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Environmental Effects of Postfire Logging: Literature Review and Annotated Bibliography

Technical Editors

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Cover photo: Severely burned stand of subalpine fir/big huckleberry plant association, August 1989, within a month after the Summit fire, Hells Canyon National Recreation Area, Wallowa-Whitman National Forest. Photo by Charles Johnson, Jr.

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Abstract

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The scientific literature on logging after wildfire is reviewed, with a focus on environmental effects of logging and removal of large woody structure. Rehabilitation, the practice of planting or seeding after logging, is not reviewed here. Several publications are cited that can be described as “commentaries,” intended to help frame the public debate. We review 21 postfire logging studies and interpret them in the context of how wildfire itself affects stands and watersheds. Results of this review are summarized in 16 major conclusions at the end of the text, most of which are based on results of no more than a handful of studies. The review is followed by an annotated bibliography and an index. Copies of all papers reviewed here are held by the Blue Mountains Natural Resources Institute, at the Forestry and Range Sciences Laboratory, Pacific Northwest Research Station, La Grande, Oregon.

Keywords: Postfire logging, salvage harvest, fuel, down wood, wildlife habitat, recovery, hydrology, wildfire, habitat structure, literature review.

Introduction

Concerted efforts at fire suppression and preferential harvest of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in the inland West over the past 90 years have led to increased fuel accumulation and continuity over much of the landscape (Agee 1996). Consequently, forest fires have become as common in recent years as they were during early settlement times (USDA 1996b) but larger and more intense, thereby creating periodic abundance of fire-killed trees. On Federal lands, standard policy has been to harvest these trees as quickly as possible to recoup their economic value (USDA 1996a). This logging practice often is called postfire salvage (Gorte 1996, SAF 1995), with the recognition that if trees in burned forests are harvested quickly, some economic value can be salvaged before they decay (Aho and Cahill 1984, Lowell and Cahill 1996, Lyon 1977). Although the term "salvage" is appropriate for operations in which the primary objective of postfire logging is economic, other objectives intended to mitigate frequently observed postfire effects have been followed (for example, fuel reduction and erosion control). For this review, we will refer to the practice as postfire logging, making no assumptions on the objectives for any particular operation or study.

Public debate on postfire logging has intensified in recent years, reaching a crescendo in 1994 with the passing of the "salvage rider" (attached to the Oklahama City Disaster Assistance and Recissions Act, U.S. Congress 1995) which directed Federal land management agencies to accelerate harvest of dead trees (killed by various means) in the Western United States (Gorton and Kays 1996). Furthermore, in the past 20 years, the proportion of timber volume sold by National Forests in Oregon and Washington that was classified as salvage (tree death by any cause) has increased, from about 14 percent from 1980 to 1988 to over 21 percent from 1989 to 1998.[1] Data from the Wallowa-Whitman National Forest of northeast Oregon are even more telling, with salvage making up 70 percent of all volume offered between 1989 and 1998, compared to just 24 percent between 1978 and 1988.[2] Although volumes of timber sold in both green tree and salvage sales for Oregon and Washington have decreased over the last 20 years, green tree volumes have declined to just 4 percent of levels sustained during the early 1980s, compared to 30 percent for salvage sales (see footnote 1). This substantial difference in the slope of the decreasing trends suggests that salvage sales will continue to make up a significant proportion of timber sale programs across the Pacific Northwest for the foreseeable future. Finally, concern over the effects of postfire logging is increasingly evident from extensive public comment received on both the eastside and interior Columbia River basin draft environment impact statements (USDA and USDI 1997a, 1997b).

What kinds of arguments are being used to frame the debate on the practice of postfire logging? Proponents include primarily land managers (agency and industrial), who have used ecological, economic, and administrative arguments to support the practice of postfire logging (table 1). Land managers generally have a strong tendency to do some form of active management after fire. In many cases, they view logging as one component in an array of rehabilitation and restoration techniques, many designed to mitigate adverse environmental effects perceived to be due to the fire itself. A recent example is the effort by the Boise National Forest to rehabilitate and restore lands

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[1] Unpublished data. On file with: Natural Resources, Pacific Northwest Region, USDA Forest Service, P.O. Box 3623, Portland, OR 97208-3623.

[2] Personal communication. 1998. Carla Tipton, timber sales officer, Wallowa-Whitman National Forest, P.O. Box 907, Baker City, OR 97814.

Table 1—Perceived effects of postfire logging

Perceived value	Type of effect	Effect
Positive	Economic	Provides value (and jobs) from salvaged timber.
	Administrative	Salvage harvest provides Knutson-Vandenberg funds that allow for site rehabilitation.
	Ecological	Harvest debris intercepts surface water flow Bole removal prevents drip erosion at base of fire-killed trees Reducing fuel reduces intensity of subsequent fires Removing dead trees slows buildup of insect pests
Negative	Economic	Recreational opportunities are lost
	Ecological logging operations	Increases soil erosion Damages soil and nutrient cycling processes by compaction and displacement Removes valuable nutrients from ecosystem Encourages spread of weeds
	Ecological structural changes	Reduces hiding cover Reduces standing snags for bird and mammal habitat Reduces down woody material as habitat and food source for birds, insects, mammals, and reptiles Reduces woody material for stream habitat

burned in the Foothills fire of 1992. In this case, practices used to mitigate postfire erosion effects included lop and scatter of logging slash (Maloney and others 1995; see also Poff 1989), placement of logs on the contour, and cross-ditching of skid trails. Other positive effects in this context include bole removal to slow drip erosion at the base of fire-killed trees (Poff 1989), timber removal to reduce fuel loads and thereby reduce the intensity of future fires that may occur in the same place (Barker 1989, Kline 1996, Morelan and others 1994, National Commission on Wildfire Disasters 1995, SAF 1996, Stalling 1996, USDA 1993), and removal of dead trees to slow buildup of insect pest populations (Amman and Ryan 1991, Salman 1934, Simon and others 1994). Megahan[3] also has observed that ground disturbance from logging equipment may disrupt water-repellent layers that develop from very hot fires, which may increase infiltration and thereby decrease overland flow and erosion from burned sites. The economic value of fire-killed timber and the Knutson-Vandenberg (KV) funds generated by management on Federal lands can be used to help pay for the total package of restoration and rehabilitation activities (Barker 1989, Thomas 1995, USDA 1996a). From this perspective, salvage logging is viewed as a management tool to be used in the postfire environment, rather than as an activity having negative environmental effects.

[3] Personal communication. 1998. Walter Megahan, principal research scientist, Forest Watershed Program, National Council of the Paper Industry for Air and Stream Improvement, Inc., 615 W Street, Port Townsend, WA 98368.

Opponents of postfire logging argue that the practice causes damage to burned sites as a result of the harvest operations themselves or removes structure that has important ecological functions (Bayles and others 1995, Beschta and others 1995, Minshall and others 1994, Perry 1994) (table 1). In particular, it has been suggested that postfire logging operations exacerbate local or watershed effects induced by fire, such as erosion, nutrient loss, and the introduction of exotic plant species, and that as a consequence, standards and guides should be at least as strict on burned sites as on "green tree" sites (Carter 1992, Frost 1995, Keene 1993, Maser 1996, Peters and others 1996, Wuerthner 1995; also see footnote 3). It also has been argued that the removal of woody structure (both standing and down) eliminates postfire wildlife habitat (Brown 1997, Stone 1993), thereby reducing the habitat value of whole landscapes, of which burned stands are an integral part (Byrnes 1988, DellaSala and others 1995). Axline (1996) suggests that the economic value of postfire logging is tempered by loss of recreational opportunities in forests that have experienced these management activities.

The passage of the salvage rider in 1995 (U.S. Congress 1995) accelerated the debate over postfire logging and led to, among other things, an exchange between a group of scientists concerned about Federal postfire policy and the Forest Service Pacific Northwest Region (Beschta and others 1995, Everett 1995). In their commentary paper to then Regional Forester John Lowe, Beschta and others (1995) argue that the only demonstrated value of postfire logging is economic and that there is no ecological need for immediate intervention after fire. In particular, they argue that no evidence existed to support the claim that removal of dead trees decreased the intensity of future fire on that site (reburn hypothesis), that no management should occur that does not protect sensitive postfire soils, that all large and live trees should be left in burned areas, and that postfire rehabilitation (seeding, planting) should be conducted only under special conditions (for example, highly erodible soils). The gist of their commentary is that the information base on environmental effects of postfire logging is so poor that it would be unwise to apply logging treatments that could compromise future management opportunities. Everett (1995), in fulfilling a request by John Lowe to respond to the Beschta commentary, suggests that although postfire logging should be evaluated case by case, the custodial postfire approach advocated by Beschta and others (1995) would be less desirable because of soil degradation in the absence of seeding and dangerous fuel accumulations in the absence of tree harvest. Everett (1995), however, concurs with Beschta and others (1995) in stating that there is little to no information available to support either the reburn hypothesis or the premise that postfire logging results in no more environmental damage than typical green tree harvest.

Our review responded to the Beschta-Everett exchange by gathering the limited scientific information on postfire logging into one document. Given the intensifying public debate on harvest of fire-killed trees, Federal land managers need the best information available on how postfire logging harvest might be expected to influence ecosystem values, such as soils, streams, and wildlife. This review summarizes available published information, through August 1998, on the environmental effects of salvage harvest of fire-killed forests. Although we recognized that, broadly defined, salvage includes harvest of dead trees killed by any means, we focused this review on logging of fire-killed timber because of the special way in which fire affects soil properties and erosion potential. We also concentrated on the environmental effects of timber removal itself and not on the practice of rehabilitation (planting, seeding) that typically occurs shortly after harvest of trees. Although clearly linked to postfire harvest in practice, rehabilitation brings up a host of additional issues that would have blurred the focus on logging. For information on rehabilitation, the reader should consult other information, such as Berg (1989). Finally, even though we recognized that socioeconomic concerns often drive natural resource issues of themselves, we have covered only literature on the ecological effects of postfire logging.

The geographic scope of this review is the dry, forested intermountain West. Key publications from other parts of North America and from abroad describe work from Florida (Greenberg and others 1994a, 1994b, 1995; Greenberg and McGrane 1996; Greenberg and Thomas 1995), Australia (Lindenmayer and Possingham 1995, 1996; Mackay and Cornish 1982), Israel (Haim and Izhaki 1994), and Portugal (Ferreira and others 1997; Shakesby and others 1993, 1994, 1996; Walsh and others 1992, 1994, 1995), all involving forest types with relatively short fire-return intervals. The assumption was that basic mechanisms behind how landscapes respond to fire and logging will be similar regardless of location. In cases where critical variables may be expected to differ substantially (for example, soils, equipment type), we tried to highlight these in both the text and the annotated bibliography.

The Annotated Bibliography

We collected and annotated documents dealing with the effects of postfire logging, including scientific studies and commentaries. Papers without specific mention of postfire logging are represented only by a citation. Although we included these papers for discussion of management activities in the postfire environment, we felt that their annotation would unnecessarily lengthen the manuscript.

Results highlighted in annotations are pertinent to postfire logging. Because harvest practices and prescriptions have changed substantially over time, we show the dates of actual logging activity and research measurements for each paper. Each study citation includes the location of the study, the forest type, a description of treatments, a list of variables measured, and the results or conclusions of the research.

The information available covers the spectrum of reliability from subjective opinion to replicated and controlled scientific studies. We have included documents of all types and categorized them as either commentary or scientific study. Commentaries were further classified as to source (scientist, manager, or advocate) to help the reader evaluate the basis of experience and perspective of the author. Scientific studies were classified into five categories: replicated experiment, unreplicated experiment, observational, modeling, or review. To be classified as an experiment, a study had to directly impose treatments; observational studies may have compared treatments of various kinds, but their imposition was not under the control of the researcher. Observational studies were further defined as retrospective, correlation, multivariate, or monitoring. For the small subset of experimental studies in which design allowed isolation of the effect of logging (table 2), the abstract from the paper is included as well.

The Literature Review

Although this review includes some unpublished reports, the primary source was the published literature through August 1998. We surveyed the scientific literature on CD-ROM (using Eastern Oregon University and Oregon State University libraries as support), in specific major journals (for example, Western Journal of Applied Forestry, Journal of Forestry, Forest Science, Northwest Science), in major agency publications (for example, research papers and general technical reports of the Pacific Northwest and Pacific Southwest Research Stations), on Internet, and through dozens of contacts with scientists, managers, and citizens interested in the salvage issue.

Table 2—Results of scientific studies that investigated logging effects and structural changes for postwildfire logging[a]

Citation no.	Study type[b]	Date	Location	Veg. type	Treatments	Variables[c]	Result
					Logging effects		
24, 25	Replicated experiment	1993	Central California, Stanislaus NF	Montane conifer	Unlogged Cable logging Tractor logging	Sediment	Increased with logging on steeper slopes but not on gentle slopes.
54	Unreplicated experiment	1970	N.-central Washington	Ponderosa pine-dominated mixed conifer	Control Logged, fertilized, and seeded	Runoff Sediment	Increased after fire and logging. Increased dramatically after fire and logging and is still 8 to 10 times prefire at 7 years.
55	Unreplicated experiment	1970	N.-central Washington	Ponderosa pine-dominated mixed conifer	Control Logged, fertilized, and seeded	Sediment	Increased 100-fold after fire. Increased even more during logging.
						Nutrients	Significant nutrient loss related to debris torrent from riparian areas.
61	Unreplicated experiment	1970	N.-central Washington	Ponderosa pine-dominated mixed conifer	Cable skidding Tractor skidding Skyline Helicopter Tractor on snow (removed all trees ≥20 inches dbh)	Soil disturbance Soil erosion Vegetation cover	Cable>tractor>tractor on snow>skyline> helicopter Cable>tractor>tractor on snow>helicopter Helicopter and tractor on snow preserved most vegetation; skyline and tractor on bare ground were intermediate; cable preserved the least.
67	Unreplicated experiment	1977-79	Australia, eastern NSW	Dry eucalyptus forest	Unlogged Clearcut No fire or logging	Water discharge (peak flow, stormflow vol., annual flow vol.)	Logging and fire (in either order) increased discharge relative to burned only, and to undisturbed. Fire caused moderate increase in discharge over undisturbed.
68	Observation monitoring	1992	Boise NF		Logged	Sediment	No accelerated erosion or sediment transport. Logging increased ground cover. Significant sediment delivery where skid trail crossed class II stream.
69	Observation monitoring	1988-89	Yellowstone NP		Unlogged Logged No fire or logging	Erosion Runoff	Erosion no greater with logging after fire than with fire only. Rate did not differ between glacial till and volcanic soil.
						Organic matter and litter	Logging had little effect compared to wildfire.
89	Modeling	1985	Northern Rocky Mountains	Conifers	Unlogged	Total water yield	Increased after logging in direct proportion to basal area removed.
					Logged (basal area loss 50-100%)	Sediment delivery (mass erosion surface erosion)	Increased with logging, especially for big fires on steep slopes.

Table 2—Results of scientific studies that investigated logging effects and structural changes for postwildfire logging[a] (continued)

Citation no.	Study type[b]	Date	Location	Veg. type	Treatments	Variables[c]	Result
					Structural changes		
14	Unreplicated experiment	1973-74	Prescott NF, Arizona	Ponderosa pine	Unlogged (32% canopy cov., 172 ft^2/acre basal area)	Shrub abundance	More in clearcut than in control. Less in partial than in control.
					Partial cut (22% canopy cov., 97 ft^2/acre basal area)	Sapling abundance	Fewer in clearcut; more in partial cut; most in control.
					Clearcut (2% canopy cov., 3.5 ft^2/acre basal area)	Ground cover	Same result as shrub abundance.
						Bird abundance and diversity	Highest in partial cut but variable depending on foraging guild.
23	Unreplicated experiment	1991-95	NW Montana, Flathead NF—logging Glacier N. Park—unlogged	Mixed conifer	Unlogged (65 ft^2/acre basal area)	Cavity-nesting bird abundance and nest density	More nests in unlogged for 16 of 17 species. Of logged sites, most birds nested only in partial cut. Tree-forager abundance higher in partial cut; mountain bluebird higher in clearcut.
					Partial cut (48 ft^2/acre basal area)		
					Clearcut (13 ft^2/acre basal area)	Nest site features	Flathead NF and Glacier NP very different in tree diameter and species. Flathead nests were in sites with tree diameter significantly higher than random. This difference less for Glacier NP. Stands around partial cuts had basal area and height greater than stands surrounding clearcuts.
50	Replicated experiment	1989-93	Israel	Pine forest	Unlogged	Rodent species composition	Returned to original mix fastest with no harvest.
					Burned trees cut		
					Burned trees cut and debris removed	Rodent species abundance	Variable depending on species.
						Rodent diversity	In short term, highest for burned, no cut. Intermediate term, highest for burned, cut, and leave debris.
52	Replicated experiment	1997	W. Montana, Idaho	Mixed conifer	Unlogged	Nest success	No difference between treatments
					Clearcut	Nest site selection	Depended on species; Lewis' woodpecker and Williamson's sapsucker preferred logged; brown creeper, 3-toed, black-backed woodpeckers preferred unlogged; hairy woodpecker, northern flicker, mountain bluebird, and red-breasted nuthatch showed no preference.
						Foraging site selection	Foraging trees were larger in diameter than nest trees or random.

Table 2—Results of scientific studies that investigated logging effects and structural changes for postwildfire logging[a] (continued)

Citation no.	Study type[b]	Date	Location	Veg. type	Treatments	Variables[c]	Result
56	Replicated experiment	1993-95	NW Montana	Mixed conifer	Unlogged Logged (removed all fire-killed trees >6 inches dbh and >15 feet tall)	Cavity nest abundance	18 species in unlogged; 8 in logged. Nest density higher in unlogged; black-backed and 3-toed woodpeckers, and red-naped and Williamson's sapsuckers present only in unlogged. More nests each year after fire.
						Nest site features	Most species selected larger than average trees.
62, 63	Modeling	1993	Australia	Eucalyptus	Unlogged Clearcut	Survival of Leadbeater's possum	Survival best with no clearcutting. Clearcutting removes hollows. Survival chances better if some unharvested patches are left. Several medium-sized reserves best.
96	Replicated experiment	1994-96	SW Idaho	Ponderosa pine and Douglas-fir	Unlogged Standard salvage (north slope: cut trees >10 inches dbh leaving 6 snags/acre; south slope: cut 2/3 of trees >12 inches dbh) Wildlife salvage (cut half of trees > 12 inches dbh)	Nest density and abundance of cavity-nesting birds	Nest density increased to 4 years postfire. Nest density higher in standard for Lewis' woodpecker, American kestrel, European starling, western bluebird; higher in wildlife salvage for flicker and western bluebird; higher in unlogged for hairy woodpecker and mountain bluebird. Abundance of black-backed woodpecker higher in unlogged; Lewis' woodpecker higher in logged.
						Vegetation	Snag density in unlogged twice that in logged; logged treatments had same snag density; shrub density same all treatments.
						Nest site features	All species chose tree density higher than random; Lewis' woodpecker and flickers chose sites with larger adjacent trees; black-backed woodpecker chose smallest average diameter nest trees.
100	Replicated experiment	1993-94	Central Idaho	Ponderosa pine	Unlogged Logged (reduced canopy cover from 13.5 to 5.3%—tractor logged over snow; helicopter on steep)	Vegetation biomass	Logging reduced forbs, shrubs, and grasses first 2 years.
						Species diversity	Logging decreased plant species richness slightly; exotics increased slightly.
						Pine and shrub growth	Lower in logged areas.
						Soil moisture (% by wt.)	Little difference.
112	Replicated experiment	1989	NW California	Douglas-fir/ hardwood	Unlogged Cable logged, planted	Shrub cover	Higher on unlogged than on logged at both 1 year and 11 years after logging.
						Forb cover	Higher in unlogged at 1 year. Higher in logged at 11 years.
						Ferns and grasses	No difference.
						Hardwood cover	No difference at 1 year. Higher on logged sites 11 years after logging.
						Conifer cover	No difference at 1 year. Small component in logged site 11 years after fire, but more than in unlogged.

[a] Only those studies were selected where harvest effect could be isolated.
[b] For definition of study type, see text.
[c] Table includes all variables reported for the study even if no difference was reported.

We found only 14 studies that isolated the actual effect of logging of burned timber compared to an unlogged control (table 2). Because available information on postfire logging is so sketchy, we therefore felt the need to augment the review with a brief summary of wildfire effects on forests of the interior Western United States. Our hope is that insight gained from this approach, together with the relatively scarce information on logging of burned timber, will allow the reader to make some inferences on how we might manage forests that have experienced severe wildfire.

General Effects of Wildfire

The effect of wildfire on forest ecosystems of western North America has been relatively well described. Numerous studies document how wildfire changes properties of the soil, which leads to changes in hydrology, erosion rates, stream characteristics,and vegetation regrowth. Other studies describe how fire removes or kills vegetation and reduces downed wood, thereby changing habitat for both terrestrial and aquatic organisms. In the following summary, we present highlights of the best documented fire effects in Western United States forests. Our focus was to describe ecological responses to the more intense wildfires, as these create the conditions that traditionally have attracted logging activity.

When wildfire sweeps across a landscape, the most conspicuous result is dead or dying vegetation, particularly trees. Although extremely intense forest fires potentially can consume all aboveground biomass, normally a much lower percentage of vegetative biomass is consumed, even in stand-replacement fires (Agee 1993). Working in forest dominated by Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) in western Washington, Fahnestock and Agee (1983) found that after a fire that had more than a 3-meter flame length, only 5 percent of stems were consumed, compared to 10 percent of branches, 100 percent foliage, 75 percent vegetation, 20 percent snag and downed logs, and 80 percent forest floor. The distribution of consumption among various vegetative and woody components obviously will differ among burned sites, depending on variables including fire intensity, topography, fuel moisture, stand composition, and structure. Likewise, whether plant death occurs depends on the above variables, as well as on species composition and stem size and age. Age-specific differences in fire-induced mortality among individual trees can reflect at the population level, producing stands that have more uniform age distributions (Muir 1993). These conspicuous effects not only reflect the loss of vegetation and down woody material, but they also signal a change in habitat for plant and animal species, and a change in the underlying soil properties that support plant succession.

Trees killed by wildfire and left standing can provide significant shade, which can slow the heating of surface waters and the soil surface (Amaranthus and others 1989) and thus modify surface microenvironmental conditions. These trees also may represent an important source for recruitment of large woody debris into streams. Dead trees attract a wide variety of bark beetle species (Amman and Ryan 1991, Salman 1934), which can build up large populations that serve as a source for infestation of adjacent green tree stands, particularly in stands dominated by Douglas-fir (Bedard 1950, Scott and others 1996) and spruce (*Picea* sp.) (Scott and others 1996). Increased abundance of certain insects in burned stands tends to attract insectivorous birds, especially those preferring more “open” habitats (Blake 1982, Sallabanks and McIver 1998, Taylor and Barmore 1980). As a consequence of changes in food composition and breeding habitat, burned forests typically support significantly different bird communities, with many species dependent on stand-replacement fires to maintain adequate subregional-scale metapopulation sizes (Hutto 1995). Compared to unburned forests, the complexion of bird communities in the postfire environment may differ as a consequence of body size (Bock and Lynch 1970), feeding guild (Hutto 1995, Lyon and Marzluff 1985, Sallabanks and McIver 1998), or nesting type (Hutto 1995), with species composition typically reflecting an increase in cavity-nesting, aerial-feeding specialists, such as woodpeckers and flycatchers.

Similarly, mammal species composition is altered by wildfire, with the complexion of mammal communities dependent to a large extent on successional stage (Gruell 1980). Deer and elk are typically attracted to burned areas, especially after some vegetative regrowth has occurred (Campbell and others 1977, Davis 1977, Grifantini and others 1991). Small mammals show a wide variety of responses, with "edge" species typically increasing, and deep forest species decreasing (Campbell and others 1977, Haim and Izhaki 1994). Similar patterns of species compositional shifts owing to fire have been reported for marsupials (Lindenmayer and Possingham 1995, 1996), reptiles (Greenberg and others 1994a), and arthropods (Fellin 1980, Greenberg and McGrane 1996; Neumann 1991, 1992). All these studies show that wildfire, like any other significant macroenvironmental effect (including management practices), will favor some species and eliminate others within any given taxonomic group; the presence of a full historical mix of species across the landscape depends ultimately on disturbance that occurs in a shifting mosaic over space and time.

Finally, stand-replacement fire restarts the plant successional process at any of several earlier developmental stages, and so the immediate postfire environment is only transitory. The extent to which plant and animal species use postfire environments depends on both their colonization ability and the suitability of the habitat at various times postfire. The species composition of bird communities, for example, may be altered first by a fire, then by development of a shrub stage, and then by succession of a young tree community (Bock and Bock 1977). Similarly, Grifantini and others (1991) show that deer habitat changed significantly from 2 to 12 years postfire, largely because of successional changes in forbs, grasses, and shrubs (particularly deer brush [*Ceanothus integerrimus*]).

The conspicuous patterns of vegetation and woody structure that fire causes are accompanied by equally significant effects on soil properties (Wells and others 1979). Although Parks and Cundy (1989) found only slight effect, others have found that severe fire tends to render soils water repellent (Campbell and others 1977, DeBano 1989, Nasseri 1989, Shakesby and others 1993), primarily through the burning of organic matter, which leads to reduction of macropore space that water can infiltrate, and the condensation of waxes and resins that accumulate on cooler soil particles (DeBano 1991). Water repellence is directly proportional to burn intensity in both the thickness and depth of the repellent layer. In severe burn situations, water repellence can reduce the hydrological soil depth from several feet to a few inches (see footnote 3). Furthermore, decreased evapotranspiration rates owing to tree death leave postfire soils more saturated and less able to accept water from big precipitation events. The result is increased overland flow capable of carrying more sediment (Walsh and others 1992), particularly if more than half the leaf area is destroyed (Potts and others 1989) and therefore able to cause much more erosion (Connaughton 1935). In general, when overland flows increase, erosion potential remains high in postfire watersheds for a greater distance compared to unburned watersheds, to the extent that surface features (vegetation, down wood) that would impede flows are burned off by the fire (Mackay and Cornish 1982). In addition, fire almost always results in loss, redistribution, or alteration of nutrients (Hungerford and others 1991) through volatilization (Campbell and others 1977, DeBano 1991, Grier 1975), leaching (Grier 1975, Helvey and others 1985), or intense heating (Ulery and others 1996). Changes in nutrient regimes can then significantly affect site productivity (Grier 1975, Harvey and others 1980, Hungerford and others 1991, Stark 1980). Overall, intense wildfire tends to increase the sensitivity of sites to further soil disturbance (Helvey 1980, Morris and Moses 1987).

Lotic ecosystems within burned areas typically exhibit parallel responses to intense wildfire, including loss of woody debris, increased sediment and nutrient transport, increased water temperature, changes in magnitude and timing of peak flows (Campbell and Morris 1988, Helvey 1972), and decreased habitat diversity (Gresswell 1999, Minshall and others 1997). These changes can be critical for salmonids, because increased sediment fills in spawning habitat (Minshall and others 1989, Tagart 1976), increased temperature kills fish (Rieman and others 1997), and loss of large woody debris decreases pool habitat for holding and rearing (Gresswell 1999, Minshall and others 1989). In general, aquatic recovery parallels forest succession after intense wildfire (Minshall and others 1989), and a mosaic of postfire conditions within a watershed likely will contribute to fish recovery (Gresswell 1999, Rieman and Clayton 1997). In a review on fire and aquatic ecosystems, Gresswell (1999) points out that native fish populations of the Columbia River basin evolved within the context of widespread, periodic disturbance like fire, and are thus adapted as populations to local extinctions or declines. Historic native fish metapopulations however, have experienced severe human-caused stress over the past 150 years, making them unusually vulnerable to periodically intense disturbances such as fire. In general, Gresswell (1999) suggests that because fire occurs within a context of various human-caused influences (logging, grazing, fire suppression effects, chemical retardants, fire lines, seeding, etc.), understanding fire effects requires studies conducted in a systems context, involving both terrestrial and aquatic components. Reeves and others (1995) further state that long-term survival of anadromous fish populations will be more likely if managers recognize the dynamic nature of disturbance regimes that create and destroy salmonid habitat and then work to design management strategies that can achieve characteristics of those disturbance regimes.

Postfire Logging

We found only 21 studies worldwide that examine the environmental effects of postfire logging. Seven of these were “management experiments,” in which the effects of various management treatments are compared without an unlogged control (Campbell and others 1977, Greenberg and others 1994b, Maloney and others 1995, Neumann 1991, Poff 1989, Shakesby and others 1994, Smith and Wass 1980). The lack of control in these studies is understandable because in most cases managers have a tendency to apply some form of treatment to all the acreage having a particular postfire condition; unlogged controls rarely are planned. Even though these studies are useful for comparing treatments having a range of potential environmental effects, only studies containing an unlogged control can be used to assess the effect of the treatment in isolation. We found only 14 such studies in the literature; they measure variables ranging from sediment yield to wildlife (table 2). In addition, of these 14 studies, only 7 were replicated experiments, which would allow inferences made in a study at one location to be generalized to other similar biophysical types. In the following discussion, we will present a review, organized by subject area, of the postfire logging studies.

Two distinct types of environmental effects occur after a harvest operation: activity effects owing directly to the logging itself, and structural effects from removal of merchantable material. The activity effects of greatest concern include soil disturbance, erosion, sediment yield, and water yield. Generally, data on activity effects of postfire logging are scanty and uneven, in part because few studies have been done and also because of the inherent difficulties in studying soil, sediment, and hydrological effects in the postfire environment. We will first discuss information available on activity effects of postfire logging and finish with a review of the implications of structural change.

Logging Activity Effects

The extent to which logging exacerbates soil, sediment, and hydrological problems in postfire landscapes will depend on site characteristics, site preparations, logging method, and whether new roads are needed. Of these, road building and continued use of roads are probably the biggest potential contributors to postfire erosion, just as they are in green tree stands (Megahan 1980). For green tree stands, for example, Megahan (1971) estimates that 90 percent of accelerated sediment transport in a logging operation is caused by road building. Beschta (1978) reports that midslope roads on steep terrain are the primary contributors to increased sediment production during logging operations in the Oregon Coast Range. Swank and others (1989) estimate that while erosion owing to timber harvesting was 7 times that of undisturbed areas, erosion rates on landings and roads were 100 times those of undisturbed areas. Similarly, Megahan and Kidd (1972) estimate that erosion rates in stands subjected to timber removal by ground cable logging increased 1.6-fold over undisturbed stands, compared to a 220-fold increase due to logging roads. The continued use of even well-constructed gravel roads can contribute substantial amounts of sediment compared to undisturbed areas (Reid and Dunne 1984). Although we could find no studies that looked at the effects of postfire road building and use per se, it is likely that roads will contribute most to sediment production in the postfire environment, just as they do in unburned stands.

Site characteristics will generally have a profound influence on whether significant sediment is produced by a logging operation. The WRENS model described by Potts and others (1985) suggests that sediment and water yields increase with catchment area and slope in logged postfire landscapes. Working on eucalyptus-dominated forests of southeastern Australia, Mackay and Cornish (1982) note that catchment area is an important variable in predicting the extent of postfire overland flow and that postfire logging can increase these flows, primarily via skid trails. Within the Stanislaus complex burn of 1987 (California), Chou and others (1994a, 1994b) measured generally higher sediment yields in harvested postfire stands that had greater slopes. Working in loblolly pine (*Pinus taeda* L.) stands with 10 to 16 percent slopes, Van Lear and others (1985) measured significantly higher sediment yields after prescribed fire, then clearcutting and skidding, compared to nonharvested controls. They describe the skid trail patterns as dendritic and suggest that much of the erosion and sediment transport was associated with these skid trails. Interestingly, they describe the fourfold increase in sediment yield in harvested stands (over nonharvested controls) as relatively benign, compared to sediment yields typically caused by more aggressive mechanical site preparation techniques, such as disking. They also observed sediment yield increases to be short term, with yields in two of the three harvested watersheds having returned to preharvest levels after 3 years; the third watershed had longer channel degradation and was still in the process of recovery when the study ended. Similar recovery rates were reported by DeByle and Packer (1972), who observed short-term increases in sediment yield after clearcutting and burning in western Montana, with a return to premanagement conditions after 4 years. Finally, very hot fires on coarse soils will tend to produce conditions more conducive to erosion, leading to increases in sediment and water yields (Megahan and Molitor 1975), primarily because of the increased probability that water-repellent soils will be formed under these conditions.

Site preparation for regeneration can itself have considerable effect on sediment losses in postfire environments. A rather extreme example of management-induced erosion is the practice of rip-plowing for postfire site preparation in dry forests of Portugal. Rip-plowing to prepare sites for eucalyptus seedlings caused soil losses exceeding 100 times background level, and watersheds sustained significant losses for up to 7 years postfire (Shakesby and others 1994), compared to 3 to 4 years for unplowed burned sites (Shakesby and others 1993). Tillage for planting of pine also can increase sediment transport (Walsh and others 1995), thereby creating a second pulse of high erosion after the initial increase from fire. Although site preparation practices such as ripplowing and tilling are unlikely to be applied in postfire watersheds in the Western United States, soil loss and erosion resulting from such practices emphasize the sensitive nature of postfire soils.

The effect of postfire logging on sediment production also depends on logging system type and the extent to which logging residue remains on a site. Like operations in green tree stands, ground-based logging can be expected to cause significant soil disturbance in the postfire environment. Logging practices, including cutting and log retrieval technologies, have differed widely over the years and across regions (table 3). Of the eight postfire studies that report logging practices, four used ground-based skidding only, one used cable skidding only, and three used a combination of systems, depending on slope and soil condition. The kind of practice used in any given project will depend on several factors: (1) slope, (2) soil conditions, (3) perceived ecological sensitivity, (4) value of merchantable material, and (5) available equipment. On Federal lands, to the extent that a timber sale is the instrument used to accomplish management objectives, the harvesting economics of postfire logging likely will dictate to a great extent not only the practices used to extract timber but also the prescriptions actually implemented.

There is very little information available on soil and erosion effects of different logging systems. It is likely, however, that ground-based skidding will have relatively greater effect than aerial systems. Although ground disturbance produced by logging operations may disrupt water-repellent layers and thus decrease overland flow during severe hydrological events (see footnote 3), in most cases managers have sought to limit such ground disturbance in postfire stands. Mackay and Cornish (1982), working on sites with coarse-grain granitic soils in southeastern Australia, measured 12 percent severe soil compaction and 24 percent moderate compaction in postfire units where logs were retrieved with conventional rubber-tired skidders. They attribute at least some of the increased overland flow they measured to logging and suggest that skid trails decreased infiltration rates (through soil compaction) and changed surface features, which increased the speed that overland water moved across the site. However, they attribute most of the increases in peak flows and overland flows to decreases in transpiration rates in the postfire environment, a conclusion illustrating the difficulty in distinguishing between erosion due to logging and that from the fire itself. How does ground-based log retrieval compare to aerial log retrieval in the postfire environment? Working on the Entiat burn of 1970 (Wenatchee National Forest), Klock (1975) and Helvey and others (1985) compared five different log retrieval systems (after hand felling) with respect to

Table 3—Harvest dates, methods, prelogging structures, and prescriptions in 20 postfire logging studies

Citation no.	Harvest date	Harvest method	Structure before harvest	Prescriptions
105	1960	Ground-based skidding	NA	Clearcut
54, 55, 61	1971-73	Tractor skidding on <30% slope (or 40% on snow); cable yarding; helicopter >40%; seeded, fertilized	NA	Cut all ≥2 feet dbh (8600 board ft/acre removed)
20	1971-75	NA	Mod. fire 103 ft^2/acre basal area Severe 40 ft^2/acre basal area	Harvested most of killed trees Moderate fire: removed 7% of sawtimber Severe fire: removed 50% sawtimber
14	1973-74	NA	172 ft^2/acre basal area 32% canopy cover	Partial cut: 3.5 ft^2/acre basal area; 22% canopy cover Clearcut: 2% canopy cover
67	1977-79	Rubber-tired skidders	NA	Clearfelling with stream buffers
47, 48, 112	1977, 1987	Cable logging	NA	Clearcut
83, 84	1982-85	NA	NA	Large logs removed
88	1988	Rubber-tired skidders	NA	Removed all material ≥3 inches dbh
69	1988-89	NA	NA	NA
50	1989-93	NA	NA	Cut all burned trees and left debris—or Cut all trees and cleared
23	1990-94	NA	65 ft^2/acre basal area	Partial cut: 48 ft^2/acre basal area Clearcut: 13 ft^2/acre basal area
40, 41, 42, 43, 44	1991-93	NA	NA	Clearcut
68	1992	Ground-based skidders	NA	NA
101, 102	1992-94	NA	NA	Clearcut
24, 25	1993	Cable logging >33% slope; tractor logging < 25% slope	N/A	Removed fire-killed trees

Table 3—Harvest dates, methods, prelogging structures, and prescriptions in 20 postfire logging studies (continued)

Citation no.	Harvest date	Harvest method	Structure before harvest	Prescriptions
62, 63	1993	NA	NA	Clearfelling
56	1993-95	NA	Avg. 12 inches dbh Avg. 53 feet tall Avg. 8 inches dbh 138 trees/acre 4-16 inches dbh 9 trees/acre>16 inches dbh	Removed all fire-killed trees >6 inches dbh and > 15 feet tall Structure after harvest: Avg. 41 feet tall 53 trees/acre 4-16 inches dbh 0.2 trees/acre >16 inches dbh
100	1993-94	Ground-based over 2 feet of snow; helicopter on steep	13% canopy cover	Cut all trees > 7 inches dbh leaving 4/acre Structure after harvest: 5% canopy cover
96	1994-96	NA	33 snags/acre 9-20 inches dbh 7 snags/acre > 20 inches dbh	Standard=north slope: cut trees >10 inches dbh, leave 6 snags/acre south slope: cut two-thirds of trees >12 inches dbh; snag retention met in 33% not harvested Wildlife prescription=cut half of trees >12 inches dbh; snag retention met in half not harvested
52	1997	NA	NA	Clearcut

NA=not available.

soil disturbance and erosion: tractor skidding over bare ground (<30 percent slope), tractor skidding over snow (<40 percent), cable skidding over bare ground, skyline (Wyssen skycrane[4]), and helicopter. The study area had slopes averaging 50 percent, but slopes of 90 percent were common. Soil depths ranged from a few centimeters to over 6 meters and were formed from weathered grandiorite colluvium covered by volcanic ash and pumice. Vegetation type was ponderosa pine at lower elevations to Douglas-fir at higher elevations. Klock (1975) found that tractor skidding over bare ground caused the greatest percentage of area of severe soil disturbance (36 percent), followed by cable skidding (32 percent), tractor skidding over snow (9.9 percent), skyline (2.8 percent), and helicopter (0.7 percent). The presence of erosion and sediment transport paralleled soil disturbance, with the highest percentage of erosion occurring in the cable skidding units (41 percent), followed by tractor skidding over bare ground (31 percent), tractor skidding over snow (13 percent), and helicopter (3.4 percent). Relative sediment yield increases also were generally higher in logged watersheds, compared to the single unlogged control (Helvey and others 1985). Two complicating factors behind these numbers, however, are the effects of different slopes among systems and the contribution of road building. In particular, because cable skidding occurs on steeper ground than tractor skidding, the measure of erosion potential is likely to be an overestimate. Further, a total of 15.3 kilometers of roads were built to facilitate the logging operation, and when this area is added to the area disturbed by log retrieval within harvest units, severe soil disturbance rises to greater than 50 percent in some units. Klock (1975) also mentions that warm temperatures in March 1972 caused intense erosive conditions at low elevations, particularly near roads. One can infer from the comparison of helicopter to ground-based systems, that postfire logging caused significant soil disturbance (>30 percent area disturbed) and substantially increased erosion potential (>30 percent) and sediment yield when traditional ground-based log retrieval systems were used. When compared to studies conducted on similar systems in green-tree stands, soil disturbance was generally higher for Klock’s study, particularly for cable skidding, probably because of the lack of understory vegetation and litter that was burned by the Entiat fire.

Although logging (particularly ground-based) can have significant effects on sediment yields in postfire watersheds, logging residue can mitigate some of these effects. Shakesby and others (1996) show that eucalyptus logging litter reduced soil loss in postfire watersheds by up to 95 percent. In a similar vein, Megahan and Molitor (1975) recommend that managers delay postfire logging until needle fall (for those burned stands in which most trees still possess needles), so that the forest floor will gain some additional protection from erosion due to excess overland flow.

Finally, the studies of Chou and others (1994a, 1994b) illustrate some of the challenges faced in measuring short-term logging effects in a postfire environment. After the Stanislaus fires of the central Sierra Nevada (1987), 22 experimental units of between 2 and 4 hectares were randomly selected out of 50 units available and categorized as cable logged on steep slope (>35 percent), unlogged steep slope, tractor logged on gentle slope (<25 percent), and unlogged gentle slope. Logging effects were estimated

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[4] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

by measuring sediment yield with dams and by estimating the percentage of area disturbed within each unit by aerial photos. Despite measuring averages of 35 percent and 18 percent of area disturbed for tractor- and cable-logged units, respectively, Chou and others (1994a) detected no difference in sediment output between logged and unlogged units, largely because of considerable among-unit variation, and because sediment contributed by logging was overwhelmed by sediment produced as a consequence of the fire itself. At least part of the among-unit variation was due to variability in the way that the logging was undertaken, in terms of timing, intensity, and spatial distribution. This study suggests that distinguishing sediment yields due to logging from those due to the fire itself will require not only replication and control at the unit level, but also careful control of logging activities within units. One can see why such studies are rare, especially those conducted in an operational context.

In reviewing the few studies that looked at postfire logging effects on vegetation, we found that most logging operations typically occur before the next crop of young trees becomes established. If logging occurs after seedling establishment, significant seedling mortality can occur. Roy (1956) reports that 75 percent of established seedlings were killed in a single postfire logging operation and suggests that earlier and more careful logging could substantially reduce seedling losses. Normally, postfire logging is undertaken before seedling establishment, and the most immediate effect is removal of large woody structure (both living and dead) from the site. In this review, we regarded the removal of large-diameter material as a treatment effect, rather than a response to treatment. Various treatments were applied in the studies we surveyed, from clearcutting to partial removal, with the latter usually focusing on the larger, more merchantable material (table 3). Of the 20 studies from which we could extract information on prescription, 9 included a clearcutting prescription, 6 specifically mentioned removal of the largest diameter trees, and 4 reported removal of all fire-killed trees. The prescriptions actually carried out depended on conditions specific to each project, including (1) postfire stand structure, (2) the number of trees damaged or killed, and (3) logging practices (cutting and log retrieval systems). In only four studies (Blake 1982, Caton 1996, Hitchcox 1996, Saab and Dudley 1998) was there evidence that prescriptions were applied in accordance with research needs; in all others, researchers appeared to develop their studies within the context of standard management protocols. Overall, it is clear that prescriptions, like practices, have over the years become more sensitive to ecological resources, a pattern probably also apparent for green tree logging.

Postfire management can influence nonmerchantable vegetation directly by physically altering plant structure or indirectly through site preparation. The studies of Grifantini (1990) and Stuart and others (1993) show that shrubs and forbs were suppressed for several years in postfire logged units, but the units also were broadcast burned after logging. Obviously, when treatments involve logging as well as other site preparation measures, it is impossible to distinguish the specific causative factor behind any observed vegetation change. Nonetheless, it is interesting that Stuart and others (1993) also found more hardwood cover in their postfire logged and burned treatments, relative to postfire unlogged controls, and that these hardwoods inhibited establishment and growth of Douglas-fir seedlings. More conclusive evidence that logging itself can directly influence vegetation was reported by Klock (1975), who found that ground-based log retrieval (skidding) results in significantly greater areas of bare ground, relative to helicopter, skyline, and skidding over snow systems. Greenberg and others (1994b) suggest that vegetation removal and soil disturbance caused by postfire logging could have encouraged colonization of several native ruderal plant species in their study on Florida scrub pine. Their inference is based on comparison of plant species composition in the postfire logged sites with other studies of postfire unlogged sites nearby (Abrahamson 1984). Working in Douglas-fir-dominated stands of western British Columbia, Smith and Wass (1980) measured a general decrease in plant growth on skid trails formed in the postfire environment, but the effect ranged from a reduction of 14.5 percent to an enhancement of 3.6 percent. Evidence that logging can affect vegetative production in the absence of significant ground disturbance was collected by Sexton (1994) in a study in central Oregon in postfire ponderosa pine stands, logged over snow. Sexton found that biomass of vegetation produced 1 and 2 years after postfire logging was 38 percent and 27 percent of that produced in postfire unlogged stands. He also found that postfire logging decreased canopy cover, increased exotic plant species, increased graminoid cover, and reduced overall plant species richness. Interestingly, pine seedlings grew 17 percent taller on logged sites in this short-term study.

Structural Change From Logging

The removal of merchantable material from a logged postfire site will be expected to affect habitat for certain species of wildlife and reduce intermediate-term fuel loadings. A number of studies of logging effects in unburned forests have shown that, to the extent that logging removes large woody structure, bird species composition will tend to shift from forest toward “open” species (Blake 1982). Similar changes in species composition have been observed in logged postfire forests, reflecting the effects of large woody debris removal on both foraging and nesting habitat, particularly of cavity-nesting species (Caton 1996, Hejl and McFadzen 1998, Hitchcox 1996, Saab and Dudley 1998). Even though these four recent studies all demonstrate species-specific response of cavity-nesting birds to postfire logging, the pattern of response differed somewhat by locality. For example, of the four species monitored by all four studies, only the black-backed woodpecker (*Picoides arcticus*) showed a consistent response to logging, with significantly more nests found in unlogged sites. Three studies observed nests of hairy woodpecker (*Picoides villosus*) and mountain bluebird (*Sialia currucoides*) more often in unlogged sites, while Hejl and McFadzen (1998) observed no preference. Similarly, three studies observed northern flicker (*Colaptes auratus*) nests more often in logged sites, and Caton (1996) observed them more often in unlogged sites. Of the four species monitored in three studies, only the three-toed woodpecker (*Picoides tridactylus*) was observed to consistently nest more often in unlogged sites; the American kestrel (*Falco sparverius*), European starling (*Sturnus vulgaris*), and red-breasted nuthatch (*Sitta canadensis*) showed variable responses. Of the seven species monitored in two studies, five showed consistent nesting preference for unlogged sites (red-naped sapsucker [*Sphyrapicus nuchalis*], downy woodpecker [*Picoides pubescens*], tree swallow [*Tachycineta bicolor*], mountain chickadee [*Parus gambeli*], house wren [*Troglodytes aedon*]), one species was split (Williamson’s sapsucker [*Sphyrapicus thyroideus*]), and one species showed consistent preference for logged sites (Lewis’ woodpecker [*Melanerpes lewis*]). Some of this variation in response to logging in these cavity-nesting bird species might be explained through the mechanisms behind nest site choice and nesting success. One of the mechanisms behind nest site preference seems to be tree diameter, with all four studies observing that nest trees were generally larger in diameter compared to randomly selected trees. Other potential mechanisms are the availability of large trees for foraging in the same or adjacent stands (Caton 1996, Saab and Dudley 1997, Hejl and McFadzen 1998), and higher tree densities in the vicinity of nest trees (Saab and Dudley 1997). In addition, features idiosyncratic to particular sites (for example, surrounding landscape characteristics, presence of hardwoods in the study area), biogeography, and history may explain portions of the variation in response to postfire logging. Finally, only one study attempts to measure productivity of these birds (Hejl and McFadzen 1998), and so far, no difference has been observed for any species relative to logging treatment. Overall, despite some variation in the pattern of individual species response, many cavity-nesting birds are attracted to postfire environments and clearly are affected by the removal of large structure through logging activities. If managers want to maintain healthy metapopulations of these birds, prescriptions that preserve sufficient nesting and feeding habitat are necessary.

When the response of whole bird communities to postfire logging are examined, more variable results typically have been obtained. Greenberg and others (1995), working in the sand pine shrub of Florida, found migratory breeding birds, canopy- and cavity-nesting birds, and bark-foraging birds only in mature forest and lacking in forests that had experienced green tree or postfire clearcut logging. No differences among treatments were observed in winter resident birds, and open shrub species were found in disturbed treatments only, suggesting that silviculture mimicked fire in this case. The study did not contain a postfire unlogged control, however, and it therefore is not possible to assess whether fire or logging caused the observed differences. In ponderosa pine forests of Arizona, Blake (1982) found that nonbreeding birds respond primarily to the openness of habitat, whether this was caused by clearcutting or fire. His census data also show that even though species richness was generally higher in unburned sites, bird species composition among sites was related to season and to foraging substrate availability, the latter substantially influenced by disturbance.

Studies on the effect of postfire logging on other vertebrate and invertebrate species generally show that removing large forest structure shifts species composition to species preferring more open habitat. Grifantini and others (1991) observed that hiding cover for deer decreases when postfire stands are logged and broadcast burned, primarily as a result of suppression of shrub cover. In their work on small mammals of pine forests in the eastern Mediterranean, Haim and Izhaki (1994) observed that fire eliminated three species of arboreal mammals and that postfire logging renders burned sites more xeric, thus delaying succession of the forest plant community and the concomitant return of arboreal mammal species. Nonarboreal small mammals, however, replaced the arboreal species in postfire logged and unlogged forests for several years. In an extreme case, postfire logging is identified as a major contributor to the rarity of the endangered Australian Leadbeater's possum (*Gymnobelideus leadbeateri*), primarily because of wholesale conversion of large-structure, forested habitats to more open, earlier successional habitats (Lindenmayer and Possingham 1995). The Leadbeater's possum is typically an old-growth species that uses hollows in large fire-killed trees as nesting and resting habitat. Consequently, survival and reproduction of this species is significantly higher in burned, unlogged stands. Population viability analysis shows that this species likely will go extinct because of the lack of large-diameter trees, that current patterns of removal of fire-killed trees significantly increases the probability of extinction, but that retention of some unharvested patches would allow local populations to persist indefinitely (Lindenmayer and Possingham 1996). Similar patterns of change in species composition after fire and logging have been observed for reptiles and ground-dwelling arthropods in Florida sand pine shrub (Greenberg and others 1994a; Greenberg and McGrane 1996) and for ground-dwelling arthropods in Australian eucalypt forests (Neumann 1991). Of particular interest is the significant increase in seed-harvesting ants after fire and logging in Australia (Neumann 1992), showing that shifts in ecological function accompany changes in species composition, which in turn are due to the habitat alterations caused by disturbance. Greenberg and Thomas (1995) also observed no differences in beetle assemblages among unburned and three clearcut treatments 5 to 7 years postfire, suggesting that species composition may have recovered in that period of time.

In general, one would expect that the optimal habitat for any given species would occur as a "shifting mosaic" over time for whole landscapes, with disturbance constantly resetting portions of various sizes. This concept of metapopulation dynamics has led some wildlife biologists to suggest that a prudent postfire management strategy would be to use a variety of different treatments (including no treatment at all) and to disperse treatments at various scales, from stand (Hutto 1995, Saab and Dudley 1997) to landscape level (Grifantini and others 1991, Lindenmayer and Possingham 1996).

One of the ecological effects of postfire logging most commonly mentioned as positive is reduction of large woody fuel, which is thought to reduce the intensity of a reburn occurring on that site in the intermediate term (Poff 1989). Following Beschta and others (1995) and Everett (1995), we found no studies documenting a reduction in fire intensity in a stand that had previously burned and then been logged. Although fuel accumulations owing to spruce budworm-caused (*Choristoneura fumiferana* [Clem.]) tree death can result in unusually severe wildfires (Stocks 1987), there is no similar information on stands killed by wildfire. In general, logging of large-diameter material in green tree stands will lead to decreases in total fuel accumulations over the intermediate term but increases in fine activity fuels over the short term (Brown 1980). Logging in postfire stands, however, would be expected to produce less fine activity fuel because the fine material burned, and one would expect removal of large-diameter material to have an intermediate-term effect similar to green tree stands. Retrospective studies that look at twice-burned stands in which different levels of fuel reduction were undertaken after the first fire would possibly shed light on the issue of postfire logging, fuel reduction, and reburn intensity.

Conclusions

We are confident that most major studies published in the primary literature are presented here, and from this it is clear that information on the environmental effects of postfire logging is scanty at best. Only 21 major studies have examined the wide range of potential effects of postfire logging, and yet this practice is likely to increase in relative importance, at least in federally managed forests. From these 21 major studies, and the available information on the effects of wildfire itself, we can list the following environmental effects likely to occur when intensely burned sites are logged:

1. Intense wildfire causes significant and fairly predictable changes in soil and vegetation structure, which often lead to catastrophic erosion (Campbell and others 1977, DeBano 1991, Durgin 1985, Megahan and Molitor 1975). Accelerated erosion usually is associated with increases in overland flow that result from decreases in infiltration (Helvey 1980). In turn, limited infiltration is generally caused by fire-induced water repellence of the soil and by decreased evapotranspiration in the tree-killed stand (Helvey 1980, Mackay and Cornish 1982, Marston and Haire 1990). These studies support work in unburned watersheds suggesting that postfire logging associated with road building, conducted with ground-based log retrieval systems, or undertaken in stands having steep slopes and sensitive soils likely will have the greatest potential for exacerbating the erosional problems typically observed in burned watersheds.

2. The scope and scale of immediate environmental effects of management in the postfire environment depend on several specific features of burned stands, including the intensity of the burn, slope, soil texture and composition, the presence or building of roads, and postfire weather conditions. Activity effects of logging systems occur within the context of these site-specific factors (Chou and others 1994a, 1994b; Potts and others 1985).

3. Log retrieval systems differ substantially in their immediate effect on soils in the postfire environment, in ways similar to those observed in green tree stands. In general, ground-based skidding causes the greatest immediate soil effect, followed by skidding over snow, skyline, and helicopter retrieval (Klock 1975).

4. Proper recovery and rehabilitation techniques by managers may be capable of mitigating soil loss and erosion problems associated with postfire logging (Simon and others 1994). For example, ground disturbance caused by postfire logging could disrupt water-repellent layers, increase infiltration, and thus decrease overland flow and sediment transport to streams (see footnote 3), which could be a benefit during severe hydrological events. This hypothesis, however, has not been tested experimentally.

5. Logging residue can decrease erosion in postfire logged sites by impeding overland flow (Shakesby and others 1996).

6. If postfire logging is undertaken after establishment of new seedlings, significant mortality of these seedlings can occur (Roy 1956).

7. If postfire logging is followed by broadcast or slash burning, significant changes in future plant succession can result (Grifantini and others 1991).

8. By creating patches of disturbed soil, postfire logging can encourage establishment of a unique array of plant species (including nonnatives), relative to postfire unlogged sites (Greenberg and others 1994b, Sexton 1994).

9. Skid trails formed in postfire stands can influence productivity of trees growing directly on them (Smith and Wass 1980).

10. Postfire logging can reduce vegetation biomass, increase exotic plant species, increase graminoid cover, reduce overall plant species richness and increase conifer growth in the first years after logging (Sexton 1994).

11. Postfire logging normally removes a great percentage of large dead woody structure and thus has the potential for significantly changing postfire habitat for wildlife (Lindenmayer and Possingham 1995, 1996). These changes include “structural” effects, such as removal of existing and future snags and large woody material, and “functional” effects, such as reduction in insect populations that serve as food for various wildlife species (Blake 1982, Saab and Dudley 1998, Sallabanks and McIver 1998).

12. Many of the insects attracted by fire-killed trees are considered pests. Through removal of vulnerable trees, postfire logging can reduce the probability that insect pest populations will build up and infest adjacent green tree stands (Amman and Ryan 1991, Salman 1934, Scott and others 1996).

13. In four recent independent studies conducted in the intermountain West, postfire logging caused significant changes in abundance and nest density of cavity-nesting birds, although the effect differed somewhat by location (Caton 1996, Hejl and McFadzen 1998, Hitchcox 1996, Saab and Dudley 1998). Most cavity-nesters showed consistent patterns of decrease after logging, including the mountain bluebird and the black-backed, hairy, and three-toed woodpeckers; abundance of the Lewis' woodpecker increased after logging.

14. Several authors point out that on a landscape scale, wildfire creates patches of highly attractive habitat for a distinct array of species (Hutto 1995). To maintain healthy metapopulations of these species over the landscape, postfire patches should be managed with great care (Caton 1996, Hejl and McFadzen 1998, Hitchcox 1996, Saab and Dudley 1998).

15. In general, postfire logging enhances habitat for some wildlife species, and diminishes it for others; the end result is changes in species composition but not necessarily in species richness (Blake 1982, Haim and Izhaki 1994).

16. No studies have specifically looked at how postfire logging alters the size distribution of fuel and the concomitant changes in future fire risk. Work examining fuels on harvested green tree stands suggests that postfire logging may increase short-term fuel loads and fire risk, owing to increased fine activity fuels, but reduce intermediate and long-term fire risk through removal of larger dead structure (Brown 1980).

We know enough about both logging activity and structural change to recommend caution. Although ground-based logging activity could mitigate for erosion problems under certain conditions, it is more likely that it will either have no effect or produce more sediment than that produced by the fire. More importantly, we do not know how site-specific effects accumulate over watersheds, and this knowledge is essential if forest management is to be linked to aquatic integrity. Operational research at the watershed level that integrates terrestrial and aquatic components is needed to inform management about the risks and opportunities available in the postfire landscape.

Similarly, four recent studies on cavity-nesting birds suggest that structural changes made by logging in postfire forests have the tendency to decrease the use of these sites by many species, probably owing to lower habitat quality. Yet we know very little about how habitat preferences translate into bird productivity at the metapopulation scale. Without productivity estimates, and a landscape perspective, it generally will not be possible to understand how postfire logging influences source and sink dynamics of these cavity-nesting bird populations.

Finally, we believe that like most practices, postfire logging is certain to have a wide variety of effects, from subtle to significant, depending on where the site lies in relation to other postfire sites of various ages, site characteristics, logging methods, and intensity of fire. Even though additional research will be necessary to more completely understand the mechanisms behind the various effects of postfire logging, there is no substitute for the practice of adaptive management, particularly if it is undertaken with unlogged controls, replicated units, and response (monitoring) variables that can be measured with good precision. Because adaptive management is by definition undertaken in an operational context, it has the unique advantage of providing the kind of information on environmental (or economic) effects that allows assessment of trade-offs. To the manager faced with making decisions in an uncertain world, information of this kind is extremely valuable. Adaptive management may be particularly useful after fire, because economic incentives encourage a postfire management response almost before the fire is out. A manager equipped with an understanding of the basic tools of experimental design can quickly develop alternative postfire treatments that can be compared through variables critical to that time and place. It is likely that postfire logging will continue, with a high degree of uncertainty about its long-term effects. Adaptive management is one way for the manager to learn by doing and to gradually reduce the uncertainty behind selected site-specific practices and prescriptions.

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5. **Amaranthus, Michael; Jubas, Howard; Arthur, David. 1989.** Stream shading, summer streamflow and maximum water temperature following intense wildfire in headwater streams. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 75-78. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

6. **Amman, Gene D.; Ryan, Kevin C. 1991.** Insect infestation of fire-injured trees in the greater Yellowstone area. Res. Note INT-398. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 9 p.

7. **Axline, Michael. 1996.** Forest health and the politics of expediency. Environmental Law. 26(2): 613-640.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Salvage logging and road building may increase risks to the health of forests.
- Salvage logging threatens the qualities that attract jobs to areas with intact National Forests.
- Supply of Federal timber has little effect on jobs compared to other market forces.
- More timber jobs may mean fewer fishing-related jobs.

Keywords: Salvage harvest rider, forest health, employment, fishing

8. **Barker, Paul F. 1989.** Timber salvage operations and watershed resource values. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 1-2. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

Type of paper: Commentary

Source: Manager

Where: California—Pacific Southwest Region

Treatment: Salvage of burned trees

Variables: Erosion, sediment transport, rehabilitation, timber receipts

Conclusions:

- 700,000 acres burned in California in 1987 (out of 6 million acres of National Forest land in California).
- Benefits of salvage:

  A. Products

  B. Removing potential for insect or disease proliferation

  C. Sediment transport reduced through removal of slash

  D. Timber sale receipts available for restoration work

Keywords: Salvage harvest, wildfire, rehabilitation, economics, sediment transport, erosion, salvage benefits

9. **Bayles, David; Minshall, G. Wayne; Frissell, Christopher. 1995.** Forest health and salvage logging: What's the connection? 2 p. Unpublished report. On file with: Interior Columbia Basin Project, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1401 Gekeler Lane, La Grande, OR 97850.

Type of paper: Commentary

Source: Scientist

Treatments: Salvage, road-building

Variable: Sediment

Conclusions:

- "No evidence that salvage logging improves watersheds…, and a great deal of evidence that it does harm."
- Dead trees serve a necessary function and are important to ecosystem recovery.
- Thinning and underburning can be beneficial in some instances, but fuel reduction cannot be done on a large enough scale.
- Limiting human effects will best help ecosystems.

Keywords: Cumulative effects, salvage harvest, road building, grazing, disturbance, fuel reduction, forest health

10. **Bedard, W.D. 1950.** The Douglas-fir beetle. Circ. 817. Washington, DC: U.S. Department of Agriculture. 10 p.

11. **Berg, N.H., ed. 1989.** Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service.

12. **Beschta, R.L. 1978.** Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research. 14: 1011-1016.

13. **Beschta, R.L.; Frissell, C.A.; Gresswell, R. [and others]. 1995.** Wildfire and salvage logging: recommendations for ecologically sound post-fire salvage logging and other post-fire treatments on Federal lands in the West. Corvallis, OR: Oregon State University. 14 p.

Type of paper: Commentary

Source: Scientist

Treatments: Salvage logging after wildfire, road building

Variables: Soil, sediment, watersheds

Conclusions:

- There is no ecological need for immediate intervention after fire; most fires should not be suppressed.
- No management should be done that does not protect soil.
- Where salvage is conducted, leave all large trees and all live trees.
- Use helicopters, cable yarding, or horse logging.
- Research is needed on effects of new equipment and techniques for their suitability.
- Postfire logging, reseeding, and replanting should be conducted only under limited conditions.
- Managers should aim to reestablish natural disturbance regimes.

Keywords: Salvage harvest, wildfire, erosion, soil, roads, natural disturbance, human disturbance, ecosystem health

14. **Blake, John G. 1982.** Influence of fire and logging on nonbreeding bird communities of ponderosa pine forests. Journal of Wildlife Management. 46(2): 404-415.

Abstract: "Nonbreeding bird communities were censused on burned and unburned study plots in ponderosa pine (*Pinus ponderosa*) habitat of Prescott National Forest, Yavapai County, Arizona. Logging had occurred on two burned and two unburned plots. Forty-nine species of birds were recorded during fall, winter, and spring. Twenty-eight species were recorded on burned, and 38 species on unburned plots. During all seasons, more species were restricted to unburned study plots; more species on unburned sites occurred on only one site. Species composition on different areas was related to foraging substrate availability and to season. Habitat alterations caused by fire and by logging appeared to have a similar influence on many components of avian communities. Patterns observed during nonbreeding seasons paralleled, in many instances, response of breeding season communities to similar habitat changes."

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1973-74

Where: Arizona—ponderosa pine

Treatments:

1. Wildfire, uncut (32 percent canopy cover; 172 square feet per acre)
2. Wildfire, partial cut (22 percent canopy cover; 97 square feet per acre)
3. Wildfire, clearcut (2 percent canopy cover; 3.5 square feet per acre)
4. Unburned uncut
5. Unburned partial cut
6. Unburned clearcut

Variables: Bird species and abundance, vegetation

Results:

- Order of treatments (for number of shrubs per acre) was (6)>(5)>(3)>(4)>(1)>(2).
- For birds, burning explains more of the variation in abundance and species composition than does logging.
- "Openness" was a very important variable; for example, for seedeaters and flycatchers.
- Winter differs from spring.
- Use of unburned clearcut sites and the burned sites suggests that openness of habitat was more important than the type of alteration.

Keywords: Salvage harvest, wildfire, bird communities, wildlife-habitat relations, ponderosa pine, clearcutting

15. Bock, Carl E.; Bock, Jane H. 1977. Patterns of post-fire succession on the Donner Ridge burn, Sierra Nevada. In: Proceedings of the symposium on environmental consequences of fire and fuel management in mediterranean ecosystems; 1977 August 1-5; Palo Alto, CA. [Place of publication unknown]: [Publisher unknown]: 464-469.

16. Bock, Carl E.; Lynch, James F. 1970. Breeding bird populations of burned and unburned conifer forest in the Sierra Nevada. The Condor. 72: 182-189.

17. **Brown, James K. 1980.** Influence of harvesting and residues on fuels and fire management. In: Proceedings, Environmental consequences of timber harvesting in Rocky Mountain coniferous forests; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 417-432.

18. **Brown, Rick. 1997.** Post-fire salvage. Natural Resource News. La Grande, OR: Blue Mountains Natural Resources Institute; 7(3): 4.

Type of paper: Commentary

Source: Advocate

Conclusions:

- A careful weighing of economic benefits versus ecological risks must be done before deciding to salvage harvest.
- Ecological effects of salvage harvests are predominantly detrimental.

Keywords: Salvage harvest, ecosystem health, economics, wildfire

19. **Byrnes, Patricia. 1988.** Fire sales. Wilderness. Spring: 30-32.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Burned areas will recover naturally, and salvage logging interferes with that process, thereby causing long-term damage.
- When roads are built, the areas containing them no longer are eligible for wilderness consideration.
- The combination of fire, logging, and roads could severely stress species in the area.

Keywords: Wildfire, salvage harvest, roads, ecosystem health, biodiversity

20. **Campbell, R.E.; Baker, M.B., Jr.; Ffolliott, P.F. [and others]. 1977.** Wildfire effects on a ponderosa pine ecosystem: an Arizona case study. Res. Pap. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 12 p.

Type of paper: Scientific

Type of study: Observation, monitoring

When: 1971-75

Where: North-central Arizona

Treatments:

1. Severe wildfire, salvage of most killed trees (50 percent of sawtimber was killed; harvest reduced basal area from 40 to 7 square feet per acre)

2. Moderate wildfire, salvage of most killed trees (7 percent of sawtimber was killed; harvest reduced basal area from 103 to 73 square feet per acre)

3. Unburned

Variables: Overstory, herbage production, ground cover, streamflow, water quality and sediment, soil nutrients, water repellency, herbivores

Results:

- Runoff, sediments, and soluble salts increased considerably immediately after fire.
- Soils became water-repellent for at least 4 years after fire.
- Deer use increased after fire, but numbers of rodents decreased.
- Considerable soil nutrients (especially nitrogen) were lost with fire.
- The ecosystem is flexible and does recover.
- Ninety percent of the pulpwood and 50 percent of the sawtimber were lost in severe fire; losses were less for moderate fire.

Keywords: Wildfire, soil, erosion, vegetation, soil nutrients

21. Campbell, William G.; Morris, Scott E. 1988. Hydrologic response of the Pack River, Idaho, to the Sundance fire. Northwest Science. 62(4): 165-170.

22. Carter, Barry. 1992. Eighty-five adverse effects of salvage logging on forest health in the insect damaged forests of the Blue Mountains of eastern Oregon. Baker City, OR: Blue Mountain Native Forest Alliance from: 10 p. Available: Web page: http://www.triax.com/bmnfa/nosalvag.htm.

Type of paper: Commentary

Source: Advocate

Conclusion:

- Catalogs negative effects of salvage logging, roads, and openings and of removing dead woody material and snags on soil, water, and forest health; catalogs positive effects of fire.

Keywords: Salvage harvest, fire effects, roads, soil, water, ecosystem health, habitat

23. Caton, Elaine Lisa. 1996. Effects of fire and salvage logging on the cavity-nesting bird community in northwestern Montana. Missoula, MT: University of Montana. 115 p. Ph.D. dissertation.

Abstract: “I studied the effects of a large, stand-replacement fire on a cavity-nesting bird community in northwestern Montana for five years, starting two years post fire. I compared bird abundances in burned and unburned mid-elevation coniferous forests, and investigated the importance of nest-site and foraging-site availability in explaining differences in abundance. Differences in abundance appeared to be due largely to differences in foraging opportunities, rather than to nest-site availability. Timber-drilling woodpeckers, aerial insectivores, and ground foragers were more abundant in post-fire habitat, whereas gleaners were less abundant. Pairs of species drawn from the same foraging guild were significantly more similar in abundance patterns than pairs drawn from different guilds, but species with similar nest sites did not show similar patterns of abundance.

"I recorded characteristics of sites used for foraging and nesting in the post-fire forest. Use of sites appeared to be determined by presence of foraging sites as well as nest-tree availability. Woodpeckers foraged on large larch, Douglas-fir, and lodge-pole pines in stands with basal areas greater than expected based on availability. Cor-respondingly, nests were placed more often than expected in stands of high basal area and large-diameter trees. Nests were predominantly in large, broken-top aspen.

"I compared habitat and bird abundances between salvage-logged and unlogged post-fire habitat. Bird abundances and nest densities were lower in post-fire forest stands that were logged, and fewer sites in logged stands were suitable for nesting. Within logged areas, birds nested in sites most similar to nest sites in unlogged habitat. Tree-foraging cavity nesters were less abundant in clearcut stands than in partially logged stands. Variation in forest stands around nests rather than in characteristics of nest trees seemed to best explain this difference in abundance.

"Fire maintains cavity nester diversity by providing plentiful foraging and nesting sites. Management actions that address only nest tree provisions will fall short of providing for all community members. Fire-created habitats that undergo little or no post-fire logging may become refugia for species facing rapidly dwindling sources of standing dead wood."

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1990-94

Where: Northwestern Montana—mixed conifer

Treatments:

1. Wildfire, clearcut (basal area 13 square feet per acre)
2. Wildfire, partial cut (logged on Flathead National Forest; basal area 48 square feet per acre)
3. Wildfire, unlogged (Glacier National Park; basal area 65 square feet per acre)

Variables: Nest and cavity nest bird abundance, nest site features

Results:

- Nest abundance higher in unlogged area for 16 of 17 cavity-nesting species.
- In logged sites, most birds nested only in partial cuts.
- Tree-forager abundance higher in partial cut; flicker and mountain bluebird more abundant in clearcut.
- Flathead National Forest and Glacier National Park very different in tree diameters and species.

- Nests in the Flathead National Forest were found in sites with tree diameters significantly higher than average; tree diameter difference between nest sites and average was less in Glacier National Park.
- Stands around partial cuts had higher diameter basal area and height, compared to clearcuts.

Keywords: Bird habitat, habitat structure, nesting, salvage harvest, clearcutting, wildlife-habitat relations

24. Chou, Yue Hong; Conard, Susan G.; Wohlgemuth, Peter M. 1994a. Analysis of postfire salvage logging, watershed characteristics, and sedimentation in the Stanislaus National Forest. In: Proceedings of ESRI users conference; 1994 [dates unknown]; Palm Springs, CA. [Place of publication unknown]: [publisher unknown]: 492-499.

Abstract: "This paper presents some results of an ongoing study evaluating the effects of postfire salvage logging on sedimentation. After the 1987 complex fires on the Stanislaus National Forest in the central Sierra Nevada, fire-killed timber was logged for minimizing economic losses and preparing sites for reforestation. Watersheds with steeper slopes were cable logged while gentler slope basins were tractor logged. Twenty-two small watersheds in the burned areas were selected for intensive investigation of relationships between sedimentation, logging operations, and surface disturbance. Dams were built for measuring sedimentation in the watersheds. ARC/INFO was used to construct a comprehensive database containing multiple layers of watershed characteristics and surface disturbance. Preliminary statistical analyses indicate that the logged and unlogged basins are similar in physical attributes. Despite the large areas of disturbance in logged basins, no differences in sedimentation were detected among treatments."

Type of paper: Scientific

Type of study: Replicated experiment

Treatment date: 1993

Where: Stanislaus National Forest, California

Treatments:

1. Wildfire followed by cable logging (>33 percent slope)
2. Wildfire followed by tractor logging (<25 percent slope)
3. Wildfire, unlogged control, steep slope
4. Wildfire, unlogged control, gentle slope

Variable: Accumulated sediment

Result:

- Differences in logging type were not detectable because of variability in logging intensity among sites and because of different timing of logging at the sites.

Keywords: Salvage harvest, postfire logging, sediment

25. Chou, Yue Hong; Conard, Susan G.; Wohlgemuth, Peter M. 1994b. Postfire salvage logging variables and basin characteristics related to sedimentation, Stanislaus National Forest, California. In: Proceeding, GIS ’94 symposium; 1994 February; Vancouver, BC. [Place of publication unknown]: [publisher unknown]: 873-878.

Abstract: “This paper presents part of the results of an ongoing project to evaluate the effects of fire and post-fire salvage logging on sedimentation. Following the Stanislaus complex fires of 1987, the Pacific Southwest Research Station and the Stanislaus National Forest jointly initiated this research to address concerns about potential interaction between fire and salvage logging on erosion. Small dams made of logs and silt-filtering cloth were constructed for measuring sedimentation in twenty-two small watersheds on the Stanislaus National Forest. Topography, vegetation, and surface characteristics were interpreted from aerial photographs. Logging operations were obtained from field data and sedimentation was measured several times from the dams. To facilitate analysis and interpretation, a comprehensive GIS database containing data related to post-fire management was constructed. Data layers include locations and boundaries of the selected basins, logging operations, hydrology, topography, roads, disturbance areas, surface types, and vegetation coverage. Forty-two variables pertaining to the study of salvage logging were generated from the database. Statistical analyses based on multiple regression models and Pearson’s correlation coefficients were used to compare the relationships between sedimentation and variables of basin characteristics and surface disturbance for basins of different slope. The results provide a basis for an intensive examination of the correlation between logging operations and sedimentation.”

Type of paper: Scientific

Type of study: Replicated experiment

Treatment date: 1993

Where: Stanislaus National Forest, California

Treatments:

1. Wildfire followed by cable logging (>33 percent slope)
2. Wildfire followed by tractor logging (<25 percent slope)
3. Wildfire, unlogged control

Variable: Accumulated sediment

Result:

- For steeper sloped basins, sedimentation was significantly correlated with surface disturbance. For gentler sloped basins, sedimentation was correlated with watershed characteristics and seemed to be independent of logging.

Keywords: Salvage harvest, postfire logging, sediment

26. Connaughton, Charles A. 1935. Forest fires and accelerated erosion. Journal of Forestry. 33: 751-752.

27. Davis, Peter R. 1977. Cervid response to forest fire and clearcutting in southeastern Wyoming. Journal of Wildlife Management. 41(4): 785-788.

28. **DeBano, Leonard F. 1989.** Effects of fire on chaparral soils in Arizona and California and postfire management implications. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 55-62. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

29. **DeBano, Leonard F. 1991.** The effect of fire on soil properties. In: Proceedings, Symposium on management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 151-156.

30. **DeByle, Norbert V.; Packer, Paul E. 1972.** Plant nutrient and soil losses in the overland flow from burned forest clearcuts. In: Proceedings of the national symposium on watersheds in transition; 1972 June 19-22; Fort Collins, CO. Urbana, IL: American Water Resources Association: 296-307.

31. **DellaSala, Dominick A.; Olson, David M.; Barth, Sara E. [and others]. 1995.** Forest health: moving beyond rhetoric to restore healthy landscapes in the inland Northwest. Wildlife Society Bulletin. 23(3): 346-356.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Real forest health is fragmentation and habitat loss.
- Removal of fuel may not reduce fire risk at the landscape scale; fire spread depends more on weather conditions.
- Conditions resulting from logging operations may actually increase fire risk.
- Logging removes nutrients from the site.
- Thinning can be beneficial but it is usually best to leave fire-killed trees in place.
- Guidelines, including leaving wildlife corridors, are given to minimize effects of thinning and postfire logging.

Keywords: Forest health, fire risk, thinning, salvage harvest, wildlife corridors, reserves, wildland-urban interface

32. **Durgin, Philip B. 1985.** Burning changes the erodibility of forest soils. Journal of Soil and Water Conservation. May/June: 299-301.

33. **Everett, Richard. 1995.** Letter dated August 16 to John Lowe. Review of Beschta document. 8 p. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1133 N. Western Ave., Wenatchee, WA 98801.

Type of paper: Commentary

Source: Scientist

Treatment: Salvage of burned areas (hands-off vs. management)

Variables: Postfire fuels, salvage effects

Conclusions:

- Generally, Everett's views are toward the active management strategy.
- Concept of "natural range of variability" invoked.
- Concurs with Beschta that no information exists on relation between salvage and reburn.
- Salvage logging should be evaluated case by case.
- Custodial approach of Beschta less desirable because of (1) soil degradation in absence of seeding, and (2) fuel accumulation in absence of harvest.

Keywords: Salvage harvest, wildfire, rehabilitation, custodial management, soil degradation, fire risk

34. Fahnestock, G.R; Agee, J.K. 1983. Biomass consumption and smoke production by prehistoric and modern forest fires in western Washington. Journal of Forestry. 81: 653-657.

35. Fellin, David G. 1980. Effect of silvicultural practices, residue utilization, and prescribed fire on some forest floor arthropods. In: Proceedings, Environmental consequences of timber harvesting in Rocky Mountain coniferous forests; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 287-316.

36. Ferreira, A.J.D.; Coelho, C.O.A.; Shakesby, R.A.; Walsh, R.P.D. 1997. Sediment and solute yield in forest ecosystems affected by fire and rip-ploughing techniques, central Portugal: a plot and catchment analysis approach. Physical Chemistry Earth. 22(3-4): 309-314.

37. Frost, Evan J. 1995. February 7 review of draft environmental assessment for the Poorman fire recovery project, Methow Valley Ranger District, Okanogan National Forest, Twisp, WA. 7 p. On file with: Methow Valley Ranger District, Twisp, WA 98856.

Type of paper: Commentary

Source: Advocate

Conclusions:

- No evidence is offered to support the claim that salvage logging will reduce future fire risk or that unsalvaged areas will be at high risk of catastrophic fire.
- Fire spread is more related to weather than to other factors.
- Logging can have detrimental effects including introduction of noxious weeds and degrading of water, fisheries, soils, site productivity, and biodiversity.

Keywords: Salvage harvest, noxious weeds, fire risk, biodiversity, soil, water, site productivity

38. **Gorte, Ross W. 1996.** Salvage timber sales and forest health. Report for Congress. 4 p. Available from: Committee for the National Institute for the Environment, 1725 K St., NW, Suite 212, Washington, DC 20006; 95-364 ENR (updated June 7, 1996).

Type of paper: Commentary

Source: Advocate

Conclusions:

Definition of "salvage" given.

- Salvage may reduce fire hazard by removing fuel but increase short-term fire hazard by increasing fine fuels.
- Ecological effects of removing material are not known.
- Accounting practices are not sufficient to determine exact economic effect of salvage.

Keywords: Salvage harvest, below-cost timber sales, forest health, timber salvage sale fund

39. **Gorton, Slade; Kays, Julie. 1996.** Legislative history of the timber and salvage amendments enacted in the 104th Congress: a small victory for timber communities in the Pacific Northwest. Environmental Law. 26(2): 641-648.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Salvage rider of 1995 Recissions Act was effort to provide jobs and reduce fire hazard.
- Litigation and regulations caused delays in salvage harvests and resulted in loss of value of harvestable material; the rider allowed expedited harvests and limited frivolous lawsuits while providing environmental protection.
- Sales awarded but not released would have been subject to over $100 million in damage claims.
- Required timber harvest is well below sustainable levels.

Keyword: Salvage harvest rider

40. **Greenberg, C.H.; Neary, D.G.; Harris, L.D. 1994a.** Effect of high-intensity wildfire and silvicultural treatments on reptile communities in sand-pine scrub. Conservation Biology. 8(4): 1047-1057.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1991-93

Where: Florida

Treatments (study lacked unlogged burn treatment):

1. Intense wildfire, clearcut, natural regeneration
2. Clearcut, roller chopped, seeded
3. Clearcut, seeded
4. 55-year-old mature forest

Variable: Amphibian and reptile response

Results:

- Frogs appeared to be unaffected by treatments.
- Lizard richness, diversity, and evenness were unaffected by treatments, but species composition in treated areas differed from that in mature forest.
- Clear felling mimicked wildfire in creating lizard habitat.
- Patchwork of age classes may be a barrier to lizard dispersal.

Keywords: Wildfire, clearcutting, grass seeding, reptiles, amphibians

41. **Greenberg, Cathryn H.; Harris, Lawrence D.; Neary, Daniel G. 1995.** A comparison of bird communities in burned and salvage-logged, clearcut, and forested Florida sand pine scrub. Wilson Bulletin. 107: 40-55.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1991-93

Where: Florida—sand pine shrub

Treatments (study lacked burned, unsalvaged treatment):

1. Intense wildfire, clearcut, natural regeneration
2. Clearcut, roller chopped, seeded
3. Clearcut, seeded
4. 55-year-old mature forest

Variables: Vegetation, birds

Results:

- Migratory breeders found only in mature forest, which had higher species richness in spring.
- Winter residents were the same in all treatments.
- Canopy nesters, cavity nesters, and bark foragers were restricted to mature forest.
- Open shrub species found equally in disturbed treatments only; silviculture mimics fire for these species.

Keywords: Birds, wildlife, habitat structure, sand pine, clearcutting, threatened species, wildfire

42. **Greenberg, Cathryn H.; McGrane, Arlene. 1996.** A comparison of relative abundance and biomass of ground-dwelling arthropods under different forest management practices. Forest Ecology and Management. 89: 31-41.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1991-92

Where: Florida—sand pine

Treatments (study lacked unlogged burn treatment):

1. Intense wildfire, clearcut, natural regeneration
2. Clearcut, roller chopped, seeded
3. Clearcut, seeded
4. 55-year-old mature forest

Variables: Ground arthropods, vegetation

Results:

- Mature forest stem density lower and mean height higher than in three disturbance treatments.
- Similar biomass and abundance found in three disturbance treatments.
- Big functional differences in habitat are clear.

Keywords: Sand pine, arthropods, silviculture, wildfire, disturbance, clearcutting

43. **Greenberg, Cathryn H.; Neary, Daniel G.; Harris, Lawrence D.; Linda, Steven P. 1994b.** Vegetation recovery following high-intensity wildfire and silvicultural treatments in sand pine scrub. The American Midland Naturalist. 133(1): 149-163.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment date: 1991

Where: Florida—sand pine

Treatments (study lacked unlogged burn treatment):

1. Intense wildfire, clearcut, natural regeneration
2. Clearcut, roller chopped, seeded
3. Clearcut, seeded
4. 55-year-old mature forest

Variables: Vegetation, species structure

Results:

- Nonwoody species respond similarly whether cut or burned and cut.
- Silviculture alone mimics burning with cutting.
- Clearcutting can influence vegetation recovery by soil disturbance and snag removal.

Keywords: Wildfire, clearcutting, sand pine, disturbance, silviculture, vegetation recovery

44. Greenberg, Cathryn H.; Thomas, Michael C. 1995. Effects of forest management practices on terrestrial coleopteran assemblages in sand pine scrub. Florida Entomologist. 78(2): 271-285.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1991-92

Where: Florida—sand pine

Treatments (study lacked burned unlogged treatment):

1. Intense wildfire, clearcut, natural regeneration
2. Clearcut, roller chopped, seeded
3. Clearcut, seeded
4. 55-year-old mature forest

Variable: Beetles

Results:

- No significant differences among treatments.
- Sample taken 5 to 7 years postdisturbance.
- Lack of differences among treatments may be due to time since disturbance.

Keywords: Beetles, clearcutting, wildfire, sand pine, wildlife-habitat relations

45. Gresswell, Robert E. 1999. Fire and aquatic ecosystems in forested biomes of North America. Transactions of the American Fisheries Society. [Vol. unknown]: [pages unknown].

46. Grier, Charles C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Canadian Journal of Forest Research. 5: 599-607.

47. Grifantini, Michael C.; Stuart, J.D.; Fox, L., III. 1991. Deer habitat changes following wildfire, salvage logging and reforestation, Klamath Mountains, California. In: Proceedings of the symposium on biodiversity; 1991 October 28-30; Santa Rosa, CA. [Place of publication unknown]: [publisher unknown]: 163-167.

Type of paper: Scientific

Type of study: Observation, retrospective

Treatment dates: 1977, 1987

Where: Northern California, Klamath National Forest—Douglas-fir

Treatments:

1. 12-year-old wildfire, salvaged, broadcast burned, and planted
2. 12-year-old wildfire, not salvaged
3. 2-year-old wildfire, salvaged, broadcast burned, and planted
4. 2-year-old wildfire, not salvaged
5. Plantation wildfire at 10 years old and replanted
6. Plantation wildfire at 20 years old and replanted
7. Unburned old growth

Variables: Unburned old-growth vegetation, species, percentage of cover, hiding cover

Results:

- Old growth has fewer species.
- Slash burning may decrease nitrogen.
- Ceanothus highest in treatment 2.
- Grasses same in all treatments.
- Forbs higher at 12 years vs. 2 years.
- Salvage decreased 12-year forbs.
- Hiding cover increased with time.
- Hiding cover decreased with salvage.
- Primary recommendation: disperse different treatments across landscape.

Keywords: Salvage harvest, wildfire, wildlife-habitat relations, nitrogen fixation

48. Grifantini, Michael Carlo. 1990. Early-seral changes following wildfire, salvage-logging and reforestation, Klamath Mountains, CA. Arcata, CA: Humboldt State University. 47 p. M.S. thesis.

Type of paper: Scientific

Type of study: Observation, retrospective

Treatment dates: 1977, 1987

Where: Northern California

Treatments:

1. 12-year-old wildfire, salvaged, broadcast burned, and planted
2. 12-year-old wildfire, not salvaged

3. 2-year-old wildfire, salvaged, broadcast burned, and planted
4. 2-year-old wildfire, not salvaged
5. Plantation wildfire at 10 years old and replanted
6. Plantation wildfire at 20 years old and replanted
7. Unburned old growth

Variables: Successional patterns, deer habitat, plant diversity, canopy cover

Results:

- Logged sites showed suppression of shrubs (perhaps because of the broadcast burn), which makes them poor deer habitat and also suppresses nitrogen-fixing shrubs.
- Burned plantations had highest diversity 12 years after fire.
- Logging removed most large snags leaving site depleted of snags and woody debris.

Keywords: Wildfire, salvage harvest, deer habitat, successional stages, plant diversity, nitrogen fixation

49. Gruell, George E. 1980. Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Volume II: Changes and causes, management implications. Res. Pap. INT-252. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 35 p

50. Haim, A.; Izhaki, I. 1994. Changes in rodent community during recovery from fire: relevance to conservation. Biodiversity and Conservation. 3: 573-585.

Abstract: "Fire is a common disturbance in the Mediterranean ecosystem. A fire that broke out in the eastern Mediterranean pine forest on Mount Carmel in September 1989 destroyed thousands of hectares of natural forest. We carried out a comparative study of rodent recovery after fire under three different management regimes in order to establish the best treatment of recovery. Rodents were used as 'bio-indicators,' because of their limited home range, to assess the best management practice to be used in the recovery of the post-fire habitat. Our results show that the three arboreal Palaeoarctic species which lived in this habitat before the fire either died during the fire or left the habitat as a result of its destruction. A succession of rodent species was observed. The untreated burned forest had the highest species diversity in the initial stage, while during a later stage the highest diversity was observed in plots where the burned trees were cut down, the trunks removed and the twigs collected into small piles. The results also suggest that removing the trunks and twigs at the initial stage of recolonization results in a more zeric and warm habitat which will postpone the reinvasion of the forest species."

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1989-93

Where: Mount Carmel, Israel

Treatments:

1. Wildfire, uncut
2. Wildfire, cut all burned trees and left debris
3. Wildfire, cut all burned trees and cleared

Variable: Rodent species composition

Results:

- Original species disappeared after fire and were replaced by species typical of forest margins.
- Species used the different treatments according to their tolerance for xeric conditions: treatment 3 drier than 2, which is drier than 1.
- Full recovery of original species would indicate recovery of the woodland.
- Noninterference (no harvest) allowed return to original species mix in shortest time.

Keywords: Rodents, wildfire, salvage harvest

51. Harvey, Alan E.; Jurgensen, Martin F.; Larsen, Michael L. 1980. Biological implications of increasing harvest intensity on the maintenance and productivity of forest soils. In: Proceedings, Environmental consequences of timber harvesting in Rocky Mountain coniferous forests; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 211-220.

52. Hejl, Sallie; McFadzen, Mary. 1998. Maintaining fire-associated bird species across forest landscapes in the northern Rockies. Summary Report. Missoula, MT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 14 p.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment date: 1997

Where: Western Montana, Idaho—mixed conifer

Treatments:

1. Wildfire, uncut
2. Wildfire, clearcut

Variables: Nest success, nest site selection, foraging site selection

Results:

- No difference in nesting success between treatments.
- Nesting site selection depended on species; two species preferred logged site (Lewis' woodpecker, Williamson's sapsucker); four species preferred neither (hairy woodpecker, northern flicker, mountain bluebird, red-breasted nuthatch); and three species preferred unlogged (brown creeper, three-toed woodpecker, black-backed woodpecker).

- Most cavity nesters preferred trees of larger than average diameter.
- Foraging trees were larger in diameter than nest trees or random trees.

Keywords: Bird habitat, habitat structure, nesting, clearcutting, salvage harvest

53. Helvey, J.D. 1972. First-year effects of wildfire on water yield and stream temperature in north-central Washington. In: Csallany, S.C.; McLaughlin, T.G.; Striffler, W.D., eds. Proceedings of the national symposium on watersheds in transition; [dates of meeting unknown]; Urbana, IL. Urbana, IL: American Water Resources Association: 308-312.

54. Helvey, J.D. 1980. Effects of a north central Washington wildfire on runoff and sediment production. Water Resources Bulletin. 16(4): 627-634.

Abstract: “Runoff was measured from a 564-ha catchment located on the Entiat Experimental Forest for 9 years before a severe wildfire in 1970 destroyed the mixed conifer vegetation. Runoff records from the Chelan River (2,393 km^2) were used as control data for determining changes in water yield during the 7 years following the fire. The first post-fire year was a period of transition in which the soil profile retained more water than in previous years and measured runoff was 8.9 cm greater than the predicted value based on pre-fire conditions. Runoff from the burned catchment during subsequent years was much greater than measured values before the fire. Measured minus predicted runoff, based on the pre-fire calibration equation, varied from 10.7 cm during the dry year of 1977 to 47.2 cm during the abnormally wet year of 1972. Flow duration curves indicated that runoff at each percent value after the fire was at least double the comparable pre-fire value. Sediment production increased dramatically after the fire because of increased flow rates, increased overland flow caused by reduced infiltration capacity, and mass soil movement. Sediment yield is beginning to decrease as stream channels become stabilized and vegetation on upper slopes improves infiltration capacity.”

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment date: 1970

Where: North-central Washington

Treatments:

1. Wildfire
2. Wildfire, salvaged (salvage=tractor skidding on <30 percent slope [<40 percent slope on snow], cable yarding, and helicopter on >40 percent slope, seeding, fertilizing, and road construction; cut all trees $\geq$2 feet diameter breast height [dbh]; 8600 board feet per acre removed)

Variables: Runoff, sediment yield (prefire and postfire)

Results:

- Runoff increased after fire and logging.

- Sediment increased dramatically after fire and logging and was still 8 to 10 times greater than prefire at 7 years postfire.
- Salvage treatment appeared to have caused greater increase in sediment yield relative to untreated control.

Keywords: Wildfire, salvage harvest, runoff, sediment

55. Helvey, J.D.; Tiedemann, A.R.; Anderson, T.D. 1985. Plant nutrient losses by soil erosion and mass movement after wildfire. Journal of Soil and Water Conservation. January-February: 168-173.

Abstract: “Annual sediment yields increased as much as 180 times above pre-fire levels after wildfire destroyed all vegetation on three forested watersheds in the Entiat Experimental Forest in the eastern Cascade Range of Washington. Sediment was transported in debris torrents, in suspension, and as bedload. Suspended sediment concentration correlated well with turbidity. Total N losses by erosion processes increased from a pre-fire average of 0.004 kg/ha/yr to 0.16 kg/ha/yr. Available P losses increased from 0.001 kg/ha/yr before the fire to 0.014 kg/ha/yr. The combined erosion loss of Ca, Mg, K, and Na increased from an average of 1.98 kg/ha/yr before the fire to 54.3 kg/ha/yr. Greatest nutrient losses occurred with mass soil movements (debris torrents). Material deposited in alluvial fans represented losses of 13.5 kg/ha of total N, 3.4 kg/ha available P, and 3,850 kg/ha of Ca, Mg, K, and Na combined. An unmeasured but certainly large quantity of soil and rock entered the river during the debris flows. Nutrient losses on eroded soil although greater than solution losses, were insignificant to site productivity and stability compared with the physical effects of channel scouring associated with greater runoff, higher peak flows, and debris torrents following the fire.”

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment date: 1970

Where: Entiat Experimental Forest, Cascade Range—Washington

Treatments:

1. Wildfire
2. Wildfire, salvaged (salvage=tractor skidding on <30 percent slope [<40 percent slope on snow], cable yarding, and helicopter on >40 percent slope, seeding, fertilizing, and road construction; cut all trees $\geq$2 feet dbh; 8600 board feet per acre removed)

Variables: Sediment yield, sediment nutrients (nitrogen, phosphorus, calcium, magnesium, sodium, potassium)

Results:

- After fire, sediment yield increased more than 100-fold in 2 years. It increased even more dramatically during logging.
- At one site, the sediment transport dropped back down again, but that likely was due to the stream being scoured down to bedrock.

- Significant nutrient loss was related to debris torrents from riparian areas.

Keywords: Erosion, sediment, wildfire, salvage harvest, peak flow, nutrients

56. **Hitchcox, Susan M. 1996.** Abundance and nesting success of cavity-nesting birds in unlogged and salvage-logged burned forest in northwestern Montana. Missoula, MT: University of Montana. 89 p. M.S. thesis.

Abstract: “I studied cavity-nesting bird communities in a northwestern Montana coniferous forest following a severe, stand-replacement fire. I surveyed for active cavity nests for 3 years following the fire. Half of the area surveyed had been salvage-logged in the winter following the fire, while the other half was left unlogged. I compared nest density, cavity re-use over time, nest tree characteristics and nesting success in the two treatments.

“Unlogged areas had more cavity-nesting bird species nesting at significantly higher densities compared to salvage-logged areas. Timber-drilling foragers like black-backed woodpecker (*Picoides arcticus*), three-toed woodpecker (*Picoides tridactylus*), red-naped sapsucker (*Sphyrapicus nuchalis*) and Williamson’s sapsucker (*Sphyrapicus thyroideus*) nested in unlogged areas in low numbers but were absent from salvage-logged areas. Several ground-brush foraging species [house wren (*Troglodytes aedon*), mountain bluebird (*Sialia currocoides*), northern flicker (*Colaptes auratus*)] nested in both salvage-logged and unlogged areas, but nested in higher densities in unlogged areas.

“Diversity and density of primary-cavity-nesting bird species was lower in salvage-logged compared to unlogged areas. Northern flicker was the main excavating species nesting in salvage-logged areas. Cavity re-use rates were higher in salvage-logged (47%) than unlogged areas (31%).

“I assessed characteristics of nest trees and their associated microsites (area within 15-m radius of nest) for 12 species of cavity-nesting birds. I examined the same characteristics at random trees, and compared these to characteristics at nest trees to estimate suitability of each random tree and associated microsite for each bird species. In general, cavity-nesting birds used trees that were larger in diameter than random trees in salvage-logged deciduous trees, western larch, and broken snags more often than expected based on the availability of these trees in either treatment. The availability of suitable nesting trees appeared to explain patterns of nest abundance for some species but not for others.

“Nesting success was assessed during the 1995 breeding season for northern flicker, mountain bluebird, and house wren. Daily survival rates for northern flicker were significantly higher in unlogged compared to salvage-logged areas. Nesting success varied form 34% for mountain bluebirds in salvage-logged areas to 95% for northern flickers in unlogged areas. Only microsite tree density in one size class (10-20 cm dbh) for one species (mountain bluebird) was significantly different between successful and failed nests. No other tree or microsite characteristics measured for any other species was correlated with nesting success.”

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1993-95

Where: Northwest Montana—mixed conifer

Treatments:

1. Wildfire
2. Wildfire, salvage (salvage=all fire-killed trees > 6 inches dbh and over 15 feet tall were removed; reduced 4- to16-inch dbh trees from 138 to 53 per acre; reduced >16-inch dbh trees from 9 to 0.2 per acre)

Note: Unlogged units had more live trees, so these likely were not as severely burned as logged units.

Variables: Cavity nest abundance, nest site features

Results:

- Most nests were secondary.
- Eighteen species nested in unlogged areas; 8 in logged areas.
- Mean nest density was higher in unlogged areas for all species.
- Black-backed woodpecker, three-toed woodpecker, red-naped sapsucker, and Williamson's sapsucker present only in unlogged areas.
- Nest abundance higher each year postfire.
- Unlogged plots had higher density tall and large-diameter trees, more live trees, and more trees with bark.
- Unlogged plots were less severely burned.
- Logged plots had higher proportions of snags.
- Logged areas appeared to have had lower tree densities before fire.
- Most species of birds selected larger than average trees for nesting in both logged and unlogged plots.

Keywords: Bird habitat, habitat structure, nesting, fire effects, wildlife-habitat relations, timber harvest effects

57. **Hungerford, Roger D.; Harrington, Michael G.; Frandsen, William H. [and others]. 1991.** Influence of fire on factors that affect site productivity. In: Proceedings, Symposium on management and productivity of western-montane forest soils; 1990 April 10-12; Boise, ID. Gen. Tech. Rep. INT-280. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 32-50.

58. **Hutto, Richard L. 1995.** Composition of bird communities following stand-replacement fires in northern Rocky Mountain (U.S.A.) conifer forests. Conservation Biology. 9(5): 1041-1058.

59. Keene, Roy. 1993. Salvage logging: health or hoax. Inner Voice. [Place of publication unknown]: Association of Forest Service Employees for Environmental Ethics; (March/April): [3 p.].

Type of paper: Commentary

Source: Advocate

Treatment: Salvage harvest

Variable: Forest ecosystem health

Conclusions:

- Salvage is a tool, to be used only to restore, not to do further damage.
- Defines salvage as "rescue," save, or heal.
- Salvage should be conducted within full context of other forest values.
- National Forest Management Act regards salvage in separate light from green tree harvesting—this is bad.

Keywords: Salvage harvest, forest health, monitoring

60. Kline, LeRoy. 1996. 1995 "forest health" update. Unpublished paper presented to the Oregon Board of Forestry. 5 p. Available from: http://www.odf.state.or.us/FH/BDFOR.HTM.

Type of paper: Commentary

Source: Advocate

Results:

- Salvage can reduce fuel and offer wood fiber, but it does not make remaining trees healthy.
- Proper spacing and species mix maintained by thinning can help prevent outbreaks of insects, spread of disease, and fuel buildup.

Keywords: Salvage harvest, thinning, silviculture

61. Klock, Glen O. 1975. Impact of five postfire salvage logging systems on soils and vegetation. Journal of Soil and Water Conservation. 30(2): 78-81.

Abstract: "The impact of five traditional and advanced logging systems on soil surface disturbance, erosion, and understory vegetation was compared under postfire salvage conditions on the east slope of the Cascade Mountains. Traditional systems included tractor skidding over bare ground, and cable skidding. Advanced systems included skyline, helicopter, and tractor skidding over snow. Traditional logging systems caused more severe soil surface disturbance and consequent erosion than advanced systems."

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1970-72

Where: Central Washington—Entiat National Forest—pine, Douglas-fir

Treatments (after intense wildfire):

1. Cable skidding
2. Tractor skidding
3. Skyline
4. Helicopter
5. Tractor skidding on snow

Variables: Vegetation, soil disturbance, erosion

Results:

- Treatments in order of decreasing soil disturbance: (1) > (2) > (5) > (3) > (4).
- Treatments in order of decreasing erosion: (1) > (2) > (5) > (4).
- Helicopter and tractor-on-snow logging preserved the most vegetation cover; logging by skyline and tractor on bare ground were intermediate; cable skidding preserved the least.
- Cites information on soil disturbance and logging in several other studies.
- Advanced systems are better than traditional ones.

Keywords: Salvage harvest, wildfire, harvest systems, erosion, soil disturbance

62. Lindenmayer, D.B.; Possingham, H.P. 1995. Modelling the impacts of wildfire on the viability of metapopulations of the endangered Australian species of arboreal marsupial, Leadbeater's possum. Forest Ecology and Management. 74: 197-222.

Abstract: "Catastrophic events such as intensive wildfires have a major effect on the dynamics of some wildlife populations. In this investigation, the computer package ALEX (Analysis of Likelihood of EXtinction), was used to simulate the impacts of wildfires on the persistence of metapopulations of the endangered species Leadbeater's possum (*Gymnobelideus leadbeateri*) which is restricted to the montane ash forests of the Central Highlands of Victoria. A range of scenarios was examined. First, the response of *G. leadbeateri* to fires in hypothetical patches of old growth forest of varying size was modelled. Metapopulation dynamics were then modelled in four existing forest management areas: the O'Shannassy Water Catchment and the Steavenson, Ada and Murrindindi Forest Blocks using GIS-derived forest inventory data on complex spatial arrangements of potentially suitable old growth habitat patches. The impacts of different fire frequencies and the proportion of forest area that was burnt in the Steavenson Forest Block and the O'Shannassy Water Catchment were examined. Finally, the combined impacts of both wildfires and post-fire salvage logging operations on the persistence of populations of *G. leadbeateri* were assessed.

"Our analyses indicated that, even in the absence of wildfires, populations of *G. leadbeateri* are very susceptible to extinction within single isolated habitat patches of 20 ha or less. The probability of persistence approached 100% in patches of 250 ha. The incorporation of the effects of wildfire was predicted to have a major negative im-pact on isolated populations of *G. leadbeateri*. In these cases, the probability of popula-tion extinction remained above 60%, even when a single patch of 1200 ha of old growth forest was modelled.

"In the absence of wildfires, there was a low probability of extinction of *G. leadbeateri* in the O'Shannassy Water Catchment where very large patches of old growth forest presently exist. The risk of extinction of the species was significantly higher in the Murrindindi and Ada Forest Blocks where there are lower total areas of, and significantly smaller, suitable habitat patches. Wildfires resulted in an increase in the predicted probability of metapopulation extinction in the four areas that were targeted for study.

"An investigation of the Steavenson Forest Block and the O'Shannassy Water Catchment revealed that the predicted values for the probability of extinction were sen-sitive to inter-relationships between the frequency of fires and the proportion of habitat patches that were burnt during a given fire event. The probability of extinction of *G. leadbeateri* was predicted to be lowest when there were frequent fires that burnt only relatively small areas of a given forest block. Conversely, the results of our analyses suggested that populations of the species are vulnerable to infrequent but intensive conflagrations that burnt a large proportion of the forest."

Type of paper: Scientific

Type of study: Modeling

Treatment date: 1993

Where: Australia—eucalyptus

Treatments:

1. Wildfire
2. Wildfire, salvage (clearfelling)

Variables: Extinction probabilities for Leadbeater's possum; time to extinction

Results:

- Survival of Leadbeater's possum best with no wildfire or salvage.
- Salvage increases extinction probability compared to wildfire alone through removal of large trees that provide hollows.

Keywords: Endangered species, wildlife-habitat relations, metapopulation, population viability, salvage harvest, wildfire, eucalyptus, possum

63. Lindenmayer, David B.; Possingham, Hugh P. 1996. Ranking conservation and timber management options for Leadbeater's possum in southeastern Australia using population viability analysis. Conservation Biology. 10(1): 235-251.

Abstract: "The conservation of the endangered Leadbeater's possum, *Gymnobelideus leadbeateri*, is one of the most contentious forestry issues in Australia. The challenge is to identify strategies to conserve the species in the significant portion of its range in the central highlands of Victoria (southeastern Australia) where timber harvesting occurs. We used ALEX, a simulation program for population viability analysis, to explore the effectiveness of potential forest management strategies to enhance the persistence of *G. leadbeateri* in areas of wood production. Our study focused on the relationship between the risk of metapopulation extinction and (1) the number and spatial arrangement of 50-ha logging areas that could be reserved from timber harvesting and (2) the impacts of post-fire salvage logging in

reserved areas. We modeled complex patch structures within two forest blocks (Murrindindi and Steavenson) that were based on maps of both existing patches of suitable habitat for *G. leadbeateri* and the location of potential logging areas. We recorded high values for the probability of extinction of metapopulations of *G. leadbeateri* when existing strategies for the conservation of the species within the Murrindindi and Steavenson Forest Blocks were modeled. Exclusion of salvage logging operations from burned, old-growth forests significantly improved the species' prospects of survival in both the short and long term. Withdrawal of timber harvesting from some proposed logging coupes made a significant, positive long-term contribution to metapopulation persistence. But there will be a delay of at least 150 years until areas set aside now make a significant contribution to metapopulation persistence. This is the time required for existing stands of regrowth to develop old-growth characteristics that are an essential habitat component for *G. leadbeateri*. We examined the effectiveness of different designs for setting aside a total reserved area of 300 ha. These ranged from a single 300-ha reserve to 12, 25-ha reserves. Populations in smaller reserves were vulnerable to extinction from demographic stochasticity and environmental variability. Conversely, a small number of larger reserves were susceptible to destruction in a single, catastrophic wildfire, highlighting the need for several dispersed reserves. Analyses of the sensitivity of various management options to variations in fire frequencey and extent, movement capability, and a wide range of other factors indicated that the conservation strategy that gave the best relative outcome for *G. leadbeateri* was both to set aside several 50 to 100-ha reserves in every forest block and to preclude post-fire salvage logging operations from these areas if they burned in a wildfire."

Type of paper: Scientific

Type of study: Modeling

Treatment date: 1993

Where: Australia—eucalyptus

Treatments:

1. Wildfire
2. Wildfire, salvage (clearfelling)

Variables: Time to extinction of Leadbeater's possum; extinction probability

Results:

- Leadbeaters's possum is likely to go extinct under current management because of lack of large-diameter trees.
- Salvage of large fire-killed trees significantly increases probability of extinction.
- Retention of some unharvested patches would decrease probability of extinction.
- Several medium-sized reserves best to deal with stochastic events.

Keywords: Old growth, endangered species, wildlife-habitat relations, population viability, metapopulation, salvage, wildlife, eucalyptus, possum

64. Lowell, Eini C.; Cahill, James M. 1996. Deterioration of fire-killed timber in southern Oregon and northern California. Western Journal of Applied Forestry. 11(4): 125-131.

65. Lyon, L. Jack. 1977. Attrition of lodgepole pine snags on the Sleeping Child burn, Montana. Res. Note INT-219. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

66. Lyon, L. Jack; Marzluff, John M. 1985. Fire's effects on a small bird population. In: Lotan, James E.; Brown, James K., comps. Fire's effects on wildlife habitat—symposium proceedings; 1984 March 21; Missoula, MT. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 16-22.

67. Mackay, S.M.; Cornish, P.M. 1982. Effects of wildfire and logging on the hydrology of small catchments near Eden, N.S.W. In: Proceedings of 1st national symposium on forest hydrology; 1982 [dates unknown]; [location of meeting unknown]. [Place of publication unknown]: Australian Forest Council: 111-117.

Abstract: "The hydrologic effects of wildfire and logging were investigated in four small catchments with granite-derived soils located near Eden, N.S.W. In undisturbed catchments, runoff was shown to occur from a variable source area. Data from large storms indicated that significant overland flow occurred when runoff source areas were large. Peak flows, stormflow volume and annual flows increased appreciably in catchments burnt by high-intensity wildfire. The largest increases were observed in a catchment that had been partially clearfelled before the fire. Further increases in peak flows and stormflow volumes occurred after post-fire salvage logging in one catchment. The effects of burning and logging on catchment transpiration and infiltration are discussed as possible causes of the observed hydrologic changes."

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1977-79

Where: Australia, eastern New South Wales

Treatments:

1. Clearcut logging
2. Clearcutting followed by wildfire
3. Wildfire only
4. Wildfire followed by clearcutting

Variables: Runoff, peak streamflow

Results:

- After wildfire, runoff flows were higher in burned areas than in unburned areas. This was attributed to lower transpiration and infiltration in burned areas.
- Changes in flow characteristics were greater in areas clearcut prior to burn and after burn, probably because of soil disturbances. Effects continued 2 years later.

Keywords: Wildfire, clearcutting, hydrology, salvage harvest, logging

68. **Maloney, P. Cavan; Thornton, John L.; Lesch, Ellen. 1995.** Executive summary: summary of watershed monitoring within the Foothills fire salvage logging area 1992-1995. Boise, ID: U.S. Department of Agriculture, Forest Service, Boise National Forest. 13 p.

Type of paper: Scientific

Type of study: Observation: Monitoring

Treatment date: 1992

Where: Boise National Forest, Foothills fire

Treatments: Wildfire, salvage (no wildfire-only control)

Variable: Sediment transport

Results:

- Over 3 years, no accelerated erosion or sediment transport resulted when best management practices were implemented.
- Salvage had positive effect in increasing ground cover with slash.
- When best management practices are followed (for example, storm proofing, creating ground cover, straw baling), new temporary roads can be built, and even ground-based logging can be used.
- Significant sediment delivery occurred when skid trail crossed class II streams.

Keywords: Wildfire, salvage harvest, harvest systems, ground cover, best management practices, lop and scatter, erosion, sediment transport, Foothills fire

69. **Marston, Richard A.; Haire, David H. 1990.** Runoff and soil loss following the 1988 Yellowstone fires. Great Plains—Rocky Mountain Geographical Journal. Laramie, WY: University of Wyoming; 18(1): 1-8.

Abstract: “Fires burned 570,000 hectares (1.41 million acres) in the Greater Yellowstone Area during 1988 with accelerated runoff and soil loss as an expected result. A rainfall simulator was used in the summer of 1989 to measure runoff and soil loss on plots representing a range in geologic substrate, logging history, fire intensity, and geomorphic-pedologic conditions. Water repellent soils were common, producing high rates of runoff and soil loss for the experimental rainfall event. Rates of soil loss were highest on sites where litter cover was minimal, percent silt content in soils was high, and logging had occurred. Rates of runoff and soil loss did not exhibit statistically significant differences between glacial till and volcanic terrain, but the logging-fire history was associated with statistically significant differences in soil loss. Soil loss was highest on sites that had been logged before the 1988 fires and then burned, and this was attributed to the higher fuel load on the forest floor.”

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1988-89

Where: Yellowstone National Park

Treatments:

1. Logged, then wildfire
2. Wildfire only
3. Wildfire, then salvage
4. Control—unlogged, unburned

Variables: Geologic substrate, soil water repellency, sediment, soil organic matter, rainfall intensity, soil loss, runoff

Results:

- Sites logged before burning showed greatest erosion, probably because higher fuel loads caused high-intensity fire.
- Water-repellent soil was common and produced more erosion.
- Rate of runoff did not differ between glacial till and volcanic terrain.
- Litter density was key to controlling soil loss.
- Postfire logging had little effect on runoff, soil loss, litter, or organic matter compared to wildfire only.

Keywords: Wildfire, logging, erosion, runoff

70. Maser, Chris. 1996. Salvage logging: the loss of ecological reason and moral restraint. International Journal of Ecoforestry. 12: 176-178.

Type of paper: Commentary

Source: Scientist

Treatments: Salvage, road building

Variable: Ecosystem function

Conclusions:

- Lists seven negative consequences of salvage.
- Questions the practice of salvage per se.
- Salvage economical, not ecological.

Keywords: Forest health, soil degradation, salvage harvest, road building, ecosystem function

71. Megahan, W.F.; Kidd, W.J. 1972. Effect of logging roads on sediment production rates in the Idaho Batholith. Res. Pap. INT-123. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

72. Megahan, Walter F. 1971. Logging, erosion, sedimentation—Are they dirty words? In: Proceedings of the Society of American Foresters national convention; 1971 [dates unknown]; Cleveland, OH. [Place of publication unknown]: Society of American Foresters: 403-407.

73. **Megahan, Walter F. 1980.** Nonpoint source polution from forestry activities in the Western United States: results of recent research and research needs. In: Proceedings of the conference on U.S. forestry and water quality: What course in the 80s?; 1980 June 19-20; Richmond, VA. Richmond, VA: Water Pollution Control Federation: 93-151.

74. **Megahan, Walter F.; Molitor, Delbert C. 1975.** Erosional effects of wildfire and logging in Idaho. In: Proceedings of a symposium on watershed management; 1975 [dates unknown]; New York. [Place of publication unknown]: American Society of Civil Engineers: 423-444.

75. **Minshall, G. Wayne; Brock, James T.; Varley, John D. 1989.** Wildfires and Yellowstone's stream ecosystems: a temporal perspective shows that aquatic recovery parallels forest succession. BioScience. 39(10): 707-715.

76. **Minshall, G. Wayne; Meyer, Judy L.; Stanford, Jack A. [and others]. 1994.** Letter dated September 19 to President Clinton on fire and salvage logging. 2 p. On file with: Pacific Rivers Council, P.O. Box 10798, Eugene, OR 97440.

Type of paper: Commentary

Source: Scientist

When: 1994

Treatments: Salvage, road building, sediment, salmonids

Conclusion:

- Letter from five respected scientists against logging after wildfire.

Keywords: Salvage harvest, sediment transport, salmonids, road building, logging, wildfire

77. **Minshall, G. Wayne; Robinson, Christopher T.; Lawrence, Deron E. 1997.** Postfire responses of lotic ecosystems in Yellowstone National Park, U.S.A. Canadian Journal of Fisheries and Aquatic Science. 54: 2509-2525.

78. **Morelan, Lynette Z.; Mealey, Stephen P.; Carroll, Franklin O. 1994.** Forest health on the Boise National Forest. Journal of Forestry. August: 22-24.

Type of paper: Commentary

Source: Manager

Where: Idaho

Conclusions:

- Supports salvage harvest after fire.
- Supports thinning and prescribed fire for restoring forest health and resilience.

Keywords: Salvage harvest, thinning, prescribed fire, public involvement, forest health

79. Morris, Scott E.; Moses, Todd A. 1987. Forest fire and the natural soil erosion regime in the Colorado Front Range. Annals of the Association of American Geographers. 77(2): 245-254.

80. Muir, Patricia S. 1993. Disturbance effects on structure and tree species composition of *Pinus contorta* forests in western Montana. Canadian Journal of Forest Research. 23: 1617-1625.

81. Nasseri, Iraj. 1989. Frequency of floods from a burned chaparral watershed. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 68-71. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

82. National Commission on Wildfire Disasters. 1995. Report of the National Commission on Wildfire Disasters. Washington, DC: American Forests. 29 p.

Type of paper: Commentary

Source: Commission of managers, scientists, advocates

Conclusions:

- Silvicultural measures to address poor forest health and fuel buildup are needed to prevent disasters.
- Increasing number of homes at the wildland interface increases risk.
- Prescribed burning, salvage, and thinning are commended.
- Will take considerable effort for several decades to reduce the problem to manageable size.

Keywords: Salvage harvest, thinning, prescribed fire

83. Neumann, F.G. 1992. Responses of foraging ant populations to high-intensity wildfire, salvage logging and natural regeneration processes in *Eucalyptus regnans* regrowth forest of the Victorian Central Highlands. Australian Forestry. 55: 29-38.

Abstract: "The effects of high-intensity wildfire plus salvage logging and fire-induced natural regeneration processes on foraging ants (Formicidae) were assessed in multiple-use *Eucalyptus regnans* (mountain ash) regrowth forest approximately 60 km east of Melbourne in the Victorian Central Highlands. The study was based on 35,912 ant specimens, and on 69,493 epigeal non-ant arthropods of 27 taxa, contained in 2,160 pitfall trap samples collected at three sites over a single pre-fire year and two post-fire years.

"Twenty ant species of sub-families Dolichoderinae, Formicinae, Myrmeciinae, Myrmicinae, and Ponerinae were identified, but only *Notoncus spinisquamis*, *Myrmecia pilosula*, and *Chelaner sculpturatus* could be validated. Two species were placed into the newly erected genus *Ochetellus* (Dolichoderinae), and one species of Myrmicinae could not be identified below sub-family rank. The biology and taxonomy of the majority of these species is uncertain, although the most

commonly trapped ant, *Prolasius ? pallidus*, is a recognised seed harvester, and two other species of *Prolasius* plus *C. sculpturatus* are suspected seed harvesters. The second most frequently trapped species, *Iridomyrmex ? foetans*, is a carnivore and scavenger. *Chelaner sculpturatus* was the most frequently trapped among 18 'minor' species.

"The rapid replacement of the ecologically complex regrowth forest by young evenaged regeneration of *E. regnans* through wildfire effects and salvage logging caused a substantial increase in foraging activity of *P. pallidu*s during the first post-fire autumn period, and activity remained high for up to 14 months depending on elevation of the forested landscape. Activity of *I.* [*F*] *oetans* declined immediately after the fire, but 8 months later, it was significantly higher than 'control plot' levels for up to 4 months. The response of the less frequently trapped 'minor' species to the wildfire, logging, and regeneration processes remained uncertain because of the low numbers trapped before and after the fire. Prolific regeneration of *E. regnans* emerged in the burnt forest, suggesting that fire-induced seed fall was sufficiently large and extensive to have caused predator satiation. The implications of this for artificial regeneration programs
in *E. regnans* forest are discussed."

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1982-85

Where: Australia, Highland—eucalyptus

Treatments:

1. Undisturbed mature forest
2. High-elevation wildfire, salvage logged
3. Low-elevation wildfire, salvage logged

Variable: Ants

Result:

- Seed harvesting *Prolasius* ant increased after fire and logging owing to increased seed fall: *Iridomyrmex* numbers declined first and then rebounded. *Prolasius* will not prevent regeneration of eucalyptus forests if seed fall is great enough to satiate predators.

Keywords: Wildfire, salvage harvest, ants, eucalyptus, wildlife-habitat relations

84. Neumann, Frederick G. 1991. Responses of litter arthropods to major natural and artificial ecological disturbances in mountain ash forest. Australian Journal of Ecology. 16: 19-32.

Abstract: "Pitfall trapping was used in commercial Mountain Ash (*Eucalyptus regnans*) regrowth forest to study the effects on epigeal arthropods of high-intensity wildfire plus salvage logging, and of harvesting by clearfelling plus slash burning, followed by fire-induced natural or artifically established regeneration respectively. The study, the first of its kind in the Victorian Central Highlands, 60 km east of Melbourne, was based on 146,922 specimens of 30 ordinal or lower level taxa collected over a 3-year period. The abrupt replacement of the ecologically complex regrowth forest by ecologically much simpler even-aged regeneration caused appreciable instability among the litter-frequenting arthropods. An immediate decline in diversity occurred due to short-term boosts in activity of some common ‘major’ taxa (notably a species of seed-harvesing ant) and the suppression of other taxa. A broad mix of functionally diverse taxa reappeared within 2 years of regeneration, and all but three rarely trapped ‘minor’ taxa present in undisturbed 43- to 46-year-old regrowth (‘control’) forest had returned within 5 years. Epigeal arthropods therefore appeared to be affected only over a short period relative to the nominal 80- to 150-year rotation of the *E. regnans* ecosystem. Research is needed at the species level to achieve a more precise assessment of arthropod responses to major ecological disturbances.”

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1982-85

Where: Australia, Highland—eucalyptus

Treatments: (no unsalvaged treatment)

1. Undisturbed mature forest
2. Wildfire and salvaged
3. Clearcut and planted
4. Clearcut and seeded

Variable: Arthropods

Results:

- Short-term decrease in species and functional diversity for all treatments.
- Short-term dominance by a seed harvesting ant.
- Most functional groups reestablished after 5 years.

Keywords: Wildfire, eucalyptus, arthropods, habitat structure, seed harvester ants

85. Parks, David S.; Cundy, Terrance W. 1989. Soil hydraulic characteristics of a small southwest Oregon watershed following high-intensity wildfire. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 63-67. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

86. Perry, David A. 1994. Testimony, August 29, Senate Hearing on Forest Health: Boise, ID. Corvallis, OR: Department of Forest Science, Oregon State University. 6 p.

Type of paper: Commentary

Source: Scientist

Treatments: Thinning, prescribed fire, salvage

Variable: Forest ecosystem health

Conclusions:

- Feedback important in regulation.
- Three categories of health problems: disturbance vulnerability, habitat loss, and soil degradation.
- Reintroduce fire.
- Fuel reduction and thinning should be applied judiciously.
- Avoid building new roads.
- Thin from below.
- Salvage decisions must strike balance between benefits and hazards of down wood.

Keywords: Forest health, ecosystem health, disturbance, wildfire, thinning, soil degradation, wildlife-habitat relations

87. Peters, Robert L.; Frost, Evan; Pace, Felice. 1996. Managing for forest ecosystem health: a reassessment of the "forest health crisis." Washington, DC: Defenders of Wildlife. 36 p. In cooperation with: Northwest Ecosystem Alliance, Bellingham, WA; Klamath Forest Alliance, Etna, CA.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Salvage logging results in damage to soils, streams, and wildlife habitat and impairs a forest's ability to recover.
- Logging may exacerbate disease.
- Salvage may not reduce fire risk, because risk depends more on weather than fuel.
- Thinning and prescribed fire can benefit forests but pose risks also.

Keywords: Salvage harvest, soil, nutrients, noxious weeds, habitat, prescribed fire, thinning

88. Poff, Roger J. 1989. Compatibility of timber salvage operations with watershed values. In: Berg, Neil H., tech. coord. Proceedings of the symposium on fire and watershed management; 1988 October 26-28; Sacramento, CA. Gen. Tech. Rep. PSW-109. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 137-140. Available from: National Technical Information Service, Springfield, VA 22161; PB89-228639.

Type of paper: Commentary

Source: Manager

Where: California, Tahoe National Forest, Indian fire—mixed conifers

Treatments:

1. Salvage after fire
2. Intentional soil disturbance
3. Fire only

Variables: Sediment transport, observation of soil layers, ground cover, soil compaction

Results:

- Salvage can improve watershed condition by—

  A. Adding ground cover

  B. Breaking up hydrophobic soils

  C. Removing trees that channel flow

- Salvage can benefit local economies through timber receipts.

Keywords: Wildfire, salvage harvest, ground cover, soil water-repellency, sediment transport, Indian fire

89. Potts, Donald F.; Peterson, David L.; Zuuring, Hans R. 1985. Watershed modeling for fire management planning in the northern Rocky Mountains. Res. Pap. PSW-177. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 p.

Abstract: "Water yield and sediment production almost always increase after wildfire has destroyed vegetative cover. The value of water generally is not as much appreciated in the water-rich northern Rocky Mountains as it is elsewhere. Increased water yield becomes economically beneficial, however, when its potential for consumptive and nonconsumptive uses is realized. Whether the effects of increased sedimentation are esthetic, biological, physical, or economic, they are usually detrimental.

"Fire management programs for the National Forests are required to be an integral part of land management planning. Managers must be able to estimate postfire changes in resource outputs and values within the context of a particular fire manage-ment program. The quantity of additional water and sediment produced is a function of fire characteristics and site-specific factors: vegetation, climate, and physical characteristics. Planning, however, requires a broad resolution analysis system. Therefore, site-specific water and sediment yield models were adapted to meet broad resolution planning objectives.

"In a study of fire-induced changes in watersheds in the northern Rocky Mountains, two simulation models were applied. Procedures from Water Resources Evaluation of Nonpoint Silvicultural Sources (WRENSS) estimated water yield, and a closely related model estimated four major components of sediment yield—natural sediment, sediment from management-induced mass erosion, sediment from management-induced surface erosion, and sediment delivery. Computerized versions of the models were used to estimate postfire water yield for 18 possible management cases and postfire sediment yield for 81 cases. Net value change of water resources was calculated with investment analysis.

"Water yield was most affected by basal area loss; the greater the loss, the greater the relative increase in water yield. Water yield increased over natural yield, however, only if fire or salvage logging or both removed greater than 50 percent of stand basal area.

"Fire had a relatively small effect on sediment production in most cases. Increases were relatively large only for fires with large areas. Natural sediment yield increased more than did management-induced sediment yield. Postfire sediment increases were severe only on sites with steep slopes and large fires.

"Increased water yields resulted in a beneficial net value change for all cases. Benefits were substantial (up to $33.42 per acre or $80.21 per hectare) in some cases and were less than $5 per acre ($12 per hectare) only in some cases with 50 percent basal area loss. Net value change was increasingly negative as basal area loss increased. Net value change for sediment yield was detrimental for all cases, but was always less than $0.01 per acre ($0.02 per hectare)."

Type of paper: Scientific

Type of study: Modeling

When: 1984

Where: Rocky Mountains

Treatments: Wildfire, silviculture

Variables: Water yield, sediment

Results:

- Water yield increases owing to basal area loss from either fire or salvage.
- Sediment yields highest after fire, then management.
- Positive economic value of water dwarfs negative value of sediment.

Note: Did not use model to predict peak discharge.

Keywords: Fire effects, sediment, water yield, watershed models, WRENSS, salvage harvest

90. Potts, Donald F.; Peterson, David L.; Zuuring, Hans R. 1989. Estimating postfire water production in the Pacific Northwest. Res. Pap. PSW-197. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 9 p.

91. Reeves, G.H.; Benda, L.E.; Burnett, K.M. [and others]. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. In: Nielsen, J.L., ed. Evolution and the aquatic ecosystem: defining unique units in population conservation. Proceedings of American Fisheries Society symposium; [dates of meeting unknown]; [location unknown]. [Place of publication unknown]: [publisher unknown]: 334-349.

92. Reid, L.M.; Dunne, T. 1984. Sediment production from forest road surfaces. Water Resources Research. 20(11): 1753-1761.

93. **Rieman, Bruce; Clayton, Jim. 1997.** Wildfire and native fish: issues of forest health and conservation of sensitive species. Fisheries. 22(11): 6-15.

94. **Rieman, Bruce; Lee, Danny; Chandler, Gwynne; Myers, Deborah. 1997.** Does wildfire threaten extinction for salmonids? Responses of redband trout and bull trout following recent large fires on the Boise National Forest. In: Proceedings, Fire effects on rare and endangered species and habitats conference; 1995 November 13-16; Coeur d'Alene, ID. [Place of publication unknown]: International Association of Wildland Fire: 47-57.

95. **Roy, D.F. 1956.** Salvage logging may destroy Douglas-fir reproduction. For. Res. Note 107. [Place of publication unknown]: California Forest and Range Experiment Station. 5 p.

Type of paper: Scientific

Type of study: Observation

Treatment date: 1954

Where: Humboldt County, CA—Douglas-fir

Treatments: Wildfire, salvage logging 3 years later

Variable: Seedlings established

Results:

- The number of Douglas-fir seedlings established in the 1951 seed year was reduced from 1981 to 417 per acre.
- Earlier and more careful logging could reduce seedling losses.

Keywords: Wildfire, salvage harvest, regeneration

96. **Saab, Victoria; Dudley, Jonathan. 1998.** Responses of cavity-nesting birds to stand-replacement fire and salvage logging in ponderosa pine/Douglas-fir forests of southwestern Idaho. Res. Pap. RMRS-RP-11. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 17 p.

Abstract: "In spring 1994, the Intermountain Research Station, Boise National Forest, and Region 4 of the Forest Service initiated long-term studies on bird responses to different fire conditions in ponderosa pine/Douglas-fir forests of southwestern Idaho. The first phase of the project is to evaluate effects of high-intensity wildfire on cavity-nesting birds and their associated habitats. During spring/summer 1994-1996 we monitored 695 nests of nine cavity-nesting bird species (including three Forest Service sensitive species: black-backed, white-headed, and Lewis' woodpeckers) and measured vegetation at nest sites and at 90 randomly located sites. The burned forests used for study areas were created in 1992 and 1994 by primarily high-intensity wildfire; thus most standing trees were snags. Nests and vegetation were monitored in three treatments: standard-cut salvage-logged, wildlife-prescription salvage-logged, and unlogged controls. Tree densities for small-diameter trees (>9" to $\leq$ 20" [> 23 cm to $\leq$ 53 cm] diameter at breast height [dbh]) in the unlogged units averaged 33 snags per acre (81 per ha) and for larger

trees (> 20” dbh [> 53 cm]) averaged 7 snags per acre (17 per ha). In salvage-logged units about 50% of the trees were harvested, tree densities for small trees averaged 17 snags per acre (43 per ha) and for large trees averaged 2 snags per acre (5 per ha). Lewis’ woodpecker was the most abundant (208 nests) and successful cavity nester on the 2- to 4-year-old burns, while black-backed and white-headed woodpeckers were rare (23 nests). Lewis’ woodpecker and American kestrel experienced the highest nesting success in the salvage-logged units, whereas northern flicker and hairy woodpecker were most successful in the unlogged units. All bird species selected nest sites with higher tree densities than that measured at random sites, and cavity nesters as a group selected clumps of snags rather than snags that were retained in uniform, evenly-spaced distributions. Among bird species, black-backed woodpeckers used nest sites with the highest tree densities, while Lewis’ woodpecker selected relatively open nest sites. Cavity-nesters as a group selected larger diameter and more heavily decayed snags than that expected based on availability of such snags. Snags with the highest probability (> 85%) of being classified as nest trees were characterized by heavy decay and broken tops that pre-dated the wildfire. We discuss management implications of stand-replacement fire and post-fire salvage logging for cavity-nesting birds. Future plans are outlined, including local and regional assessments of bird and plant responses to different fire conditions (stand-replacement fire, fire suppression, and prescribed fire) in the interior Columbia River Basin. The intent of this work is to provide information on the action and no action alternative to the Forest Health Initiative.”

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1994-96

Where: Southwestern Idaho—ponderosa pine and Douglas-fir

Treatments:

1. Wildfire, standard salvage: north slopes cut trees >10 inches dbh, leave 6 snags per acre; south slopes cut two-thirds of trees >12 inches dbh
2. Wildfire, wildlife prescription salvage: cut half of trees >12 inches dbh
3. Wildfire, unlogged

Variables: Nest density and abundance of nine species of cavity-nesting birds, vegetation, nest site features

Results:

- Total nesting density has increased through 4 years postfire.
- Nest density higher in “standard salvage” area for Lewis’ woodpecker, American kestrel, starling, western bluebird; higher in “wildlife prescription” stand for northern flicker and western bluebird; higher in unlogged area for hairy woodpecker and mountain bluebird.
- Abundance of black-backed woodpecker higher in unlogged area; Lewis’ woodpecker more abundant in logged area.

- Snag density in unlogged area was twice that in both logging treatments; no difference in snag density between the two logging treatments; shrub density same in all treatments.
- All species chose sites with higher than random tree density. Lewis' woodpecker and flickers chose sites with larger adjacent trees; black-backed woodpecker chose nest trees averaging smallest diameter.

Keywords: Bird habitat, habitat structure, nesting, wildlife-habitat relations, salvage harvest

97. Sallabanks, R.; McIver, J.D. 1998. Response of breeding bird communities to wildfire in the Oregon Blue Mountains: the first three years following the Twin Lakes fire, 1995-1997. In: Fire and wildlife in the Pacific Northwest: research, policy and management: Proceedings, annual meeting of the northwest section of the Wildlife Society; 1998 April 6-8; Spokane, WA. [Place of publication unknown]: [publisher unknown]: 85-89.

98. Salman, K.A. 1934. Entomological factors affect salvaging of fire injured trees. Journal of Forestry. 32: 1016-1017.

99. Scott, Donald W.; Szymoniak, John; Rockwell, Victoria. 1996. Entomological concerns regarding burn characteristics and fire effects on tree species during prescribed landscape burns: burn severity guidelines and mitigation measures to minimize fire injuries. BMZ-97-1. La Grande, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest, Blue Mountains Pest Management Zone. 48 p.

100. Sexton, Timothy O. 1994. Ecological effects of post-wildfire salvage-logging on vegetation diversity, biomass, and growth and survival of *Pinus ponderosa* and *Purshia tridentata*. Corvallis, OR: Oregon State University, Department of Rangeland Resources. 28 p. Unpublished manuscript. On file with: Department of Rangeland Resources, Strand Agriculture Hall, Oregon State University, Corvallis, OR 97331.

Abstract: "Salvage logging following wildfire is a common practice in the western United States yet few studies have quantified the vegetation response to this land use activity. The effects of post-wildfire salvage logging on vegetation composition, aboveground biomass production, and growth and survival of *Pinus ponderosa* and *Purshia tridentata* was quantified in the Lone Pine Fire area on the Winema National Forest in the Klamath Basin, Oregon. Prior to the fire, the area was dominated by uneven-aged stands of *Pinus ponderosa* with *Purshia tridentata* and *Stipa occidentalis* in the understory. The fire was stand-replacement disturbance, where the majority of trees and understory shrubs were killed.

"Biomass of the understory was significantly lower in salvage-logged areas compared to areas that were not logged following fire. In 1993, the understory of salvage-logged sites produced 38.2% (322 kg/ha vs 843 kg/ha) of the aboveground biomass produced on nonsalvaged sites. In 1994, salvage-logged sites produced only 27.3% (402 kg/ha vs 1468 kg/ha) of the biomass produced on nonsalvaged sites."

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1993-94

Where: Central Oregon, Chiloquin Ranger District—ponderosa pine and *Purshia*

Treatments:

1. Wildfire and salvaged—skidders on snow, helicopter on steep ground; trees larger than 7 inches dbh taken
2. Wildfire and not salvaged

Variables: Soil moisture, vegetation biomass, species diversity, pine growth and survival, *Purshia* growth

Results:

- Salvage decreased canopy cover (13.5-5.3 percent).
- Salvage lowered forb and shrub biomass in the first 2 years.
- Salvage reduced species richness (23-20 in 1993; 22-16 in 1994).
- Salvage increased exotic species.
- Salvage increased graminoids.
- Pine seedlings grew 17 percent higher on salvaged sites.

Keywords: Salvage harvest, wildfire, regeneration, ponderosa pine, vegetation effects

101. Shakesby, Richard A.; Boakes, David J.; Coelho, Celeste de O.A. [and others]. 1996. Limiting the soil degradational impacts of wildfire in pine and eucalyptus forests in Portugal: a comparison of alternative post-fire management practices. Applied Geography. 16(4): 337-355. ISSN: 0143-6228/96.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment dates: 1992-94

Where: Portugal—pine, eucalyptus

Treatments (for both pine and eucalyptus):

1. Wildfire and salvage
2. Wildfire, salvage, and low litter
3. Wildfire, salvage, and high litter
4. Wildfire, salvage, ripped, and planted
5. Unburned mature forest

Variables: Sediment transport, overland flow

Results:

- Eucalyptus litter and pine needles decrease soil loss.
- Minimum tillage causes less soil loss than ripping.

Keywords: Rip-plowing, sediment transport, litter, wildfire, erosion, pine, eucalyptus

102. Shakesby, Richard A.; Coelho, Celeste de O.A.; Ferreira, António D. [and others]. 1993. Wildfire impacts on soil erosion and hydrology in wet mediterranean forest, Portugal. International Journal of Wildland Fire. 3(2): 95-110.

Type of paper: Scientific

Type of study: Unreplicated experiment

Treatment dates: 1986, 1988, 1989

Where: Portugal

Treatments (variety of vegetation types and management practices):

1. Mature, unburned site
2. New wildfire (0-2 years)
3. Old wildfire (3-4 years)

Variables: Soil loss; rain splash, soil hydrophobicity, infiltration capacity, ground-level changes

Results:

- Forest fire increased soil loss, but loss returned to normal in 3 to 4 years.
- Hydrophobicity of soil was increased by fire.
- Infiltration capacity remained diminished 3 to 4 years after fire.
- Leaving fire-damaged trees in place until after fall of leaf litter (a few weeks) may help protect soil from erosion.

Keywords: Fire effects, erosion, hydrology

103. Shakesby, Richard A.; Coelho, Celeste de O.A.; Ferreira, António D. [and others]. 1994. Fire, post-burn land management practice and soil erosion response curves in eucalyptus and pine forests, north-central Portugal. In: Sala, M.; Rubio, J.L., eds. Soil erosion and degradation as a consequence of forest fires. Logroño, Spain: Geoforma Ediciones: 111-132.

104. Simon, Jerry; Christy, Stephen; Vessels, Joseph. 1994. Clover-Mist fire recovery: a forest management response. Journal of Forestry. November: 41-44.

Type of paper: Commentary

Source: Manager

Treatment date: 1988

Where: Wyoming

Treatments: Salvage harvest and rehabilitation projects, public involvement

Variables: Wildfire

Conclusions:

- A variety of project requirements and safeguards were implemented to minimize effects of salvage.
- Projects enhanced long-term recovery of resources.

Keywords: Salvage harvest, rehabilitation, wildfire, Yellowstone National Park

105. Smith, R.B.; Wass, E.F. 1980. Tree growth on skidroads on steep slopes logged after wildfires in central and southeastern British Columbia. BC-R-6. Victoria, BC: Canadian Forestry Service; Pacific Forest Research Centre. 27 p. [ISBN-0709-9991].

Type of paper: Scientific

Type of study: Observation

Treatment dates: 1960, 1961

Where: British Columbia

Treatments:

1. Wildfire, clearcut—skid road
2. Wildfire, clearcut—off road

Variables: Tree growth, foliage color

Results:

- Site productivity was reduced where ground skidding was used, although effects appeared minimal or even favorable on some sites.
- Adverse effects can be reduced by using cable yarding, small tractors, or yarding over snow.

Keywords: Wildfire, logging, tree growth, site productivity, skidroads

106. Society of American Foresters. 1995. Below cost timber sales on the national forests: the role of salvage and sanitation harvesting in the restoration and maintenance of healthy forests [Position statement]. Bethesda, MD: Society of American Foresters. 3 p.

Type of paper: Commentary

Source: Scientist

Treatments: Salvage, sanitation harvest

Variables: Those related to “forest health”

Conclusions:

- Sanitation is designed to reduce risk of insect and disease; salvage is designed to recover value.
- Forest health defined: a condition in which forest influences do not threaten future options.
- SAF endorses salvage as part of a package that includes sanitation and other “preventative” measures.

Keywords: Salvage harvest, sanitation harvest, salvage harvest rider, forest health, prescribed fire

107. Society of American Foresters. 1996. The role of “salvage” and “sanitation” harvesting in the restoration and maintenance of healthy forests [Position paper]. Available from: Society of American Foresters web page: www.safnet.org.

Type of paper: Commentary

Source: Scientist

Conclusions:

- SAF supports using salvage harvest as part of an active management scheme.
- Salvage sales are not solely to make a profit but also to improve forest health; delays only add to the cost.

Keywords: Salvage harvest, sanitation harvest, prescribed fire, integrated pest management, thinning, forest regeneration, salvage harvest rider

108. Stalling, David. 1996. Forests, fires and elk: Logging for healthy habitat? Bugle. [Missoula, MT]: Rocky Mountain Elk Foundation; Spring: [5 p.].

Type of paper: Commentary

Source: Advocate

Where: Montana, Idaho

Conclusions:

- Logging and fire can be used in a way to improve forest health and reduce risk of wildfire.
- Fire is a part of the ecosystem function and cannot be excluded indefinitely.
- Restoration logging should leave the largest and healthiest trees, thin to reasonable stocking rates, and remove or burn excess fuel.
- Some dead trees need to be left on site for healthy forests.
- At Tiger Creek, previous logging and prescribed fire reduced severity of wildfire.

Keywords: Disturbance, fire effects, restoration logging, prescribed fire, fire risk

109. Stark, Nellie M. 1980. The impacts of utilization on nutrient cycling. In: Proceedings, Environmental consequences of timber harvesting in the Rocky Mountain coniferous forests; 1979 September 11-13; Missoula, MT. Gen. Tech. Rep. INT-90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 123-136.

110. Stocks, B.J. 1987. Fire potential in the spruce budworm-damaged forest of Ontario. Forestry Chronicle. 63(1): 8-14.

111. Stone, Richard. 1993. Spotted owl plan kindles debate on salvage logging. Science. 261: 287.

Type of paper: Commentary

Source: Advocate

Conclusions:

- Moderate salvage will reduce fire risk and disease outbreaks.
- Dead wood is an important forest component, but the large-diameter material is most important for wildlife use.

Keywords: Salvage harvest, insect outbreaks, tree disease, nutrients, wildlife

112. Stuart, John D.; Grifantini, Michael C.; Fox, Lawrence, III. 1993. Early successional pathways following wildfire and subsequent silvicultural treatment in Douglas-fir/hardwood forests, NW California. Forest Science. 39(3): 561-572.

Abstract: “Early successional sites were contrasted with old-growth Douglas-fir/hardwood forests to detect community-level, life form, and species diversity differences due to postwildfire silvicultural treatments. Treatments included: (1) salvage logged after wildfire; (2) not salvage logged after wildfire; and (3) previously established plantations. These silvicultural treatments were compared 2 years after a 1987 wildfire and 12 years after a 1977 wildfire. There was more forb and shrub cover on 1987 unsalvaged sites than on salvaged. Sites salvaged following the 1977 fire had more hardwood cover but less shrub cover than unsalvaged sites. Old-growth sites, however, were less diverse than all treatment sites combined. Based on these and results from other studies, tanoak and other hardwoods inhibited the establishment and growth of Douglas-fir on salvaged sites, while deerbrush and other shrubs inhibited Douglas-fir on unsalvaged sites.”

Type of paper: Scientific

Type of study: Observation, retrospective

Treatment date: 1989

Where: Northwest California, Klamath National Forest—Douglas-fir

Treatments:

1. 12-year-old wildfire, salvaged, broadcast burned, and planted
2. 12-year-old wildfire, not salvaged
3. 2-year-old wildfire, salvaged, broadcast burned, and planted

4. 2-year-old wildfire, not salvaged
5. Plantation wildfire at 10 years old and replanted
6. Plantation wildfire at 20 years old and replanted
7. Unburned old growth

Variable: Vascular plant cover

Results:

- Old-growth area different from burned areas.
- Salvaged area diverged from unsalvaged area more with time.
- Salvage influences succession.
- Greater hardwood cover resulting from salvage may hinder Douglas-fir regeneration.

Keywords: Salvage harvest, biodiversity, disturbance, old growth, forest regeneration, successional stages, wildfire, Douglas-fir, nitrogen fixation

113. Swank, W.T.; DeBano, L.F.; Nelson, D. 1989. Effects of timber management practices on soil and water. [Place of publication unknown]: U.S. Department of Agriculture, Forest Service: 79-106.

114. Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Seattle: University of Washington. 101 p. M.S. thesis.

115. Taylor, Dale L.; Barmore, William J., Jr. 1980. Post-fire succession of avifauna in coniferous forests of Yellowstone and Grand Teton National Parks, Wyoming. In: Management of western forests and grasslands for nongame birds. Gen. Tech. Rep. INT-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 130-145.

116. Thomas, Jack Ward. 1995. Forest health: what is it, what we're doing about it. Remarks presented at the 60th North American wildlife and natural resources conference; 1995 March 27; Minneapolis, MN. 8 p. Available from: Public Affairs Office, USDA Forest Service, P.O. Box 96090, Washington, DC, 20090-6090.

Type of paper: Commentary

Source: Scientist

Treatment: Salvage

Variable: Forest ecosystem health

Conclusions:

- Salvage is lumped with other preventative measures (for example, prescribed fire, thinning).
- Salvage is identified as key to meeting fiber needs.
- Salvage is one tool of many.

Keywords: Forest health, salvage harvest, ecosystem management, western forest health initiative

117. Ulery, A.L.; Graham, R.C.; Bowen, L.H. 1996. Forest fire effects on soil phyllosilicates in California. Soil Science Society America Journal. 60: 309-315.

118. U.S. Congress, 104th. 1995. Emergency Supplemental Appropriations for Additional Disaster Assistance, for Anti-Terrorism Initiatives, for Assistance in the Recovery from the Tragedy that Occurred at Oklahoma City, and Recissions Act. 1995. Public Law 104-19.

119. U.S. Department of Agriculture, Forest Service. [1993]. Value of timber salvage program in forest health recovery. [Place of preparation unknown]: Wallowa-Whitman National Forest; Umatilla National Forest. 3 p. Available from: Steve Fletcher, Wallowa-Whitman National Forest, P.O. Box 907, Baker City, OR 97814.

120. U.S. Department of Agriculture, Forest Service. 1996a. Forest health and salvage. Washington, DC. 2 p. Forest health issue paper. Available from: Director, Forest Management, USDA Forest Service, P.O. Box 96090, Washington, DC 20090-6090.

Type of paper: Commentary

Source: Manager

Conclusions:

- Salvage harvests provide wood and help local economies, reduce spread of insects, and reduce fire risk.
- Revenue can offset cost of site rehabilitation; however, there are possible adverse environmental effects of the operation, of removing nutrients, and of administrative expenses.
- Salvage must be conducted in accordance with environmental laws and forest plan standards.

Keyword: Salvage harvest

121. U.S. Department of Agriculture, Forest Service. 1996b. Status of the interior Columbia basin: summary of scientific findings. Gen. Tech. Rep. PNW-GTR-385. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 144 p.

Type of paper: Commentary

Source: Manager

Conclusions:

- Timber salvage is one of the tools used in forest health recovery.
- Probably less than 10 percent of acres affected by insects and disease will be salvaged because of various regulatory or practical restrictions.

Keywords: Salvage harvest, prescribed fire, thinning, forest health, insect pests, employment

122. U.S. Department of Agriculture; U.S. Department of the Interior. 1997a. Eastside draft environmental impact statement, volume 1. [Place of publication unknown].

123. U.S. Department of Agriculture; U.S. Department of the Interior. 1997b. Upper Columbia River basin draft environmental impact statement, volume 1. [Place of publication unknown].

124. Van Lear, D.H.; Douglass, J.E.; Cox, S.K.; Augspurger, M.K. 1985. Sediment and nutrient export in runoff from burned and harvested pine watersheds in the South Carolina piedmont. Journal of Environmental Quality. 14(2): 169.

Type of paper: Scientific

Type of study: Replicated experiment

Treatment date: 1979

Where: South Carolina—piedmont, loblolly pine

Treatments:

1. Undisturbed control
2. Prescribed fire, prelogging
3. Prescribed fire and postlogging (clearcut)

Variables: Sediment, nutrient export, runoff

Results:

- Runoff increased with treatment.
- Sediment export increased significantly after harvest.
- Nutrient export concentrations did not change; however, because of increases in runoff, harvest caused increases in nutrient loss.

Keywords: Sediment transport, erosion, prescribed fire, nutrient cycling, runoff, clear-cutting

125. Walsh, R.P.D.; Boakes, D.; Coelho, C.[de] O.A. [and others]. 1994. Impact of fire-induced hydrophobicity and post-fire forest litter on overland flow in northern and central Portugal. In: Proceedings of the 2d international conference on forest fire research; 1994 November; Coimbra, Portugal. [Place of publication unknown]: [publisher unknown]: 1149-1159. Vol. II.D.38.

126. Walsh, R.P.D.; Boakes, D.J.; Coelho, C. de O.A. [and others]. 1995. Post-fire land use and management and runoff responses to rainstorms in northern Portugal. In: McGregor, D.F.M.; Thompson, D.A., eds. Geomorphology and land management in a changing environment. New York: John Wiley & Sons: 283-308. Chap. 17.

127. Walsh, R.P.D.; Coelho, C. de O.A.; Shakesby, R.A.; Terry, J.P. 1992. Effects of land use management practices and fire on soil erosion and water quality in the Agueda River Basin Portugal. GEOÖKOplu*s*. 3: 15-36.

128. **Wells, Carol G.; Campbell, Ralph E.; DeBano, Leonard F. [and others]. 1979.** Effects of fire on soil: a state-of-knowledge review. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service. 34 p. Available from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402; 1979 O—634-532/1047.

129. **Wuerthner, George. 1995.** Salvage logging: the real threat to forest health. International Journal of Ecoforestry. Victoria, BC: Woodland Planning Publications; [vol. no. unknown]: [3 p.].

Type of paper: Commentary

Source: Scientist

Treatments: Salvage, road building

Variables: Wildlife, sediment

Conclusions:

- Essay criticizes USDA Forest Service salvage policy.
- Suggests that foresters do not understand forest ecology.

Keywords: Salvage harvest, road building, forest health

Index of Keywords

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