Effects of Thinning Young Forests on Chanterelle Mushroom Production

David Pilz, Randy Molina, and Jim Mayo

ABSTRACT

Chanterelle productivity responses were investigated in a replicated, landscape-scale thinning experiment in 50-year-old Douglas-fir stands in the Cascade Range of Oregon. Chanterelle numbers and weight were significantly decreased by thinning the first year after logging, more so in heavily thinned stands than lightly thinned stands for chanterelle numbers. Nearly all evidence of differences in chanterelle productivity among thinning treatment means disappeared within 6 years. Management implications and mitigation measures are discussed.

Keywords: chanterelle productivity, *Cantharellus*, young stand thinning, nontimber forest products

Edible chanterelle mushrooms that grow wild in the moist coniferous forests west of the Cascade Range in Oregon and Washington are avidly sought each summer and autumn by mushroom hunters. The Pacific golden chanterelle (*Cantharellus formosus*, Redhead et al. 1997; formerly known as *Cantharellus cibarius* Fr.) and the white chanterelle (*C. subalbidus* A.H.S. & Morse) are the two most commonly collected chanterelle species in the Pacific Northwest (Pilz et al. 2003). Both fruit in young dense Douglas-fir (*Pseudotsuga menziesii* [Mirbel] Franco) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) stands that are common throughout the region as a result of logging native forests during the latter half of the 20th century.

Many of these young stands are now slated for thinning to produce wood fiber, enhance the growth and health of residual trees, and meet other management goals. On national forestlands, these other goals include multiple use, increasing the biological diversity of plantations and in some cases accelerating the development of late-successional habitat. The commercial harvest of forest products (timber and nontimber) is one of the many uses that managers of national forests are expected to provide for the public in perpetuity. Before the 1980s, chanterelles were predominantly harvested for personal use but now have become important nontimber forest products. Schlosser and Blatner (1995) report that 1.1 million pounds of chanterelles were commercially harvested in Oregon, Washington, and Idaho in 1992. Mushroom buyers paid harvesters $3.6 million for the crop; the chanterelles were then marketed locally, nationally, and internationally. Pacific Northwest chanterelles continue to contribute to a global trade in wild edible mushrooms that is large and multifaceted (Boa 2004). Although timber production has long been integral to forest management, foresters are grappling with how to fit forest products such as chanterelles into their management plans because so little is known about how various management practices and silvicultural regimes affect their persistence and productivity. For context regarding forest management for nontimber forest products, Jones et al. (2002) provide an overview of nontimber forest product issues in the United States, Kerns et al. (2003) provide a review of research on compatible management of timber and commercially harvested understory species, Pilz and Molina (2002) discuss issues regarding the management and monitoring of edible forest mushrooms, and Alexander et al. (2002) describe comparisons of the value of timber and mushrooms comanaged in the same forest.

Chanterelles and other renowned edible forest mushroom species in the Pacific Northwest also are integral functional components of forest ecosystems. Chanterelles, boletes (*Boletus* species), American matsutake (*Tricholoma magnivelare* [Peck] Redhead), truffles (*Tuber gibbosum* Harkn. and *Leucangium carthusianum* [Tul. & C. Tul.] Paol.), and hedgehogs (*Hydnum repandum* L. ex Fr.), among others, are ectomycorrhizal fungi; i.e., they grow symbiotically in association with the roots of particular host tree species (Molina et al. 1993, Hosford et al. 1997, Cairney and Chambers 1999, Pilz et al. 2003). Both Douglas-fir and western hemlock are ectomycorrhizal with chanterelles; hence, we hypothesize that their removal during stand thinning is likely to reduce, at least temporarily, the food supply that is available for the fruiting of chanterelles. Similar effects might be expected with other edible ectomycorrhizal species of fungi, although the influence of thinning likely differs by species (Kropp and Albee 1996). We anticipate, however, that as the

Table 1. Thinning treatments, plot descriptions, and timeline.

Timber sale (replicate)	Thinning treatment	Strip plot length (chains)	Plot area (ft^2)	Years sampled and thinning status[a]					
				1994	1995	1996	1997	1999	2001
Flat Thin	Control	7	7,579	O	O	O	O	O	O
Flat Thin	Light	7	7,579	O		O	X	X	X
Flat Thin	Heavy	7	7,579	O		O	X	X	X
Mill Thin	Control	20	21,654	O	O	O	O	O	O
Mill Thin	Light	19	20,571	O		X	X	X	X
Mill Thin	Heavy	20	21,654	O		X	X	X	X
Tap Thin	Control	9	9,744	O	O	O	O	O	O
Tap Thin	Light	16[b]	17,323	O		X	X	X	X
Tap Thin	Heavy	9	9,744	O		X	X	X	X
Walk Thin	Control	7	7,579	O	O	O	O	O	O
Walk Thin	Light	7	7,579	O		X	X	X	X
Walk Thin	Heavy	7	7,579	O		X	X	X	X

[a]O, not thinned when sampled; X, thinned; blank, not sampled that year because of logging activity hazards. The Flat Thin timber sale replicate was thinned a year later than the other three replicates.
[b]One of the five plots is 17 chains long for a plot area of 18,406 ft^2.

leave trees resume vigorous growth and reoccupy the site, chanterelle fruiting should rebound, perhaps to levels higher than before thinning because the remaining trees will be growing more vigorously. In this study, we investigate stand-level chanterelle productivity responses during 4 of 6 years after the thinning of 50-year-old Douglas-fir forests.

Young Stand Thinning and Diversity Study

Study Context. Landscape-scale studies of forest thinning are expensive; therefore, this study was a part of a larger integrated study entitled the Young Stand Thinning and Diversity Study (YSTDS). The YSTDS is a cooperative venture between the Cascade Center for Ecosystem Management in Blue River, Oregon; Oregon State University in Corvallis, Oregon; the Pacific Northwest Research Station, USDA Forest Service; and the McKenzie and Middle Fork Ranger Districts of the Willamette National Forest in the central Cascade Range of Oregon. The overall goal of the YSTDS was to investigate the environmental effects of several thinning regimes, including a heavy thin that might be used to speed the development of late-successional stand characteristics such as large-diameter trees, a multiple-layered canopy, tree species diversity, and snags for wildlife habitat. The YSTDS objectives included investigating the effect of young stand thinning on ecosystem variables such as understory vegetation, woody debris, tree regeneration, songbird and small mammal populations, and chanterelle production, as well as analyzing the costs, soil compaction, and residual tree damage associated with different logging systems. More information about the ongoing YSTDSs may be obtained by contacting the Cascade Center for Ecosystem Management (2003).

Study Design. Each thinning treatment was applied to a forest stand of 50–100 ac and with trees around 50 years old. Treatments consisted of a nonthinned control (≈250 trees per ac [tpa]), a light thin (≈100–120 residual tpa), a heavy thin (≈50 residual tpa), and a light thin with 20% of the area in gaps (½-ac clearings). The four stand treatments were replicated in each of four timber sales (located from 2 to 20 miles apart) in forests that were climatically, physiographically, edaphically, and ecologically similar. For the chanterelle portion of the study we chose to sample only the control, light, and heavy thinning treatments, not the light thin with gaps. Logging methods included harvester-forwarder, tractor, and skyline, but the logging systems were not replicated (Kellogg et al. 1998).

Chanterelle Sampling. Prethinning chanterelle productivity was sampled in autumn 1994. Earlier that summer, crews who were sampling understory vegetation had established parallel transects through each stand along cardinal compass directions. These transects were marked at each chain (1 chain = 66 ft = 20.12 m). We chose to sample chanterelles along these transects to save the expense of establishing new plot locations. We established five strip plots in each stand to obtain estimates of variation among plots within each stand. The strip plots (elongated rectangles) that we delineated were 16.4 ft (5 m) wide. We determined the side boundaries by measuring 8.2 ft (2.5 m) on either side of the central transect. Because the treatment stands differed in size, we selected strip plot lengths that would provide systematic coverage of conditions within each stand but strove to maintain standard plot lengths for all the treatment stands within a replicate timber sale. Practical considerations during plot establishment resulted in several instances where plots differed in length.

Leave tree densities differed somewhat within the thinned stands, and some areas (such as protection buffers along streams and roads) were not thinned even in the light and heavy thin treatments. Postthinning forest floor conditions that might inhibit chanterelle fruiting or make the mushrooms hard to find (soil disturbance, soil compaction, deep slash, or burned slash piles) also were distributed irregularly within our stands. Our strip plots were established before thinning and traversed these smaller-scale conditions without prior knowledge of their location. The plots also were established before we knew where, or even if, chanterelles fruited in each stand. As a result, we obtained unbiased stand-scale estimates of thinning effects.

Table 1 gives replicate timber sale names, thinning treatments, plot lengths in chains, plot area in square feet, the year each stand was sampled, and whether the stand had been thinned yet. All chanterelles found during a sampling visit were collected, counted, and weighed by plot. Subsamples from each plot were dried to determine moisture content for dry weight analyses. An effort was made to collect all chanterelles that grew during the fruiting season. Crews began sampling when autumn rains elicited the first flush of chanterelles (typically, mid-September) and continued until snow made sampling impractical (typically, early to mid-November). Usually, two complete rounds of sampling were conducted, occasionally three. The sequence of sampling was left to the crew leader's discretion each year

Table 2. Chanterelle productivity and 90% confidence intervals in control stands.

		1994	1995	1996	1997	1999	2001	Mean
Flat Thin	Number per acre	3 ± 7	49 ± 51	101 ± 91	14 ± 18	0 ± 0	29 ± 41	33 ± 18
	Pounds per acre	0.16 ± 0.33	1.72 ± 1.68	12.04 ± 13.94	0.87 ± 1.17	0 ± 0	1.16 ± 1.61	2.66 ± 2.17
Mill Thin	Number per acre	19 ± 26	186 ± 131	129 ± 117	139 ± 110	40 ± 65	216 ± 124	121 ± 38
	Pounds per acre	0.85 ± 1.14	6.87 ± 4.62	8.1 ± 6.7	7.17 ± 5.05	1.69 ± 2.36	12.09 ± 7.12	6.13 ± 1.91
Tap Thin	Number per acre	143 ± 111	222 ± 200	227 ± 139	277 ± 308	105 ± 127	518 ± 349	249 ± 79
	Pounds per acre	6 ± 4.26	6.83 ± 6.74	12.36 ± 4.95	10 ± 9.26	3.35 ± 4.66	23.19 ± 15.25	10.29 ± 3.22
Walk Thin	Number per acre	75 ± 100	620 ± 569	232 ± 257	422 ± 365	124 ± 131	315 ± 333	298 ± 114
	Pounds per acre	4.75 ± 5.87	26.36 ± 20.71	14.74 ± 15.01	29.92 ± 24.76	5.18 ± 6.51	14.14 ± 14.4	15.85 ± 5.64
Mean	Number per acre	60 ± 36	269 ± 143	172 ± 65	213 ± 109	67 ± 41	269 ± 116	175 ± 38
	Pounds per acre	2.94 ± 1.69	10.44 ± 5.59	11.81 ± 4.22	11.99 ± 6.61	2.56 ± 1.73	12.65 ± 5.17	8.73 ± 1.87

and varied by logistical considerations such as crew travel time, not by observed patterns of fruiting. The same individual supervised fieldwork each year to maintain sampling consistency and relocate plots obscured by logging activities. Thorough mapping also helped with relocating plots. All project data and metadata were accessioned into the Forest Science Data Bank (2005).

Analysis. Numbers and fresh weight of chanterelles per acre per year were derived by summing values from repeated seasonal visits to each plot and then averaging across the five plots within each stand to obtain the stand-level values used in analysis of variance (ANOVA) calculations. Productivity varied from 0 to 153 chanterelles/ac and 0 to 6.8 lb per ac among all stands in the prethinning baseline year of 1994, but an ANOVA of 1994 values showed no preexisting or inherent bias in productivity associated with intended thinning treatments (Chanterelles per ha = chanterelles per ac × 2.47, and kilograms per ha = pounds per ac × 1.12).

One replicate timber sale, Flat Thin, was logged a year later than the other replicates. We chose not to include the out-of-sequence Flat Thin replicate in our ANOVA for testing thinning treatments but did include estimates of the productivity of its control stand in Table 2. We used repeated-measures ANOVAs to compensate for the spatial autocorrelation inherent in sampling the same plots each year, and the data were analyzed with the SAS JMP statistical package (SAS Institute, Inc., Cary, NC, USA). Before conducting these ANOVAs, the skewed weight and count distributions were normalized with a $\ln(x + 1)$ transformation (Sabin and Stafford 1990).

We chose not to report analyses of dry weights because the results were very similar to fresh weight analyses and fresh weight is the value of interest to commercial harvesters. We originally attempted to sort chanterelles into quality grades used by mush-

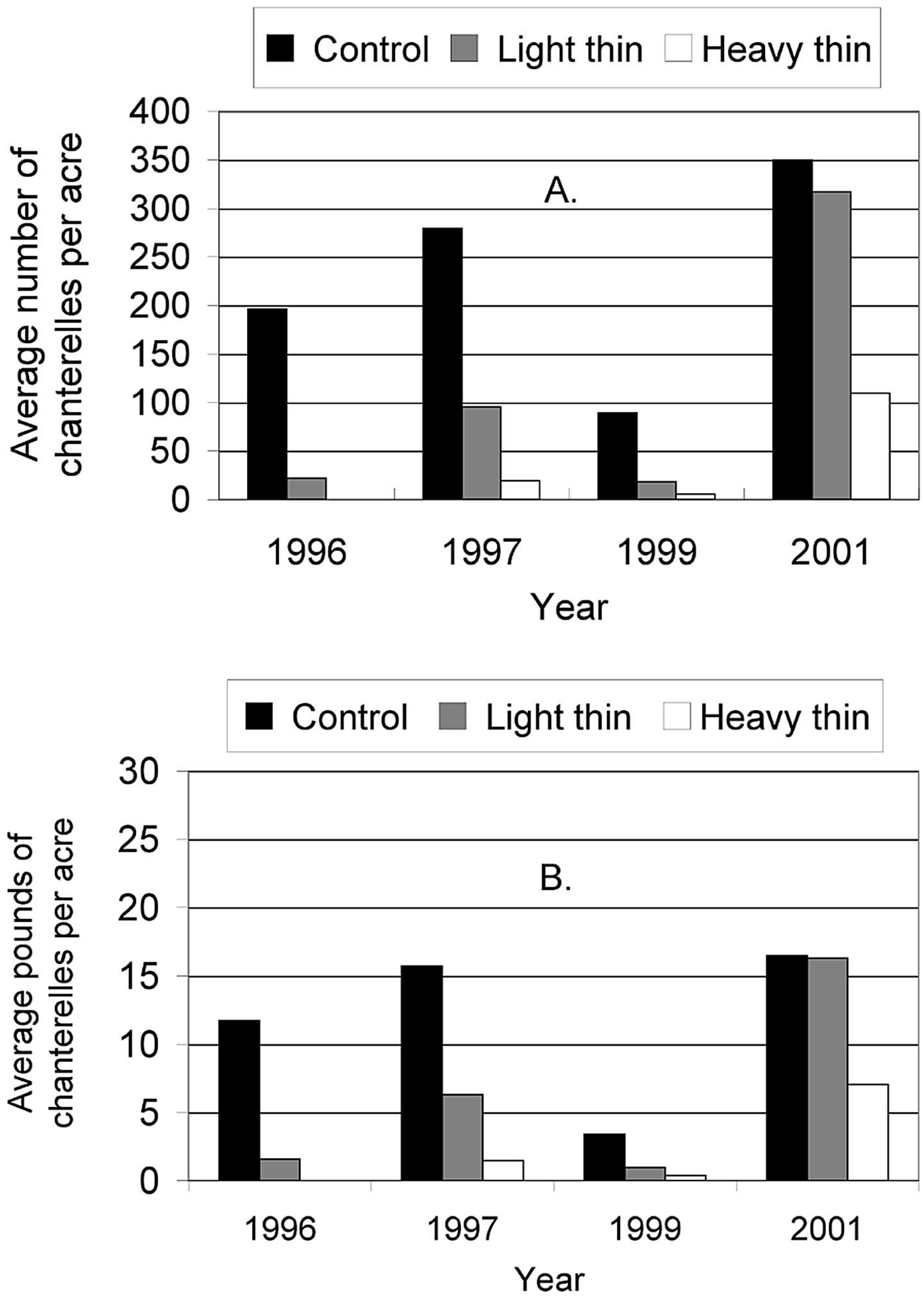

Figure 1. Number and weight of chanterelles per acre per year by thinning treatment and year.

room buyers but stopped because our harvesting and sampling procedures did not match those practiced by harvesters, and commercial grade criteria often are specific to the buyer and intended market.

Crew observations suggested that chanterelles fruited later in thinned stands; therefore, we graphed (by treatment) the cumulative percentage of the total number and weight of chanterelles that fruited by a given date (averaged over three replicate sites and 4 years).

Results. During the 6 years they were sampled, the four control stands averaged 175 chanterelles/ac (range = 0–620) and 8.73 lb/ac (range = 0–29.92). To illustrate typical annual variation among nonthinned stands, the productivity values for each control stand, each year it was sampled, are presented (Table 2). The 90% confidence intervals for these values were calculated from the five strip plots within each stand.

After thinning, both numbers ($P < 0.0447$) and fresh weight ($P < 0.0571$) of chanterelles per acre per year followed the trend of control > light thin > heavy thin. As anticipated from the annual variation noted in Table 2, productivity among treated stands also differed greatly by year ($P < 0.0001$) for both counts and weights. No significant interaction was noted between thinning treatment and year for weights ($P < 0.2293$), but there was a significant interaction ($P < 0.0035$) between thinning treatment and year for numbers of chanterelles. Figure 1 graphically illustrates productivity by thinning treatment over the postlogging period we sampled. Because post hoc tests are inappropriate for comparing specific levels of within-factor effects (years) or interactions (years × thinning treatments) in repeated-measure ANOVA models, we conducted separate ANOVAs to compare thinning treatments each postthinning year (Table 3). Tukey's conservative honestly significant difference post hoc test suggests that significant differences ($\alpha = 0.05$) in chanterelle productivity only occurred in 1996, the first year after thinning when no chanterelles fruited in our plots in the heavily thinned stands. As late as 1999, both weight ($P < 0.0569$) and number ($P < 0.0720$) productivity still might have varied by treatment, but by 2001, any possible differences among thinning treatments had largely disappeared, especially between control and lightly thinned stands (Figure 1).

As observed by our crews, Figure 2 suggests that the more heavily a stand was thinned, the later in the season the chanterelles fruited.

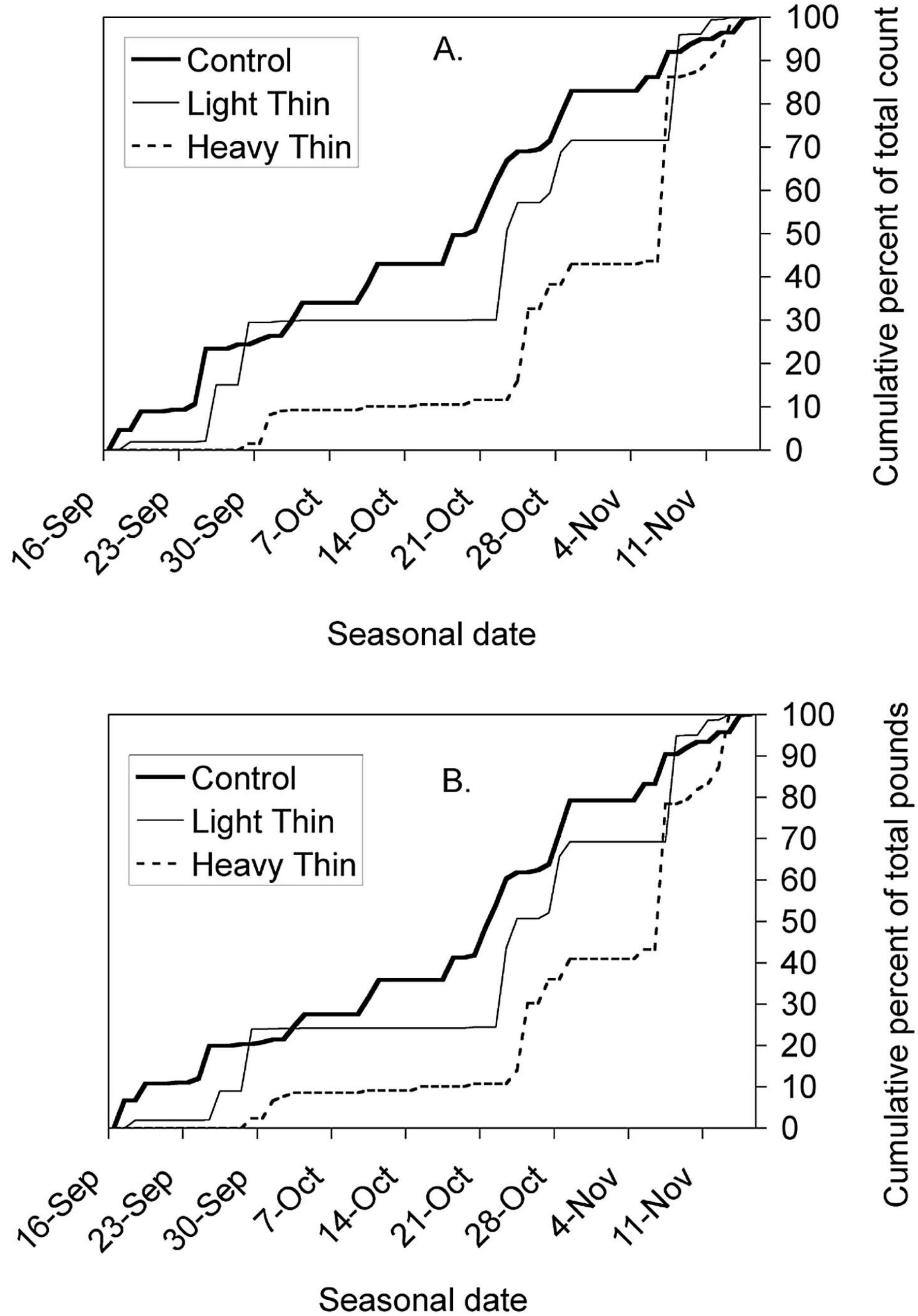

Figure 2. Cumulative percentage (by treatment) of the number and weight of chanterelles fruiting by a given date over all replicate sites and all years.

Discussion. As postulated, thinning diminished chanterelle productivity, at least the first year after thinning. The graphed means and the post hoc tests of chanterelle numbers in 1996 (Table 3) suggest that the more trees removed, the greater the impact on chanterelle productivity. By 2001, 6 years after thinning, little evidence remained that thinning still might affect chanterelle productivity. If a forester wanted to maintain chanterelle fruiting in a stand slated for repeated thinning, one might reasonably infer that frequent light thinning would impact cumulative chanterelle productivity over time less than infrequent heavy thinning. Unless mitigated, however, the additional soil compaction from frequent logging entries could impair the long-term health and fruiting of ectomycorrhizal fungi such as chanterelles (Amaranthus et al. 1996).

Table 3. Interaction between year and thinning treatment for transformed chanterelle weight (A) and count (B) productivity. ANOVA values are for differences among thinning treatments when years were analyzed separately.

			Thinning treatment		
Calendar year	Years after thinning	ANOVA Prob. < F	Control	Light	Heavy
			Weight productivity		
1996	1	0.0004	A	B	B
1997	2	0.1115	A	A	A
1999	4	0.0569	A	A	A
2001	6	0.5021	A	A	A
			Count productivity		
1996	1	0.0001	A	B	C
1997	2	0.1306	A	A	A
1999	4	0.0720	A	A	A
2001	6	0.4014	A	A	A

Different letters in the "thinning treatment" columns represent significant differences in Tukey's honestly significant differences post hoc comparisons at $\alpha = 0.05$.

Not all species of trees are ectomycorrhizal, and of those that are, not all form mycorrhizae with chanterelles. Leave tree selection and underplanting in this study were designed to increase tree species diversity. Presently, most of the large leave trees are still Douglas-fir or western hemlock, species that form ectomycorrhizae with chanterelles. As tree species such as western red cedar (*Thuja plicata* D. Don), incense cedar (*Calocedrus decurrens* [Torrey]) Florin) big leaf maple (*Acer macrophyllum* Pursch), red alder (*Alnus rubra* Bong.), golden chinkapin (*Castanopsis chrysophylla* [Hook.] A. DC.), and Pacific yew (*Taxus brevifolia* Nutt.) mature and become more dominant in such stands, chanterelle productivity could decline because none of these species are known to form ectomycorrhizae with Pacific golden or white chanterelles.

Conditions on the forest floor that effect the development of mushrooms (such as light, temperature, and moisture regimes) are altered by slash disposal techniques and the increased growth of herb and shrub communities under a sparser canopy. Interactions among these factors are complex. For instance, forest floor conditions appeared much drier in the thinned stands than in the control stands during the autumn seasons we sampled. Although brief rainfall events can penetrate the open canopy of thinned stands more rapidly than the closed canopies of nonthinned stands, the forest floor also dries more quickly when sunny weather returns. Even when chanterelles started fruiting in thinned stands, they were more likely to slow or abort growth during subsequent intervals of dry weather than chanterelles in the nonthinned stands. These considerations could account for the observation that thinning delayed fruiting. Indeed, we speculate that delayed fruiting accounted for some of the difference in total seasonal productivity among thinning treatments because snowfall terminated each fruiting season in November. Note that this observation applies to weather patterns in the Pacific Northwest (where late-summer drought is common) and might be less applicable in climates with higher summer rainfall and humidity.

The effects of thinning on chanterelle production could be mitigated somewhat at the scale of mushroom patches or clumps of trees. Highly productive mushroom patches could be protected with nonthinned or lightly thinned buffer areas or by locating skid roads and slash piles elsewhere. Edge effects and satisfactory buffer zones for conserving the health and productivity of ectomycorrhizal mushroom colonies still are not adequately understood. Retaining nearby host trees as a source of carbohydrates and maintaining a humid forest floor microenvironment for mushroom growth are likely both important for chanterelle persistence and productivity. Managers wishing to select appropriate buffer zones for their circumstances can refer to Chen et al. (1995), Hagermann et al. (1999), Stockdale (2000), Gray et al. (2002) for additional information. Of course, to mushroom harvesters in the know, such leave areas would advertise the location of the mushroom patches!

The practice of multiple-resource forestry is replete with time and site-dependent tradeoffs. The challenge for managers is to understand these relations sufficiently well to produce an optimal mix of forest products and amenities over time and across the landscape. Although producing both mushrooms and timber entails some tradeoffs, there also is ample opportunity to enhance their coproduction.

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David Pilz (david.pilz@oregonstate.edu) is forest mycologist, Oregon State University, Department of Forest Science, Corvallis, OR 97331-5752. Randy Molina (rmolina@fs.fed.us) is research botanist, Pacific Northwest Research Station, USDA Forest Service, Forestry Science Laboratory, Corvallis, OR 97331-4401. Jim Mayo (jmayo@fs.fed.us) is forester (retired), USDA Forest Service, McKenzie River Ranger District, Willamette National Forest, McKenzie Bridge, OR 97413.

Rita Claremont (faculty research assistant, Fisheries and Wildlife Department, Oregon State University, Corvallis, OR 97331) and Luther Skills (forestry technician, McKenzie River Ranger District, Willamette National Forest, McKenzie Bridge, OR 97413) ensured multiyear data consistency and quality.