The selective harvest of ponderosa pines also changed the forest composition and altered the fire regime by allowing other species to move into the warm-dry area. Other habitats experienced similar changes; years of fire suppression increased fuel loadings and in turn increased the risk of large, high severity, and high intensity fires. The historic fire regime is still at risk due to past years of forest management and current ecosystem conditions that prevent the re-establishment of the desired regime (POWR 2002).

HRV invasive plants—Invasive plants have been introduced to the area through human sources such as farming, timber production, and grazing animals such as cattle and sheep. These disturbances also provide environmental conditions that allow establishment of non-native species (Parks *et al.* 2005). Invasive plants alter ecosystem processes, modify existing plant communities, alter biodiversity and change disturbance regimes, such as fire regimes, within an area (Harrod 2001).

The most common invading plants are annual grasses, perennial grasses, perennial forbs, and species of knapweeds (*Centaurea* spp.). Yellow starthistle (*Centaurea solstitialis*), dalmation and yellow toadflax (*Linaria genistifolia* spp. *dalmatica* and *Linaria vulgaris*), scotch thistle (*Onopordum acanthium*), and leafy spurge (*Euphorbia esula*) are some invasive species in the study area; there are 65 total species listed

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as noxious weeds within the area (Wallowa-Whitman Invasive Plants Treatment Proposed Action, Harrod 2001). One of the most serious invaders is *Potentilla recta*, a perennial that has a similar appearance to native plants in the region. Lower elevation regions in grassland or warm-dry forest habitats are more susceptible to invasive plants (Parks *et al.* 2005). Ideal HRV for invasive plants would lower numbers or eliminate invasives, if feasible, as well as prevent further introduction.

HRV insects—Insects are part of the natural disturbance regime of the Upper Grande Ronde watershed, and outbreaks are expected to occur. The frequency of outbreaks, as well as the size and severity, have increased in recent decades, which has impacted the ecosystem by moving the entire area further from the desired HRV. These insect outbreaks can be related to forest management practices that increase the number of similar age stands and decrease age and size variability. Due to these practices, large contiguous areas are susceptible to insect infestations above background levels (Swetnam and Lynch 1993; Hummel and Agee 2003). Low rainfall conditions also affect insect outbreaks, and due to the past management of the land that has left single-aged stands of trees of the same species, these outbreaks are more likely to become severe.

Forest resources: recreation, hunting/fishing, grazing, and timber—The Upper Grande Ronde region is also important for recreational uses such as hiking, camping, boating, and swimming. Forest Service lands provide these opportunities, as do state parks and private lands. The preservation of lands for these activities has been identified as an important endpoint for the area. Hunting and fishing are another type of recreation practiced within the watershed, for sport as well as for sustenance and tradition in areas on the Umatilla Indian Reservation (Gildemeister 1998).

The Upper Grande Ronde is an important area for grazing and the Wallowa-Whitman National Forest contains allotments leased for cattle grazing. The Starkey Experimental Forest, which studies native ungulate grazing, is also located within the region. Grazing has been important economically in the area historically and is still a valuable resource. Studies within the experimental forest on grazing effects of native species as well as cattle are important to range management in the west (Riggs *et al.* 2000; Vavra *et al.* 2004). Grazing is also an important natural disturbance within the habitats (Hobbs 1996).

Timber has been an important source of revenue in the Grande Ronde sub-basin since European settlement. The timber industry led to growth in the area and also re-shaped forests across the landscape (Gildemeister 1998; Langston 1995). Before Forest Service management, most logging was clear-cutting, and splash damming was a common practice used to float logs down rivers and streams. Old growth ponderosa pine and larch were the favored timber, and the introduction of railroads and mills in the area allowed increased timber production (Langston 1995). Today timber still provides important revenue on Forest Service lands as well as private lands in the Upper Grande Ronde, although the logging is practiced in a more sustainable fashion (Gildemeister 1998).

Description of Habitats

Riparian, warm-dry forest, cool-moist forest, cold forest, grassland, and aquatic are the habitats distributed within the area (Figure 3). These habitats were derived

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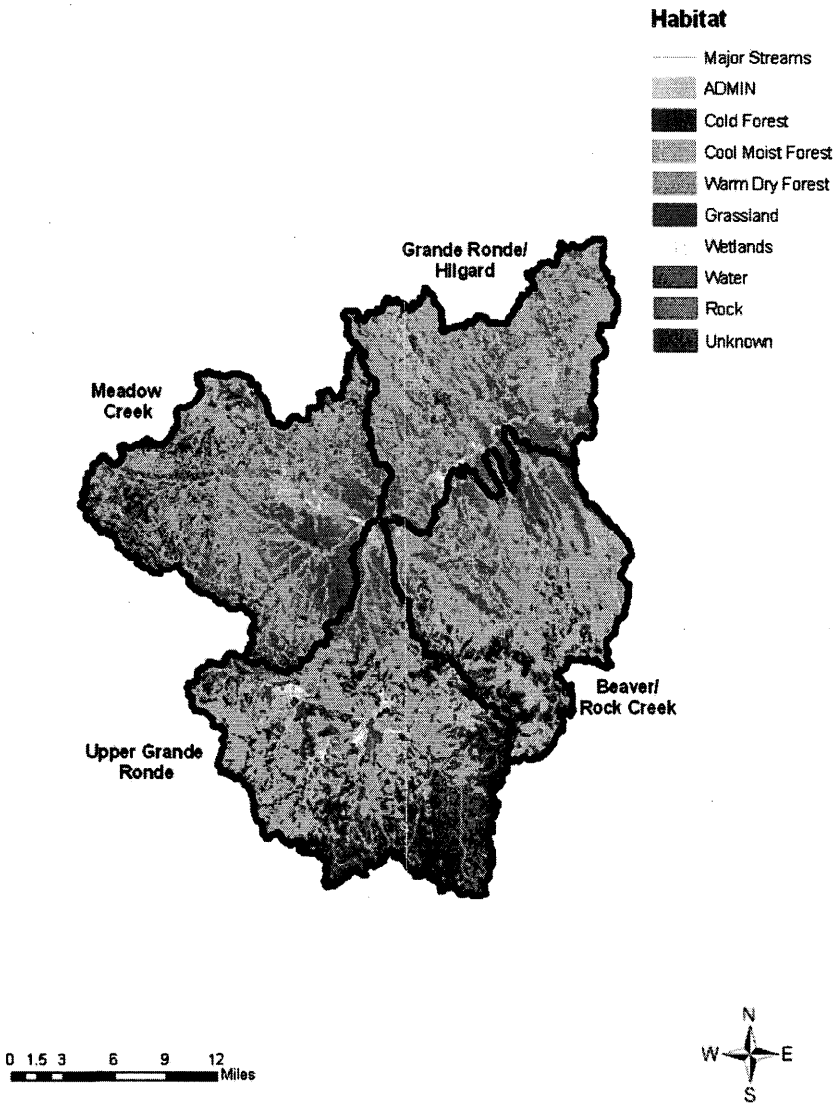

Figure 3. Map of the habitat types in the Upper Grande Ronde watershed. (Color figure available online.)

from Barbour *et al.* (2004) during previous research in the area. Riparian habitat estimates were based on riparian habitat conservation areas within USFS lands, which are determined to be 300 ft on each side of class 1 and 2 streams, 150 ft on class 3 streams, and 100 ft on class 4 streams (Bettinger *et al.* 1998). Warm-dry forest was a mixed conifer and grassland habitat dominated by ponderosa pines in a park-like setting. Cool-moist forests are mostly mid-elevation with lodgepole pine and grand fir as the dominant species. Cold forests are upslope and dominated by subalpine fir and lodgepole pine. Grasslands were determined to be any areas described as meadows, land dominated by wheatgrass, bluegrass, and oatgrass or any ecosystem with grass as the primary species. Aquatic habitat was all streams

and rivers in the watershed. Lakes comprised an insignificant amount of area and were not calculated in the aquatic habitat. All habitats were determined by ecoclass descriptions from Forest Service data and were calculated from Forest Service GIS data available online (http://www.reo.gov/waw/frmain.htm; http://www.fs.fed.us/pnw/lagrande/inlas/data/inlas/).

Conceptual Model

The conceptual model (Figure 4) is based on the framework of the RRM (Figure 1). The cause–effect pathways between sources, stressors, habitats, and endpoints are illustrated in the conceptual model diagram.

Analysis

The analysis phase consists of relating the exposure and effects to each other and investigating routes to impacts on the endpoints (USEPA 1998). The relative risk methodology has been used to determine comparative risks at large scales (Hart Hayes and Landis 2004; Obrey and Landis 2002; Wiegers *et al.* 1998). The RRM ranks risk components and filters for each possible pathway.

Development of source and habitat ranks

Source ranks—Sources were ranked based on GIS data from the state of Oregon for land use and zoning within the Upper Grande Ronde region (Table 1). Ranks of 0, 2, 4, or 6 were assigned based on amount of each land use/zoning combination compared to overall area of the Upper Grande Ronde watershed. Rainfall source

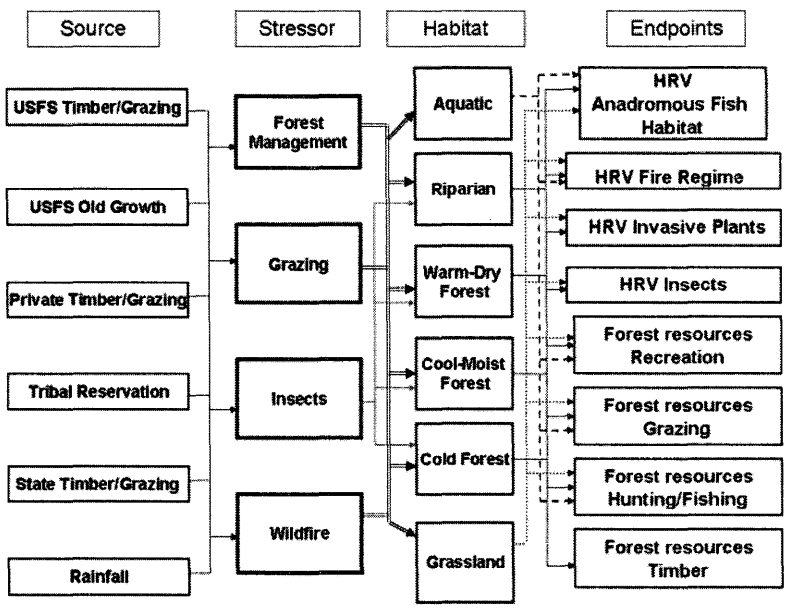

Figure 4. Conceptual model. Complete pathways are indicated with connecting lines. The same model is used for each risk region although the ranks and filters are altered specifically for each calculation.

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Table 1. Criteria for source and habitat ranks.

Source	Ranking criteria sources		Rank	Value range
Anthropogenic Sources-USFS, Private, State and BIA Land	Percent of land use type area per risk region	Zero	0	0–1%
		Low	2	1.1–24.99%
		Medium	4	25–49.99%
		High	6	50–100%
Non-Anthropogenic Sources- Rainfall	Percent of area within low rainfall range	Zero	0	0–1%
		Low	2	1–24.99%
		Medium	4	25–49.99%
		High	6	50–100%
Habitat	Habitats			
Warm-Dry Forest, Cool-Moist Forest, Cold Forest, Riparian, Grassland	Area of habitat in risk region/total area in risk region	Zero	0	0
		Low	2	1–14%
		Medium	4	15–35%
		High	6	36–50%
Aquatic	Length of streams within risk region/total length of streams in study area	Zero	0	0
		Low	2	1–11%
		Medium	4	12–21%
		High	6	22–35%

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data were from the USFS. Jenk's optimization were used to determine natural breaks (low, medium, and high) in rainfall averages for the entire region. Natural breaks are the best arrangement of values into classes by comparing the sum of the squared differences of values from the means of their class. For some rankings this was impossible and data were grouped by visually obvious divisions. Ranks for each watershed were then based on the amount of each risk region that was within each low, medium, and high break.

Habitat ranks—Habitat ranks (Table 1) were based on USFS data on the INLAS region. Vegetation maps were used to identify which ecoclass cover types were identified with determined habitat types. From that information, area of each habitat types in each risk region was calculated. The area of each habitat was then compared to the overall area of the risk region to produce percentage of land cover values for ranking.

Development of exposure and effects filters

Values of 0, 0.5, and 1 were assigned to exposure and effect filters. A value of 0 indicates an incomplete pathway, a value of 1 indicates a complete pathway, and a value of 0.5 indicates a partial or somewhat probable pathway. Exposure filters are based on whether the source will release the stressor and whether the stressor that is released will occur and persist in the habitat. In this study we also considered whether the stressor would exist in the habitat as a direct or indirect result of the source. Filters for USFS land, private timber/grazing, state timber/grazing,

reservation timber/grazing, and USFS old growth were determined using literature resources. For example, the insect stressor was assigned filter values of 0.5 for riparian; 1 for warm-dry, cool-moist, and cold forest; and 0 for grassland and aquatic habitats in the USFS timber/grazing source. The value of 1 for all forest types shows that a complete pathway is present. In the riparian zone, trees may be affected by insects, but often other plant species are present in the riparian zone and do not experience infestation (Upper Grande Ronde WQMP 2000). This is reflected in a 0.5 filter: the riparian habitat may be affected, but it is less probable. The grassland and aquatic habitats have filter values of zero because no host trees are present. Rainfall filters were assigned based on literature resources mostly regarding fire and insect impacts.

Effects filters are based on whether or not an endpoint occurs in and utilizes a habitat and whether exposure will affect the endpoint. A value of 1 was assigned to the filter when there were data to support that the habitats were utilized by the endpoints, a 0 indicated no use of the habitat by the endpoint. A value of 0.5 was assigned when the habitat may have been utilized by the endpoint, but there were no site-specific data. All effects filters were based on literature about the endpoints and the study site. For example, the fire regime endpoint had a filter value of 1 for all habitats except for aquatic. This is because within each of these habitats the fire regime may not be within the HRV. Aquatic is assigned a filter value of 0.5 because fire may be important to the aquatic system and it is affected by lack of fire in the other habitats, but there is no established regime for the aquatic habitat (Gresswell 1999; Hann and Strohm 2003).

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Risk Characterization

To calculate the relative risks within the study area and the risk regions, all the ranks and filters were assigned values and calculations were performed for all pathways in the conceptual model (Figure 4). First, habitat exposure is calculated by multiplying source ranks, habitat ranks, and exposure filters together. For example, the habitat exposure for USFS timber/grazing forest management in warm-dry forests would be calculated by multiplying together the USFS timber/grazing source rank, the warm-dry forest habitat rank, and the warm-dry forest–forest management exposure filter. The calculated habitat exposures and effects filters are multiplied together to become the risk score. The risk scores are then summed in each risk region, in each habitat, and for risk to each endpoint and contribution of each source to risk. The calculation is:

$$\text{Risk Score} = S_{ij} \times H_{ik} \times W_{jk} \tag{1}$$

where i = the risk region (UGR, BRC, GRH, MC), j = the source (USFS Timber/Grazing, Private Timber/Grazing... Rainfall), k = the habitat (aquatic, ... grassland), S_{ij} = rank chosen for the sources between risk regions, H_{ik} = rank chosen for the habitats between risk regions, W_{jk} = weighting factor established by the exposure or effect filter.

To provide the total score for the source or habitat, the risk scores were summed per risk region with the following calculation.

$$\text{Risk Score source} = \sum (S_{ij} \times H_{ik} \times W_{jk}) \text{ for } j = 1 \text{ to } n \quad (2)$$

$$\text{Risk Score habitat} = \sum (S_{ij} \times H_{ik} \times W_{jk}) \text{ for } k = 1 \text{ to } n \quad (3)$$

Uncertainty and Monte Carlo analysis

The uncertainty related to the ranks and filters in the relative risk model was classified as low, medium, or high depending on data and knowledge available. Uncertainty shows where more data are needed to increase the accuracy of the model. It also shows a clearer picture of the relationships between final calculated risk scores for the components of the model. The uncertainty provides the range of values that are possible for the risk score, showing how the risk scores are related to each other and how much uncertainty exists in each component.

Monte Carlo analysis was applied to statistical distributions that were assigned to the ranks and filters with medium or high uncertainty valuations (Table 2). The ranks and filters with low uncertainty were not assigned distributions; they retained their assigned values.

Riparian habitats were assigned medium uncertainty ranks because riparian area map data were only available on forest service land. The percentage of forest service land that was riparian was assumed to be a representation of the riparian area for the entire risk region. Other habitats were assigned medium uncertainty if a 20% change in the value would change the rank and high uncertainties were assigned if a 10% change in value would change the ranks. This is because there are unknown areas of habitat within the region and possible mapping error. Source uncertainties were assigned based on the same principle. Due to the nature of the ranks, when a value was uncertain it was skewed toward one end of the value. Because of this, alternative possible distributions were assigned for rank values

Table 2. Assigned distributions used to represent each level of uncertainty for the rank scores.

		Assigned rank probability rank value			
Assigned rank value	Uncertainty level	0	2	4	6
0	Medium	80	20	0	0
	High	70	30	0	0
2	Medium	0	80	20	0
	High	0	70	30	0
4	Medium	0	0	80	20
	Alternate medium	0	20	80	0
	High	0	0	70	30
	Alternate high	0	30	70	0
6	Medium	0	0	20	80
	High	0	0	30	70

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of 4 depending on whether the value was closer to being above or below that (Table 2).

Exposure filters for the source of USFS timber/grazing for grazing in cold and cool-moist forests have medium uncertainty because cattle may be grazing those habitats or may be impacting the habitats by utilizing them as a pathway between grazing areas. Specific data on these habitats were unavailable. Medium uncertainty was also assigned to wildfire impact on aquatic ecosystems. Data suggest that there is an impact of fire on the aquatic habitat, but site-specific data are limited. Exposure filter for the old growth forest source in the cool-moist forest for the wildfire stressor was assigned a medium uncertainty due to the nature of the forest type. Moist forests are less likely to have fire as a stressor, but the pathway cannot be ruled out. Wetter habitats such as aquatic, riparian and moist forests may serve as natural fire breaks (Dwire and Kauffman 2003), or these habitats may be too wet to sustain fire spread.

Private timber/grazing filters were similar to USFS timber/grazing, but riparian forest management was assigned a medium uncertainty. No site-specific data were available for private land management of riparian areas. All the uncertainty distributions in Reservation areas were assigned due to lack of site-specific data. State timber/grazing source exposure filters were the same as USFS timber/grazing source. Rainfall exposure filters for insects and wildfire were medium uncertainty in the riparian habitat. The effect of rainfall on insects and wildfire in the riparian zone lacks specific data and may be less severe due to the moisture of a riparian area.

Effects filters were medium uncertainty for the invasive plant endpoint because no invasive plants are currently in the aquatic habitat, but the pathway may still potentially exist. Medium uncertainty was also assigned for grazing in the cool-moist and cold forest habitats for the lack of specific data on usage of that habitat by grazers. Medium uncertainty was also assigned to forest resources-timber in the riparian habitat. While the riparian habitat has certain regulations protecting it, timber removal may be necessary for fuels reduction projects. It is also possible that timber removal may occur in the riparian habitat in private or reservation lands where data were not available.

Crystal Ball 7.3.1® (Oracle) was used to perform the Monte Carlo simulations and the uncertainty and sensitivity analyses. The sensitivity analysis determines which parameters in the model are contributing the most influence to the uncertainty of the model. Correlation coefficients are generated by the comparison between the defined uncertainty parameters and the defined forecasts. Parameters with the highest correlation coefficients are those driving the results of the simulation.

The simulations were run for 10,000 iterations with random selection from the input distributions. Each output was graphed and the sensitivity correlations compiled.

RESULTS

Risk Calculations

Calculations of risk scores provided the following information: (1) risk score for each risk region, (2) risk score for each endpoint, (3) risk score for each habitat, (4) risk contribution of each source, and (5) risk contribution for each set of stressors. To obtain the total risk score for a category, all the risk scores for that category

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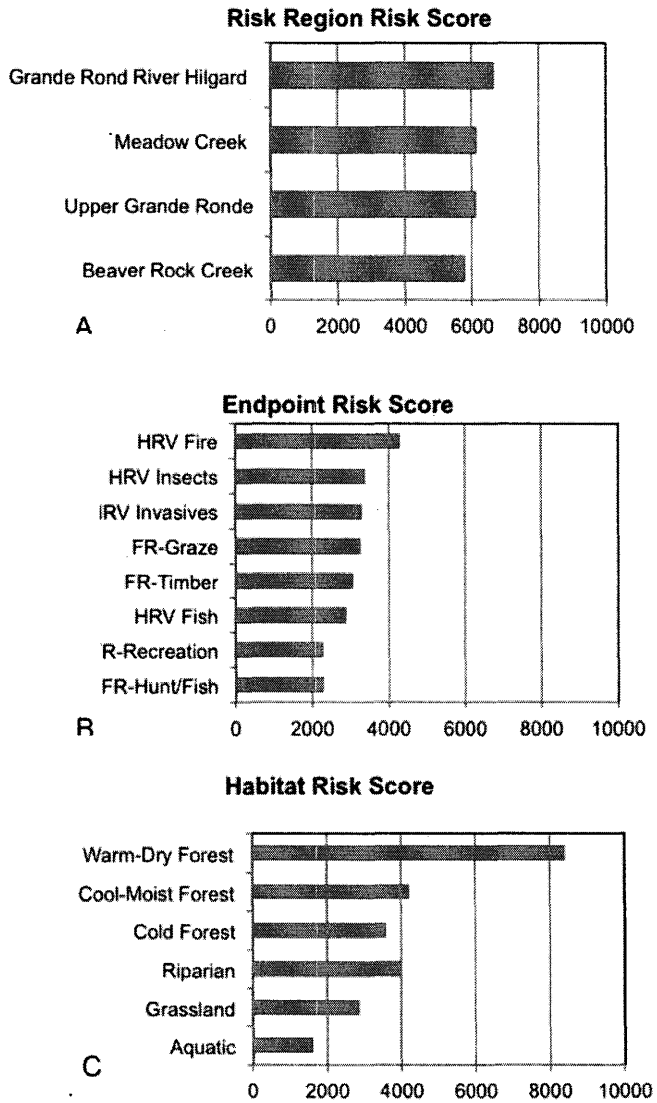

Figure 5. Bar graphs of calculated risk scores for (A) risk region, (B), endpoint and (C) habitat.

are summed together. For example, summing all the risk scores related to the forest management source gives the risk contribution from the forest management source.

Because a Monte Carlo analysis was done for each of the endpoints the distribution of scores can also be analyzed. In the following discussion the risk scores will be presented first. A comparison of the scores in rank from highest to lowest are presented in Figure 5 and the graphs representing the distribution of scores are presented in Figure 6. Similarly the risk due to sources and stressors are illustrated in Figure 7 and the distributions in Figure 8. Comparison of the risk scores to the mean and mode of the output distributions indicated good agreement, even with the cases where multiple peaks can be observed.

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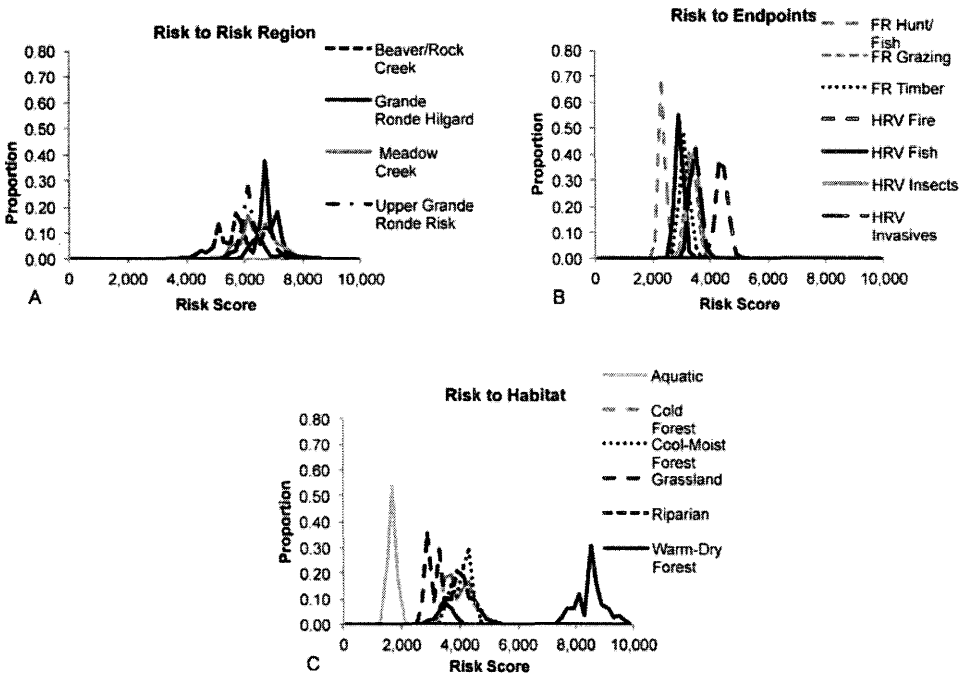

Figure 6. Monte Carlo distributions for (A) risk region, (B) endpoint, and (C) habitat. These graphs provide an estimate of uncertainty for the outputs depicted in Figure 5.

The four risk regions had close risk scores, with the Grande Ronde/Hilgard having the highest risk and Beaver/Rock Creek having the lowest (Figure 5A). The distribution of risk scores demonstrated an overlap (Figure 6A), signifying that the overall risk to each region was very similar.

HRV fire was the endpoint most at risk (Figure 5B) and the resultant distribution is different from the remaining endpoints (Figure 6A). The scores for HRV insects, HRV invasives, and FR-Graze are very close and their distributions almost indistinguishable. FR-Recreation and FR-Hunt/Fish are the same scores and an examination of the model indicates that they are derived from the same inputs.

Warm-dry Forest had the highest risk score (Figure 5C) and does not overlap with any other endpoint (Figure 6C). The risk scores for cool-moist forest, cold forest, riparian, and grassland have similar scores and a great deal of overlap in the distributions. Aquatic habitat has the lowest risk score without overlap with the adjacent endpoints.

Sensitivity Analysis

For each forecast risk estimate, a sensitivity analysis was run to determine parameters with high influences on overall risk uncertainties. The parameters with the highest correlations have the most influence on the uncertainty.

Sources—The highest correlation for USFS timber/grazing was for the corresponding source rank for Beaver/Rock Creek with a value of 0.63. Other parameters

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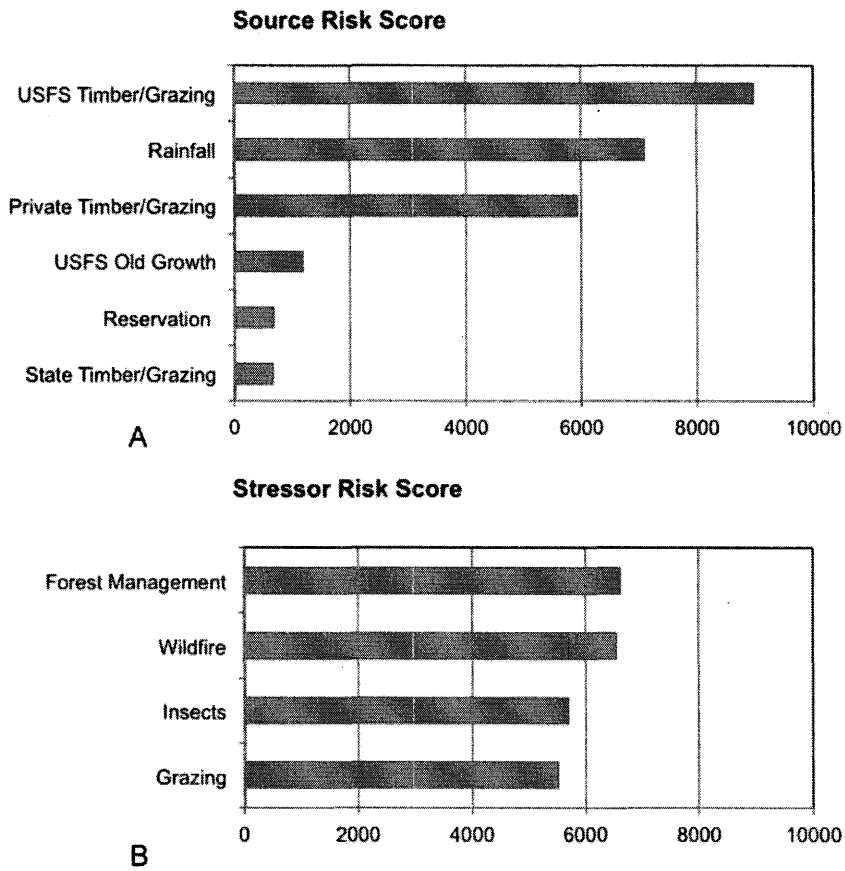

Figure 7. Calculated risk score graphs for (A) sources and (B) stressors.

were less than half of that correlation. Private timber/grazing and rainfall were also most highly correlated with the corresponding source rank for Meadow Creek and Upper Grande Ronde risk regions, respectively, with values of 0.65 and 0.55. Rainfall was also correlated with the corresponding source rank in the Beaver Rock Creek risk region with a value of 0.54. State timber/grazing, USFS old growth and BIA were all most highly correlated with habitat rank parameters. State timber grazing was most highly correlated with riparian habitat in the GRH risk region (0.64), USFS old growth with warm-dry forest habitat in the UGR risk region (0.50) and BIA with cold forest and cool-moist forest in MC risk region with correlation values of 0.59 and 0.53.

Habitats—For riparian and warm-dry forest habitats, the corresponding habitat value in the UGR risk region had the highest correlation, followed by the corresponding habitat in other risk regions. For the cool-moist forest, cold forest, grassland, and aquatic habitats, the parameter that had the highest correlation value was the corresponding habitat value in the MC risk region. Parameters from habitat ranks of corresponding habitat were the most influential for all habitats.

Stressors—Stressors did not have specific high parameters that were most correlated. Habitat rank for cold forest in the Meadow Creek risk region was the highest

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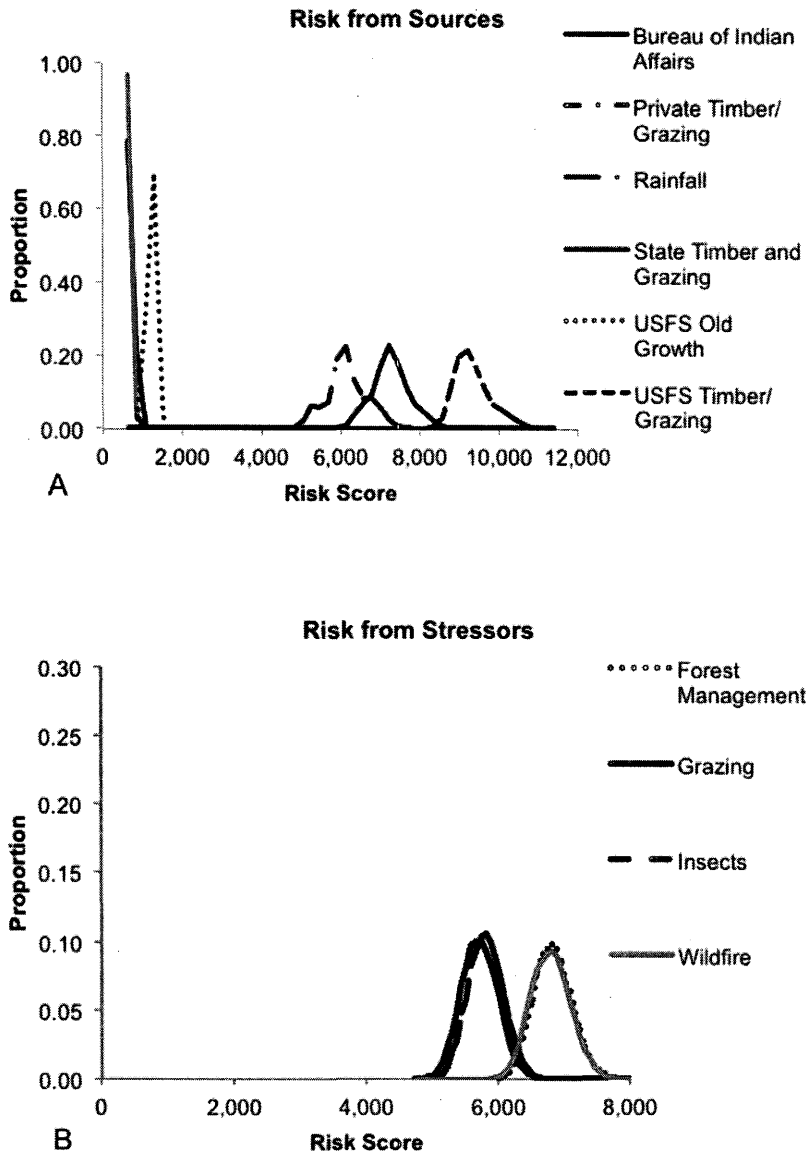

Figure 8. Monte Carlo results for risk from (A) sources and (B) stressors. In (A) the distributions for scores of different management schemes (sources) are presented for the INLAS region. (B) Illustrates the risk due to the stressors resulting from these management actions.

correlation for insect and wildfire stressors with values of 0.33 and 0.30, respectively. Source ranks for private timber/grazing in MC and BRC risk regions were the highest correlations for forest management with correlation values of 0.34 and 0.30. The parameter with the highest correlation for the grazing stressor was the exposure filter for grazing in cold forest habitat in USFS timber/grazing land with a correlation of 0.31. Grassland habitat rank value for GRH risk region was also correlated with

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the grazing stressor with a correlation value of 0.29. The correlation values for the stressors were all between 0.20 and 0.30.

Endpoints—Most endpoints did not have one definitive parameter that had high rank correlations. The correlations were all around 0.3. Forest resources grazing had the highest rank correlation with the effect filter parameter for the corresponding endpoint in UGR cold forest habitat. For HRV fish, HRV fire, HRV insects, and forest resources timber endpoints, the highest parameter correlation was with a habitat ranking; cold forest in the MC risk region for all but HRV fish, that endpoint correlation was highest with riparian habitat in the GRH risk region. The HRV invasives, forest resources recreation and forest resources hunting/fishing endpoints all had a high correlation parameter of source rank for private timber/grazing in MC risk region. The top parameter correlations were not significantly higher than the other parameter correlations.

Risk regions—For the Upper Grande Ronde (UGR) risk region, warm-dry forest and riparian habitat ranks with 0.58 and 0.45 correlations, as well as rainfall source rank with 0.51 correlation are the highest rank correlation parameters. For Beaver/Rock Creek (BRC), the highest parameters were source ranks for USFS timber/grazing and private timber/grazing, followed by habitat rank for warm-dry forest habitat with correlation values of 0.46, 0.41, and 0.41. The Grande Ronde/Hilgard (GRH) risk region highest parameters are riparian and grassland habitat ranks with correlations of 0.65 and 0.57. The Meadow Creek (MC) risk region highest parameters are the source rank for private timber/grazing with a correlation of 0.54 and habitat ranks for cold forest and cool-moist forest with correlations of 0.48 and 0.43. BRC and MC risk regions had a greater number of highly correlated parameters than the GRH and UGR risk regions.

DISCUSSION

The calculated risk scores and their associated uncertainty presented in the results section should be evaluated as an integrated entity. The addition of the uncertainty provides a more accurate picture of actual relative risk of the parameters in the model.

Risk Regions

The risk regions all had similar risk score values and wide uncertainty curves making the risk essentially equivalent across the risk regions. This corresponds with the stressors, where some areas may have higher risk for one component and at the same time lower risk for another, while another area may display the opposite. While these scores indicate an even spread over the entire study area, sub-areas within the risk regions differ in their aspects of risk.

Sources

The source totals for state timber/grazing land, USFS old growth land and BIA land were all low with narrow uncertainty distributions. This was most likely because of the small amount of land within the region that these sources represented. USFS

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timber/grazing and private timber/grazing had much higher risk score values and represented a much larger portion of the area. Because of the large amount of area that the sources cover, habitats at risk and stressors are more likely to be present in the USFS and private lands. The rainfall source also had a high risk value, and with uncertainty considered, overlapped with the private timber/grazing land source indicating that the sources could be close to each other in risk. Rainfall is an important source because of the role that drought plays in stressors like wildfire and insects. All three of these stressors had high uncertainty with very wide and low probability distributions. This was related to uncertainty in the ranking scheme from the available data. An inaccuracy in measurement or computation may have changed the rank value for several components included in the final source risk score.

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Habitats

The habitat at the greatest relative risk in the model is the warm-dry forest (Figure 5B). This habitat comprises a large part of the study area and is subject to all four of the stressors. Even when uncertainty is taken into account, the risk is still greatest for this habitat. Aquatic habitat is the lowest risk in this model, though that may be inaccurate. Because endpoints are weighted equally in this model, and few of the endpoints utilize aquatic habitat, less relative importance is placed on that habitat type. This may be an underestimation, as aquatic habitats are impacted by upslope habitats. Stressors such as wildfire and insects do not have the immediate direct impact on aquatic habitat seen in other forested habitat types. The other habitats; cool-moist forest, cold forest, riparian, and grassland all have overlapping risk distributions.

Stressors

The stressors in this relative risk assessment were approximately equal when uncertainty is considered. This could occur for several reasons. Within the four risk regions, one stressor had higher rank totals in two and lower rank totals in two, while another stressor would be just the opposite. For example, the grazing stressor totals were higher in the risk regions with more grassland habitat, while the insect stressor totals were higher in risk regions with more warm-dry forest habitat. Because of the distribution of habitat over the entire study area, this ended up giving the stressors similar risk score values. The forest management stressor is high throughout, but somewhat higher in risk regions that are almost entirely Forest Service lands. Wildfire stressor is also high in most risk regions, but regions with more warm-dry forest type have slightly higher scores. Once again, this ended up with nearly equal risk score values. The findings indicate that over the entire study region, these four risks are nearly equal, although they may be more focused in various areas within the region.

Endpoints

The endpoint most at risk is the historic range of variability of fire, or the historic fire regime (Figure 5C). This is due to the amount of habitat area that this endpoint occurs in and the relationship between the endpoint and all four stressors. Endpoints for forest resources recreation and forest resources hunting/fishing had identical

final risk scores and uncertainty curves. These endpoints had the lowest final risk values, though they occur in all habitats they were not considered likely to utilize the entire area and were assigned 0.5 effects filter values. Other endpoints including historic ranges of variability for insects, fish habitat, and invasive plants and forest resources timber and grazing had close final risk scores and overlapping uncertainty curves, making it difficult to identify differences among the risk values to these endpoints.

Uncertainty

Reduction of uncertainty could be accomplished by including expert opinions concerning the study area and/or within the components of the model. The highest sources of uncertainty in this study were related to maps of habitats and zoning. The uncertainty was most often due to values being close to the breaks between rank value assignments. When a value was close to the break, a small change could possibly change the rank value. The data had uncertainty associated with it and therefore assignment of ranks also had to have uncertainty, which would be removed if map accuracy could be increased. For habitat calculations, habitat classes were combined to provide new totals, also increasing the uncertainty, and some areas within the region were unclassified. Riparian habitats had high uncertainty because only riparian area within USFS lands was known and this was used to approximate for the entire risk region. The riparian habitat also overlapped with other habitat types. Zoning maps from the state of Oregon were used to calculate land use and ownership, and uncertainties within the data and rank assignments resulted in uncertainties in the final forecasts.

Comparison of the Risk Assessment to the Prioritization of Watershed Restoration (POWR) Report

The Wallowa-Whitman National Forest conducted a study entitled the Prioritization of Watershed Restoration (POWR). This study (POWR 2002) examined all the watersheds in the National Forest, including the watersheds in this study, to better develop a restoration strategy on the watershed level. The study fully incorporated laws such as the Clean Water Act and findings from the ICBEMP. The POWR report used a number of indicators to indicate the level of ecosystem function. A team of specialists from different aspects of the ecosystem analyzed the information to provide rankings in the study. From this Forest Service study, managers hoped to maintain highly ranked ecosystems and restore ecosystems with lower rankings.

A highly ranked indicator (H) would be found in a less degraded ecosystem, or one with a lower RRM score. According to the study, a sign of an undesired ecosystem was the presence of disturbances too large, intense or frequent for the system (POWR 2002). Four indicators were used to indicate integrity: aquatic, vegetation, terrestrial wildlife, and hydrologic function. Aquatic integrity was based on presence of threatened or endangered fish species, connectivity of habitat and relative abundance of species. Vegetation integrity was a comparison between current conditions and desired target conditions as well as structural stages present, especially abundance of late and old growth. Terrestrial wildlife integrity was calculated from

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threatened and endangered species presence, old growth present, and road density. Hydrologic integrity was determined by water quality standards, stream channel morphology, and soil-hydrologic function. For example, a high aquatic integrity rating would indicate an abundance of species, presence of large numbers of threatened and endangered species, and high connectivity of habitat.

Stressors in the POWR report were identified as effects that pushed the ecosystem further from the HRV. High levels of a stressor (H) indicate that the system is further from HRV, and would have a high RRM score, while low stressor levels in POWR indicate a level closer to HRV with a low RRM score. Five stressors were identified: fire, insect and disease, noxious weed invasion, road-stream connectivity, and road-wildlife security. Fire risk was determined by potential natural vegetation, and current vegetation including canopy closure and structure. Insect and disease risk was calculated using the UPEST model. Noxious weed risks were calculated by including climatic conditions, existing weed sources, proximity to roads, and grazing activities. Road-stream connectivity was based on road-related effects and hydrologic function and road-wildlife security was based on road density in the watershed.

Since the area of this RRM study and the POWR report included the four watersheds comprising the Upper Grande Ronde sub-basin a comparison was made. The stressors and indicators in POWR differ from those in the RRM, but some similarities can be identified between insect and fire stressors (Table 3), as well between the grazing and invasive plant endpoints in the RRM and the vegetation indicator in POWR (Table 3). The POWR report also ranked watersheds by the amount of late stage/old growth forest required to obtain an HRV (POWR 2002). Three of the four watersheds were in the bottom of the medium category, while Grande Ronde/Hilgard was in the low category, indicating a large departure from historic levels of old growth forest habitat (Table 3).

There are several clear differences in the approaches of the two methods. Uncertainty is not quantified in the POWR report and actual values of rankings are not provided. With the RRM, values are provided with assigned uncertainty to indicate a range of possible values for each rank. The cause–effect pathways are defined by the conceptual model of the RRM and in the structure of the calculations. A sensitivity analysis can be performed using the RRM to identify the key factors driving the risk results. A lack of data on the site can increase the uncertainty of the RRM so that there is a limited ability to identify differences in risk; an approach such as the POWR can be very robust in this regard. However, in the case of the INLAS study area data were adequate for the analysis.

Application to Management and Forecasting

One of the key elements of this study and the RRM is the ability to assist in the decision-making process for allocation of resources. The risk manager can break the risk down per region or per habitat and make other comparisons to determine where the most efficient application of funding would be. For example, the risk manager could examine an endpoint in this model and from the factors that are affecting that endpoint determine how to best mitigate the risk. An example of such an endpoint is HRV Invasives. If a manager had funding to manage invasive plants, the model

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Table 3. Comparison charts between POWR report and the RRM risk assessment.

	POWR stressor ranks					RRM stressor risk score			
Risk region	Road/ Stream	Road/ Wildlife	Insect/ Disease	Weeds	Fire regime	Forest fanagement	Graze	Insects	Wildfire
				Stressors					
UGR	M	M	H	M	L	1740	1428	1407	1525
BRC	L	M	M	L	L	1554	1326	1344	1546
GRH	M	H	H	M	H	1770	1503	1608	1774
MC	M	H	H	M	M	1560	1257	1344	1707

Indicators/Endpoints

	POWR "indicator" ranks				RRM endpoint risk score							
Risk region	Aquatic	Vegetation	Wildlife	Hydrologic function	Fish	Fire	HRV invasive plants	Insects	Recreation	Graze	Hunting/ Fishing	Timber
UGR	H	M	M	M	726	1060	741	902	566	725	566	814
BRC	H	M	M	H	680	1000	785	760	536	785	536	688
GRH	M	L	M	M	745	1157	939	898	604	900	604	808
MC	H	M	L	L	724	1063	836	812	569	831	569	732

UGR: Upper Grande Ronde; BRC: Beaver/Rock Creek; GRH: Grande Ronde/Hilgard; MC: Meadow Creek; HRV: Historical range of variability.

indicates that the highest risk for invasive plants is in the Grande Ronde/Hilgard risk region, followed by the Meadow Creek risk region. Those areas could be prioritized for treatment, and within each region, the model indicates that warm-dry forest and grassland are the habitats at the most risk for the HRV Invasives endpoint. Using this information, the risk manager could create an effective treatment plan tied to the mission of the funding source or agency.

A question still remains as to the type and amount of management action that would have to be taken to reduce risk. The RRM can be used to create forecasts. In creating a forecast the ranks representing a variety of management actions can be changed. Subsequently the analysis can be performed to examine if the risk has changed and in the proper direction. An advantage to this approach is that risks to other endpoints are also calculated and the output can be examined for unintended consequences. In this manner a number of management scenarios can be examined. A similar process has been performed for the Codorus Creek, PA, watershed (Thomas 2005; Landis and Thomas 2009).

A drawback to this technique is that the forecasts require an extensive manipulation of the model. The cells corresponding to the source, stressor, habitat and the filters have to be manipulated. This manipulation requires an extensive knowledge of the model and its construction to perform.

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ACKNOWLEDGMENTS

Suzanne Anderson thanks everyone at the USFS Pacific Northwest Station and La Grande Ranger District for all their effort in helping us access data, especially Alan Ager, Miles Hemstrom, Kurt Wiedenmann and Paul Boehne. Sarah Christensen was the hardworking intern for this project. She also thanks April Markiewicz and Dorene Gould for their support and the mentoring of Valerie Chen regarding the use of the RRM. Funding for this project was provided by the Joint Venture Agreement No. PNW 06-JV-11261900–070 with the U.S. Department of Agriculture and the Western Wildland Environmental Threat Assessment Center. Thanks also to Charles (Terry) Shaw of the USFS for his continued encouragement and support of this project.

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