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Density and Development of Bracken Fern *(Pteridium aquilinum)* in Forest Plantations as Affected by Manual and Chemical Application

Philip M McDonald, Celeste S Abbott, and Gary O Fiddler |

ABSTRACT

Logging disturbance on 5 study areas (forest plantations) in northern California favored development of bracken fern (*Pteridium aquilinum* [L.] Kuhn var. *pubescens* L. Underw.), which can be an impediment to successful reforestation. Velpar herbicide (hexazinone) offered short-term control of vegetation, including bracken fern, sufficient to establish ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings and ensure vigorous growth. Our examination of site preparation techniques, including burning residual logging debris followed by chemical and mechanical control of vegetation, indicated that bracken fern density, foliar cover, and height were highly variable both within and among study areas. After 5 growing seasons, bracken density in the control (site preparation only) ranged from 5800 to 40850 fronds/ha (2345 to 16 530 fronds/ac), foliar cover from 1% to 24%, and height from 0.5 to 0.6 m (1.8 to 1.9 ft). Among conifer release treatments (control of unwanted vegetation), Velpar effectively controlled bracken, but Garlon herbicide aided bracken by killing competing shrubs. After 10 growing seasons, more than 22 000 bracken fronds/ha (8910/ac) were present in all treatments. Bracken fern demonstrated remarkable ecological amplitude, was virtually independent of other species, and was only moderately influenced by a wide range of environments. Growers and planters should be aware of these findings and use herbicides that show demonstrated effectiveness.

KEY WORDS

ecology, conifer plantations, interference, northern California, ponderosa pine, *Pinus ponderosa*

NOMENCLATURE

(trees) Little (1979); (plants) Hickman (1993)

Few people grow bracken fern *(Pteridium aquilinum* [L.] Kuhn var. *pubescens* L. Underw.) and even fewer plant it in their fields or forests. Many growers and planters, however, have lost outplantings of more valuable species to this widespread and competitive fern. Knowledge about bracken's morphology, development, and control could be key to successful establishment of other desirable species. Currently, only limited information is available on the autecology of bracken fern in California and even less on its response to various physical and chemical treatments.

Taxonomists agree that the genus *Pteridium* is monotypic with one worldwide species and several morphologically distinguishable varieties. In North America, bracken fern is found throughout California, north to Alaska, in northwestern Mexico, eastern Canada, and in the northeastern US (Hickman 1993). It is found from sea level to an elevation of 3050 m (10 000 ft). Bracken grows well in a variety of environmental conditions and specifically in a wide range of soils, moisture regimes, and amounts of sunlight. It has remarkably few natural enemies in terms of herbivores, insects, or diseases, is well protected from fire, and thrives on disturbance. Most animals do not prefer bracken as food. If eaten too much, it can produce a urinary disease that is lethal to cattle (Radosevich 1978) and to llamas (Peauroi and others 1995) and can create various deficiencies in sheep and horses. Bracken's effect on the larvae of several lepidopteran species is to impair development (Hendrix 1977).

Not only is bracken competitive for moisture, nutrients, and light, it also lessens competition by smothering plants with its senescent fronds (Grime 1979) and through chemical interference (allelopathy) (Stewart 1975; Ferguson and Boyd 1988). Herbaceous plants are particularly susceptible to chemical interference.

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Figure 1. Well-developed year-old bracken ferns surrounding a polypropylene mulch mat with a dead ponderosa pine seedling in the center.

In southern California, Gliessman and Muller (1978) found that toxins leached from dead standing bracken fronds by the first rains in the fall were largely responsible for herb suppression.

In addition to its adaptability and competitiveness, the worldwide success of bracken is attributable to its efficient reproductive mechanism and a flexible growth habit. The spores are light and carried far and wide by the wind. After germination, a small heart-shaped gametophyte is produced, which after fertilization, grows upward to form a vertical stem. After 7 to 9 leaves have formed, the stem forks and plunges downward into the soil. This stem (now a rhizome) forks again and again, forming a system of leafless long shoots and short shoots on which fronds are borne (Minore 1966). Although millions of spores are produced, few result in new plants, and elongation of rhizomes is the primary means of expansion.

Once established, sections of rhizomes die and rot, leaving living pieces at each end. Thus, 2 genetically similar plants are formed each time this happens. In general, rhizome systems advance at their periphery and decay farther back. The resulting colony of plants and rhizomes can spread rapidly over large areas. In England, Watt (1940, 1943) found that rhizome extension was 0.3 to 0.9 m/y (1 to 3 ft/y), the longest main rhizome was 27 m (89 ft), and the total length of rhizomes on one plant was 397 m (1301 ft). The age of individual bracken plants was estimated at 35 to 72 y.

Bracken fern is notorious for being an aggressive and persistent species in young forest plantations. Such plantations occur after various combinations of logging, burning, and site preparation. Initially, they are characterized by substantial amounts of bare mineral soil, planted conifer seedlings, and few plants of other species. Belowground, however, the rhizomes of bracken fern are mostly unscathed. In this environment, soil moisture and nutrients are plentiful and bracken becomes a vigorous pioneer species (Figure 1). In terms of percent cover, bracken fern was 1 of the 13 principal species found in the first decade after a major forest fire in northern Idaho (Stickney 1986). In northern California, bracken ranked among the top 4 species in terms of density and foliar cover each year for 5 y after clearcutting (McDonald 1999). During this period, second-year values were density, 25 286 fronds/ha (10 233/ac); foliar cover, 3%; and height, 0.3 m (1 ft). Once established, bracken often persists and dominates for many years.

Plainly, bracken fern is capable of colonizing a recently disturbed area with many vigorous plants, but how do these plants survive and grow in ensuing years? More specifically, how does bracken fern develop on different sites with differing amounts and different categories (conifer seedlings, shrubs, forbs, and grasses) of competing vegetation?

Our study objectives were to quantify the density and development of bracken fern over a 5- to 10-y period in young conifer plantations in northern California, to relate this development to various factors in the environment (elevation, site potential, precipitation), and to examine its response to several physical and chemical plantation release treatments.

METHODS

Location and Site Characteristics

As part of a National Administrative Study by the USDA Forest Service on alternative methods for controlling unwanted vegetation around conifer seedlings (releasing from competition) (Fiddler and McDonald 1984), many individual species and cate-

TABLE 1

Location and physical characteristics of 5 study areas in northern California.

Study area	Location	Site productivity	Elevation (m)	Average annual precipitation (mm)	Plant community
Beartrap	Central Coast Range	Medium-low	427 [a]	3175 [b]	forbs, grasses [c]
Deans Valley	Northern Sierra Nevada	Medium-high	1372	1016	shrubs, forbs, grasses [d]
Latour	Southern Cascade Range	Medium	1586	1168	shrubs [e]
Nooning Creek	Central Coast Range	Medium	702	3175	hardwoods, shrubs [f]
Yolla Bolla	Klamath Mountains	High	1159	1397	shrubs, forbs, grasses [g]

[a] Conversion: 1 m = 3.3 ft.
[b] Conversion: 1 mm = 0.04 in.
[c] McDonald and others (1994a).
[d] Data on file at Pacific Southwest Research Station, Redding, California.
[e] McDonald and others (1999).
[f] McDonald and others (1994b).
[g] McDonald and Fiddler (1997).

gories of species (shrubs, for example) were quantified. Bracken fern was one of these. Data were gathered from 5 study areas in northern California where it was both well established and well distributed. Specific information on plantation release treatments, experimental design, sampling, statistical analysis, and results have been published for 4 of the 5 areas. The 5 areas (citation in parentheses) were titled Beartrap (McDonald and others 1994a), Deans Valley (data analyzed but not yet published), Latour (McDonald and others 1999), Nooning Creek (McDonald and others 1994b), and Yolla Bolla (McDonald and Fiddler 1997). The study areas were located in plantations containing newly planted coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) or ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) seedlings. Before planting, the study areas had been disturbed by both a timber harvest and site preparation. Site preparation involved removing unmerchantable conifer and hardwood trees, as well as logging debris and shrub clumps, and bulldozing them into windrows for eventual burning. Broadcast burning also was employed. The study areas were located in several mountain ranges at moderate elevations, had different levels of site productivity, and received different amounts of precipitation (Table 1).

One factor all study areas had in common was the Mediterranean climate typical of California, which is characterized by long, hot, dry summers and cool, wet winters. May through September often are rainless. Even the Beartrap and Nooning Creek study areas, which were directly influenced by the Pacific Ocean, had a summer dry period of at least 2 mo.

Although the 5 study areas had a diverse and rapidly developing plant community, the composition of the community differed (Table 1).

Design and Sampling

Each of the 5 study areas had an untreated, but planted, control and 3 to 6 release treatments. Each study area had a specific set of treatments and only a few were installed on more than 1 study area. The control represented the vegetation that originated naturally after site preparation. The treatments were the herbicides Escort (metsulfuron), Garlon (tryclopyr), and Velpar (hexazinone), and the manual release treatments were grubbing with hand tools 2 and 3 times. The treatments that were applied were broad spectrum in the sense that they were known to be effective on several plant species in at least 2 vegetation categories. No treatment was specifically aimed at controlling bracken fern, although at least one (Velpar) was suspected as being effective.

Velpar is a soil-active herbicide and the others are foliage active. The herbicides were applied directly with a backpack apparatus in May and October according to label recommendations. Spraying took place between 07:00 and 09:00 PST on clear days with little or no wind. A guide was used to ensure uniform coverage of the herbicides and to avoid overlapped and skipped areas. To avoid possible spray damage, plastic bags were used to cover conifer seedlings. Manual release involved cutting plants below the root crown. This removed bracken fronds but did only minor damage to roots and rhizomes. Because this treatment was applied 2 or 3 times, the vigor of bracken probably was negatively affected.

The experimental design was completely randomized with 1-way or 2-way treatment structure. All release treatments in each study area were replicated at least 3 times. Each replicate was termed a "plot." Sampling intensity for conifer seedlings was 20 to 35 seedlings per plot, and for all other vegetation was 5 to 7 randomly chosen, seedling-centered, 0.0004-ha (0.001-ac) subplots in each plot (Figure 2). Sampling generally took

Photo by Philip McDonald, USDA Forest Service

Figure 2. Sampling frame in place on a 0.0004-ha subplot treated with Velpar herbicide.

place for growing seasons 1 through 5 and at the end of the study after 10 growing seasons. However, tight budgets limited data collection at Yolla Bolla for the first 5 seasons and after 5 seasons at Nooning Creek and Beartrap.

Principal species or categories of vegetation were measured for density, foliar cover (the sum of shadows that would be cast by stems and leaves expressed as a percent of the land surface [Daubenmire 1968]), and average dominant height. More specifically, density was the number of plants per subplot expressed on a per-hectare basis, foliar cover was an ocular estimate, and height was a direct measurement.

RESULTS

Bracken fern responded well to disturbance from site preparation and plantation release. After 1 growing season, average density in the control ranged from 6000 to 28000 fronds/ha (2400 to 11340/ac) and height between 0.3 and 0.4 m (1 and 1.3 ft). Among the 5 release treatments, bracken density ranged from more than 22000 to 46000 fronds/ha (8800 to 19000/ac) in 4 of the 5 treatments after 1 growing season, and height from 0.2 to 0.3 m (0.7 to 1.0 ft).

No strong relationship of mean bracken fern density, foliar cover, or height with site productivity, amount of competing vegetation, elevation, or amount of precipitation was found (Tables 1, 2). In the control, which received no release treatments, bracken fern density was highest after 2 to 4 growing seasons and then declined (Figure 3A). Variation was high with ferns averaging more than 47 000 fronds/ha (19 000/ac) at Nooning Creek after 2 growing seasons to more than 2100/ha (850/ac) at Deans Valley after 10 seasons. Foliar cover followed the same trend of increasing and declining, except at Beartrap, where it increased steadily for the 5 growing seasons in which it was measured. Foliar cover ranged from 24% at Beartrap to less than 1% at Deans Valley (Figure 3B). Average height tended to increase with time in the control in all study areas and ranged about 0.6 to 0.8 m (2 to 3 ft) after 10 growing seasons (Figure 3C). Of note was that the relative rankings in mean density, foliar cover, and height remained the same among study areas for each growing season.

Among release treatments, the general developmental trend for bracken was to increase in mean density and foliar cover and then decline, and for height to increase during the study (Figures 4A–4C). Velpar consistently produced lower values of mean bracken density, foliar cover, and height, and Garlon generally produced the highest density and cover values. Height values generally increased during the study. After some early switching between the 2 manual release treatments, the relative rankings of treatments tended to become constant after the fourth growing season. Of particular note was that density exceeded 20000 fronds/ha (8100/ac) in all treatments where data were collected after 10 growing seasons; height exceeded 0.6 m (2 ft) after 10 seasons in all treatments; and foliar cover values were low at the end of the study (Figure 5).

DISCUSSION AND CONCLUSIONS

Vegetative development in new conifer plantations in northern California is best characterized as dynamic. Almost all

TABLE 2

Relationship of bracken fern fronds to other vegetation and planted conifer seedlings in the control, northern California, after 5 growing seasons.

Study area	Bracken fern [a]			Other vegetation			Conifer
	Density *number/ha* [b]	Cover %	Height *m* [c]	Density *number/ha*	Cover %	Height *m*	height *m*
Beartrap	11962	24	0.5	1 414 704	50	0.8	1.9
Deans Valley	5807	1	0.6	143 318	47	0.7	0.7
Latour	32 289	3	0.5	89 616	51	0.8	1.1
Nooning Creek	40 853	4	0.5	51 313	49	0.8	1.2

[a] For bracken fern, standard errors for density ranged from 2506 to 9439 fronds/ha, for other vegetation from 5009 to 135 912 plants/ha; standard errors for foliar cover of bracken ranged from less than 1% to 6%, and for other vegetation from 5% to 10%; standard errors for height of bracken ranged from 0.03 to 0.1 m, for other vegetation from 0.03 to 0.2 m, and for conifer seedlings from 0.06 to 0.4 m.

[b] Conversion: Fronds/ac = (fronds/ha)/2.5.

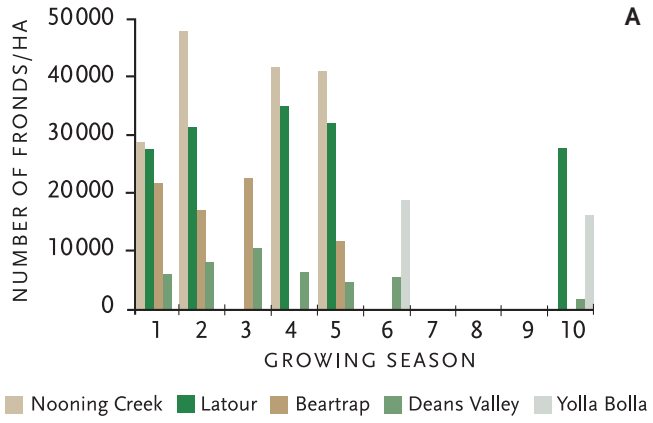
[c] Conversion: 1 m = 3.3 ft.

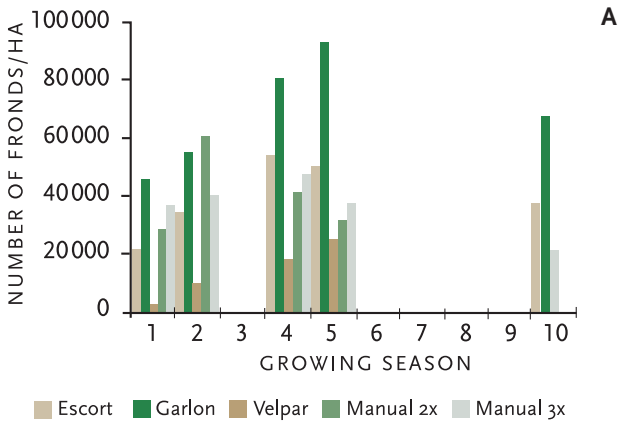
plant species have adapted a strategy to grow as fast as they can, as soon as they can, and to reproduce before the onset of summer drought. Many species from several reproductive strategies (Grime 1979) compete for increasingly scarce site resources. Forest openings become occupied by shrubs, forbs, and grasses soon after disturbance, and the diversity, density, and development of the plant community increases rapidly (McDonald 1999). In general, those species with in-place root systems (root crowns or rhizomes) are the most competitive because they capture site resources before competitors.

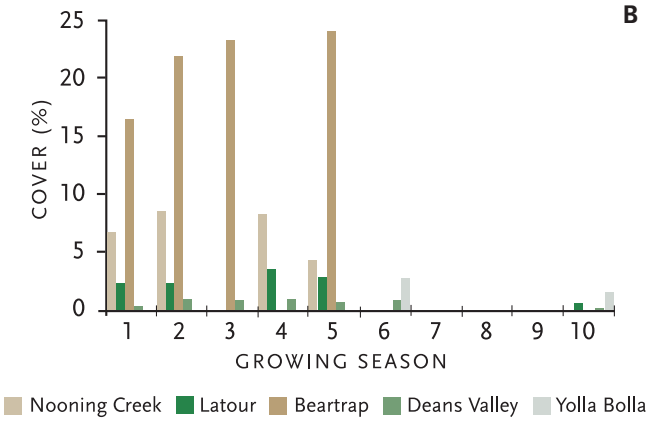
Plainly, disturbance from site preparation and release favored bracken fern. After 1 growing season, high density values were present in the controls with even higher values in the released plots. Garlon also favored bracken by eliminating or weakening shrub plants, thereby freeing site resources for utilization by the fern (McDonald and others 1999). Conversely, the only agent that negatively impacted bracken, at least for the first few seasons, was Velpar. By the end of the study, however, bracken density and height indicated that it was rapidly regaining ground lost to this herbicide.

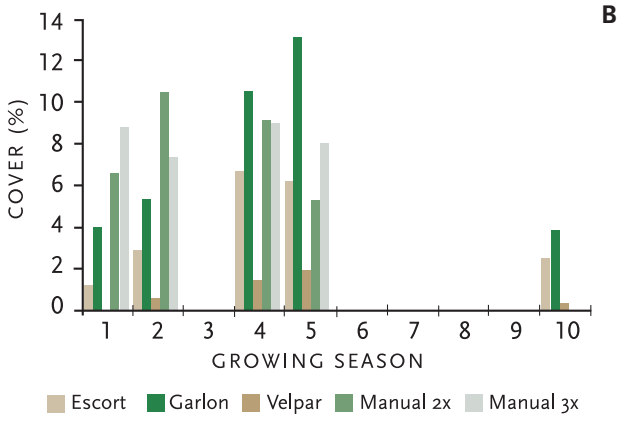
Other than the above, we could find very little, either environmentally or biologically, that affected this fern. Environment, site quality, and competition had no marked effect. The trend of increase and then decline in density and foliar cover in treated areas and controls indicated a response to competition, but not one of major significance. After 10 growing seasons, at least 22000 tall fronds were present on each hectare in treated areas and in the controls.

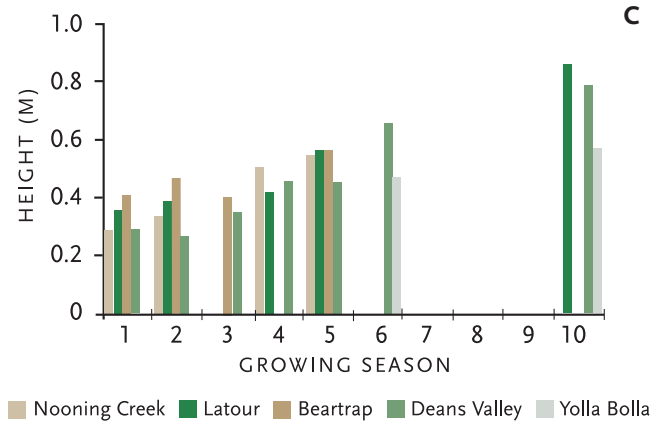
Results from the 5 study areas reported here and many others worldwide (Gjerstad and Glover 1992) note that it is the











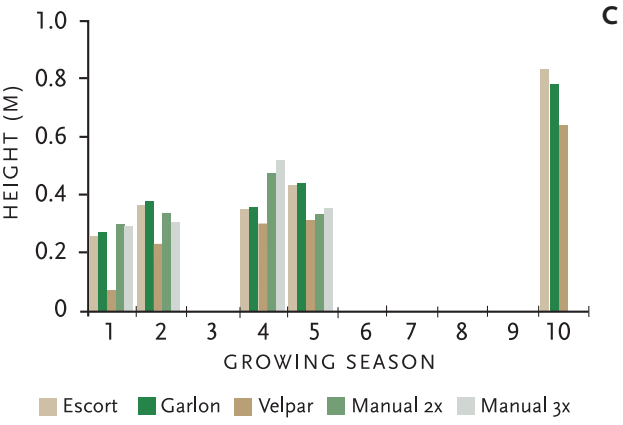


Figure 3. Mean density (A), foliar cover (B), and height (C) of bracken fern in the control on 5 study areas, northern California. Standard errors ranged from 5181 fronds/ha after 1 growing season to 10726/ha after 4 seasons; for foliar cover from 0.4% to 11.2% in seasons 10 and 3, respectively; and for height from 0.02 to 0.09 m. Conversions: 1 m = 3.3 ft; fronds/ac = (fronds/ha)/2.5.

Figure 4. Mean density (A), foliar cover (B), and height (C) of bracken fern in 5 treatments, northern California. Standard errors ranged from 7320 fronds/ha the first growing season to 13626/ha the tenth season; for foliar cover from 1% in growing season 10 to 1.8 % in growing season 5; and for height from 0.02 to 0.06 m. Conversions: 1 m = 3.3 ft; fronds/ac = (fronds/ha)/2.5.

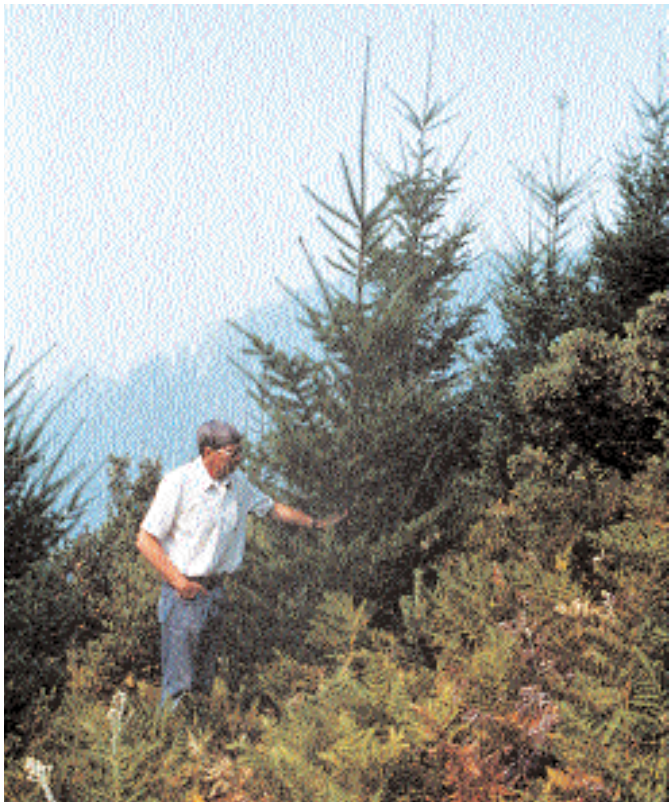


Photo by Philip McDonald, USDA Forest Service

Figure 5. Dense bracken fern and planted Douglas-fir seedlings occupy this treated site in a young plantation in northern California. Fern density was much lower when the seedlings were young.

amount of competition during the first 3 growing seasons that determines the future growth of conifer seedlings, not that present at age 10. Consequently, Velpar herbicide, which decreased the density and growth of competing vegetation, including that of bracken fern, produced statistically significant increases in ponderosa pine seedling growth (mean height, 57%; diameter, 81%; foliar cover, 295%; crown diameter, 98%) over that in the control in 10 years.

Determining ecological and developmental characteristics about a specific plant species in a plant community of many species is difficult, especially when some species are inherently taller and wider. It is even more difficult when several plant communities with different environments are involved. Bracken fern is one of the few plant species where such characteristics can be determined. Its many adaptations to environment, resistance to damaging agents, flexible growth habit, and efficient reproductive mechanisms allow it to become established, reproduce, and compete throughout its extensive natural range. Minore (1966) found that bracken from 4 widely different sources did not grow uniformly when brought together in 1 environment. Moreover, he found that the nutrient content of bracken fronds was not related to the nutrient concentration of the forest soils in which they grew.

In our study, we noted that variation in frond density, foliar cover, and height was high at each study location and for each treatment. Furthermore, variation in bracken characteristics often was high within a single plot. Plants tended to be tallest in partial shade, intermediate in shade, and shortest in full sunlight. Competition from taller conifers and shrubs created shade levels that led to taller ferns. Indeed, the height of some ferns at Nooning Creek reached 1.4 m (4.6 ft) at the edge of, and even under, Douglas-fir seedling crowns. Nevertheless, the fact that relative rankings remained the same among study areas for each growing season in the control and among treatments suggest an influence by the environment at an intermediate scale. Thus, there is large variation in bracken developmental characteristics among plants on a fine (sun/shade) scale, less variation for plants at an intermediate (study location or treatment) scale, and if a speculation is permitted—probably will be little or no variation at the coarse (mountain range) scale.

This study has increased knowledge on fern density and development in a wide variety of environments that have differing degrees of human-caused disturbance. We also identified Velpar as a helpful agent. Radosevich (1978) found that "numerous methods of bracken fern control have been tested: controlled fire, mechanical removal, tillage, and herbicides are some examples. However, little success has been achieved with any method." Later, Cole and Newton (1989) found that 2 formulations of glyphosate herbicide (Roundup and Accord)

controlled bracken fern in a young Douglas-fir plantation in western Oregon. Still later, Johnson (2000) noted that glyphosate was the preferred herbicide for controlling bracken fern in California because of its effectiveness.

Although the practical gain from our study was small, the gain in biological knowledge, although modest, should be helpful to ecologists and vegetation managers. Along with much density and developmental information, we have noted bracken fern's wide ecological amplitude. This makes it virtually independent of other species and only moderately influenced by the environments created by various treatments. Plainly, it is an aggressive and well-adapted species. By recognizing the large amount of ecotypic variation in *Pteridium aquilinum,* managers will be cautious when recommending manipulation strategies and prescribe only those herbicides that have proven to be effective.

REFERENCES

Cole EC, Newton M. 1989. Seasonal efficacy comparison of two glyphosate formulations. In: Proceedings of the Western Society of Weed Science 42:136–142.

Daubenmire RF. 1968. Plant communities: a textbook on plant synecology. New York (NY): Harper and Row. 300 p.

Ferguson DE, Boyd RJ. 1988. Bracken fern inhibition of conifer regeneration in northern Idaho. Ogden (UT): USDA Forest Service, Intermountain Research Station. Research Paper INT-388. 11 p.

Fiddler GO, McDonald PM. 1984. Alternatives to herbicides in vegetation management: a study. In: Proceedings 5th annual forest vegetation management conference; 1983 Nov 2–3; Sacramento, CA. Redding (CA): Forest Vegetation Management Conference. p. 115–126.

Gjerstad D, Glover GR. 1992. Abstracts: international conference on forest vegetation management—ecology, practice, and policy; 1992 April 27–May 1; Auburn (AL): Auburn University School of Forestry. Report 1992:1. 140 p.

Gliessman SR, Muller CH. 1978. The allelopathic mechanisms of dominance in bracken (*Pteridium aquilinum*) in southern California. Journal of Chemical Ecology 4(3):337–362.

Grime JP. 1979. Plant strategies and vegetation processes. New York (NY): John Wiley and Sons. 222 p.

Hendrix SD. 1977. The resistance of *Pteridium aquilinum* (L.) Kuhn to insect attack by *Trichoplusiani ni* (*Hubn.*). Oecologia 26(4):347–361.

Hickman JC, editor. 1993. The Jepson manual, higher plants of California. Berkeley (CA): University of California Press. 1400 p.

Johnson S. 2000. Personal communication. Sacramento (CA): Wilbur-Ellis Co. Sales Manager.

Little EL. 1979. Checklist of United States trees (native and naturalized). Washington (DC): USDA Forest Service, Agriculture Handbook 541. 375 p.

McDonald PM. 1999. Diversity, density, and development of early vegetation in a small clear-cut environment. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. Research Paper PSW-RP-239. 22 p.

McDonald PM, Abbott CS, Fiddler GO. 1999. Development of a shrub-fern-ponderosa pine community eleven years after site preparation and release. Western Journal of Applied Forestry 14(4):194–199.

McDonald PM, Fiddler GO. 1997. Vegetation trends in a young ponderosa pine plantation treated by manual release and mulching. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. Research Paper PSW-RP-234. 15 p.

McDonald PM, Fiddler GO, Harrison HR. 1994a. Mulching to regenerate a harsh site: effect on Douglas-fir seedlings, forbs, grasses, and ferns. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. Research Paper PSW-RP-222. 10 p.

McDonald PM, Fiddler GO, Harrison HR. 1994b. Repeated manual release in a young plantation: effect on Douglas-fir seedlings, hardwoods, shrubs, forbs, and grasses. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. Research Paper PSW RP-221. 11 p.

Minore D. 1966. The growth of *Pteridium aquilinum* (L.) Kuhn var. *pubescens* in relation to geographic source, soil nutrients, and forest site. [PhD dissertation]. Berkeley (CA): University of California. 96 p.

Peauroi JR, Mohr FC, Fisher DJ, and others. 1995. Anemia, hematuria, and multicentric urinary neoplasia in a llama (*Lama glama*) exposed to bracken fern. Journal of Zoo and Wildlife Medicine 26(2):315–320.

Radosevich SR. 1978. Bracken fern control with several herbicides. California Agriculture 32(6):7–8.

Stewart RE. 1975. Allelopathic potential of western bracken. Journal of Chemical Ecology 1:161–169.

Stickney PF. 1986. First decade plant succession following the Sundance forest fire, northern Idaho. Ogden (UT): USDA Forest Service, Intermountain Research Station. General Technical Report INT-197. 26 p.

Watt AS. 1940. Contributions to the ecology of bracken (*Pteridium aquilinum*). I. The rhizome. New Phytologist 39:401–422.

Watt AS. 1943. Contributions to the ecology of bracken (*Pteridium aquilinum*). II. The frond and the plant. New Phytologist 42:103–126.

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