THE IMPORTANCE OF WINTER MORTALITY IN THE NATURAL CONTROL OF THE EUROPEAN CORN BORER IN NEW ENGLAND.[1]

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Among the factors that limit the spread and occurrence of an injurious insect in numbers sufficient to cause injury to crops, the ability of a species to withstand the rigors of winter occupies an important place, particularly in colder climates. If an insect is unable to pass successfully through this troublesome period of the year, it probably will rarely become a pest of first importance, although by means of annual migration it may occur frequently in some numbers. Such a condition is found, for example, in the case of the corn earworm (*Heliothis obsoleta* Fab.) which as far as our knowledge goes cannot successfully winter in New England or other northern sections of the United States. However, this insect appears nearly every summer in numbers ranging from a mere trace to serious abundance in such areas, and as the writer has shown, (Jour. Agri. Res. 1924, XXVII p. 65) it became a pest of importance in New England in 1921. The accepted explanation of this phenomenon is that the moths of this insect migrate northward each spring and summer, arriving in larger numbers some years than in others, and in the case of favorable growing seasons, possibly pass through a partial second generation, in which case injury is most noticeable.

It may happen in the case of another species that a large number of individuals may perish in the overwintering stage, more dying during severe winters than during mild winters. This too may result in the species becoming injurious during some seasons and unimportant during others following a high or low rate of mortality during the preceding winter.

Investigations of the European corn borer (*Pyrausta nu-*

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bilalis Hübn.) in the New England area have been conducted for several years to determine the importance of winter mortality as a limiting factor in the spread and injurious occurrence of this insect. It has been found that the spread of the insect has been greatest along the coast of New England and least inland from

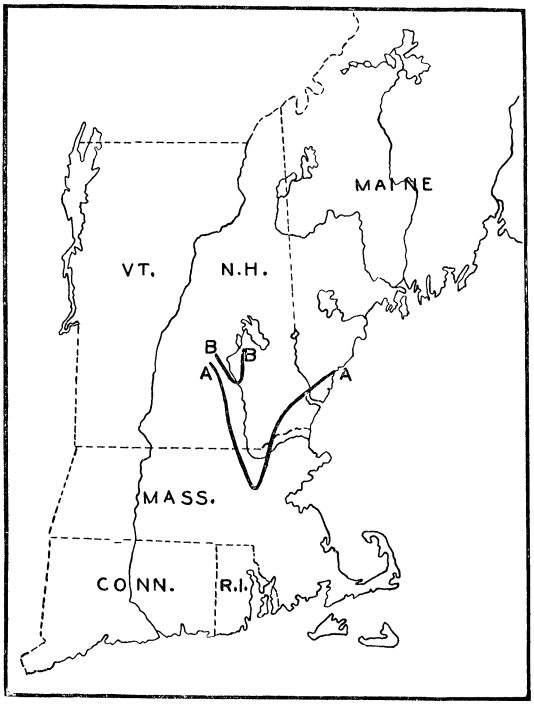

Fig. 1. Map showing the southern extent of the area of high winter mortality of the European corn borer in New England during the winters of 1922-1923 (AA) 1923-1925 (BB).

the sea. This condition may be due in part to an ability of the overwintering larvæ to survive more successfully along the coastal region where the winter temperatures due to the moderating effect of the ocean are less severe than farther inland where such a moderating effect is less noticeable. On the other hand no such condition may exist, and the more rapid spread along the coast may be the result of other causes.

In the following account of winter mortality of the European corn borer, information has been obtained in two ways. Field counts of larvæ in the spring have usually been made in localities where the insect occurs abundantly and in host plants that have remained undisturbed. Over much of the area now infested in New England, however, the insect occurs in insufficient numbers to permit such counts in numbers large enough for accuracy. In this case experiments were placed in the field in representative localities in the fall after activity of the insect had ceased and collected in the spring before activity was resumed. In the studies of the results obtained in this work, the conditions found to exist in the spring of 1922, 1923 and 1924 may be considered separately.

Observations in the spring of 1922.

During the spring of 1922 observations of winter mortality were confined to host plants that had passed the winter undis-

TABLE No. 1.

WINTER MORTALITY FOUND IN THE SPRING OF 1922 IN SEVERAL HOST PLANTS THAT HAD PASSED THE WINTER UNDISTURBED.

Host Plant	No. of localities	Total No. larvae examined	No. larvae dead	Aver. % winter mortality	Greatest % winter mortality for any locality	Least % winter mortality for any locality
Sweet Corn.....	9	901	100	11.1%	16%	6.2%
Cocklebur (Xanthium sp.)....	5	644	33	5.1%	7%	2%
Barnyard Grass (*Echinochloa crus-galli* (L). Beauv).	4	273	30	10.9%	13%	10%
Smartweed (Polygonum sp.)...	2	150	4	2.7%	4%	0%
Beggar-ticks (Bidens sp.).....	2	210	16	7.6%	8%	0%
Pigweed (*Amaranthus retroflexus* L.).....	2	200	42	21%	27%	15%
Lamb's quarters (*Chenopodium album* L.).....	1	100	8	8%	....	....

turbed. These observations were in corn and certain other host plants in which the insect occurs abundantly. The observations were also confined to that section of New England where the insect occurred in large numbers, an area bounded by Marblehead, Mass., on the north, Arlington, Mass. on the west and Quincy, Mass. on the south. The results of these observations are shown in Table I.

For all these localities and in all host plants the average winter mortality was 9.4 per cent, being highest in pigweed (*Amaranthus retroflexus* L.) and least in Cocklebur, (*Xanthium* sp.) and Smartweed (*Polygonum* sp.).

TABLE No. 2.

WINTER MORTALITY FOUND IN THE SPRING OF 1923 IN VARIOUS HOST PLANTS.

Host Plant	Number of Collections	Number of localities	Total number of larvae	Number larvae dead	Mean per cent larvae dead	Highest per cent dead-in any collection	Lowest per cent dead, in any collection
Sweet Corn.....	50	20	5,150	415	8%	24.5%	1%
Beggar-ticks (Bidens sp.).....	9	7	800	66	8.2%	19%	0%
Pigweed (*Amaranthus retroflexus* L.).	9	5	850	119	14%	24%	7%
Horseweed (*Erigeron canadensis* L.)....	1	1	100	9	9%	.....	...
Cocklebur (Xanthium sp.).....	10	6	1,050	67	6.4%	15%	1%
Barnyard grass (*Echinochloa crusgalli* (L.) Beauv.)....	8	5	750	72	9.6%	20%	4%
Smartweed (Polygonum sp.).....	7	5	650	43	6.6%	18%	0%
Dahlia (Dahlia sp.)..	4	2	400	26	6.5%	12%	3%
Prince's feather (*Polygonum orientale* L.).....	1	1	50	2	4%	.....	...
Hemp (*Cannabis sativa* L.).....	2	1	200	9	4.5%	7%	2%
Flase ragweed (*Iva xanthifolia* Nutt.).	1	1	100	17	17%	.....	...

Observations in the spring of 1923.

Investigations of winter mortality during the spring of 1923 were of two distinct sorts; first, observations of the winter mortality in host plants that had remained undisturbed through the winter and second, observations of the winter mortality in corn stalks placed in representative localities the previous fall for the purpose of obtaining information on this subject.

In Table 2 the results of the observations of winter mortality in host plants that had remained undisturbed during the winter are shown. The highest rate of winter mortality was found in pigweed (*Amaranthus retroflexus* L.) and false ragweed (*Iva xanthifolia* Nutt.); the least mortality in prince's feather (*Polyfonum orientale* L.) and hemp (*Cannabis sativa* L.). These examinations were confined to localities within the heavily infested area of Massachusetts as were the corresponding observations of the preceding spring. The average winter mortality for all localities and host plants was found to be 8.3 per cent.

In table 3 winter mortality is compared in corn stalks that had passed the winter in various conditions. Here mortality appears to have been highest in corn stubble and lowest in corn that was piled up in the fall and passed the winter in this condition.

TABLE No. 3.

WINTER MORTALITY IN CORN STALKS THAT PASSED THE WINTER IN SEVERAL CONDITIONS.

Condition of corn stalks	Number of collections	Number of localities	Total number of larvae	Number of larvae dead	Mean per cent of larvae dead	Greatest winter mortality, in any collection	Least winter mortality, in any collection
Standing stalks.....	25	19	2450	186	7.6%	14%	1%
Stalks lying on surface of soil.....	12	10	1300	101	7.8%	13%	3%
Stalks placed in piles in the fall.....	5	3	500	26	5.2%	12%	1%
Corn stubble.....	8	6	900	100	11.1%	24.5%	2%

None of the localities summarized in tables 2 and 3 were far enough inland to show any marked difference in winter mortality that might be associated with any climatic factor. In fact all these localities are in a very small area, somewhat larger than the area covered by the examinations of the previous year but confined to the heavily infested regions for the reason previously stated.

The experimental work, on the other hand, shows very clear differences in winter mortality. An experiment was placed in the late fall of 1922 in each of twenty localities representing all sections infested by this insect at that time. These experiments were placed in the field in November, 1922, after activity of the insect had ceased and were recovered in April, 1923, before spring activity began. Migration of larvæ from the corn stalks was for this reason limited to a few individuals. Each experiment consisted of ten stakes to each of which were fastened six infested stalks. The findings in the spring of 1923 may be best shown in the following table.

TABLE No. 4.

WINTER MORTALITY FOUND IN THE EXPERIMENTAL MATERIAL IN THE SPRING OF 1923.

Locality	Date placed in field	Date re-covered	Total number of larvae re-covered	Number of larvae dead	Per cent of winter mortality	Average per cent of winter mortality in group
Bristol, N. H.	11–8–22	4–26–23	1397	307	41.9	
Farmington, N. H.	11–7–22	4–25–23	1341	559	41.7	35.5
Wells, Me.	11–7–22	4–25–23	1132	507	44.8	
Tyngsboro, Mass.	11–8–22	4–14–23	990	161	16.3	22.6
Concord, Mass.	11–4–22	4–10–23	854	256	29.8	
Methuen, Mass.	11–2–22	4–14–23	1014	52	5.1	
Worcester, Mass.	10–26–22	4–11–23	1222	34	2.8	
Walpole, Mass.	11–6–22	4–11–23	661	32	4.8	3.9
Quincy, Mass.	11–4–22	4–11–23	944	31	3.3	
Manomet, Mass.	10–30–22	4–6–23	1081	14	1.3	
Wareham, Mass.	11–1–22	4–8–23	1066	10	.9	
Falmouth, Mass.	10–31–22	4–7–23	1135	13	1.1	.88
Harwich, Mass.	11–1–22	4–6–23	909	9	1.	
Wellfleet, Mass.	10–31–22	4–7–23	1106	1	.09	

Several of the experiments placed in the field and recovered are not shown in this table because birds removed such a large number of the larvæ from the stalks that too few remained from which to draw conclusions. However, several areas stand out rather distinctly as showing considerable difference in the extent of winter mortality. First, an area represented by three stations in southern New Hampshire and Maine where winter mortality averaged 35.5 per cent; second, two localities in Massachusetts in inland river valleys where winter mortality averaged 22.6 per cent; third, four localities in eastern Massachusetts where mortality averaged 3.8 per cent; and fourth, five stations on Cape Cod where winter mortality averaged only .88 per cent.

Observations in the spring of 1924

In the fall of 1923 a series of experiments similar to those described for the previous year were placed in the field in the infested area of New England. As in the former instance the experiments were placed in the field in the fall after activity of the larvæ had ceased and they were recovered in the spring before activity commenced so that the loss through larval migration was expected to be limited to a few individuals. Each experiment consisted of four stakes to each of which were attached five infested corn stalks. The stations, 50 in number, were chosen in an attempt to represent the whole infested area in as fair a manner as possible. Using Arlington, Mass., as a center, these stations were run out in lines as far as the infestation was known to exist to the northeast, the north, the north by northwest, the northwest, the west, the southwest, the south and the southeast. On these stations 47 were recovered in good condition, 16 of which exhibited considerable feeding by birds. The average winter mortality of these 16 stations which were all located in Massachusetts was 1.7 per cent of the total number of larvæ recovered. The extent of winter mortality is shown in table 5. In this table the stations are grouped in three main divisions similar to those into which the area seemed to be naturally divided the previous spring.

TABLE No. 5.

EXTENT OF WINTER MORTALITY IN EXPERIMENTS EXAMINED IN THE SPRING OF 1923.

Maine and New Hampshire		Eastern Massachusetts		Cape Cod	
Per cent of winter mortality	Number of stations	Per cent of winter mortality	Number of stations	Per cent of winter mortality	Number of stations
1%	1	0%	2	0%	1
3 to 4%	3	less than 1%	7	less than 1%	1
4 to 5%	2	1 to 2%	2	1 to 2%	3
7 to 8%	2	2 to 3%	8	2 to 3%	1
8 to 9%	1	3 to 4%	3		
9%	1	4 to 5%	2		
24%	1	5 to 6%	3		
39%	1	6 to 7%	1		
		7 to 8%	1		
Average mortality 9.3%		Average mortality 2.6%		Average mortality 1.3%	
Average mortality omitting the two highest 5.4%					

Although the mortality was not nearly as extensive as it had been during the preceding winter, the same general conditions are noted; that is, a relatively higher rate of mortality at stations in Maine and New Hampshire and an extremely low rate on Cape Cod. Only two stations showed an important mortality—Concord, N. H. (39 per cent) and Bristol, N. H. (24 per cent). Why these stations should have shown extensive winter mortality while other stations in the same region did not, is a point not clearly understood. They were in more exposed locations, however, and may not have benefited by snow protection to so great an extent as the other stations.

The following table exhibits the protecting influence of snow as found in an experiment overwintering in Wells, Maine and examined April 28, 1923.

TABLE No. 6.

THE EFFECT OF SNOW PROTECTION ON THE EXTENT OF WINTER MORTALITY.

	Sweet Corn (24 stalks)			Longfellow flint corn (29 stalks)		
	Total No. of larvae	Number dead	% of winter mortality	Total No. of larvae	Number dead	% of winter mortality
Top foot of stalks.....	130	67	51%	92	55	60%
Middle section of stalks...	435	190	43%	223	92	41%
Bottom foot of stalks.....	68	13	19%	49	13	26.5%

It is believed that the top of these stalks was exposed most of the winter, that the middle sections were exposed some of the time during the winter months and that the bottom foot was covered with snow during the whole period of severe winter weather.

Since it has been shown that the variation in winter mortality of this insect has been quite marked during the two winters, 1922-1923 and 1923-1924, it may be useful to examine the temperatures of the area covered by experiments during these winters. The extent of the area infested by this insect in New England is only some 80 miles east and west and about 175 miles north ands outh, while the extent of the injurious occurrence is only a small portion of this area. This is indeed a small area in which to study climatic conditions, but on the other hand, these conditions will be shown to be quite variable. There is considerable difference between the conditions on Cape Cod and the winter climate of the hills of Central New Hampshire where much more variable winter temperatures are experienced.

In tables 7 and 8 certain figures are presented for 15 localities throughout this larger area. These are divided into groups to correspond with the main sections of the area into which the results of the study of winter mortality seem to fall. Five localities represent the conditions of southern Maine and New Hampshire; three localities, the river valleys of northeastern Massachusetts; five localities, eastern Massachusetts and two localities

TABLE

SYNOPSIS OF WINTER TEMPERATURES

Locality	Elevation in feet	Precipitation (Total)	Minimum temperature	Date of minimum temp.	No. days minimum below 32°
Portland, Me	99	19.19	−8	Feb. 17	116
Plymouth, N. H.	500	10.47	−21	Dec. 20	117
Franklin, N. H.	440	11.06	−23	Jan. 7	118
Concord, N. H.	350	7.96	−14	Feb. 18	116
Durham, N. H.	88	12.27	−10	Dec. 20	112
Lawrence, Mass.	51	16.80	−13	Feb. 17	113
Lowell, Mass.	100	13.53	−18	Feb. 18	115
Concord, Mass.	139	14.79	−13	Feb. 17	108
Rockport, Mass.	25	12.33*	—4	Feb. 17	106
Fitchburg, Mass.	550	14.29	—9	Feb. 17	113
Worcester, Mass.	518	10.46	−3	Feb. 17	114
Boston, Mass.	124	10.06	2	Feb. 17	100
Fall River, Mass.	200	17.51	1	Feb. 24	104
Plymouth, Mass.	50	14.15	−2	Feb. 17	115
Provincetown, Mass.	40	15.95	8	Feb. 17 Mr. 29	99

*Record for March Missing.

TABLE

SYNOPSIS OF WINTER TEMPERATURE

Locality	Elevation in feet	Precipitation (Total)	Minimum temp.	Date of minimum temp.	No. days minimum below 32°
Portland, Me.	99	12.81	−18	Jan. 27	97
Plymouth, N. H.	500	11.26	−19	Jan. 27	110
Franklin, N. H.	440	9.67	−28	Jan. 28	114
Concord, N. H.	350	9.03	−18	Jan. 27	100
Durham, N. H.	88	12.95	−18	Jan. 27	101
Lawrence, Mass.	51	14.50	−14	Jan. 27	98
Lowell, Mass.	100	15.01	−18	Jan. 27	111
Concord, Mass.	139	13.40	−10	Jan. 27	105
Rockport, Mass.	25	13.15	−10	Jan. 27	84
Fitchburg, Mass.	550	11.49	−16	Jan. 27	99
Worcester, Mass.	518	11.20	−9	Jan. 27	100
Boston, Mass.	124	12.91	−6	Jan. 27	75
Fall River, Mass.	200	17.84	−2	Jan. 27	86
Plymouth. Mass.	50	11.39*	−3	Jan. 27	96
Provincetown, Mass.	40	13.25	2	Jan. 27	78

*Records for December Missing.

No. 7.

DECEMBER 1, 1922 TO MARCH 31, 1923.

No. days minimum below 0°	Total amount temp. below 32°	Total amount temp. below 0°	Greatest range in a 24 hr. period	Average daily range	Detail of greatest range in a 24 hr. period	Winter mortality averaged in groups	Number of localities
9	2204	33	38	15.3	36 to −2		
29	2826	235	39	19.	44 to 5	33.5%	3
34	2980	300	51	23.2	33 to −18		
19	2399	106	45	18.5	35 to −10		
13	2269	66	44	18.9	35 to −9		
9	2084	68	48	19.3	36 to −12		
25	2404	201	46	22.6	36 to −10	22.6%	2
23	2366	141	49	20.4	37 to −12		
1	1359	4	33	14.8	41 to 8		
12	1999	39	42	18	36 to −6		
4	1718	7	31	13.2	35 to 4	3.9%	4
0	1347	0	37	14.7	42 to 5		
0	1410	0	37	15.5	42 to 5		
2	1701	3	36	17.5	54 to 18	.88%	5
0	987	0	24	11.9	36 to 12		

No. 8.

DECEMBER 1, 1923 TO MARCH 31, 1924.

No. days minimum below 0°	Total amount of temp. below 32°	Total amount of temo. below 0°	Greatest range in a 24 hr. period	Average daily range	Detail of greatest range in a 24 hr. period	Winter mortality averaged by groups	Number of localities
5	1430	55	48	14.5	36 to −12		
11	2052	83	38	16.1	38 to 0		
22	2296	175	53	21.2	39 to −14	9. %	12
9	1677	65	40	17.3	45 to 5		
3	1624	31	39	17.6	43 to 4		
6	1407	27	41	18	40 to −1		
10	1711	49	38	21.6	38 to 0		
8	1558	35	37	19.1	41 to 4		
1	940	10	35	15.3	45 to 10		
4	1409	32	39	17.7	59 to 20	2.6%	29
4	1241	17	34	14.2	28 to −6		
					55 to 21		
2	806	9	37	13.8	37 to 0		
1	892	2	25	14.4	25 to 0		
					33 to 8		
					37 to 12		
2	1126	4	32	16.8	42 to 10	1.3%	6
0	710	0	33	13.	45 to 12		

represent Cape Cod. The information contained in these tables has been computed from records of the United States Weather Bureau and information is restricted to localities for which this Bureau obtained detailed records during the periods covered by this study. The records were mostly of maximum and minimum daily temperatures, columns headed "total amount of temperature below 32 degrees" and "total amount of temperature below 0 degrees" being obtained by adding minimum temperatures experienced at each locality. The information contained in these tables is presented as comparisons between different localities and as a comparison of the two winters. They are not intended to show that any one set of factors explains the variation in winter mortality that was found in the several localities where experiments were placed.

Several interesting points may be noticed in a study of these tables; 1, the moderating effect of the sea is shown in those stations that are located on the sea coast *i. e.*, Portland, Me., Rockport, Boston, Plymouth and Provincetown, Mass. 2. In all localities the fact that the winter of 1922-1923 was severe in comparison to the mild winter of 1923-1924, is clearly indicated. The mortality rate for each winter is for the most part readily compared with this difference in severity. 3. A distinct correlation is shown for the winter of 1922-1923 between high percentages of mortality and winter severity.

It does not appear that a slow westward spread of this insect in New England is to be accounted for by winter mortality except that barriers of high mortality may in severe winters appear, such as was represented by Concord, Mass. during the severe winter of 1922-1923 when mortality there was found to be 30 per cent. Worcester, Mass., the station located farthest west in the experiments of 1922-1923 showed 2.8 per cent of mortality (table 4) and in the experiments of 1923-1924 the average winter mortality of the six stations located farthest west in Massachusetts was but 3.6 per cent.

To the north, however, it does seem that the insect may be entering territory in which it will suffer annual winter mortality sufficient to keep its numbers below that which would allow serious injury to crops, at least in certain areas. In Merriam's

map of Life Zones of the United States (1910-Check-List of North American Birds, 3d ed., rev.; also published in separate form, Biol. Survey, U. S. Dept. Agr.) the Boreal region is shown to extend southward into central New Hampshire in the shape of a long arm. It is interesting to note that the experiments placed in Bristol, N. H. in the fall of 1922 showed the following spring 22 per cent of winter mortality and the material placed in the same location a year later and examined in April of 1924 showed winter mortality of 24 per cent. This town is located within the southern point of the boreal region referred to above and is the only locality that showed considerable winter mortality during each of the two years. Furthermore, the only other locality that showed a high percentage of mortality during the winter 1923-1924 (Concord, N. H. with 39 per cent of mortality) lies just without the southern edge of this region. This is the only area in New England where infestation by this insect is known to approach the boreal zone as portrayed in the map referred to. The information is not sufficient to warrant a prediction as to whether this insect would thrive in the Boreal zone, but it may be highly suggestive of a condition that may eventually be found to exist.

Summary.

The studies recorded in this paper were undertaken to determine what importance winter mortality played in the natural control of the European corn borer in New England. Examinations of several host plants of this insect in the spring of 1922 and the spring of 1923 showed that mortality was greatest in pigweed (*Amaranthus retroflexus* L.) and barnyard grass (*Echinochloa crusgalli* (L.) Beauv.), the mortality in pigweed averaging 21 per cent in 1922 and 14 per cent in 1923, while in barnyard grass 10.9 per cent were found dead in 1922 and 9.6 per cent perished in 1923. The average mortality in all host plants and localities was 9.4 per cent in 1922 and 8.3 per cent in 1923. All of these examinations were made in the heavily infested area of the New England infestation, bounded by Marblehead, Mass., on the north, Arlington, Mass., on the west and Quincy, Mass., on the south.

In the fall of 1922 and again in the fall of 1923 experiments consisting of corn stalks tied to stakes were set out in 20 localities the first year and 50 localities the second year, throughout the area known to be infested by this insect in New England. The results obtained by the examination of these experiments in the spring of 1923 and the spring of 1924 showed somewhat greater mortality during the winter of 1922-1923 than during the winter of 1923-1924. Winter mortality was found to be greater in localities farther north than in localities in the southern part of the infested area. Thus on Cape Cod, 5 localities averaged 0.88 per cent of mortality in the spring of 1923 and 6 localities averaged 1.3 per cent of mortality in the spring of 1924: In the remainder of the infested area in Massachusetts, 4 localities not in river valleys averaged 3.9 per cent of mortality, and 2 localities in river valleys averaged 22.6 per cent of mortality in the spring of 1923, while 29 localities averaged 2.6 per cent of mortality in the spring of 1924. In the infested area of Maine and New Hampshire 3 localities averaged 33.5 per cent of mortality in the spring of 1923 while 12 localities averaged 9.3 per cent of mortality in the spring of 1924.

From a study of winter weather of 15 localities representing the entire invested area, no one factor alone seems to be responsible for winter mortality, but the extent of mortality seems to be associated with winter severity. While winter mortality seems to be of minor importance in the area infested by the European corn borer in New England at the present time, areas of rather high mortality have appeared, and these must play some part in limiting the advance and increase of the infestation in such localities.