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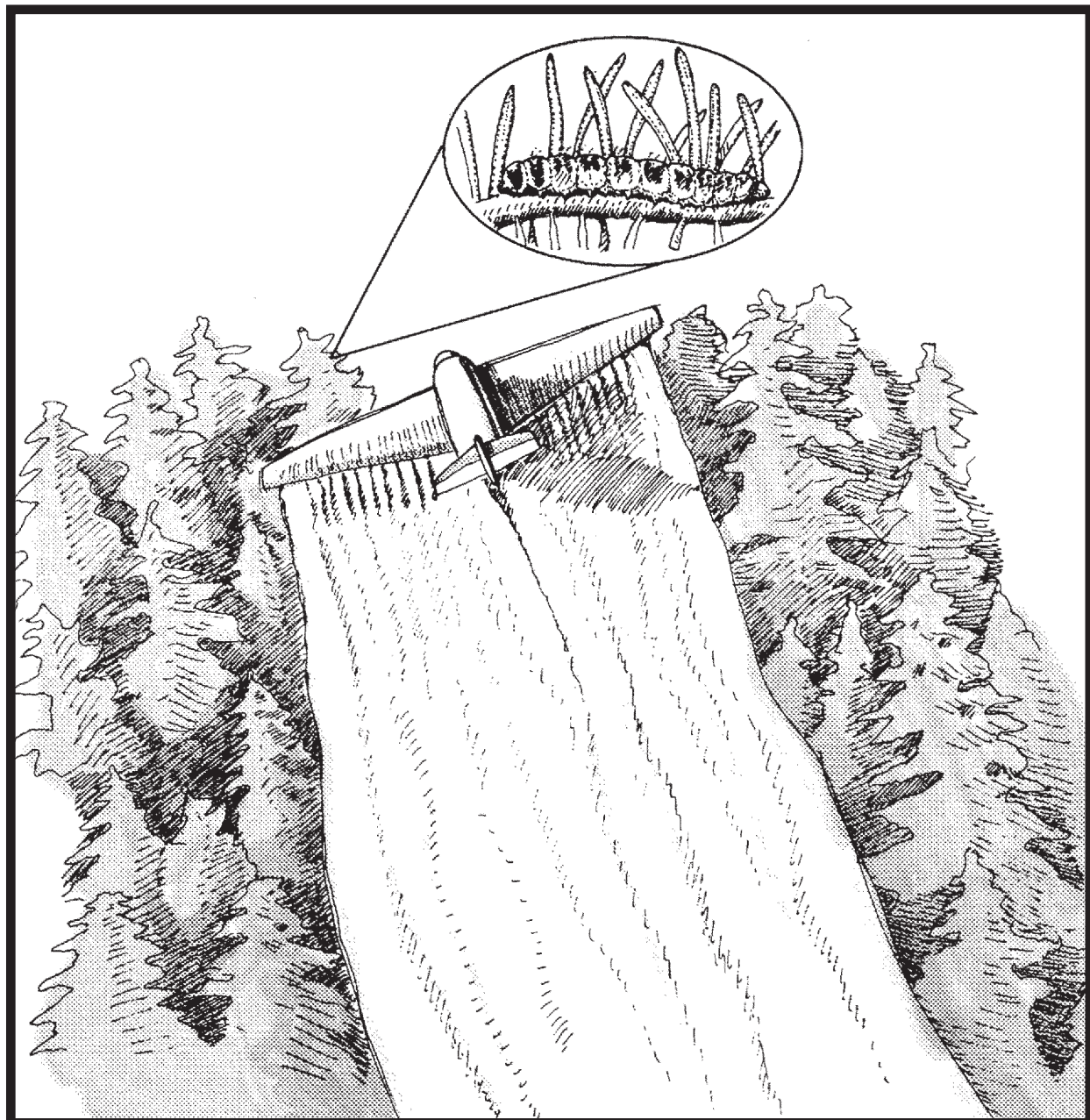
Pacific Northwest  
Research Station

General Technical  
Report  
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# Effects of Insecticide Treatments on Subsequent Defoliation by Western Spruce Budworm in Oregon and Washington: 1982-92

Katharine A. Sheehan



This publication reports analyses involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

## **Author**

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## Abstract

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Effects of insecticide treatments conducted in Oregon and Washington from 1982 through 1992 on subsequent defoliation by western spruce budworm (*Choristoneura occidentalis* Freeman) were evaluated by using aerial sketchmaps and a geographic information system. For each treatment, the extent and severity of defoliation was calculated for the treated area and a set of four nested rings surrounding the treated area (0-0.5 mile, 0.5-1 mile, 1-2 miles, and 24 miles) for up to 8 years: 3 years prior to treatment, the year of treatment, and 4 years following treatment. Insecticide treatments applied in 1982 and 1983 coincided with reduced percentages of defoliation by western spruce budworm during the year following treatment. However, the percentage of defoliation usually returned to pretreatment levels by the second year, and defoliation severity in treated and adjacent untreated areas was nearly identical following treatment. For the period from 1985 through 1992, defoliation patterns (including both extent and severity) following treatment were generally similar in treated and adjacent untreated areas.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, defoliation, insecticides, effects, suppression projects.

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## Introduction

Western spruce budworm, *Choristoneura occidentalis* Freeman (Lepidoptera: Tortricidae), is commonly regarded as one of the most important defoliators of western coniferous forests (Fellin and Dewey 1982, Furniss and Carolin 1977, Johnson and Denton 1975). Defoliation by budworm larvae feeding primarily on developing buds and new foliage may lead to tree growth loss, topkill, and mortality (Van Sickle 1987).

Over 2.1 million acres have been treated with insecticides to suppress western spruce budworm populations in Oregon and Washington since the current outbreaks began in 1980 (appendix A). The objective of this analysis was to answer several questions regarding the effectiveness of these treatments: What are the effects of treatment on defoliation extent and severity in subsequent years? How long do the treatment effects last? Is there any evidence that budworms from untreated areas invade adjacent treated areas after treatment? Answers to these questions would help managers evaluate the costs and benefits of using insecticides to suppress western spruce budworm populations.

Year-to-year changes in defoliation extent or severity do not necessarily reflect proportional changes in budworm density, because similar densities may result in a wide range of defoliation levels (Campbell 1993). One year of defoliation observations alone also cannot be used to predict tree responses (for example, reduced growth, topkill, mortality) because many other factors such as drought, previous defoliation history, and site conditions also affect tree responses (Crookston 1991, Nichols 1988). However, economic analyses conducted during the environmental assessment process usually incorporate assumptions regarding defoliation patterns with and without insecticide treatment (USDA 1987, 1991), and very little information is available to quantify those assumptions.

Most insecticide treatments aimed at western spruce budworm from 1980 to the present were operational projects with no comparable untreated areas established to evaluate treatment effectiveness. A direct, statistically based evaluation of the effects of treatment on subsequent defoliation therefore is not possible. Instead, defoliation within treated areas is compared to defoliation in adjacent untreated areas.

## Analysis Methods Observed Defoliation

In Oregon and Washington, aerial sketchmapping has been conducted annually since 1947 through a cooperative project involving both states and the USDA—Forest Service. In most years, all forested lands (both public and private) are surveyed during July and August (Dolph 1980). Flying in reconnaissance planes at about 1,000 to 2,000 feet aboveground, two observers—each mapping a 2-mile swath on their side of the plane—sketch the location of insect and disease activity onto 1:126,720 (Oregon) or 1:100,000 (Washington) maps; the causal agent and severity are also recorded for each polygon.<sup>1</sup> In any given year, the aerial survey was always flown after any insecticide treatments scheduled for that year had been applied, and usually after defoliation by the current budworm generation had been completed. Aerial sketchmaps of defoliation by western spruce budworm were scanned or digitized for 1980 through 1994 as described by Sheehan (in press).

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<sup>1</sup> Personal communication. 1995. David R. Bridgewater, entomologist, Pacific Northwest Region, P.O. Box 3623, Portland, OR 97208-3623.

## Identifying Spray Projects and Surrounding Rings

Two systems for rating defoliation severity have been used during this period: either three defoliation classes or four defoliation effects classes. Sketchmaps from 1980 to 1984 display three classes of defoliation severity: light, medium, and heavy. In 1985, severity was not rated for most areas defoliated by western spruce budworm; the unrated areas were arbitrarily assigned to the light defoliation class for this analysis. From 1986 to the present, Oregon sketchmaps display four classes based on defoliation effects (1 = defoliation of current year foliage is visible from the air; 2 = defoliation is visible, some bare tops are present; 3 = many bare tops, though some foliage is present; 4 = most crowns are bare, virtually no foliage is left); most Washington sketchmaps continue to display the three defoliation classes. The defoliation severity ratings are intended to reflect the cumulative effects of several consecutive years of defoliation. Defoliation should be mapped and rated for severity only in those areas where budworm is currently active.

Most spray projects conducted from 1980 through 1993 were located in Oregon; therefore, results of this analysis are reported by defoliation class for 1980-84 and by defoliation effects class for 1985-93. For graphs or analyses that reference observations from both periods, "light defoliation effects" refers to defoliation effects class 1 and light defoliation; "moderate defoliation effects" refers to defoliation effects class 2 and medium defoliation; and "severe defoliation effects" refers to defoliation effects classes 3 and 4 plus heavy defoliation.

A total of 59 different projects aimed at western spruce budworm during 1980-93 were identified (Hadfield 1992, 1994, [n.d.]; Howes and Wallesz [n.d.]; Ragenovich 1988; Sheehan [in press]; Skyler and others 1990). The three projects conducted in 1991 were primarily aimed at Douglas-fir tussock moth, *Orgyia psuedotsugata* (McDunnough) (Lepidoptera: Lymantriidae), although western spruce budworm also was present. Maps of the spray project areas suitable for digitizing could not be obtained for 10 of those projects (covering about 32,570 acres, or 1.5 percent of the total acres treated; see appendix B), and those projects were not considered further in this analysis. Spray project boundaries for the remaining projects were either scanned or digitized from paper copies of the project as described in Sheehan (in press).

For each spray project, the project boundary and four surrounding "rings" around the project were delineated (fig. 1). The four rings were from 0 to 0.5 mile from the project boundary, from 0.5 to 1.0 mile, from 1.0 to 2.0 miles, and from 2.0 to 4.0 miles from the project boundary. These rings were created by using a buffer command within a geographic information system (GIS). Untreated areas inside the general project boundary were assigned to the appropriate ring depending on the size of the untreated island. Projects treated in the same year and located within 4.0 miles of each other were treated as one project for this analysis.

The location of each project relative to other projects conducted in different years was also examined. Any portion of a project or ring within 1.0 mile of another project was excluded from this analysis so that the effects of one spray project would not be confounded by effects of other projects. Two projects were dropped from the analysis because over 95 percent of each project area was overlapped by projects conducted in other years (Halfway: 4,217 acres treated in 1989 [100-percent overlap with the 1991 Hells Canyon-Pine-Catherine project], and Warm Springs: 71,172 acres treated in 1993 [97-percent overlap with the 1988 Barlow-Dalles-Warm Springs-Hood River County project]).



## Topological Analyses

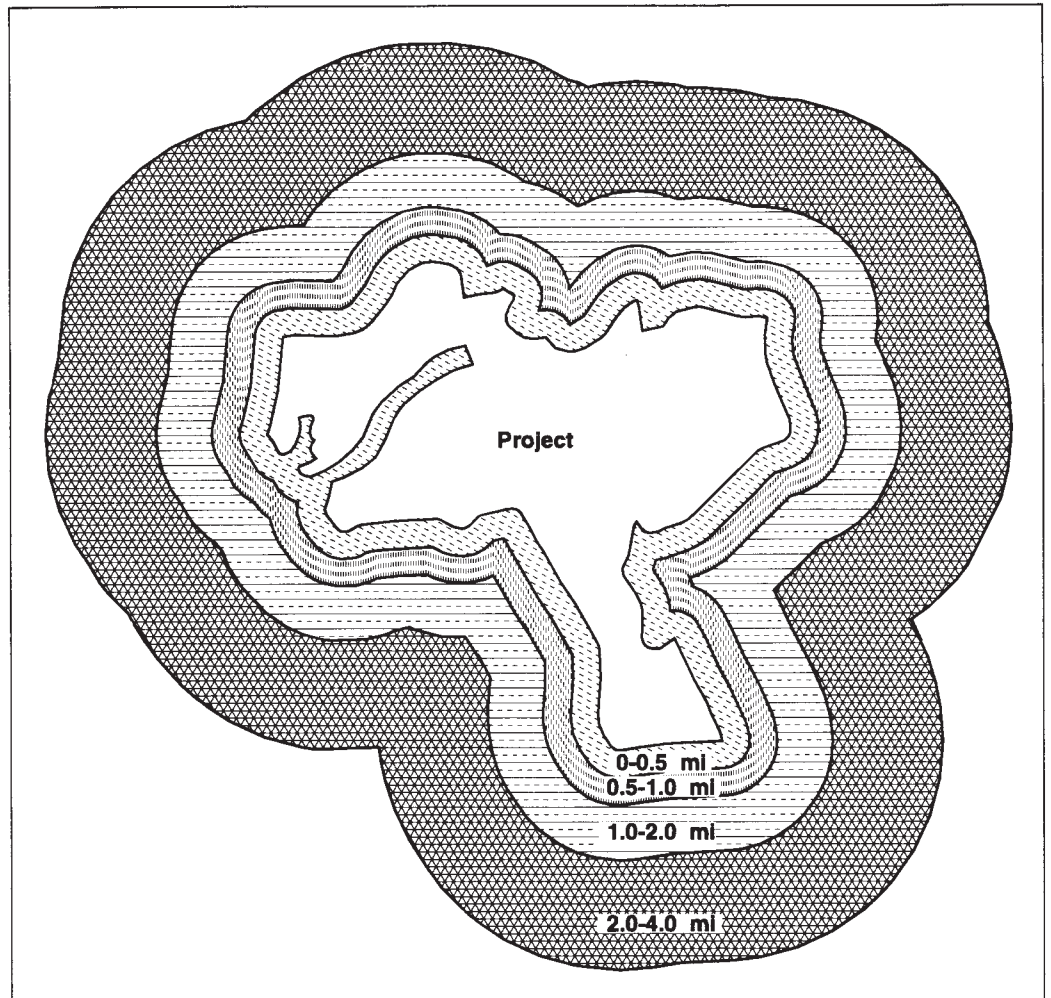


Figure 1—The Canyon 1987 suppression project and four adjacent, surrounding “rings.”

UP to 8 years of data were analyzed for each spray project: the 3 years preceding the project, the year of the project, and the 4 years following the project. For each analysis year, a GIS (Arc/Info) was used to overlay the boundaries of the project area and the four surrounding rings onto the observed defoliation by western spruce budworm for that year. The number of acres defoliated was first summed by severity class for the project area, the four surrounding rings, and the entire region. Four variables summarizing defoliation extent and severity were then calculated for each year:

### Extent—

- Percentage of defoliation (percent defoliation) for the entire project or ring (all severity classes combined)

### Severity—

- Percentage of the defoliated area within a project or ring that was rated as light defoliation or light defoliation effects

- Percentage of the defoliated area within a project or ring that was rated as medium defoliation or moderate defoliation effects
- Percentage of the defoliated area within a project or ring that was rated as heavy defoliation or severe defoliation effects

Differences among treated areas and adjacent rings were evaluated for both defoliation extent and severity. To quantify differences in defoliation severity, the absolute value of the difference between a treated area and each surrounding ring was averaged for the 4 years following treatment for each project. When groups of projects were evaluated (such as all projects conducted in 1982 and 1983), results from each individual project were weighted by the area of that project (in acres).

## Results

About 2,195,000 acres were treated between 1982 and 1993 (fig. 2, appendix A), including some areas treated more than once. The spray projects included in this analysis represent a wide range of active ingredients, formulations, and application rates (appendix B). The relative effects of different insecticides or formulations could not be analyzed because so few treatments were replicated exactly.

A set of four graphs was prepared for each project (see appendix C). They display defoliation extent or severity for up to 8 years (from 3 years prior to treatment to 4 years after treatment). One graph shows total percent defoliation (combining all severity classes) and the others show percent defoliation by severity class for the treated area and the four surrounding rings. For reference, the first figure of appendix C shows acres of defoliation by severity class for all of Oregon and Washington.

Visual inspection of the graphs shown in appendix C indicated that projects treated in certain years resulted in similar defoliation patterns. Projects were then clustered into four analysis groups based on year of treatment (fig. 3).

### Projects: 1982-83

About 823,200 acres were treated in 1982 and 1983, 13.6 percent of which were excluded from the analysis because they were within 1.0 mile of projects treated in other years. Defoliation on the remaining ~711,200 acres was analyzed. Sevin-4-oil was the most commonly used insecticide during these years (fig. 4).<sup>2</sup>

Projects conducted during 1982 and 1983 generally resulted in decreased percent defoliation (all severity classes combined) within the treated area for 1 year after treatment (fig. 5). The average decrease in percent defoliation (change in percent of the project area defoliated weighted by the acres treated during that project) for the year following treatment was 64.1 percent (range = 0.4 to 100 percent). By the second year after treatment, percent defoliation had returned to levels within 10 percent of those reported during the year of treatment in all but one project and was higher than in the year of treatment for 37.8 percent of the area analyzed for 1982 and 1983. The one exception (Opal-1982) represented 2.2 percent of the area analyzed and was 100 percent defoliated during the third year after treatment.

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<sup>2</sup> 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.



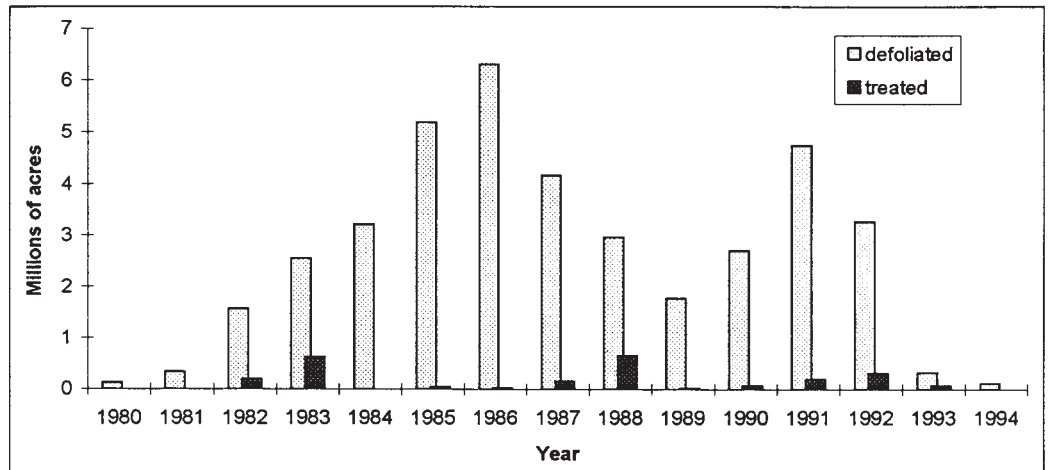


Figure 2—Acres defoliated by western spruce budworm (as recorded during aerial surveys) and acres treated with aerially applied insecticides, Oregon and Washington, 1980-94.

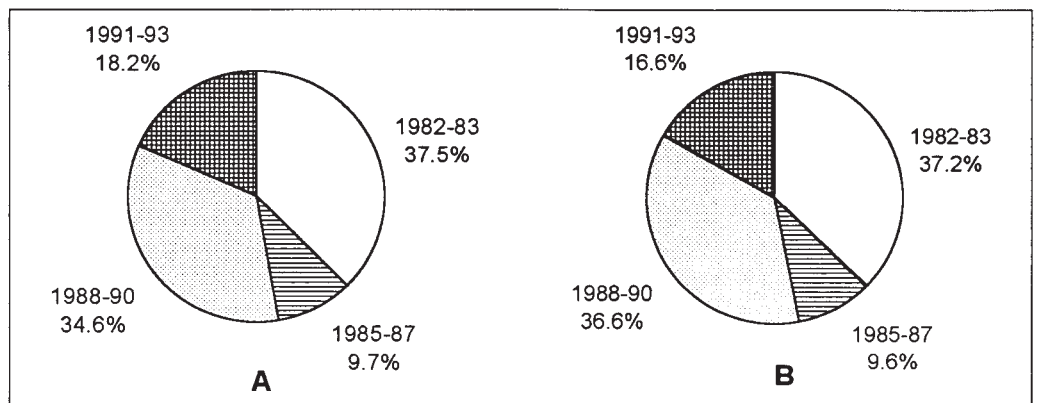


Figure 3—Treated area (1982-93) partitioned into analysis groups: A = total treated areas, and B = analyzed area (excludes treated areas with no available maps or within 1.0 mile of areas treated in other years).

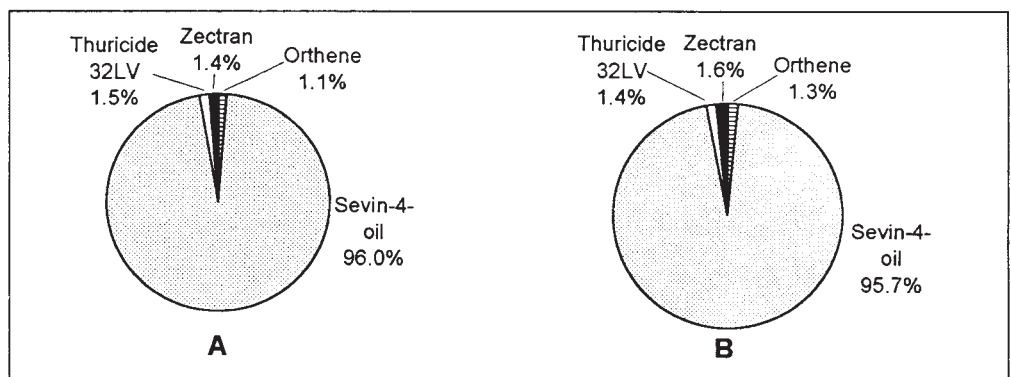


Figure 4—Insecticides applied during projects conducted in 1982 and 1983: A = total treated area, and B = analyzed area (excludes treated areas within 1.0 mile of areas treated in other years).

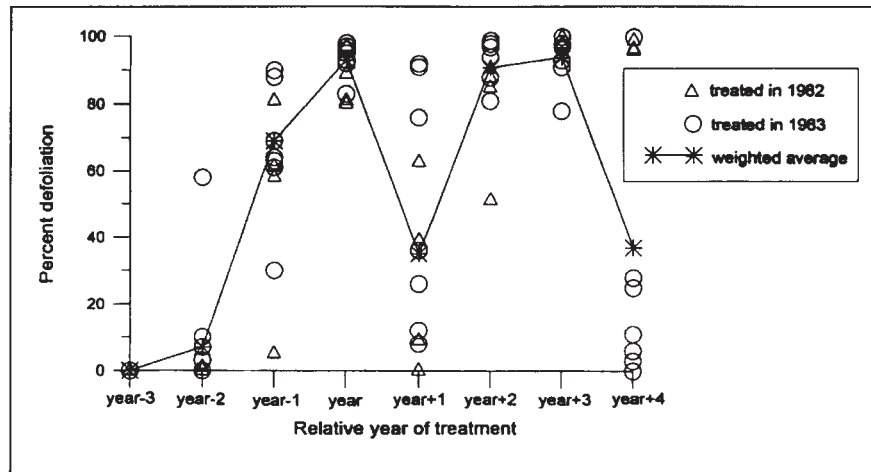


Figure 5—Percent of treated area defoliated (all severity classes combined) for projects treated in 1982 and 1983, and average percent defoliation weighted by project area.

For most projects, percent defoliation (all severity classes combined) also decreased for 1 year following treatment in the innermost surrounding ring but not the three outer rings. Two projects (King-1983 and Pogue-P.A.-1983, representing 8.8 percent of the area analyzed in 1982 and 1983) showed an increase in defoliation for the innermost ring in the year after treatment. When weighted by project area, average percent defoliation within the inner ring decreased by 23.6 percent in the year following treatment. Percent defoliation in the outer three rings generally increased over time through 1986 as did the regional defoliation estimates, and those trends appeared to be unaffected by the insecticide treatments.

Most projects were treated during the second year of extensive visible defoliation. Only one project (Pearson-1983, representing 3.6 percent of the area analyzed) experienced greater than 10 percent defoliation for more than 1 year prior to the year of treatment. Defoliation during the year prior to treatment was generally rated as medium to heavy for 1982 projects and light for 1983 projects.

During the year of treatment and the following 2 years (for 1982) or 1 year (for 1983), defoliation severity was generally light. For both treated areas and all surrounding rings, less than 5 percent of the total area was rated as medium or heavy defoliation with one exception (King-1983, representing 2.4 percent of the area analyzed). Defoliation was not rated in 1985 and thus was arbitrarily assigned to the light defoliation class for the graphs shown in appendix C. In 1986, defoliation severity was most commonly rated as medium regardless of year of treatment.

During the 4 years following treatment, the average absolute difference between treated areas and surrounding rings for percentage of the area rated in a given severity class was calculated separately for each ring and severity class. Years when less than 5 percent of the project area was defoliated were excluded from the analysis. For all projects conducted in 1982 and 1983, the average difference (weighted by project area) between treated areas and surrounding rings in percentage of the area rated in a given severity class was less than or equal to 10 percent in all rings and severity classes. In other words, defoliation severity within the treated areas following treatment was nearly identical to that observed within the surrounding rings, except when very little defoliation occurred.

## Projects: 1985-87

About 213,000 acres were treated in 1985 or 1987. About 7.9 percent of those acres were excluded from the analysis because they were within 1.0 mile of projects treated in other years, and 6.4 percent were not included because suitable maps for two projects (Boise Cascade-1986 and Burns-1987) were not available. Defoliation on the remaining ~182,700 acres was analyzed. Thuricide 48LV was the most commonly used insecticide during these years (fig. 6).

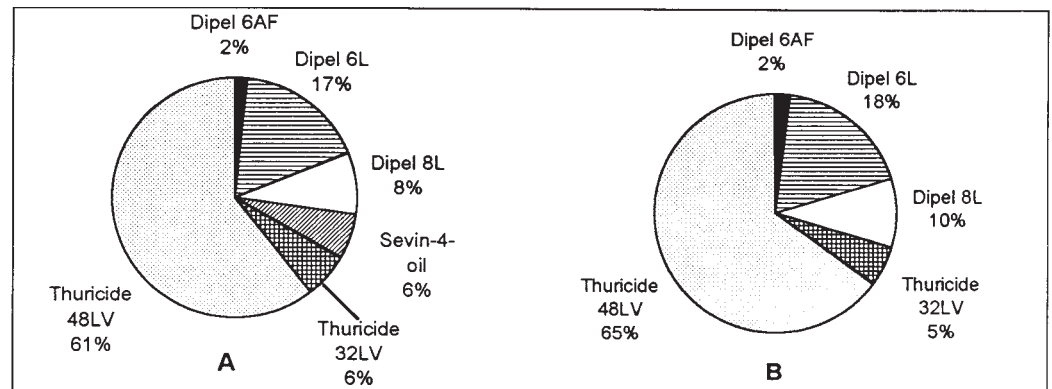


Figure 6—Insecticides applied during projects conducted in 1985 through 1987: A = total acres treated, and B = analyzed acres (excludes treated areas with no available maps or within 1.0 mile of areas treated in other years).

For areas treated in 1985 or 1987, percent defoliation decreased sharply in 1987 and generally remained low for at least 3 years. Average percent defoliation in treated areas (all severity classes combined, weighted by the acres treated for each project) is shown in figure 7. Only one area (Flat-Dixie-1987, representing 35.5 percent of the area analyzed in 1985 and 1987) was over 10 percent defoliated in 1987. This same project was the only area to exceed 8 percent defoliation in any of the 4 years following treatment; it was rated as 48.4 percent defoliated in 1991.

Percent defoliation (all severity classes combined) also decreased sharply in the surrounding rings in 1987 for all areas treated in 1985 or 1987. For each project, year-to-year trends were similar for all four rings. Defoliation was less than 15 percent in all rings for all projects in 1988 and 1989. In both 1990 and 1991, percent defoliation in the surrounding rings remained low (less than 7 percent) in 54.2 percent of the area analyzed, increased in 1990 to 29.4 percent and then declined to 0 percent in 1991 for 10.3 percent of the area analyzed (Canyon-1987), and increased steadily to 51.2 percent in 1991 for the remaining 35.5 percent (Flat-Dixie-1987). In general, percent defoliation was lower in the surrounding rings than in the treated area prior to treatment; during the year of treatment and in following years, percent defoliation in the treated area and in the surrounding rings were very similar.

Defoliation severity was generally rated as light in 1984 and then moderate in 1986 (except for Starr-1987, representing 0.2 percent of the area analyzed, which increased to severe in 1986; severity was not rated in 1985). For those areas where defoliation increased in either 1990 or 1991, or both years, severity was rated as light or moderate. From 1984 through 1987, defoliation in treated areas was generally rated as either more severe than or identical to defoliation in surrounding rings; for the one exception (Burnt Cabin-Crooked-Rail-Scotty-1985, representing 17.8 percent of the area analyzed in 1985 and 1987), defoliation was less severe in the treated area in 1986, which was the year following treatment.

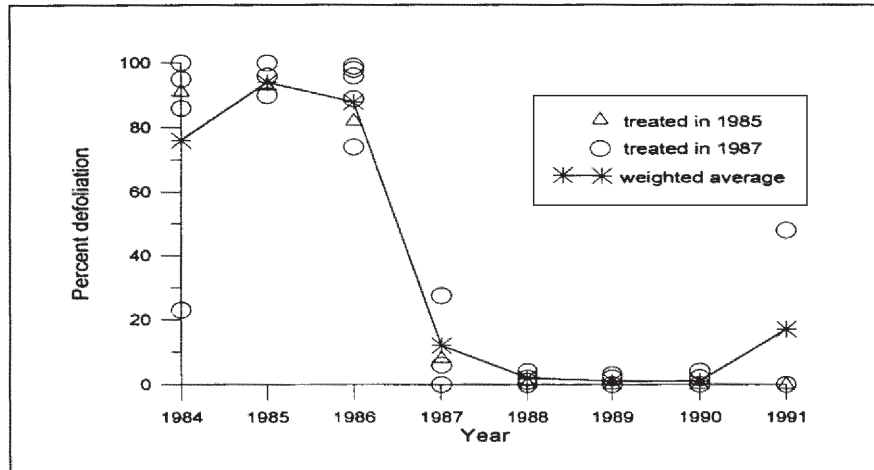


Figure 7—Percentage of treated area defoliated (all severity classes combined) for projects treated in 1985 or 1987, and average percent defoliation weighted by project area.

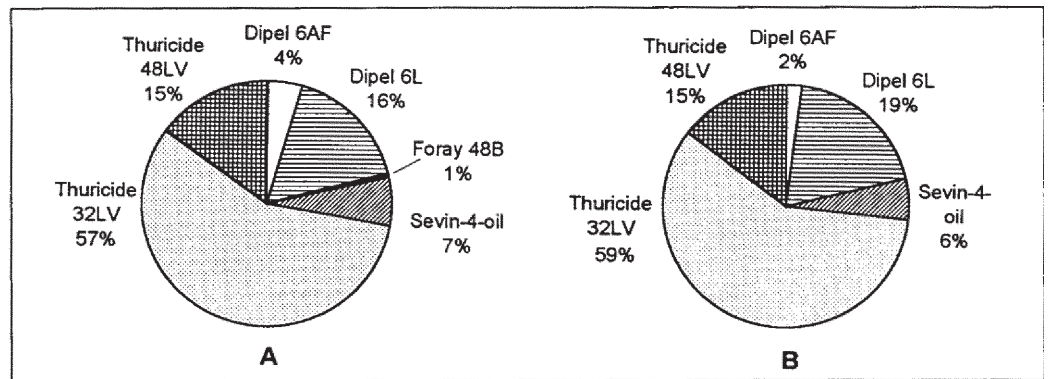


Figure 8—Insecticides applied during projects conducted from 1988 through 1990: A = all treated areas, and B = analyzed areas (excludes treated areas with no available maps or within 1.8 mile of areas treated in other years).

**Projects: 1988-90**

From 1988 through 1991, percent defoliation was so low that differences in defoliation severity between treated areas and surrounding rings were difficult to evaluate. When percent defoliation was greater than 5 percent, defoliation severity within the treated area was very similar to that observed within the surrounding rings, with one exception: Canyon-1987 (representing 11.1 percent of the area analyzed), in 1990, when defoliation was rated as more severe in the outer two rings than in the inner two rings or treated area. Virtually no defoliation was reported in either the treated areas or the surrounding rings from 1988 through 1991 for 54.2 percent of the area analyzed, and in the remaining 45.8 percent of the area analyzed, percent defoliation exceeded 10 percent in only one or two years.

In 1988 through 1990, about 761,000 acres were treated. About 5.6 percent of those acres were excluded from the analysis because they were within 1.0 mile of projects treated in other years, and no maps were available for 2.6 percent of the total area treated. Defoliation on the remaining ~698,300 acres was analyzed. Thuricide 32LV was the most commonly used insecticide during these years (fig. 8).

Percent defoliation (all severity classes combined) in areas treated from 1988 through 1990 generally decreased slightly in the year of treatment, then sharply in the year following treatment (fig. 9). In the one exception (Starkey-1988, representing 0.6 percent of the area analyzed), percent defoliation decreased sharply in the year of treatment, remained low during the year after treatment, and then returned to pretreatment levels for the next two years. Percent defoliation remained low for 1 (0.6 percent of area analyzed), 2 (32.8 percent), or 3 (66.6 percent) years following treatment, then increased to either moderate or high levels (relative to percent defoliation prior to treatment). In some treated areas (Meacham-1988, Starkey-1988, and High Rock-1989, together representing 7.3 percent of the area analyzed), defoliation declined sharply in the fourth year after treatment. For these projects, defoliation averaged 13.6 percent when weighted by project area, while in the remaining treated areas defoliation averaged 39.4 percent.

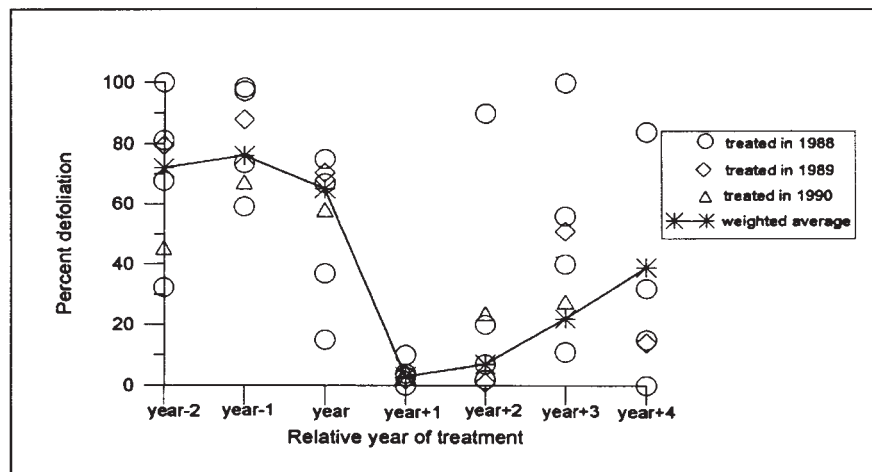


Figure 9—Percentage of treated area defoliated (all severity classes combined) for projects treated in 1988 through 1990, and average percent defoliation weighted by project area.

The defoliation trend in all four surrounding rings generally followed the same pattern as for treated areas. For 19.3 percent of the treated area analyzed (Meacham-1988, Starkey-1988, and Tollgate-1988), percent defoliation during the year after treatment declined in the surrounding rings but remained higher than in the associated treated areas. For those projects, the average decrease in percent defoliation from the year prior to treatment to the year after treatment was 68.3 percent in the surrounding rings compared to 97.2 percent for those projects (changes were averaged for all four rings for each project and then weighted by project area). For the remaining 80.7 percent of the area analyzed, percent defoliation during the year after treatment averaged 3.7 percent for treated areas and 7.4 percent for the associated rings (percent defoliation was averaged for all four rings and then weighted by project area).

Defoliation severity was generally rated as light or moderate before treatment, and ratings were either very similar or somewhat more severe in treated areas compared to the four surrounding rings. In the 4 years following treatment, the average difference between treated and untreated areas in percent of the area rated in a given severity class was less than 17 percent for all rings and severity classes (averages for all 1988-90 projects weighted by project area, excluding years when less than 5 percent of the area was defoliated). Meacham-1988 (representing 5.1 percent of the area analyzed for 1988-90) had a consistently greater difference in severity ratings for treated and untreated areas than the rest of the analyzed area, and relatively large differences were found for High Rock-1989 (representing 1.1 percent of the area analyzed) in 1992 only. For most projects, though, there was little difference in defoliation severity between treated areas and surrounding rings.

#### **Projects: 1991-93**

About 400,000 acres were treated in 1991 through 1993. The primary target for the 1991 projects was Douglas-fir tussock moth, but western spruce budworm populations also were present in the treated areas. About 3.9 percent of the total area treated was excluded from the analysis because it was within 1.0 mile of projects treated in other years. Areas treated in 1993 (representing 16.7 percent of the area treated from 1991 to 1993) were excluded because only 1 year has elapsed since treatment; also, nearly all (96.5 percent) of the Warm Springs area treated in 1993 was within 1.0 mile of a previous spray project. Defoliation on the remaining ~317,400 acres was analyzed. Thuricide 48LV was the insecticide most commonly used during these years (fig. 10).

Percent defoliation (all severity classes combined) peaked in either 1991 (98.1 percent of treated area analyzed) or 1992 (1.9 percent) (fig. 11). Defoliation declined to less than 2 percent in 1993 for all treated areas, and no defoliation was reported in 1994. Regional defoliation also peaked in 1991 and then declined steadily through 1994.

Percent defoliation in the four surrounding rings matched the pattern in the treated area for all but one project. In the exception (Suttle—1992, representing 1.9 percent of the area analyzed for 1991-93), defoliation in the surrounding rings peaked in 1992 rather than 1991 (when defoliation peaked within the treated area); no defoliation was recorded in 1993 for either the Suttle project area or its associated rings.

Defoliation severity was rated as either predominantly light (28.4 percent of the area analyzed) or a mixture of light and moderate (71.6 percent) both before and during the year of treatment. So little defoliation was recorded in the analyzed area during the years after treatment that differences in defoliation severity between treated areas and surrounding rings could not be evaluated.



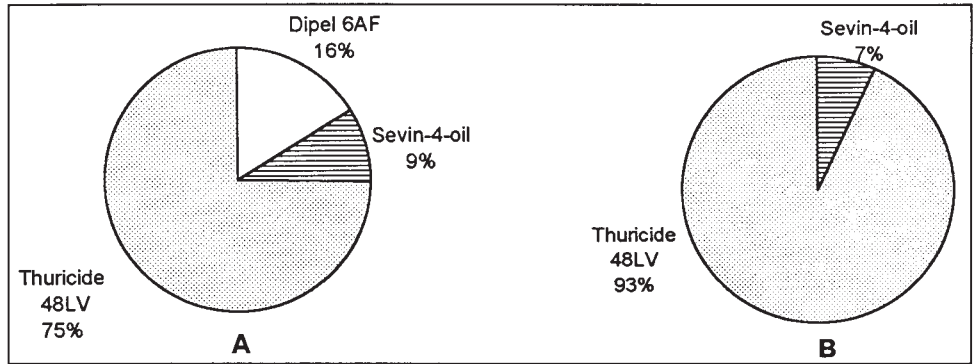


Figure 10—Insecticides applied during projects conducted from 1991 through 1993: A = total treated area, and B = analyzed areas (excludes treated areas within 1.0 mile of areas treated in other years).

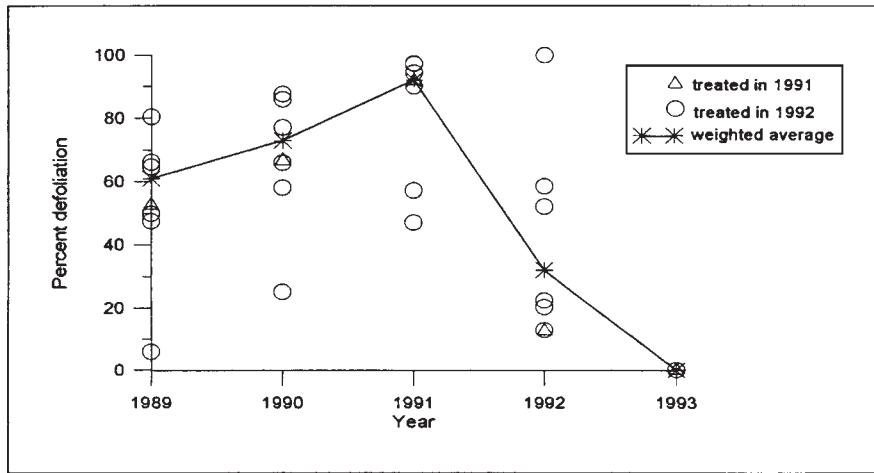


Figure 11—Percentage of treated area defoliated (all severity classes combined) for projects treated in 1991 and 1992, and average percent defoliation weighted by project area.

## Discussion

In areas treated during 1982 and 1983, percent defoliation declined sharply for 1 year following treatment within the treated area (and usually in the innermost ring) yet increased or remained nearly constant in the three outermost rings. The decreases in percent defoliation commonly observed within the innermost surrounding ring during this period might result from drift of insecticides from the treated areas into that ring. For 98 percent of the area analyzed, percent defoliation returned to pretreatment levels (or higher) during the second year following treatment in the treated areas and all surrounding rings. The remaining 2 percent of the area analyzed was 100 percent defoliated during the third year after treatment.

Torgersen and others (1995) reported that in one of the treated areas (Aldrich-1983), both budworm densities and defoliation declined in the year following treatment but then rebounded to pretreatment levels by the second year after treatment. Despite one or two years of foliage protection, they found no differences in radial growth rates.

For 1982 and 1983 treatments, virtually no differences in defoliation severity were found between treated areas and surrounding rings except when very little defoliation occurred. Regional percent defoliation trends increased steadily during this period, and it is possible that the rapid return to pretreatment defoliation levels may have been caused by massive inflights of adult females from either the outer surrounding rings or more distant sources.

For treatments conducted from 1985 through 1992, however, declines in percent defoliation within treated areas during or after the year of treatment were generally accompanied by very similar declines in all four surrounding rings. For 19 percent of the area analyzed for 1988 through 1990 (10 percent of the area analyzed for 1985 through 1992), defoliation declined in adjacent rings but remained higher than in the treated areas; however, even for those projects, defoliation in the adjacent rings declined by 68 percent, compared to a 97 percent decline in the treated areas. Similarly, Powell (1994) reports no statistically significant differences in percent defoliation, topkill, or tree mortality between treated and untreated inventory plots in the Malheur National Forest in Oregon. Powell examined some or all of the 1982, 1983, 1985, and 1987 projects included in this analysis (see Powell [1994] p. 73 and p. 83 for details). Some observers have suggested that insecticide treatment may reduce the severity of subsequent defoliation in treated areas, thus providing benefits even when the number of acres defoliated is not reduced. For the entire period analyzed, however, defoliation severity following treatment was generally very similar in both treated areas and all four surrounding adjacent rings except when only a small percentage (less than 5 percent) of the area was defoliated. When percent defoliation is very low, a few small polygons may greatly affect the defoliation severity graphs shown in appendix C (graphs B through D).

Four explanations could account for similar defoliation patterns in both treated areas and surrounding rings for projects conducted from 1985 through 1992: (1) aerial sketchmaps may not detect real differences in defoliation extent or severity between treated and untreated areas, (2) treatments may have caused effects in all four surrounding rings that were similar to effects caused within the treated area, (3) treatments may have removed major sources of budworm female moths that had been sustaining defoliation in both treated areas and the surrounding rings, or (4) treatments may have had no net detectable effect on subsequent defoliation within treated areas.

The first explanation cannot be discounted because this analysis does not address the accuracy of aerial sketchmaps. Many spray project boundaries, though, have been based mainly on aerial sketchmaps—the boundaries are often placed where defoliation had been mapped previously. The overall quality of aerial sketchmaps differs with observer experience, local weather conditions, regional fire activity, tree species composition, and other local conditions. There is no reason to expect that aerial application of insecticides would affect subsequent sketchmap quality, however. Sketchmaps judged adequate for identifying potential project boundaries therefore should be adequate for evaluating the effect of those projects on subsequent defoliation. Further, Powell (1994) used on-the-ground surveys and found similar results for projects conducted in the Malheur National Forest in 1982, 1983, 1985, and 1987: no significant differences in either topkill or tree mortality between treated and untreated plots.

The second explanation implies that extensive insecticide drift occurred, consistently affecting areas up to 4 miles away from the target area. Where evidence of possible insecticide drift was noted for 1982 and 1983 projects, that evidence was apparent only within 0.5 mile of the treated area and not in the three outer rings. Given the small size of spray droplets and local conditions typical of budworm spray projects, some degree of insecticide drift would be expected for most projects. It is highly unlikely, though, that drift would consistently be so extensive that no attenuation of effect was detected even 4.0 miles away from the project boundary.

The third explanation assumes that project boundaries were so accurately identified that they encompassed those areas that (in the absence of treatment) export large numbers of gravid females into the surrounding rings which otherwise would not experience as much subsequent defoliation. Following treatment, defoliation would decline in both treated and nearby areas because the major source of budworm eggs (that is, females produced within the treated area) has been greatly reduced. Most project boundaries are based on sketchmaps from previous years, vegetation information (mostly used to identify areas with significant portions of nonhost), ground-based samples of budworm populations, and ecological and economic analyses of potential effects. For many projects, large portions of the adjacent rings (especially the innermost ring) were defoliated in the year prior to treatment, and it is very unlikely that observers could accurately separate areas that export budworms (that is, potential treatment areas) from areas that import budworms (the surrounding rings under this third explanation) during either ground or aerial surveys. In addition, although adults are thought to disperse long distances (120 miles or more) in at least some years (Campbell 1993), local weather is thought to have a greater influence on defoliation than adult dispersal in most years through its effect on host-budworm synchrony and subsequent larval survival (Shepherd 1985, 1994).

The fourth explanation—that treatments generally have no net detectable effect—is the most plausible and could result from several scenarios. In some cases, problems with the application of insecticides (such as poor timing relative to budworm and foliage development, poor meteorological conditions during application) may have reduced insecticide efficacy such that any effect on subsequent defoliation was not detectable by aerial surveys. Many of the projects from this period (1985-92) were conducted in areas defoliated for several years; in these areas, budworm populations may have already begun to decline owing to other reasons (for example, increases in natural enemy activity, decreases in foliage availability or quality), so that insecticide treatments may have merely replaced other factors that would have reduced defoliation in subsequent years. In another scenario, budworm populations may have been reduced in treated areas, only to have the effects of that reduction on subsequent defoliation masked by a massive outflight of adult females from both treated and untreated areas. Campbell (1993) reports that several years of extensive defoliation are sometimes followed by apparent massive outflights of adult females—and many areas treated during this period had sustained defoliation for 2 to 3 years. Different scenarios may have affected budworm defoliation patterns in different years or different projects, and in some cases, more than one scenario have operated concurrently.

Carbaryl was the most commonly used active ingredient for those treatments where reduced percent defoliation was observed for 1 year; *Bacillus thuringiensis* (Bt) was the most commonly used active ingredient for those treatments where little or no net effect on defoliation was generally detected. Direct comparison of the two ingredients is confounded, though, because different years (and therefore different weather regimes, different stages within the regional outbreak pattern, and so forth) also were involved. This analysis therefore should not be used to compare the relative effectiveness of the two insecticides.

## Conclusion

The results of this analysis support the synthesis of Shepherd (1994), who writes that outbreaks of sustained defoliators such as western spruce budworm "...are often large in size, and high larval mortality is difficult to obtain consistently through aerial spraying." In general, the suppression projects conducted in Oregon and Washington from 1982 through 1992 apparently reduced subsequent defoliation extent for 1 year at most. More commonly, there were little or no detectable differences between treated and adjacent untreated areas in either extent or severity of defoliation .

## Acknowledgments

Many thanks go to Shelly Hayden for digitizing historical records of both aerial survey observations and suppression project boundaries. Julie Johnson rescued me from many ARC dilemmas. Brian M. Spears initiated me into the mysterious world of ARC amls. James S. Hadfield, John W. Hazard, Timothy J. McConneil, David L. Overhulser, and Torolf R. Torgersen critiqued an earlier draft of this manuscript, though I am responsible for any errors that remain. This analysis would not have been possible without the annual aerial sketchmaps that are produced by a dedicated team of aerial survey observers and mapping specialists. The aerial survey is an ongoing cooperative project sponsored jointly by the States of Oregon and Washington and the USDA-Forest Service.

## Metric Equivalents

1 acre = 0.40 hectare

1 foot = 0.31 meter

1 mile = 1.61 kilometers

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## Appendix A

**Table 1—Acres defoliated by western spruce budworm (as recorded during aerial surveys) and acres treated with aerially applied insecticides in Oregon and Washington, 1980-94**

Year	Acres defoliated	Acres treated
1980	126,003	0
1981	339,158	0
1982	1,566,442	202,703
1983	2,549,757	620,527
1984	3,214,258	800
1985	5,192,609	40,821
1986	6,312,829	13,200
1987	4,172,903	158,979
1988	2,969,381	674,952
1989	1,774,177	14,412
1990	2,699,798	71,677
1991	4,753,244	114,048
1992	3,271,060	219,214
1993	331,595	66,792
1994	122,986	0

Appendix B

Table 2—Characteristics of suppression projects conducted against western spruce burworm in Oregon and Washington, 1982-93

Year	Project	Total acres treated	Acres analyzed	Active ingredient	Insecticide	Dilution	Oz/acre	Dose/acre	Source <sup>a</sup>
1980	(Daterman)	200	<sup>b</sup>	Pheromone					S1
1982	Baldy	32,660	26,603	Carbaryl	Sevin-4-oil	diesel	64	16 oz	H1
1982	Madison	61,948	43,539	Carbaryl	Sevin-4-oil	diesel	64	16 oz	H1
1982	Middle Fork-A	59,402	53,641	Carbaryl	Sevin-4-oil	diesel	64	16 oz	H1
1982	Middle Fork-B	9,423	9,423	Acephate	Orthene	water	128	8 oz	H1
1982	Opal	35,965	15,743	Carbaryl	Sevin-4-oil	diesel	64	16 oz	H1
1983	Aldrich	118,824	111,785	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Butte	6,094	6,094	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Logan	107,751	98,763	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	King	16,991	16,991	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Matlock	88,883	83,624	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Miller Prairie	132,670	105,392	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Putney	40,266	39,046	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Pearson	25,270	25,270	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Pogue Pt-A	14,121	7,760	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Pogue Pt-B	11,123	11,123	Mexacarbate	Zectran	diesel	128	2 oz	B1
1983	Pogue Pt-C	12,280	10,160	Bt	Thuricide 32LV	water	96	12 biu	B1
1983	PA	16,899	16,899	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Rudio Mtn	23,978	23,978	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1983	Snow	5,377	5,377	Carbaryl	Sevin-4-oil	diesel	64	16 oz	B1
1984	Prineville	800	<sup>b</sup>	Bt	Thur. 32LV/San415	water	97	20-30 biu	R1

Table 2—Characteristics of suppression projects conducted against western spruce burworm in Oregon and Washington, 1982-93 (continued)

Year	Project	Total acres treated	Acres analyzed	Active ingredient	Insecticide	Dilution	Oz/acre	Dose/acre	Source <sup>a</sup>
1985	Rail	9,660	9,660	Bt	Dipel 8L	none	24	12 biu	R1
1985	Scotty	10,389	5,224	Bt	Thuricide 32LV	none	32	12 biu	R1
1985	Crooked-A	12,113	8,966	Bt	Thuricide 32LV	water	96	12 biu	R1
1985	Crooked-B	863	863	Bt	Thuricide 32LV	water	64	15 biu	R1
1985	Burnt Cabin	7,796	7,796	Bt	Dipel 8L	water	48	12 biu	R1
1986	Boise Casc.	13,202	<sup>b</sup>	Carbaryl	Sevin-4-oil	diesel	64	16 oz	S1
1987	Flat	47,794	47,794	Bt	Dipel 6L/Thur.48LV	water	96	12 biu	R1
1987	Dixie	18,145	17,134	Bt	Dipel 6AF/Thur.48LV	water	96	12 biu	R1
1987	Canyon	22,826	18,836	Bt	Dipel 6L/Thur.48LV	water	96	12 biu	R1
1987	Lost Cabin	23,764	20,335	Bt	Dipel 6L/Thur.48LV	water	96	12 biu	R1
1987	Starr	333	333	Bt	Dipel 6L	water	96	12 biu	R1
1987	Rimrock	45,757	45,757	Bt	Thuricide 48LV	water	96	12 biu	R1
1987	Burns	360	<sup>b</sup>	Bt	Dipel 6L	varied	43-96	30-40 biu	R1
1988	Meacham-T	42,856	22,237	Bt	Thuricide 48LV	none	43	16 biu	A1,S1
1988	Meacham-D	34,127	13,167	Bt	Dipel 6AF	none	43	16 biu	1,S1
1988	Tollgate	97,126	95,529	Bt	Thuricide 32LV	none	64	16 biu	S1
1988	Starkey	3,608	3,608	Bt	Thuricide 32LV	none	64	16 biu	S1
1988	Barlow-D	115,528	115,528	Bt	Dipel 6L	none	43	16 biu	S1
1988	Barlow-T	25,822	25,822	Bt	Thuricide 32LV	none	64	16 biu	S1
1988	Warm Springs	184,991	184,991	Bt	Thuricide 32LV	none	64	16 biu	S1
1988	Dalles	116,626	116,626	Bt	Thuricide 32LV	none	64	16 biu	S1
1988	Hood River-S	35,331	35,331	Carbaryl	Sevin-4-oil	diesel	64	16 oz	S1
1988	Hood River-B	6,137	6,137	Bt	Thuricide 32LV	water	96	12 biu	S1

Table 2—Characteristics of suppression projects conducted against western spruce burworm in Oregon and Washington, 1982-93 (continued)

Year	Project	Total acres treated	Acres analyzed	Active ingredient	Insecticide	Dilution	Oz/acre	Dose/acre	Source <sup>a</sup>
1988	Sisters (W)	300	<i>b</i>	Bt	Foray 48B	none	43	16 biu	S1
1988	Tollgate (BC)	12,500	<i>b</i>	Carbaryl	Sevin-4-oil	diesel	64	16 oz	S1
1989	High Rock	7,595	7,595	Bt	Dipel 6L	none	43	16 biu	S1
1989	Halfway	4,217	0	Bt	Foray 48B	none	43-64	16 biu	S1
1989	Boise Cascade	2,000	<i>b</i>	Carbaryl	Sevin-4-oil	diesel	64	16 oz	S1
1989	Enterprise	600	<i>b</i>	Bt	Condor AD		97	3 doses	S1
1990	Yakima	71,677	71,677	Bt	Thuricide 48LV	none	43	16 biu	H2
1991	Hells Canyon	15,266	10,703	Bt	Thuricide 48LV	none	43	16 biu	U
1991	Pine	78,650	67,333	Bt	Thuricide 48LV	none	43	17 biu	U
1991	Catherine Cr.	20,132	20,132	Bt	Thuricide 48LV	none	43	18 biu	U
1992	Boise Casc. <sup>c</sup>	29,216	29,216	Carbaryl	Sevin-4-oil	diesel	64	16 oz	U
1992	Indian Creek	20,690	20,690	Bt	Thuricide 48LV	none	64	24 biu	H3
1992	Mill	5,985	5,985	Bt	Thuricide 48LV	none	64	24 biu	H3
1992	Morgan	27,513	27,513	Bt	Thuricide 48LV	none	64	24 biu	H4
1992	Kuhn-Chesn.	42,935	42,935	Bt	Thuricide 48LV	none	64	24 biu	H4
1992	Suttle Lake-S	5,434	5,434	Carbaryl	Sevin-4-oil	diesel	64	16 oz	U
1992	Suttle Lake-T	511	511	Bt	Thuricide 48LV	none	64	24 biu	U
1992	Mt.Emily	25,913	25,913	Bt	Thuricide 48LV	none	64	24 biu	H3
1992	Thimbleberry	33,868	33,868	Bt	Thuricide 48LV	none	64	24 biu	H3
1992	Meacham	27,149	27,149	Bt	Thuricide 48LV	none	64	24 biu	H3

Table 2—Characteristics of suppression projects conducted against western spruce burworm in Oregon and Washington, 1982-93 (continued)

Year	Project	Total acres treated	Acres analyzed	Active ingredient	Insecticide	Dilution	Oz/ acre	Dose/ acre	Source <sup>a</sup>
1993	Warm springs	64,182	0	Bt	Dipel 6AF	none	64	24 biu	H5
1993	Hood River Co.	2,530	<i>b</i>	Carbaryl	Sevin-4-oil	diesel	64	16 oz	U
1993	(Grimble)	80	<i>b</i>	Bt	Thuricide	water	96	16 biu	U
Totals		<u>2,198,327</u>	<u>1,909,597</u>						

<sup>a</sup> = These projects were located within 4 miles of each other and were therefore analyzed as one treatment.

<sup>a</sup> Source for total acres treated and acres analyzed is electronic data files on file at Forest Insects and Diseases, Natural Resources, Pacific Northwest Region, USDA-Forest Service, P.O. Box 3623, Portland, OR 97208. Sources for insecticide-related information are A = USDA-Forest Service (1988), B = Bridgwater (n.d.), H1 = Hostetler (n.d.), H2 = Hadfield (1992), H3 = Hadfield (n.d.), H4 = Hadfield (1994), H5 = Howes and Wallez (n.d.), S = Skyler and others (1990), R = Ragenovich (1988), U = unpublished data on file with: Forest Insects and Diseases, Natural Resources, Pacific Northwest Region, USDA-Forest Service, P.O. Box 3623, Portland, OR 97208-3623.

<sup>b</sup> No suitable map available for digitizing.

<sup>c</sup> Portions of the areas treated by Boise Cascade in 1992 were located within 4 miles of the Indian Creek, Kuhn-Chesnimnus, or Meacham projects and were therefore analyzed with those projects.



## Appendix C

Figure 12 summarizes defoliation by western spruce budworm in Oregon and Washington by severity class. For 1980 through 1984, severity was classified as light, medium, or heavy. In 1985, severity was not rated; all 1985 defoliation is shown in figure 12 as light for display only. For 1986 through 1994, defoliation was classified as light, medium, or heavy in most of Washington, and as classes 1 through 4 for Oregon and the Blue Mountains in southwestern Washington. The four classes are class 1 = defoliation visible from the air; class 2 = defoliation visible, and bare tops visible on some trees; class 3 = many trees with bare tops, though some green foliage present; and class 4 = most tree crowns bare, and virtually no foliage left.

The remaining pages summarize defoliation observed for one suppression project (or several projects if located within 4.0 miles of each other and treated in the same year). Graph A (top left) shows the percentage of the total area that was defoliated (all defoliation classes combined) by year for the treated areas (solid diamonds), the 0- to 0.5-mile ring (squares), the 0.5- to 1.0-mile ring (triangles), the 1.0- to 2.0-mile ring ("x"s), and the 2.0- to 4.0-mile ring (circles).

Graphs B through D show defoliation severity for the treated areas and the four surrounding rings. For that portion of the treated area or ring that was defoliated, graph B shows the percentage rated as light defoliation or light defoliation effects (class 1), graph C shows the percentage rated as medium defoliation or moderate defoliation effects (class 2), and graph D shows the percentage rated as heavy defoliation or severe defoliation effects (classes 3 and 4).



Arrows mark the year of treatment. Specific projects are shown on separate pages in chronological and alphabetical order.

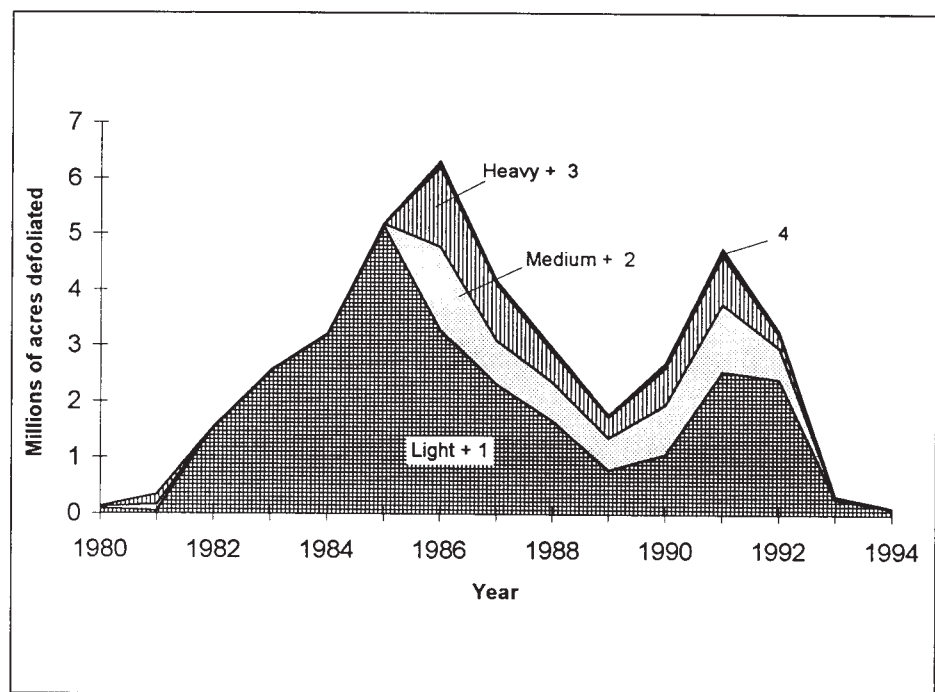
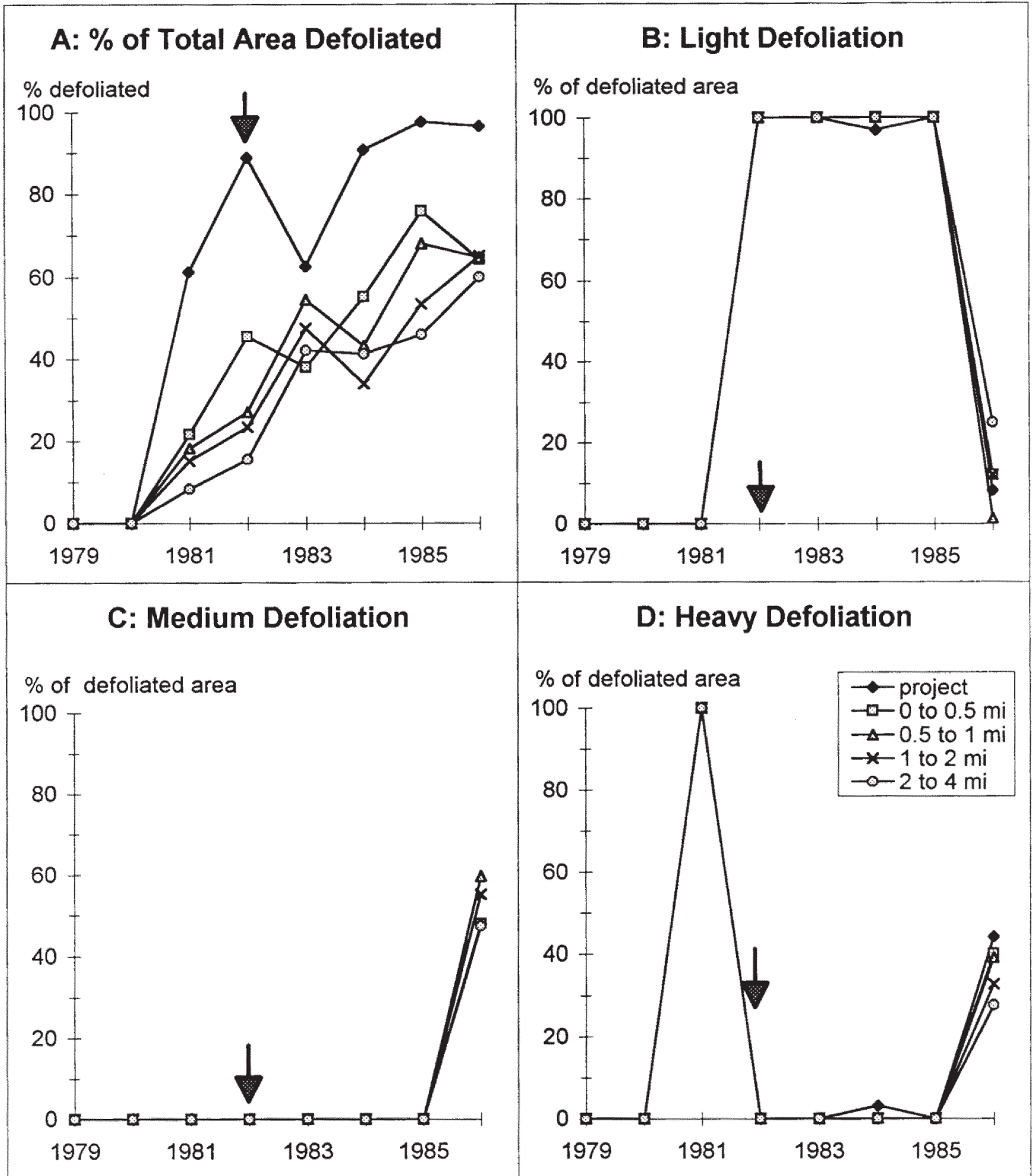


Figure 12—Acres defoliated by western spruce budworm in Oregon and Washington by severity class.

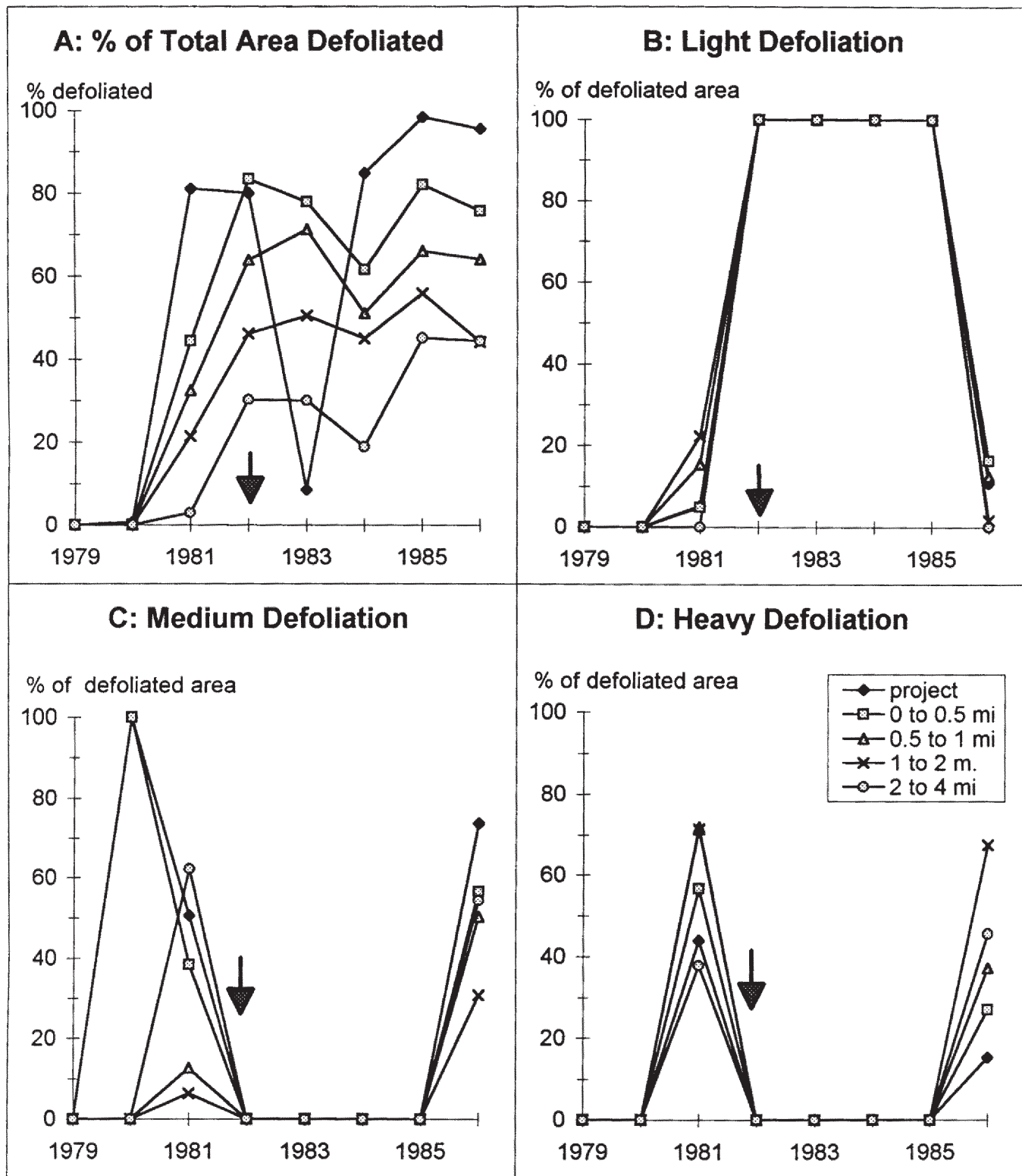
1982--Baldy

Project area analyzed = 26,600 acres (74% of project)



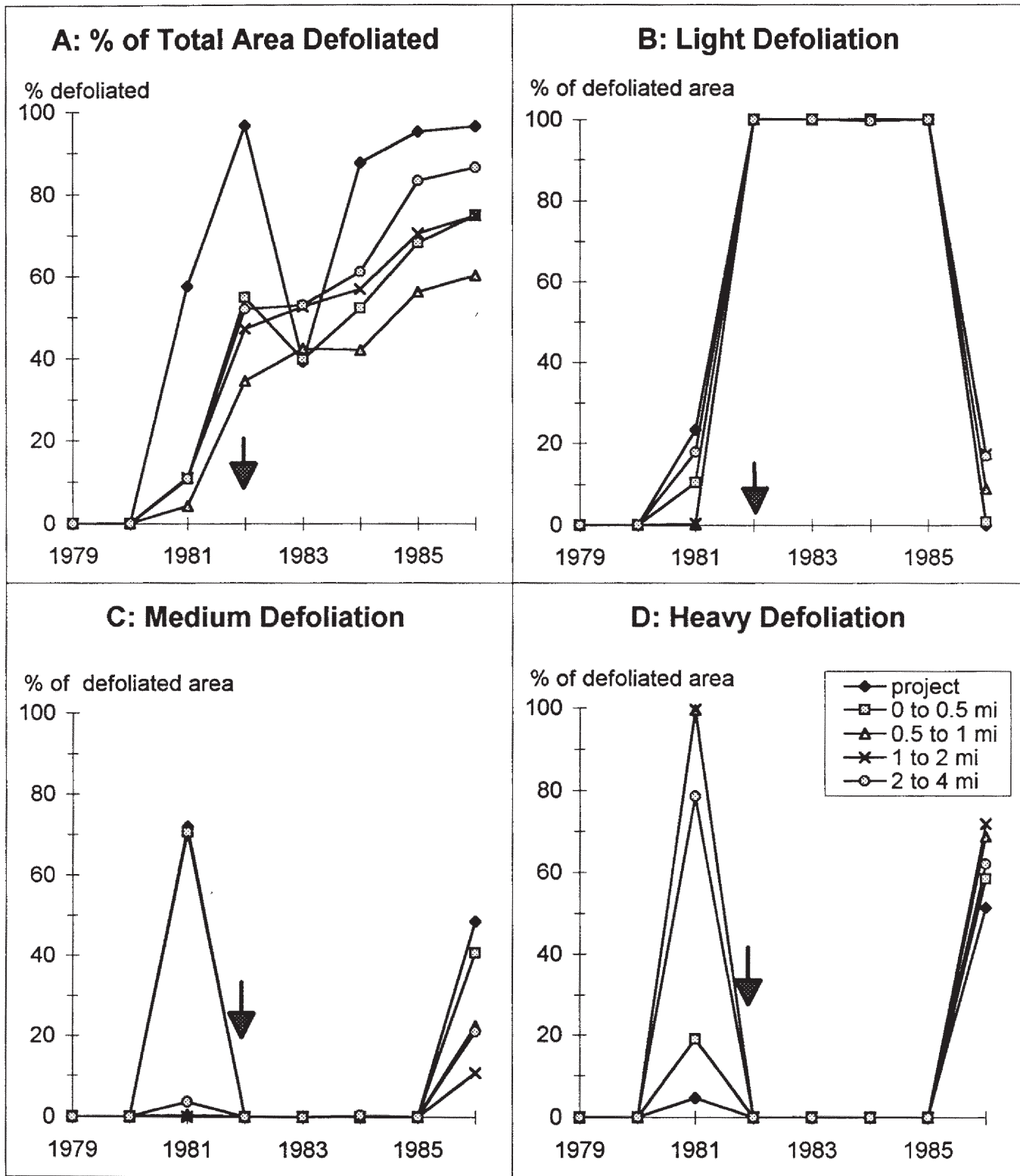
**1982--Madison**

**Project area analyzed = 43,540 acres (70% of project)**



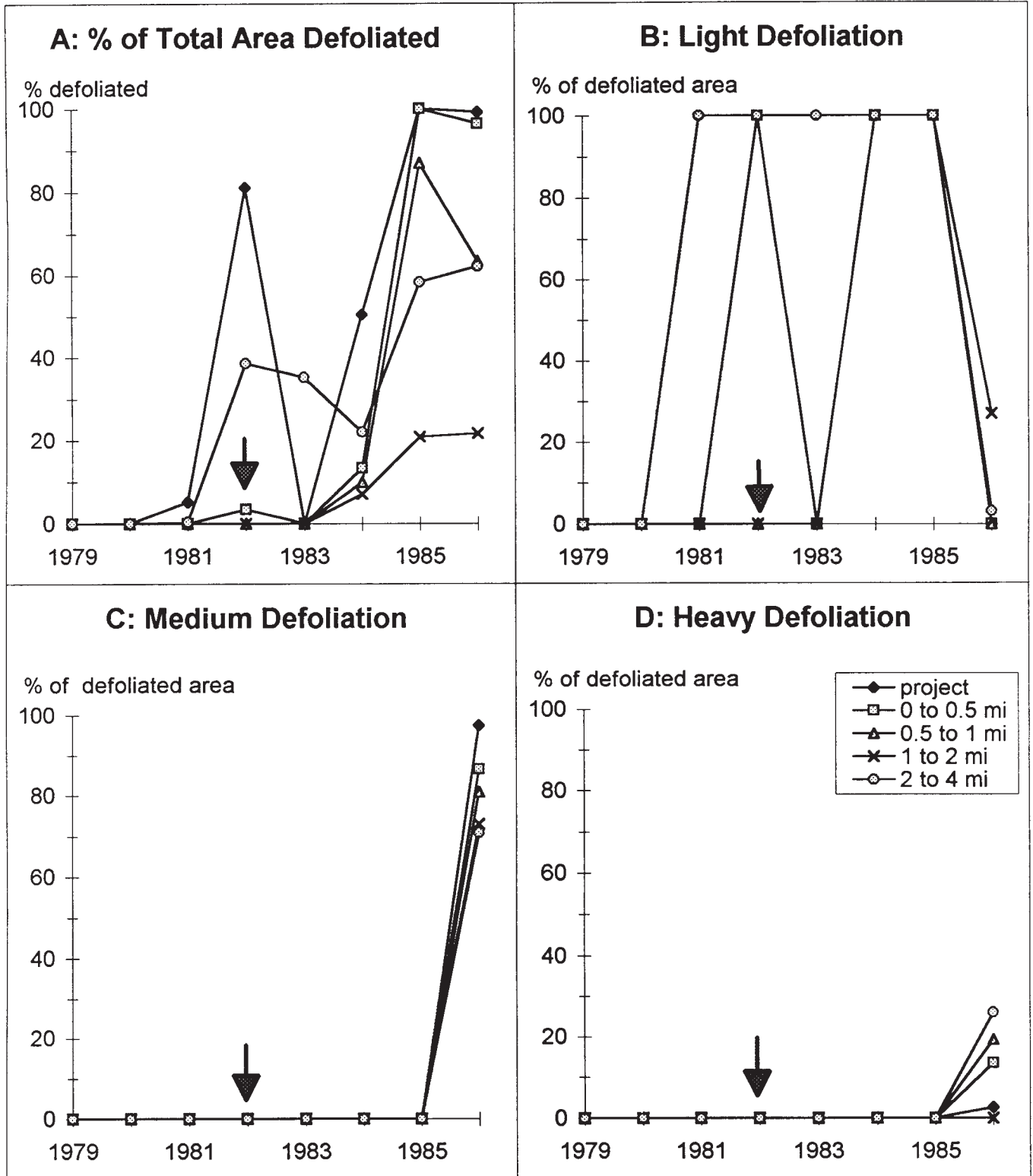
1982--Middle Fork

Project area analyzed = 63,070 acres (92% of project)



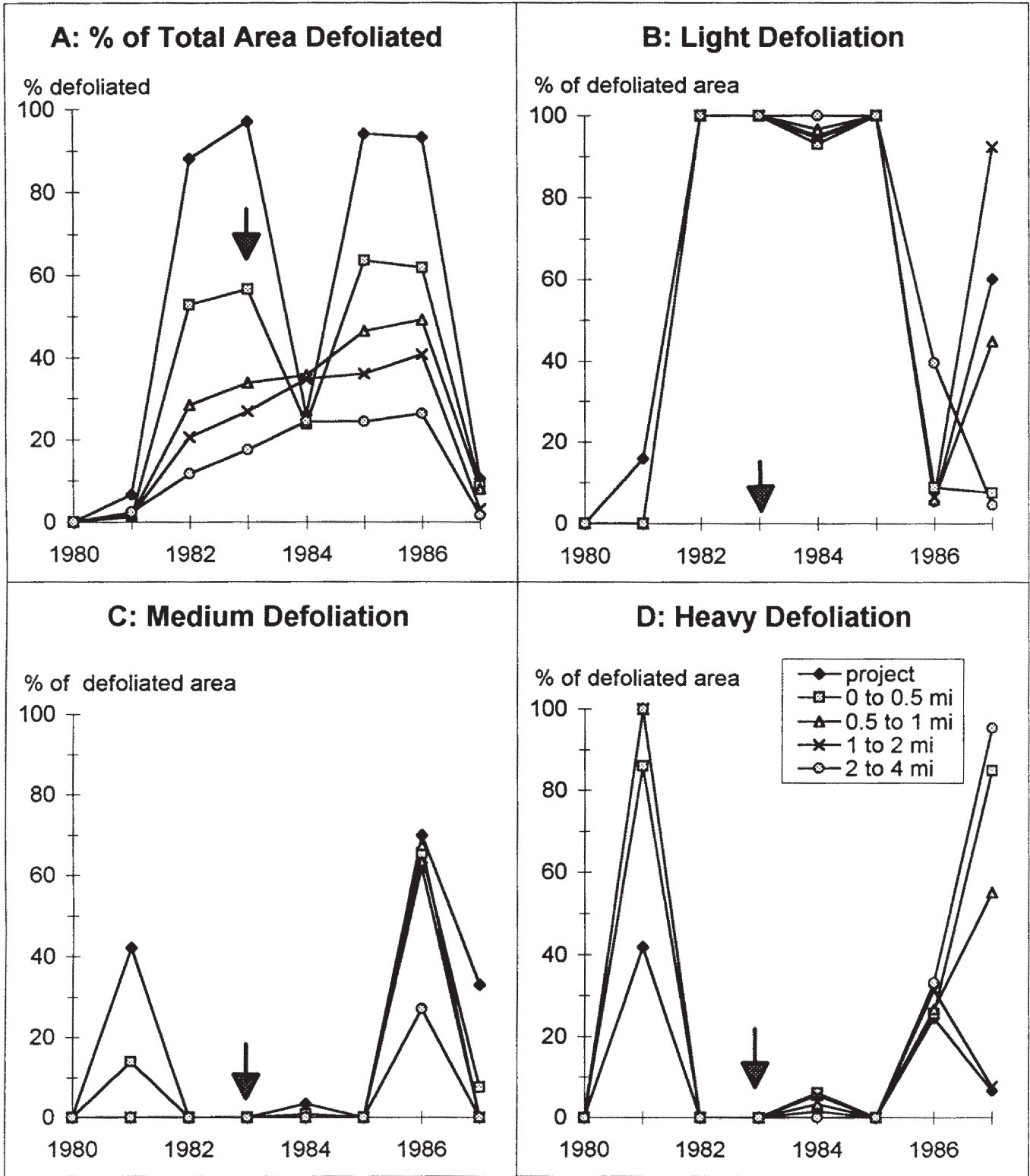
1982--Opal

Project area analyzed = 15,740 acres (44% of project)



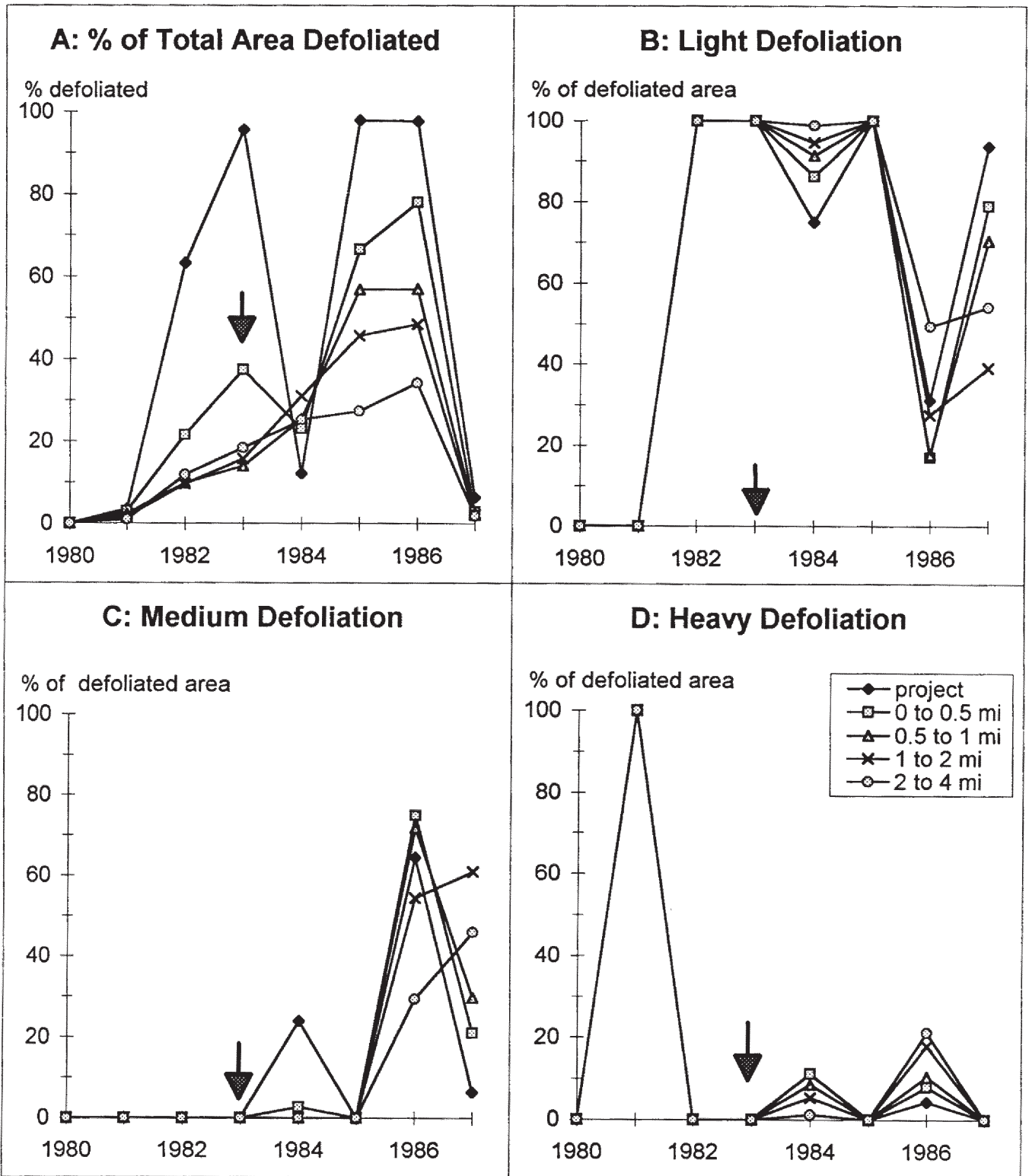
**1983--Aldrich**

**Project area analyzed = 111,800 acres (94% of project)**



1983--Butte-Logan

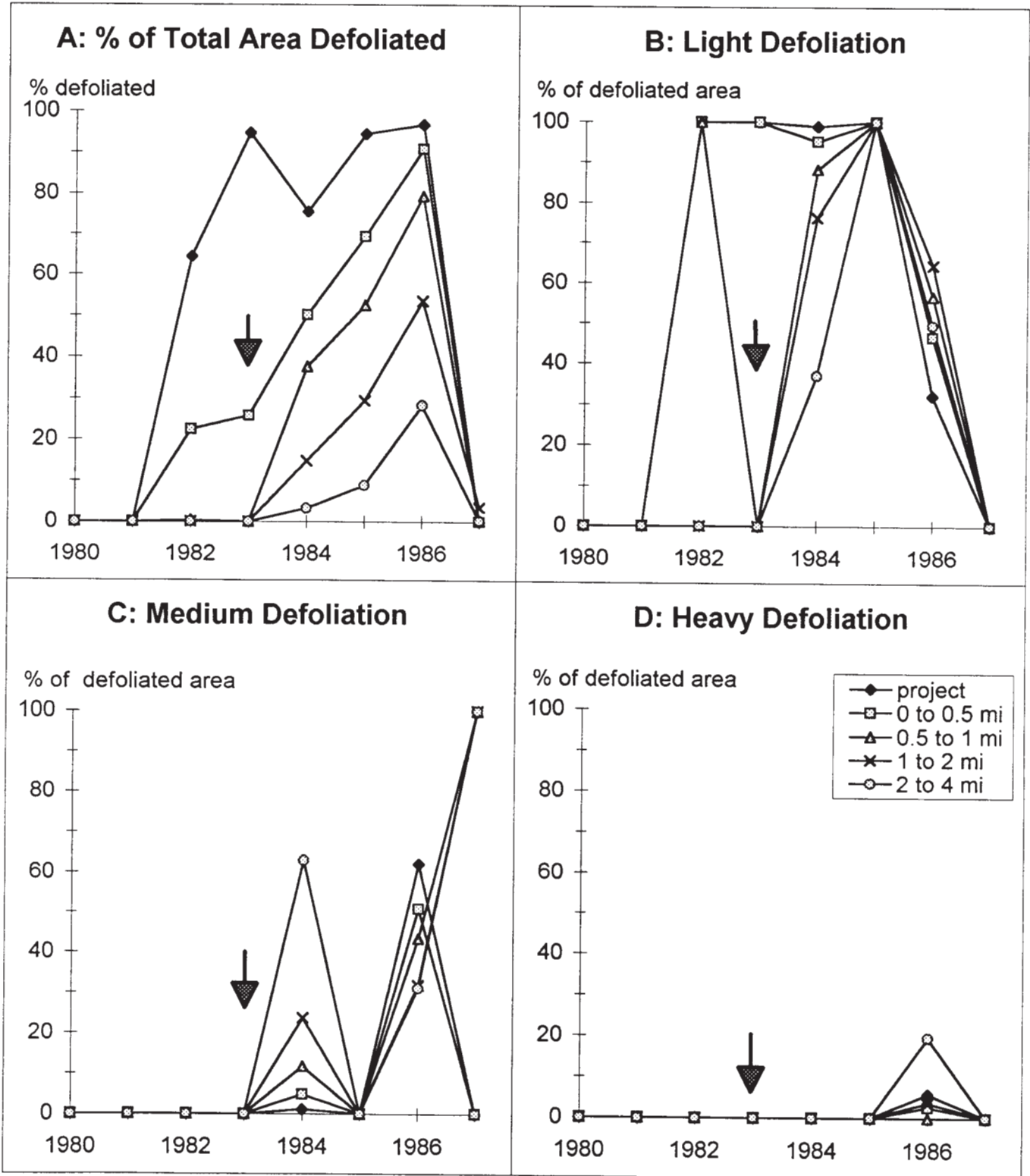
Project area analyzed = 104,900 acres (92% of project)





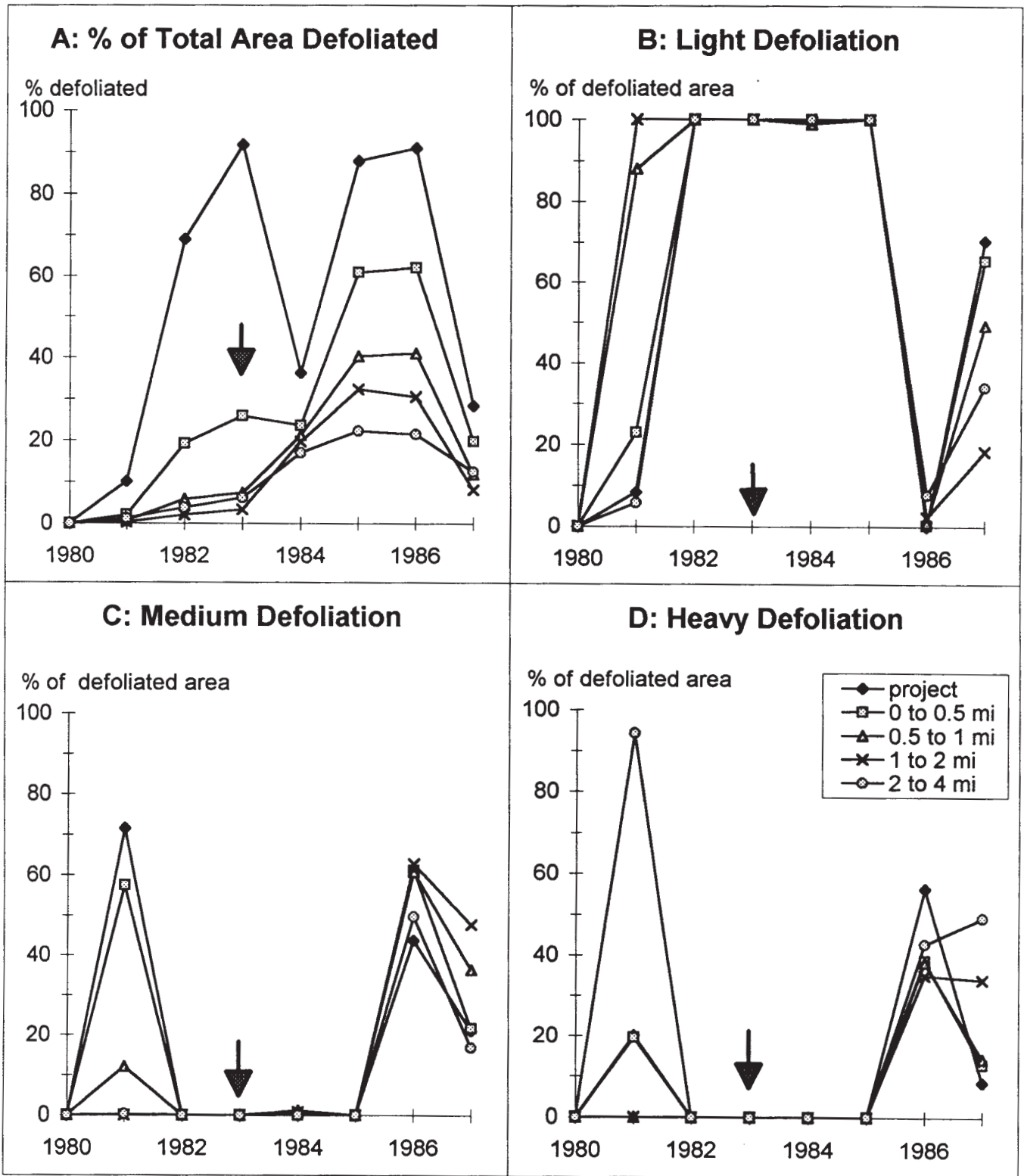
**1983--King**

Project area analyzed = 16,990 acres (100% of project)



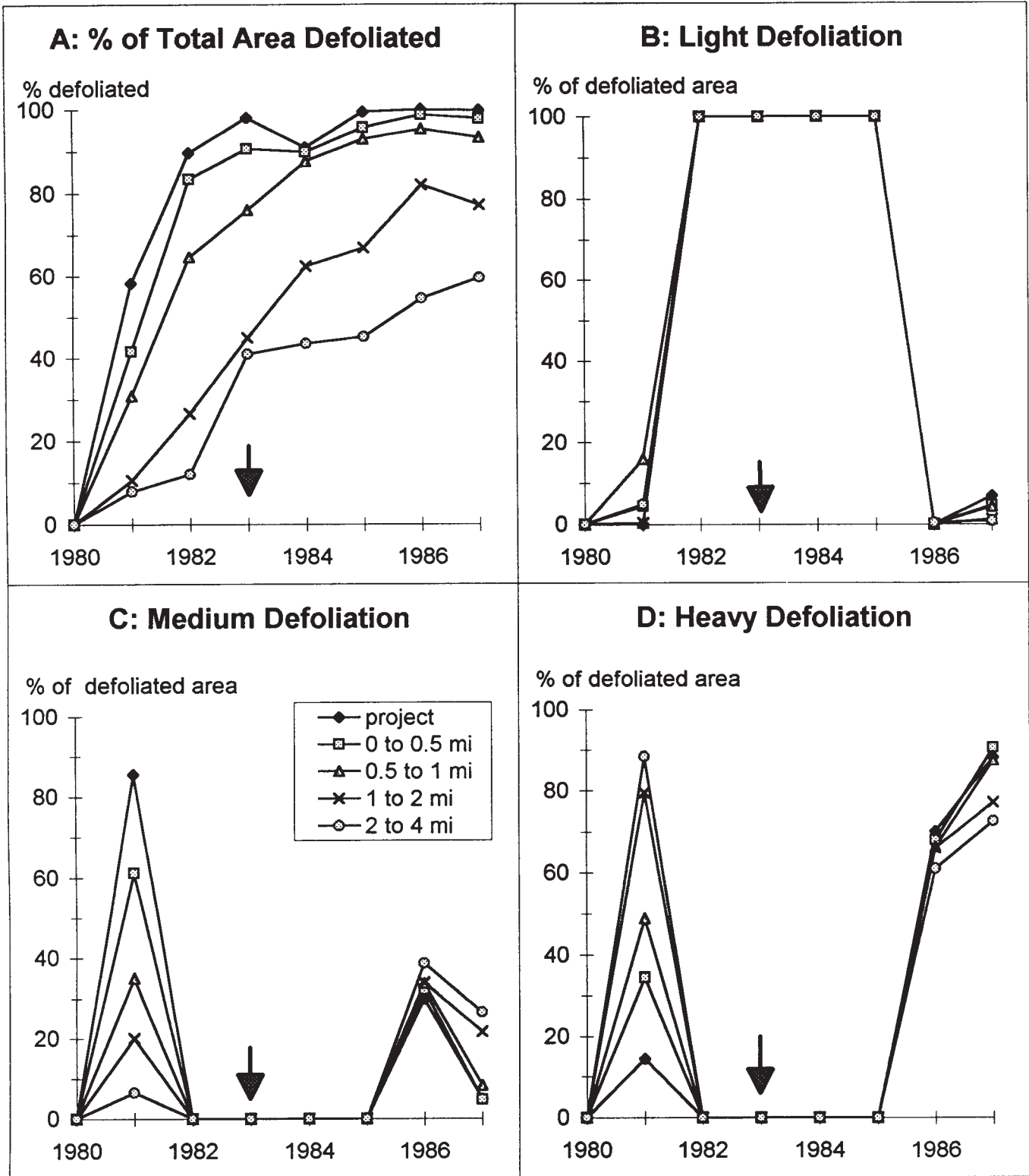
**1983--Matlock-Miller Prairie-Putney**

Project area analyzed = 228,100 acres (87% of project)



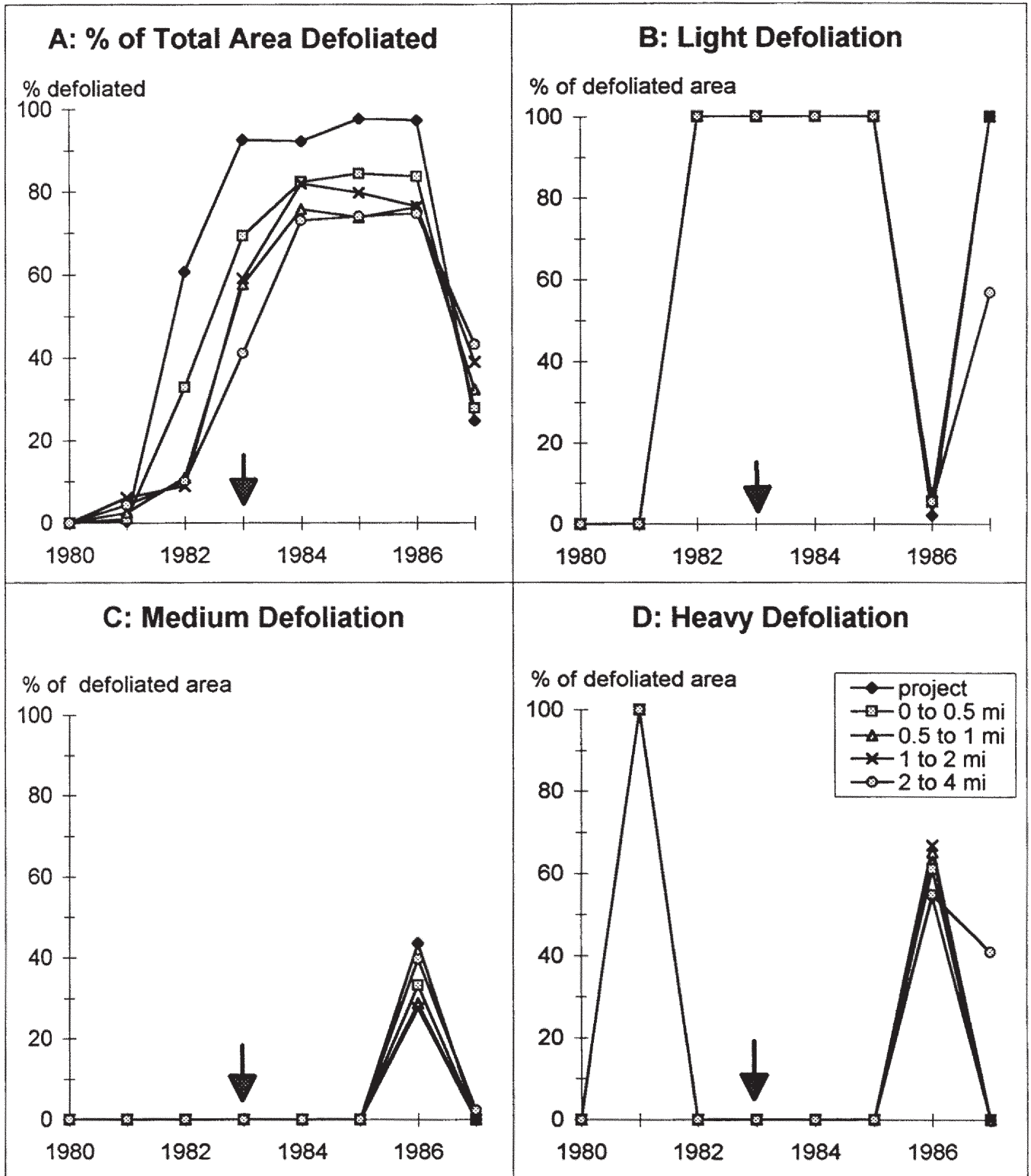
1983--Pearson

Project area analyzed = 25,270 acres (100% of project)



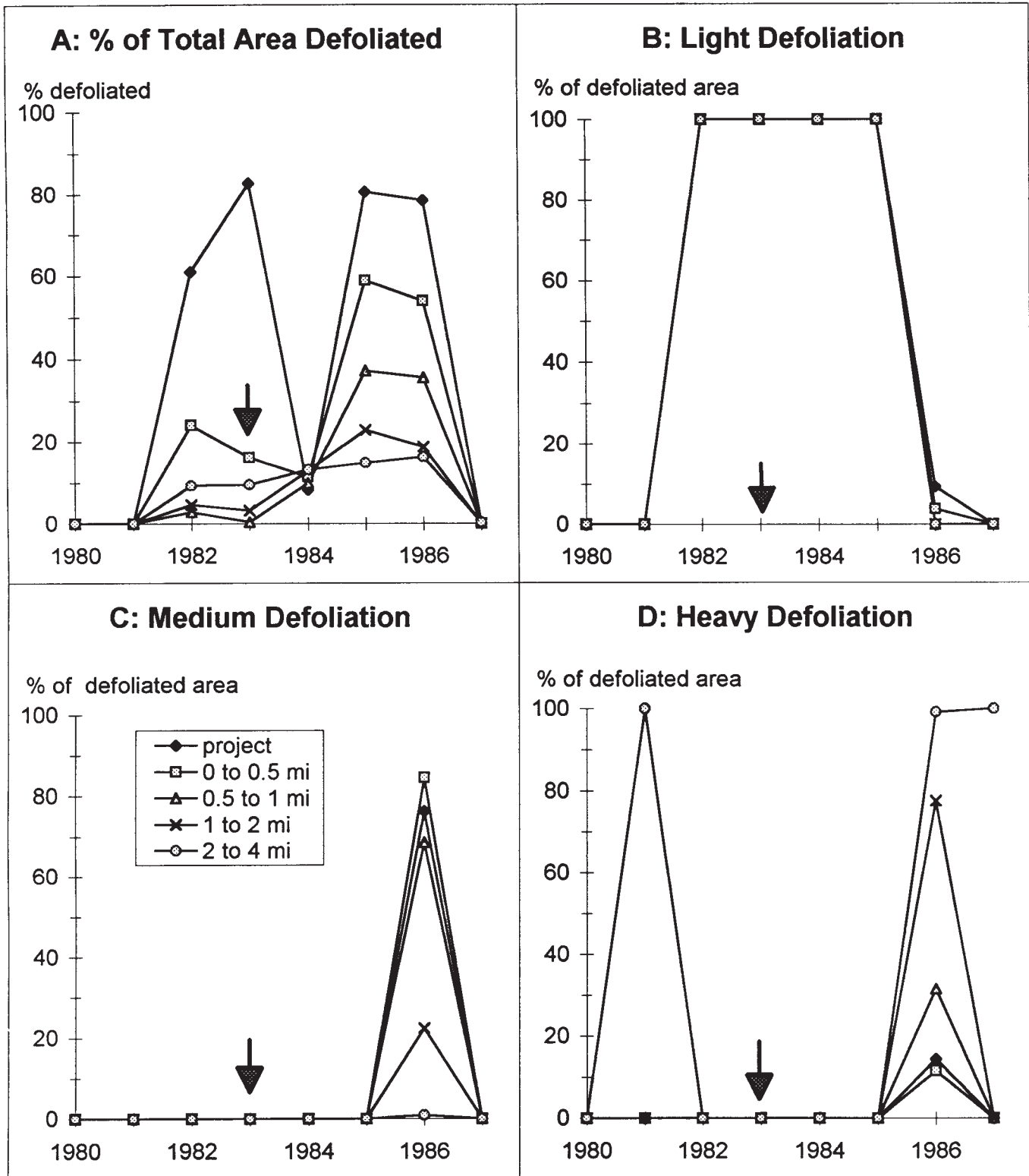
1983--Pogue-P.A.

Project area analyzed = 45,940 acres (84% of project)



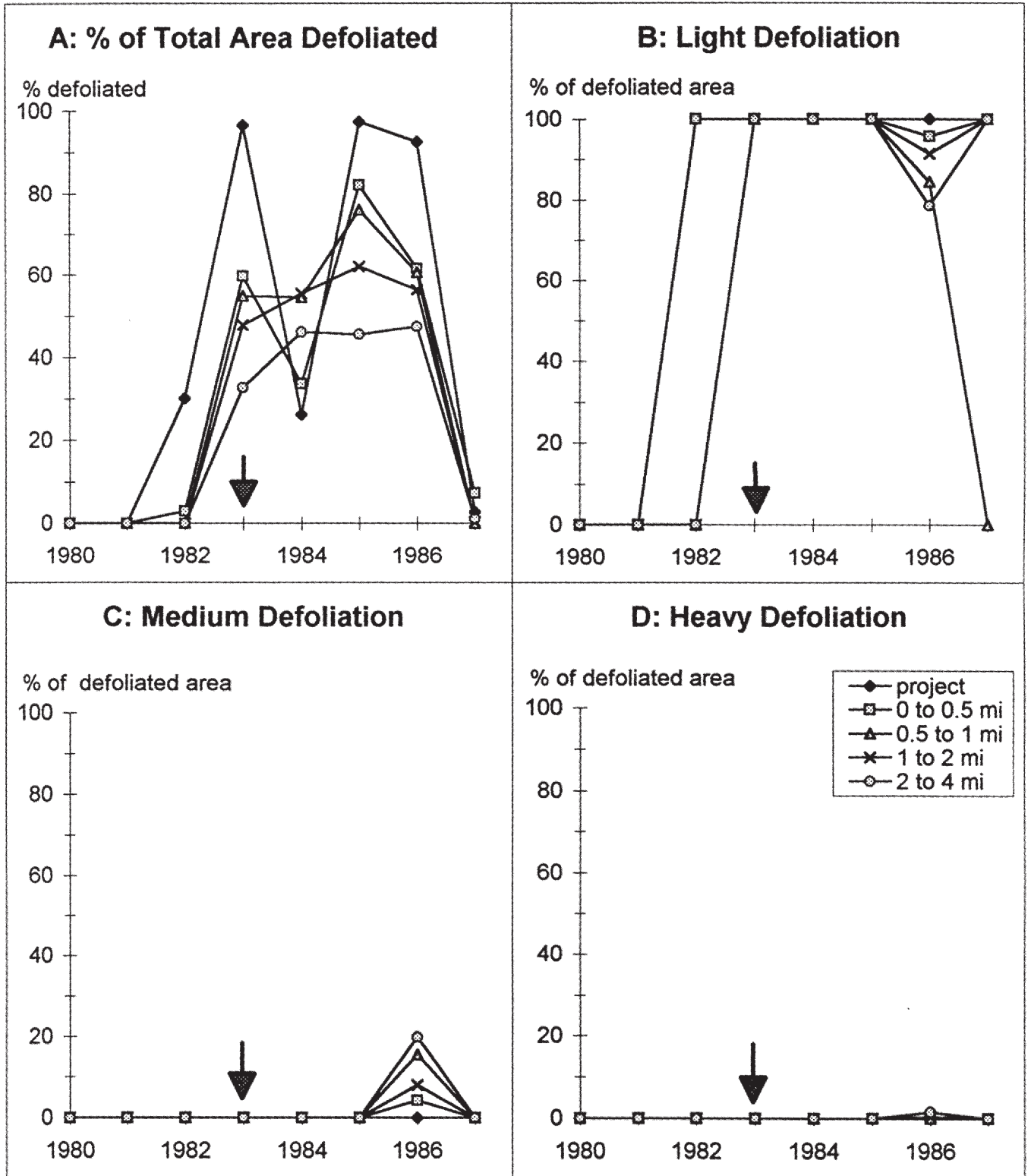
**1983--Rudio Mountain**

Project area analyzed = 23,980 acres (100% of project)

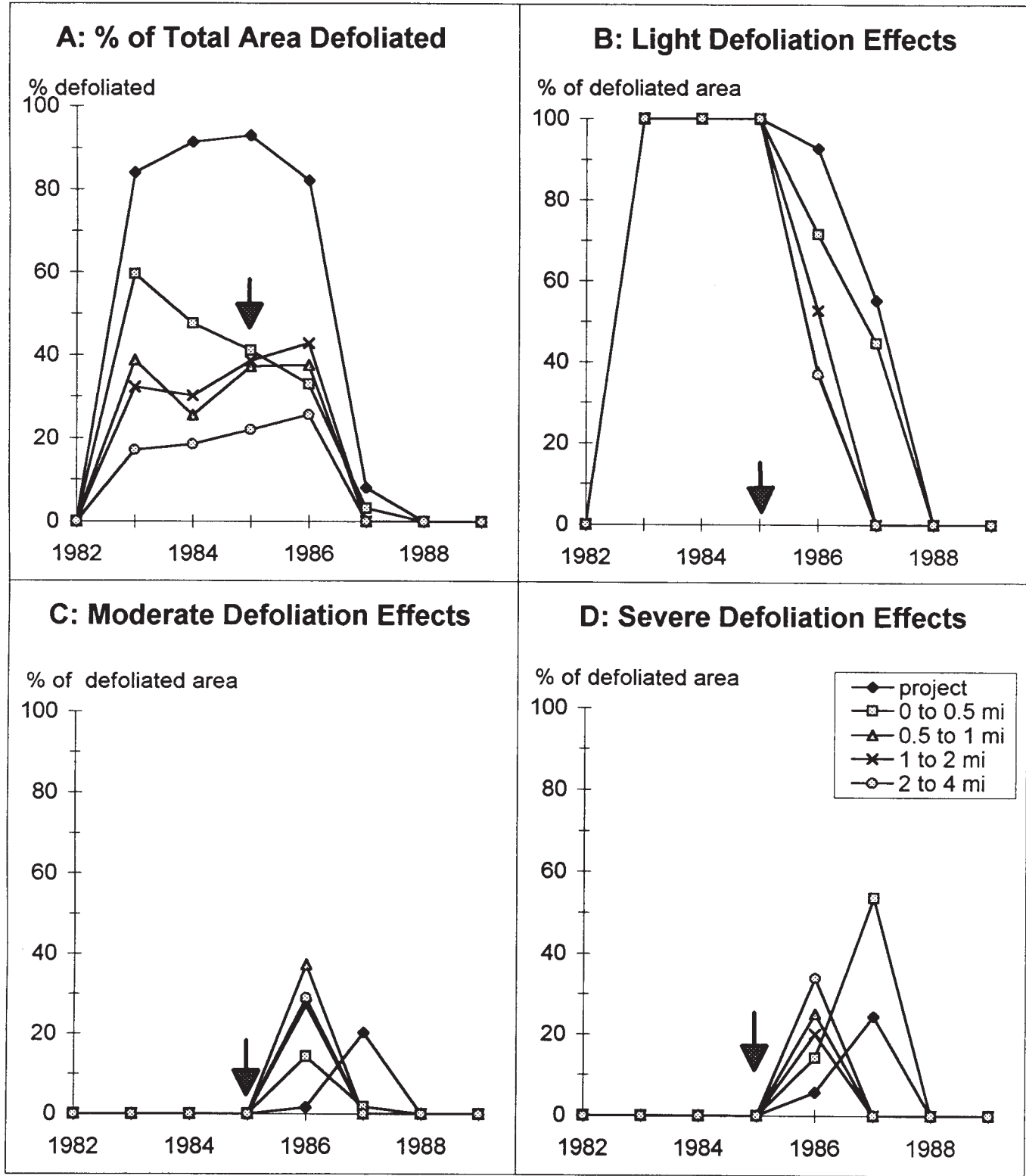


1983--Snow

Project area analyzed = 5,377 acres (100% of project)



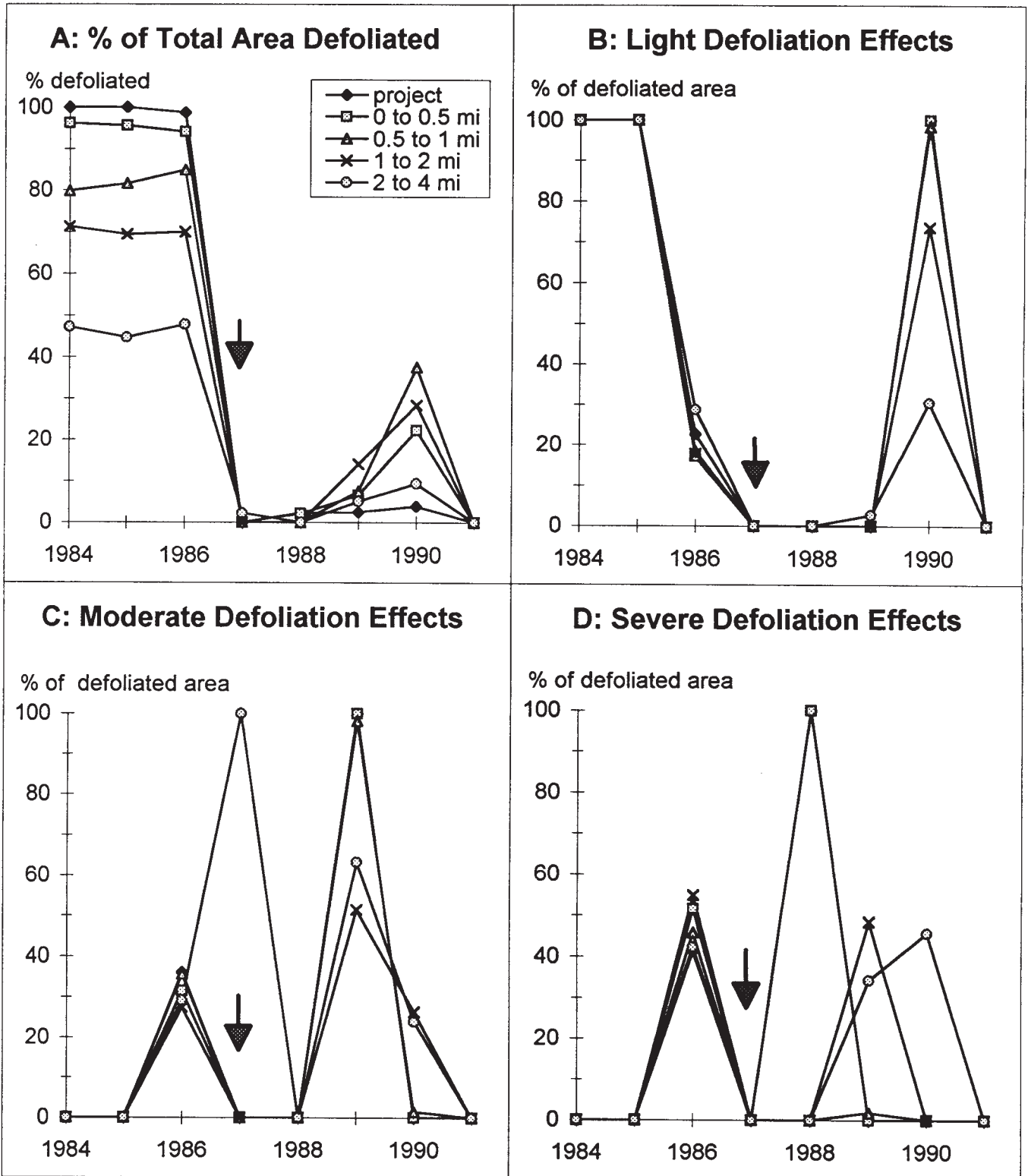
**1985--Rail-Scotty-Crooked-Burnt Cabin**  
**Project area analyzed = 32,510 acres (80% of project)**





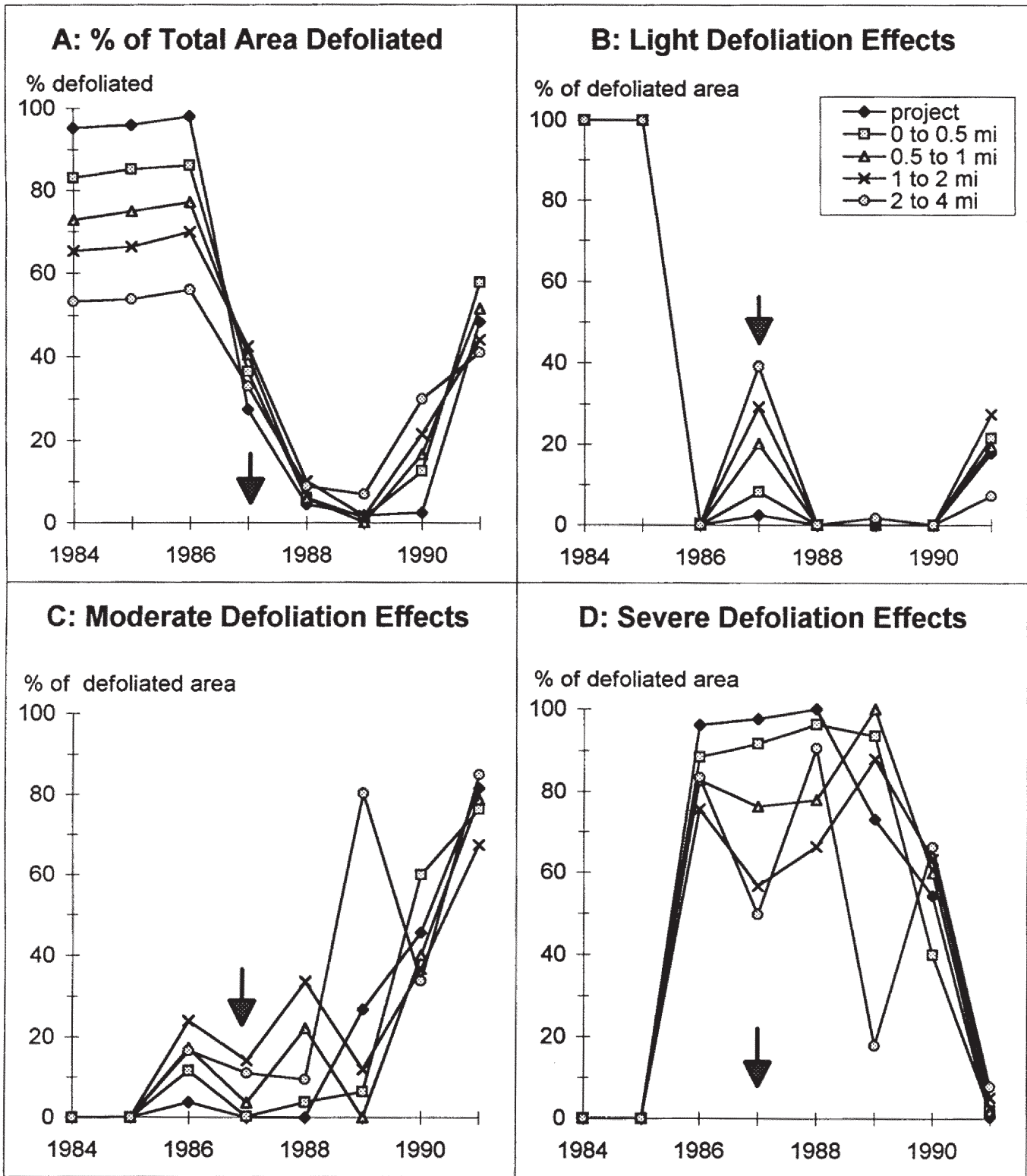
1987--Canyon

Project area analyzed = 18,840 acres (83% of project)



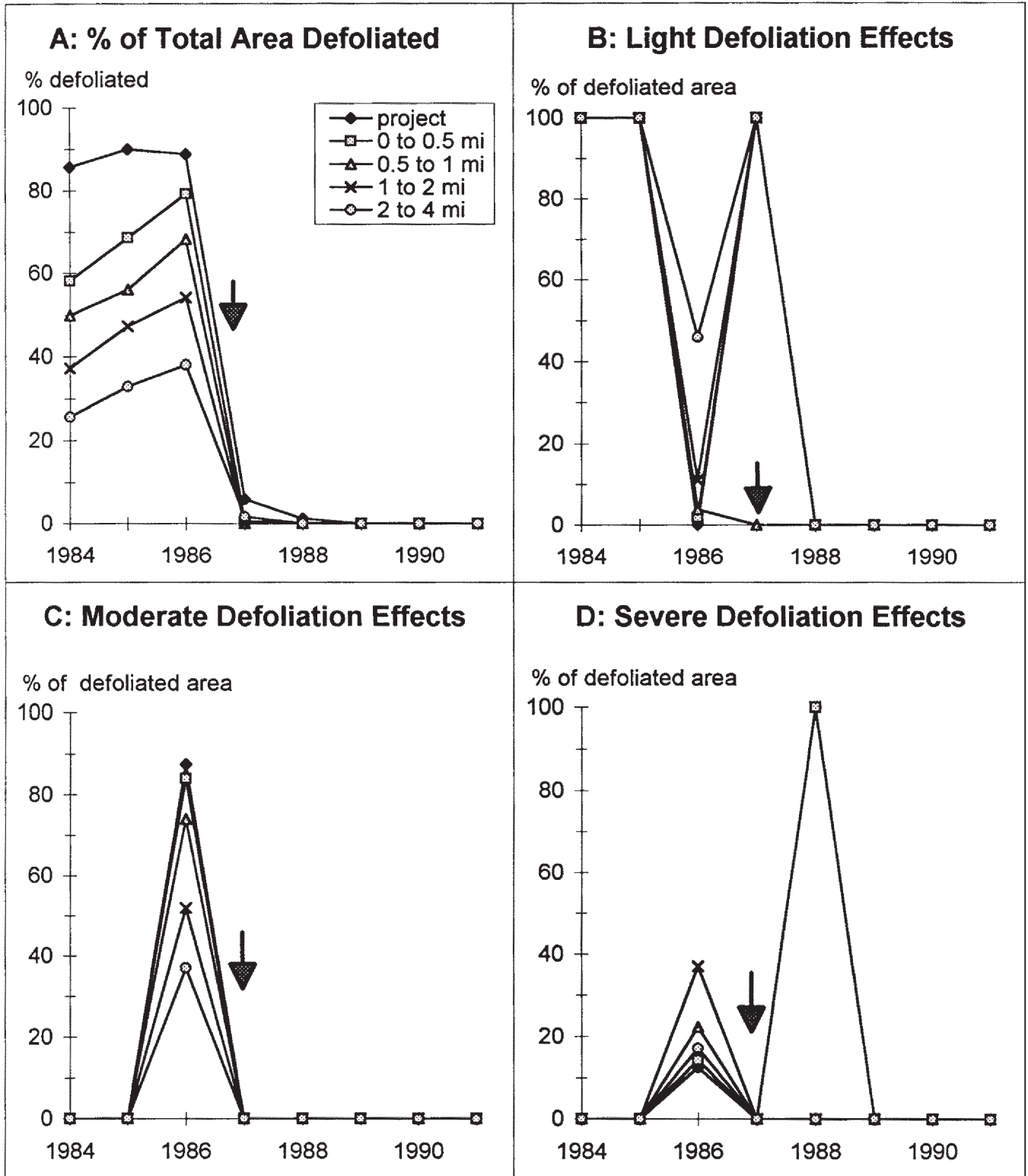
**1987--Flat-Dixie**

**Project area analyzed = 64,930 acres (98% of project)**



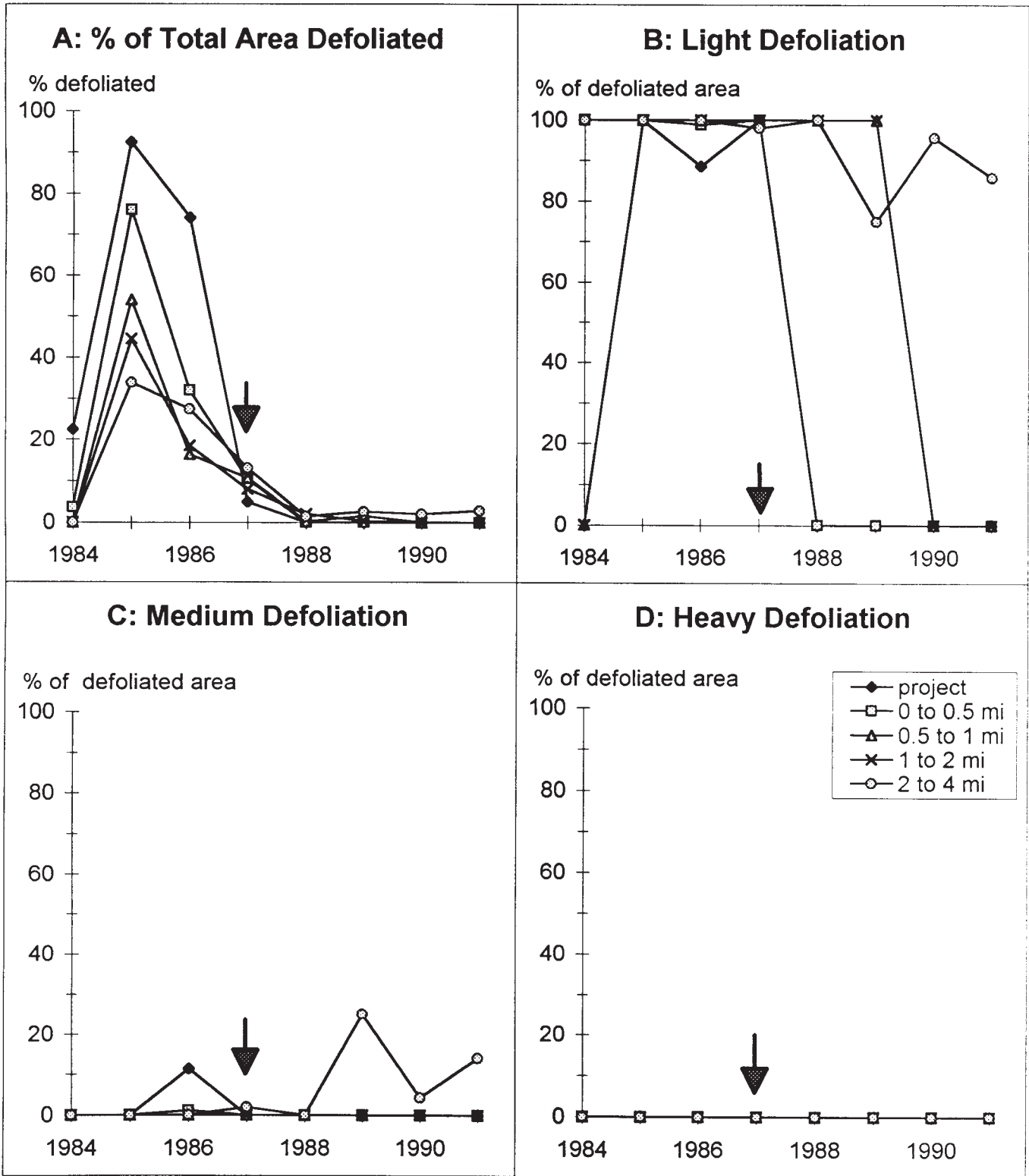
**1987--Lost Cabin**

**Project area analyzed = 20,340 acres (86% of project)**



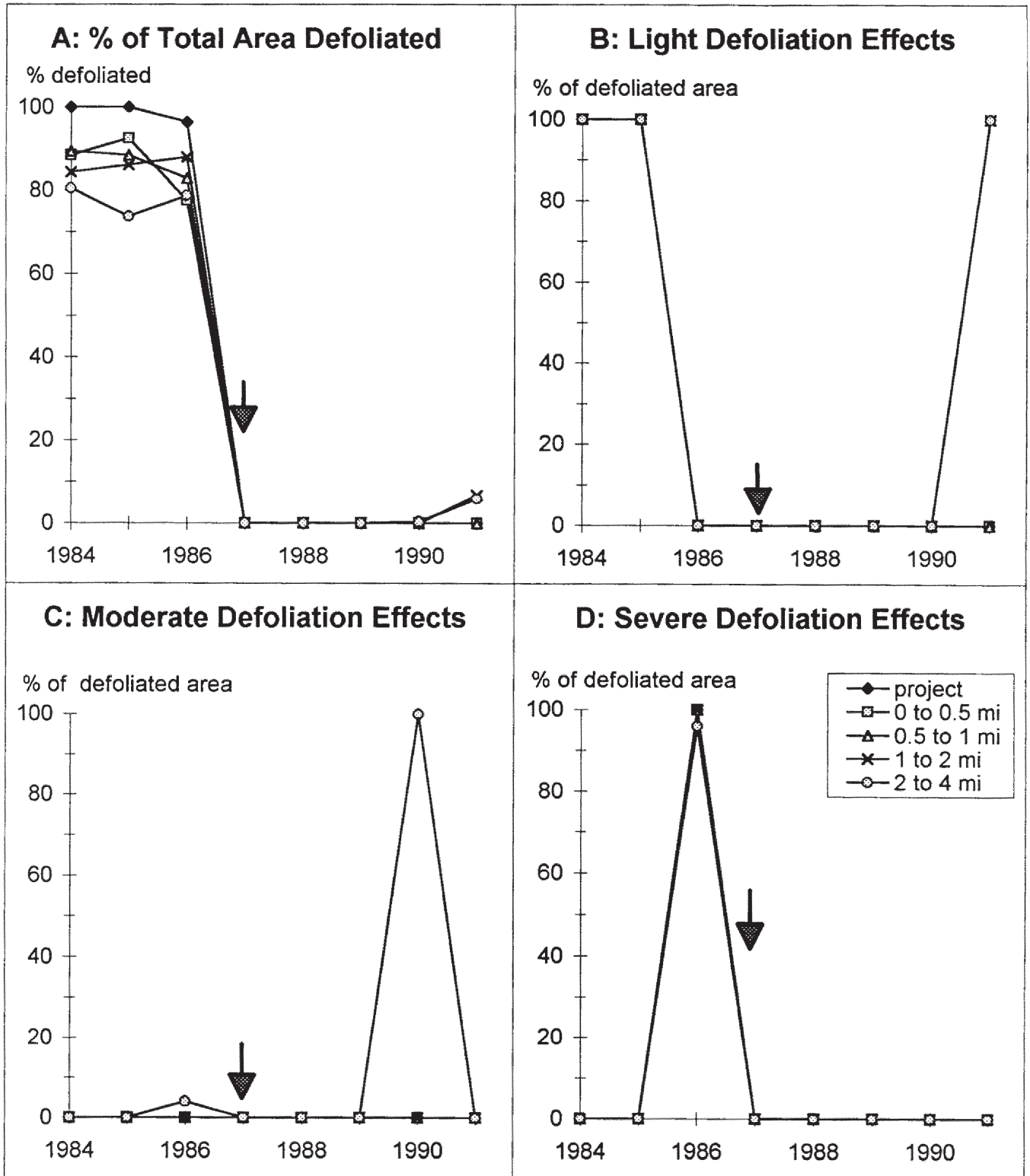
**1987--Rimrock**

Project area analyzed = 45,760 acres (100% of project)



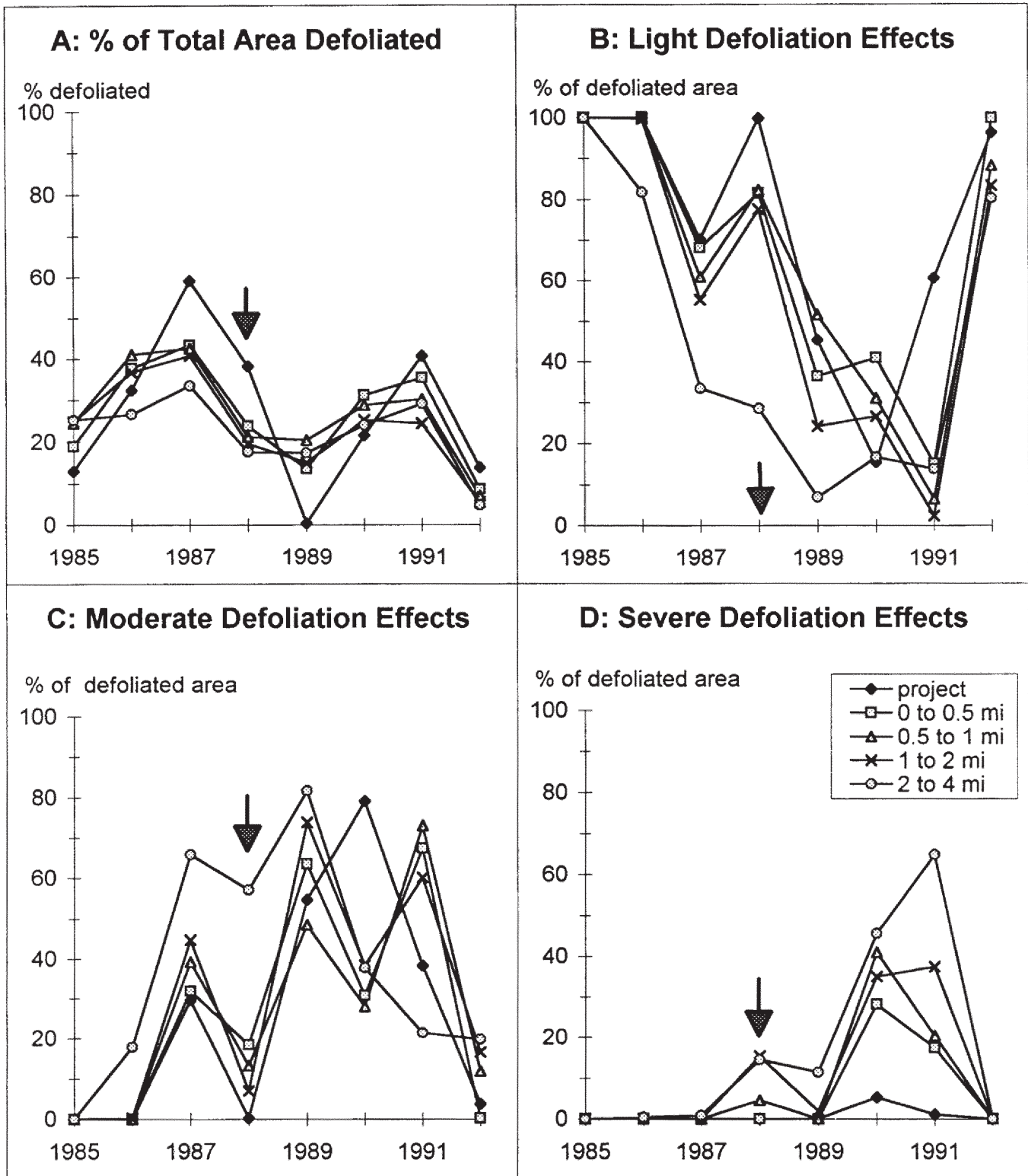
1987--Starr

Project area analyzed = 333 acres (100% of project)

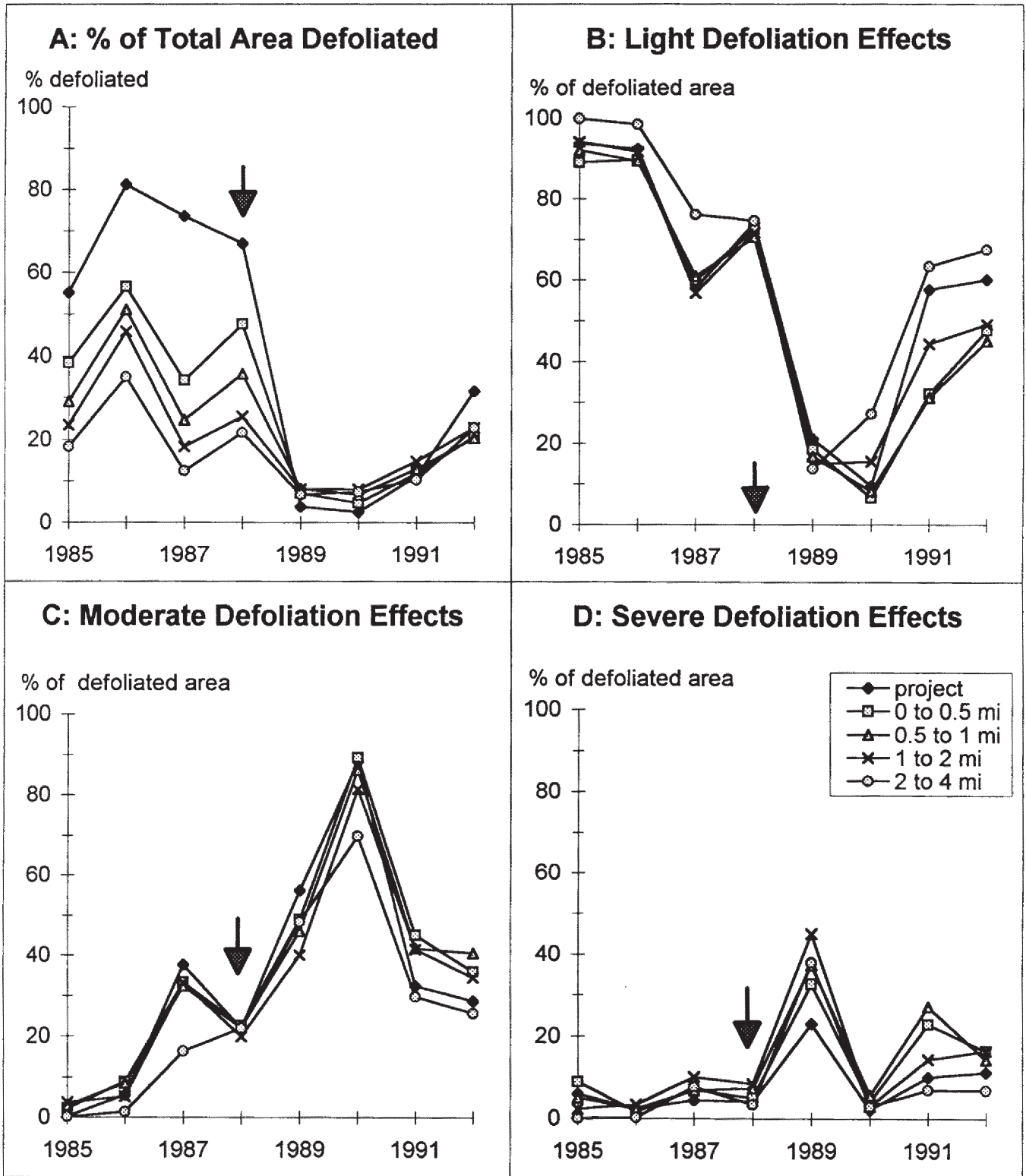


**1988--Meacham**

Project area analyzed = 35,490 acres (46% of project)



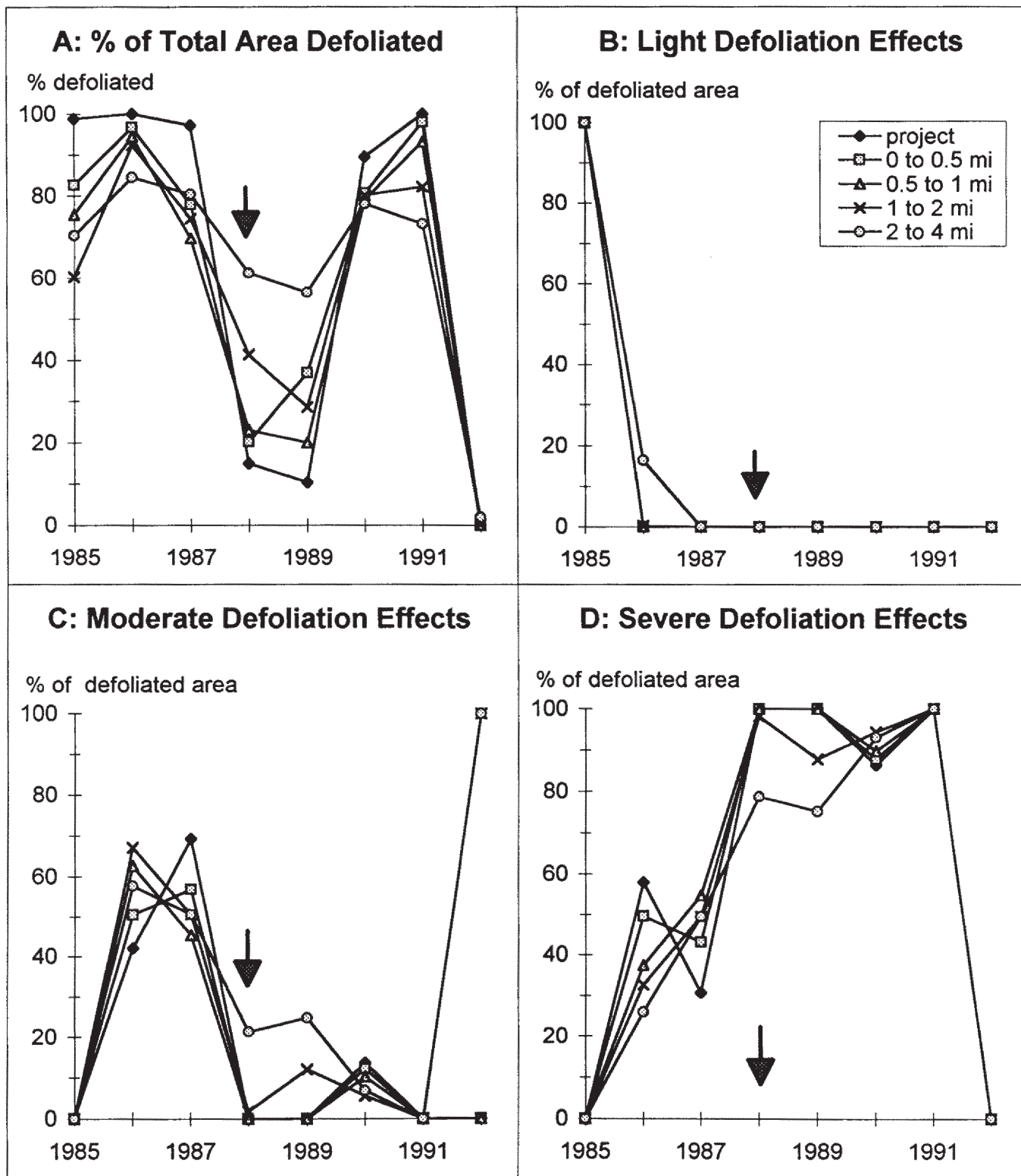
**1988--Barlow-Dalles-Hood River Co.-Warm Springs**  
**Project area analyzed = 484,400 acres (100% of project)**





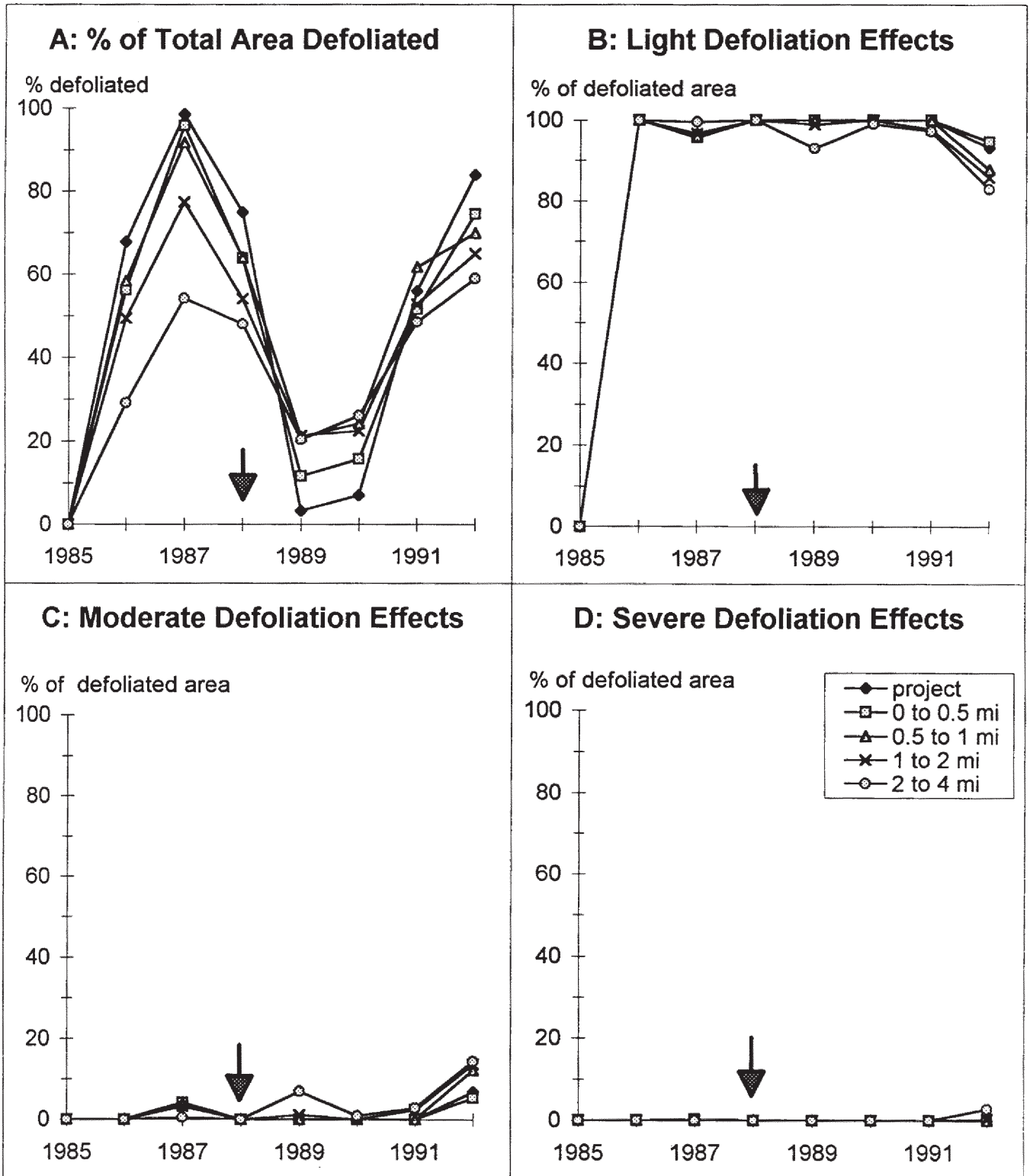
**1988--Starkey**

Project area analyzed = 3,608 acres (100% of project)



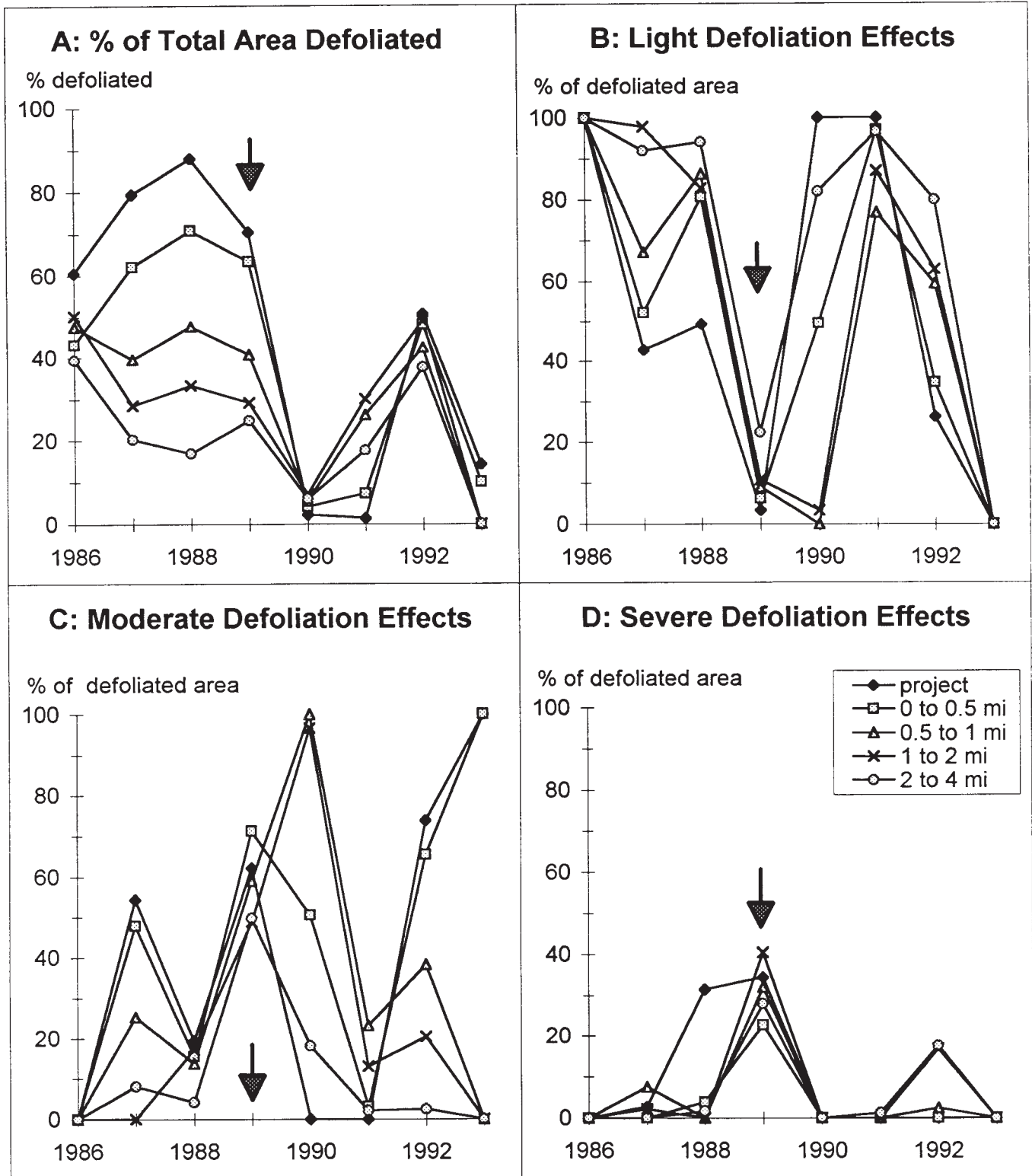
**1988--Tollgate**

Project area analyzed = 95,530 acres (98% of project)



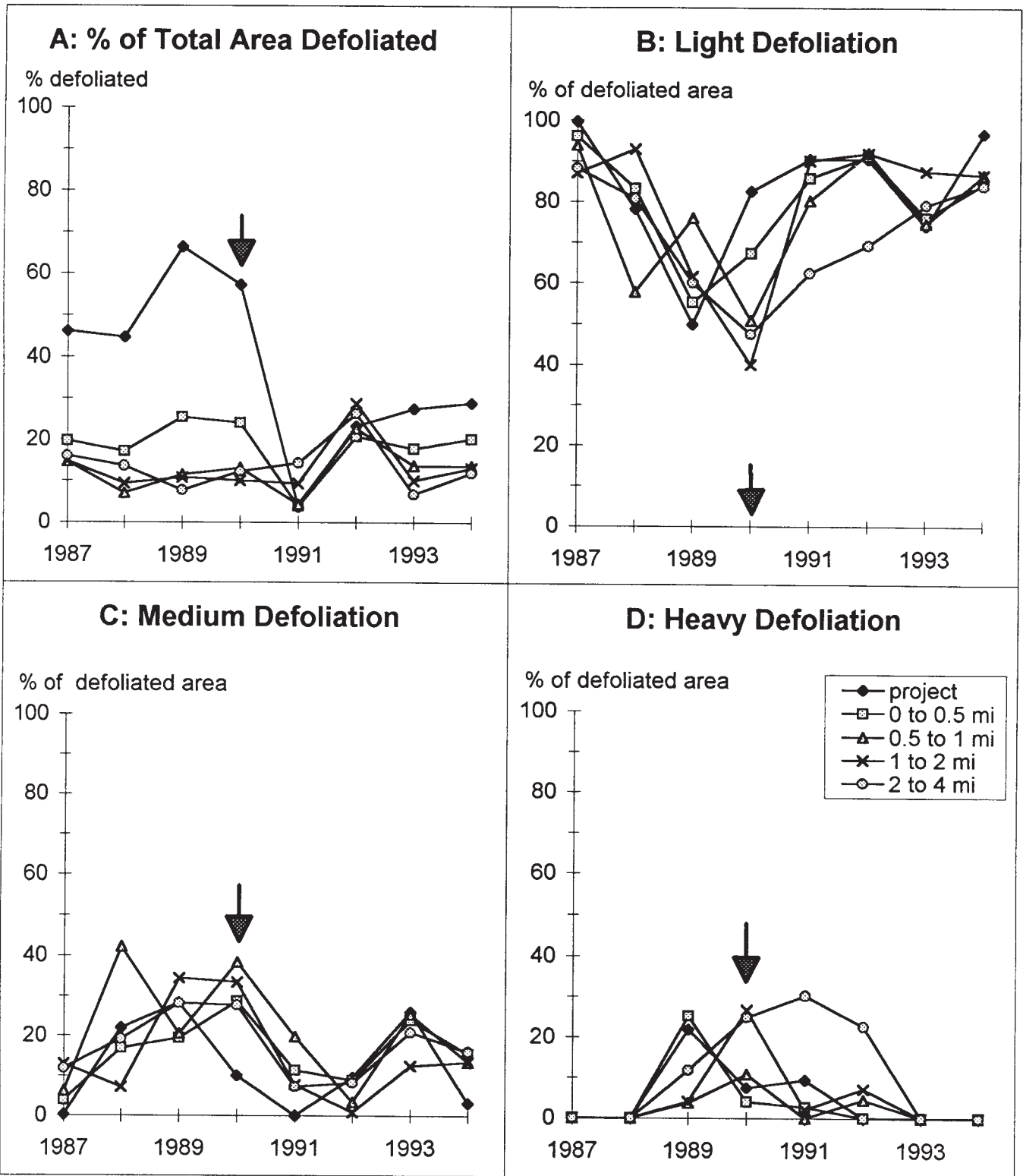
**1989--High Rock**

Project area analyzed = 7,595 acres (100% of project)

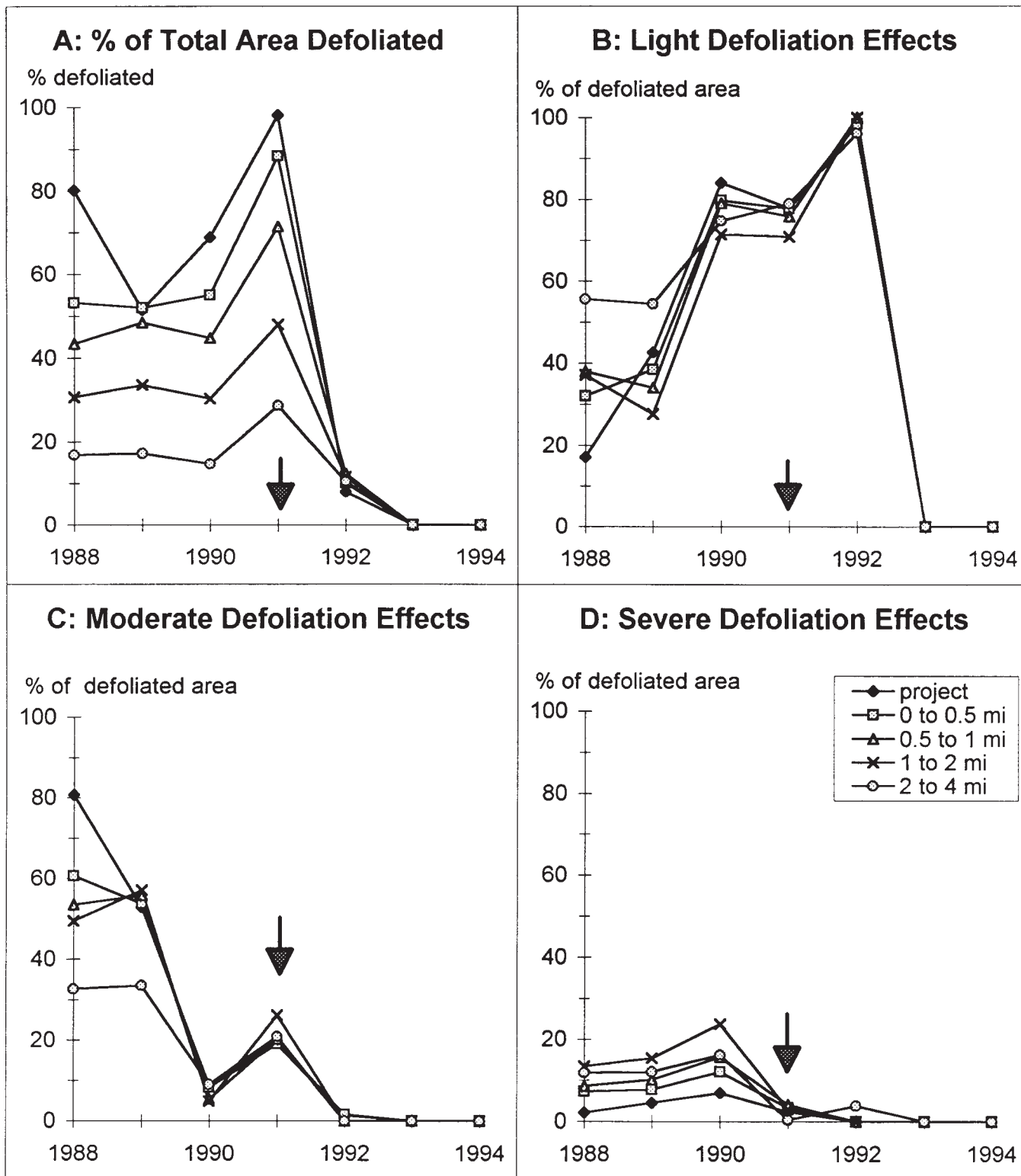


**1990--Yakima**

Project area analyzed = 71,680 acres (100% of project)

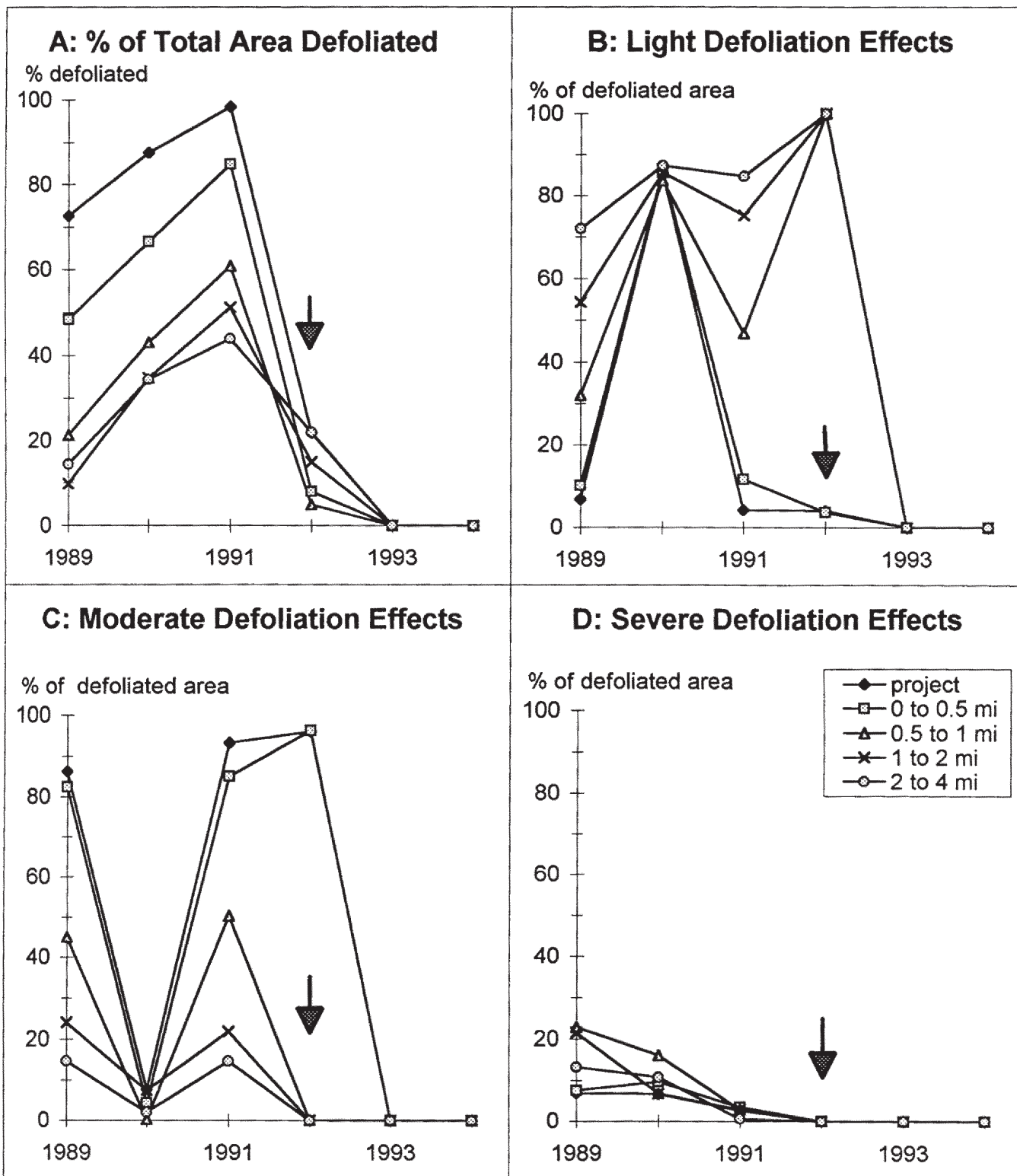


**1991--Catherine Creek-Hells Canyon-Pine**  
**Project area analyzed = 98,170 acres (86% of project)**

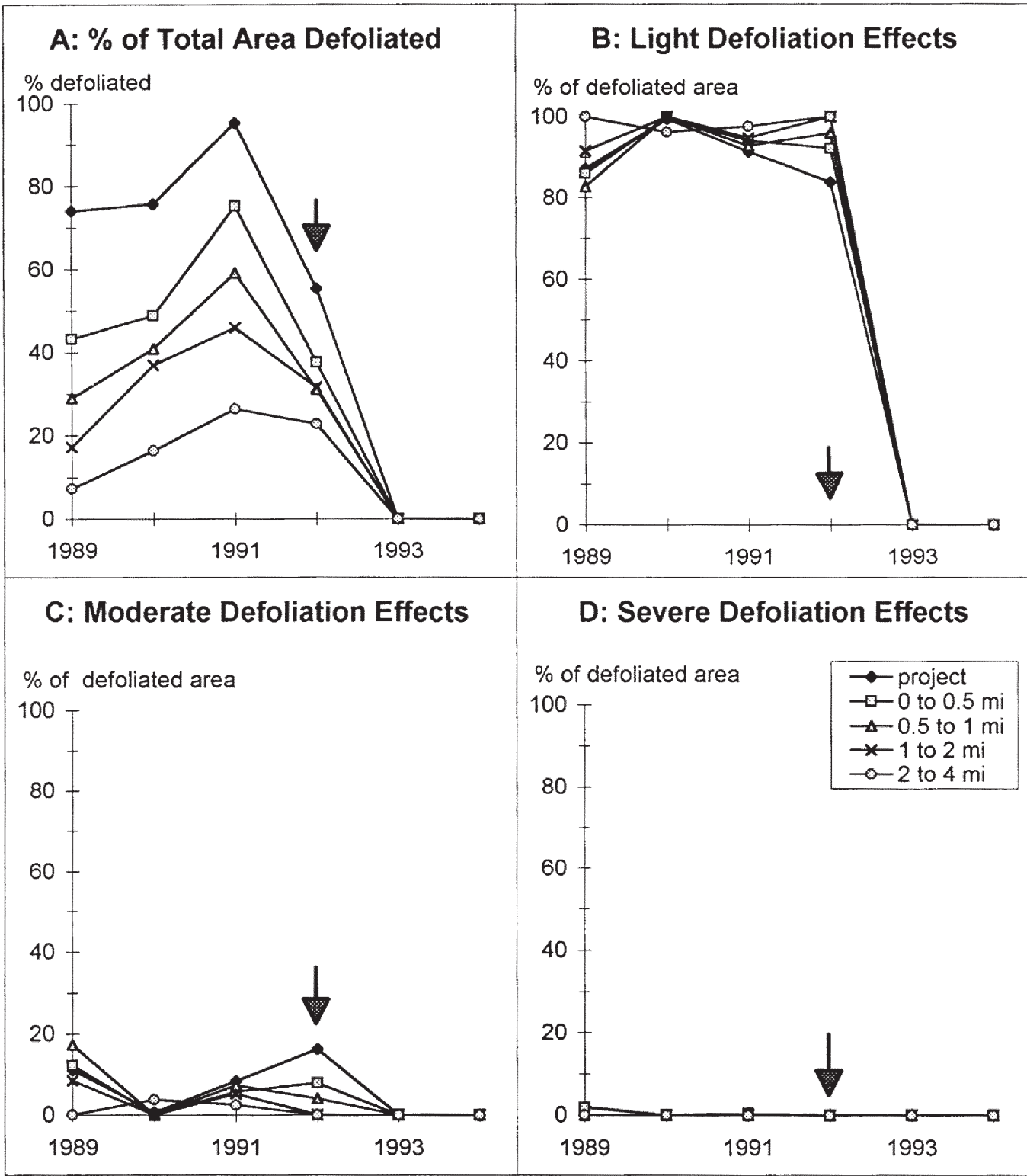


**1992--Indian Creek-Boise Cascade**

Project area analyzed = 31,570 acres (100% of project)



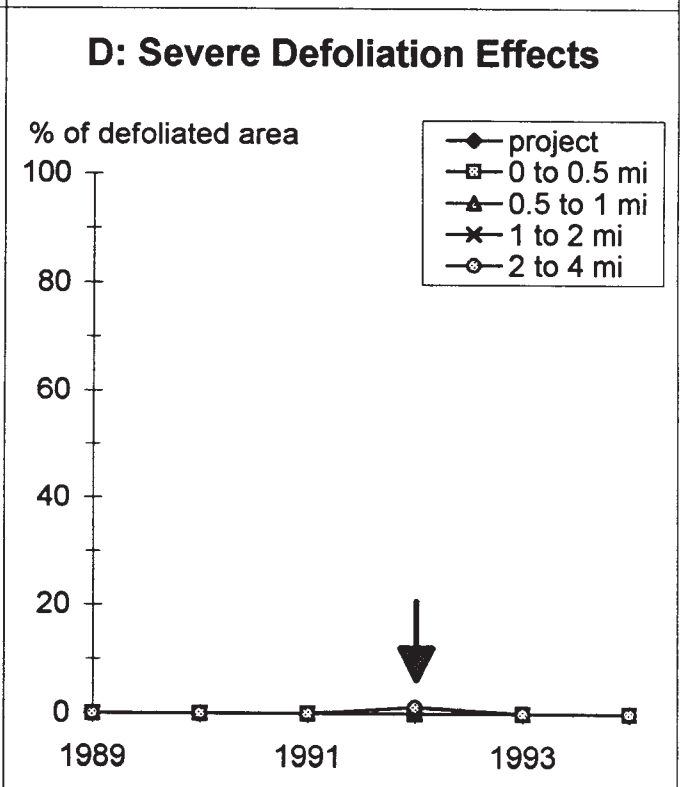
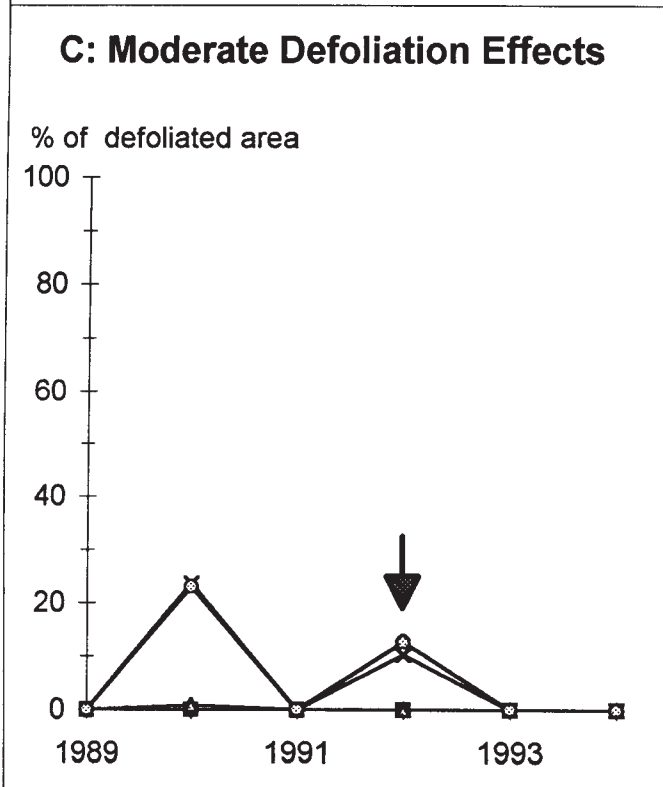
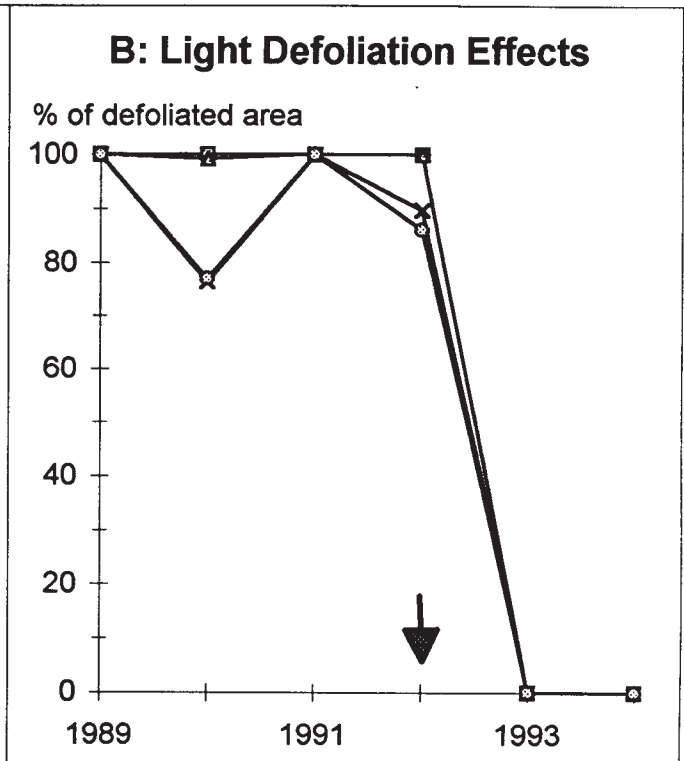
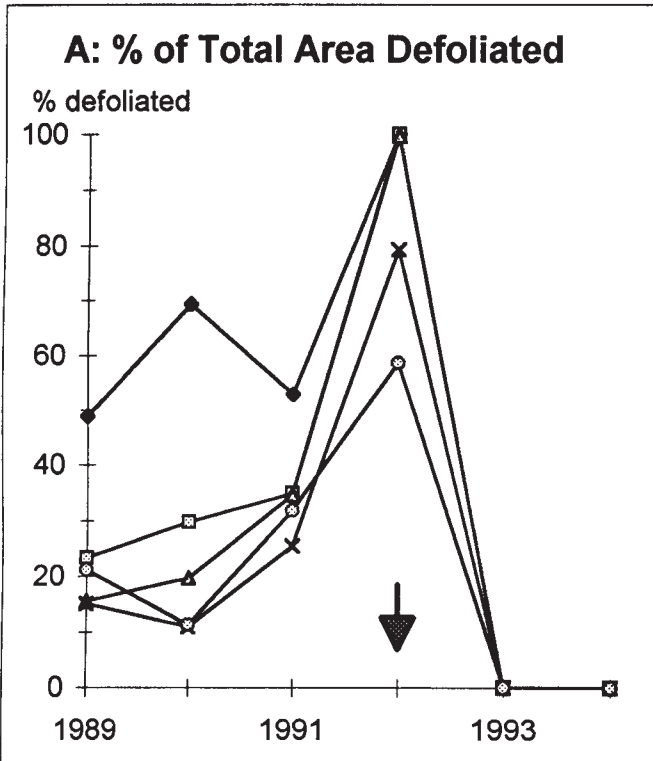
**1992--Kuhn-Chesnimnum-Boise Cascade**  
**Project area analyzed = 56,540 acres (100% of project)**





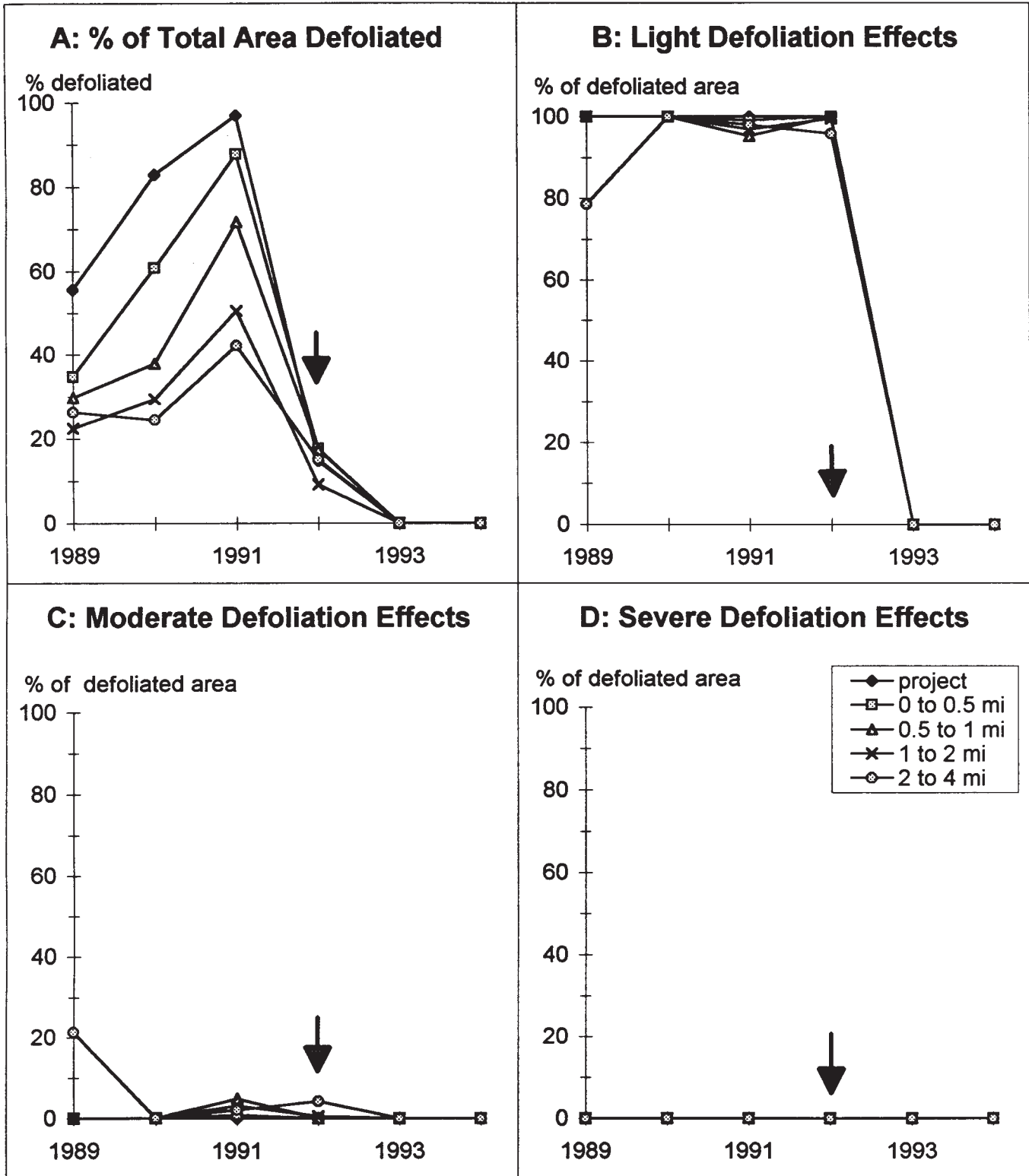
**1992--Mill**

**Project area analyzed = 5,985 acres (100% of project)**

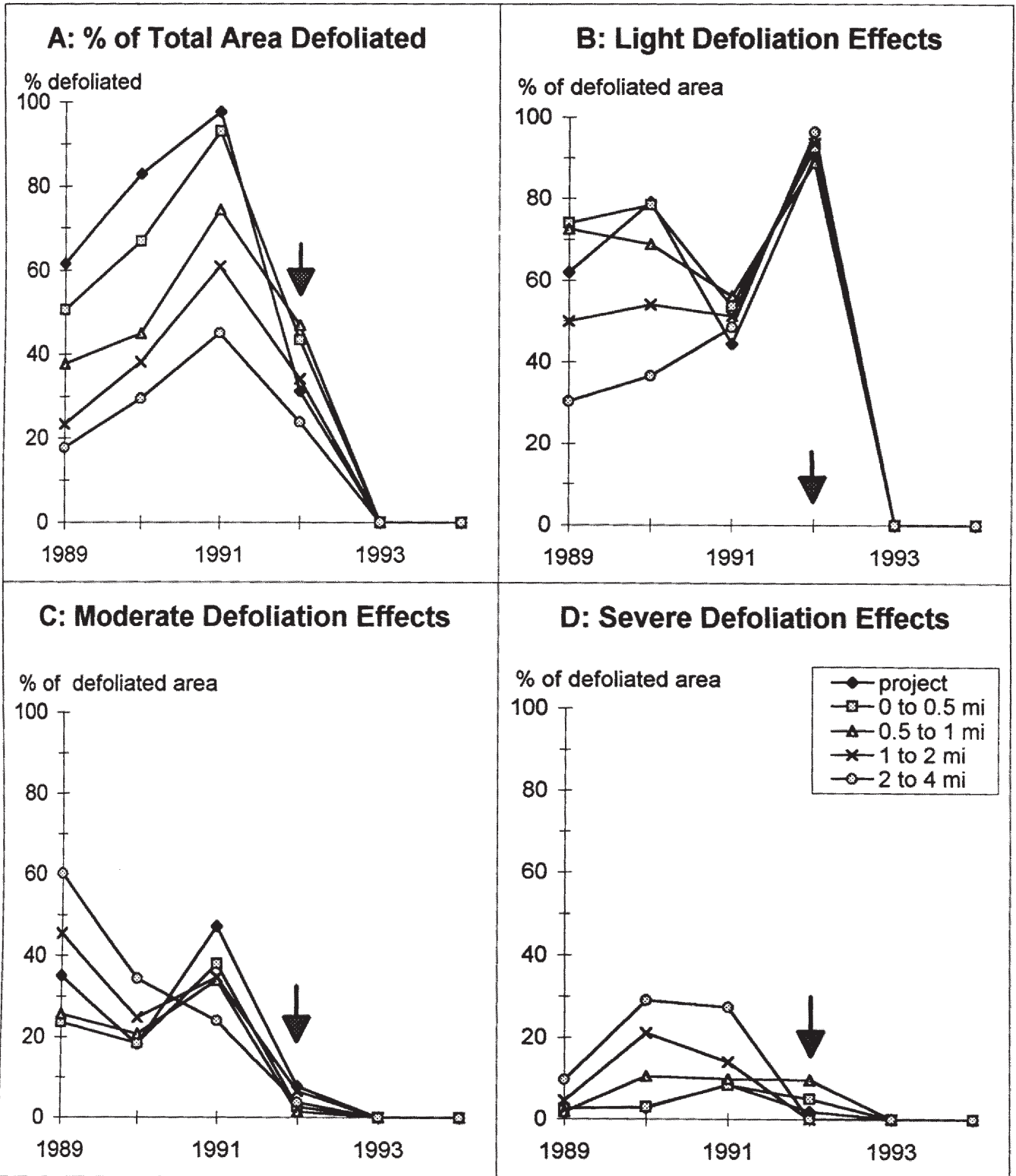


**1992--Morgan**

Project area analyzed = 27,510 acres (100% of project)

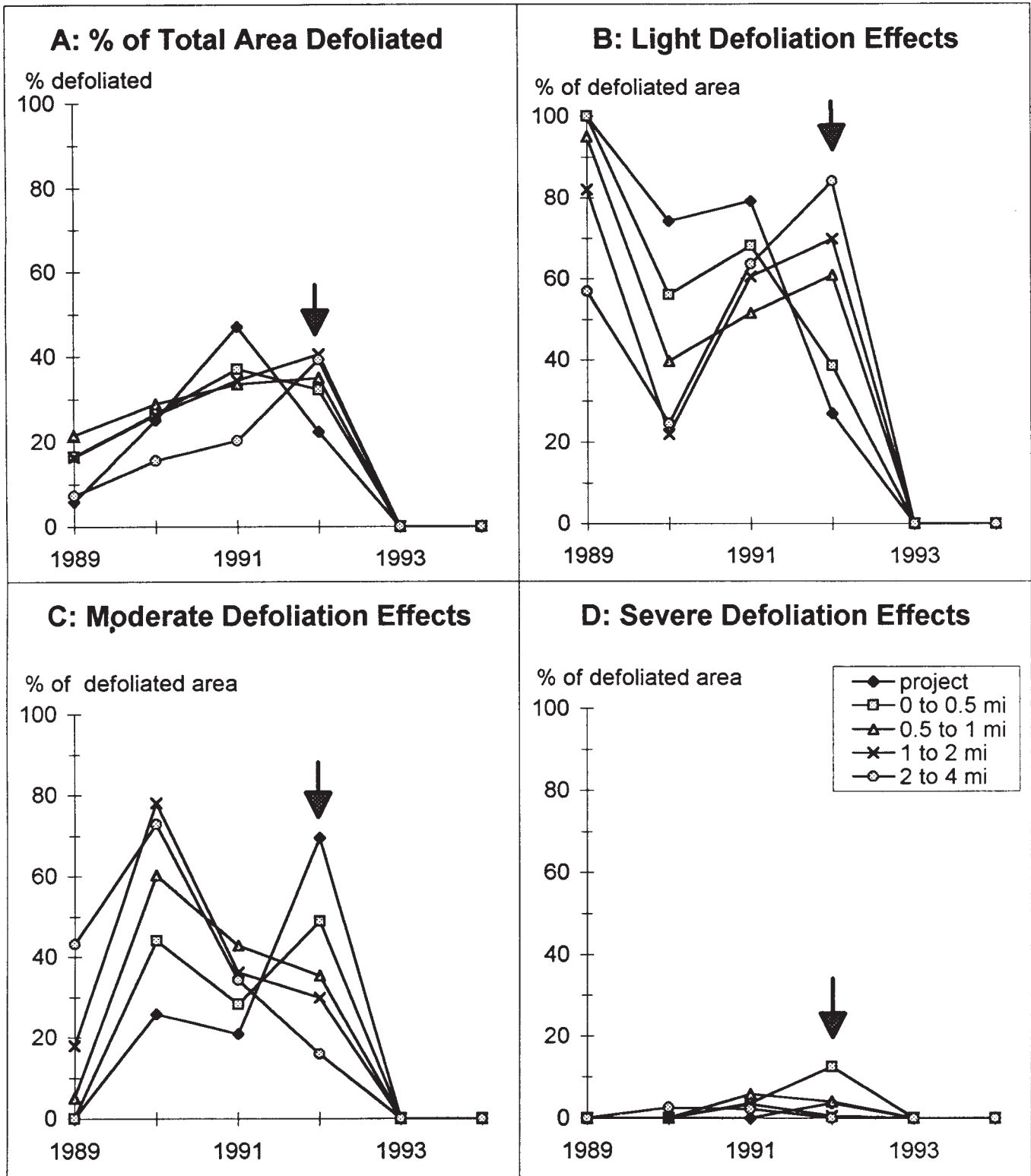


**1992-Mt. Emily-Thimbleberry-Meacham**  
**Project area analyzed = 92,440 acres (100% of project)**



**1992--Suttle Lake**

Project area analyzed = 5,945 acres (100% of project)



**Sheehan, Katharine A. 1996.** Effects of insecticide treatments on subsequent defoliation by western spruce budworm in Oregon and Washington: 1982-92. Gen. Tech. Rep. PNW-GTR-367. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p.

Effects of insecticide treatments conducted in Oregon and Washington from 1982 through 1992 on subsequent defoliation by western spruce budworm (*Choristoneura occidentalis* Freeman) were evaluated by using aerial sketchmaps and a geographic information system. For each treatment, the extent and severity of defoliation was calculated for the treated area and a set of four nested rings surrounding the treated area (0-0.5 mile, 0.5-1 mile, 1-2 miles, and 2-4 miles) for up to 8 years: 3 years prior to treatment, the year of treatment, and 4 years following treatment. Insecticide treatments applied in 1982 and 1983 coincided with reduced percentages of defoliation by western spruce budworm during the year following treatment. However, the percentage of defoliation usually returned to pretreatment levels by the second year, and defoliation severity in treated and adjacent untreated areas was nearly identical following treatment. For the period from 1985 through 1992, defoliation patterns (including both extent and severity) following treatment were generally similar in treated and adjacent untreated areas.

Keywords: Western spruce budworm, *Choristoneura occidentalis*, defoliation, insecticides, effects, suppression projects.

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