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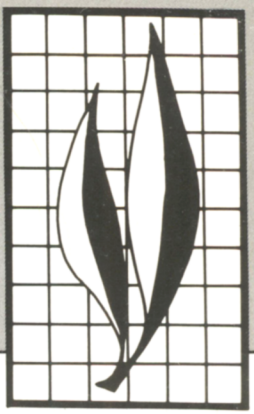

Ecology and Management of *Mindarus kinseyi* Voegtlin (Aphidoidea: Mindaridae) on White-Fir Seedlings at a California Forest Nursery

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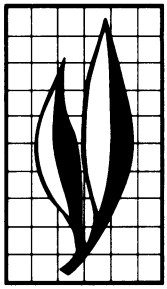

ABSTRACT

In recent years, an aphid identified as balsam twig aphid, *Mindarus abietinus* Koch, was observed on seedlings of white fir (*Abies concolor* [Gord. & Glend.] Lindl.) at the USDA—Forest Service Nursery near Placerville, California. Both first- and second-year seedlings were infested and aphid-induced stunting of seedlings was observed. Investigations during 1989–92 revealed that the aphid had a life cycle that differed from that reported for *M. abietinus*. The following stages were detected: egg, fundatrix, vivipara (apterous and alate), sexupara (apterous and alate), and sexualis (male and ovipara). Third and subsequent generations of apterous viviparae were observed; these, plus the alate viviparae and the apterous sexuparae, have not been recorded for other *Mindarus* species. Aphid populations first appeared in spring, but persisted throughout the summer, fall, and well into winter. The aphid was recently described as *Mindarus kinseyi* Voegtlin.

Ecological studies of *M. kinseyi* revealed that initial infestation of first-year seedlings was coincident with the discrete flight period of alate viviparae. Alates presumably originated in nearby plantings of second-year seedlings, or in white fir growing at other nearby sites. Alate colonization generally led to an aphid population that was distributed in patches in first-year seedlings. Mean aphid density peaked at >25 per seedling (>100 per infested seedling), and up to 21% of the first-year seedlings were infested. Initial infestation of second-year seedlings was due to either overwintering eggs (deposited on first-year seedlings), alate viviparae, or both. Early infestations were also patchily distributed, and in some cases, over 50% of the seedlings were eventually infested. Aphid eggs were also present on about 20% of the harvested seedlings destined for outplanting. Naturally occurring predators and parasites were not able to maintain aphid populations at low levels. The aphid's major enemies at the nursery were aphidophagous predators, primarily larvae of syrphid flies.

Survival of marked seedlings from emergence to harvest was very high (97.3%). However, cull-rate at harvest was independent of previous aphid infestation. Mean height, stem diameter, and dry weight of marked

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INTRODUCTION

VIRTUALLY ALL CONIFERS are exploited by one or more species of aphids (Doane et al. 1936; Carter and Maslen 1982; Blackman and Eastop 1994). In the western United States, as in many other regions of the world, conifer aphids are not generally considered to be among the major insect pests in forests (Furniss and Carolin 1977), although green spruce aphid (*Elatobium abietinum* [Walker]) is a notable exception to this (Keen 1939; Watt et al. 1990). However, aphids can present serious problems for seedling conifers, such as those grown at nurseries and newly established plantations. This is particularly true for aphids in the genus *Cinara* that cause problems on conifer seedlings in various parts of the world (Johnson 1965; Fox and Griffith 1977; Furuta and Takai 1983; Holopainen and Soikkeli 1984; Kidd 1988; Connor and Hoffard 1989; Sutherland et al. 1989). Of lesser importance are aphids in other genera, such as *Mindarus*.

Balsam twig aphid (BTA), *Mindarus abietinus* Koch, is a widespread species in the Holarctic region where it is primarily associated with true firs (*Abies* spp.) (Rather and Mills 1989). Aphid colonies characteristically develop on the new growth, and dense populations can cause stunting and deformation of terminal needles. An aphid that was initially identified as BTA was detected in 1987 on seedlings of white fir (*Abies concolor* [Gord. & Glend.] Lindl.) at the USDA—Forest Service Nursery near Placerville, California. A relatively high percentage of both first- and second-year seedlings was infested at certain times of the year, and the aphid-induced stunting of seedlings was of major concern to nursery management. As there was virtually no information available on BTA in such an ecological setting, a cooperative research program was initiated in 1989 by scientists from the USDA—Forest Service and the University of California, Davis.

By the end of our first year of research, it was apparent that the life history of the aphid in question differed considerably from published accounts of the life history of BTA (cf. Varty 1966, 1968; Stary 1975; Nettleton and Hain 1982). By the end of the second year, our results suggested that this aphid was indeed a new species of *Mindarus*. A systematic analysis of the genus *Mindarus* confirmed this, and the aphid has now been described as *Mindarus kinseyi* Voegtlin (Voegtlin 1995). Thus, previous reports on the Placerville aphid (either as *M. abietinus* Koch or *M. victoria* Essig) refer to the new species, *M. kinseyi*. This would include papers by Ferrell (1989), Koehler et al. (1990), Stein and Haverty (1990, 1991), Stein (1991), Stein and Smith (1991), Munson et al. (1991), Stein and Trummer (1993), Moran et al. (1993), and Moran and Baumann (1994). Whether or not *M. abietinus* occurs in California is still open to question (see Voegtlin 1995).

The purpose of the present paper is twofold: to summarize the life history and population ecology of *M. kinseyi*, as determined primarily at the Placerville Nursery; and to assess the impact of this aphid on growth of white-fir seedlings and outline an implementable management program for the aphid at forest nurseries.

LIFE HISTORY

Mindarus kinseyi is a holocyclic, monoecious (= autoecious) aphid that displays numerous morphs—i.e., adult phenotypes that can be distinguished within the life cycle of a given clone. A clone is defined as a group of individuals of equal genotype (Eastop 1972). The relevant morphs are listed below. The terminology follows that of Hille Ris Lambers (1966) and Miyazaki (1987):

Fundatrix, viviparous parthenogenetic female that hatches from the overwintering egg (= stem mother);

Vivipara, viviparous parthenogenetic female produced by the fundatrix;

Sexupara, viviparous parthenogenetic female that produces sexual females and males; and

Sexualis, oviparous female (ovipara) or male.

The phenology of the various morphs of *M. kinseyi* at the Placerville Nursery is summarized in figure 1. (Figures 1–6 appear in the center color section. Remaining figures begin on p. 41.) Detailed information on these morphs is given below. Behavioral observations were made primarily in the laboratory.

Egg

The newly deposited egg is green, but after two or three days it turns entirely black (fig. 2A). The surface of the newly laid egg is sticky, and this adhesive glues the egg to most substrates. Before the adhesive dries (within minutes), the oviparae coat the eggs with white crystals that are secreted by paired, posterior-lateral abdominal glands. The mature eggs are ovoid, with a mean (SEM)[1] length of 0.366 (0.011) and width of 0.168 (0.011) mm (n = 10). Although comparative measurements were not made, there were no obvious differences in the external characters (i.e., size, color, wax coatings) of eggs collected at the nursery and those found within 3.2 km of the nursery (e.g., USDA—Forest Service's Institute of Forest Genetics, or on local Christmas-tree farms). This is not surprising, as all aphids from these sites were determined to be *M. kinseyi* (see Voegtlin 1995).

There is, however, considerable variation in egg size and appearance, and in oviposition behavior among *Mindarus* spp. in western North America. Eggs closely associated with adults of *M. victoria* that were collected April 23, 1991 by M. I. Haverty in Victoria, British Columbia and examined by one of us (Kinsey) were larger than those of *M. kinseyi* (mean length of 0.616 [0.019] and width of 0.211 [0.006] mm, n = 12) and frequently had only a few white wax crystals. Essig (1939) reported a mean egg length of 0.65 mm for *M. victoria* from the same general location in British Columbia; he also noted that the eggs were covered with a "waxy pulverulence" and were laid on the undersides of the needles. Eggs of *M. victoria* that one of us (Kinsey) collected in the Siskiyou National Forest in northern California were similar to those from British Columbia and often were not thoroughly coated with wax. The oviparae of *M. kinseyi* from the nursery and immediate vicinity tend to oviposit inside of the bud cap that persists following bud-break (fig. 2B). At the nursery, oviparae on first-year seedlings (where no bud

[1]The standard error of the mean (SEM) is reported parenthetically throughout the text.

cap is present) laid eggs in the apical whorls of distorted needles, or in soil at the base of the seedling. In contrast, oviparae of *M. victoria* from the Siskiyou National Forest selected the mid-vein depression on the upper surface of the needle. Two or three eggs could be found in this surface groove on a single needle. Oviparae of *M. kinseyi* from the Stanislaus National Forest selected the needle, bud cap, and bracts (most frequently using the bud cap); those from the Eldorado National Forest selected the bud cap and petiole bracts. Eggs of *M. obliquus* (Cholodkovsky) collected by one of us (Kinsey) from Sitka spruce seedlings at a British Columbia nursery were similar in appearance to those of *M. kinseyi*, but like those of *M. victoria*, they were deposited along the midvein on the upper surface of the needles. Morphologically, *M. obliquus* is very similar to *M. kinseyi*; however, this species is not known to occur in California.

During 1989, white-fir seedlings at the nursery were sampled either weekly or biweekly to determine aphid infestation levels (see Population Ecology section). Both first- and second-year seedlings were also examined for aphid eggs. In November, eggs were detected on first-year seedlings. Most of these were deposited in the distorted, apical-needle whorls that presumably were generated by the plant's response to previous aphid feeding. Some eggs were found at the base of the seedlings in the spaces that occur between the soil and stem. Eggs were periodically found on these seedlings during the winter of 1989-1990 and until April 1990. No unhatched or newly laid eggs were found on second-year seedlings until August 21, 1990. Eggs were then found from October through December, and were also detected when the seedlings were evaluated at harvest in February 1991.

The earliest that eggs were detected at the nursery was late August. These eggs were probably laid earlier, but were just not detected in samples. Evidence to support this was obtained during 1990. Ten fourth-instar alatoid nymphs were collected on July 3 and allowed to complete development (within 24 hr) in a growth chamber. Five of the new adults were dissected, and both male and female embryos were evident, indicating that the adults were sexuparae. The remaining five adults gave birth to only sexuales. These early sexuales would have become adults and the oviparae would have deposited eggs during mid to late July. During 1991, sexuales were collected at the nursery as early as the second week in July.

The presence of aphid eggs on seedlings at harvest suggested that transplanted seedlings in the national forests could become infested with aphids that had originated at the nursery. Therefore, studies of hatching success were conducted on harvested seedlings (following culling and cold storage). On November 28, 1989, 100 seedlings were collected and returned to the laboratory for inspection. In this case, 25 seedlings were taken along transects in each of four quadrants in the field under study. Eggs were detected on 25% of the seedlings (range 16–36%). Among plants with eggs, most had more than one egg per plant (mean 4.85, range 1–29). In January 1990, 200 randomly selected plants, harvested and processed from the same field, were potted, and cultured in a greenhouse. Under these conditions, seven seedlings (3.5%) developed aphid colonies. These results suggest that postharvest storage reduces egg viability; nevertheless, some eggs may survive, eventually hatch, and initiate infestations on transplanted seedlings. This possibility should be taken into account, particularly when assessing the overall economic impact of the aphid.

Fundatrix

The stem mother at birth is a pale, blue-green and about 1 mm in length (fig. 3A). There are four nymphal stages. During all but the first stage, a white waxy substance is secreted, giving the later stages a powdery appearance. During the last immature stage, and especially in the adult stage, long filaments of wax extend from several of the dorsal, most posterior gland openings. The adults are generally similar to other apterous, viviparous morphs (fig. 3B). However, the stem mother has black or dark brown simple eyes (fig. 3C); thus it can be easily distinguished from the other morphs, which have light brown to red compound eyes (fig. 3D).

For laboratory studies, eggs were collected from white fir at a Christmas-tree farm within 1.6 km of the nursery. As the nymphs hatched they were transferred to white-fir seedlings and their behavior was observed. Upon hatching, the minute fundatrices immediately sought out and settled on any newly emerged needles. They apparently preferred partially opened buds to those that were flushed and fully open. Stem mothers that hatched prior to bud-break sometimes attempted to feed (i.e., labial contact and stylet penetration were observed) at the base of older needles; one stem mother survived these conditions for 7 days, until bud-break occurred. Observations of recently hatched stem mothers further suggest that these aphids are attracted to opening buds and fresh needles immediately after bud-break.

The earliest date that a fundatrix was detected in the vicinity of the nursery was April 26, 1989. The observation was made at the Camino Arboretum of the USDA—Forest Service's Institute of Forest Genetics. The earliest date at the nursery was May 1, 1990, when a single fundatrix and nine nymphs were found. The offspring of stem mothers initiate infestations on second-year seedlings at the nursery, whereas alate viviparae (which occur later) disperse and presumably initiate infestations on first-year seedlings. This has important implications for managing aphid populations at the nursery (see later sections).

Developmental time, longevity, and fecundity were measured for fundatrices (n = 9) confined to white-fir seedlings maintained at 21°C (14:10 [L:D] photoperiod). Mean developmental times for the four nymphal stages were 3.33 (0.33), 1.89 (0.20), 2.22 (0.4), and 1.89 (0.2) days, respectively. Mean number of days from hatch to adulthood was 9.33 (0.69), whereas mean longevity (hatch to death) was 25 (2.29) days. Mean number of progeny per female was 22.1 (4.26).

Vivipara

The viviparous progeny of the fundatrix can be either apterous or alate, as can subsequent viviparous morphs during the season (fig. 4). However, alate offspring of the fundatrix and third-generation alate and apterous viviparae have apparently not been recorded for any other *Mindarus* species.

Apterous Vivipara

The apterous vivipara is the predominant form found on both first- and second-

year seedlings during June, July, and early August (figs. 4A-C). All stages produce honeydew and a shiny, waxy substance; the latter is valuable in detecting infested plants. The early infestations of apterae induce the first obvious distortions of apical growth in the first-year seedlings.

Three second-generation apterous viviparae were collected at birth, confined to white-fir seedlings, and held at a constant temperature (21°C) and 14:10 (L:D) photoperiod. Mean developmental times for the four nymphal instars were 2.0 (0.58), 2.0 (0.0), 2.0 (0.0), and 1.67 (0.33) days, respectively. Mean developmental time from birth to adulthood was 7.67 (0.33) days, and adults deposited an average of 33.7 (9.17) progeny per female. Average longevity (birth to death) was 34.3 (2.67) days. Laboratory studies of subsequent apterous viviparae were based on progeny of alate viviparae collected (as alatoid nymphs) at the nursery. Nymphs were collected at birth, transferred to white-fir seedlings, and held in a growth chamber. The temperature varied from 14.4°C (night) to 26.7°C (day), and the photoperiod was set at 16:8 (L:D). Mean developmental time (n = 24) from birth to adult was 6.8 (0.15) days. Longevity and fecundity were not assessed.

Depending on environmental conditions, apterous viviparae may give birth to any of four different morphs: apterous vivipara, alate vivipara, apterous sexupara, or alate sexupara. This flexibility in life history enables *M. kinseyi* to undergo continuous generations at the nursery, even into fall and winter. In 1989, aphids were present well into December; however, no colonies were evident following subfreezing conditions in January 1990. In 1990, the first apterous adult viviparae were detected May 8 on second-year seedlings; colonies were present throughout the growing season and persisted through the fall into early winter. In 1991 the growing season was followed by a mild winter; both apterous viviparae and apterous sexuparae were detected surviving in colonies until February 1992, but only colonies of viviparae were observed in March.

Alate Vivipara

The alate vivipara was common at the nursery once large colonies of aphids derived from the fundatrices had developed (fig. 4F). A similar effect was noted on white fir grown in the immediate vicinity of the nursery—e.g., Christmas-tree farms, Institute of Forest Genetics and its Camino Arboretum. There are no apparent morphological characters for separating alate viviparae from alate sexuparae. However, alate viviparae generally occur earlier in the season than alate sexuparae, although there is some overlap in phenology. Other than waiting for the birth of offspring, dissecting each alate to determine embryo type is currently the only way to differentiate these two alate forms.

Developmental studies, like those conducted for apterous viviparae, revealed four nymphal instars. Mean developmental time from birth to adulthood (n = 37) was 8.3 (0.102) days. Longevity and fecundity were not measured.

Molting of the first three nymphal instars usually occurs within the whorls of needles of an infested plant. However, just prior to eclosion, the fourth-instar alatoid nymph (fig. 4D) moves out onto a peripheral needle to complete the final molt. Movement to the periphery occurs in late afternoon or early evening; molting occurs at night; alates disperse the next day, usually in the morning. The

resulting exuvia are evident, and remain firmly attached to the plant for several days (fig. 4E).

Alate viviparae (fig. 4F) were observed as early as May at the nursery. They were typically found on second-year seedlings and were presumably the progeny of either fundatrices or second-generation viviparae. In one case, an alate was observed among the progeny of a single fundatrix. Alate viviparae reached peak levels in second-year seedlings in June and July, but alates were not detected after early August. These alates, and those from white fir in the vicinity, are presumably the source of initial infestations in the first-year planting. Alate viviparae were also commonly observed on first-year seedlings in July, but gradually declined by early August.

Sexupara

Both apterous and alate sexuparae occurred at the nursery, and unfortunately, there are no apparent morphological differences between these morphs and the respective viviparae. At present, the vivipara and sexupara can only be distinguished by either dissection (to observe the type of embryos present) or observing the kind of offspring produced. An apterous sexupara has apparently not been described for any species of *Mindarus*.

Apterous Sexupara

Apterous sexuparae were detected only in the fall and winter. They were first detected on October 30, 1990, and again on November 16 (on first-year seedlings). They were detected the following year on October 30 and November 14, 1991, and on January 17, 1992. All possessed a white waxy bloom, and produced copious amounts of white, filamentous wax. They usually occurred in larger, well-established colonies. With only short-range movement possible (for both sexupara and its sexual progeny), the apterous sexupara can be a critical link to the next season's infestation. It is also possible that this morph could be present on seedlings at harvest; however, none were found during a detailed examination of several hundred seedlings.

Laboratory observations revealed that an individual, late-fall apterous female could be either a vivipara, sexupara, or both (i.e., giving birth to both sexuales and viviparae). On November 6, 1990, third- and fourth-instar apterae were collected from first-year seedlings at the nursery, caged on similar seedlings, and held in a growth chamber at 21°C and 14:10 (L:D) photoperiod. Adult eclosion occurred for most individuals within two days. The morphs of the progeny were recorded for 10 adults. Six gave birth to both viviparae and sexuales. Two gave birth to only viviparae, and the remaining two produced only sexuales. The adults that produced both viviparae and sexuales generally produced viviparae first, usually within the first five days; also, only oviparae (i.e., no males) were produced. The two adults that produced only sexuales gave rise to seven (one ovipara, six males) and six (five oviparae, one male) progeny, respectively. These data could be an indication of the fecundity of the apterous sexupara. These findings add to the complexity and flexibility of the aphid's life cycle.

Alate Sexupara

Alate sexuparae were found at the nursery during July, August, and well into fall and winter. Ten alatoid nymphs, collected on July 3, 1990 and observed until eclosion, were all found to be sexuparae. July was the earliest month that this morph was detected at the nursery. During 1989, alate sexuparae were not detected until August. In both 1989 and 1991, alate sexuparae were present at the nursery through November. They were also found on seedlings collected in January 1992. Like its apterous counterpart, the alate sexupara gives rise to both male and female sexuales; however, there is no evidence that individuals of this morph can produce both sexuales and viviparae. The nymphal stages of this morph are not distinguishable from those of the apterous sexupara until the third instar, when external wing pads become evident. Examination of progeny (fig. 5A) and dissection of sexuparae (alate and apterous) provide relatively simple and quick methods for identification. The morphology of the embryos contained in adult viviparae and sexuparae are distinctly different, as are male and female embryos in the sexuparae (fig. 5B). However, when adults are preserved in ethanol the embryos lose their color and become distorted.

Longevity and fecundity for alate sexuparae were measured. In October 1991, 12 alatoid nymphs were collected at the nursery, transferred to seedlings, and held in a growth chamber at 26.7°C (day)/15.6°C (night) and 15:9 (L:D) photoperiod. Six nymphs did not survive to adulthood. For the six survivors, mean adult longevity was 9.0 (0.29) days, during which the aphids produced a mean of 5.0 (0.20) progeny per female—2.83 (0.10) females (= oviparae) and 2.17 (0.21) males. The expected fecundity as determined through dissection was considerably higher, however. In this case, adults less than 24 hr old that had not previously given birth were dissected in physiological saline. The number and types of viable embryos were recorded. The mean number of embryos per female was 10.2 (range 3–24, n = 60). The sexual dimorphism that occurred in the immature and adult sexuales was also evident in most of the embryos. Those female embryos in the most distal part of the oviduct were large (1 mm long × 0.4 mm wide, larger than when mature) and contained yellow pigmented, viscous liquids in the hemocoel. Males were smaller (0.29 × 0.17 mm) and contained blue pigments within the hemocoel (fig. 5B). The embryonic sexual dimorphism thus provides a means for determining the primary sex-ratio. The sex-ratio of the clearly defined embryos was 0.54 male (n = 524). About 14% of the embryos (n = 88) were not developed enough to clearly show sexual dimorphism (mean of 1.5 per adult).

Sexualis

Male

The male is blue to blue green, about 0.64 mm long × 0.27 mm wide at birth, and gradually decreases in size as it matures to an adult (0.5 × 0.23 mm) (fig. 6A,C). Most of the blue pigment occurs in what appear to be the mycetocytes that contain the bacterial symbionts common to aphids. The immature is not readily distinguishable from the adult, except for the decrease in size as it matures. Mean

developmental times for nymphs (n = 7) held at 21°C (day)/7°C (night) (10:14 [L:D] photoperiod) in a growth chamber were 1.14 (0.14), 1.86 (0.34), and 1.86 (0.26) days for instars one, two, and three, respectively. Mean developmental time from birth to adulthood was 4.7 (0.42) days. The rearing conditions for these nymphs were designed to simulate end-of-season conditions.

Immediately after birth, males were found with the labium in contact with the surface of a needle. This gave the appearance of feeding, although males were successfully reared to adulthood in the laboratory without feeding. During the first 24 hr, the male left the birth site on the needle and spent most of the immature stage at a secluded site. This was usually beneath a dry bud cap or loose petiole bract. Often, all three exuvia were found in these secluded sites. Succulent foliage was not readily available at these sites. After adult eclosion, the males were very active, and often moved about the seedling until they located a receptive female. They then moved onto the dorsum of the female and maintained this position as she moved about. Often the male took this position while the female was still in the pre-adult stage; in such cases, the male remained with the female until she completed adult eclosion. One male was observed to couple with three successive females. This male was moved to each of three cages containing a single female and held for approximately one hour, then moved into the next cage. All three matings occurred in the morning.

Males were first observed in the nursery during July. Sexuparae, collected as alatoid nymphs from second-year seedlings at the nursery on July 3, 1990, gave birth to males and oviparae. Males were found again on infested seedlings July 9, 1991. Males were found throughout the remainder of the season on both first- and second-year seedlings.

Ovipara

Both immature and adult oviparae appear yellow or gold (fig. 6B-D). The first-instar nymphs are about 0.7 mm long × 0.4 mm wide and do not greatly change in size as they develop to adulthood (0.75 × 0.35 mm). The yellow-gold pigments within the hemocoel appear early during embryonic development and can be used to discriminate female embryos from the blue-green male embryos. These pigmental differences are maintained through adulthood. During the immature stages, oviparae, unlike viviparae, do not produce copious amounts of wax. The adult does, however, produce what appears to be white wax crystals from two paired, posterior-lateral glands (fig. 6D). The presence of these glands provides a means for separating immatures from adults.

Developmental time for oviparae (n = 17) was determined in a growth chamber set at 21°C (day)/7°C (night) and 10:14 (L:D) photoperiod. Mean developmental times for the four instars were 2.47 (0.15), 2.12 (0.17), 1.71 (0.22), and 1.77 (0.14) days, respectively. Mean time from birth to adulthood was 8.06 (0.25) days. Most mature females contained two eggs (mean of 1.88, range 1-2).

The newly deposited nymphs appeared to feed. The labium was in contact with the needle (usually the upper surface), and nymphs often maintained the same position and location throughout the first instar. The exuvia from the first two, and sometimes the third, molt were frequently found grouped on the same needle with the stylets of the exuvia still penetrating the needle. Soon after the second

or third molt, the oviparae left their feeding site and became more active. No pre-adult (fourth instar) or adult oviparae were observed to feed. Under laboratory conditions, second- and third-instar nymphs caged without food eventually matured and laid eggs.

Third-instar nymphs ultimately moved into a secluded, well-protected site preparatory to mating and oviposition. Clusters of males were commonly found with a female at these sites. In certain holocyclic aphids, oviparous females attract males by means of a volatile sex pheromone (Pickett et al. 1992). A similar pheromone may exist in *M. kinseyi.* As noted earlier, mature males were found clasped to the dorsum of immature females, and mating occurred soon after adult eclosion (usually within 2 or 3 days). Matings occurred almost immediately when three day-old mature females were exposed to mature males. It was not uncommon to find the third- and fourth-instar exuvia and adult ovipara, along with males and eggs, all inside one bud cap.

Immediately after laying an egg, the female backed over it and, while moving forward, used the hind tarsi to brush crystals from her posterior-lateral glands onto the egg. This process might be repeated several times, until the egg was thoroughly coated. When two eggs were deposited by one female, the first usually received more crystals than the second.

Oviparae first appeared at the nursery in early July and remained throughout the fall and early winter. Apterous and alate sexuparae, collected January 17, 1992, gave birth to oviparae, so it would appear possible to have sexual females present throughout the winter, so long as the temperature remains favorable.

Discussion

The life cycle of *M. kinseyi* on white-fir seedlings at the Placerville Nursery is clearly different from that reported for *M. abietinus* in the Holarctic region. Major differences include location of overwintering eggs, presence of third-generation apterous viviparae, second and third-generation alate viviparae, apterous sexuparae, and the extended life cycle. With a generation time of 10 days or less, it is possible for *M. kinseyi* to complete 20 or more generations by the end of the growing season. In both Europe and eastern North America, *M. abietinus* develops through only three or four generations—i.e., fundatrix, vivipara (apterous), sexupara (alate), and sexuales (Varty 1966, 1968; Stary 1975; Nettleton and Hain 1982). There are no further generations during summer and fall, and we are aware of at least one report that suggests the same type of life history where *M. abietinus* is a pest of fir in forest nurseries (Raddi et al. 1991). Although *M. kinseyi* is a monoecious or autoecious aphid, the multiple generations displayed at the nursery are more characteristic of heteroecious (host alternating) species (see Dixon 1987). Interestingly, *Mindarus* is generally considered to be a primitive genus (Heie 1987). This complex life history and phenotypic flexibility enables *M. kinseyi* fully to exploit white-fir seedlings at the Placerville Nursery. Phenotypic flexibility includes apterous/alate viviparae, apterous/alate sexuparae, and within-morph variation in type of progeny of apterous viviparae. As a result, aphid clones can persist so long as host plant and other environmental factors are favorable. Overwintering eggs ensure that aphids survive the winter to produce

new generations the following spring; in mild winters, viviparae may continue reproducing (albeit at a low rate), and these clones may even survive to initiate infestations the following spring. However, these clones are not necessarily anholocyclic because when apterous viviparae were collected in the middle of winter and returned to the laboratory, they gave rise to apterous sexuparae. In addition, apterous sexuparae were virtually always a component of field colonies collected from October through February. Leather (1992) noted that some aphids can be both anholocyclic and holocyclic, depending on genotype, climate, or location; *M. kinseyi* may be an example.

The holocycle for *M. kinseyi* can be completed at the nursery in any of three ways (fig. 7). (Figures 7–39 begin on p. 41.) In the first scenario, fundatrices give rise to alate viviparae that in turn give rise to apterous viviparae that give rise to alate sexuparae. The latter give rise to the sexuales, such that overwintering eggs are produced by late summer (about 45 days after egg hatch). The occurrence of alate viviparae early in the season is critical for the aphid at the nursery for it permits colonization of the newly emerged seedlings. In the second scenario, apterous viviparae derived from fundatrices give rise to alate sexuparae that in turn give rise to the sexuales. As a result, the eggs are deposited earlier, often by mid-July (about 35 days after egg hatch). The third scenario involves either apterous or alate sexuparae produced by apterous viviparae much later in the season. This particular cycle occurs during the fall months and, if environmental conditions (e.g., temperature) are favorable, into winter as well. Although both apterous and alate sexuparae occur, the former were more common during the winter months. During the last week of March 1992, the incidence of sexuparae declined until eventually only apterous viviparae were present. Thus, in mild winters it is quite likely that apterous viviparae can successfully overwinter and initiate new colonies the following spring.

Apart from the nursery and nearby areas, one of us (Kinsey) has collected *M. kinseyi* on white fir throughout the Sierra Nevada from Tulare County (in the south) to Siskiyou County (in the north). Infestations in these areas generally do not display the multiple generations that occur at the nursery; instead, they conform to the second scenario in figure 7. However, additional generations can occur on trees that produce a second flush of new growth. Infestations may also persist on seedlings on the forest floor. At Christmas-tree farms, infestations may develop throughout the season, so long as new growth is available. Pruning and irrigation enhance this effect.

The life history of *M. kinseyi* at the nursery also differs from that of *M. obliquus* in British Columbia. This closely related aphid has become a pest of spruce seedlings in recent years (Sutherland et al. 1989; Shrimpton 1991). However, observations by one of us (Kinsey) during 1993 clearly indicate that *M. obliquus* in British Columbia does not display the multiple generations so typical of *M. kinseyi*. Although *M. obliquus* is taxonomically similar to both *M. abietinus* and *M. kinseyi*, it is restricted to spruces (*Picea* spp.) rather than true firs (*Abies* spp.), and is considered to be a distinct species of *Mindarus* (Robinson and Chen 1969; Carter and Eastop 1972).

POPULATION ECOLOGY

The Placerville Nursery is located at approximately 850 m elevation in the foothills of the Sierra Nevada mountain range. It is part of a mosaic of agricultural crops (e.g., apple, pear, grape), Christmas-tree farms, and forested areas. The nursery maintains both first- and second-year white-fir seedlings; in a few cases, seedlings are maintained for a third year. Seeds are usually sown in April, and by late May or early June, the seedlings are well established. Plants are grown in beds (1.2 m wide) containing eight rows of seedlings. Seeds are gathered from numerous locations in different national forests throughout California. Growth characteristics and phenology for plants can vary among seed sources. A given field of white fir is thus a mosaic of genetically variable seedlings. Seedlings are irrigated and fertilized as needed, and in the winter of their second year (e.g., January), the seedlings are "lifted" (i.e., harvested) from the field for eventual transplantation in reforestation programs. Additional aspects of nursery production of bareroot seedlings in the west are described by Duryea and Landis (1984).

Methods and Materials

The first study was conducted with second-year seedlings, beginning in April 1989. The primary purpose of this investigation was to determine the percentage of seedlings infested with aphids, and how this varied over the season. The study plot consisted of a 0.9 acre (0.36 ha) field containing 37 beds of white fir. The field was divided into quadrants, and these were sampled on a regular basis from April 18 to November 28. Usually, 25 plants were sampled per quadrant. Each quadrant was systematically sampled on the diagonal so that each bed, and virtually all of the seed sources, would be sampled. Both destructive and non-destructive sampling were employed, depending on the type of information desired. Destructive sampling was necessary whenever the seedlings were to be examined in the laboratory. These samples were examined with the aid of a dissecting microscope; aphids, aphid eggs, parasitized aphids, and predators were noted. Non-destructive sampling consisted of visual determination of infested plants in the field. When the first infestations were detected in the spring, the entire plot was surveyed on four successive dates to map the changing spatial structure of the aphid population.

The second study initiated at the nursery in 1989 was a long-term investigation of the ecology of aphids on white-fir seedlings. A small "ecology plot" was specially planted for this purpose. The plot consisted of five beds (1.2 m wide × 45.7 m long), each sown to eight rows of seedlings from the same seed source (five seed sources, one per bed). Each bed was divided into 10 units, each about 4.6 m in length. The ecology plot was located in a field of first-year pine seedlings and was thus isolated from the operational white-fir beds. During the course of the investigations, this plot was culturally maintained in a manner similar to the operational beds. Plants in the ecology plot were sampled on a regular basis (weekly, biweekly, or monthly) throughout the course of the study. The first sample was taken on June 6, 1989, 7 days post-emergence. On a given sample

date, 10 seedlings were systematically chosen from each unit and examined (i.e., 100 per bed, total of 500). If an infested plant was detected among the 10, a single, infested plant was carefully removed and returned to the laboratory. These were stored in 70% ethanol; at a later date the plants were examined, and the number of aphids (adults, nymphs, alatoid nymphs, and alates) and associated enemies was determined. However, this analysis was restricted to seedlings collected from July 18 to October 18, 1989. During summer and early fall of 1989, the plot was sampled at 7-day intervals. This interval was extended by a week or more, beginning in November. Monthly samples were taken from December 1989 to February 1990 when aphids were at very low levels. In this case, 100 plants were removed (two per unit), transferred to the laboratory, and carefully examined for aphids, eggs, etc. This method was also employed each week during March. As the plot was rather small, special care was taken so as not to influence greatly the aphid population by removing a large number of infested seedlings (especially those that may have contained eggs). The regular sampling program was reinstituted in early April; however, the number of plants observed per unit was reduced to five (50 per bed, total of 250 per date). The plot was sampled each week through November. On December 4, 1990, and Jaunary 8, 1991, two seedlings were removed from each unit (20 per seed source, total of 100), transferred to the laboratory, and examined for aphids and overwintering eggs. All seedlings remaining in the plot were harvested on February 7, 1991 and processed according to normal nursery procedure.

In late May of 1990 two aphid suction-traps were installed, one at the nursery and the other at the nearby Institute of Forest Genetics. These traps were patterned after the original suction traps developed in Europe by Johnson and Taylor (1955) (see also Taylor and Palmer 1972; Muirhead-Thomson 1991). Such suction traps are well suited for monitoring airborne aphids and have been used extensively to monitor aphid migration in Europe (Cavalloro 1987). Our particular traps were about 8 m high × 30 cm diameter, and were slightly modified versions of the trap originally developed at Washington State University and employed in a network in the western U.S. for monitoring aphid populations (Allison and Pike 1988; Pike et al. 1989). The suction trap at the Placerville Nursery is shown in figure 8. During the summer of 1989, trap catches were collected at 3 to 4 day intervals; later in the season, the interval was extended to one week, and this was maintained throughout the course of the investigations. Insects captured in the traps accumulated at the base of the trap in a jar containing a 9 to 1 mixture of 70% ethanol and ethylene glycol. Trap contents were later transferred to 70% ethanol and then examined for aphids, potential aphid predators, and other arthropods of interest.

The final study was conducted in a first-year planting during the summer of 1992. Approximately one acre (0.4 ha) was seeded to white fir on May 30. The field consisted of 14 beds, each 180 m long. Each bed was divided into 40 units, each about 4.5 m long. Beds were surveyed either weekly or biweekly to determine foci of aphid infestations, with particular reference to the spatial distribution of newly infested patches in the planting. Sampling began on June 25 and the last sample was taken on November 18.

Results and Discussion

1989 Studies

In the spring of 1989, aphids were first detected in the second-year planting in late May (fig. 9). On May 23 (fig. 9A) several infested patches were noted, and numerous additional infested patches were detected on May 30 (fig. 9B), June 6 (fig. 9C) and June 13 (fig. 9D). The first infestations noted in May were presumably the result of colonies initiated by fundatrices that hatched from overwintering eggs. However, later infestations (in June) were most likely due to within-field dispersal by alate viviparae and possibly alate viviparae from other white-fir trees in the area. By mid-June, there were many new infested patches, and older patches had expanded; as a consequence a relatively large part of the field was infested (fig. 9E). At that time, about 10% of the plants were infested and by the end of June, about 50% were infested; the percentage of plants infested remained at this level during much of July, and gradually declined to low levels in August where it remained for the remainder of the year (fig. 10). The pattern depicted in figure 9 reveals the patchy nature of the aphid population and that in figure 10 illustrates how it can develop in second-year seedlings when no suppressive or management tactics are employed. The evidence also indicates that suppressive measures could be applied as spot treatments. Microscopic examination of seedlings revealed the presence of overwintering eggs in early October, and by the end of the growing season, eggs were detected on approximately 20 to 25% of the seedlings (fig. 11).

Ecology Plot

The percentage of seedlings infested in each seed-source bed of the ecology plot during 1989 and 1990 is summarized in figure 12. Seedlings were first colonized by aphids in mid July 1989; this coincided with the peak infestation level in the nearby second-year planting (fig. 10), clearly suggesting that alate viviparae from such plants are an important source of infestations in first-year plantings. In four of the five seed sources, the percentage of infested seedlings gradually increased in August and September, exceeding 40% in one case. The precipitous drop in late September followed a series of storms over a two-week period that deposited two inches (5.1 cm) of rain; shortly thereafter, the percentage of infested seedlings gradually increased to relatively high levels in some cases, but declined to zero by mid winter. Aphid eggs were detected on December 6 and throughout the winter. On February 7, 1990, aphid colonies were actually detected on seedlings covered with snow. However, no aphids were observed to survive the winter. In the spring of 1990, the first aphids were detected in early May; these colonies presumably resulted from fundatrices that hatched from overwintering eggs. Aphids were prevalent on these plants (now in their second year) throughout the 1990 growing season, regardless of seed source. Percentage of seedlings infested was under 30 and did not display the type of clear peak observed for seedlings in 1989 (fig. 10). Colonies were present into December. Seedlings in the ecology plot were harvested during the first week of February 1991.

The number of aphids per infested first-year seedling is summarized in figure 13. Total number of aphids per seedling varied from about 40 to 130 (fig. 13A). Nymphs were most abundant (fig. 13E), followed in order by adults (fig. 13D), alatoid nymphs (fig. 13C), and alates (fig. 13B). The data for alates are probably conservative because many of these aphids apparently dispersed from infested seedlings during the sampling process. The density of alatoid nymphs was generally correlated with total density per seedling ($Y = -1.19 + 0.85X$, $r^2 = 0.48$, $P = 0.01$). This suggests that alate production was density related (i.e., due to crowding), a finding that is generally consistent with previous studies of aphid polymorphism and morph determination (Dixon 1977, 1985; Kawada 1987; Moran 1992). The mean number of aphids per infested seedling was lowest in plants from the Plumas National Forest and highest in plants from the Stanislaus National Forest (fig. 14). Only eight Plumas seedlings were infested over the season compared to 49 or more in the other seed sources, suggesting there can be considerable variation in host-plant susceptibility at the nursery. A similar pattern is evident in percentage of first-year seedlings infested (fig. 12). The percentage of seedlings infested for the entire plot peaked in September and varied with the average aphid density (i.e., mean number of aphids per seedling, averaged over all seedlings sampled) (fig. 15); these variables were highly correlated for the first 14 sample dates on which infested plants were detected (fig. 16). This suggests that the percentage of plants infested is a reasonable predictor of aphid density, a finding that is relevant to monitoring aphid populations.

Natural Enemies

A number of predators were observed in association with aphids on infested seedlings at the nursery. The major predators were syrphid larvae, and included the following: *Allograpta obliqua* Say, *Eupeodes volucris* Osten Sacken, *Eupeodes* sp., and *Heringia* sp. Convergent lady beetle (*Hippodamia convergens* Guerin-Meneville) was also important, particularly in the early part of the season. However, these and other predators were not very abundant in the ecology plot and showed no great response to increase in prey density (fig. 17). Although the relationship in figure 17 is statistically significant, the r^2 value was relatively low, as was the mean number of predators per infested plant. Thus, we have not drawn the regression line in the figure. Predators were not detected on infested plants until there were about 50 aphids per plant. This suggests a threshold effect as described by Hagen (1976) for aphid predators associated with alfalfa aphids (see also Frazer 1988). Hagen reported that convergent lady beetles must consume at least 100 large pea aphids within five days to produce enough eggs to stimulate oviposition. An upper threshold effect may occur in some syrphids, where oviposition may actually be deterred at higher aphid densities (Hagen 1976; Chambers 1988, 1991). These kinds of reproductive responses among predators at the nursery could easily account for the results shown in figure 17.

Parasitoids of *M. kinseyi* were essentially absent from the nursery. However, a parasitoid in the genus *Areopraon* (Hymenoptera: Aphidiidae) was reared from aphid mummies collected from white fir at a nearby Christmas-tree farm. This parasitoid was common in most of the well-established aphid colonies at the farm, and preliminary observations indicated that parasitization was an important

mortality factor. *Areopraon* spp. are associated with primitive aphids, and the species in question may be undescribed (M. Mackauer, personal communication). If so, this would apparently be the first report of an *Areopraon* in the Nearctic region (Johnson 1987). Mackauer (1967) described *A. antiquum* (ex: *Mindarus* sp., probably *abietinus* Koch) from West Pakistan, whereas Stary (1975) described *Pseudopraon mindariphagum* from *M. abietinus* in central Europe. The latter species of *Pseudopraon* has also been collected in the Nearctic region (Stary and Remaudiere 1982). *Areopraon* and *Pseudopraon* are closely related, and whether or not additional species in these genera are associated with *Mindarus* spp. in the Nearctic region is unknown.

Suction Traps

The aphid suction traps captured a diverse array of aerial arthropods, including numerous species of interest to the field investigations at the nursery. Alate aphids were captured in comparatively large numbers during the growing seasons, at both the nursery and the Institute of Forest Genetics. For example, at the nursery from the last week of May to the end of October, the trap captured over 2200, 1400, and 800 aphids in 1990, 1991, and 1992, respectively. At the Institute during the same period in 1990, 1991, and 1992, the trap caught over 3600, 2200, and 1100 aphids, respectively. A relatively discrete flight period for *M. kinseyi* was evident at both locations—i.e., alate aphids were captured only during a brief interval in late spring and early summer (fig. 18). In 1991, most of the alates were captured during the last week in July; the greatest number were captured at the Institute. A similar flight pattern was observed for *M. abietinus* in Canada (Adams et al. 1976). Because alate aphids can be transported for hundreds of miles in the atmosphere (Klingauf 1987; Isard et al. 1990), the origin of alate *M. kinseyi* captured in the suction traps is not known. These alates could have originated from a number of sources, including second-year seedlings at the nursery, older white-fir trees in the general vicinity (e.g., Christmas-tree farms), or white-fir trees in the national forest. The incidence of alate *M. kinseyi* in the traps is also consistent with that of alate viviparae at the nursery. Those trapped later in the flight period may have been sexuparae; because we lacked definitive methods for separating the two alate morphs once they were preserved in ethanol, this hypothesis could not be confirmed. However, the complete absence of alates for the remainder of the season indicates that alate sexuparae, which were present on seedlings, may not migrate great distances. Although the flight period was consistent at each location and in each year, the number of alates captured during a given flight period was variable—i.e., fewer than 10 were captured at either location in 1990 and 1992, whereas larger numbers were captured in 1991. Similar patterns in trap catch exist for other aphids, and this may be evidence of regulatory processes in the population dynamics of these aphids (see Dixon 1977).

Among potential aphid predators, adult lacewings (Chrysopidae) were most abundant in the trap catches. At the nursery, a total of 200 adults was captured from the last week in May to October 30, 1990, and 297 during the same period in 1991. At the Institute, 311 and 505 adult lacewings were captured during the same period for 1990 and 1991, respectively. The most abundant lacewing was

Chrysoperla carnea (Stephens); at the nursery, it comprised 89% of the specimens compared to 53.6% at the Institute. Interestingly, most of the *carnea* specimens were female—i.e., 91.6% and 86% at the nursery and Institute, respectively (C. A. Tauber, personal communication). Other species collected included *Chrysopa coloradensis* Banks and *C. nigricornis* Burmeister. Despite the relative abundance of lacewing adults in the trap catches, lacewing larvae were seldom encountered on aphid-infested seedlings at the nursery. Adult syrphid flies were not particularly abundant in the trap catches, despite their relative abundance on infested seedlings. For the same May to October sample period, a total of 100 and eight syrphids were captured at the nursery in 1990 and 1991, respectively. At the Institute, 38 were caught in 1990, compared to only four in 1991. Potential aphid predators were not evaluated in trap catches for 1992.

1992 Studies

During 1992, over 180 infested patches were detected during the growing season in the operational, first-year planting (fig. 19A). The data suggest two colonization episodes (fig. 19B). The first occurred during late June and most of July, presumably representing colonization by alate viviparae; and the second took place during August, September, and early October, presumably the result of within-field dispersal of apterous viviparae. For infestations in the latter category, there was a strong tendency to occur near an older infestation. Just over 100 infestation foci were detected during the aphid flight period; this suggests that a relatively small number of alates successfully colonized the approximately one-acre (0.4 ha) planting. Thus, an aphid management program, based on regular monitoring and spot treatment of newly infested patches with biological or chemical agents, would be a feasible strategy for the nursery.

Ecology at the Nursery

These investigations, plus additional observations made over the past four years, enable us to present the following overview of the ecology of *M. kinseyi* at the Placerville Nursery. Shortly after emergence of the seedlings, the aphid flight season occurs and alate viviparous aphids initiate colonies of viviparae on the seedlings, primarily on those which have new growth present. Colonies continue to develop during the summer, fall, and even persist throughout the winter when environmental conditions permit. At the same time, the sexual generation of the aphid develops (with some clones, as early as July), resulting in overwintering eggs on a small proportion of the seedlings. The following spring the second-year seedlings become infested, either from overwintering eggs, alate viviparae (from either distant or local hosts), overwintering apterous viviparae, or combinations of these. These colonies develop in a manner similar to those on first-year seedlings, although considerably more overwintering eggs may occur on second-year seedlings prior to harvest in January or February. Natural enemies of *M. kinseyi* at the nursery are primarily predators (especially syrphid larvae), but these are not particularly abundant, such that aphid populations are free to increase to relatively high densities (e.g., >100 aphids per infested seedling).

In a spatial context, the aphid population is patchily distributed in both first- and second-year plantings. Such a spatial pattern may be greatly influenced by variation in both aphid preference and host susceptibility among the various seed sources in a given planting of white fir at the nursery. As noted by Blackman (1990), colonization by alate aphids can be highly selective, and there may be specific associations between particular aphid genotypes and varieties of host plant. In the case of *M. abietinus,* host trees from different provenances vary in susceptibility (DeHayes 1981; Carter and Nichols 1985; Mattson et al. 1989). Such differences may be correlated with phenology of bud-break and flushing of new growth which can vary with provenance (Hallgren and Helms 1992); however, other factors may also be involved. Ferrell (1989) also noted variation in both flushing time and injury by *M. kinseyi* (reported as *M. abietinus*) in western provenances at the Camino Arboretum; however, he found little evidence that aphid injury was directly related to flushing time. Our observations at the nursery indicate that population increase of *M. kinseyi* usually correlates with a flush of new growth. Because of the phenological variation among seed sources in a given field of white fir at the nursery, there is usually an ample supply of such new growth to permit continuous development of aphid populations (albeit not on the same seed source) throughout the growing season.

Although the available evidence is indirect, there is reason to believe that the aphid problem at the nursery is part of a larger, regional problem. In other words, white fir at nearby Christmas-tree farms, older stands of white fir nearby (such as those at the Institute of Forest Genetics and its Camino Arboretum), and white fir at higher elevations in the national forest all may be important sources of aphids at the nursery. If so, suppression of aphid infestations on both first- and second-year seedlings in a given year would not necessarily result in reduced infestation levels the following year.

IMPACT ON SEEDLINGS

Any assessment of the impact of *M. kinseyi* on white-fir seedlings must take into account the effect of the aphid on (1) seedling mortality, growth, and cull rate at the nursery, and (2) survival and vigor of transplanted seedlings from the nursery in the national forests. While most of our investigations concerned aphid impact at the nursery, we supplemented these studies with investigations at two out-plantings in national forests.

Methods and Materials

On July 18, 1989, 400 newly emerged seedlings in the ecology plot (see Population Ecology section) were tagged with poultry leg rings. In a given unit of bed, eight plants were carefully tagged, one in each row of the bed (80 per bed, total of 400). The eight marked seedlings in a given unit were chosen systematically along a diagonal line across the rows in the bed. Tags were replaced as needed. On June 19, 1990, a 20 cm strip of green plastic tape was carefully attached to each ring so that the larger, second-year plants could be more easily located. Just

prior to harvest (January 1991), an aluminum tag was attached to each plant so that the marked seedlings could be retrieved following harvest.

These 400 plants were observed individually on a regular basis, normally at the same time the other plants in the ecology plot were sampled. Weekly inspections were made from July 20 through October 18, 1989. From November 1, 1989 through March 20, 1990, seedlings were observed either biweekly or monthly. The one-week sampling interval was resumed after March 20 and continued to July 24, 1990 when a biweekly interval was adopted for the remainder of the growing season. On a given sample date, the presence of aphids and the general condition of the seedlings were noted. The height of each seedling was measured on August 22, September 26, and November 22, 1989, and on November 1, 1990. In this way, the infestation history of each seedling could be charted from emergence to harvest, and correlated with growth characters, including those which might result in culling at harvest.

At harvest, the marked seedlings were immediately retrieved and subjected to culling standards for the nursery. Seedlings under 8 cm in height and/or 4 mm in stem diameter were subject to culling. Following this all seedlings (including those that would ordinarily be culled) were returned to the laboratory where the following measurements were made for each:

1. Height (distance from cotyledon scar to apex),
2. Stem diameter (at just above the cotyledon scar), and
3. Apical length from the bud scar (representing growth during the second year).

Plants were also carefully inspected for aphids and particularly for aphid eggs. An additional 400 plants (eight from each unit) were also taken at random as a control (i.e., to assess any effect on the marked seedlings due to handling, etc., over the past year and a half). These plants were also examined for aphids and measured as described above. Finally, the marked seedlings were placed in a drying oven at 60 to 66°C for 48 hr; the dry weight was determined for each seedling shortly thereafter.

In the spring of 1991, outplanted seedlings from seed sources C and E (of the ecology plot) were marked at sites in the Stanislaus and Eldorado National Forests, respectively. The Eldorado plot was located about 45 km southeast of the town of Sly Park; the planting was about 155 × 90 m at an elevation of approximately 1800 m. A total of 200 newly transplanted, white-fir seedlings was systematically selected along seven parallel transects. On June 11, each seedling was tagged with an aluminum label, and a 1 m wooden stake was driven into the adjacent soil. The latter was helpful in locating seedlings as the area became overgrown with vegetation. Stem diameter and height were determined for each seedling on June 11, and any evidence of aphid infestation (i.e., from the nursery) was noted. Seedlings were inspected weekly from June 25 to August 13, and biweekly from August 28 to October 23, 1991. On each sample date, the condition of the seedling and presence of aphids were noted. On the last sample date in October, each surviving seedling was measured (i.e., stem diameter and height). The following year (1992) seedlings were inspected on May 7 and October 28. Surviving seedlings were also measured on the latter date. A similar approach was followed at the Stanislaus site located about 18 km northeast of the town of West Point at approximately 1400 m elevation. In this case, 100 seedlings

were selected at random in each of two adjacent plots, 84 × 76 m and 65 × 70 m, respectively. These seedlings were tagged, staked, and measured on May 16 and 21, 1991. Seedlings were inspected weekly from June 24 to August 1, and biweekly from August 1 to October 24. Each surviving seedling was also measured on the latter date. The following spring, surviving seedlings were inspected on July 15, and again on October 13, 1992 when final measurements were taken.

The final analysis was conducted at the nursery on March 26, 1992 in the operational planting. In this case, seedling height was measured in 11 previously infested patches and compared to that for noninfested, adjacent seedlings. Infested patches had been monitored and mapped since initial infestation during the first season; only patches infested prior to August 1, 1991 were chosen. The controls were selected at the nearest noninfested location, albeit within the same bed and seed source; most were less than 1 m from the infested patch to be measured. In a given patch, all seedlings in a 15 cm transect through the center of the patch were measured.

Results and Discussion

Of the original 400 marked seedlings, 389 (97.3%) survived and were retrieved at harvest. There was no apparent effect of aphid infestation on cull-rate (table 1). The overall rate for infested seedlings was slightly lower than that for seedlings that were never infested. The cull-rate among all marked seedlings (9.0%) was lower than that for the 400 control seedlings (19.2%), indicating that the marked seedlings were not adversely affected during sampling over the course of the study. Among non-culled seedlings, aphid-infested plants and non-infested plants were about equally divided. About 7% of the seedlings infested only during the first season were culled compared to about 14% of the seedlings infested during both seasons. However, mean height, mean stem diameter, and mean dry weight of harvested seedlings were not significantly affected by infestation history (fig. 20).

When harvested seedlings were grouped according to infestation status when measurements were taken during the first or second seasons, some significant effects on final measurements were detected. For seedlings infested only during the first season, both height and dry weight were significantly reduced in seedlings infested before August 22, 1989 compared to seedlings infested later or not infested at all; there was no significant effect on stem diameter (fig. 21). Seedlings infested later in the first season actually displayed more growth than the noninfested seedlings (much of it during the first season), and we interpret this to mean that such plants became infested because they were vigorous and possessed considerable new growth. Analysis of covariance (ANCOVA), with the August 22, 1989, measurement as a covariate, revealed that seedlings infested early (prior to August 22) in the first season did not fully recover during the second season ($F = 15.67$, $P = 0.001$, d.f. = 3, 280). These displayed significantly less growth during the second season compared to either noninfested plants or those infested later during the first season ($P = 0.05$, Duncan's Multiple Range Test [DMRT]). These results clearly suggest that aphid infestations during the early part of the first season can greatly reduce seedling height, and that infested

seedlings may not fully recover during the second year. However, such seedlings could still exceed the cull standards.

For seedlings infested only during the second year, mean height, stem diameter, and dry weight at harvest were not significantly affected by time of infestation during the season (fig. 22). However, the amount of growth during the season was significantly affected. In this case, ANCOVA (with the height measurement of November 22, 1989 as a covariate) revealed a significant effect ($F = 4.8$, $P = 0.0001$, d.f. = 3, 259): seedlings infested early (i.e., before July 3, 1990) grew significantly less than seedlings infested later ($P = 0.05$, DMRT). However, this reduction in height would not ordinarily result in culling of such seedlings. Seedlings infested later showed significantly more growth than noninfested seedlings ($P = 0.05$, DMRT), again suggesting that taller, more vigorous plants are more likely to become infested.

For seedlings infested during both seasons, final height and dry weight (but not stem diameter) were significantly reduced for seedlings infested early in the first year compared to those infested later (fig. 23). These results provide further support for the view that aphid infestation can have a significant effect on plant growth (but not necessarily cull-rate), particularly early in the first year.

Another measure of aphid impact is the incidence of overwintering eggs on harvested seedlings destined for outplanting. Among the marked seedlings, 4.1% (n = 389) had eggs at harvest compared to 8.8% (n = 400) of the control seedlings (overall mean of 6.5%, n = 789). Among seedlings with eggs, most possessed either one or two (mean 2.55, range 1–12). The percentage of seedlings with eggs at harvest was somewhat lower than that for seedlings sampled (n = 100) on December 4, 1990 (mean 17%, range 1–15) and on January 8, 1991 (mean 14%, range 1–50). This suggests that harvest and subsequent handling may actually reduce the number of eggs on seedlings.

For seedlings from these plots that were monitored following outplanting in the Eldorado and Stanislaus National forests, a considerable proportion at each site was infested with aphids at some time during the season (fig. 24). At Eldorado, the percentage of seedlings infested exceeded 40 on four dates during the season; by the end of the season, 49% of the initial 200 seedlings had been infested compared to 91.6% of those that survived. At Stanislaus, the percentage of seedlings infested did not exceed 20 on any sample date; by the end of the season, 18.9% of the initial seedlings had been infested compared to 29.8% of those that survived. Many of these infestations were presumably due to overwintering eggs from the nursery. However, there was no apparent relationship between aphid infestation (at the outplanting) and percentage survival of seedlings (table 2). At the Eldorado site, over 70% of the seedlings survived the first season compared to over 80% at the Stanislaus site. For seedlings that survived, the increases in mean height and mean diameter over the season were not significantly different between infested and noninfested seedlings at both sites (fig. 25). At Eldorado, both height and diameter of infested plants were significantly greater, both at the beginning of the season and at the end. This suggests that bigger, more vigorous plants are more likely to be infested. At the Stanislaus site, stem diameter (but not height) was significantly greater among infested plants, both at the beginning and at the end of the season. From these results, it is clear that comparisons of seedlings made at the end of the season can

be misleading if comparable measurements were not made at the beginning of the growth season.

The source of aphids at these sites was evaluated by comparing phenology of aphid colonies detected on the outplants with that of colonies on adjacent white fir. At Eldorado, 40% of the infested plants were infested within two weeks of the first detected infestation. Although infestations occurred simultaneously in adjacent white fir, about 6% of the infestations in the outplanting occurred early enough to be attributed to overwintering eggs from the nursery. At the Stanislaus site, early infestations were detected at the same time in both the outplanting and adjacent white fir. However, nearly 47% of the outplanted seedlings were infested prior to detection of alate aphids in adjacent trees, a clear indication that overwintering eggs from the nursery were a major source of these infestations. In summary, it appears that aphid eggs deposited on seedlings at the nursery survive harvest, cold storage, and transplanting in sufficient numbers to initiate infestations of seedlings at outplantings. Whether or not the nursery race of *M. kinseyi* persists into the following season(s) is not known.

Waters (1969) suggested that life tables could be employed to assess the impact of insects and other factors on survival of trees, especially seedlings (see also Hett and Loucks 1968; Waters et al. 1991). We developed life tables for two hypothetical cohorts of white-fir seedlings based on results from the marked seedlings at the nursery and those at outplantings in the National Forests. These are summarized in table 3. In each case, seedling "mortality" at the nursery was about 10%, due primarily to culling. Culling was not necessarily due to aphids. At the outplantings, mortality during the first season was considerable, and especially due to disease. In this case, seedlings were scored as diseased when the following combination of symptoms were observed two or more weeks prior to death: most needles with severe chlorosis, no evidence of bud-break or meristematic growth, older needles turning brown or dying, and no evidence of transplant damage. Often, affected seedlings showed root or stem necrosis. Among the remaining mortality factors, deer destroyed over 10% of the seedlings at Eldorado whereas poor transplanting technique apparently led to the death of over 8% of the seedlings at the Stanislaus site. The impact of deer is probably an overestimate, as the animals were evidently attracted by the aluminum labels at the base of the seedlings; in the process of chewing on the labels, many seedlings were uprooted. A few seedlings were destroyed by either rodents or cattle, while some mortality was not accounted for (i.e., residual). Additional seedlings were lost over the first winter and during the second growing season, such that by the end of the second season, over half of the hypothetical cohort that had originated from the nursery was lost. The relatively high rate of mortality following transplanting is consistent with previous investigations involving various conifers (Stone 1955; Margolis and Brand 1990; Waters et al. 1991).

The last assessment of aphid impact on first-year seedlings at the nursery yielded results consistent with those obtained earlier (table 4). In this case, analysis of over 2000 seedlings in 11 paired infested versus noninfested patches in the spring of 1992 revealed that average seedling height was significantly reduced among seedlings that were infested prior to August of the previous season. Many of the infested seedlings were severely stunted and some seedling mortality was observed. Seedling mortality was also reflected in the difference in average

sample sizes (97.5 in the control, 85.2 in the infested) which suggests that about 13% of the infested seedlings failed to survive the first season.

Pest Status

Our results reveal that, whereas *M. kinseyi* can infest white-fir seedlings both at the nursery and in outplantings, its pest status will depend upon the circumstances involved. The most serious effect on seedlings can be expected to occur early in the first season, when dense aphid infestations can either kill or severely stunt the seedlings. Mortality of seedlings is not reflected in the cull-rate at harvest, and there may well be instances in which management of aphid infestations is required to prevent substantial loss of first-year seedlings. Reduction in seedling growth is more problematic, as our investigations revealed that such stunting did not necessarily lead to an increase in cull-rate at harvest. However, cull standards are rather arbitrary and can be changed in response to a customer's demand. Thus, there may be instances in which management of aphids (to prevent stunting of first-year seedlings) is justified. Management of infestations in the second-year crop may be necessary too, as these infestations can be a major source of alate colonists in the first-year seedlings. These alates may also colonize white fir at nearby Christmas-tree farms where aphid infestations are of considerable concern. As for other bareroot forest nurseries in the west, cull standards for white fir vary; thus, *M. kinseyi* might be considered a pest at one nursery but not at another.

Changes in production practices at the nursery should also be considered. For economic reasons, there is considerable interest in harvesting white-fir seedlings at the end of the first season. If this were to be implemented, *M. kinseyi* would most likely become a more serious pest. Such a situation may already exist at the USDA–Forest Service's Tree Improvement Center at Chico where seedlings are grown in containers for only one season. While our investigations provide no justification for suppression of aphids at outplantings of second-year seedlings, the situation could be very different for outplantings of first-year seedlings. At the Placerville Nursery, *M. kinseyi* is one of the primary reasons why the management has not shifted to a single-season production schedule. There is also interest in growing first-year seedlings without the shading provided by the lath fencing. If this were to be implemented, it could result in a considerable increase in the colonization rate of alates. The resulting infestation would likely be much more extensive than normal and could increase seedling mortality.

In summary, the pest status of *M. kinseyi* at forest nurseries must be addressed on a case-by-case basis. Mortality and stunting of first-year seedlings, cull standards, and commercial white fir in the immediate vicinity (e.g., Christmas-tree farms) must all be taken into account. Thus, the need for an aphid-management program may vary, both among nurseries and from year to year at a given nursery.

MANAGEMENT AT THE NURSERY

Our understanding of the life history and population ecology of *M. kinseyi* at the Placerville Nursery is sufficient to form the basis for an aphid management program, and the final phase of our research was devoted to its development and evaluation. The proposed management program is based on careful monitoring, especially during the first season, and spot treatment with compatible suppressive measures, including biological control. This program can be implemented at the Placerville Nursery as deemed necessary. It can also be adapted for other forest nurseries, and elements of the program (e.g., suppressive measures) can be applied at Christmas-tree farms.

Monitoring

Sampling is an important cornerstone for any pest-management program. The first-year seedlings should be monitored on a regular basis (e.g., weekly), beginning shortly after emergence. As the aphid flight season generally coincides with the latter, the incidence of alates in the aerial suction trap can also be monitored (preferably at 3 to 4 day intervals during the flight season). For at least the first 10 weeks after emergence, the seedlings should be sampled intensively—i.e., the entire field should be inspected so that infested areas can be mapped. Infested patches should be treated immediately (see below) and continuously monitored for reappearance of aphids. Because the impact of aphids on seedling growth and survival appears to be most severe during the early part of the first season, it is critical that aphid populations be carefully monitored during this period. Once the flight season is over (e.g., mid-August), it is unlikely that many new infestations will occur in treated fields because of the absence of alate viviparae. Alates subsequently observed on seedlings should be sexuparae, not viviparae. A similar approach should be utilized the following spring in the second-year seedlings, if for no other reason than to reduce the potential number of alate viviparae which might otherwise infest the new planting. Suppression of aphids in second-year seedlings later in the season (i.e., after the flight period) may not be necessary.

The percentage of first-year seedlings infested is a reasonable method for tracking the aphid population over time. As shown in fig. 16, there was a good correlation between percentage of seedlings infested and average aphid density on a given date. However, there can be considerable variation in number of aphids per seedling, so this "presence/absence" method should be used with some caution. The use of percentage of seedlings infested as a measure of the aphid's impact is more problematic. An infested plant can have one to more than 100 aphids, and the impact on plant growth is presumably directly related to aphid density. Impact is also a function of the amount of time (i.e., weeks) that a given seedling is infested. Weekly estimates of percentage of seedlings infested may very well underestimate the cumulative percentage infested. For example, among the 400 marked seedlings in the ecology plot, 31.9% were infested at some point during the first season; however, the average percentage of seedlings infested on a given date never exceeded 20% for the same seedlings. Whereas infested patches of seedlings generally remain infested during the growing sea-

son, aphid colonies on individual seedlings in such patches may disappear after a few weeks.

Prevention

It is well known that aphids in flight respond to light (Kring 1972; Robert 1987). Many species are "yellow sensitive" and are repelled by shortwave light. Certain surfaces (e.g., aluminum), that reflect shortwave, longwave, and varying amounts of infrared radiation, can reduce the number of alate aphids alighting on associated plants (Kring 1972; Klingauf 1987; Gibson and Rice 1989). Such reflective surfaces have been used to prevent aphids from colonizing crops, and are thus useful in crop protection. We therefore explored the use of reflective materials to prevent colonization of first-year seedlings by *M. kinseyi.*

Methods and Materials

White-fir seedlings at the nursery are shaded after germination and during their early development (e.g., June-August). This is accomplished by horizontally suspending lath fencing 30–40 cm above the seedling bed. Lath boards are approximately 5 × 120 cm. The upper surface of the lath thus provided a means for attaching reflective materials. In 1989, three types of materials were employed in seven widely spaced 4.5 m sections of bed: (1) silver metallic paint applied to each of the boards, in two sections; (2) 5 cm strips of highly mirrored, metallic vinyl-plastic stapled to four sections of lath fencing in different patterns (horizontal vs. longitudinal); and (3) a 5 cm rippled, gold metallic, vinyl-plastic stapled to each lath board in one section of lath. Forty seedlings in each section beneath the treated lath were sampled, along with 40 seedlings in each of eight surrounding control sections of equal size. In each plot, samples were taken along five systematically chosen transects. The first sample was taken when the reflective materials were installed on July 25. Weekly sampling continued until the end of August when the lath was removed from the field. This experiment was put in place near the end of the presumed aphid flight period for 1989 (cf. fig. 18). However, of the 63 plots under study, only two had infested seedlings on the first sample date (total of five). Infestations detected two weeks or so after this date would presumably represent colonies initiated by alate viviparae, whereas those detected later in August would represent within-field movement by apterous viviparae. Unfortunately, we were unaware of the aphid flight period in 1989; otherwise, this experiment would have been initiated much sooner.

In 1990, half of the operational field of first-year seedlings was utilized. This field consisted of 30 beds, and each was subdivided into 18 units, each about 4.5 m long. On May 29, two rectangular sections of lath were covered with longitudinal strips of the silver, vinyl metallic plastic employed in 1989. Each treated section was centrally located in the field, and consisted of five beds (22.5 m) buffered on each side by five additional beds of white fir (10 beds between the treated areas). The entire field was subsequently overgrown with weeds and this greatly interfered not only with sampling, but presumably aphid colonization as well. Nevertheless, a thorough sample of the entire field was carried out on July

31 (near the end of the flight season). In this case, 16 seedlings were sampled in each unit (along two transects, one plant in each of eight rows), for a total of 288 per bed, including 400 per treated area. This sample was taken shortly after the aphid flight season ended and thus provided an appropriate test of the working hypothesis.

Results and Discussion

The pattern of aphid infestation in both years was consistent with a treatment effect. In 1989, virtually all aphid-infested plants were detected outside of the treated area. On August 8, a total of 49 infested seedlings was detected adjacent to treated areas (0.88 per plot) compared to none under the treated lath. By August 30, there were 47 infested seedlings adjacent to treated areas, compared to only one in the latter. (However, as previously noted, our study began late in the season; by this date, many of the newly infested seedlings in the field could have been infested as a result of short-range dispersal by apterous viviparae.) In the 1990 experiment, infested seedlings were scarce during the experimental period; however, nine infested patches were found outside of the treated areas compared to none in the latter. Although the results were not particularly striking, they did suggest that a reflective lath might deter alate *M. kinseyi* and thereby reduce the incidence of infestation on first-year seedlings. The lath itself may also provide some degree of deterrence by simply interfering with the alate's ability to detect the presence of suitable host plants. This possibility should be investigated, for as noted earlier, there is some interest in growing white-fir seedlings without lath shading.

Biological Control

Naturally occurring enemies of *M. kinseyi* at the nursery consist primarily of predators, but as was shown earlier, these agents are not abundant and do not maintain aphid populations at relatively low levels. In view of this, two major approaches to biological control are feasible: importation of exotic natural enemies (classical biological control) and release of insectary-produced enemies, such as those available from commercial sources (augmentative biological control). The former approach must await systematic revision of the genus *Mindarus* so that the native home of *M. kinseyi* can be determined. Therefore, our research concentrated on augmentative control.

Two commercially available lacewings were evaluated: *Chrysoperla rufilabris* (Burmeister) and *C. carnea* (Stephens) (Neuroptera: Chrysopidae). The former is native to eastern North America, including the midwestern U.S. and northeastern Mexico, whereas the latter is Holarctic in distribution (Tauber 1974). Although these two species are closely related, only *C. carnea* occurs naturally in California; *C. rufilabris* is particularly prevalent in the humid southeastern U. S. (Tauber and Tauber 1983). In both species, the larva is predaceous (feeding especially on aphids) while the adult is free living (feeding especially on honeydew). Both predators have been used effectively in augmentative release programs. Historically, *C. carnea* has been the primary species utilized (cf. Ridgway and Murphy

1984; Tulisalo 1984), with *C. rufilabris* being utilized only in recent years (e.g., Nordlund et al. 1991; Breene et al. 1992).

Methods and Materials

Eggs of *C. rufilabris* were obtained from Beneficial Insectary (14751 Oak Run Rd., Oak Run, CA 96069). The eggs were refrigerated for two days after arrival and then maintained at room temperature (24°C) until hatching (3–4 days). The larvae used in all tests were introduced to aphid hosts within 24 hr after hatching. All predation studies were conducted in the laboratory at 24°C. The aphids used in these tests were field collected from first-year seedlings at the nursery.

In the first test, roots of infested seedlings were cut 4 to 6 cm below ground level. After the seedlings were returned to the laboratory, the small remaining root of each was inserted into a hole in a styrofoam raft floating on water. Each styrofoam raft was 28 × 19 cm and 8 mm thick. A total of 20 infested seedlings was inserted into each of two rafts. Seedlings maintained in this way appeared to be suitable hosts for the aphids, even for as long as 30 days. Each seedling contained approximately 100 aphids. (An exact count for each plant was not taken, as this would have greatly disturbed the aphid colonies.) In this test, designed to simulate field conditions, the seedlings were touching; therefore the lacewing larvae could readily move between infested seedlings. On one raft, 100 first-instar larvae (five each per seedling) were placed on the infested seedlings; on the second (totally isolated from the first), only one larva was placed on each seedling.

The purpose of the second study was to determine the number of aphids eaten during the predator's larval stage. Only the third, fourth, and adult stages of the aphid were used; these were removed from infested plants and caged on field-collected, uninfested seedlings. Cages were constructed from clear plastic cylinders 18 cm long and 2.5 cm in diameter. The top of each cage was covered with 100-mesh, stainless-steel screen. Roots of seedlings were removed and the remaining stem was inserted into a split latex stopper so that about 2.5 cm was protruding. The foliage of the seedling was inserted into the cage containing the lacewing larva and aphids. These units were then placed on styrofoam rafts with the stems submerged in water. Initially, larvae of *C. rufilabris* were provided daily with 15 aphids per larva; this was increased to 25 after the second molt and maintained at this level until pupation. Eggs of *C. carnea* were obtained from Rincon-Vitova Insectaries (P.O. Box 1555, Ventura, CA 93002); newly emerged larvae were used in all cases. First-instar larvae were provided 10 aphids per day, compared to 20 and 25 for second- and third-instar larvae, respectively. Larvae of both *C. rufilabris* (n = 10) and *C. carnea* (n = 29) were held in a rearing room at about 24°C. Each cage was inspected daily to determine larval survival and number of aphids eaten.

Results and Discussion

The first test revealed that larvae of *C. rufilabris* readily fed on *M. kinseyi*, including viviparae, sexuparae, and sexuales. The wax and honeydew produced by the aphid did not impede the predator, nor did the tight whorls and distorted

apical needles. On seedlings with one lacewing larva, aphids were eliminated on only one of the 20 infested seedlings after 7 days; after 14 days, aphids had increased on most of the remaining seedlings, and the lacewing larvae were pupating. At predator densities of five larvae per seedling, aphids were eliminated on nine of 20 infested seedlings within 7 days, and populations on the remaining seedlings were reduced to less than five aphids per seedling. After 14 days, all aphids were eliminated from the latter seedlings and the lacewing larvae had begun to pupate.

In its development, an individual larva of *C. rufilabris* or *C. carnea* consumed over 100 aphids during the 10 to 12 days required from hatch to pupation (fig. 26). The consumption rate was directly related to age of the larva, with mature third instar-larvae consuming as many as 25 aphids in 1 day. For both species, survival of larvae was 100% and developmental times (10-12 days) were not prolonged. Clearly, *M. kinseyi* is a suitable host for these predators. Under field conditions, aphid density often exceeds 100 per infested seedling; thus, a release rate of more than one larva per seedling may be required. The first experiment with *C. rufilabris* revealed that five larvae per infested seedling were sufficient.

Insecticidal Soap

Because of concerns for the environment and for the safety of field workers, there is a concerted effort to minimize the use of traditional chemical insecticides at the nursery. However, aphid populations may at times require treatment, so it is critical to have a "least toxic material" available. In view of this, we investigated the efficacy of Safer® insecticidal soap (now M-Pede™ Insecticide). Previous studies have shown soap sprays to be effective against a range of arthropod pests, including aphids (Pinnock et al. 1974; Moore et al. 1979; Osborne 1982; Koehler et al. 1983; Hastings et al. 1986).

Methods and Materials

During the 1991 growing season, infested first-year seedlings in operational plantings at the nursery were sprayed with Safer® soap and compared to adjacent control seedlings. In each test, a portion of a row of infested seedlings was sprayed with a mixture of 2.5 fluid ounces (74 ml) of 49% concentrate in one gallon (3.8 l) of water (approximately a 1% concentration of soap). Plants were sprayed until runoff. After two hours, 10 consecutive seedlings in the sprayed zone were carefully removed, along with 10 consecutive control seedlings immediately adjacent to those that were sprayed. All seedlings were returned to the laboratory and immediately examined for aphids. This experiment was repeated on five dates: August 23 and 29; and September 5, 11, and 18.

A second experiment was conducted in the laboratory. In this case, aphids from the nursery were placed on filter paper in petri-dish bottoms (20–30 per dish, five replications) and sprayed with a 1% concentration of soap. Sprays were applied with a hand-compression sprayer in a manner sufficient to moisten the filter paper and ensure contact with aphids. In a second treatment, aphids were added to the petri dishes two hours after application of soap so as to assess any residual

activity. These treatments were compared to a spray of distilled water and a dry control. Alive and dead aphids were counted after 30 minutes, 1 hr, and 24 hr. The same treatments were applied against late first- and early second-instar larvae of *C. rufilabris* (obtained from Beneficial Insectary, Oak Run, CA). In this case, five larvae were placed in each dish, along with 10 *M. kinseyi*; this was replicated 10 times. Spray application and observation intervals were as above.

Results and Discussion

In the field spray test, laboratory examination confirmed that all seedlings (treatment and control) were infested at the time of treatment and that excellent suppression of aphids was obtained with soap spray. Of the 50 treated seedlings, only two had live aphids, a 96% reduction in infested plants; the mean number of live aphids per treated seedling was 0.1 (n = 50) compared to 28 (n = 30) in the control (a 99.6% reduction in aphid density). Dead aphids were numerous on treated seedlings (mean 26.1, n = 10) relative to control seedlings (mean 0.06, n = 50). In the laboratory tests, the soap spray killed 100% of the aphids and the lacewing larvae; however, the soap's residue was toxic to neither. There was no mortality in the water treatment and the control.

Clearly, insecticidal soap can be an effective management tool for *M. kinseyi* at the nursery and it should be utilized whenever necessary. However, insecticidal soap cannot be expected to provide residual suppression of aphids, so thorough coverage of infested seedlings is required. Repeat applications may also be necessary, particularly when aphids are secluded in highly distorted apical whorls. Larvae of chrysopids are generally considered to be relatively tolerant of conventional insecticides (Bigler 1984). However, this was not the case with Safer® soap, as virtually all the larvae died within 30 minutes of being sprayed. But because there is no residual activity, insecticidal soap and lacewing larvae can be employed in a compatible manner if lacewing releases are made two hours or so after the application of soap. Because insecticidal soap may not always kill 100% of the target aphids, subsequent releases of lacewing larvae could thus be employed to "clean up" the remaining aphid population.

Management Demonstration

The final phase of our research was devoted to the demonstration of a management program for *M. kinseyi* at the nursery. This program was based on ecological information obtained earlier, and involved preventive and suppressive tactics that were compatible and environmentally sound. The entire planting of white fir for 1991 was made available for this purpose.

Methods and Materials

In the spring of 1991, the white-fir crop was seeded in two separate plots (fig. 27). Eleven beds of white fir were designated for the management program compared to nine for the control (i.e., no treatment). Each bed was subdivided into 18 units; each unit was about 4.5 m long and delineated by the support

beams for the lath. The management plot had slightly more units than the control (177 vs. 162). Both plots contained several different seed sources, including some in common. Because this demonstration qualified as a "pseudoreplicated" experiment (cf. Hurlbert 1984), no inferential statistical analyses were performed on the data.

In the management plot, one preventive and two suppressive tactics were employed. First, two coats of a metallic, reflective paint ("Chromatone Silver," Crescent Bronze Powder Company, Inc., Los Angeles, CA) were applied to the upper side of the lath boards at a rate of one gallon per 600 sq. ft. (3.8 l/56 m^2). This reflective surface was designed to prevent alate colonization of first-year seedlings and was in place by June 11, 1991. During the first season, aphid colonies were treated with either Safer® insecticidal soap, larvae of *C. rufilabris*, or both (i.e., lacewing larvae released two hours after soap spray); during the second season, all infested patches were treated with Safer® soap. Soap was mixed at the recommended rate (2.5 fl oz of 49% active ingredient per gal of water) and applied with a hand sprayer until runoff. Special care was taken to get good coverage of infested portions of the seedlings, particularly during the second year. For lacewing releases, "prefed" larvae were obtained from Beneficial Insectary and released in infested patches at a rate of about two larvae per infested seedling. Prefed larvae arrived from the insectary as first or early-second instars, and proved to be voracious predators on *M. kinseyi* under field conditions. Initial experiments with release of eggs of *C. rufilabris* were discouraging, as most of the released eggs were either eaten by resident predators or compacted into the soil by the sprinkler irrigation that was applied almost daily on the first-year seedlings. Viability of eggs was very high, and most likely did not contribute to failure of the releases. Field releases of *C. carnea* were not evaluated in this study.

Plots were sampled on a regular basis during the growing seasons. In 1991, the seedlings were sampled weekly from June 6 through October 30. Additional samples were taken on November 13 and 21, and on February 28, March 12, and March 26, 1992. Weekly sampling resumed on April 9 and continued until May 14; from then until June 22, plots were sampled twice a week (because of the aphid flight season). Weekly sampling resumed on June 29, and was maintained from July 7 through August 4. Four additional samples were taken on August 13 and 26, September 9, and October 14, 1992.

A variety of sampling methods was employed. On a few occasions, the entire planting was mapped for aphid infestations. In this case, the location of an infested patch in a given unit of the bed was noted. This enabled us to prepare a composite picture of the infested areas in the two plots. In other cases, systematically chosen transects across the bed were carefully inspected in each unit. During the first season, the lath boards were occasionally rolled up by nursery workers to allow closer inspection of the seedlings. Once the lath was removed at the end of the season, sampling became much easier; following this, we simply recorded the presence or absence of aphids (in a given unit of bed) on most dates. From June 22 to August 13, 1992, only the management plot was sampled, as each of the 162 units of bed in the control was infested.

Seedlings were harvested from January 29 to February 5, 1993. As the harvested seedlings were processed, samples of culled material from each seed source in both plots were collected and placed in cold storage. Later, each seedling was

examined in the laboratory for aphid or mechanical damage. The overall cull rates for the two plots were also estimated—i.e., by subtracting the number of seedlings packed from the estimated number in the field at harvest.

Results and Discussion

Aphids were first detected on the seedlings on June 25, 1991 (in the control plot); aphids were not detected in the management plot until July 9. Thereafter, aphid infestations were detected in both plots on virtually every sample date. By October 2, about 10% of the seedlings in the control had been infested at one time or another compared to about 1% in the management plot (fig. 28). By October 11, the infestation was widespread in the western half of the control plot, whereas the management plot had only a few, scattered plants that were infested (fig. 29). We attribute the latter condition to treatment of over 140 infested patches with lacewing larvae, Safer® soap, or both.

Although the first aphid colonies were not detected in the management plot until two weeks after the first colonies were observed in the control plot; there was no major effect of reflective lath on alate colonization during the aphid flight period (fig. 30). Twenty-two new infestations were detected in the control (2.44 per bed) compared to 16 in the management plot (1.6 per bed). Thus, the entire planting may have been colonized by fewer than 40 alate viviparae. While the reflective lath may have prevented some alate colonization, a sufficient number of alates colonized the management plot, and these would have led to a wide spread infestation if they had not been treated. Thus, whether or not reflective lath serves as a preventive measure is uncertain.

The 36 infested patches that were treated with larvae of *C. rufilabris* were monitored during the remainder of the first season. Approximately 75% of these were free of detectable aphids for 21 days whereas over 20% were free of aphids for 56 days (fig. 31). When infested seedlings were subsequently detected in previously treated patches, in virtually every case, only a few isolated seedlings were involved. These were usually at the periphery of the treated area, and were presumably the result of a few viviparae that the lacewing larvae did not discover. No adults of *C. rufilabris* were detected in the release areas or in the nearby suction trap. Thus, *C. rufilabris* apparently did not undergo additional generations at the nursery. From an experimental viewpoint, this was very helpful because the control plot was never colonized by this predator. Unfortunately, this also indicates that releases of *C. rufilabris* cannot be expected to provide long-term control of *M. kinseyi.*

Safer® soap provided effective aphid suppression in many cases, but in over half of the treated patches, a second treatment was required after 7 days (fig. 32). Similar results were obtained in 45 patches previously treated with eggs of *C. rufilabris.* In virtually every case, the second treatment was needed because a few infested seedlings were detected a week after the first. As in the case of lacewing larvae, these seedlings were usually at the periphery of the treated patch. In view of this, a buffer area was sprayed in subsequent trials so as to ensure coverage of newly infested seedlings which might show no evidence of infestation. When lacewing larvae were released following application of Safer® soap, most infested

patches were free of detectable aphids for 21 days or more (fig. 33). A total of 198 g of active ingredient was applied during the first season.

Aphids were detected sporadically in the control plot during the winter of 1992 and a few apterous vivipare evidently survived to initiate colonies in the spring. By the end of April, there were several infested patches in the control, presumably the result of overwintering eggs. The number of infested units continued to increase in the control until June 22 when all 162 units had at least one infested patch. In the management plot, Safer® soap was applied on a regular basis throughout the aphid flight season, as alates (many presumably from the control) continued to initiate new colonies. By the end of the season, virtually every unit in the management plot had detectable aphids at one time during the season; all were treated with Safer® soap. A total of 1915 g of active ingredient was applied during the second season. (This should be considered an extraordinary amount; it was necessitated by the influx of alates from the nearby control plot.) By August 26, the aphid population had crashed, but the damage from two years of infestation was apparent and widespread in the control plot compared to a negligible amount of damage in the management plot (fig. 34). Surveys taken on September 9 revealed that about 20% of the seedlings in the control plot were damaged by aphids compared to only about 3% in the management plot (fig. 35). By that time, the aphid population in both plots was at a very low level and it remained this way for the remainder of the season.

At harvest, the estimated cull-rate was over 30% for the entire crop of seedlings, and was actually higher in the management plot (mean of 40.8%) compared to the control (mean of 34.1%). However, this had little to do with aphid damage. Most of the culled seedlings (> 80%) had no apparent aphid damage. Whereas a few culled seedlings had mechanical damage, most were simply under-sized. This suggests that production practices, such as altering the density of seedlings to reduce competition, could reduce the cull-rate considerably. However, under conditions of reduced competition, seedlings might well be more vigorous. This could lead to more severe aphid infestations, as more vigorous seedlings may be more attractive to alate colonists and can support higher densities of aphids. Genetical factors could also be involved—i.e., some seed sources may have been poorly adapted to nursery conditions. Although aphid damage was of secondary importance in this study, the effect of the management program was evident—i.e., only 1.8% of the culled seedlings in the management plot had aphid damage compared to 11.3% in the control. Also, for the two seed sources that occurred in both the management and control plots, the percentage of culls with aphid damage was much lower in the former (3.1 and 1.1 vs. 8.4 and 19.7). Nevertheless, these results are consistent with previous findings that suggest that *M. kinseyi* is not necessarily a major pest at the nursery.

Further Evaluation

With the success of the management demonstration, we further evaluated the management program for *M. kinseyi* at the nursery. This was conducted in the first-year planting during the summer of 1992. Dimensions of the field and sample dates were given earlier (see Population Ecology section). Nursery personnel were

trained to inspect the seedlings for aphids, map the infestations, and release lacewing larvae (*C. rufilabris*), or apply Safer® soap as needed. Just over half the field was covered with painted reflective lath; however, by the end of the growing season, there was no apparent treatment effect (fig. 36). Of the almost 100 infested patches that were detected during the aphid's flight season, over half (63) were under the reflective lath. Prefed lacewing larvae were released in 69 infested patches during July and August; of these patches, 62% were free of detectable aphids for ≥ 21 days and 24% were free of aphids for over 35 days (fig. 37). The remaining infested patches were treated with Safer® soap, as were numerous lacewing-release patches that eventually required treatment. A total of 2139 g of active ingredient was applied to 205 infested patches during July and August 1992. These treatments provided good suppression of aphids in most cases (fig. 38). In over half of the sites, there were no detectable aphids for 14 or more days following treatment. As in the management demonstration, many sites that required retreatment after 7 days had only a few isolated, infested seedlings at the edges of the previously infested (and treated) area. By the end of the season, there were hardly any aphid-infested patches in the field. On May 11, 1993, four infested patches were detected whereas 11 were detected on June 2. At this point, the aphid population that remained was well under control. No additional samples were taken.

In the summer of 1994, we assessed releases of *C. carnea* at the nursery. First-year seedlings were not shaded with lath and an extensive aphid infestation developed. As expected, the infestation was very patchy. In early July, we selected 19 sites where two infested patches occurred in close proximity (i.e., within 2–4 m). On July 7, the total number of infested seedlings/m^2 was determined in all plots and 100 prefed lacewing larvae were released in one plot of each pair. Plots were sampled for the remainder of July. Infestation in the treatment and control plots were comparable on July 7, but 7 days later, lacewing releases had resulted in an approximate 4× reduction in infested seedlings (fig. 39). This difference was highly significant and was sustained for two weeks posttreatment. By this time, the lacewing larvae had completed development, and the aphid population resurged shortly thereafter. No adult *C. carnea* were detected following these releases. Additional releases were made on August 2 at a rate of 100 larvae per infested patch, with virtually every patch in the planting receiving treatment. While these provided considerable aphid suppression, there was again no evidence for a second generation of lacewings. Thus, neither releases of *C. rufilabris* nor *C. carnea* can be expected to provide season-long aphid suppression at the nursery. The underlying reason(s) for this lack of persistence is in need of investigation.

Future Perspective

The aphid management program can now be implemented (as needed), both at the Placerville Nursery and other nurseries in the West. However, if aphid management is to be practiced on a regular basis, some additional investigations are warranted. Because repeated releases of lacewings apparently did not result in additional generations in release areas, augmentative releases of other species of lacewings should be assessed. A commercially available lacewing that can

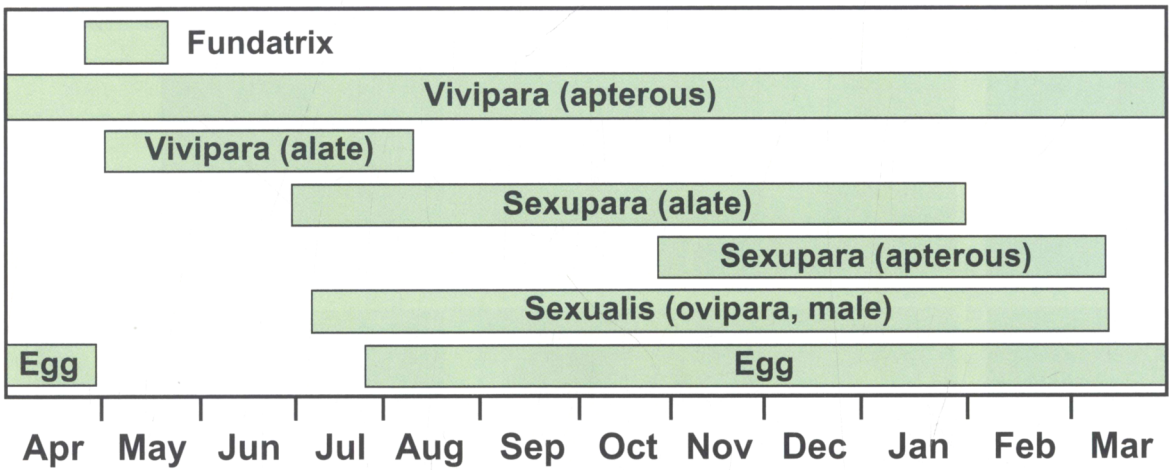
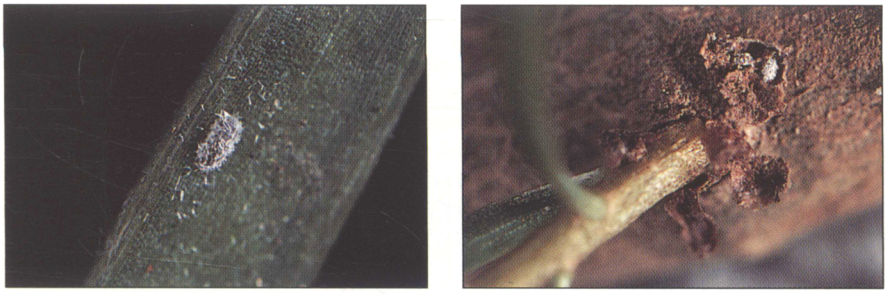
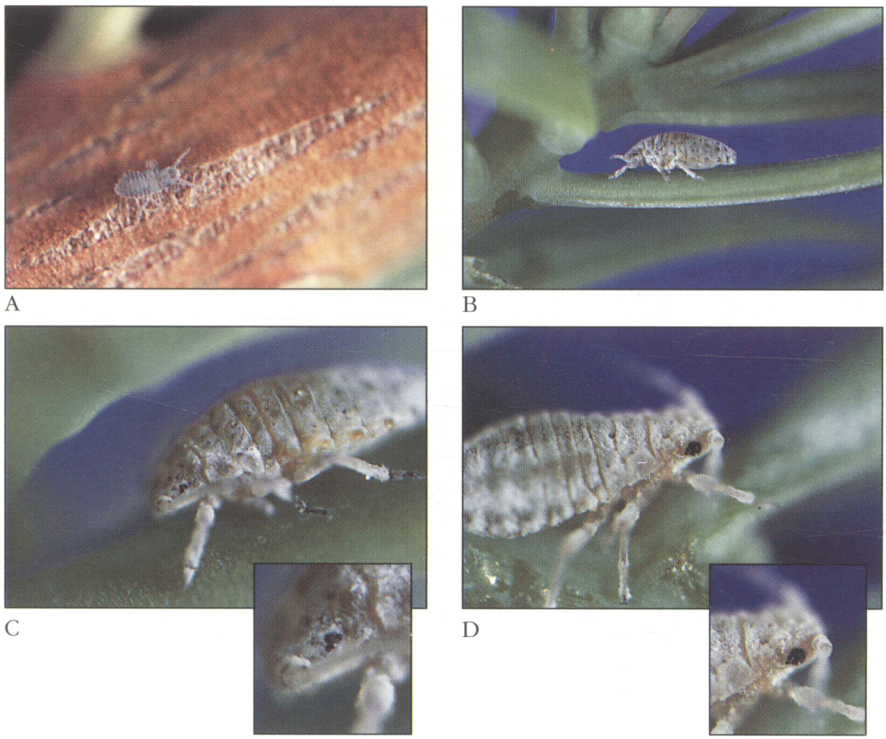


Fig. 1. Approximate phenology of overwintering eggs and the various morphs of *M. kinseyi* at the Placerville Nursery. Length of each bar is based on a composite of samples collected during 1989-92.



A B

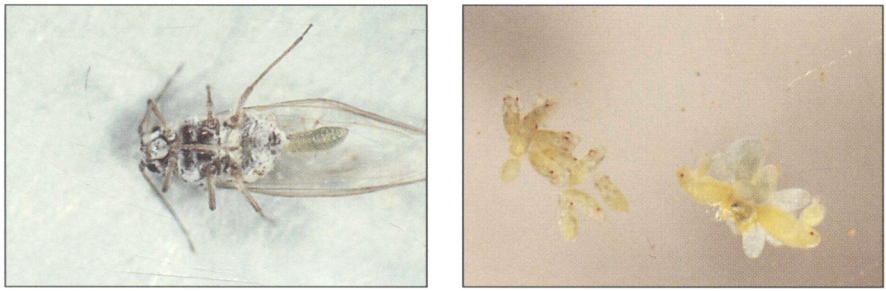
Fig. 2. Egg of *M. kinseyi*: (A) single egg on a white fir needle; (B) eggs in bud cap of second-year seedling.



A B C D

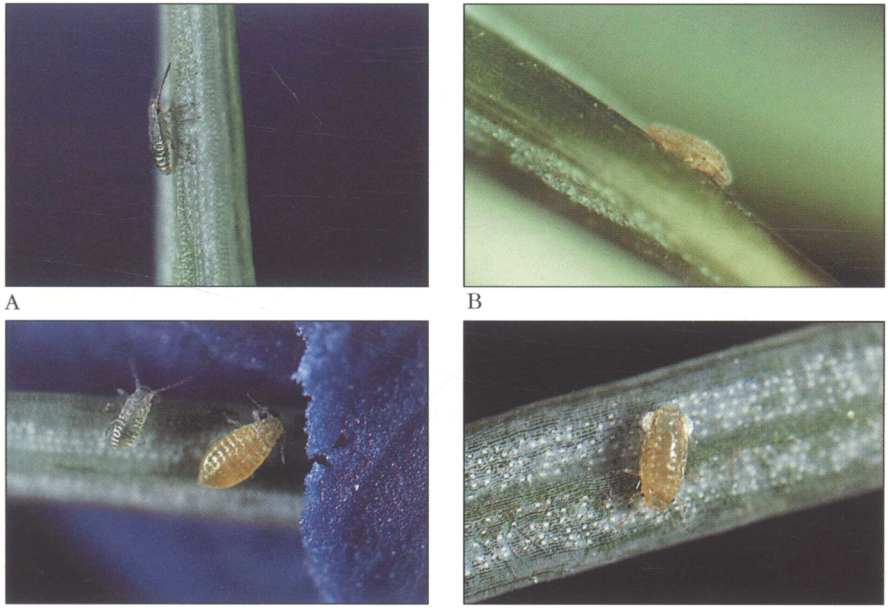
Fig. 3. Fundatrix of *M. kinseyi*: (A) first-instar nymph; (B) mature adult; (C) close-ups of adult showing simple eye; (D) close-ups of apterous vivipara (for comparison) showing compound eye.

Fig. 4. Vivipara of *M. kinseyi*: (A) first-instar nymph; (B) larger nymphs in needle whorl of infested seedling; (C) apterous adult; (D) alatoid nymph; (E) cast skin of alatoid nymph on host needle; (F) alate.



A B

Fig. 5. (A) Alate sexupara of *M. kinseyi* giving birth to a male; (B) embryos from an alate vivipara (left) and an alate sexupara (right). Larger, amber colored embryos from sexupara are female (ovipara) and smaller, bluish ones are male.



A B C D

Fig. 6. Sexualis of *M. kinseyi*: (A) first-instar male; (B) immature female (ovipara) apparently feeding on needle; (C) mature male and near-mature ovipara; (D) mature ovipara.

sustain populations during the first season would clearly be preferable to a species that must be released repeatedly. The efficacy of insecticidal soap should also be monitored so that any resistant clones of *M. kinseyi* can be detected early and dealt with accordingly. Croft (1992) lists several principles for limiting or managing pest resistance, including the following: "Leave unselected populations of pests in refugia or maximize immigration and hybridization of susceptible biotypes with selected resistant population." As there may be considerable aphid immigration, the rate of resistance developing to soap should be reduced. Ovicidal materials have been successfully employed against aphids (Harrewijn and Minks 1989) and should be explored. Although preliminary experiments at a nearby Christmas-tree farm were not encouraging (Koehler et al. 1990), experimental trials involving seedlings are warranted. Finally, several conventional insecticides are effective against *M. kinseyi* (Stein and Haverty 1990, 1991), and selective use of such chemicals (e.g., during the aphid's flight period) could be a sound management technique. However, any emphasis on "least toxic" chemicals might have to be relaxed.

Concluding Remarks

A recent report from the Committee on Forestry Research of the National Research Council noted that the relationship between forestry and agriculture needed to be enhanced and improved, and that a new sense of partnership was required (NRC 1990). This report noted that many developments in the agricultural sector are relevant to forestry. A good example is the concept of integrated pest management (IPM). IPM is clearly relevant to forestry (Branham and Hertel 1984), especially in forest nurseries where seedlings are grown in a manner similar to agricultural row crops (cf. Dixon and Foltz 1984; Mexal 1984; Sutherland 1984). However, management programs for insect pests in forest nurseries have generally lagged behind those that have been developed and implemented in agricultural crops. We suggest that our management program for *M. kinseyi* is an exception to this trend. Furthermore, this program may also serve as a model for pest management in agricultural and related settings where labor-intensive and environmentally sensitive crop production is required.

TABLE 1. INFLUENCE OF APHID INFESTATION ON CULL RATE OF 389 MARKED SEEDLINGS FROM THE ECOLOGY PLOT AT THE NURSERY*

History of seedlings	Percentage of seedlings	
	Culled (n = 35)	Not culled (n = 354)
Infested (n = 177)	8.5	91.5
First year only (n = 73)	6.8	93.2
Second year only (n = 53)	5.7	94.3
Both years (n = 51)	13.7	86.3
Not infested (n = 212)	9.4	90.6

*Chi-square = 2.57, d.f. = 3, P = 0.46.

TABLE 2. INFLUENCE OF APHID INFESTATION ON SURVIVAL OF TRANSPLANTED SEEDLINGS DURING 1991*

Condition of seedlings	Percentage of seedlings			
	Eldorado National Forest		Stanislaus National Forest	
	Infested (n = 87)	Not infested (n = 55)	Infested (n = 36)	Not infested (n = 112)
Dead	29.9	23.6	16.7	17.9
Alive	70.1	76.4	83.3	82.1

*Survival from transplantion through October 23 (Eldorado, n = 142) and October 24 (Stanislaus, n = 148). Chi square with df = 1 as follows: 0.66, P > 0.40 for Eldorado and 0.03, P > 0.50 for Stanislaus.

TABLE 3. LIFE TABLES FOR HYPOTHETICAL COHORTS OF WHITE-FIR SEEDLINGS FROM TWO SEED SOURCES AT THE NURSERY AND AT RESPECTIVE OUTPLANTINGS IN THE NATIONAL FORESTS*

		Eldorado			Stanislaus		
x	dxF	lx	100qx	100rx	lx	100qx	100rx
Emergence to	Disease	100	0	0	100	2.5	2.5
end of 1st season	Residual		0	0		1.3	1.3
Beginning of	Weeding	100	1.3	1.3	96.2	1.3	1.3
2nd season to harvest	Culled		6.3	6.2		7.9	7.5
Cold Storage	Not assessed	92.5	—	—	87.4	—	—
Transplanting to	Disease	92.5	30	27.8	87.4	23.5	20.5
end of	Deer		13	12		0	0
1st season	Rodents		1	0.9		0	0
	Cattle		0	0		1.5	1.3
	Planting		0	0		8.5	7.4
	Residual		2.5	2.3		4.5	3.9
End of 1st season to	Disease	49.5	8.4	4.2	54.3	1.6	0.9
beginning of 2nd	Rodents		2.8	1.4		0	0
	Cattle		0	0		2.4	1.3
	Planting		4.7	2.3		0	0
	Residual		0	0		4	2.2
Beginning to end	Disease	41.6	5.6	2.3	49.9	1.8	0.9
of 2nd season	Rodents		2.2	0.9		0	0
	Residual		4.4	1.8		8.8	4.4
Totals		36.6	—	63.4	44.6	—	55.4

*Key to symbols: x = age interval, dxF = mortality factor, lx = number alive at the beginning of x, 100qx = percentage mortality of individuals entering stage x, and 100rx = percentage mortality of individuals in stage x as a function of initial lx for the cohort.

TABLE 4. EFFECT OF APHID INFESTATION ON GROWTH OF FIRST-YEAR SEEDLINGS IN 1991*

	Seedling height (cm)			
	Infested		Not infested	
Site	Mean	n	Mean	n
1	2.38	63	2.84	58
2	2.32	123	4.4	126
3	2.63	86	4.5	120
4	1.93	112	2.77	107
5	1.88	93	2.45	102
6	2.14	76	3.8	95
7	2.43	87	5.55	108
8	2.64	113	4.73	124
9	2.52	61	2.3	91
10	2.32	46	4.73	50
11	2.93	77	4.29	91
Grand mean	2.37		3.85	

*Results for paired t test: t = 4.98, d.f. = 10, P = 0.0006.

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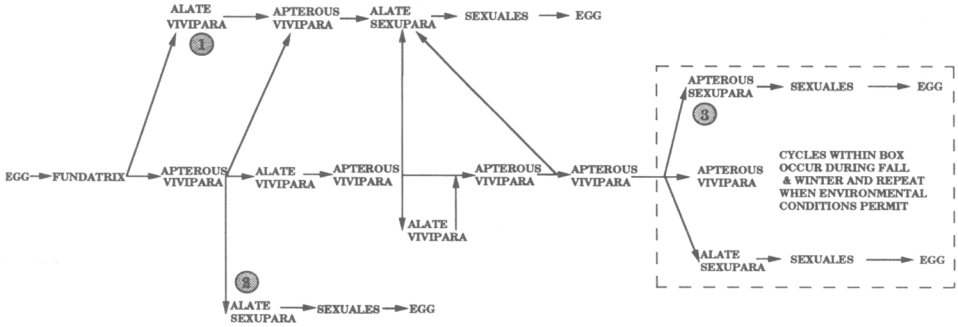


Fig. 7. Three avenues by which the holocycle of *M. kinseyi* can be completed at the Placerville Nursery.

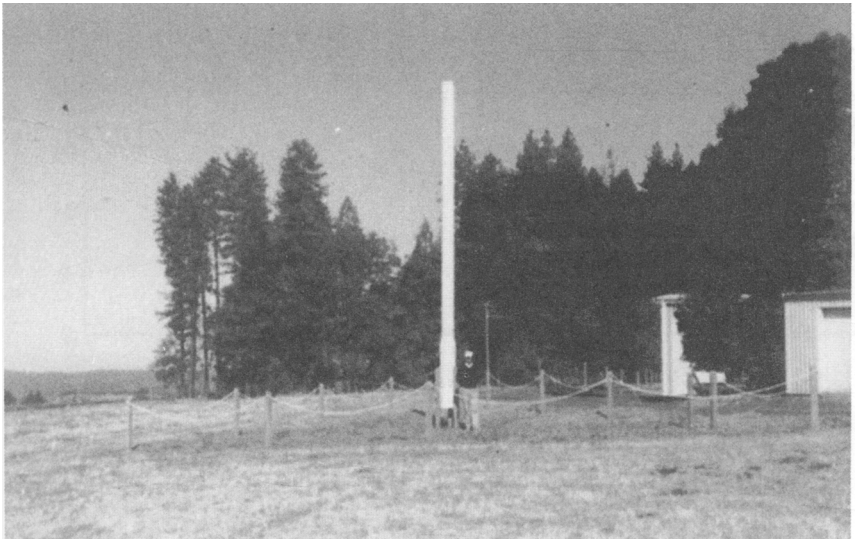


Fig. 8. The aerial suction trap employed to monitor flight of *M. kinseyi* at the Placerville Nursery.

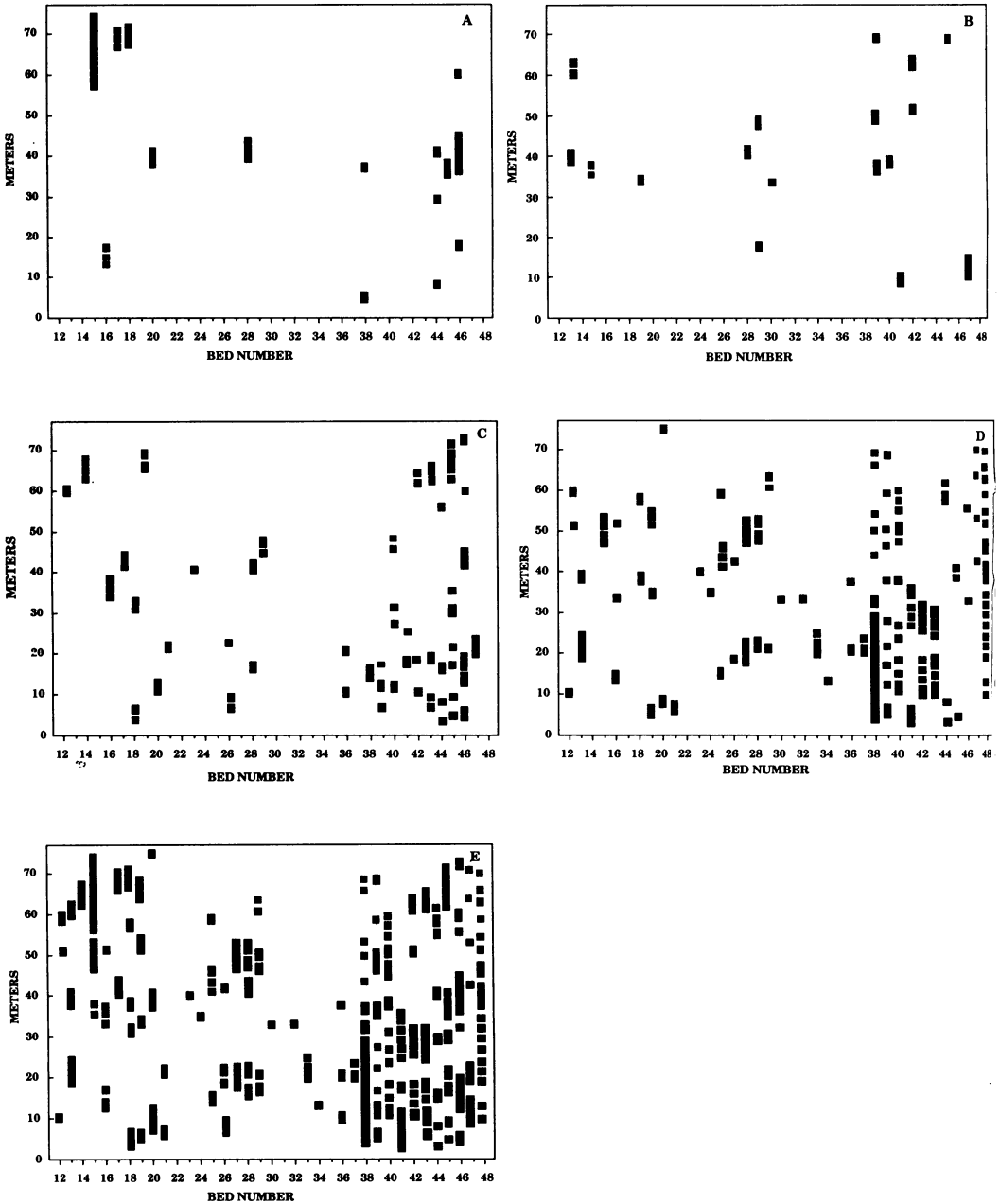


Fig. 9. Approximate spatial distribution of infested, second-year plants during spring of 1989. Only newly detected, infested patches are depicted in A (May 23), B (May 30), C (June 6), and D (June 13) compared to spatial structure of the total infestation on June 13 (E).

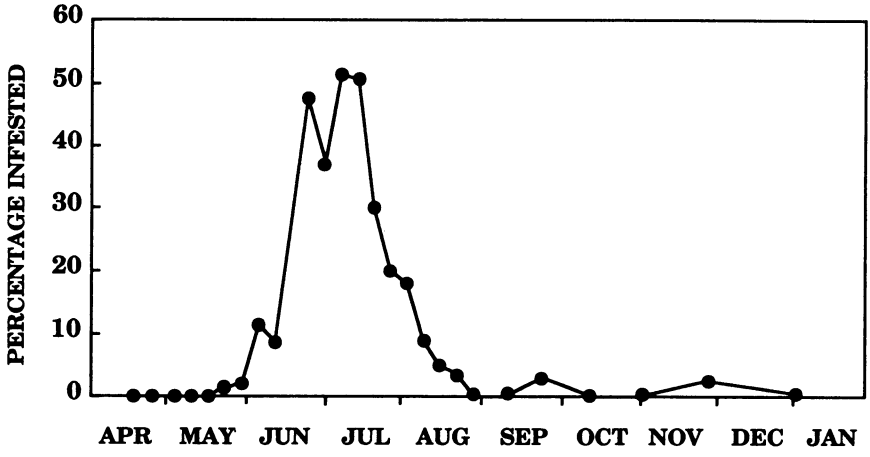


Fig. 10. Percentage of second-year seedlings infested by *M. kinseyi* during 1989-90.

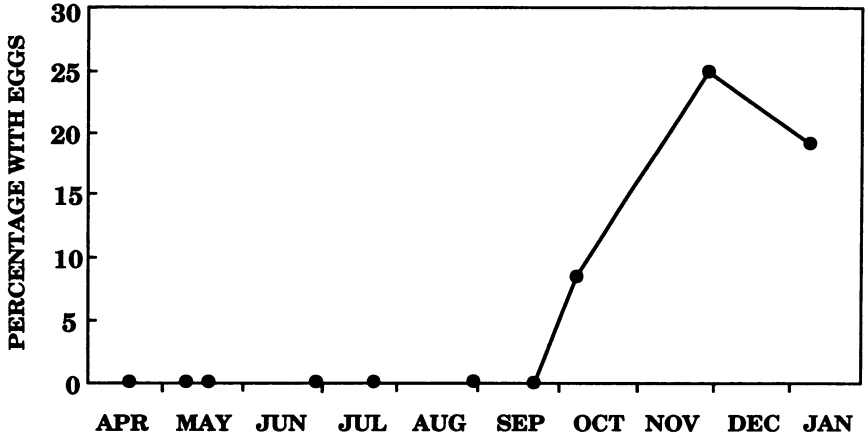


Fig. 11. Percentage of second-year seedlings with one or more eggs of *M. kinseyi* during 1989-90.

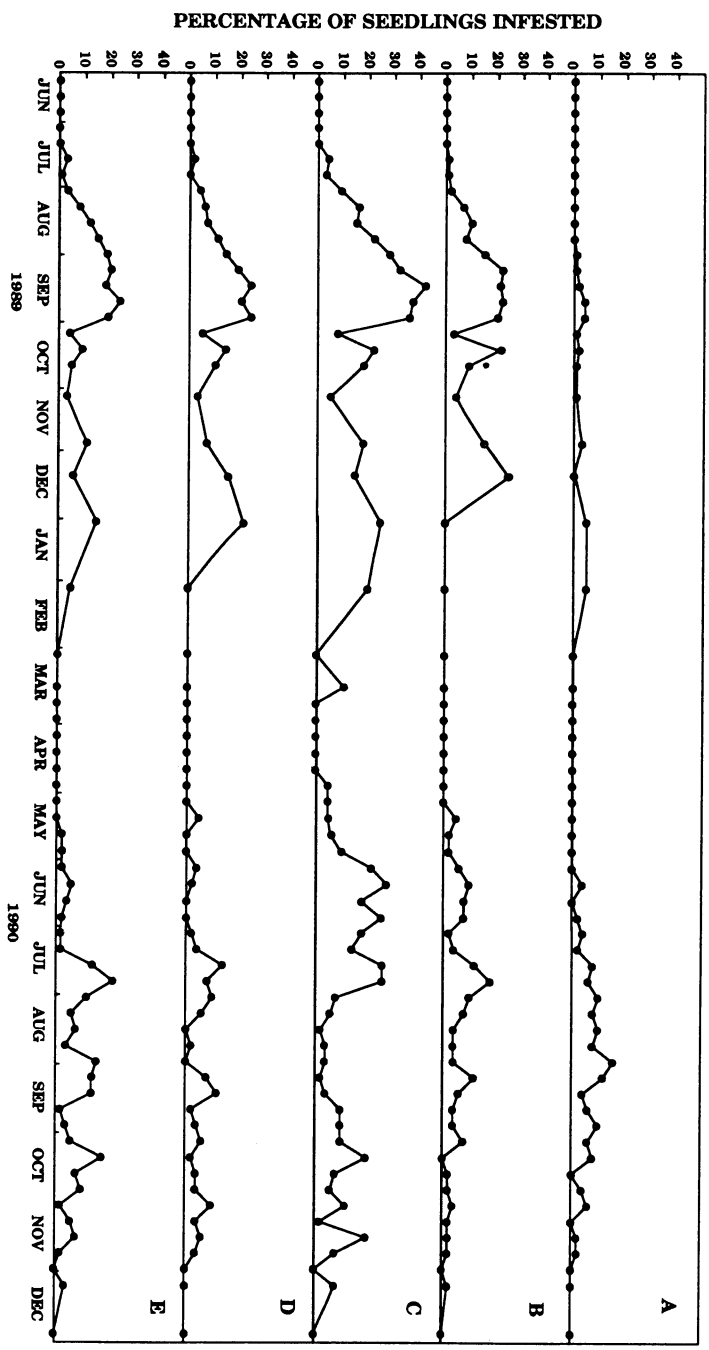


Fig. 12. Percentage of seedlings in the ecology plot infested by *M. kinseyi* during 1989-90. Seed sources as follows: A, Plumas National Forest; B, Tahoe National Forest; C, Stanislaus National Forest; D, Sierra National Forest; E, Eldorado National Forest.

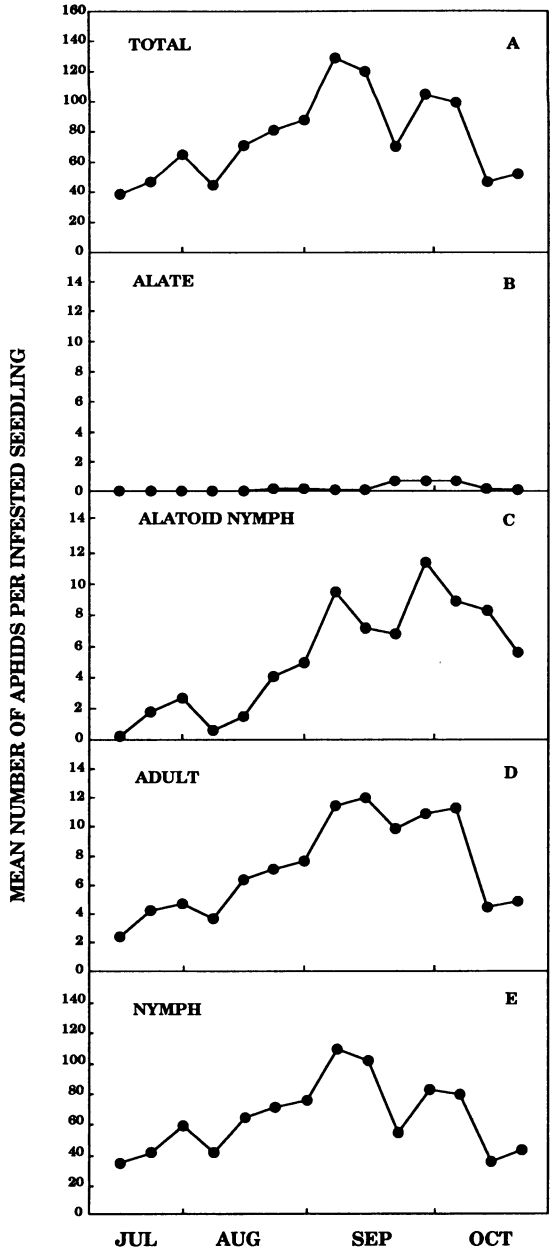


Fig. 13. Mean number of *M. kinseyi* per infested, first-year seedling in the ecology plot during 1989.

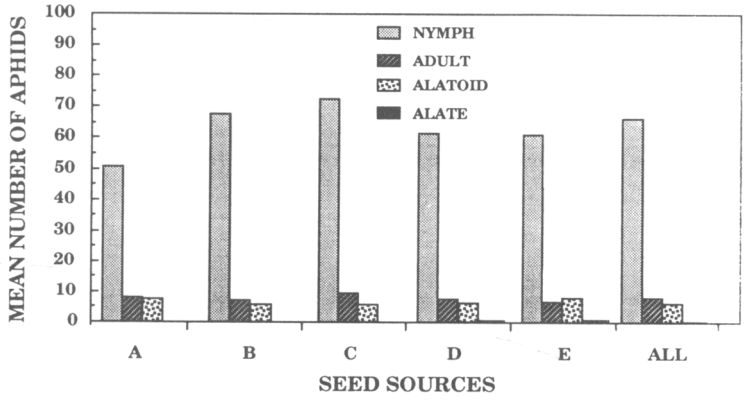


Fig. 14. Mean number of *M. kinseyi* per infested, first-year seedling as a function of seed source in the ecology plot. Seed sources as follows: A, Plumas National Forest; B, Tahoe National Forest; C, Stanislaus National Forest; D, Sierra National Forest; E, Eldorado National Forest. Means calculated for all sample dates (n = 14) during 1989 in which infested seedlings were detected.

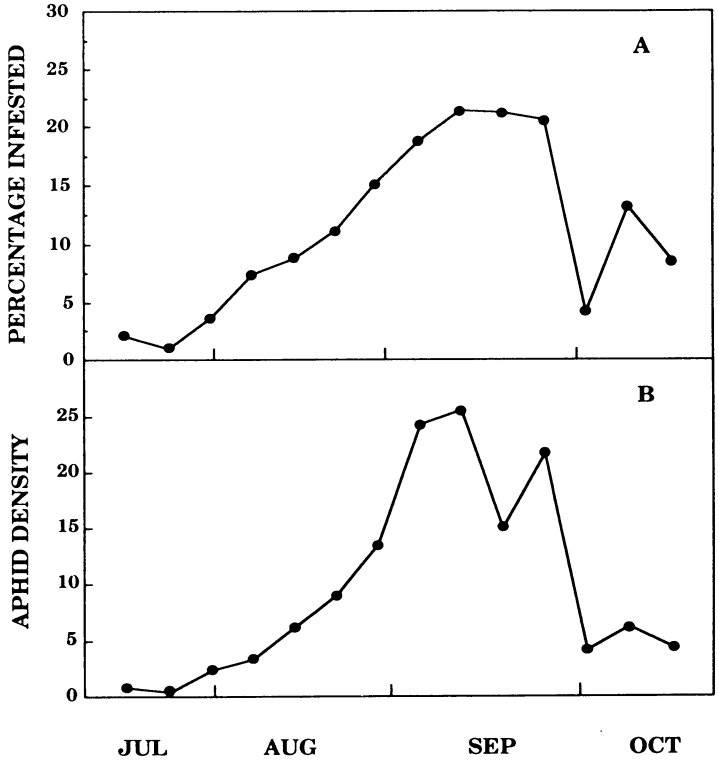


Fig. 15. Overall percentage of infested, first-year seedlings (A) and mean density (*M. kinseyi* per plant) (B) in the ecology plot during 1989.

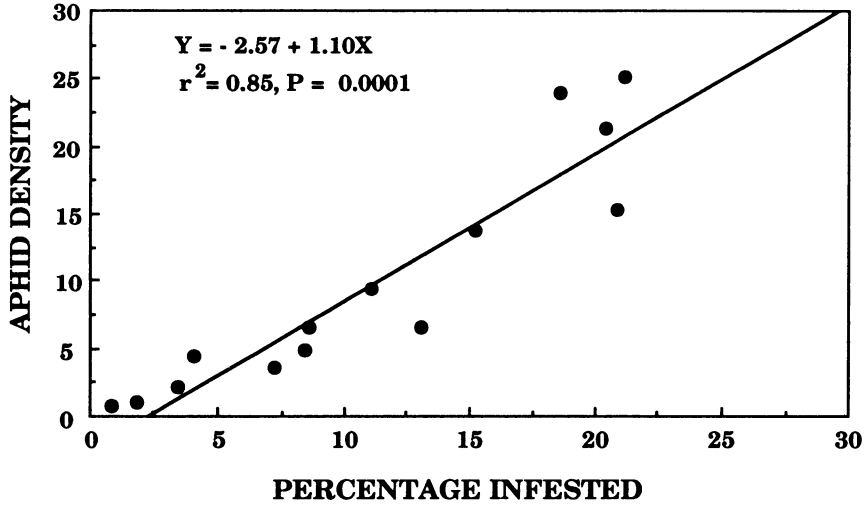


Fig. 16. Relationship between mean density of *M. kinseyi* and percentage of first-year seedlings infested in the ecology plot for 14 sample dates in 1989.

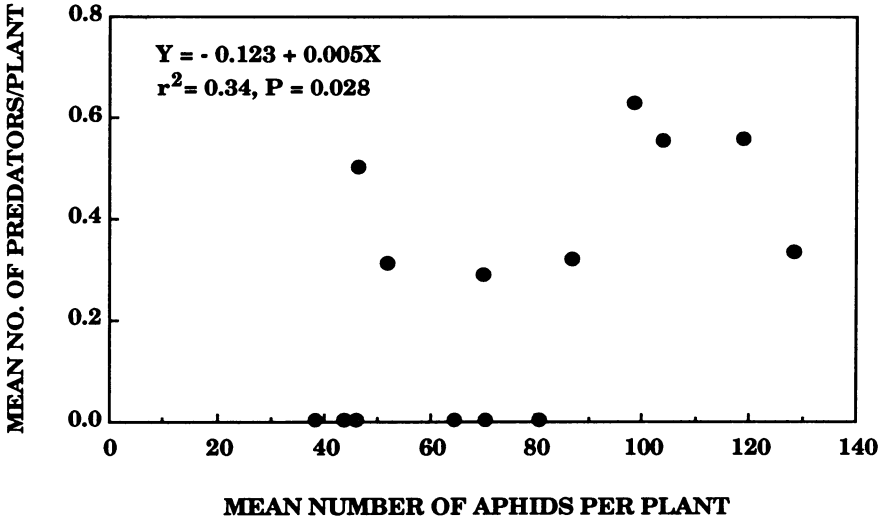


Fig. 17. Relationship between mean number of predators (eggs + larvae) and mean number of *M. kinseyi* per infested, first-year seedling in the ecology plot during 1989.

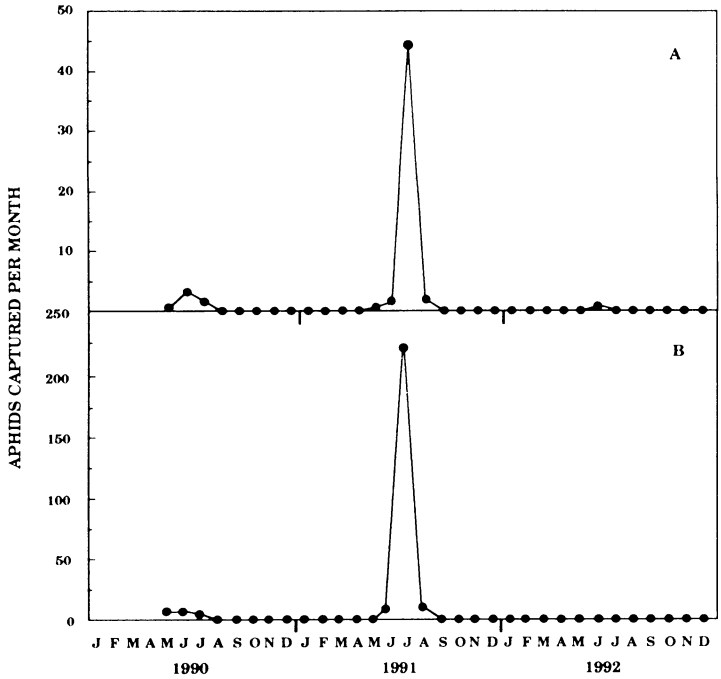
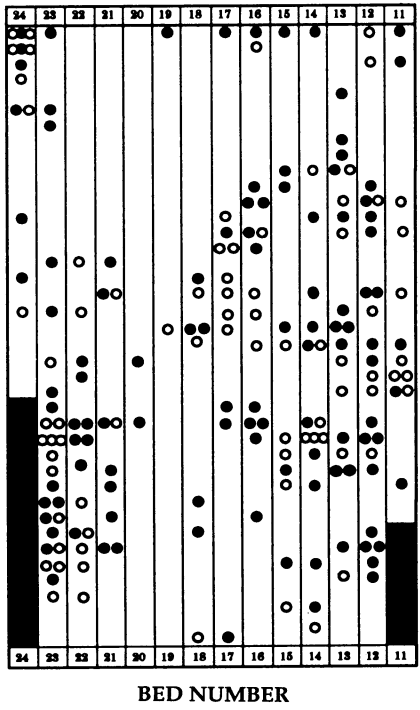


Fig. 18. Number of *M. kinseyi* captured in the aerial suction trap at the Placerville Nursery (A) and the Institute of Forest Genetics (B) during 1990-92 (each point represents total number captured per month).



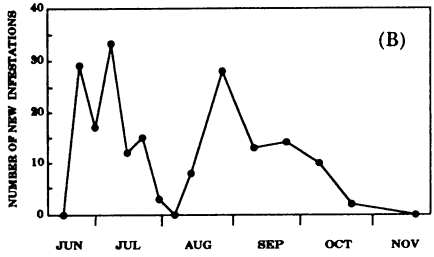


Fig. 19. Approximate spatial distribution of infestation sites within a field of first-year, white-fir seedlings during 1992 (A), left, and number of newly-infested sites over the growing season (B), above. Closed circles in A indicate infestations first detected from June 11 to August 6; open circles indicate patches first detected from August 14 to November 8. Shaded portions in A were not planted to white fir.

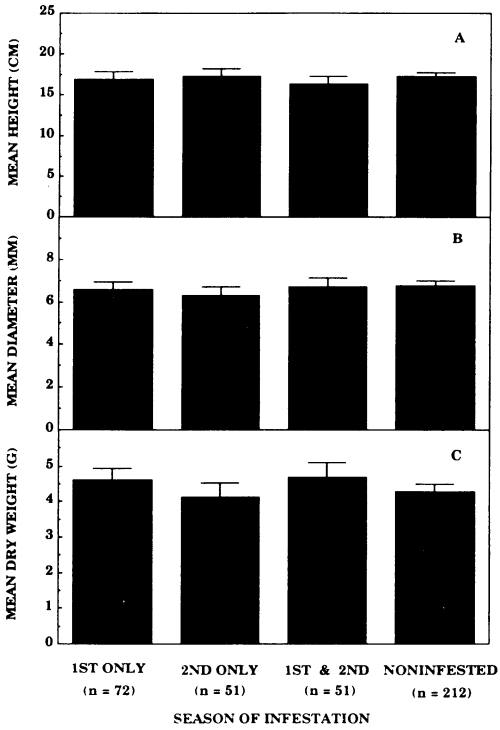


Fig. 20. Relationship between mean (SEM) height, stem diameter, and dry weight of marked seedlings at harvest, and the season in which the indicated seedlings were infested by *M. kinseyi*. Results for one-way analysis of variance with df = 3, 384: (A) F = 0.25, P = 0.86; (B) F = 0.32, P = 0.81; (C) F = 0.54, P = 0.65.

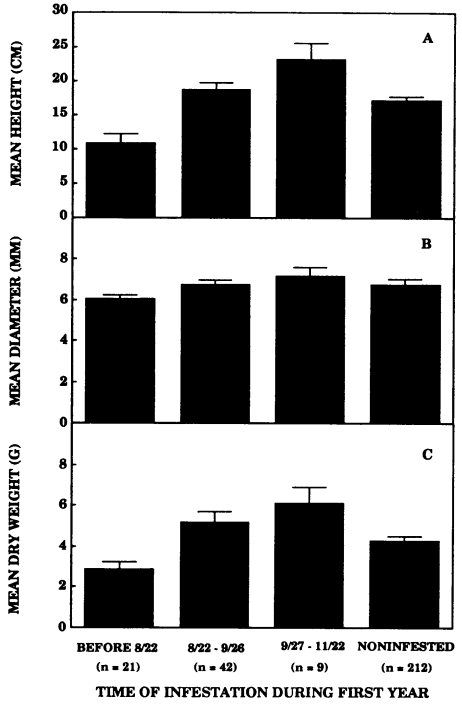


Fig. 21. Relationship between mean (SEM) height, stem diameter, and dry weight for marked seedlings at harvest, and the time of infestation for seedlings infested by *M. kinseyi* only during the first season. Results for one-way analysis of variance with df = 3, 280: (A) F = 8.88, P = 0.0001, significant comparisons for (Before 8/22) vs. (8/22-9/26), (9/27-11/22), & noninfested, and for (9/27-11/22) vs. (8/22-9/26) & noninfested (Duncan's Multiple Range Test, P = 0.05); (B) F = 0.31, P = 0.81; (C) F = 4.0, P = 0.008, significant comparisons for (Before 8/22) vs. (8/22-9/26) & (9/27-11/22) (Duncan's Multiple Range Test, P = 0.05).

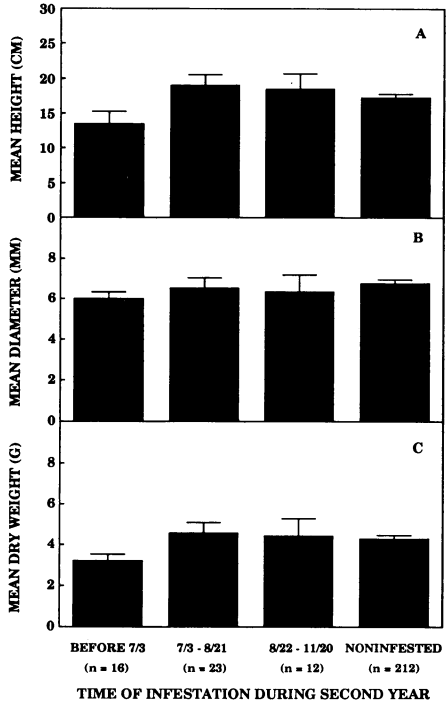


Fig. 22. Relationship between mean (SEM) height, stem diameter, and dry weight of marked seedlings at harvest, and time of infestation for seedlings infested by *M. kinseyi* only during the second season. Results for one-way analysis of variance with df = 3, 259: (A) F = 2.06, P = 0.11; (B) F = 0.25, P = 0.86; (C) F = 0.80, P = 0.49.

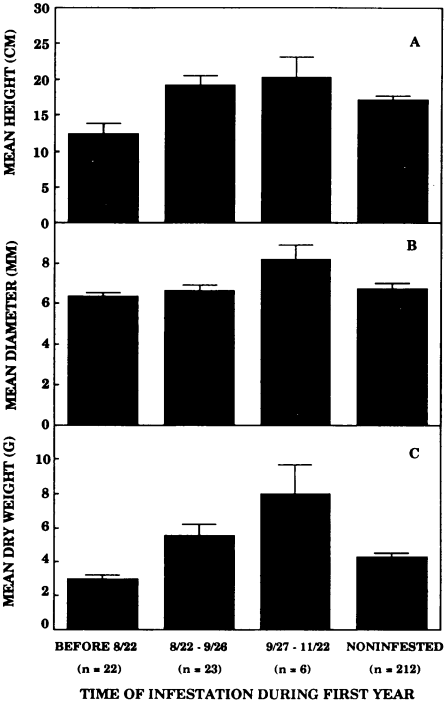


Fig. 23. Relationship between mean (SEM) height, stem diameter, and dry weight of marked seedlings at harvest, and time of infestation during the first year for seedlings infested by *M. kinseyi* during both the first and second seasons. Results for one-way analysis of variance with df = 3, 260: (A) F = 4.62, P = 0.004, significant comparisons between (Before 8/22) vs. (8/22-9/26) & (9/27-11/22) (Duncan's Multiple Range Test, P = 0.05); (B) F = 0.41, P = 0.75; (C) F = 6.05, P = 0.0005, significant comparisons as in A, plus (9/27-11/22) vs. (8/22-9/26) & noninfested (Duncan's Multiple Range Test, P = 0.05).

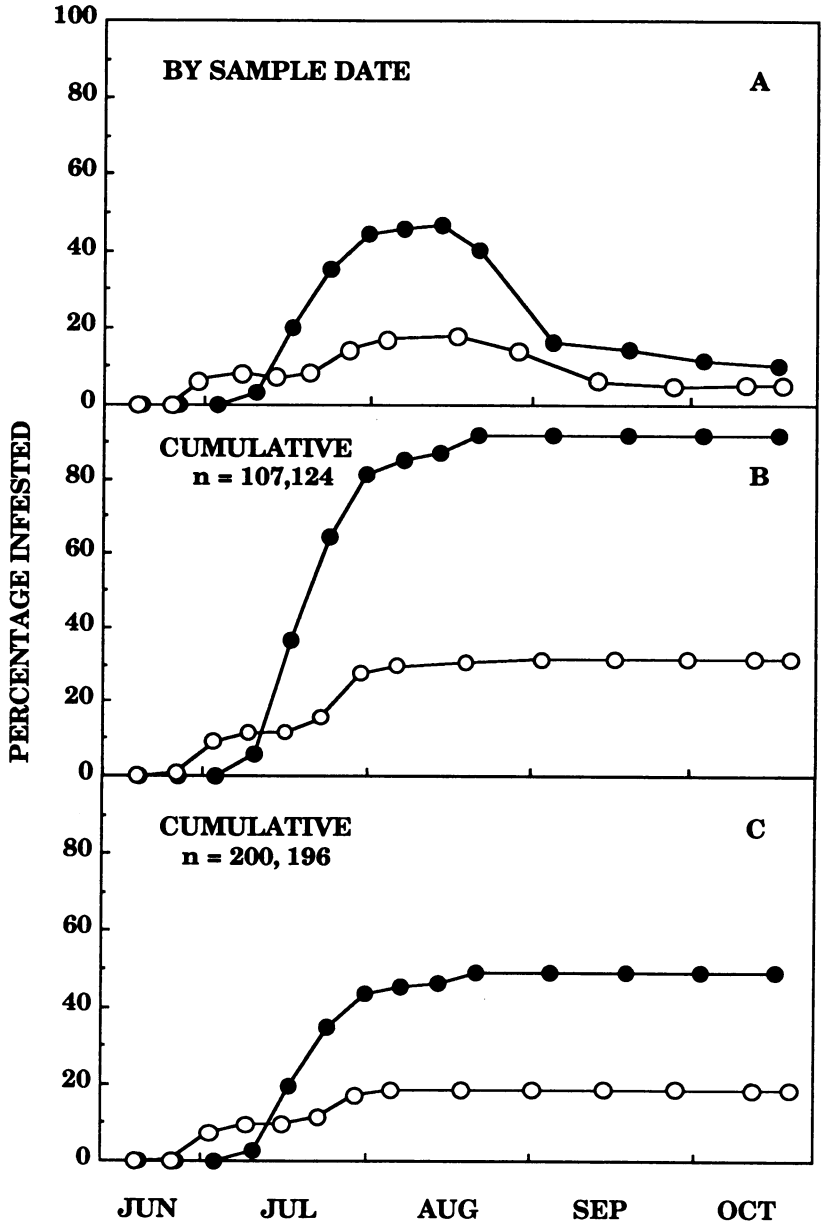


Fig. 24. Percentage of marked, transplanted seedlings infested with *M. kinseyi* at the Eldorado (solid points) and Stanislaus (open points) outplantings on a given sample date in 1991 (A) versus cumulative percentages infested based on either the number of seedlings that survived the season (B) or were marked at the beginning of the season (C). Sample sizes refer to Eldorado and Stanislaus, respectively.

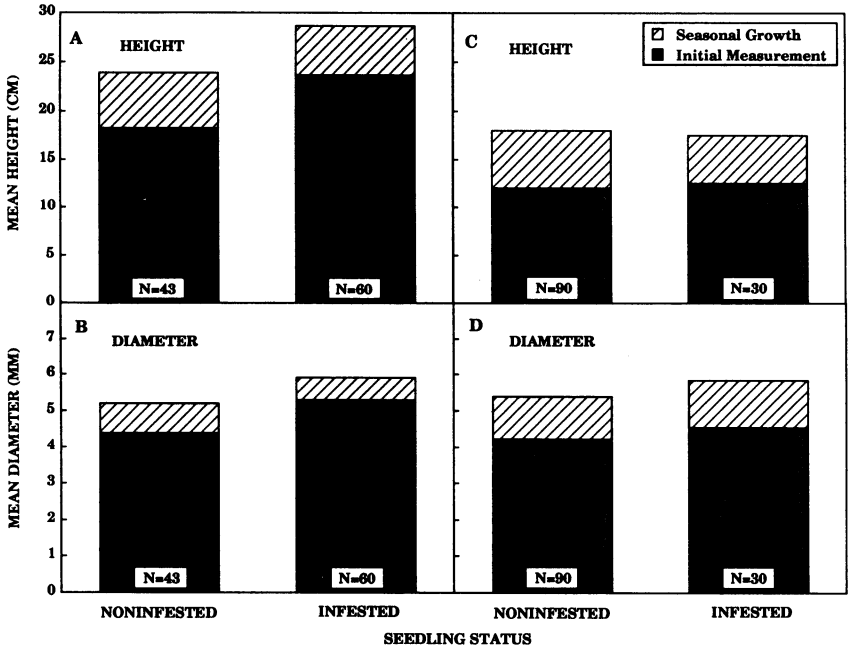


Fig. 25. Relationship between seasonal increase in mean height & stem diameter and infestation status of transplanted seedlings during 1991 at the Eldorado (A, B) and Stanislaus (C, D) outplantings. Results for one-way analysis of variance: (A) F = 13.5, P = 0.004 for initial measurements, F = 9.58, P = 0.003 for final measurements, and F = 2.12, P = 0.15 for seasonal growth (d.f. = 1, 101); (B) F = 16.42, P = 0.0001 for initial measurements, F = 8.31, P = 0.005 for final measurements, and F = 2.25, P = 0.14 for seasonal growth (d.f. = 1, 101); (C) F = 0.73, P = 0.39 for initial measurements, F = 0.4, P = 0.53 for final measurements, and F = 2.88, P = 0.09 for seasonal growth (d.f. = 1, 118); (D) F = 4.16, P = 0.04 for initial measurements, F = 4.11, P = 0.04 for final measurements, and F = 0.442, P = 0.51 for seasonal growth (d.f. = 1, 118).

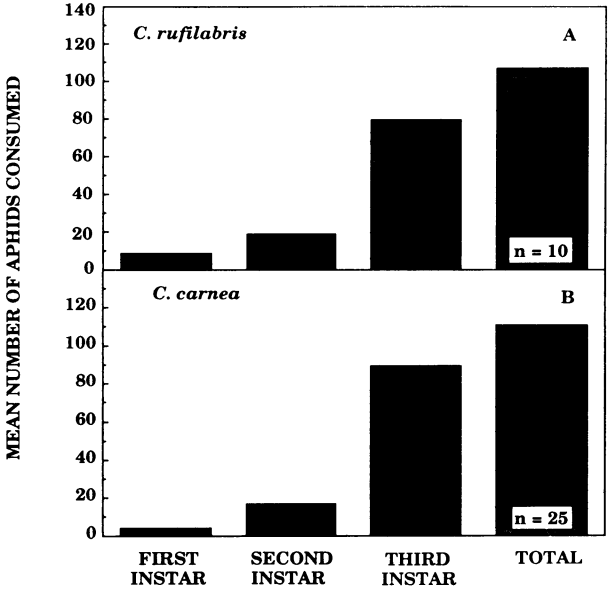


Fig. 26. Mean number of *M. kinseyi* eaten per larva of two species of lacewing, *C. rufilabris* (A) and *C. carnea* (B), during their development in the laboratory.

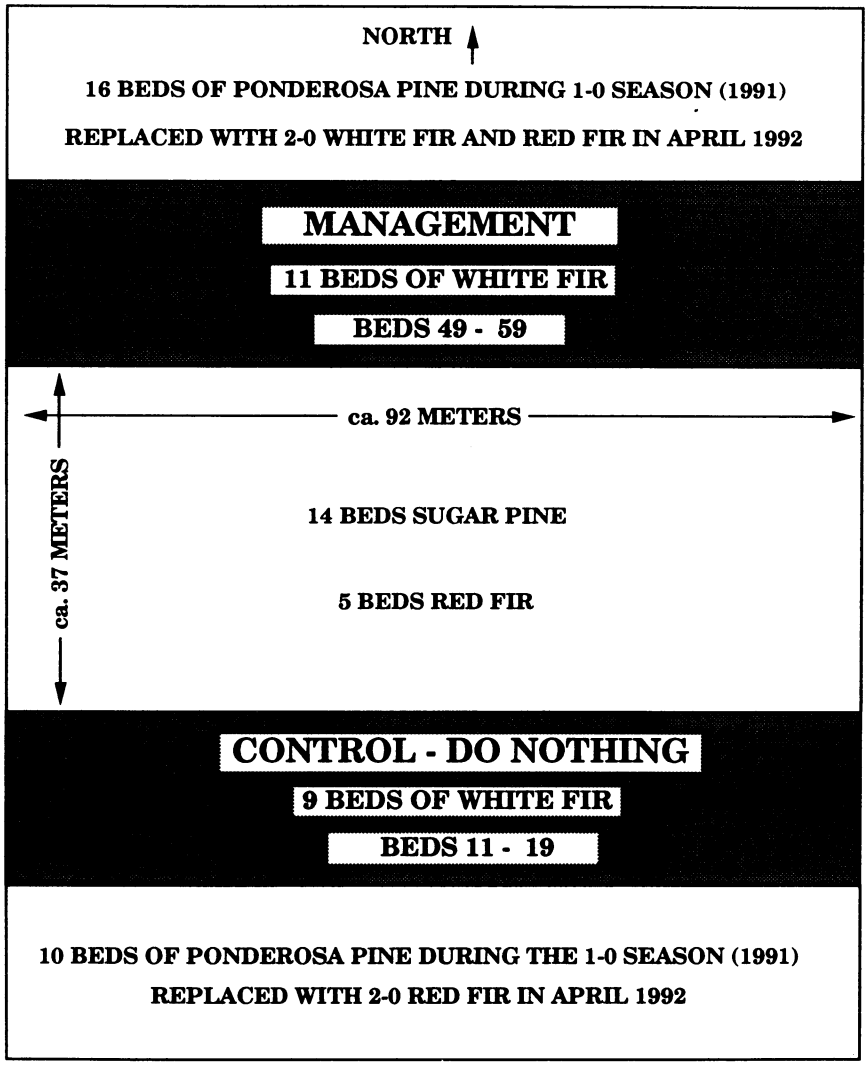


Fig. 27. Plot map for the management demonstration at the Placerville Nursery.

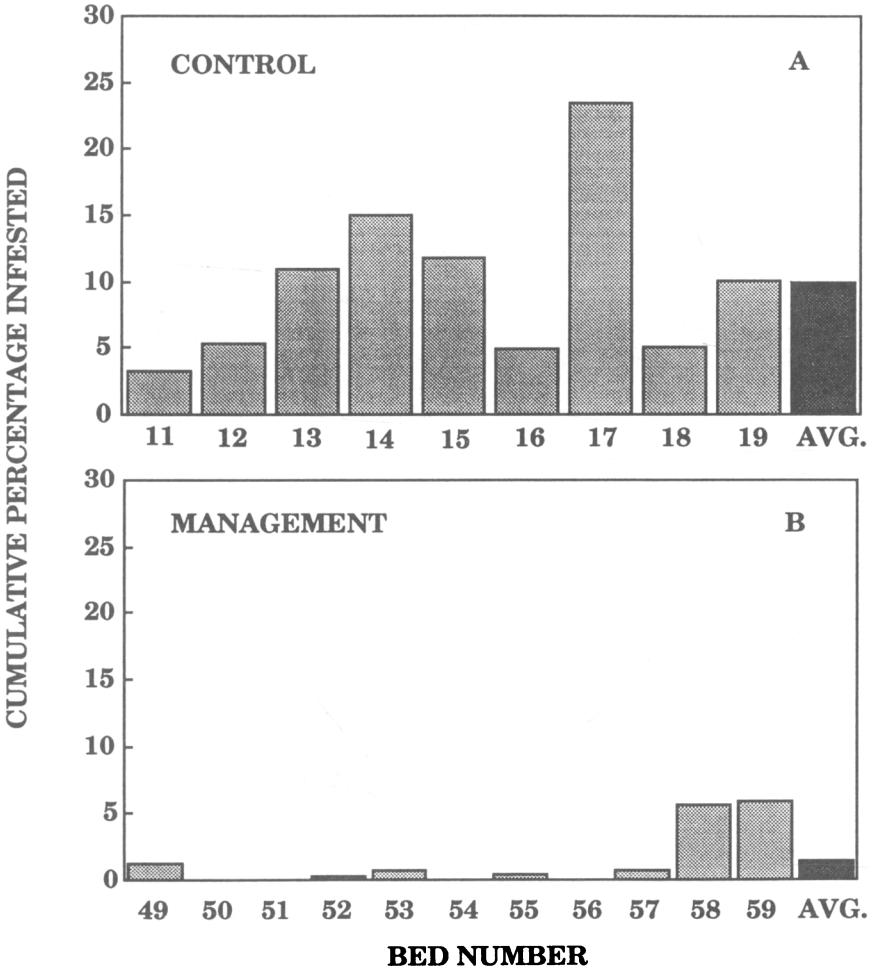


Fig. 28. Cumulative percentage of first-year seedlings infested by *M. kinseyi* in the control (A) and management (B) plots as of October 2, 1991. (Sample size = 432 seedlings per full bed; total of 3888 for A, 4248 for B).

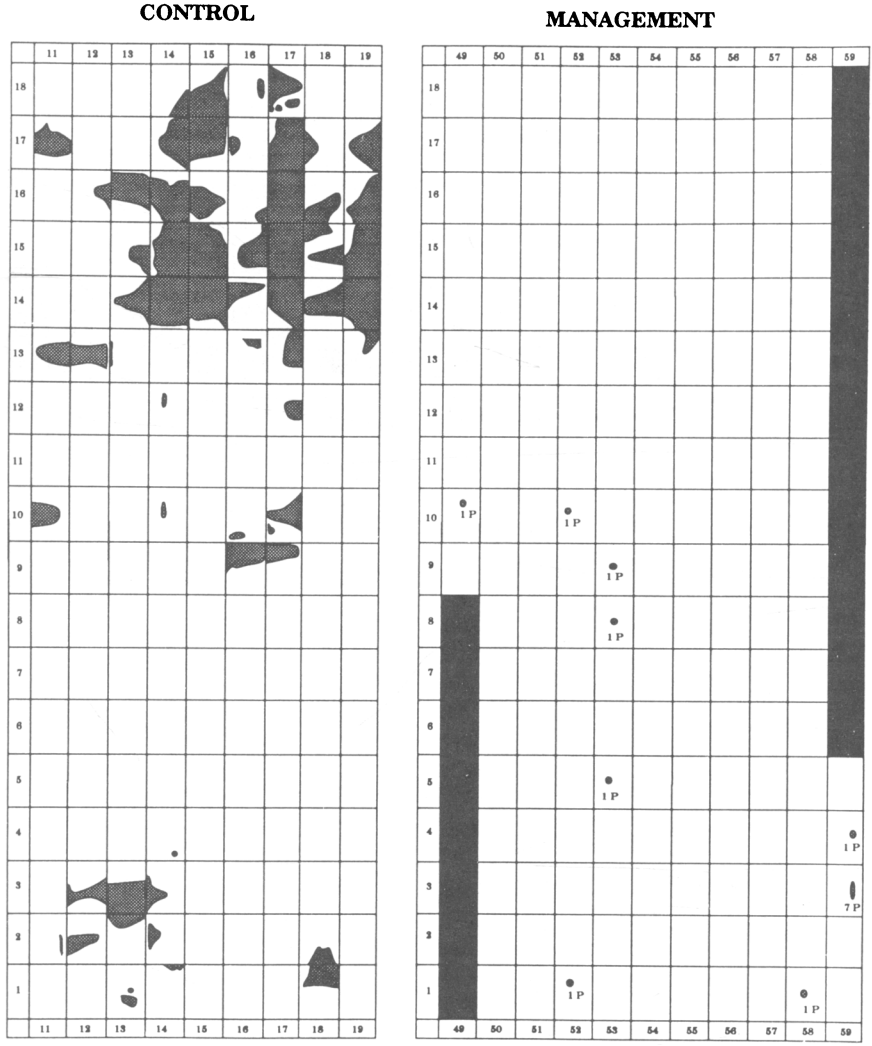


Fig. 29. Approximate spatial distribution of infested patches of first-year seedlings in the management demonstration as of October 11, 1991. Blackened area in management plot was not planted to white fir. (P = number of plants infested in management plot; single, infested plants not detected in control plot.)

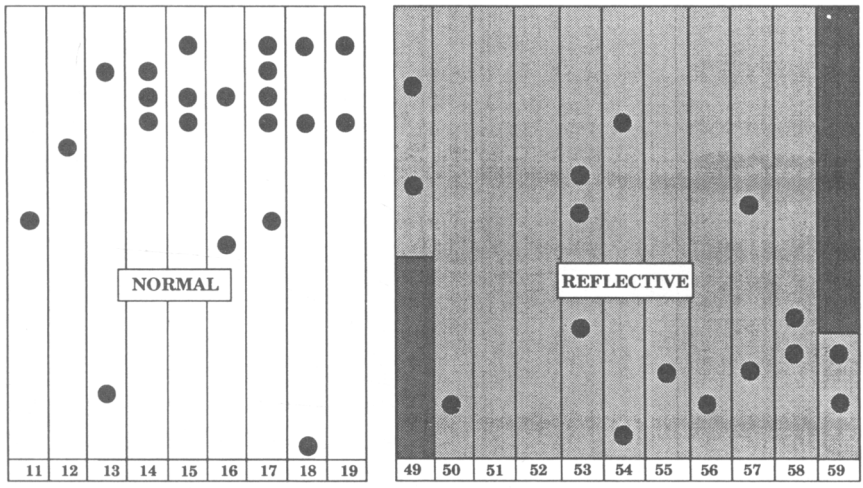


Fig. 30. Approximate spatial distribution of new infestations of *M. kinseyi* among first-year seedlings in the management demonstration during the aphid flight period in 1991 for the control (normal) and management (reflective) plots.

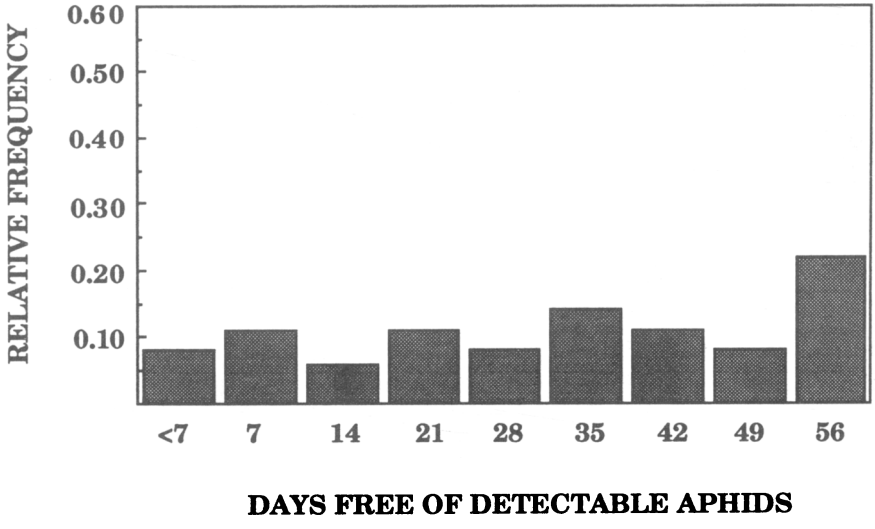


Fig. 31. Relative frequency of reinfestation by *M. kinseyi* in patches of first-year seedlings previously treated with prefed larvae of *C. rufilabris* (n = 36) in the management plot during 1991.

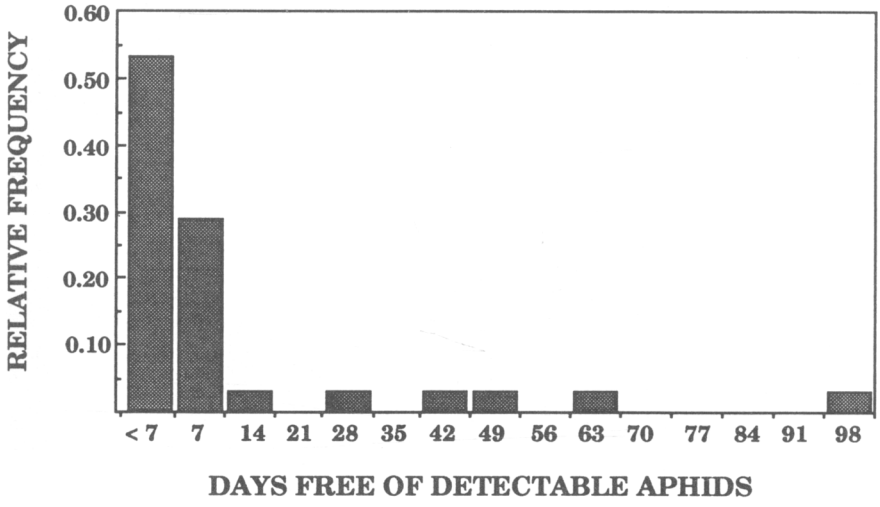


Fig. 32. Relative frequency of reinfestation by *M. kinseyi* in patches of first-year seedlings previously treated with Safer® insecticidal soap (n = 34) in the management plot during 1991.

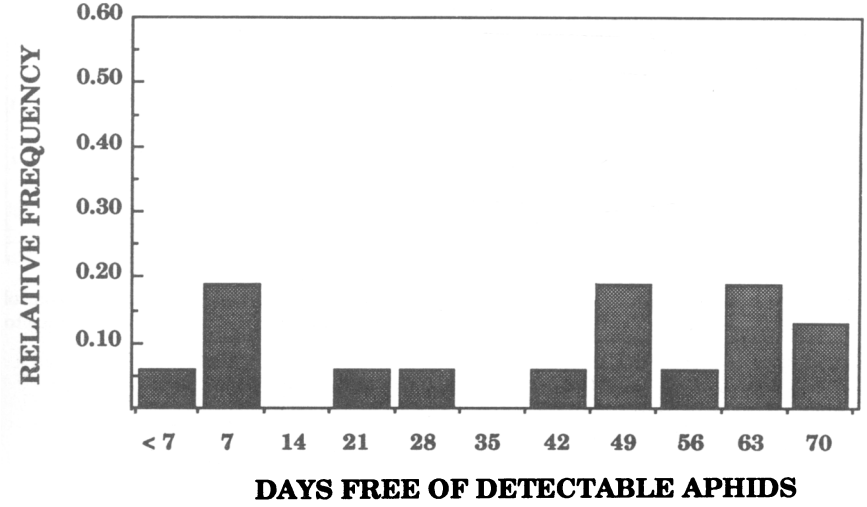


Fig. 33. Relative frequency of reinfestation by *M. kinseyi* in patches of first-year seedlings previously treated with Safer® insecticidal soap plus prefed larvae of *C. rufilabris* (n = 16) in the management plot during 1991.

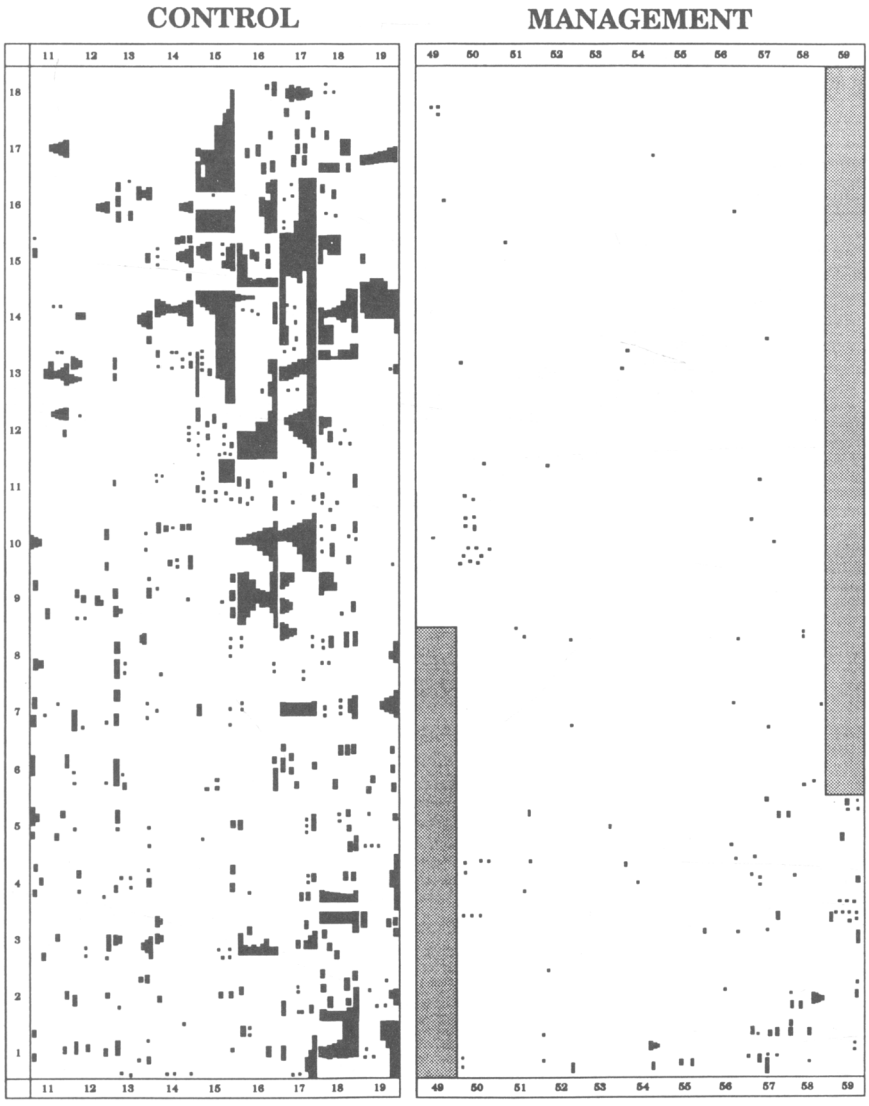


Fig. 34. Approximate spatial distribution of aphid-damaged second-year seedlings in the control and management plots on August 26, 1992. Shaded area in management plot was not planted to white fir.

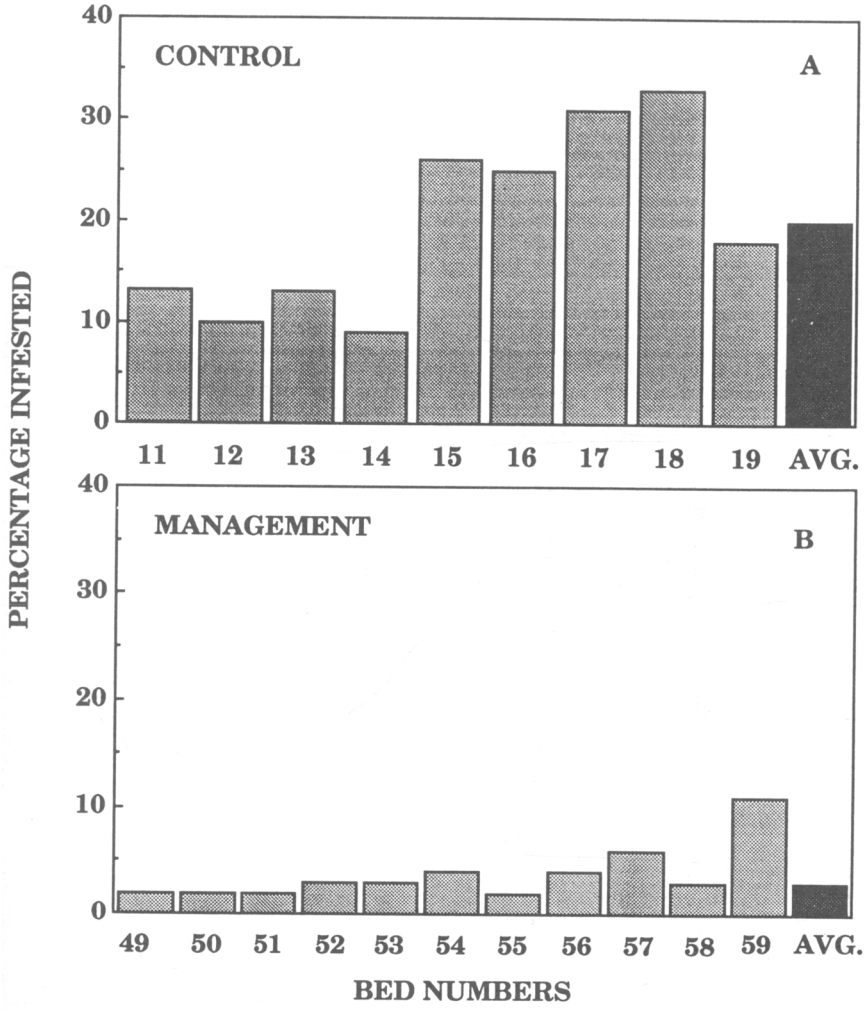


Fig. 35. Percentage of second-year seedlings that showed evidence of aphid infestation (from both seasons) in the control (A) and management (B) plots on September 9, 1992. (Sample size = 720 seedlings per full bed; total of 6480 in A, 7080 in B.)

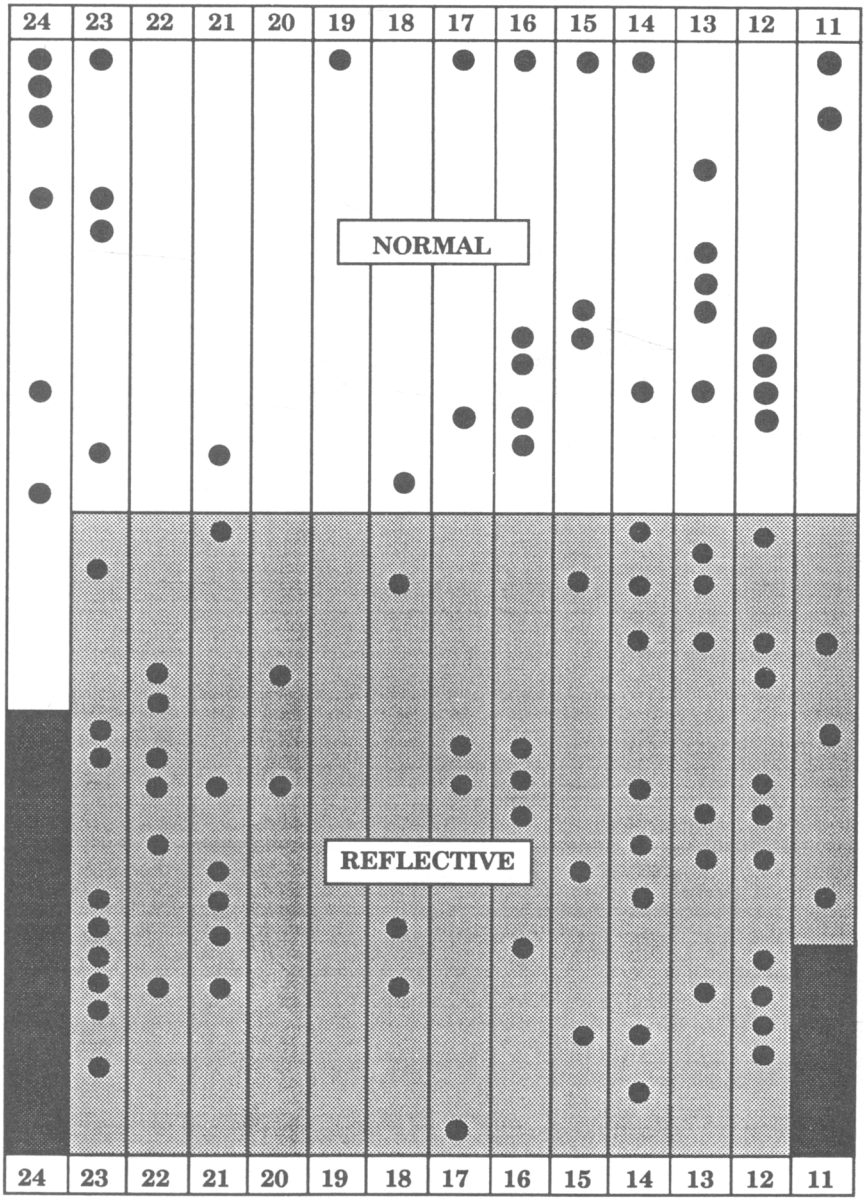


Fig. 36. Approximate spatial distribution of infested patches of first-year seedlings in the white-fir planting during 1992 in relation to normal vs. reflective lath shading. Heavily shaded portions of the latter were not planted to white fir.

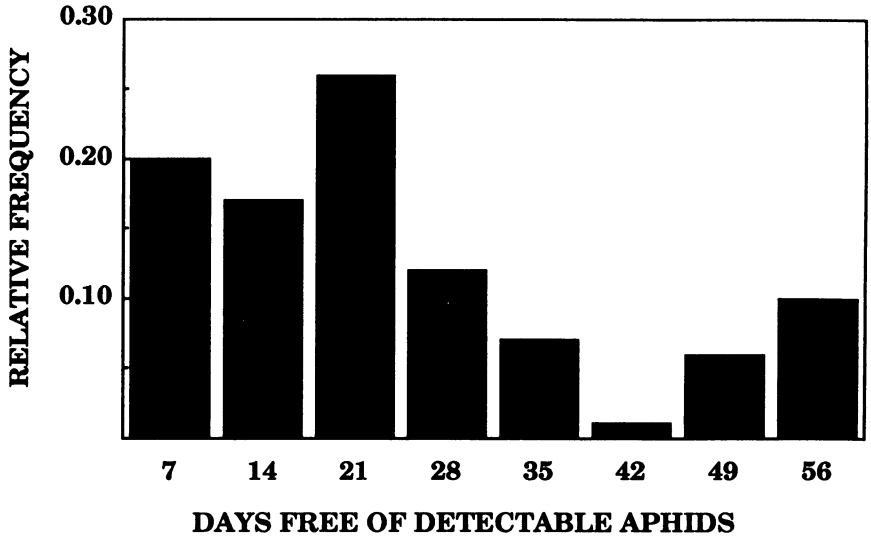


Fig. 37. Relative frequency of reinfestation by *M. kinseyi* in patches of first-year seedlings previously treated with prefed larvae of *C. rufilabris* (n = 69) during 1992.

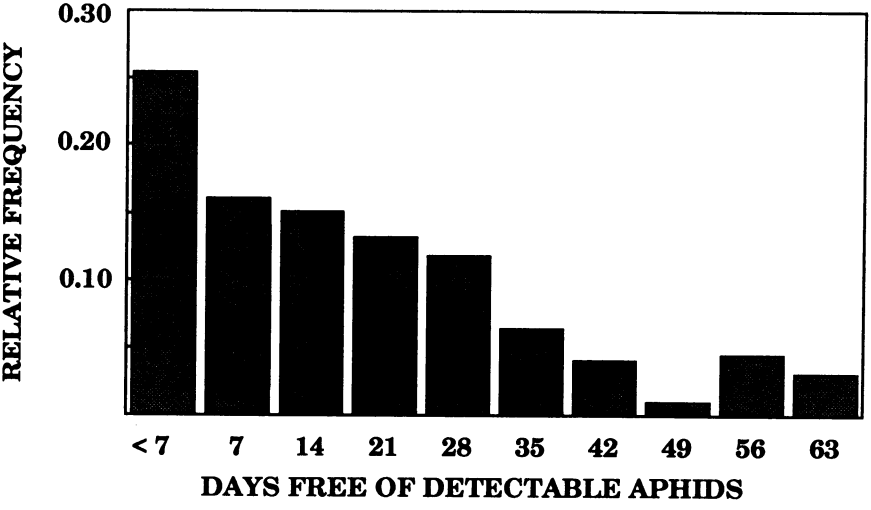


Fig. 38. Relative frequency of reinfestation by *M. kinseyi* in patches of first-year seedlings previously treated with Safer® insecticidal soap (n = 205) during 1992.

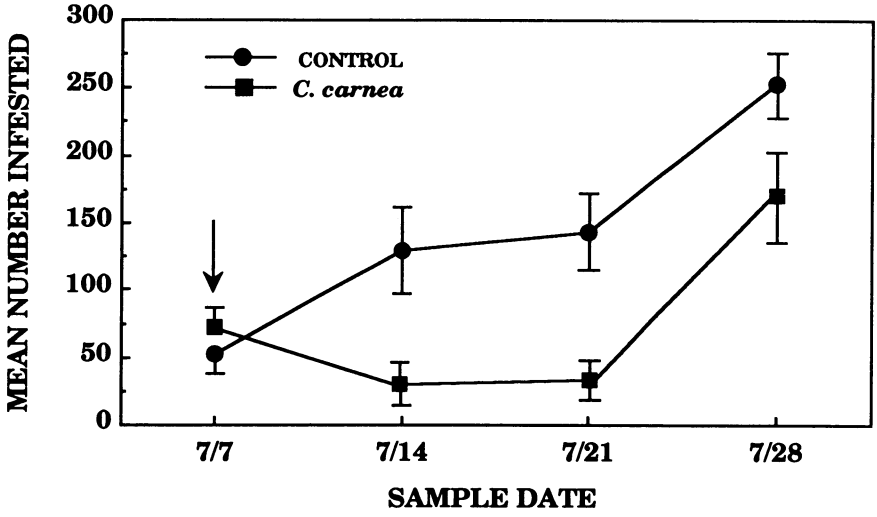


Fig. 39. Mean (SEM) number of seedlings infested by *M. kinseyi* in control and lacewing release plots. Arrow indicates date of the release of prefed larvae of *C. carnea*. Results for paired "t" test with d.f. = 18: 7/7, t = 1.31, P = 0.21; 7/14, t = 5.51, P = 0.0001; 7/21, t = 5.28, P = 0.0001; 7/28, t = 2.94, P = 0.009.

Continued from inside front cover

seedlings at harvest were not significantly reduced by aphid infestation. However, for marked seedlings infested early during the first season, both final height and dry weight were significantly reduced. Thus, aphid infestations can have a significant impact on growth of seedlings, but this does not necessarily lead to an increase in cull-rate at harvest. However, aphid caused mortality of first-year seedlings must also be considered. Additional seedlings were monitored at outplantings in the Eldorado and Stanislaus National Forests during 1991 and 1992. Seedlings were infested with aphids during the first year; however, seedling mortality was independent of aphid infestation during the season.

A management program for *M. kinseyi* was developed and evaluated at the nursery. The program was based on careful monitoring, particularly during the aphid flight season, and spot treatment with compatible suppressive measures. The use of reflective lath fencing (placed horizontally over first-year seedlings) was not effective in reducing alate colonization. Larvae of the lacewings *Chrysoperla carnea* (Stephens) and *C. rufilabris* (Burmeister) were released in infested patches and provided good aphid suppression in most cases. Safer® insecticidal soap was also successfully employed as a spot treatment. In a management demonstration, about 10% of the first-year seedlings in the control group (without treatment) were infested by the end of the season compared to only about 1% in the management plot; all infestations in the latter were treated with either larvae of *C. rufilabris,* Safer® soap, or both. During the second season, all infested patches in the management plot were treated with Safer® soap; by the end of the season, about 20% of the seedlings in the control showed aphid damage compared to approximately 3% in the management plot. At harvest, the cull rate for both plots was relatively high, but independent of aphid infestation. The management program was evaluated again in 1992 with similar results. The pest status of *M. kinseyi* should be evaluated on a case-by-case basis and the management program implemented as needed. The primary aphid-suppression tactics (soap sprays, lacewing larvae) that were effective in a nursery setting could also be employed against *M. kinseyi* at Christmas-tree farms.

READER PLEASE NOTE:

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