3-1-1974

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TECHNICAL BULLETIN 68 MARCH 1974

LIFE SCIENCES AND AGRICULTURE EXPERIMENT STATION
UNIVERSITY OF MAINE AT ORONO

Acknowledgement

Research reported herein was supported by funds made available through the Hatch Act.

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ABSTRACT

Sequential survey procedures are described for classifying damage to white pine produced by the pine leaf chermid. Damage classes are based on degree of needle stunting, and field procedures for making measurements are given. Survey procedures are also presented for classifying infestation levels of two stages of the insect. These allow prediction of damage levels before damage occurs.

INTRODUCTION

This bulletin describes field procedures for classifying damage to white pine (*Pinus strobus* L.) produced by the pine leaf chermid, *Pineus pinifoliae* (Fitch). It also relates numbers of some stages of the insect to damage, allowing prediction of damage before it occurs. Collection, measuring and counting methods are simplified as much as possible, consistent with reasonable precision. Sequential sampling plans are described to economize on the activities of field survey personnel.

As with many aphidoid insects, the pine leaf chermid has a complex life cycle (Balch and Underwood 1950), which is briefly reviewed below. The chermid is holocyclic, requiring two host plants to complete four or five distinct generations spanning two years. Red spruce (*Picea rubens* Sarg.) and black spruce (*P mariana* (Mill.) B.S.P.) serve as primary hosts, with the former much more heavily attacked.

One winter is spent as the first instar of the fundatrix generation. All are located at the bases of spruce buds with stylets inserted. Development to the apterous adult is rapid in early spring and results in early initiation of growth of infested buds, producing incipient galls. Eggs of the fundatrix produce crawlers of the gallicola migrans generation, and these enter the incipient galls, causing their full development in a few

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days, and finally emerging as alate adults. Adult gallicolae fly, in June, to the secondary host, eastern white pine, alighting on 1-year-old or older needles. Eggs give rise to the crawler (neosistens) of the sexupara-exsule generation. The neosistentes descend the pine needles and crawl to the expanding current shoots where they insert stylets and enter apparent diapause, without development through the summer and second winter. In spite of the lack of activity, damage to pine occurs at this point with heavily infested shoots yellowed, wilted or dead by late summer (DeBoo *et al.* 1964, Allen and Dimond 1968).

Early in the second spring, most of the neosistentes mature to alate sexuparae which migrate back to spruce. A small proportion may mature to apterous exsules which produce a second generation on pine. The sexuparae produce apterous sexuales, which mate and give rise to the first instar fundatrix, completing the cycle.

Significant damage occurs only to pine, is produced only by the neosistentes, and is restricted to alternate years. In prolonged outbreaks this leads to thinning of crowns, reduction of radial growth, and some tree mortality. Spruces tolerate heavy gall formation without apparent impact.

A widespread outbreak of the chermid occurred over much of the northeast between 1953 and 1963. Earlier outbreaks of unknown extent were mentioned by Balch and Underwood (1950) and Patch (1909). Between general outbreaks, local patches of intense infestation can be found.

METHODS

Ten years' accumulation of chermid population counts and damage measurements from study plots in eastern and central Maine were used. Exact methods of counting and measuring are described in a series of papers dealing with population sampling for life table studies (Howse and Dimond 1965, Ford and Dimond 1973, Dimond and Allen 1974). While the data served as a basis for the present analysis, they were re-worked and simplified. The precision required for survey purposes can be less than that needed for population studies, and lowered labor cost is a more dominant feature.

Damage classes—Forest entomologists commonly express tree damage as light, moderate, and heavy for survey purposes. Henson and Stark (1959) formalized these damage classifications by basing them upon the biological productivity of trees and suggested the terms tolerable, critical, and intolerable as more appropriate descriptions of damage. While the terminology used may be unimportant, their establishment of definite criteria for damage levels is important; their criteria were followed here.

Degree of damage to pine produced by the chermid was based on the degree of stunting of needles. This is a single, quantifiable measure applicable to all damage classes, although it may be supplemented by considering dead or yellowed, drooping shoots of the higher chermid intensities.

Chermid populations related to damage classes—Needle stunting and dead shoots on pine result from infestation by the neosistens stage of the exsule-sexupara generation. Because of small size, this stage is difficult to count, particularly in the field. Needle length is an efficient estimator of numbers of neosistentes under most conditions (Dimond and Allen 1974). Using their regression, numbers of neosistentes corresponding to specified damage classes were calculated.

While useful for damage surveys, needle stunting has no predictive value, a necessity for planning control activities. The parent generation of the damage-causing neosistens, the gallicola migrans, is readily counted on pine (Ford and Dimond 1973). Since there is little or no redistribution between trees from the alighting of the gallicolae on pine to the production of neosistentes, populations of gallicolae also correlate significantly with needle stunting and can be used to predict damage several weeks before stunting or shoot killing becomes apparent.

A regression estimate of numbers of gallicolae per 10 fascicles on pine shoots (X) to resulting needle length (Y) on the same plots several weeks later was obtained using 41 mean plot values from different plots or the same plots different years.

At this point the field procedure for survey purposes was simplified. Counting gallicolae on fascicles is tedious at high populations when a fascicle may contain 15+ insects (Ford and Dimond 1973). If fascicles can be recorded simply as infested or uninfested, most tedium is removed. A regression estimate of numbers of gallicolae/fascicle (X) to percent of fascicles infested (Y) was calculated using data from single twigs of 79 trees from a variety of plots and years representing a wide range of damage levels. The X variable was in the form of $\log_{10}$ gallicolae per 100 fascicles +1 to avoid negative logs and allow inclusion of completely uninfested twigs (zero counts).

Prediction of damage to pines is also possible one stage earlier in the cycle of the pine leaf chermid, using numbers of galls produced on spruce as a population index. Precision of this prediction should be less since there is population redistribution between the time of gall formation on spruce and infestations of pine, with possibilities for immigration or emigration from a particular plot. Also, susceptible forests vary in their relative components of spruce and pine (Dimond and Bishop 1968). Chermids from heavily infested spruce will distribute themselves lightly over pine where there is high pine volume relative to spruce volume. Similarly lightly infested spruce may lead to heavy populations on sparse pines.

Gall count data on file were derived by pruning 4 branches per tree, one at each vertical crown quarter, measuring the branches and expressing galls as numbers/ft^2 of branch surface (Howse and Dimond 1965). This intensity of sampling seemed more than that required for survey purposes, and the data were re-examined using only one B-level branch per tree, expressing population as galls per branch with no correction for branch size. This is the simplest procedure for field workers. Plot means, based on such counts (X), were related to mean needle length of pine (Y) on 29 plots where both types of data were available. The resulting regression relationship was further refined by segregating plots into those predominantly pine and those predominantly spruce.

Survey methods and sequential sampling—Sequential survey tables were compiled for classifying damage from needle length measurements and for predicting damage from counts of pine needle fascicles infested with gallicolae and from counts of galls on spruce. Calculations followed Waters (1955) and required equations for a normal distribution in the case of needle length, for a binomial distribution with infested fascicles, and for a negative binomial distribution in the case of gall counts. With the latter, common k was calculated by the regression method of Bliss and Owen (1958).

RESULTS

Damage classes—With the pine leaf chermid, the first visible sign of damage to pine is a stunting of current needle growth (DeBoo *et al.* 1964, Allen and Dimond 1968). This provides a separation between tolerable damage levels where there is little or no stunting, and critical or intolerable damage, where marked needle stunting or greater effects are observed.

Where there is no needle stunting, there is no other macroscopic evidence of damage, and this is clearly tolerable. Some degree of stunting is tolerable, however, because of the alternate-year nature of chermid attack on pine. Pines apparently withstand the alternation of slight attacks and recovery for an indefinite period with no other noticeable effect on any growth parameter. This situation does not completely fit the tolerable or critical damage categories of Henson and Stark. Here, I include it in the tolerable category (Table 1).

Table 1. Classification of degrees of damage produced by the pine leaf chermid on white pine and population levels of several life stages that produce those degrees of damage.

Damage category	Damage description	Number of neosistentes per cm of shoot	Number of gallicolae/10 fascicles on pine shoots	% fascicles infested by galicolae	Galls per branch; stands mostly pine	Galls per branch; stands mostly spruce
Tolerable	—needles normal length, >70 mm, or slightly stunted, up to 5 mm.	<5	<0.6	<5.5	<5	<1
Critical	—needles moderately stunted, 15-25 mm; (needle length 45-55 mm), some shoots chlorotic or dead.	12-38	1.7-5.5	10.4-30.1	13-20	3-7
Intolerable	—needles heavily stunted, >35 mm; (needle length <35 mm), many shoots chlorotic or dead.	>165	>25	>65	>28	>10

At greater chermid intensities, there is greater stunting of needles, and a shortening of branch internodes the year following attack (DeBoo *et al.* 1964). Here is additional evidence of compromise of productivity, persisting through the alternate years of no attack, raising the damage level to critical. Needle stunting of 15-25 mm (normal length ca. 70 mm) is placed in this category (Table 1). It is accompanied by marked chlorosis of some needles, with some shoots (not exceeding 30%) dying in late summer. Some impact on radial growth is expected at this damage level, but because of the alternate-year nature of attack, it is difficult to separate from normal annual variation in growth. Most trees survive damage of this intensity for the several years that outbreaks of the chermid have been known to endure.

Intolerable damage occurs when mean needle lengths are reduced to 35 mm or less (about half normal length). Needles less than 20 mm rarely occur because they usually develop to this length before attack. At these damage levels, up to 100% of current shoots are dead or severely yellowed and drooping by late summer. Radial growth is reduced and continues to decline over several years despite alternate-year attacks (DeBoo *et al.* 1964). Pines of low vigor succumb after about 6 years (3 attacks) and some co-dominant trees are dead after 10 years (5 attacks).

Chermid populations related to damage classes—The numbers of neosistentes that correspond to damage classes, calculated from the regression estimates of Dimond and Allen (1974), are presented in Table 1. A new regression estimate was required to relate gallicola numbers to damage. The relationship of numbers of gallicolae per 10 fascicles (X) to resulting needle length in mm (Y) was calculated as:

$$\log_e Y = 4.093 - 0.167 \log_e X$$

$$r = -0.79,\ t = 5.16,\ d.f. = 39,\ p = <0.05$$

The numbers of gallicolae/10 fascicles that correspond to damage classes were calculated from this (Table 1). The calculated values for needle length (Y) were subtracted from normal needle length (70 mm) to express the figures in terms of stunting.

The regression estimate of percent fascicles infested with one or more gallicolae (X) to numbers of gallicolae/100 fasciles +1 (Y) was calculated as:

$$\log_{10} Y = 0.243 + 0.685 \log_{10} X$$

$$r = 0.98,\ t = 34.02,\ d.f. = 77,\ p = <0.05$$

The entries in Table 1 relating percent infested fascicles to damage classes were calculated using both regression estimates above.

Using all plot data, the regression estimate relating numbers of galls per B-level branch on spruce (X) to needle length (Y) was:

$$Y = 59.42 - 0.861\ X$$

$$r = -0.59,\ t = 3.88,\ d.f. = 27,\ p = <0.05$$

While the correlation coefficient was significant, the low coefficient of determination (r^2) indicated poor predictive powers. To improve this, the plots were segregated into those which were predominantly pine and those predominantly spruce. The few plots presenting difficult choices were omitted. This produced the two following regression equations:

A. Pine predominant

$$Y = 72.16 - 1.333\ X$$

$$r = -0.96,\ t = 9.69,\ d.f. = 9,\ p = <0.05,\ n = 11$$

B. Spruce predominant

$$Y = 61.51 - 2.488\ X$$

$$r = -0.82,\ t = 4.77,\ d.f. = 11,\ p = <0.05,\ n, = 13$$

Use of the two equations allowed calculations of two sets of gall counts corresponding to the damage classifications on pine (Table 1).

Survey methods and sequential sampling—Needle length was estimated according to Dimond and Allen (1974) who recommended pruning one twig (=1 current internode) per tree and estimating needle length from measuring 10 fascicles located centrally on the twig.

In practice the survey party should prune one branch from the mid-crown of a tree, select one twig from about the mid-portion of the branch, remove 10 fascicles from the center of the twig, align the 10 fascicle bases against a flat surface, and hold the fascicle bundle against a metric rule. The lengths of the 10 fascicles will be quite uniform, but any difference can be integrated visually.

Undamaged needles range from 65-85 mm, and 70 mm is specified as the undamaged length. For each twig, any reduction of needle length under 70 mm is entered on a tally sheet. Needle lengths of 70 mm and over are considered zero stunting.

A sequential table (Table 2) was compiled for the first 20 twigs (= trees) examined on a plot. This number of observations should be sufficient to reach a decision on damage intensity; if not, additional entries can be compiled using the equations at the bottoms of the columns.

Damage surveys should not be conducted until elongation has been completed, probably no earlier than September. Thereafter, this record of damage persists for two years (range 1-3 years) in most stands. Factors other than the pine leaf chermid can cause needle stunting, and the field worker should be sufficiently familiar with the chermid that

Table 2

Sequential table for classifying pine leaf chermid damage on white pine, using needle stunting as the criterion. Calculated at 90% confidence level, using equations for a normal distribution.

Number of twigs	Cumulative stunting (<70 mm) in mm					
examined – n	Tolerable–d_1		Critical–d_2	Critical–d_3		Intolerable–d_4
1	–		–	–		43
2	7		33	47		73
3	17		43	77		103
4	27		53	107		133
5	37		63	137		163
6	47		73	167		193
7	57		83	197		223
8	67		93	227		253
9	77		103	257		283
10	87	Continue sampling	113	287	Continue sampling	313
11	97		123	317		343
12	107		133	347		373
13	117		143	377		403
14	127		153	407		433
15	137		163	437		463
16	147		173	467		493
17	157		183	497		523
18	167		193	527		553
19	177		203	557		583
20	187		213	587		613

$d_1 = 10n - 13.18$ $d_2 = 10n + 13.18$ $d_3 = 30n - 13.18$ $d_4 = 30n + 13.18$

other possible causes can be eliminated. In general, the chermid infests pine more or less uniformly over large areas, with the exception that edge trees along roads and around clearings attract a disproportionate share, apparently carried to exposed trees by wind currents. Such trees should be avoided in sampling or included only in proportion to their importance in the stand.

Sampling of the gallicola migrans stage on pine must be done in a restricted time period, from the time all have alighted, early June, until the dead gallicolae drop from the needles about two weeks later. Even after dropping, however, debris from the egg masses remains for several days, identifying infested fascicles.

Collecting twigs for gallicola counts is as specified above for needle measurements, except that 1-year-old rather than current internodes are used. Once the internode is selected, each fascicle is removed and categorized as infested or uninfested. All fascicles on the twig are examined. If the total number of fascicles examined is less than 100, a second twig from the same branch is examined in entirety, with additional twigs examined until the total fascicles exceed 100. At this point, the percentage of fascicles infested is calculated and results compared with the sequential table (Table 3).

Table 3

Sequential table for classifying damage potential of the gallicola migrans stage of the pine leaf chermid on pine. Calculated at 90% confidence level, using equations for a binomial distribution.

Number of trees examined – n	Cumulative % infested fascicles Tolerable–d_1		Critical–d_2	Critical–d_3		Intolerable–d_4
1	–		–	–		
2	–		–	–		-
3	–		–	–		249
4	7		52	52		292
5	15		59	95		335
6	22		66	138		378
7	30		74	181		421
8	37		81	224		464
9	44		89	267		507
10	52	Continue sampling	96	310	Continue sampling	550
11	59		103	353		593
12	66		111	396		636
13	74		118	439		679
14	81		126	482		722
15	89		133	525		765
16	96		140	568		808
17	104		148	611		851
18	111		155	654		894
19	118		163	697		937
20	126		170	740		980
$d_1 = 7.39n-22.06$	$d_2 = 7.39n+22.06$			$d_3 = 43.0n-119.9$		$d_4 = 43.0n+119.9$

Sampling for galls on red and black spruce can commence about mid-May, when the rapid enlargement of infested buds allows discrimination from uninfested buds. Counting becomes easier as galls enlarge. They reach maturity in late May or early June; however, at this point pruned branches should be handled gently as the ripe galls may detach from their own weight. A pruning head with grasping clamps for lowering branches is preferable. Spent galls, from which the gallicolae have left, may be counted for perhaps two additional weeks, but thereafter the rate of abcission increases markedly. In sampling mature and spent galls, some will be noted as "imperfect" galls (Howse and Dimond 1965) which produced no gallicolae. These should not be counted.

The sampling plan is based on removing one branch per tree from the B crown level (second crown quarter from the top). The branch is pruned as close to the trunk as possible. Galls are counted and recorded. Black and red spruce are sampled in the proportions that they occur in the stand. Understory spruce is ignored; suppressed trees rarely bear galls.

Calculation of a sequential plan for galls (Tables 4, 5) presented some problems due to extreme between-crown variance in gall counts. Distribution of galls is highly overdispersed, e.g., a range of 0-165 galls per branch in one plot, deriving largely from differential infestation levels

Table 4

Sequential table for classifying damage potential of galls produced by the pine leaf chermid on spruce, where pine is a greater component of the stand than spruce. Calculated at 90% confidence level for tolerable vs. critical and at 70% level for critical vs. intolerable, using equations for a negative binomial distribution. Common k=0.901.

Number of trees	Cumulative number of galls per branch					
examined – n	Tolerable–d_1		Critical–d_2	Critical–d_3		Intolerable–d_4
1	–		–	–		95
2	–		–	–		119
3	1		–	–		144
4	9		–	–		168
5	17		–	–		193
6	25		69	75		217
7	32		77	100	Continue sampling	241
8	40	Continue sampling	85	124		265
9	48		93	148		290
10	56		100	173		314
11	64		108	197		339
12	71		116	221		363
13	79		124	246		387
14	87		131	270		412
15	95		139	294		436
20[a]	134		178	416		558
25	173		217	538		680
30	212		256	660		801
35	251		295	782		923
40	290		335	903		1045
45	329		374	1025		1167
50	368		413	1147		1289
$d_1 = 7.81n-22.21$	$d_2 = 7.81n+22.21$			$d_3 = 24.30n-70.80$		$d_4 = 24.30n+70.80$

[a] Missing values between 21 and 49 can be calculated using equations at bottom of columns.

on red spruce and black spruce (Howse and Dimond 1965). Preliminary calculations of a sequential plan suggested that very large numbers of trees would need to be sampled to reach decisions on infestation levels, particularly at high chermid population densities. Removing more than one branch per tree would not help since the major component of variance was between trees. Stratifying the sampling to consider black spruce and red spruce separately is helpful, but this requires difficult species determinations by field crews, particularly where hybrid spruces are common. The only recourse was to reduce the confidence level of sampling. Here, confidence level was held at the usual 90% level for light populations but reduced to 70% for heavy populations.

The reduction in precision can be justified by presenting data for calculations of Average Sample Number (ASN) curves for different precision levels. These predict the average sample size needed to reach a

Table 5

Sequential table for classifying damage potential of galls produced by the pine leaf chermid on spruce, where spruce is a greater component of the stand than pine. Calculated at 90% confidence level for tolerable vs. critical and at 70% level for critical vs. intolerable, using equations for a negative binomial distribution. Common k=0.901.

Number of trees	Cumulative number of galls per branch					
examined – n	Tolerable–d_1		Critical–d_2	Critical–d_3		Intolerable–d_4
1	–		–	–		33
2	–		–	–		41
3	–		–	–		49
4	1		–	–		58
5	3		14	17		66
6	4		16	26		74
7	6		18	34		83
8	8		19	42		91
9	9		21	51		99
10	11		23	59		108
11	13	Continue sampling	25	67	Continue sampling	116
12	15		26	76		124
13	16		28	84		133
14	18		29	92		141
15	20		31	101		150
20[a]	28		40	142		191
25	37		48	184		233
30	45		57	226		275
35	54		65	267		316
40	62		74	309		358
45	71		83	351		400
50	80		91	393		441
	$d_1 = 1.71n-5.78$		$d_2 = 1.71n+5.78$	$d_3 = 8.34n-24.37$		$d_4 = 8.34n+24.37$

[a] Missing values between 21 and 49 can be calculated using equations at bottom of columns.

decision at different population levels (Waters 1955). Calculations were made for the critical vs. intolerable decision. At a precision of 90%, ASN values ranged from 27-216 trees sampled on the average. With precision at 80%, this range dropped to 22-133; and at 70% it dropped further to 9-83. The last seemed the most reasonable compromise between precision and practical field effort. Reducing precision was not required at the lower populations and lower variability involved in the tolerable vs. critical decision.

To save space, some values in Tables 4 and 5 have been omitted. These can be calculated with the equations at the bottoms of the d columns.

DISCUSSION

The survey plans presented provide for the classification of damage to pine on plots, and for the prediction of damage through sampling the gallicola migrans stage of the chermid, either through direct counts of that stage on pine or by using spruce galls as an index to gallicola abundance. Through sampling galls at an early stage, one can in mid-May, predict the infestation levels of neosistentes on pine that will occur a month later. A month is short lead-time for considering control procedures.

Sampling earlier stages in the chermid cycle would be beneficial in providing greater lead-time, perhaps as much as a year. These earlier generations, the fundatrix, the sexuales, and adult sexuparae on spruce are all difficult to count. Either they are very tiny, requiring microscopic examination of foliage samples, or though somewhat larger, spread lightly over very large foliage-surface areas. The gain in lead-time does not justify the greatly increased effort involved in sampling these stages at present, but methods could be devised if warranted.

Surveys described are recommended for evaluation of damage or population levels on plots. Damage and infestation levels appear to be rather uniform within uniform forest stands. One plot or collection point is probably adequate to assess hazard in a uniform stand, but different stands vary considerably in susceptibility (Dimond and Bishop 1968) and should be treated separately in extensive surveys. Experience with the survey plan will indicate the numbers and spacing of plots needed to reach desired objectives.

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