

Coarse-Scale Restoration Planning and Design in Interior Columbia River Basin Ecosystems: An Example for Restoring Declining Whitebark Pine Forests

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During the last 2 years, many people from numerous government agencies and private institutions compiled a scientific assessment of the natural and human resources of the Interior Columbia River Basin (Jensen and Bourgeron 1993). This assessment is meant to guide the development of a coarse-scale Environmental Impact Statement for all 82 million hectares comprising the Interior Columbia River Basin (fig. 1). A myriad of spatial data products has been generated from this immense effort, including a wide variety of coarse-scale GIS data layers that describe historical, current, and future Interior Columbia River Basin environmental and vegetation conditions. These spatial data products can be valuable for planning ecosystem restoration activities at multiple scales. Presented in this paper is a proposed strategy for the incorporation of these coarse-scale data layers into the planning and design of restoration projects within the Interior Columbia River Basin. An application of this approach is also presented for a declining fire-dependent vegetation type—the whitebark pine (*Pinus albicaulis*) ecosystem.

Interior Columbia River Basin Scientific Assessment

After the Timber Summit held in Seattle, Washington, in May 1993, President Clinton directed the USDA Forest Service and the USDI Bureau of Land Management (BLM) to develop a scientifically sound, ecosystem-based strategy for the management of Federal forest lands in the Interior Columbia River Basin. The Chief of the Forest Service and the Director of the BLM further directed that a comprehensive ecosystem management framework and assessment be completed for all Forest Service and BLM lands in the Columbia River Basin (Jensen and Bourgeron 1993). This scientifically-based appraisal, called the Interior Columbia River Basin Scientific Assessment, was started in the winter of 1994 and was largely completed by the spring of 1995.

The Interior Columbia River Basin scientific assessment yielded an abundance of information that spatially describes many Columbia River Basin resources. These are databases,

spatial data layers, and simulation models. Nearly all data layers in the coarse-scale assessment were created at a 1 km² pixel resolution. Ecological attributes were mapped at the same precision across all ecosystems and across the entire extent of the Interior Columbia River Basin (that is, continuous or “wall-to-wall” coverage). When describing landscape ecology, emphasis was put on mapping those mechanisms that control Interior Columbia River Basin ecosystems rather than ecosystem traits, so most data layers describe ecosystem process rather than ecosystem state. An ecological process would be an exchange of energy within the system while an ecosystem state is a current description of an ecological condition. A detailed discussion of some general Interior Columbia River Basin data sources are provided in Keane and others (1995b). Although there are over 200 coarse-scale data layers developed specifically for the Interior Columbia River Basin scientific assessment, this paper will discuss only those data layers used in a sample analysis for whitebark pine ecosystems.

Biophysical Environment

Spatial data layers for temperature, precipitation, and radiation were simulated by Thornton and Running (1995) using an extension of the weather extrapolator MTCLIM

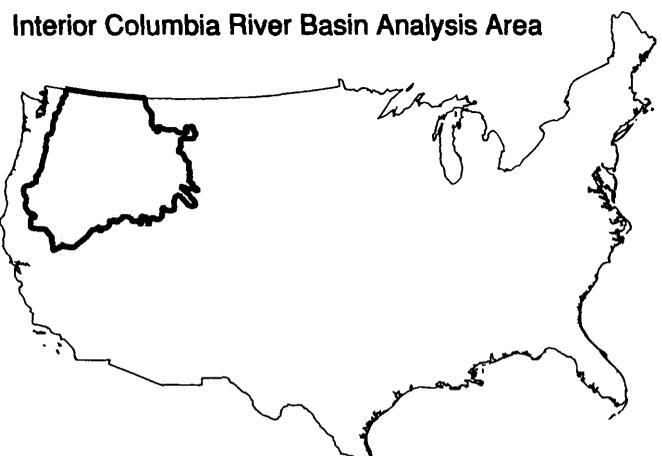


Figure 1—Geographic distribution of the analysis area for the Interior Columbia River Basin Scientific Assessment.

In: Hardy, Colin C.; Arno, Stephen F., eds. 1996. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

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(Hungerford and others 1989) called MTCLIM-3D. Elevation, aspect, and slope were calculated from a digital elevation model (DEM) provided by the Defense Mapping Agency. Parent material and other geological attributes were provided by the U.S. Geological Survey.

Vegetation

Three current and three historical data layers describing Interior Columbia River Basin vegetation were used in this paper:

1. The Current and Historical Potential Vegetation Type (PVT) Map. A potential vegetation type identifies a biophysical setting that could conceptually support a unique climax plant community. Each PVT is comprised of a group of similar habitat types or plant associations (Daubenmire 1968), and these groups were developed at a series of workshops attended by scientists and land managers. Biophysical settings were mapped from elevation, aspect, slope, and soil characteristics by geographical and ecological region (Reid and others 1995). The final PVT Map was derived by assigning coarse-scale potential vegetation types to biophysical settings based on temperature, moisture, and soils criteria. The PVT Map is roughly the same for historical and current conditions except for urban, agricultural, and industrial areas.

2. Current and Historical Cover Type Maps. The Current Cover Type Map was based on a land cover characteristics data base developed by Loveland and others (1991, 1993) from broad-scale, time series satellite imagery. Hardy and Burgan (1995b) reclassified this map to display the distribution of major forest (Eyre 1980) and range (Shiflet 1994) cover types across the Interior Columbia River Basin. Losensky (1994) developed the Historical Cover Type Map from archived maps, publications, and photos. This map portrays vegetation conditions at approximately the turn of the century (circa 1900).

3. Current and Historic Structural Stage Maps. The current Structural Stage Map was created from fine-scale data layers using discriminant analysis statistical techniques. The Historical Structural Stage layer was generated stochastically based on historical records of structural stage by cover type by county (Losensky 1994).

All vegetation data layers were then modified for input to the vegetation dynamics simulation model CRBSUM (Keane and others 1995a). This involved ensuring agreement between vegetation types across all maps. For example, all ponderosa pine cover types were removed from whitebark pine PVT's. Additional information on these data layers and the model can be obtained in a variety of impending publications summarized in Keane and others 1995b.

Fuels and Fire

Spatial descriptions of fuels and fire effects were generated by linking an extensive data base developed by Hardy and Burgan (1995a) with the cover type and structural stage data layers. A coarse-scale fire regime map was created by Morgan and others (1995) to describe severity and frequency

of fire across the entire Interior Columbia River Basin for both historical and current conditions.

Simulation Models

Two simulation models were developed for the Interior Columbia River Basin scientific assessment to predict landscape changes in vegetation cover and structure over time as a result of disturbance and succession. CRBSUM is a spatially explicit, deterministic model with stochastic properties (Keane and others 1995a). It simulates vegetation dynamics using a multiple pathway approach that integrates the effects of disturbance on successional development (Noble and Slatyer 1977). The Vegetation Dynamics Development Tool (VDDT) is essentially the same as CRBSUM but is not spatially explicit (Beukema and others 1995). It was developed to efficiently design successional pathways and quantify disturbance parameters for CRBSUM simulation. Both models simulate disturbance as a stochastic event, and the probabilities change by management scenario.

The Declining Whitebark Pine Ecosystem

Whitebark pine (*Pinus albicaulis*) is an important tree species in upper subalpine forests of the northern Rocky Mountains and northern Cascades (Schmidt and McDonald 1990). A rapid decline in whitebark pine has occurred during the last 30 years as a result of three interrelated factors: (1) epidemics of mountain pine beetle (*Dendroctonus ponderosae*); (2) the introduced disease white pine blister rust (*Cronartium ribicola*); and (3) successional replacement by shade-tolerant conifers, specifically subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and mountain hemlock (*Tsuga mertensiana*) probably as a result of fire exclusion policies of the last 60-80 years (Kendall and Arno 1990; Keane and Arno 1993; Keane and others 1994).

Whitebark pine benefits from fire because it is able to survive low severity fires better than its competitors (Arno and Hoff 1990). Also, after large, stand-replacement fires, it readily recolonizes because its seeds are transported from distant stands and cached in the soil by Clark's nutcrackers. The nutcrackers can disperse whitebark pine seeds up to 100 times further than wind can disperse seeds of subalpine fir and spruce (Hutchins and Lanner 1982).

Integrating Coarse-Scale Data Into Mid-Scale Planning

This paper presents a scheme to integrate Interior Columbia River Basin coarse-scale data layers into mid-scale or project level restoration planning and design. This strategy is presented as a four step approach using the declining whitebark pine ecosystem of the Bob Marshall Wilderness Complex, Montana, USA to illustrate how this procedure and the Interior Columbia River Basin data can be used to plan restoration activities. The Bob Marshall Wilderness Complex consists of approximately 520,000 hectares or

about 0.6 percent of the Interior Columbia River Basin with about 40 percent of the Bob Marshall Wilderness Complex composed of whitebark pine forests in the middle to advanced stages of decline due to blister rust and fire exclusion (Keane and others 1994). Only a few of the Interior Columbia River Basin data sources are used to illustrate this approach, but many more data layers and models are available to help guide restoration planning (see Keane and others 1995b).

Step 1: Describe the Ecosystem

Any mid-scale restoration plan should contain a detailed description of ecosystem processes and their associated characteristics to help identify the appropriate mechanisms or states to restore. The Interior Columbia River Basin information can be used in this description to identify several important elements, such as geographic context, major ecological processes, and related management issues (table 1).

Geographic Context—The importance, distribution, and status of the damaged ecosystem to be restored can be

Table 1—Land area (km²) occupied by the two whitebark pine cover types stratified by PVT and time (historical and current).

Cover types by time period	Potential vegetation types			
	SF Harsh PVT ^a		WBP/AL PVT ^b	
	ICBR	BMWC	ICBR	BMWC
----- km ² -----				
Current (circa 1990)				
WBP ^c	217	0	9,135	934
WBP/AL ^d	0	0	99	0
Historical (circa 1990)				
WBP	9,327	563	5,793	374
WBP/AL	0	0	2,108	560

^aSF Harsh PVT = spruce fir PVT on harsh environments, usually high elevation, xeric forests.

^bWBP/AL PVT = whitebark pine/alpine larch PVT, usually high elevation cold, xeric forests.

^cWBP = whitebark pine cover type.

^dWBP/AL = whitebark pine/alpine larch cover type.

spatially described with the Interior Columbia River Basin PVT, Cover Type, and Structural Stage data layers. For example, a GIS query of vegetation layers show two PVTs could support whitebark pine: (1) Spruce-Fir Harsh PVT (SF Harsh PVT; upper subalpine climax spruce and subalpine fir types on harsh, cold and xeric sites) and (2) Whitebark Pine/Alpine Larch PVT (WBP/AL PVT; high elevation mosaic of whitebark pine and alpine larch climax types).

Two Interior Columbia River Basin cover types contained whitebark pine as a dominant species based on the plurality of basal area: (1) Whitebark Pine (WBP CT) and (2) Whitebark Pine/Alpine Larch (WBP/AL CT). The whitebark pine forests of the Bob Marshall Wilderness Complex currently account for approximately 10 percent of all Interior Columbia River Basin whitebark pine forests, and comprised about 8 percent of the pre-1900 Interior Columbia River Basin landscape (table 1). So, although whitebark pine has been declining across the Interior Columbia River Basin, it has remained at near-historical levels in the Bob Marshall Wilderness Complex, indicating the high importance of the Bob Marshall Wilderness Complex whitebark pine forests in the Interior Columbia River Basin.

Ecological Processes—A spatial analysis of the causal mechanisms that control damaged ecosystems is needed so that restoration techniques can be designed to mimic these critical ecosystem processes. Important process relationships for the Bob Marshall Wilderness Complex are compared with their average across the entire Interior Columbia River Basin in table 2. These data indicate a wetter and warmer whitebark pine habitat in the Bob Marshall Wilderness Complex. In some vegetation types, such as ponderosa pine, Interior Columbia River Basin wildfires are more lethal today than they were at the turn of the century 1900 (Agee 1993), but the Bob Marshall Wilderness Complex seems to have maintained much of its pre-1900 fire regime.

Successional processes can be characterized by comparing the historical and current Structural Stage data layers (table 3). Structural stages are defined by the stand development phases rather than dimensional characteristics of trees (for example, d.b.h., basal area) (O'Hara and Latham 1995; Oliver 1981; Oliver and Larson 1990). There is a relatively even distribution of structural stages across whitebark cover types under historical conditions, but a

Table 2—General description of important ecosystem processes across the Bob Marshall Wilderness Complex and entire Interior Columbia River Basin for both SF Harsh and WBP/AL PVTs.

Ecosystem process	Current conditions		Historic conditions	
	ICBR	BMWC	ICBR	BMWC
Precipitation (mm)	973	1271	NA	NA
Radiation (kW m ⁻²)	317	251	NA	NA
Temperature (°C)	0.8	1.6	NA	NA
Fuel loading (kg m ⁻²)	7.3	6.1	4.1	5.0
Fire regime-frequency ^a	Very infrequent	Infrequent	Infrequent	Infrequent
Fire regime-severity	Stand replacement	Mixed	Mixed	Mixed
Parent material	Calcareous intrusive	Meta-siltstones	Calcareous intrusives	Meta siltstones

^aVery infrequent = greater than 150-300 years, infrequent = 75-150 years.

^bStand-replacement = all trees killed, mixed patchy = patchy fire killing all trees in some places or only killing a portion of the trees.

Table 3—Current and historic land area (km²) occupied by each structural stage for both whitebark pine cover types (WBP and WBP/SL Cts) across the Interior Columbia River Basin and the Bob Marshall Wilderness Complex.

Structural stage	Current		Historical	
	ICRB	BMWC	ICRB	BMWC
Stand initiation	176	0	2,540	233
Stem exclusion	29	0	1,127	117
Stem reinitiation	50	0	1,669	105
Old growth	17	0	2,592	303
Young multistrata	41	0	2,275	303
Old single strata	9,138	934	7,025	482
Totals	9,451	934	17,228	1,497

skewed distribution today with most land area in the old single strata structural stage. This seems true for both the Interior Columbia River Basin and the Bob Marshall Wilderness Complex. The old single strata structural stage is either created from repeated, low severity surface fires, or from high snowfall and cold conditions found in the severe WBP/AL PVT. The even distribution of structural stages under historical conditions probably indicates a mixed or stand-replacement fire regime in the SF Harsh PVT where whitebark pine cover types are in all stages of development (Arno 1986). This seems consistent with the fire regimes data layer.

Related Management Issues—Current management issues are sometimes directly dependent on the health of an

ecosystem. Whitebark pine seeds are an important food for many species of wildlife, especially the endangered grizzly bear. GIS analyses reveal that Bob Marshall Wilderness Complex whitebark pine forests comprise about 38 percent of all whitebark pine forests that are within the current range of the grizzly bear, indicating that restoration of this ecosystem might increase grizzly bear numbers. Another GIS query shows that most Interior Columbia River Basin whitebark pine forests (40 percent) are contained in wilderness areas. This would suggest the maintenance of ecosystem health in wilderness depends on restoration of whitebark pine.

Step 2: Simulate Possible Consequences

Investigation of the possible consequences of management actions is accomplished using simulation models. The models CRBSUM and VDDT were used to simulate changes in whitebark pine land cover under current management policies and under a possible restoration alternative (for example, remediation intervention such as planting rust-resistant whitebark pine and restoring historical fire regimes) for the Interior Columbia River Basin (fig. 2) and Bob Marshall Wilderness Complex (fig. 3). Long-term trends show an increase (about 20 percent) in whitebark pine land cover (km²) with remediation intervention but a rapid decrease in whitebark pine cover under current land management (fig. 2). Spatial simulation of these vegetation dynamics reveal that small isolated sites will lose whitebark pine faster than large, contiguous whitebark pine stands.

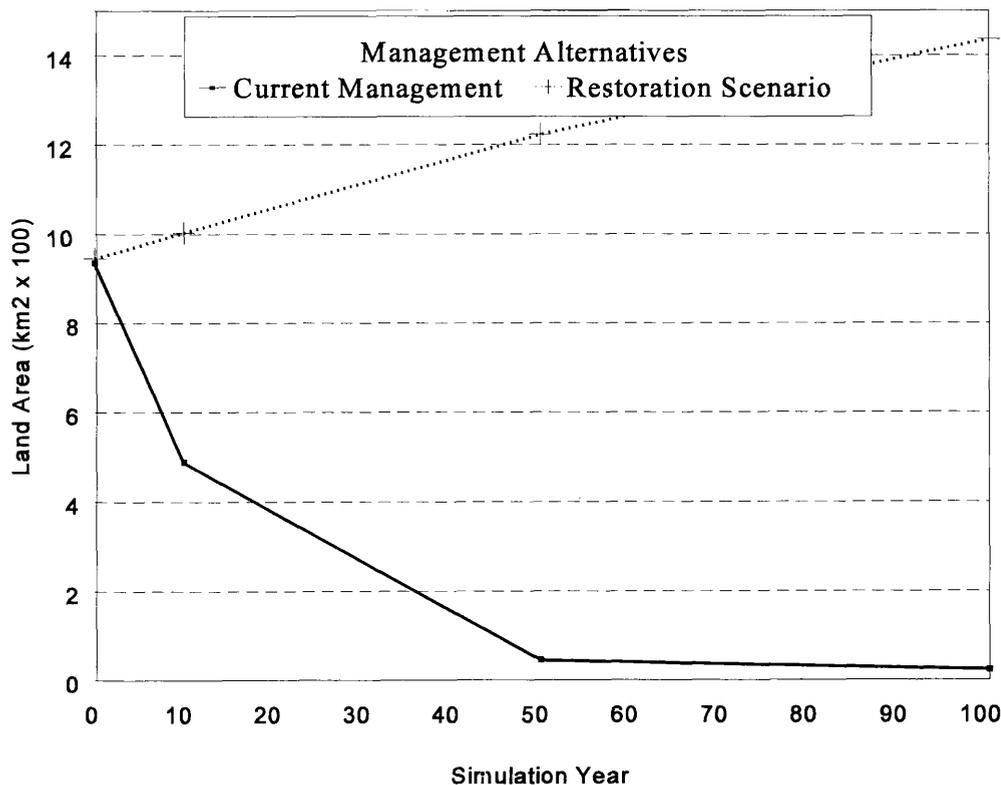


Figure 2—Model predictions of whitebark pine cover type extent (km²) for the Bob Marshall Wilderness Complex under two management scenarios—Current Management and Restoration Scenario.

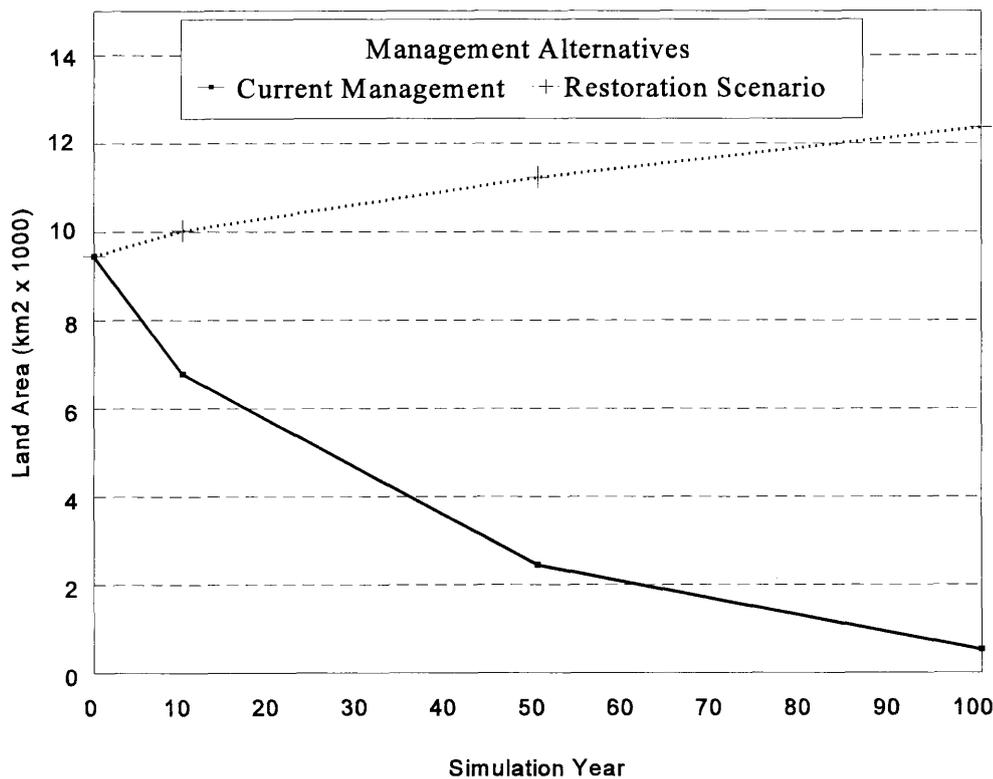


Figure 3—Model predictions of whitebark pine cover type extent (km²) for the entire Interior Columbia River Basin under two management scenarios—Current Management and Restoration Scenario.

Step 3: Prioritize Restoration Areas

Perhaps the most critical step in restoration planning is to identify those areas that need immediate treatment. Coarse-scale data layers and simulation models allow a quantitative analysis of potential restoration sites. Model runs of CRBSUM and VDDT show succession more rapid in the SF Harsh PVT, resulting in a more rapid loss of whitebark pine, but also a faster recovery. GIS queries on the fire regime map indicate that mixed and stand-replacement fire regimes are more common in this PVT. These are the types of fire that are currently excluded on the landscape (Schmidt and McDonald 1990). This suggests restoration projects should target the SF Harsh PVT and that a possible remediation tool should include prescribed fire, especially prescribed natural fires. However, the WBP/AL CT on the WBP/AL PVT is found mostly in the Bob Marshall Wilderness Complex (table 1), so this may be an important condition to maintain or restore.

Advanced GIS analysis of the coarse-scale data layers may also assist in the prioritization of restoration sites. For example, a buffer zone of 15 km in width around whitebark pine cover type pixels will define an effective area of species migration since this is about the distance limit for effective nutcracker seed dispersal (Schmidt and McDonald 1990). Those pixels without overlapping buffers (islands) are areas where nutcracker caches will only have seeds from the local population, and genetic migration from surrounding populations is limited by dispersal distance. These areas can be targeted for planting rust-resistant, nursery-grown seedlings because transportation of natural rust-resistant seed will be limited, and post-fire whitebark regeneration may be

poor when stand-replacement fires burn these isolated areas. Whitebark pine stands in northwestern Montana and northern Idaho might receive high priorities because these whitebark pine forests are in grizzly bear recovery zones and in wilderness areas as assessed from GIS queries.

Step 4: Decide on Restoration Techniques

The objectives of the restoration effort and the current status of ecosystem processes will dictate the techniques used to remediate damaged environments. Objectives of the Bob Marshall Wilderness Complex whitebark pine restoration attempt might be to promote tree establishment and improve cone production. Since the Bob Marshall Wilderness Complex is in a mixed and stand-replacement fire regime, this would indicate the need for an implementation of prescribed mixed and stand-replacement fires in the upper subalpine forests to restore fire's role in ecosystem maintenance. Another objective might be to mitigate blister rust damage in these ecosystems. This could involve the costly planting of rust-resistant seedlings or the less expensive creation of naturally maintained rust-resistant stands of whitebark pine using silvicultural cuttings and prescribed fire.

Ecosystem process conditions will also dictate possible restoration activities. Fire has been excluded from most whitebark pine ecosystems in the Interior Columbia River Basin and the Bob Marshall Wilderness Complex, except for the last two decades when some fires have been allowed to burn under certain prescriptions in the Bob Marshall Wilderness Complex. Consequently, it would seem logical to

incorporate prescribed fire as a tool in restoring ecosystem condition. The introduced blister rust has caused the majority of whitebark pine decline in the northern Rocky Mountains, so restoration plans should include some actions to increase rust-resistance in whitebark pine populations. This might involve the creation of large, burned over areas to encourage nutcracker caching, or the planting of rust-resistant seedlings in critical areas. Subalpine fir replaces whitebark pine in the successional process, indicating that silvicultural cuttings to remove subalpine fir competition would retard or reverse succession and increase whitebark pine abundance and reproductive success.

Conclusions

Coarse-scale information such as the Interior Columbia River Basin spatial data can aid in restoration projects by providing information to plan and design remediation procedures. Coarse-scale GIS layers allow a description of the damaged ecosystem in the context of the entire Interior Columbia River Basin. They also allow a quantification of the processes that affect ecosystem conditions. Simulation models can be used as "gaming" tools to predict the consequences of a restoration procedure on ecosystem health and status.

A general restoration plan for Bob Marshall Wilderness Complex whitebark pine forests has been designed using Interior Columbia River Basin data layers. First, historical fire regimes must be reintroduced to the Bob Marshall Wilderness Complex where mixed and stand-replacement fires burn at infrequent (150-300 years) intervals. Stands of the SF Harsh PVT will be targeted for burning because whitebark pine will be lost first on these types. However, the WBP/AL cover type on the WBP/AL PVT is also targeted for restoration because that cover type occurs mostly in the Bob Marshall Wilderness Complex and rarely elsewhere in the Interior Columbia River Basin. Isolated whitebark pine stands can be targeted for the planting of rust-resistant whitebark pine seedlings.

References

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Arno, S.F. 1986. Whitebark pine cone crops—a diminishing source of wildlife food? *W. Jour. of Applied Forestry* 1: 92-94.

Arno, S.F. and R. Hoff. 1990. *Pinus albicaulis* Engelm. Whitebark Pine. pp. 268-279. In: *Silvics of North America. Vol. I. Conifers.* USDA For. Serv., Agr. Handbook 654.

Beukema, S.J. and W.A. Kurtz. 1995. Vegetation dynamics development tool user's guide. Report prepared by ESSA Technologies Ltd., Vancouver, BC, Canada. 51 pp.

Daubenmire, R. 1968. *Plant communities: a textbook of plant synecology.* New York: Harper and Row. 300 p.

Eyre, F.H. (Editor). 1980. *Forest cover types of the United States and Canada.* Society of American Foresters, 5400 Grosvenor Lane, Washington, DC, USA. 147 pages.

Hardy, C.; R.D. Ottmar; and R. Burgan. 1995a. A fuel and smoke emissions database for three fire-weather scenarios in the Interior Columbia River Basin. Manuscript. [In preparation.]

Hardy, C.; R. Burgan; and J.P. Menakis. 1995b. Development of a current vegetation map for the Interior Columbia River Basin Scientific Assessment. Manuscript in preparation.

Hungerford, R.D.; Nemani, R.R.; Running S.W.; Coughlan, J.C. 1989. MTCLIM: A mountain microclimate simulation model. Research Paper INT-414. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 52 p.

Hutchins, H.E. and R.M Lanner. 1982. The central role of Clark's nutcrackers in the dispersal and establishment of whitebark pine. *Oecologia* 55:192-201.

Jensen, Mark E.; Patrick S. Bourgeron. 1993. *Eastside Forest Ecosystem health assessment—Volume II: Ecosystem Management: principles and applications.* USDA Forest Service General Technical Report PNW- . 256 p.

Keane, R. and S. Arno. 1993. Rapid decline of whitebark pine in western Montana: Evidence from 20-year remeasurements. *W. Jour. of Applied Forestry* 8(2): 44-47.

Keane, R.E.; P. Morgan; and J.P. Menakis. 1994. Landscape assessment of the decline of whitebark pine (*Pinus albicaulis*) in the Bob Marshall Wilderness Complex, Montana, USA. *Northwest Science* 68(3): 213-229.

Keane, Robert E.; James P. Menakis; Donald Long; Wendel J. Hann; and Collin Bevins. 1995a. Simulating coarse-scale vegetation dynamics with the Columbia River Basin Succession Model—CRBSUM. USDA Forest Service, Gen. Tech. Rep. INT-XXX. (In press).

Keane, Robert E.; James P. Menakis; Donald Long; and Wendel J. Hann. 1995b. Summary of coarse-scale data describing landscape ecological processes in the Interior Columbia River Basin. USDA Forest Service, Gen. Tech. Rep. INT-XXX. (In preparation).

Kendall, K. C. and S. F. Arno. 1990. Whitebark pine—an important but endangered wildlife resource. Proceedings of the symposium: whitebark pine ecosystems: ecology and management of a high mountain resource, March 29-31, 1989, Bozeman, MT, USA. USDA For. Serv. Gen. Tech. Rep. INT-270. Pp. 264-274.

Losensky, B.J. 1994. Historical vegetation types of the Interior Columbia River Basin. Report on file at the Intermountain Fire Sciences Laboratory for completion of RJVA INT-94951-RJVA. 102 p.

Loveland, Thomas R. and Ohlen, Donald O. 1993. Experimental AVHRR land data sets for environmental monitoring and modeling. In: Goodchild, M.F.; Parks, B.O.; Steyaert, L.T. *Environmental Modeling with GIS.* Oxford University Press. New York, U.S.A. Pages 379-385.

Loveland, Thomas R.; Merchant, J.M.; Ohlen, Donald O.; Brown, J.F. 1991. Development of a land-cover characteristics database for the conterminous U.S. *Photogrammetric Engineering and Remote Sensing.* 57(11):1453-1463.

Morgan, P.; S. Bunting; A. Black; T. Merrill; D. Long; S. Barrett; G. Wright. 1995. Fire regimes in the Interior Columbia River Basin: Past and Present. In press in *Proceedings of a Interior Fire Council Meeting "Fire Management Under Fire—Adapting to Change,"* Nov. 1-3, 1994, Coeur d'Alene, ID, USA.

Nobel, I.R. and R.O. Slatyer. 1977. Postfire succession of plants in Mediterranean ecosystems. In: *Proceedings of the symposium Environmental Consequences of Fire and Fuel Management in Mediterranean Climate Ecosystems.* H.A. Mooney and C.E. Conrad, eds. USDA Forest Service General Technical Report WO-3. Washington, DC: 27-36.

O'Hara, K. and P. Latham. 1995. Forest structural stages of the Columbia River Basin. In preparation as a final report.

Oliver, Chadwick D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management* 3:153-168.

Oliver, Chadwick D. and Bruce C. Larson. 1990. *Forest Stand Dynamics.* McGraw Hill, Inc. New York, USA. 467 pages.

Reid, M; P. Bourgeron; H. Humphries; M. Jensen. 1995. Documentation of the modeling of potential vegetation at three spatial scales using biophysical settings in the Columbia River Basin. Report on file at Northern Region Ecosystem Management Project for completion of contract 53-04H1-6890.

Schmidt, W. and K. McDonald, comps. 1990. *Proceedings—Symposium on whitebark pine ecosystems: ecology and management of a high-mountain resource.* USDA For. Serv., Gen. Tech. Rep. INT-270. 386 p.

Shiflet, T.N. (Editor). 1994. *Rangeland cover types of the United States.* Society of Range Management, 1839 York Street, Denver, CO, USA. 151 pages.

Thornton, P.E. and S.W. Running. 1995. Mapping daily surface meteorological variables in complex terrain with MTCLIM-3D. *Journal of Hydrology* (In press).