AN ABSTRACT OF THE THESIS OF

James D. Calkin for the degree of Master of Science in Entomology presented on February 20, 1991.

Title: Distribution of *Oligonychus (Oligonychus) ununguis* (Jacobi) (Acari: Tetranychidae) and Predator Mite Species (Acari: Phytoseiidae) on Field-Grown Douglas-Fir (*Pseudotsuga menziesii* [Mirb.] Franco) Christmas Trees

Abstract approved: Redacted for Privacy

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The shake and wash technique (samples placed in a jar with alcohol added and shaken to remove the mites) was effective in removing 100% of the predator mites, and adult spruce spider mites from Douglas-fir foliage and 98% of the spruce spider mite nymphs. Eighty-eight percent of the spruce spider mite eggs was removed. This technique was considered efficient for removal of spruce spider mite and its predators from Douglas-fir foliage. Sodium hypochlorite (0.84%) added to the alcohol did not increase the number of spruce spider mites or phytoseiid mites removed from the foliage.

The intracanopy distribution of spruce spider mite and its predator mites was studied on Douglas-fir Christmas trees in the Willamette Valley, Oregon. When overwintering spruce spider mite egg densities populations were low (<5 eggs/19 cm of stem), significantly more eggs were found on the current season's growth. No significant differences were found between top and bottom halves of the tree or between compass directions.

Differences between current and previous season's growth were not found when egg densities were high (>40 eggs/19 cm of stem), but significant differences were found between levels for current season's growth with more eggs found in the upper portion of the canopy. Quadri-directional differences did not exist with either low or high mite populations. Sampling tip or basal stem-halves with low overwintering egg populations did not bias population estimates.

Heavy spring rainfall appeared to reduce mite populations as has been reported elsewhere by washing them off the tree and causing increased mortality. Spruce spider mite disperse to the current season's growth shortly after budbreak. Population density rapidly increased in late May and then abruptly declined in mid-July.

Distribution of *Oligonychus* (*Oligonychus*) *ununguis* (Jacobi)

(Acari: Tetranychidae) and Predator Mite Species (Acari: Phytoseiidae) on Field-Grown

Douglas-Fir (*Pseudotsuga menziesii* [Mirb] Franco) Christmas Trees

by

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DISTRIBUTION OF *OLIGONYCHUS* (*OLIGONYCHUS*) *UNUNGUIS* (JACOBI) (ACARI: TETRANYCHIDAE) AND PREDATOR MITE SPECIES (ACARI: PHYTOSEIIDAE) ON FIELD-GROWN DOUGLAS-FIR (*PSEUDOTSUGA MENZIESII* [MIRB.] FRANCO) CHRISTMAS TREES

Introduction

Oligonychus ununguis (Jacobi), the spruce spider mite, was first described in 1905 on spruce in Germany (Jacobi 1905). Since then, it has been recorded on hemlock, noble fir, grand fir, arborvitae, juniper, larch, redwood, yew, cypress, false cypress, incense cedar, pine, and chestnut (Charlet & McMurtry 1977, Loyttyniemi 1970, Reeves 1963, Gotoh T. 1984, Johnson & Lyon 1988). Spruce spider mite is considered to be the most important phytophagous mite on conifers world-wide (Boyne & Hain 1983a, Furniss & Carolin 1977, Johnson & Lyon 1988).

Spruce spider mite was reported heavily infesting mature Douglas-fir trees in Wyoming in 1929 (Johnson 1958). This was the first record of Douglas-fir as a host. Subsequent infestations were reported in Montana in 1957 in areas treated with insecticides for other pest problems (Johnson 1958). The insecticide used may have eliminated the natural enemies of spruce spider mite allowing it to increase unchecked. Spruce spider mite was recorded on Douglas-fir Christmas trees in British Columbia, Alberta and in the western United States, but not at pest levels in 1958 (Johnson 1958). Since then it has been identified on most conifers grown commercially.

Included in its host range are most tree species grown for commercial Christmas tree production in the United States (Boyne & Hain 1983a, Antonelli 1980, Johnson 1958, Miller

& Roach 1977). In the Pacific Northwest, Douglas-fir accounts for approximately 70% of the commercial Christmas tree acreage (Popenoe & Malone 1989). Most commercial growers of Douglas-fir Christmas trees in Washington and the Willamette Valley of western Oregon consider spruce spider mite to be the key pest in their plantations (Antonelli 1980, Regan 1989).

Natural enemies associated with this mite have been recorded and studied (Loyttyniemi 1970, Helle & Sabelis 1985b). Phytoseiid (Acari: Phytoseiidae) mites are considered important predators of phytophagous mites and certain species are associated with spruce spider mite (Chant 1959). *Typhlodromus* species are the most common predators of *O. ununguis* (Johnson 1958, Fellin 1968). However, species in other genera are also associated with this mite. Preliminary field observations of several Fraser fir plantations showed a decline in *O. ununguis* (Jacobi) infestations with a sharp increase in the phytoseiid predator, *Neoseiulus fallacius* (Garman) (Boyne & Hain 1983b). A survey of major Willamette Valley crops found only *Amblyseius andersoni* (Chant) on Christmas trees. *Typhlodromus pyri* (Scheuten), *T. occidentalis* (Nesbitt) and *A. andersoni* (Chant) were common on other crops surveyed in the region (Hadam et al. 1986).

The objectives of this study were two-fold. The first was to develop a simple, economic and efficient sampling technique to obtain population estimates for spruce spider mite and its acarine predators on plantation grown Douglas-fir Christmas trees. The second was to characterize the within-tree distribution of all life stages of spruce spider mite and its phytoseiid predators throughout the growing season.

Literature Review

Spruce spider mite. Spruce spider mite has been described in the literature under several synonyms and is presently known as *Oligonychus ununguis* (Jacobi) (Jeppson et al. 1975). Its life history has been studied by numerous authors (Johnson 1958, Loyttyniemi 1970, Jeppson et al. 1975). Spruce spider mites overwinter as bright orange to reddish eggs at the bases of needles and on rough surfaces or protected areas of twigs (fig. 1). Eggs usually begin hatching in early April. Development (fig. 2) proceeds through three immature stages to an adult in 5 to 23 days depending on environmental conditions. An adult female lays an average of 25 eggs at the rate of 2 to 3 eggs per day during her lifetime. Sixty to eighty percent of the eggs hatch into females (Jeppson et al. 1975). As many as seven overlapping generations are produced each summer with all stages usually present at any time.

Optimal average temperature for population growth is approximately 26°C (Boyne & Hain 1983). High temperatures may reduce egg survival and initiate a summer diapause during which time population growth slows or even declines. In the Pacific Northwest, feeding and reproduction may continue through the summer into early fall. Overwintering eggs are laid during the fall. Spruce spider mite populations are usually highest in the spring and fall (Regan 1990).

Silken threads are produced by mites and are used to fasten eggs to the surfaces and to help mites maintain contact with the substrate. Dispersal of mites from a localized infestation on a tree is very slow. As populations increase and overcrowding occurs, mites disperse by ballooning on silken threads during windy periods.

Climatic and physical factors may affect the within-tree distribution of spruce spider mite. Several days of rainy weather during the spring or fall was detrimental to the population growth of spruce spider mite on Fraser fir (Ryle 1925). A laboratory study simulating heavy rainfall (2.54 cm/30-40 min. application time) on Fraser fir showed a reduction in all spruce spider mite stages compared to the control (Boyne & Hain 1983a). Rainfall may temporarily alter the within-tree distribution of spruce spider mite by washing mites off of the plants. Eggs, resistant to the adverse effects of rain, may provide a

Figure 1. Shoot of Douglas-fir showing overwintering eggs (A) and hatched eggs (B).

A

Needles cut
for observation

B
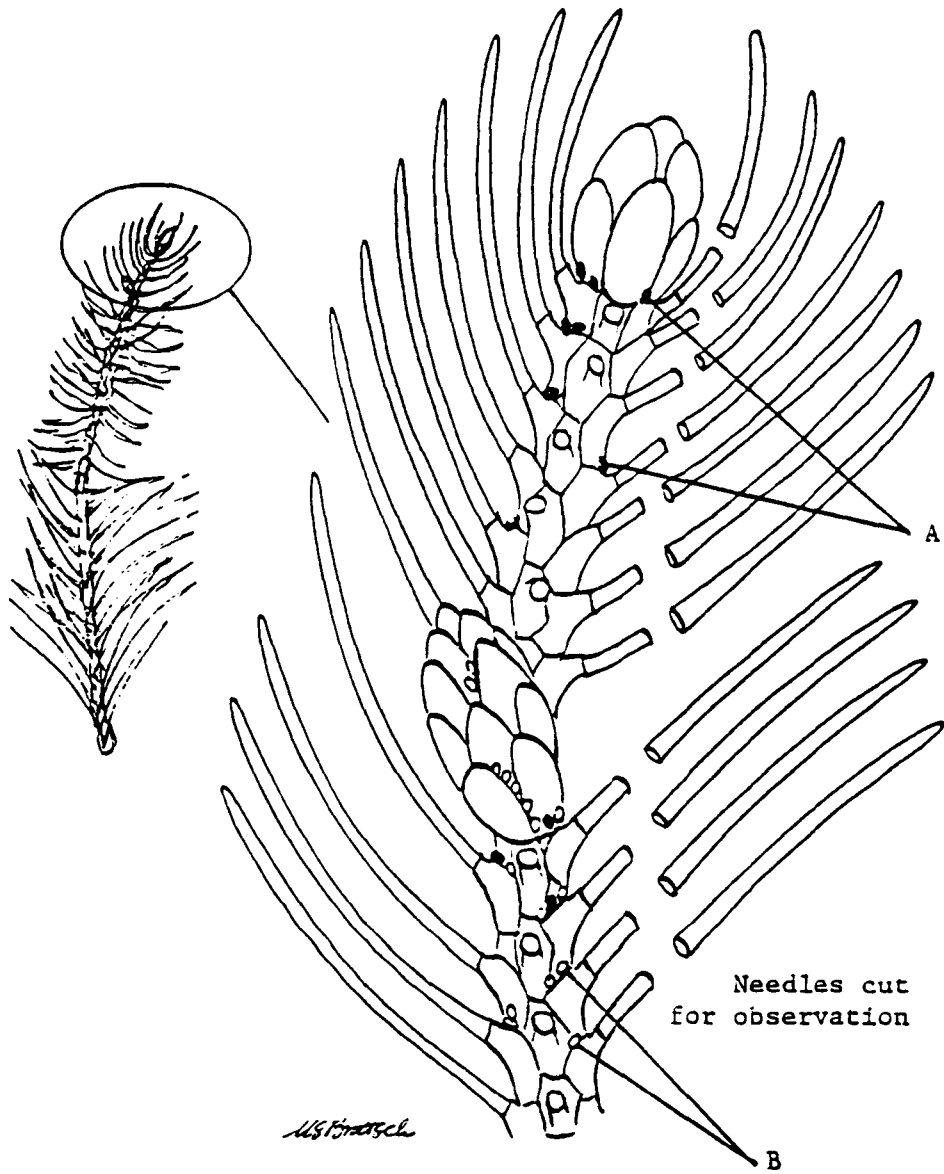
Figure 2. Annual development of Douglas-fir Christmas trees and spruce spider mite (*Oligonychus ununguis*) life cycle.

	Douglas-fir
Dormancy	
Bud Break	
New Growth	
Lammas Growth	
	Spruce spider mite
Adults	
Immatures	
Overwintering Eggs Laid	
Overwintering Eggs Hatch	

J F M A M J J A S O N D
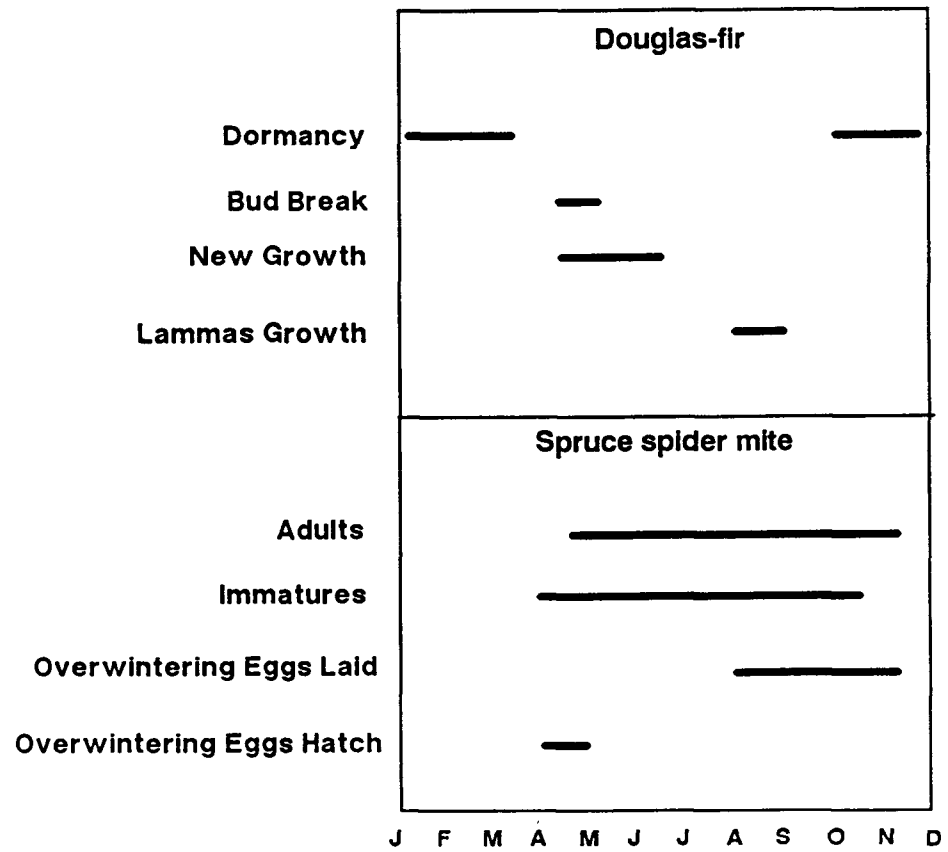
reservoir from which mite populations may recover (Boyne & Hain 1983a).

Dust on the foliage and stems may be associated with the build-up of some spider mite species because of effects on predator mite development (Antonelli 1980). However, not all researchers are in agreement as to the effects of dust on mite populations. The presence of road dust and other inert material on the foliage has been reported to provide sites for egg laying and web attachment for some spider mite species, but had no effect on other species (DeBach 1947, Hazan et al. 1974). Several researchers have demonstrated that predation is inhibited by road dust (Jeppson et al. 1975) while other studies reported no inhibition (DeBach 1947, Oi & Barnes 1989). It has been suggested that population differences may be due to species preference, differences in plant structure, or higher temperatures and water stress of roadside trees rather than effect of dust (Oi & Barnes 1989).

All motile spruce spider mite stages feed on needles. Stylets are inserted into the epidermal and palisade cells of needles and cell contents are removed. Mites feed on individual cells rapidly moving from one cell to another. As feeding continues, needles become chlorotic or stippled, eventually turning brown. Severe infestations cause needle drop and may result in death of the tree (Boyne & Hain 1983a). Damage from mite feeding is mainly aesthetic, reducing the value of the Christmas trees.

As mite populations establish in the spring, feeding is concentrated at the base of needles. As populations increase, mites feed nearer to needle tips with stippling extending over the entire needle. Damage on large trees is first observed in the lower portions of the canopy and progresses upward as the population increases. Damage on small trees has a similar progression, but spreads over the entire canopy more quickly.

Distribution. Very little research has been done on the spatial distribution of arthropods on Christmas trees, and no research has been conducted on spruce spider mite on Douglas-fir Christmas trees. Studies on chestnut and coniferous trees concluded that the most important factors initiating migration of *O. ununguis* were overcrowding and deterioration of the food source (Akita 1971, Wanibuchi & Saito 1983). A distributional study of *O. ununguis* and its

predators on Fraser fir found more mites in the upper portion of the crown than in the lower portion, but with no significant differences in directional aspect (Hain & Nettleton 1974). Also, mites migrated to current year's foliage as it developed, resulting in a distribution skewed towards the new terminal growth. Sampling a 5 inch (12.7 cm) terminal section of current year's growth was considered adequate to detect population fluctuations on Fraser fir (Hain & Nettleton 1974).

The spatial distribution of mites on peaches and almonds is determined to some extent by the character of surface of the bark, especially the degree of roughness (Summers & Baker 1952). On young peach or almond trees, *Bryobia praetiosa* Koch does not congregate in masses on the smooth-textured bark. Populations are higher on convoluted or undulated bark at the bases of leafy shoots and lateral stems (Summers & Baker 1952). In another distribution study, late summer, fall, and winter infestations of *O. subnudus* (McGregor) on Monterey pine were most abundant near the middle of current year's growth (Koehler & Frankie 1968). In early spring of the following year, as the current season's growth developed, mites migrated to the new needles with the highest densities on the new needles. By midsummer, population densities were again highest near the middle of the stem. Wide variation in population densities between trees was found for *O. subnudus*, but not for its phytoseiid predators, *Typhloseiopsis conspicuus* (Garman) and *T. arboreus* (Chant) (Koehler & Frankie 1968) .

In general, spider-mite infestations usually begin in the lower portion and center of a tree, possibly due to selection of overwintering sites (Tanigoshi et al. 1975, Zalom et al. 1984, Helle & Sabelis 1985a). Mite populations in trees do not vary with compass direction, but may be affected by temperature-dependent growth rates and the distribution of sun exposure over the plant (Flaherty & Huffaker 1970, Herbert & Butler 1973b, Wilson et al. 1984). Other factors, such as host-plant resistance, predation, pesticide application, rainfall and relative humidity may have an effect on the distribution of mites within a tree (Boyne & Hain 1983a, Helle & Sabelis 1985a, Trumble 1985; Holtzer et al. 1988, Braun et al. 1989). A study comparing colonies of *Tetranychus mcdanieli* (McGregor) observed more mites on

younger leaves than on the oldest leaves of apple trees (Tanigoshi et al. 1975).

Comparisons of within and between tree variation of mite numbers on leaves found the within tree variation to be smaller (Daum & Dewey 1960, Herbert & Butler 1973b, Croft et al. 1976, Nachman 1981a). The large between-tree variation of both tetranychid and phytoseiid mite populations may be due to their limited dispersal ability (Croft et al. 1976). A study of *Panonychus ulmi* showed that a predator population that readily disperses can change the within-tree distribution (Croft et al. 1976).

A study on apple trees described a clumped distribution females of *Tetranychus mcdanieli* (McGregor) (Tanigoshi et al. 1975). Early in the growing season the highest initial rate of establishment of *T. mcdanieli* was on the oldest foliage, but these colonies had the lowest density. At the same time, the young foliage had the lowest rate of establishment, but had the highest mean colony density. The population trend was a shift towards the upper canopy. In the absence of predators, intense intraspecific competition occurs resulting in a subsequent population decline. Deviation from this appears to be associated with a downward migration from heavily infested leaves (Tanigoshi et al. 1975).

A study of the distribution of phytophagous and predator mites on apple trees found phytophagous mites to be more numerous in the lower portions of the tree while the reverse was true for the predator mites and their eggs (Herbert & Butler 1973b). It was theorized that, since conventional sprayers distribute the pesticide more effectively in the lower level of the tree than in the upper levels, more predator mites would be found in the upper portion. The reverse may be true in Douglas-fir Christmas trees. Most acaricides are aerially applied and penetration of the canopy decreases from top to bottom, thus creating a refugia for phytophagous and predacious mites near the bottom of the canopy.

Egg Distribution. The spatial distribution of overwintering spruce spider mite eggs on Douglas-fir has not been studied, but some research has been conducted on Fraser fir. Spruce spider mite with-in tree distribution was not to be influenced by cardinal direction and oviposition sites are predominately on current year's foliage in the upper portion of the crown (Hain & Nettleton 1974).

A distributional study of European red mite (*Panonychus ulmi*, Koch) on apple demonstrated that most eggs were laid on rough surfaced areas (i.e., budscale scars). The most useful measurement for studying egg distribution was the log of the egg counts and the analysis was based on counts/cm of twig sampled (Gooderwardene & Kwolek 1975).

Predators. The spatial distribution of predatory mites of Douglas-fir Christmas trees has not been previously studied. A survey, however, was conducted of phytoseiid mites occurring on major Willamette Valley crops. *Amblyseius andersoni* (Chant) was the only phytoseiid found on Christmas trees, although *Typhlodromus pyri* (Scheuten), *T. occidentalis* (Nesbitt) and *A. andersoni* (Chant) were common on other crops in the region (Hadam et al. 1986). Unpublished data on phytoseiid mites of Douglas-fir Christmas trees identified *T. pyri* as the most common species. A few *A. andersoni* were found. Recently, specimens of *T. pyri* from these studies were identified by J. A. McMurtry (Prof. of Ent., U.C. Riverside, CA. 1990) as *T. exhilaratus*, a closely related species.

An important aspect of population character is the distribution of predator and prey within their environment. To have maximum effect on its prey, a predator should be present and active in all places inhabited by its prey. Therefore, the distribution of the predator in relation to its prey may influence prey distribution (Chant 1959). Preliminary field observations of several Fraser fir plantations described a decline in *O. ununguis* infestations following an increase in *Neoseiulus fallacis* (Garman) populations (Boyne & Hain 1983b). Laboratory studies with this phytoseiid predator have shown it to be an effective predator of *O. ununguis* on Fraser fir seedlings (Boyne & Hain 1983b). Variability in the effectiveness of a predator influences the between-tree variation of both predator and prey and increases the number of samples necessary to describe this variability (Helle & Sabelis 1985b).

Phytoseiids demonstrate preference for certain parts of their host plants (Gambaro 1988). The distribution of a predator within a tree can be affected by its prey distribution which tends to be clumped. Predators aggregate around patches of high prey density. Initially, predators will spend more time in areas where prey are found with little searching

time (Hassell 1978). A study of the seasonal history of *Typhlodromus pyri* (Scheuten) on apple indicated that the spatial distribution of developmental stages changed during the growing season which was influenced by the spatial distribution of the prey (Zacharda 1989).

Tree phenology and morphometrics. The Douglas-fir Christmas tree consists of a live crown and a central leader or trunk. Whorls of needle-covered branches radiate out from the trunk to form a tapered cone (fig. 3) (Proebsting 1982, Scarlet et al. 1984). The handle is the trunk of the tree below the bottom whorl of branches which extends vertically 10-12 inches (25.4-30.48 cm) above the ground. The crown consists of everything above the handle. Each branch (fig.4) consists of primary (1°), secondary (2°), and tertiary (3°) shoots (Leverenz 1981). In the Willamette Valley, buds usually break in the spring (early April) and new growth is produced until sometime in July. Some trees produce an abnormal second flush of growth late in the season (late August-early September), called lammas growth. The initial new growth and lammas growth until bud break of the following year are referred to as current year's growth. Old or previous year's growth is all growth occurring behind the breaking buds.

Shearing. Under natural conditions in most gymnosperms, the terminal leader elongates more than the lateral branches below it, resulting in a conical tree form (Kramer & Kozlowski 1979a). If apical dominance of the central leader and branches is eliminated by pruning, then shorter internodes in the main stem or trunk and branches develop. Also, dormant buds are stimulated to grow as well as the formation and expansion of new buds. This results in a more dense or bushy tree.

To maintain competitiveness in the Christmas tree market, growers have switched from the production of natural uncultured trees to cultured stands on plantations. Shorter rotation times and improved quality have been accomplished by fertilizing and shearing trees and controlling pests. Trees are fertilized to promote faster growth, increase needle retention, and improve color. Shearing is done to improve shape and density of the Christmas tree (Turner 1979, Proebsting 1982).

Figure 3. Christmas tree structure and shearing line.

Leader

Top Whorl

Stem

Lateral Branch

Basal Whorl

Handle

Shearing
Line

Live
Crown
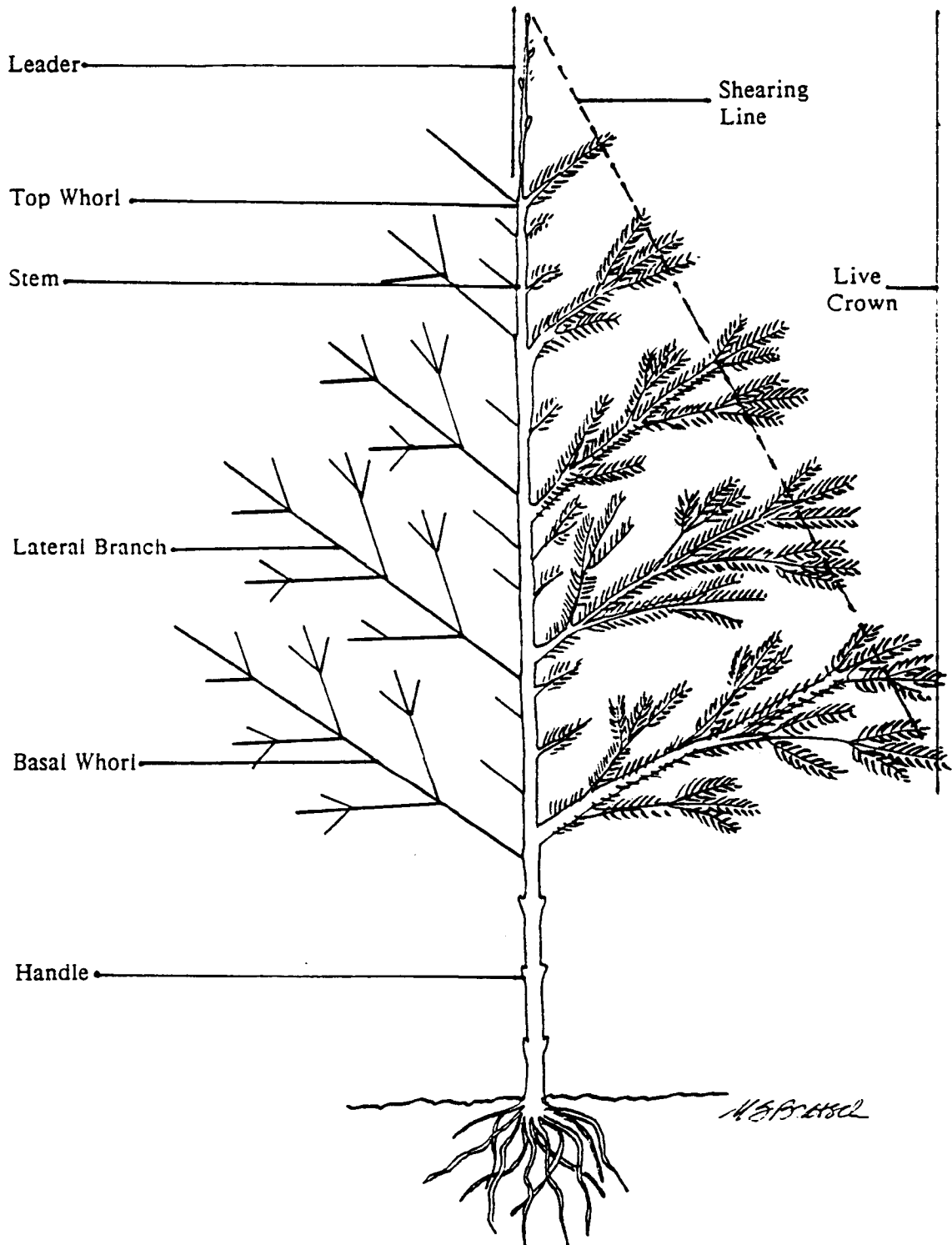
Figure 4. Diagram of a lateral branch of Douglas-fir with primary (1°), secondary (2°), and tertiary (3°) shoots.

In general, shearing is an annual cultural practice to shape Christmas trees as a cone and to cause them to fill in the open areas between branches. This process cuts back the current year's growth or prunes the tips of lateral branches to produce a more bushy, high-quality tree. Approximately 1/3 to 1/2 of the new growth is removed and the clippings are left on the ground. Pruning the leader controls tree height and reduces the internode distance while increasing canopy density. Basal pruning increases air circulation in lower branches and establishes a handle (Proebsting 1982, Scarlett et al. 1984). Side shearing starts when trees are about 5 feet (1.52 m) tall and have more than 50% taper (Proebsting 1982). A shearing tool (knives, hedge shearers, or power clippers) is used to taper the tree downward and outward from the top in a straight line to the bottom whorl to form a uniform cone-shaped tree (fig. 3) (Proebsting 1987). During the final shearing before harvest, the percent taper is increased to about 60% to make a more natural appearing tree. **Sampling techniques.** When studying the biology, distribution, and control of small arthropods, one of the inherent difficulties is the selection of a sampling technique. To determine population levels it is often necessary to remove portions of the population from the vegetation. Several examples of techniques developed for sampling mites in a particular habitat are presented in the literature and of these, two were considered for use on Douglas-fir.

The first technique considered was the use of a mite-brushing machine. This technique has been used on Douglas-fir foliage and found to remove at least 96% of the active stages and eggs after each sample was brushed twice (Fellin 1967). Although the method was effective, it did present some problems. Unremoved mites and eggs were found in debris, webbing, and on the inner side of the needle petioles. Some eggs brushed from the foliage were stuck to the inside of the cylinder of the machine. Tender current season's growth often became entangled in the brushes. These were replaced periodically due to wear. Debris and budscales dislodged during brushing accumulated on the plates which made counting mites difficult.

The second method considered used a water sodium-hypochlorite, and soap solution

to wash the samples. It has been used to process large numbers of samples to obtain tetranychid mites for predator production (Scriven and McMurtry 1971). Another study developed a "mite rinse" machine that circulated a sodium hypochlorite solution to dissolve silk and separate mites from leaves and silt (Leigh et al. 1984). This solution was then filtered through four progressively smaller screens to collect all mite developmental stages. The screens were rinsed with 70% alcohol and filtered (Whatman no. 4 filter paper) through a Buchner funnel. The mites were then counted with a counting grid and a stereomicroscope. This same technique was used to study the distribution of spider mites on cotton (Wilson et al. 1983). In a more recent study, a leaf-washing technique was used to monitor phytoseiid mites in apple orchards and was found to be 10-20% more efficient than direct counting (Zacharda et al. 1988). This method consisted of placing a sample into a 0.5 or 1-liter jar and then adding 300-500 ml of 80-90% ethanol. The jar was closed and shaken vigorously for 5-10 s. After a 60 s rest it was shaken again more vigorously and then filtered. This technique was efficient for removal and recovery of all developmental stages of mites of this predator-prey complex.

When studying the distribution of arboreal insects, a leaf is usually the sampling unit and the leaf age, location, height above ground, and tree age must be considered as factors (Southwood 1978). The proportion of the habitat to be sampled must be quantified in order to estimate population size. Sampling units are composed of equal subdivisions of the habitat which are nonoverlapping and represent the whole of the population (Helle & Sabelis 1985a). Sampling units for spider mite populations usually consist of leaves, but this is not always adequate (Helle & Sabelis 1985a). Different stages of mites may be found on non-leaf parts of plants. *Panonychus ulmi* (Koch) overwinters on apple trees as an egg on the wood. Therefore, the sampling unit for the egg consisted of the wood only (Goonewardene & Kwolek 1975). The frequency that samples should be taken during a growing season to monitor population growth should be based on the growth rate of the population. Spider-mite populations can double in 2-4 days, but low night temperatures, predators, and unstable age distributions lengthen this time period. Therefore, 1 week intervals are generally

sufficient to record a 2-fold increase in spider-mite populations (Helle & Sabelis 1985a).

To relate density and distribution of predators to the prey, the same samples or similar sampling techniques should be used. This usually does not present any difficulty since the main arena of interaction between predators and prey is the leaf surfaces (Helle & Sabelis 1985b). Sheltered resting places of phytoseiids on the leaf or twig can cause some to be missed with brushing. Therefore, the technique used is very important to obtain accurate counts (Chant & Fleschner 1960, Fellin 1967). Factors such as foliage level in the canopy and leaf age may affect the spatial distribution of predators and prey (Chant & Fleschner 1960, Nachman 1981b). Intraleaf differences may introduce sampling errors unless samples are taken so that all gradients of mite density are represented. Sampling both sides of a leaf or twigs and foliage decreases the chance of sampling error (Chant & Fleschner 1960, Helle & Sabelis 1985b).

Materials and Methods

Study sites. This study was conducted from April 1989 to May 1990 at two locations in the Willamette Valley, Oregon, in 4, 6, and 8 year old Douglas-fir Christmas trees. Several sites were initially surveyed to select spruce spider mite infested plantations. One site was located 8 km east of Salem, OR and the other site was 2.4 km west of Alpine, OR. The blocks of 6 and 8 year old trees were harvested in the fall of 1990. The 4 year old trees were not harvested. All normal Christmas tree production practices (ie. fertilization, shearing, weed control, etc.) for each research site were conducted by the growers.

The Salem site was selected because of its high population of overwintering eggs and that both 4 and 6 year old plantings of Douglas-fir were available. Trees were planted on a 1.52 x 1.52 m spacing on an approximately 3% SW slope. The 4 and 6 year old trees were approximately 1.2 m and 1.8 m tall, respectively. An acaracide application had been made during the previous season. Fungicides were not used in this planting prior to or during the study period. Tree rows and alleyways were kept weed-free with herbicides.

The Alpine site had both 4 and 8 year old trees which were approximately 1.2 and 2 m tall, respectively. Both plantings were planted on a 1.52 x 1.52 m spacing on an approximately 4% SW slope. The within and between row areas were kept free of vegetation with herbicides. The experimental trees in both plantings were unsprayed until late in the season, but buffer trees surrounding the study trees were sprayed with an acaricide/fungicide/insecticide (dicofol [1 lb ai/ac]/chlorothalonil [2 lb ai/ac]/endosulfan [1 lb ai/ac], respectively) tank mix. Both young and old plantings had low, overwintering egg populations.

Shake-and-wash method. Lateral branches were measured from the sheared stem tip back towards the trunk to determine the length of branch with live needles (fig. 3). Preliminary observations made in April 1989, indicated that live needles were generally present 25 cm back from the sheared tip. Beyond this distance the stem was bare because of shading. An unsharpened #2 lead pencil measuring 19 cm in length was selected as a readily available, economical measuring device approximating the length of stem with foliage. Therefore, the

sample unit consisted of a 19 cm twig measured from the previous year's sheared tip back towards the tree trunk. This method was used for all the following studies.

All samples were processed with a modified shake-and-wash technique (Zacharda et al. 1989). Modification involved reducing the volume of ethanol from 300-500 ml to 100 ml and its concentration from 80-90% to 70%. Sodium hypochlorite (Clorox 5%) added to the solution was reported to increase the number of mites recovered (Scriven & McMurtry 1971). A preliminary study was conducted to determine if the addition of sodium hypochlorite increased the number of mites removed from Douglas-fir foliage. It was added to the solution for all studies. Plant material, consisting of five 19 cm stems, was placed in the bottom of a wide-mouth quart mason jar on a screen platform (Fig. 5). All stems were placed with tip-ends toward the open end of the jar. One hundred ml of a 70% alcohol/0.84% sodium hypochlorite (Clorox 5%) solution was added. The jar was capped and vigorously shaken for two 15 second periods with a 1-2 minute pause in between. The liquid in the jar was allowed to drain for 1-2 minutes before the plant material was removed. The alcohol solution containing the mites was then vacuum-filtered through a Whatman #4 filter paper in a Buchner funnel. The jar was then rinsed with alcohol and the rinsate filtered through the same paper.

The washing and filtering system is inexpensive, except for the Buchner funnels. To reduce cost and increase portability of the system, these were replaced later in the study. The new system used gravity filtration of the liquid through a paper coffee filter (20 cm dia.) placed on a wire screen set on top of a plastic two quart container. Multiple funnels could be set-up enabling many filtrations to be completed simultaneously. Grid lines were drawn on the filter paper with a lead pencil to facilitate mite counts.

The efficiency of the washing technique for removal of mites from the foliage was evaluated 5 different times during the study. After the stems were processed, they were examined with a stereomicroscope and all mite stages remaining on the sample unit recorded. These data were then compared to the combined total of mites remaining on the sample and those removed. The proportion of mites removed was calculated to determine the efficiency

Figure 5. Shake-and-wash jar.

Lid

Quart jar

Wire handle

Sample

Wire stage
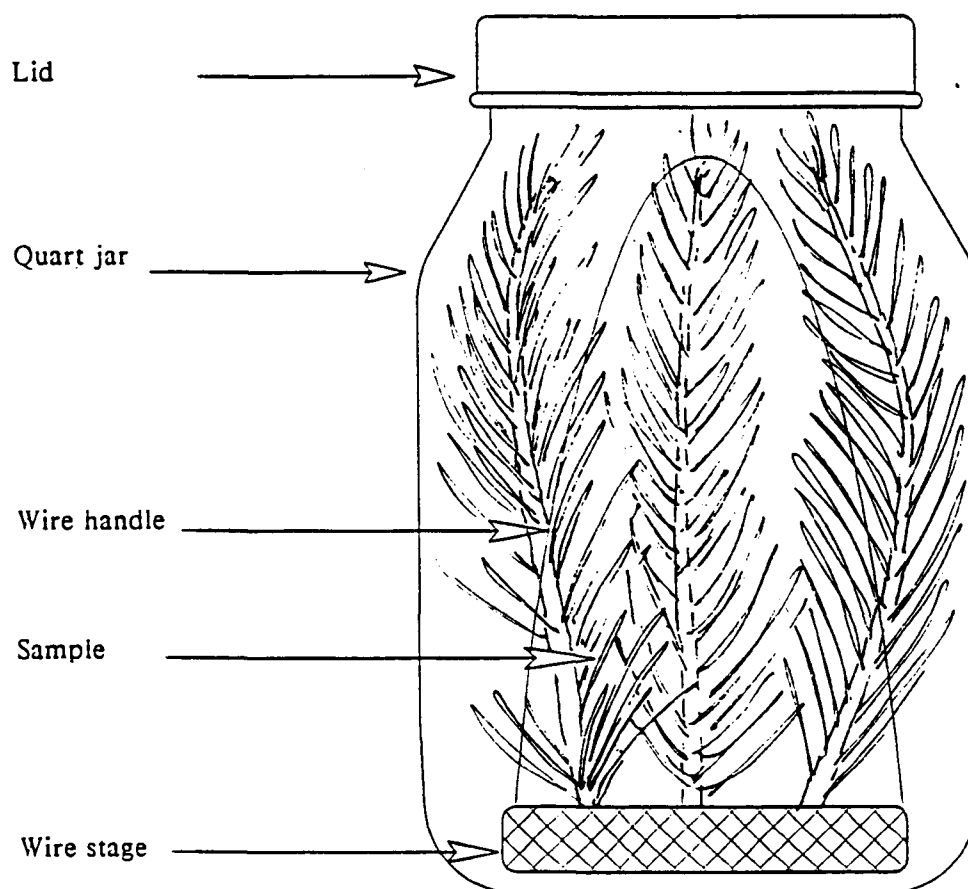
of the technique.

A stereomicroscope (30x) was used to count all phytophagous and motile predatory mite life stages present on the entire filter paper in each of the following studies. Filter paper samples were kept refrigerated at 4°C to immobilize the mites until examined.

Seasonal distribution studies. Fifteen mite-infested trees in each of four commercial Christmas tree blocks were selected and tagged as experimental units to determine the within-tree seasonal distribution differences of spruce spider mite and its predators. The number of trees sampled was limited by the time available for this study, cost of the trees used, personnel expenses, and growers limiting the number of trees and area in a block for the study. Therefore, five of the fifteen trees were sampled initially and on each subsequent sample date until the canopy structure was altered. Then a second group of five trees in each block was sampled until their canopy was also altered. A third group of five was sampled until the end of the study. Each tree sampled was surrounded by 4 buffer trees and none were selected from the field border rows. Growers sheared the sample trees during this study. The same five trees being monitored prior to shearing were sampled after shearing. Since the terminal portion of current season's stems extending past the shearing line was cut-off during shearing, stems selected for processing were unsheared.

Each tree canopy was partitioned into an upper and lower level (upper = top 1 meter; lower = remainder of canopy). Each level was further divided into north, south, east, and west compass directions (fig. 6). Samples from the upper half of the canopy were taken 0.5 meters from the sheared central leader tip. Samples from the lower half of the canopy were taken at the mid-point of the lower portion of the crown which varied from 0.5 to 0.7 m above the ground.

Weekly samples selected from each sector of the tree consisted of both current and previous year's growth. Nineteen cm of previous year's growth was removed from each sector. After budbreak, a sample of current year's growth, growing directly from this stem, was taken. Samples collected were transported in ice chests to the laboratory for processing.

In the laboratory, all current year's growth was excised from each 19 cm length of

Figure 6. Partitioning of Douglas-fir canopy by level and compass direction for sampling *Oligonychus ununguis* (Jacobi).
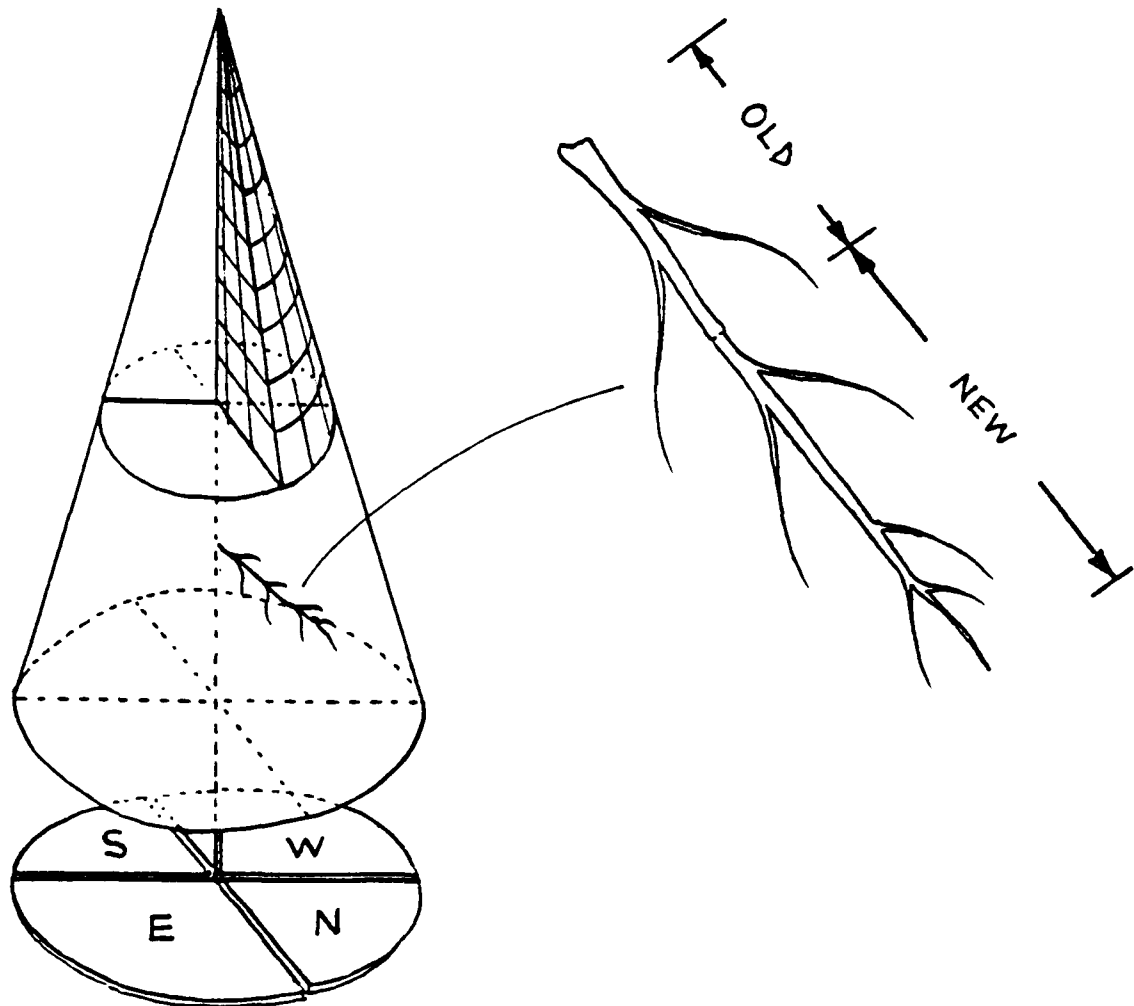
previous year's growth and measured to determine total length (fig. 7). From this total, a 19 cm sample was selected. If a stem selected was not at least 19 cm long, an additional current year's stem was selected and included to make the total length of 19 cm. The additional stem was measured from the tip towards the base and any excess removed. Previous and current year's growth were processed separately and all mite stages recorded. Excess dirt and debris from previous year's growth stems slowed filtration and increased the difficulty of finding larval and small nymphal stages on the filter paper. Consequently, samples were divided in half and washed and filtered separately.

Spatial distribution of egg and motile stages on stems of current season's growth. Samples of current season's growth were sometimes composed of portions of two or more stems to satisfy the 19 cm requirement. To determine if mites were differentially distributed on the terminal or basal section of a stem, 10 trees (8 year old) were selected for study. Each tree was divided into upper and lower quadri-directional levels (N, S, E, and W) as described earlier. Two, new growth stems were cut from each sample and their total length recorded. These were cut in half and apical and basal halves washed separately. This experiment provided 160 samples on each of two separate collection dates (6/29/89 & 8/17/90) from the same block for evaluation. All life stages of phytophagous and the motile stages of predacious mites were recorded.

Overwintering egg distribution. Two blocks of 7 (Alpine) and 6 (Salem) year old trees were sampled (3/10/90 & 4/1/90 respectively) to determine the distribution of overwintering eggs. Five infested trees were sampled in each block. Trees were partitioned and sampled as described earlier for the within-tree distribution studies. Samples (each 19 cm long) of both current and previous season's growth were processed. All samples were examined under a stereomicroscope and the number of eggs recorded. Twigs of current seasons growth from the Salem plantation were subdivided into top and bottom halves to determine if there was a preference for egg laying position on a stem with high populations.

Data analysis. Data were analyzed using one-way and two-way analysis of variance (ANOVA). A log $(x + 1)$ transformation was used to normalize the distribution and satisfy

Figure 7. Lateral branch of Douglas-fir showing current (3) and previous (1 & 2) season's growth.
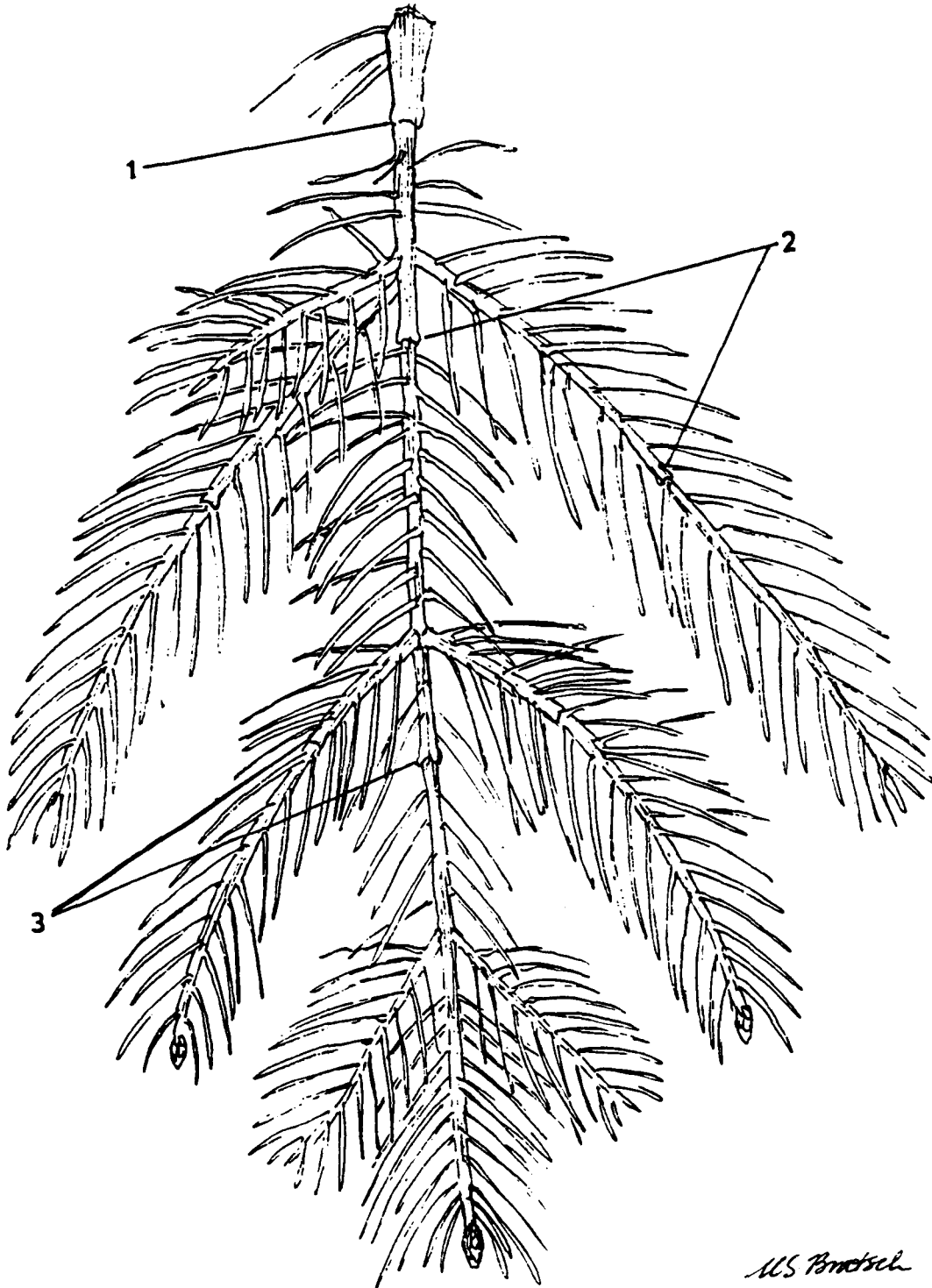
the requirements for the analysis of variance for the spatial distribution on current season's growth data. Data for this study were converted to counts/cm before being transformed. A log (x + 0.5) transformation was used to normalize the distribution and satisfy the requirements for the analysis of variance of the overwintering egg distribution data. Multiple range analysis (95% confidence interval) was used to separate differences between means (Statgraphics, 1989). Data for the seasonal distribution study were converted to counts/cm and a graph of the seasonal population trends for each study site was made.

Results and Discussion

Evaluation of the modified shake-and-wash technique. In this study, eggs, nymphs, and adults of spruce spider mite, and motile forms of predator mites occurred on both the needles and stems. Most eggs were attached to the stem and concentrated near or on the nodes or rough surface areas. Some eggs were deposited in protected areas of bud scales and on both upper and lower surfaces of needles.

The addition of sodium hypochlorite (0.84%) to the washing solution did not increase the number of spruce spider mites or phytoseiid mites removed from Douglas-fir foliage (Table 1). Recovery of all motile stages was 100% whether or not solutions contained sodium hypochlorite. The eggs of spruce spider mite were the most difficult to remove and fewer eggs were removed when sodium hypochlorite was added. A possible explanation may be that sodium hypochlorite softened the eggs and made them more susceptible to damage during sample processing. This processing method has a more vigorous physical action compared to similar methods described in the literature.

The modified shake and wash technique removed 100% of the phytoseiid mites and adult spruce spider mites from both current and previous year's foliage (Table 2). Predatory mites did not die immediately after being washed off. Therefore, after the samples were processed, the filter paper was immediately refrigerated at approximately 4°C to prevent escapes. The one-minute pause in the shaking process was thought to have provided sufficient time for predators to attempt to escape from their hiding places in the open bud scales of Douglas-fir. In addition to the violent shaking, this may have been a contributing factor in 100% efficiency of the washing technique for predators. In a study conducted on apples, researchers observed that the two predatory mites, *Typhlodromus pyri* and *Amblyseius finlandicus*, did not die immediately and were easily washed off while trying to escape from refuges on the leaf (Zacharda et al. 1988).

One-hundred percent of the nymphs were removed from the previous season's growth and nearly all nymphs were removed from the current season's growth (Table 2). During the processing of samples, the vigorous shaking of the container occasionally caused

Table 1. Comparison of the proportion of eggs and motile stages of spruce spider mite (*Oligonychus ununguis*) and predators removed from previous season's Douglas-fir foliage by washing in a solution with or without sodium hypochlorite (NaClO). $\bar{x} \pm$ S.E. (n).

	Spruce Spider Mite				
Treatment	All Stages	Eggs	Nymphs	Adults	Predator mites
w/NaClO	0.92 ± 0.20 (16)	0.84 ± 0.34 (13)	1.00 (15)	1.00 (7)	1.00 (13)
w/out NaClO	0.95 ± 0.09 (13)	0.87 ± 0.16 (7)	1.00 (11)		1.00 (5)

Table 2. Proportion of eggs and motile stages of spruce spider mite (*Oligonychus ununguis*) and predators removed from Douglas-fir foliage by washing in a solution containing sodium hypochlorite (NaClO). $\bar{x}$ ± S.E. (n)

			Spruce Spider Mite		
Foliage Sampled	All Stages	Eggs	Nymphs	Adults	Predator mites
Current [a]	0.92 ± 0.11 (12)	0.89 ± 0.16 (12)	0.98 ± 0.06 (11)	1.00 (5)	1.00 (1)
Previous [b]	0.94 ± 0.14 (37)	0.88 ± 0.24 (28)	1.00 (32)	1.00 (13)	1.00 (23)

[a] Current year's growth after bud break.

[b] Previous year's growth.

the more succulent, current season's growth to be forced down on the stage in the jar bottom. Also, the newest needles on current season's growth are very soft and limp. Nymphal mites on the less rigid stems may have been trapped between the needles and twig surface causing a reduction in the number of mites removed from some samples. Efficiency of this technique for all motile stages was 98-100%.

Eggs were the most difficult stage to remove from the foliage with this technique. Efficiency for current season's and previous season's growth was 88-89%. Previous and current season's growth are usually pubescent for several years with the pubescence eventually being sloughed off on the older stems (Hitchcock et al. 1969). It was assumed that eggs would be more easily washed off the previous season's growth since the surface is not as pubescent and is more rigid than the young, current season's growth. However, some samples of previous season's growth were from trees sampled from one study site which had excessive amounts of soil particles on the stems. In a previous study, debris on stems provided more sites of attachment for webbing to hold eggs more securely to the twig (Oi & Barnes 1989). The overall average efficiency of the shake-and-wash technique for all mite species and stages combined for both previous and current season's growth was greater than 92%. Overall efficiency was reduced due to a lower percentage of eggs being removed in comparison to the motile stages.

The total washing time for each sample was about 10 minutes. Another 10-15 minutes was required to examine the filter paper. A grid marked on the filter paper prior to filtration helped reduce the time necessary for counting. The washing and filtering system used was inexpensive, except for the Buchner funnels. Replacing the Buchner funnels with wire screens and filtering by gravitation helped reduce cost. Several filtrations could be accomplished at once and the system was more portable for field and laboratory use. Cost, portability, and time are important considerations when trying to develop a method for field use by growers or consultants. This technique was not compared to direct counting in this study. In an earlier study on apples leaves, washing was demonstrated to be 10-20% more efficient than direct counting (Zacharda et al. 1988). Douglas-fir foliage

does not have a flat surface and needles obstruct the view of the twig surface. Therefore, more time may be required to examine a sample.

Seasonal distribution. The pattern of distribution and seasonal abundance for spruce spider mite and its predators varied between the four study sites (figs. 8, 10, 11, and 12). In the young (four-year-old) trees at the Alpine site, predator mite populations were very low during the entire study with the only increase occurring in late June-early July on the previous season's growth (fig. 8). Spruce spider mite population levels increased on previous and current season's growth in mid to late-April, but sharply decreased by late-May. Mite numbers increased again, and peaked in mid-July. This increase was followed by a sharp decline with mite numbers remaining low for the rest of the study period which ended in late October. The decline in May could be attributed to rainfall (approximately 5.42 inches or 13.77 cm) occurring during this period (fig. 9). The second decline did not coincide with any precipitation. Trees were not treated with an acaricide nor were they sheared until late in the season.

The young trees at the Salem site were not sampled until the beginning of July (fig. 10). The mite population had already peaked and was rapidly declining. The spruce spider mite population in this block was higher than in the young Alpine site. All stages of spruce spider mite stages recorded on the previous season's growth followed a similar rate of decline (fig. 10). Egg counts on the current season's growth were much higher than the motile stages. A slight increase was recorded on julian date 220 (fig. 10). The second set of five trees were first sampled on this date, which may have been the reason for the increase in mite numbers. Egg counts on the current season's growth were very high, but the motile stages did not follow the pattern of decline recorded on the current season's growth. Egg mortality appeared to be high.

The two older Christmas tree sites located near Alpine had low spruce spider mite populations and very low predator mite populations (fig. 11 and fig. 12). Early mite populations in both north and south Alpine sites appeared to be affected by rainfall (approximately 5.42 inches or 13.77 cm) received during this period (fig. 9). The number

Figure 8. Seasonal abundance of spruce spider mite and predator mites on previous and current season's growth of four-year-old Douglas-fir Christmas trees at the Alpine site, 1989.

□ Total Motiles   △ Eggs   ○ Nymphs

✳ Adults   ■ Predators
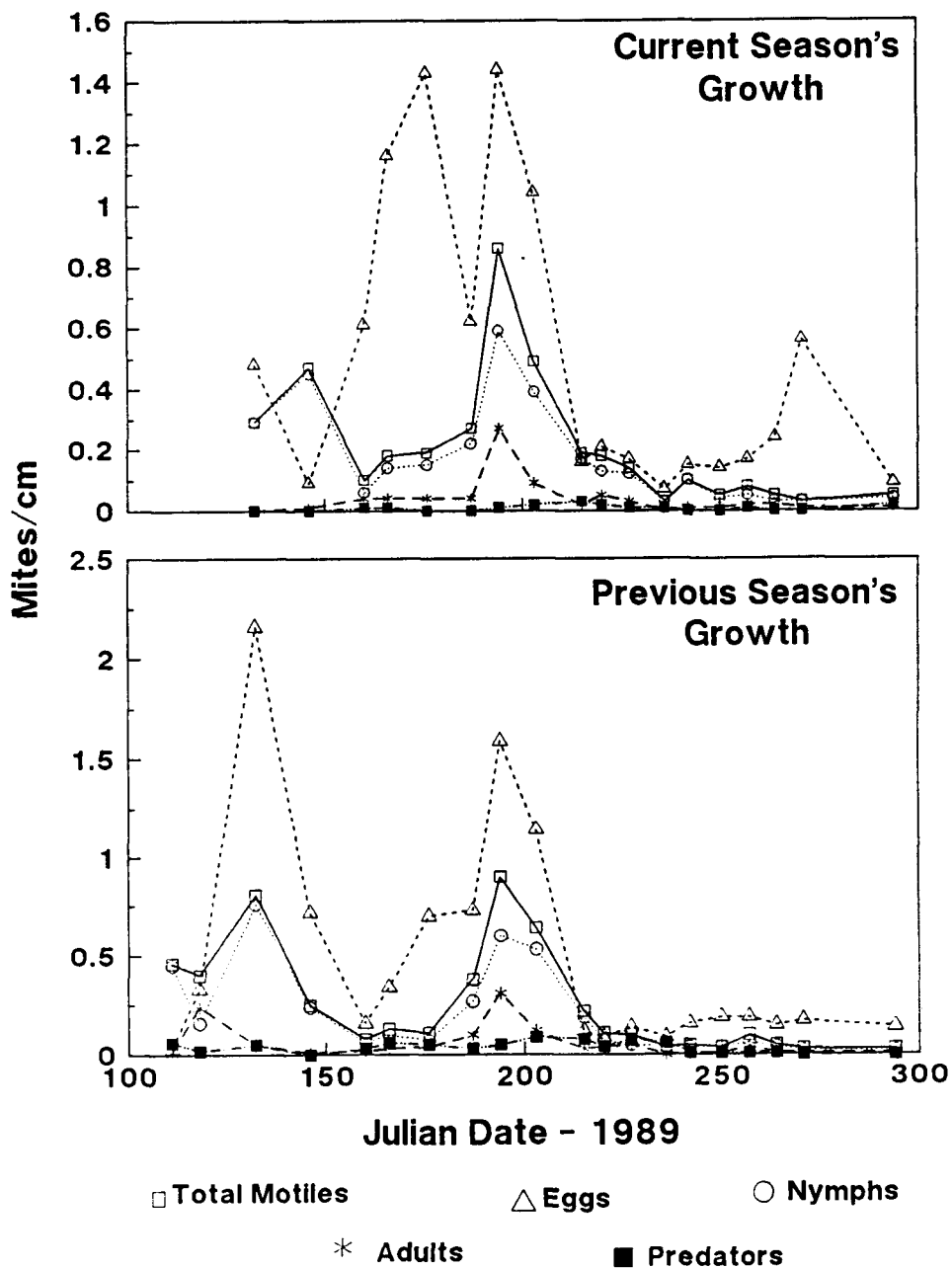
Figure 9. Precipitation recorded at the south Alpine site, 1989.

Figure 10. Seasonal abundance of a high spruce spider mite population and its predator mites on previous and current season's growth of four-year-old Douglas-fir Christmas trees at the Salem site, 1989.
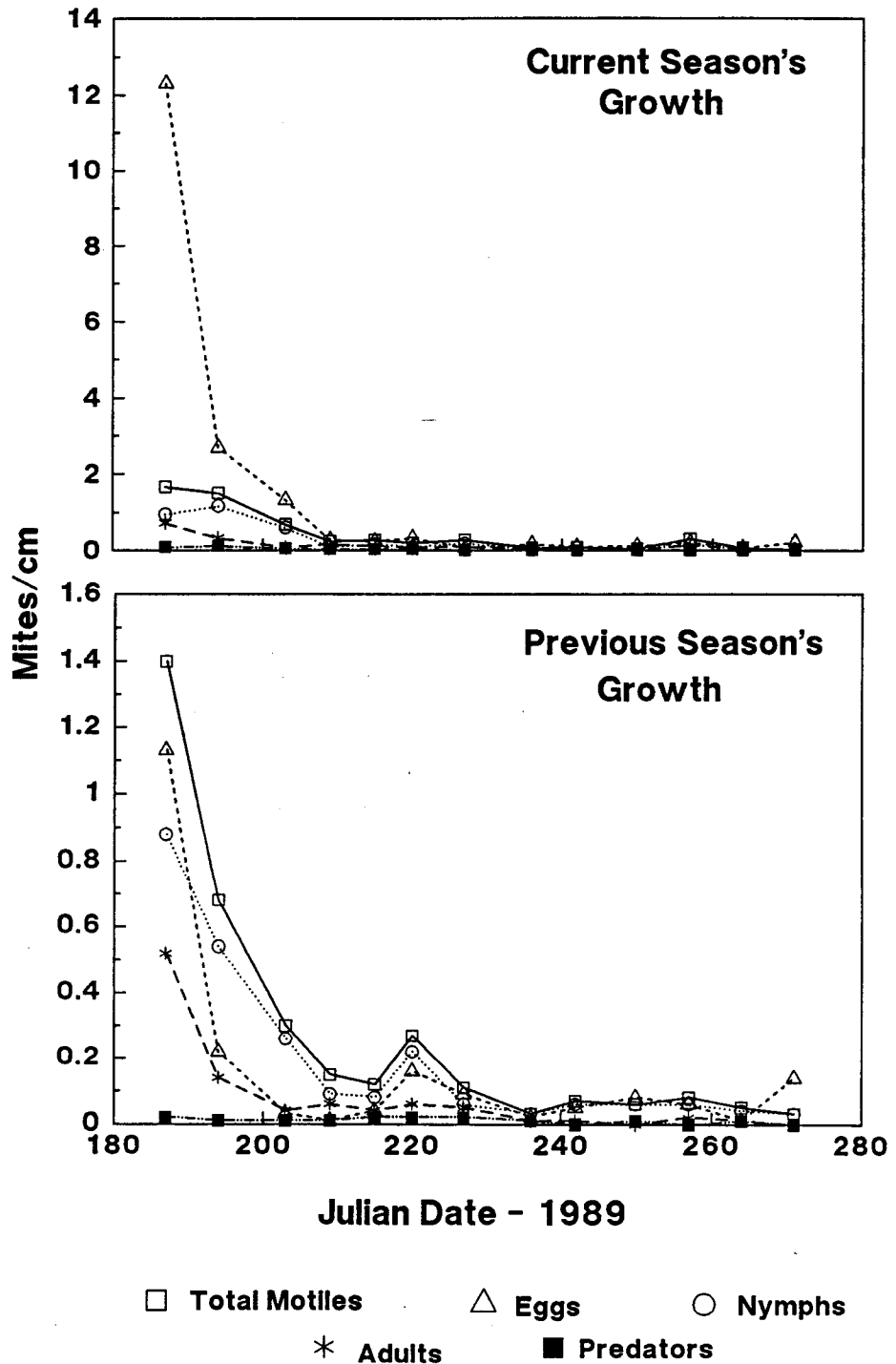
Figure 11. Seasonal abundance of spruce spider mite and its predators on previous and current season's growth of eight-year-old Douglas-fir Christmas trees at the south Alpine site, 1989.

Figure 11.

□ Total Motiles   △ Eggs   ○ Nymphs   * Adults   ■ Predators

Previous Season's Growth top-half

Current Season's Growth top-half

Previous Season's Growth bottom-half

Current Season's Growth bottom-half

Mites/cm

Julian Date - 1989

Figure 12. Seasonal abundance of spruce spider mite and its predator mites on previous and current season's growth in the upper and lower halves of eight-year-old Douglas-fir Christmas trees at the north, Alpine site, 1989.
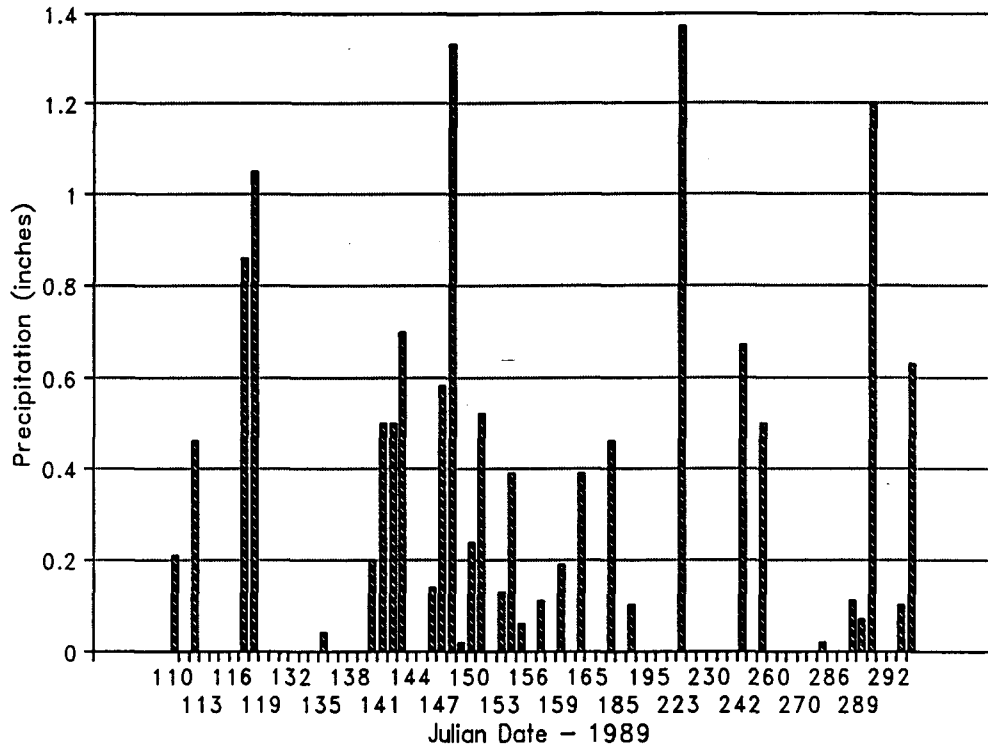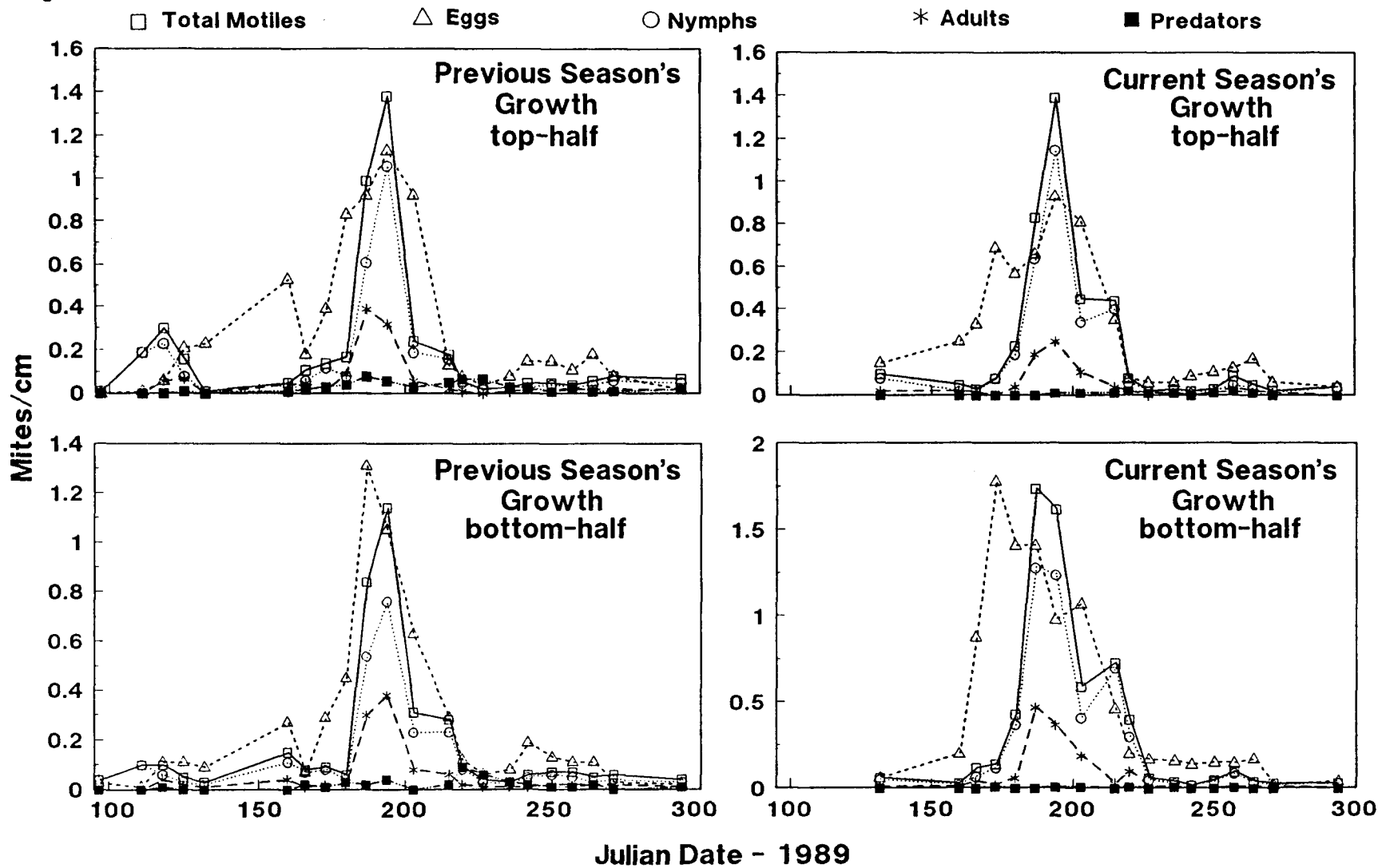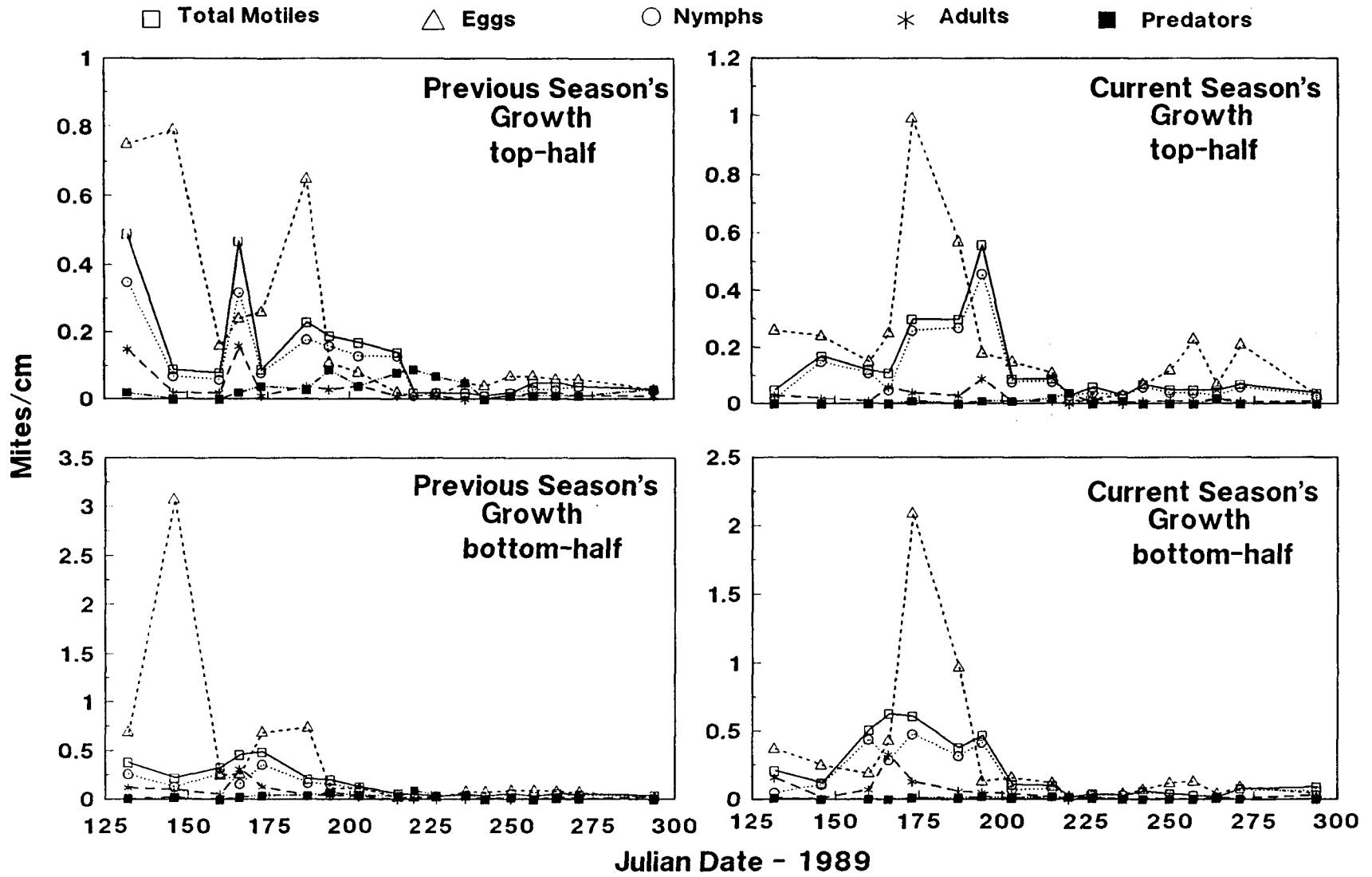
Figure 12.

of motile stages (adults and nymphs) were reduced, but the population density increased after the rainy period ended. The population in the south Alpine block peaked in the second week of July followed by a rapid decline (fig. 11). Measurable rainfall and shearing occurred after the mite population declined and therefore can not be the cause of the decline. Switching sampling from one set of five trees to another set did not appear to have a strong affect on population trends. Population levels on previous and current season's growth in both the top and bottom of the trees were very similar. Patterns of increase and decrease followed the general pattern observed in the younger trees: egg counts increased with adult populations and decreased as adult numbers decreased. Trends for the north Alpine block (fig. 12) were very similar to those of the south Alpine block. This study site received an acaricide application (propargite 1.8 lb ai/ac) on July 13, 1989. The spruce spider mite population on the current season's growth was already declining, but decreased sharply after the acaracide application. Mites on the previous season's growth continued to decline at a rate similar to that occurring prior to the acaricide application.

Increasing and decreasing densities of spruce spider mite populations through the season may be related to rainfall, relative humidity, temperature, water stressed plants, and fluctuating nitrogen levels or a combination of these factors. The spruce spider mite population declined in May at all three Alpine sites (fig 10, 11 and 12) and appeared to coincide with rainfall received during May (fig 9). Heavy rainfall occurring daily caused a decrease in spruce spider mite populations on Fraser fir (Boyne & Hain 1983). If it rains every other day or less frequently, population levels may recover rapidly or rain may have very little effect on the population. The amount of rainfall recorded in this study and the response of the mite population is similar to the results reported in the study on Fraser fir (Boyne and Hain 1983). Relative humidity levels of 50-60% are optimal for spruce spider mite development, but longevity is reduced with 88-98% humidity levels (Boyne and Hain 1983). The number of females reaching maturity is low (41%) when humidity is high and total eggs per female and eggs per day is significantly less (Boyne & Hain 1983). Also, relative humidity has an effect on feeding. High humidity prevents the loss of evaporative

moisture through the cuticle and reduces the amount of feeding (Boudreaux 1958). In addition to rainfall, high humidity may be a contributing factor to slowly increasing populations in the spring.

Another factor contributing to the observed population trends may be nitrogen. Nitrogen levels in current season's growth of shoot tips are the highest in late spring and summer, but decline in late summer. Bud break and increasing nitrogen levels in the spring roughly coincide with each other (Proebsting & Chaplin 1983). The increase and decrease of spruce spider mite populations in this study is very similar to the pattern of nitrogen levels in Douglas-fir. A study of leaf nitrogen levels and two-spotted spider mite (*Tetranychus urticae* Koch) population trends documented that as nitrogen levels increased, sex-ratio, oviposition rate, eggs/female/day, intrinsic rate of natural increase, and the net reproductive rate increase. A decrease in the generation time occurs as nitrogen levels increase. As these population parameters are stimulated by higher nitrogen levels, a faster growth rate and dispersal by females occurs (Wermelinger & Delucchi 1990). Nitrogen levels in Douglas-fir may be causing a similar response in spruce spider mite.

Several studies have reported that spruce spider mite does well in warm, dry conditions (Boyne & Hain 1983). As temperature increased, developmental times and longevity of all stages decreased for spruce spider mite. The number of progeny produced increases until an upper temperature tolerance level is reached. Spruce spider mite eggs do not survive at temperatures greater than 29°C (84.2°F), but population growth is the greatest at moderate temperatures around 26°C (78.8°F) (Boyne & Hain 1983). Mid-summer populations on Fraser fir decreased to extremely low levels when daily temperatures were highest, however temperature is not the only factor found to regulate population levels on Fraser fir. Total fecundity also decreased with rising temperature, but the rate increased with higher temperatures. The mid-season decline which occurred in all four study sites may be related to temperature as well as a combination of the previously discussed factors.

Another factor to consider is what affect changes in soil moisture levels during the growing season have on the trees and the mite population. Douglas-fir is not irrigated and

very little rainfall occurs during the summer months. Douglas-fir is grown on well drained soils so the trees may become water stressed during the summer. Plants that are water-stressed can have a negative or positive effect on spider mite population growth. It is possible for both responses to occur in the same season for a particular mite. *Tetranychus urticae* populations on apple trees declined as the trees became more stressed. *Oligonychus pratensis* mites on corn increased as plant stressed increased, then decreased as plants became overly stressed (English-Loeb 1989). Water-stressed Douglas-fir trees may be causing a similar response in spruce spider mite populations.

Egg mortality appeared to be high in the two younger blocks and the north Alpine site, because motile mite numbers were low in comparison to egg counts (tables 3, 5, and 7). The cause of this suspected mortality was not determined, but may be due to a combination of rainfall washing mites off the tree and high humidity negatively affecting nymph survival. A similar pattern was found in a study on Fraser fir but no explanation was given for observed differences (Hain & Nettleton 1974). Egg counts and the number of motile mites recorded followed general patterns of increase and decrease with increasing numbers of adults producing increasing numbers of eggs and nymphs. Predator mite populations remained low for the entire study period in the four study sites. This may have been due to the use of acaricides during the previous season.

Spatial distribution on twigs of current season's growth. The densities of spruce spider mite motile and egg stages on current season's growth were very low for both sample dates (6/29/90 and 8/17/90). The mean number of mites in all stages was <17 and <3 for the early and late sample dates, respectively. Predator mite densities also were low (<0.25/19 cm). The reason for the decline in the predator population is not clear, but a similar population decrease was recorded in all studies. Comparisons made between directional aspects and quadrants on both sample dates for all mite stages exhibited no statistically significant differences. This observation is similar to the distribution of spruce spider mite on Fraser fir (Hain & Nettleton 1974).

Nymphs, adults, and combined counts of motile stages of spruce spider mite

occurring in the top half of sampled trees were not significantly different from those found in the bottom half on the early sample date (Table 3). The percentage of eggs recorded in the bottom half of the tree was significantly higher than in the top half of the canopy. Overwintering egg populations were not recorded prior to this study. Very little feeding damage was observed in trees sampled. It is possible that this was a new infestation which had more overwintering eggs in the lower canopy. After egg hatch, these mites may have fed and laid eggs before dispersing from the lower portion of the canopy. No acaricides or insecticides had been applied to the trees prior to the early sample date. Further data analysis did not reveal any significant differences for all spruce spider mite life stages between the terminal and basal stem sections in the top or bottom portion of sampled trees (Table 3).

Extremely low numbers were recorded for all mite stages in the late season sample with values significantly higher in the bottom half of the tree (Table 4). The higher population levels in the lower canopy may be due to an acaricide (propargite) applied aerially on 7/13/89. If more propargite was concentrated on the upper half of the trees, it could have caused differences in mite distribution. Comparison of terminal and basal stem sections for all mite stages showed no significant differences in densities between stem sections (Table 4). The percentage of all mite stages found in the terminal half increased from the earlier sample date. Though not statistically significant, densities were slightly higher in the terminal sections than in the basal sections. In a study on Fraser fir, the distribution of spruce spider mite on current season's twigs was skewed toward the terminal section (Hain & Nettleton 1974). However, population levels for all mite stages in the Fraser fir study were much higher than in my study.

The lack of significant differences between directions and quadrants on current season's growth within a tree indicated that random selection of foliage samples from around the tree would result in a unbiased estimate of spruce spider mite density. Also, a 19 cm stem sample composed of more than one twig or portions of current season's growth should not bias population estimates if selected from either the tip or basal section. Distributional

Table 3. Percentage of spruce spider mite eggs, nymphs, adults and motile stages distributed on twig samples of current season's growth of Douglas-fir (Alpine site, 6/29/89).

	Spruce Spider Mite			
Area Sampled[a]	Eggs	Nymphs	Adults	Motile Stages
Tree				
Top	41.3	43.8	50.8	49.8
Bottom	58.7	56.2	49.2	50.2
P[b]	0.02*	0.12	0.89	0.15
Stem				
tip-half	47.8	49.9	46.3	52.7
basal-half	52.2	50.1	53.7	47.3
P	0.57	0.98	0.49	0.89

[a] Level is divided (n=80) between the top and bottom half of the tree and stems sectioned (n=40) into tip and basal halves.

[b] ANOVA procedure (95% C.I. test), Statgraphics 1987; Value followed by * significant at P< 0.05.

Table 4. Percentage of spruce spider mite eggs, nymphs, adults, and motile stages distributed on twig samples of current season's growth of Douglas-fir (Alpine site, 8/17/89).

| Area Sampled[a] | Spruce Spider Mite | | | |
	Eggs	Nymphs	Adults	Motile Stages
Tree				
Top	21.2	14.1	24.3	15.8
Bottom	78.8	85.9	75.7	84.2
P[b]	0.00*	0.00*	0.04*	0.00*
Stem				
tip-half	51.99	51.0	53.9	51.6
basal-half	48.01	49.0	46.1	48.4
P	0.78	0.88	0.75	0.81

[a] Level is divided (n=80) between the top and bottom half of the tree and stems sectioned (n=40) into tip and basal halves.

[b] ANOVA procedure (95% C.I. test), Statgraphics 1987; Value followed by * significant at $P < 0.05$.

differences for a high population were not studied so it is not known if a bias would occur if one portion of a stem was selected over the other.

Overwintering egg distribution. Egg densities on trees at the Alpine and Salem study sites were very different. Trees selected at the Alpine site had a low egg population and the between tree density was similar. Examination of the within tree distribution showed a lack of significant differences between quadrants, between directions, and in vertical (height) distribution (Table 5). Spruce spider mite on Fraser fir did not exhibit any directional preference, but did show a significant preference for the upper crown areas at high population levels (Hain & Nettleton, 1974). Similarly, the lack of significant difference between quadrants is similar to their distribution on Fraser fir.

There was a highly significant difference ($P < 0.05$) between egg counts from previous and current year's growth with mean egg counts higher on current (1989) year's growth (Table 5). These findings agree with the results of Hain & Nettleton's (1974) who should that spruce spider mite preferred newer growth. There was no significant difference in egg counts on current season's growth between the top and bottom portions of the canopy. The large differences between current and previous season's growth may be due to preference by adults for more succulent growth. Several studies have shown that mites are more fecund on younger foliage and have a higher fecundity and shorter developmental time on leaves with higher nitrogen content (Helle & Sabelis 1985a). In Douglas-fir shoot tips, nitrogen levels are highest during the active growing period, then decline in late summer, but remain relatively constant through the fall and winter months (Proebsting & Chaplin 1983). More current season's growth is produced in the upper portion of Douglas-fir trees (fig. 13). Higher nitrogen content and succulent young growth may be the reason for preference as egg deposition sites on current season's growth.

Data analysis for the high population density site (Table 6) showed a highly significant difference ($P < 0.001$) between trees sampled, with a two-fold difference between tree number 3 and the other trees. Analysis conducted without this tree showed that density was still significant ($P \approx 0.017$). The mean mite densities among trees were very close so the

Table 5. Within-tree spatial distribution of overwintering spruce spider mite (*Oligonychus ununguis*) eggs on Douglas-fir Christmas trees at low population density site (Alpine site).

Tree	$\bar{x}$ [a] (n)	95 % C.I.	P[b]
Growth			
Previous	0.49 (40)	0.27-0.79	0.001
Current	3.96 (40)	2.91-5.33	
Height			
top-half	1.53 (40)	0.92-2.41	0.80
bottom-half	1.67 (40)	1.02-2.61	
Height/Current			
bottom-half	3.89 (20)	2.50-5.92	0.91
top-half	4.03 (20)	2.60-6.12	
Direction			
W	1.03 (20)	0.43-2.04	0.39
E	1.41 (20)	0.65-2.66	
S	2.00 (20)	1.01-3.63	
N	2.17 (20)	1.11-3.92	

[a] Values represent counts/19 cm twig.

[b] ANOVA procedure (95% C.I.test), Statgraphics 1987.

Figure 13. Mean total of current season's growth on 19 cm sample lengths of previous season's growth in small and large sheared Douglas-fir Christmas trees.
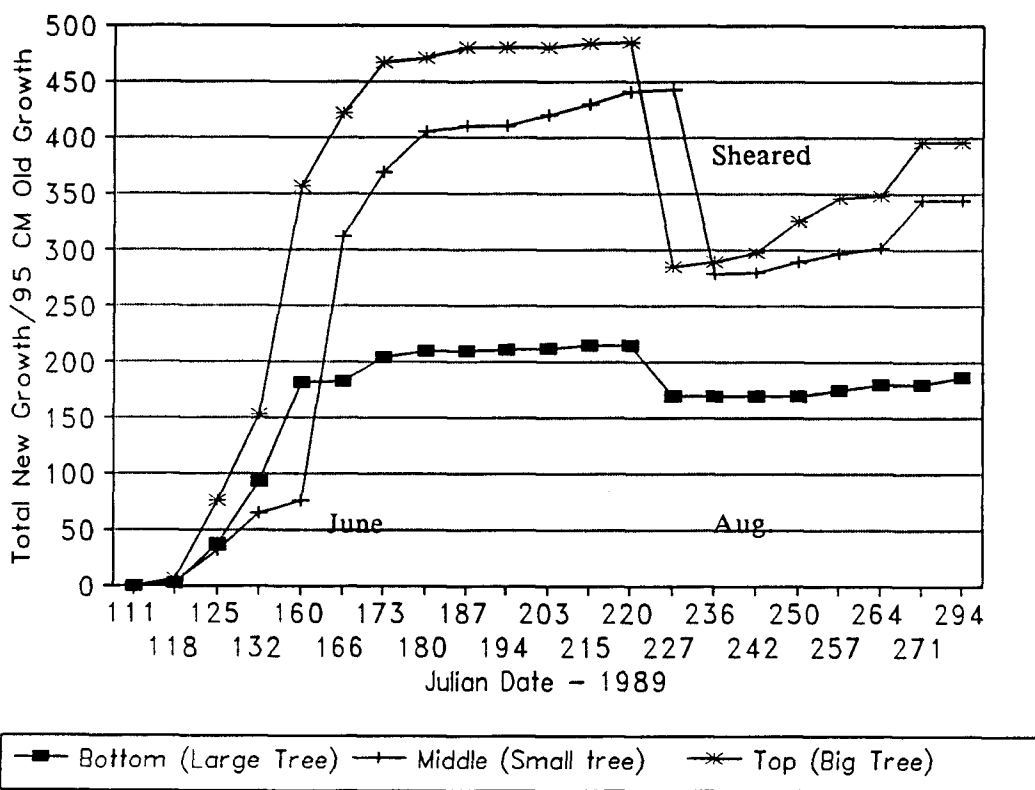
Table 6. Within-tree spatial distribution of overwintering spruce spider mite eggs on Douglas-fir Christmas trees at a high population density site (Salem site).

Tree	$\bar{x}$ [a] (n)	95 % C.I.	P[b]
Growth			
Current	66.15 (32)	42.55-102.68	0.82
Previous	70.99 (32)	45.68-110.17	
Height			
bottom-half	46.40 (32)	30.38-70.50	0.01
top-half	101.08 (32)	66.61-153.27	
Height/Current			
bottom-half	40.55 (16)	22.44-72.96	0.02
top-half	107.21 (16)	59.97-193.15	
Direction			
W	54.89 (16)	29.34-102.31	0.57
S	58.70 (16)	31.39-109.38	
N	70.34 (16)	37.67-131.00	
E	97.24 (16)	52.15-180.92	

[a] Values represent counts/19 cm twig.

[b] ANOVA procedure (95% C.I. test), Statgraphics 1987.

analysis was completed without tree number 3. Further justification for elimination of this tree was based on its probable use in an acaricide trial conducted in this block the previous season.

There was no significance differences (P > 0.05) for egg deposition between quadrants, compass direction, or between previous and current season's growth. Also, there were no significant difference between the upper and lower halves of the twig sampled. These results are similar to the spruce spider work on Fraser fir except that there was no significant difference between growth stages in my study (Hain & Nettleton 1974). Hain and Nettleton (1974) reported that only infrequently, under crowded conditions, would spruce spider mite re-infest the previous season's growth of Fraser fir. Differences in vertical distribution of eggs in the canopy were significant for current season's growth, but not for previous season's growth. Average counts on current season's growth were 2.6 times higher in the upper portion of the tree. Though the vertical distribution of mite eggs in previous season's growth were not significant (P = 0.196), mean mite egg densities in the upper canopy were 1.8 times higher than densities in the lower canopy.

This study indicated that preferential sites for spruce spider mite egg deposition were on current season's growth. Egg deposition may occur on previous season's growth under crowded conditions, however. No information is available to explain directional variation in egg density. Data indicate that sampling from anywhere around the canopy of a Douglas-fir Christmas tree or different levels in the tree in a unbiased fashion would not bias estimates of egg population density. Sampling new growth in the mid to top half of the tree would provide a good estimate of overwintering egg populations.

Summary and Conclusions

One of the objectives of this study was to develop a sampling method which was economical and efficient for obtaining population estimates of spruce spider mite *Oligonychus ununguis* and its predators on Douglas-fir Christmas tree foliage. An existing technique was modified for this purpose. The second objective was describe the intra-canopy distribution of all life stages of spruce spider mite and its predator mites during the growing season.

A simple method was developed to determine the population of mites on a Douglas-fir tree. Equipment for the shake and wash technique used in this study is less costly than that required for mite brushing. It is efficient for removing predator mites and the motile stages of spruce spider mite. Egg removal was difficult using this technique, but was as efficient as the mite brushing process used in another study on Douglas-fir (Fellin 1968).

Analysis of the within-tree distribution of spruce spider mite, *Oligonychus ununguis*, on Douglas-fir Christmas trees indicated that this species is distributed randomly between the four directional aspects for both low (<5 mites/19 cm) and high (>40 mites/19 cm) mite populations. There was no difference in distribution between height (bottom and top-halves) in trees for low density overwintering egg populations and summer motile stages and eggs. Overwintering eggs are significantly more abundant on the current season's growth. A tree height difference does exist when overwintering egg populations are high with more eggs deposited in the upper portion of the canopy on current season's growth. Overwintering, spruce spider mite eggs were commonly found on current season's growth and in the middle to upper portions of the tree. Spruce spider mites feed on this current season's growth in the spring until budbreak, then move to the newly developing foliage. When populations levels become high, it appears that the mites move back to the previous season's foliage. This is similar to the response reported on Fraser fir (Hain & Nettleton 1974).

The absence of significant differences between compass directions within a tree indicated that directional aspect does not need to be considered when selecting a sample.

Sampling the middle portion of the canopy will give a reliable estimate of mite presence. Selection of a sample from current season's foliage for overwintering eggs and during mid to late-summer should provide a good population estimate.

Reviewing other studies and the results of my study have raised several questions. Information on predator mite distribution and their effect on spruce spider mite populations is needed for the development of treatment thresholds. The effect of environmental factors, plant nutrients, and soil moisture or plant stress on spruce spider mite populations should be measured. This information is needed to better understand the reasons for the spring and mid-summer decline in the spruce spider mite population. The distribution of mites along the length of a 19 cm sample should be determined to decrease the amount of foliage sampled and possibly reduce the amount of time spent processing samples.

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