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JOURNAL OF AGRICULTURAL RESEARCH

VOL. 46 WASHINGTON, D. C., APRIL 1, 1933 NO. 7

HIBERNATION OF THE MEXICAN BEAN BEETLE IN THE ESTANCIA VALLEY, N. MEX.[1]

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INTRODUCTION

The investigation described in this paper formed part of a comprehensive study of the hibernation of the Mexican bean beetle (*Epilachna corrupta* Muls.) made in the Estancia Valley, N. Mex., from 1923 to 1929. The investigation was undertaken to determine, if possible, the relative effects of hibernation material, snowfall coverage, temperature, precipitation, and climatic fluctuation on the overwintering of the beetle. In addition, information was sought which would be useful in determining the possible economic importance of this insect in noninfested bean-growing areas in advance of its spread to these areas.

Repeated observations have shown that the Mexican bean beetle is a major pest of beans only when they are grown near suitable hibernation quarters. In the Estancia Valley beetles begin their fall migration in search of hibernation quarters early in September and reach their maximum flight during the latter part of September or the first part of October, depending on the seasonal variation in weather conditions, especially the occurrence of killing frost, and on the time the bean plants are harvested. The beetles begin to leave their winter quarters and appear in the fields early in June. The peak of the infestation of overwintered beetles occurs in the foothill fields during July, the exact time depending on the quantity of rainfall. In this paper winter survival and overwintering refer to the entire hibernation period.

METHODS OF INVESTIGATION

In these studies 216,340 beetles were used. They were collected from the following places: In 1923–24, from irrigated gardens in the Estancia Valley; in 1924–25, from the foothills of the Estancia Valley and the Rio Grande Valley, between Belen and Los Lunas, N. Mex.; in 1925–26 and 1926–27, from irrigated bean fields near Hoehne, Colo., and in the Rio Grande Valley north of Albuquerque, N. Mex.;

[1] Received for publication May 21, 1932; issued May, 1933.

[2] The writer's thanks are due J. E. Graf, formerly in charge of the Division of Truck-Crop Insects, Bureau of Entomology; W. H. White, in charge of the Division of Truck Crop and Garden Insects, and Neale F. Howard, in charge of the bean-insect investigations, for encouragement, inspiration, and suggestions; and to the temporary field assistants who were stationed at Estancia during the period of study discussed in the paper.

in 1927–28 and 1928–29, from the Rio Grande Valley, near Albuquerque and Belen.

In making the collections the plants were jarred with a thin board and the beetles fell into a specially constructed pan. After several hundred beetles had been collected, they were emptied into cloth sacks which the collectors carried in their belts. At intervals the contents of the sacks were dumped into a cage, in which they were transported to the laboratory by autotruck. At the laboratory the beetles were fed twice daily, the old refuse being removed from the cage at the time of feeding. Wet gunny sacks were placed over the cages to reduce the temperature and increase the humidity. The beetles were counted in the order of collection, so that each group was held at the laboratory approximately the same length of time. They were first placed in wide-mouth bottles and chilled in ice water to reduce their activity and permit rapid and accurate counting. When the desired number of beetles had been counted, they were placed in cylindrical carrying cases containing bean foliage and transferred to the hibernation cages in the field at a time when field beetles were seeking hibernation quarters.

During the season of emergence from hibernation, the cages in the foothills and valleys were observed as often as time and conditions would allow, generally daily or at least every other day. The cages located on the mountain were observed less frequently. After emergence had become general, the active beetles were removed from the cages on days when examinations were made and the numbers thus removed were recorded as the ones that had survived. These numbers were used in computing the percentages given in Table 2.

DESCRIPTION OF CAGES

The hibernation cages were constructed of 2 by 4 inch lumber, and measured 4 feet wide, 6 feet long, and 2½ to 4 feet high. They were covered with 14-mesh screen wire and had removable tops. (Fig. 1.) After the beetles had become dormant, the tops were removed and the cages covered with 1-inch mesh wire. This permitted snow to enter the cages but excluded intruders. The original tops were replaced in the spring before the beetles resumed their activity. In this manner conditions closely approximating those prevailing in the surrounding area were secured. Extra heavy wire screening was placed vertically in the soil to a depth of 12 inches around the base of each cage to prevent burrowing animals from gaining access to the hibernating beetles. When the cages were placed in the soil, care was taken to preserve the forest floor or natural cover.

LOCATION OF CAGES

Details as to the location of the hibernation cages are given in Table 1. Cage 1 was located near the upper edge of the fir-spruce association, or Canadian Zone, and cages 2 and 3 near the lower border of this zone. Cage 4 was placed at the upper edge of the ponderosa (western yellow) pine forest, or Transition, zone, and cages 5, 6, 7, and 8 in the lower half of this zone. Cage 9 was located in the piñon or nut-pine association that clothes the lower rolling foothills bordering the valley on the west and the ponderosa pine forest zone. Cages 10, 11, and 12 were placed in the short-grass or semidesert formation of the Estancia Valley. The line of hibernation cages extended in an eastern and western direction for 25 miles and ascended from an elevation of 6,100 to one of 9,000 feet.

Cage 2 was placed against the base of a high rim rock, which afforded some protection and decreased the amount of precipitation entering the cage. Cages 5 and 7 were located on the south side of Tajique Canyon just below the first rim rock and were also well protected.

FIGURE 1.—Type of cage used in hibernation investigation, with instrument shelter in background

Cage 8 was placed at the base of a steep hill, 30 feet from the canyon stream, where it received a large amount of moisture from both precipitation and seepage. Cage 11 was set between the laboratory and the insectary, where it received the maximum quantity of snow and, being protected from the wind, the hibernation material was evenly covered. The remaining cages were not protected from the wind and in them the snow coverage was not evenly distributed over the hibernation material.

WEATHER RECORDS

The temperature, precipitation, and snowfall records have been compiled from the meteorological records of cooperative observers of the United States Weather Bureau and from records taken at the Estancia laboratory. The three cooperating weather stations are located as follows: (1) At Rea's ranch, on Bosque Mountain, at an elevation of 9,215 feet, latitude 34° 46′ N., longitude 106° 20″ W., in the Canadian Zone, near cages 1 to 4, inclusive; (2) near Tajique, in the foothills at an elevation of 7,100 feet, latitude 34° 48′ N., longitude 106° 18″ W., 3 miles northeast of the foothill cages in the Transition Zone; (3) at Estancia, in the Upper Sonoran Zone, at an elevation of 6,100 feet, latitude 34° 45′ 20″ N., longitude 106° 3″ W., in the short-grass or semidesert formation, near cages 10, 11, and 12.

TABLE 1.—*Location of hibernation cages*

Cage No.	Situation	Slope of situation	Elevation	Exposure	Topography	Soil	Environment	Plant association
					CANADIAN ZONE			
		Degrees	*Feet*					
1	Mountain	45	9,000	North	Mountain side	Black loam	Dense forest of fir and spruce, a few maple and black locust.	Fir-spruce.
2	do	45	8,400	do	Midway on slope of mountain canyon.	do	Dense forest of scrub oak, maple, and a few fir and spruce.	Do.
3	do	45	8,400	do	do	do	do	Do.
					TRANSITION ZONE			
4	Mountain	10	8,400	Southeast	Mountain side	Black loam	Dense forest of scrub oak, a few pine, cedar, and black locust.	Pine.
5	Foothill	20	7,050	North	On side of broad canyon	do	Open forest of pine and white oak, dense near cage.	Do.
6	do	20	7,050	East	Hill, near center of slope	Sandy black loam	Open forest of pine and white oak, large pines near cage.	Do.
7	do	7.5	7,000	do	On side of broad canyon	Black loam	Open forest of pine and white oak	Do.
8	do	45	6,975	North	Near bottom of narrow canyon.	do	Open forest of pine and white oak, dense near cage.	Do.
					UPPER SONORAN ZONE			
9	Foothill	2	6,800	North	Hill, near top	Red clay loam	Open forest of cedar and piñon	Piñon-juniper.
10	Valley	0	6,100	Open	Broad valley	Sandy gray loam	Sod	Short grass or semidesert.
11	do	0	6,100	do	do	Black loam	Transplanting bed near insectary and laboratory	Do.
12	do	0	6,100	do	do	Sandy gray loam	Sod	Do.

GENERAL FEATURES OF ESTANCIA VALLEY

PHYSIOGRAPHY

Estancia Valley [3] (fig. 2) extends from about latitude 34° 20′ to 35° 17′ N., and longitude 105° 42′ to 106° 24′ 30″ W. Its drainage basin forms a depression with no outlet, having a maximum extent of about 65 miles north and south and 40 miles east and west, and includes an area of about 2,000 square miles.

Four physiographic areas are recognized in the valley—the valley floor, hills, mesas, and mountains. Estancia Valley is separated from the Rio Grande Valley by the Manzano Mountain range, which extends north and south and parallels the two valleys for 30 miles as an unbroken mountain wall. This range has an abrupt slope fronting

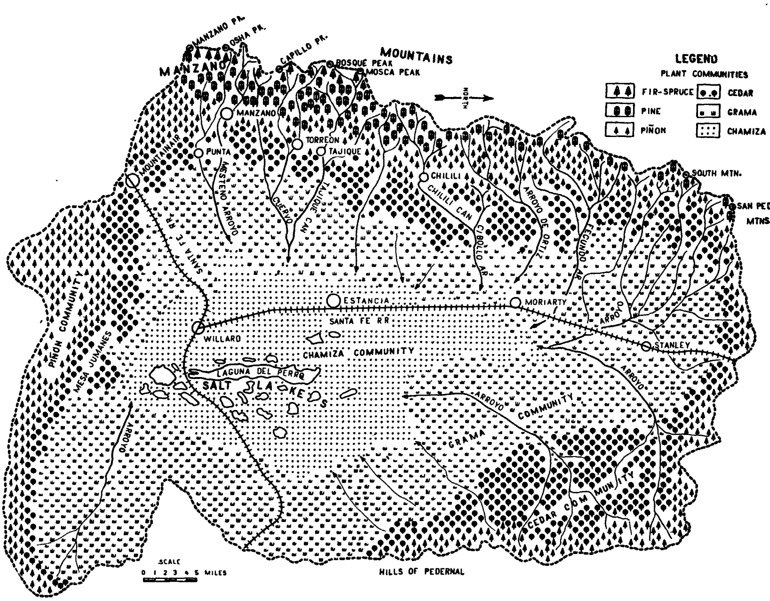

FIGURE 2.—Sketch of Estancia Valley, showing plant communities

the Rio Grande Valley by reason of an uplift which exposes the rock strata on its western slope in the form of a precipitous escarpment of about 4,000 feet. The long eastern slope follows the dip of these strata and gradually descends into the foothills of Estancia Valley. (Fig. 3.) At the northwest corner of the valley are South Mountain and the San Pedro Mountains, two isolated masses. Between South Mountain and the north end of the Manzano Range, a distance of nearly 15 miles, the mountain wall is interrupted, the divide between the Estancia and Rio Grande Valleys here being formed by a rugged hilly tract. From the center of the valley northward the surface rises gently to a point where the plain ends abruptly in an escarpment. On the northeast the valley is bordered by a mesa. Farther south are the Hills of Pedernal, which divide the valley from the treeless grass-

[3] MEINZER, O. E. GEOLOGY AND WATER RESOURCES OF ESTANCIA VALLEY, NEW MEXICO, WITH NOTES ON GROUND-WATER CONDITIONS IN ADJACENT PARTS OF CENTRAL NEW MEXICO. U. S. Geol. Survey Water-Supply Paper 275, 89 p., illus. 1911.

land plains of the Pecos slope. The hills that inclose the valley on the southwest are lower and less rugged. On the southeast the valley is terminated abruptly by the Mesa Jumanes, whose escarpment, 500 feet high, forms an imposing physiographic feature. The area drains into a series of large salt lakes in the southeastern part of the valley.

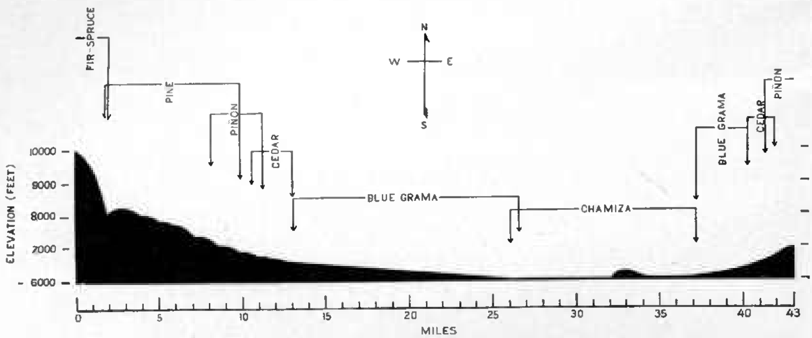

FIGURE 3.—Cross section of the plant associations in the Estancia Valley

The lowest point in the valley has an elevation of about 6,000 feet and the highest point in the Manzano Mountains is about 10,000 feet.

The climate of this area, with its cool summers and cold winters, is determined by its elevation, its inclosed nature, and the altitudinal range of approximately 4,000 feet. The highest and lowest temperatures occur at the lowest elevations.

PLANT ASSOCIATIONS

The valley floor is divided into two plant zones, the alluvial slopes or plains and the ancient lake-bed region. The alluvial slopes are covered with a short-grass sod in which blue grama (*Bouteloua gracilis*)

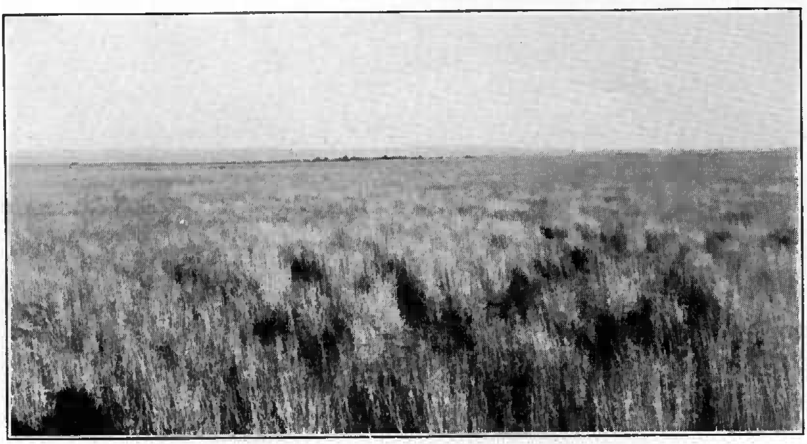

FIGURE 4.—Blue grama (*Bouteloua gracilis*) sod

(fig. 4) predominates. The lake-bed area is dominated by a small-leafed shrub, fourwing saltbush (*Atriplex canescens*), commonly called chamiza in New Mexico. (Fig. 5.) In the fourwing-saltbush community are extensive areas that have a shallow water table and a high alkali content. These areas are covered by bluestem (*Andropogon furcatus*). Although most of the central part of the valley is flat,

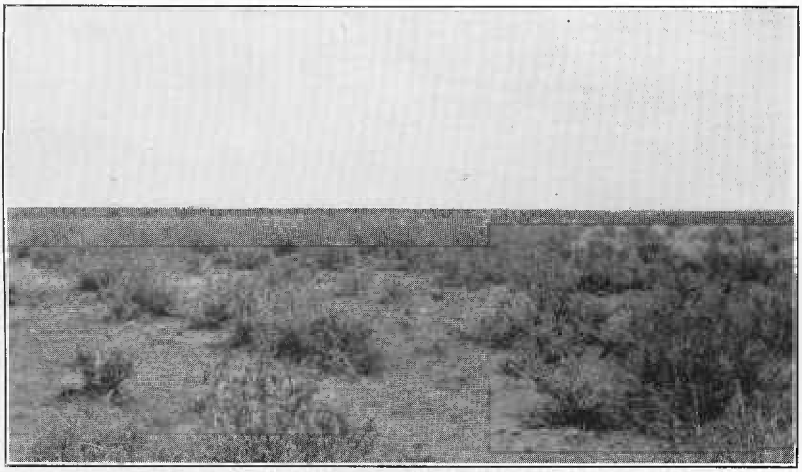

FIGURE 5.—Fourwing saltbush (*Atriplex canescens*) that is found on the extensive areas of the old lake and the salty mud flats

extensive depressions containing salty mud flats (salt basins) devoid of vegetation are found.

The western foothills are divided into four forest zones (fig. 2), whereas the other sides of the valley afford only two. The lower roll-

FIGURE 6.—Cherrystone juniper (*Juniperus monosperma*) that sparsely clothes the lower rolling hills

ing hills that border the valley on the east and west are sparsely clothed with cherrystone juniper (*Juniperus monosperma*). (Fig. 6.) The mesa and the intermediate forest or nut-pine region are covered with piñon (*Pinus edulis*). (Fig. 7.) (These types of vegetation fall within the Upper Sonoran Life Zone of Merriam.) The ponderosa pine (*Pinus ponderosa*) covers the higher rolling hills (Transition Zone)

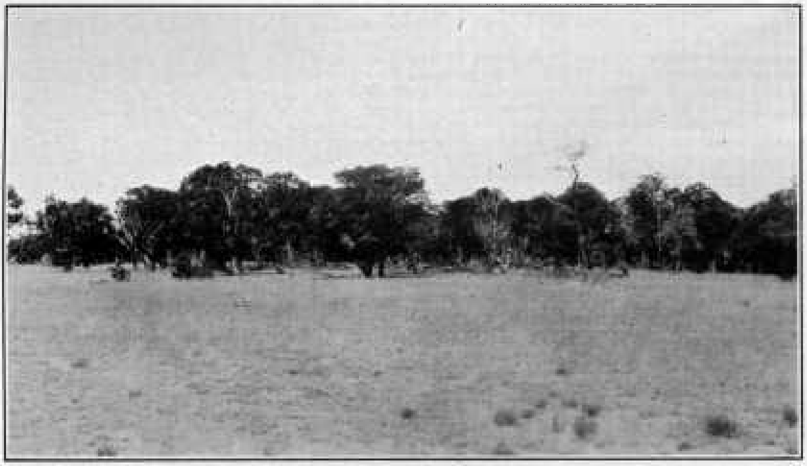

FIGURE 7.—Piñon (*Pinus edulis*) that covers the mesa and intermediate forest or nut-pine region

along the foot of the Manzano Mountains and the lower and drier slopes of the mountains. (Fig. 8.) In places there are relatively open stands of this pine with a clean floor, but more often there is an under-

FIGURE 8.—Ponderosa pine (*Pinus ponderosa*) that covers the higher rolling hills and the lower and drier slopes of the mountains

growth of trees and shrubs, the most common being the oak (*Quercus gambelii*). In the elevated areas of the Manzano Mountains (Canadian Zone) the dominant evergreen trees are Douglas fir (*Pseudotsuga mucronata*) and Engelmann spruce (*Picea engelmanni*). White oaks

(*Quercus utahensis* and *Q. novomexicana*), Rocky Mountain maple (*Acer glabrum*), and quaking aspen (*Populus tremuloides*) are the deciduous trees occurring in greatest abundance.

HIBERNATION OF BEETLES IN THE VARIOUS LIFE ZONES

CANADIAN ZONE

The results obtained in the Canadian Zone in a period of five years show that in four of the years no beetles survived and in the fifth year (1926–27) only 42, or 0.56 per cent, survived. (Table 2.) During the 5-year period a total of 38,500 beetles was used, and during 1926–27, 7,500 beetles were used; the percentage survival for the five years was therefore 0.11. The winter of 1926–27 was unusually warm, with an average daily departure from normal temperature of 2° F. The precipitation was nearly normal.

In order to determine whether the character of the hibernation material was an important factor in the survival of beetles in this zone, pine needles were added to the oak leaves in cages 2 and 3 in the fall of 1926 and in the following years. (Table 2.) In 1927–28, when the average daily temperatures was 0.9° F. above normal and the precipitation 0.21 inch below normal (Table 9), no beetles survived. In 1928–29 the departures from normal were −1.4° F. and +0.26 inch of precipitation, and again no beetles survived. It is evident that in this zone winter mortality is due to climatic factors, and not to the character of the material used as a shelter for the beetles.

TRANSITION ZONE

In the Transition Zone 133,340 beetles were used in six years, with a total survival of 13,114, or 9.84 per cent. At the upper edge of the ponderosa pine belt (cage 4) 5.01 per cent survived over a period of six years. In cages 5 and 7 more than 12 per cent survived the dormant period. The locations of these cages are typical of favorable natural hibernation quarters. Cage 8 showed the lowest percentage of survival in this zone, 3.16 per cent. It is doubtful whether beetles in search of hibernation quarters would under natural conditions attempt to hibernate in locations in which moisture conditions were so unfavorable as they were in this cage.

The results of the six years' experiments indicate that the ponderosa pine forest zone (fig. 8) is the natural hibernation quarters of the beetle in the West and that it is even more favorable when oak trees are present in the association. This indication is confirmed by the fact that beetles are found hibernating naturally chiefly in this zone.

UPPER SONORAN ZONE

In the Upper Sonoran Zone 44,500 beetles were employed with a total survival of 1,210, or 2.72 per cent, in all four cages (Nos. 9 to 12) where materials both native and foreign to the zone were used as shelter. In cases 9 and 10, where the sheltering material was native to the zone, the percentage of beetles which hibernated successfully averaged 0.34. This average does not include the results for cage 9 in the season 1926–27, when the compact piñon needles in that cage were loosened in order to test the suitability of masses of needles as hibernation material. In the loosened needles 16.68 per cent of the insects

TABLE 2.—*Hibernation results, 1923–24 to 1928–29*

Cage No.	Season	Hibernation material	Date beetles were introduced	Beetles introduced	Beetles survived	
				Number	*Number*	*Per cent*
		CANADIAN ZONE				
1	1924–25	Spruce needles and cones	Sept. 30	5,000	0	0
	1925–26	Maple leaves and spruce needles	Oct. 10	2,500	0	0
	1926–27	do	Sept. 29	2,500	2	.08
	1927–28	do	Oct. 4	1,000	0	0
	1928–29	do	Sept. 28	2,500	0	0
2	1924–25	Oak leaves and fir needles	Oct. 2	3,000	0	0
	1925–26	do	Oct. 8, 15	5,000	0	0
	1926–27	Oak leaves and pine needles	Sept. 29	2,500	28	1.12
	1927–28	do	Oct. 4	1,000	0	0
	1928–29	do	Sept. 28	2,500	0	0
3	1925–26	Oak leaves and fir needles	Oct. 8, 15	5,000	0	0
	1926–27	Oak leaves and pine needles	Sept. 29	2,500	12	.48
	1927–28	do	Oct. 4	1,000	0	0
	1928–29	do	Sept. 28	2,500	0	0
		TRANSITION ZONE				
4	1923–24	Oak leaves and pine needles	Oct. 9	5,004	208	4.16
	1924–25	Oak leaves and cedar needles	Oct. 7	2,000	9	.45
	1925–26	do	Oct. 15	1,500	36	2.40
	1926–27	do	Sept. 29	1,500	248	16.53
	1927–28	do	Oct. 4	1,000	3	.30
	1928–29	do	Sept. 28	2,500	172	6.88
5	1924–25	Oak leaves and pine needles	Oct. 15	1,296	130	10.03
	1925–26	do	Oct. 10, 12	5,000	1,112	22.24
	1926–27	do	Oct. 2	10,000	2,829	28.29
	1927–28	do	Oct. 3, 5	10,000	75	.75
	1928–29	do	Sept. 29	10,000	295	2.95
6	1925–26	Pine needles	Oct. 19	1,500	339	22.60
	1926–27	do	Oct. 4	1,500	[a] 206	13.73
	1927–28	do	Oct. 6	2,500	[b] 123	4.92
	1928–29	do	Oct. 4	2,500	[b] 38	1.52
7	1923–24	Oak leaves and pine needles	Oct. 17	5,540	1,304	23.54
	1924–25	do	Oct. 5, 7	5,000	363	7.26
	1925–26	do	Oct. 11	5,000	1,812	36.24
	1926–27	do	Oct. 3, 9	15,000	2,433	16.22
	1927–28	do	Oct. 3, 5	10,000	230	2.30
	1928–29	do	Oct. 4	10,000	358	3.58
8	1925–26	do	Oct. 10 to 20	10,000	183	1.83
	1926–27	do	Oct. 4	5,000	516	10.32
	1927–28	do	Oct. 5	5,000	90	1.80
	1928–29	do	Oct. 4	5,000	2	.04
		UPPER SONORAN ZONE				
9	1925–26	Piñon needles	Oct. 11	2,500	70	2.80
	1926–27	Piñon needles (loosened material)	Oct. 4	2,500	417	16.68
	1927–28	Piñon needles	Oct. 6	2,500	0	0
	1928–29	do	Oct. 4	2,500	0	0
10	1923–24	Russian thistles and other weeds	Oct. 23	2,500	4	.16
	1924–25	Bean hulls and Russian thistles	Oct. 11	2,000	0	0
	1925–26	do	Oct. 10	2,500	0	0
	1926–27	do	Oct. 7	2,500	0	0
	1927–28	do	do	2,500	0	0
	1928–29	do	Oct. 10	2,500	0	0
11	1925–26	Oak leaves and pine needles	Oct. 18	2,500	545	21.80
	1926–27	do	Oct. 7	5,000	103	2.06
	1927–28	do	do	2,500	23	.92
	1928–29	do	Oct. 4	2,500	28	1.12
12	1926–27	do	Oct. 8	2,500	20	.80
	1927–28	do	Oct. 7	2,500	0	0
	1928–29	do	Oct. 4	2,500	0	0

[a] On May 3 shelter placed over cage to exclude natural precipitation.
[b] On May 10 shelter placed over cage to exclude natural precipitation.

passed the winter successfully. In the three seasons that cage 9 contained compact masses of needles, not a single beetle survived during two seasons and only 2.8 per cent during another season, the average survival for the three seasons being 0.93 per cent. These results indicate that the natural hibernating material in the cherrystone juniper and piñon forest zone does not provide proper conditions for winter survival of the beetle, owing primarily to the fact that few of the beetles are able to enter the compact masses of needles. This conclusion conforms with observations made by Graf,[4] who did not find a single beetle hibernating in the piñon pine and cherrystone juniper needles in the foothills during the season of 1921–22, when the heaviest infestation of beetles ever known in the Estancia Valley was recorded. The needles of the piñon and cherrystone juniper trees are very short, and only a light fall occurs yearly, resulting in a scant compact mass around the base of each tree. Judging from the results obtained in cage 9 during 1926–27, however, it may be concluded that if the beetles were able to penetrate these masses of needles they would find proper protection for winter survival.

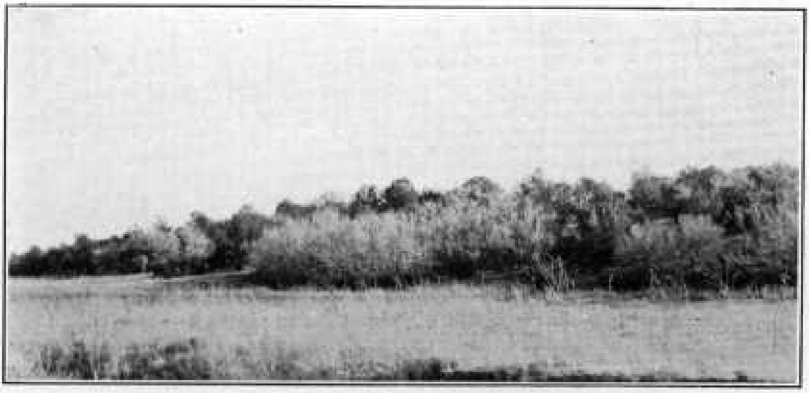

FIGURE 9.—Oak "mottes" found along the streams in the cedar and nut-pine forest zones

The results from cage 10, which contained materials common to the cultivated and sod areas of the Sonoran Zone, showed that there was only one season out of the six in which any beetles survived. Of the 14,500 beetles used in this experiment, 4 lived through the winter of 1923–24. Where oak leaves and pine needles, material which is foreign to the zone, were used as hibernation shelter (cages 11 and 12), 3.6 per cent of the beetles survived. Where protection from the wind was afforded, which allowed for an even distribution of snow and decreased sand coverage, as in cage 11, the percentage of beetles that overwintered averaged 5.59. In cage 12, which contained the same material but which was exposed to the wind, only 0.27 per cent passed the winter during the three years the experiment was in progress.

These facts show that sheltering material found naturally in the open areas of this zone does not provide the beetle with proper coverage for successful winter survival. The greater survival in the cages containing oak leaves and pine needles explains why beetles can hibernate in oak "mottes" (fig. 9) found along streams and

[4] Graf, J. E. Unpublished data.

canyons. The oak mottes represent an outcropping of the Transition Zone at the upper edge of the Upper Sonoran Zone due to topography, exposure, temperature, and soil moisture in that particular vicinity.

MISCELLANEOUS FACTORS AFFECTING MORTALITY OF BEETLES

DUST STORMS

In the Estancia Valley dust storms occur frequently in the spring and occasionally in other seasons. These storms may last for a few hours or for several days, and the quantity of dust carried at times is enormous. It has been found that the quantity of dust deposited is in direct proportion to the quantity and size of any obstruction in its path and the efficiency of this obstruction as a windbreak. Russian thistle (*Salsola pestifer*) is the most abundant and widely distributed weed in the Estancia Valley. When mature it breaks off at the surface of the ground and rolls before the wind. These weeds finally lodge and pile up along fences (fig. 10), where they

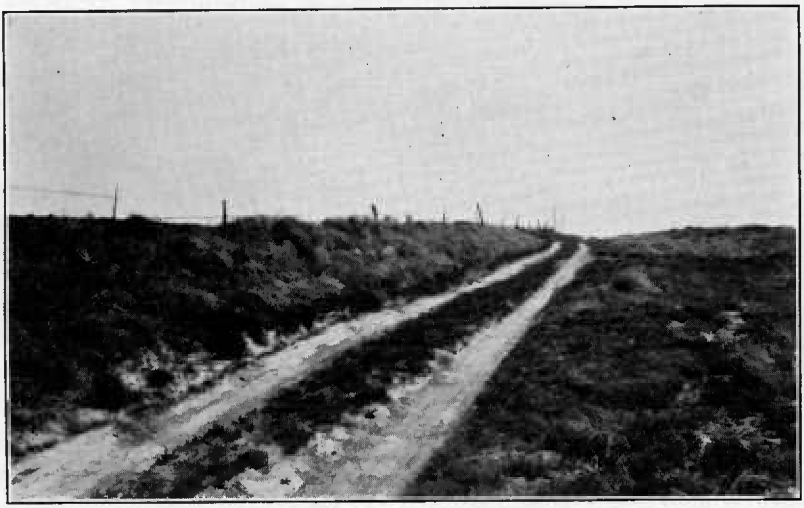

FIGURE 10.—Russian thistles (*Salsola pestifer*) piled up along a fence by the wind

break the force of the wind so that it deposits a large quantity of sand and dust on the leeward side of the fence, until the fence is finally covered. This accumulation alone prevents the successful hibernation of the bean beetle on the alluvial slopes and valley floor.

CHARACTER OF HIBERNATION MATERIAL

The character of the hibernation material is an important factor in the successful overwintering of the insect. A suitable material is one that permits beetles to enter and emerge readily, and at the same time protects them both from low temperature and from rapid changes of temperature. It must also be able to retain moisture so that too rapid desiccation of the beetles will not occur. A mixture of oak leaves and pine needles, such as is often found in well-protected places, is the most favorable material. This finding confirms the results of Howard and English [5] and Thomas [6] obtained in studies of the beetle in the Southern States. Compact material, such as juniper and piñon needles, is unsuitable because the beetles are unable to enter it. Weeds are the most unsatisfactory material because they permit rapid changes in temperature and moisture.

SNOWFALL

A protection of snow during periods of subzero weather is essential for successful hibernation. The following example will illustrate this point. On December 19, 1927, a thermograph measuring air temperature registered −20° F., as compared with 21° (fig. 12, D) registered by a distance thermograph that was recording the temperature of the hibernation material of oak leaves and pine needles under 8 inches of snow in cage 7 near by. Again on February 10, 1929, the air temperature was −27° at Estancia, as compared with a temperature of 25° under a 6-inch blanket of snow in the hibernation material of oak leaves and pine needles in cage 11 near by. (Fig. 12, A.) At the same time the temperature in the hibernation material in the adjacent cage 10, where Russian thistles were used, was −1°. (Fig. 12, B.) Weeds hold the blanket of snow off the ground and permit lowering of temperature. The water content of 1 inch of snow may vary from 0.03 to over 0.10 inch,[7] according to temperature, altitude, etc., and this variation may affect its insulating properties.

DRAINAGE

A comparison of the results obtained from cages 5 and 8 shows that drainage is a factor of importance in the successful hibernation of the beetle. Both cages were located on the northern exposure under similar climatic conditions and with the same type of hibernation material. The former cage had good drainage, while the latter stood on ground that was constantly wet by seepage. During the seasons of 1925–26 and 1926–27 the percentage survival in cage 5 was 22.24 and 28.29, respectively, while in cage 8 it was only 1.83 and 10.32.

TIME OF KILLING FROST

The time at which the first killing frost occurs is an important factor in winter survival. From 1923 to 1928 the time of the first killing frost ranged from September 14 to October 22, with September 23 as the average. The growing season in the Estancia Valley is comparatively short, and the reproduction period of the Mexican bean beetle is still shorter, for the beetles do not emerge from hibernation until stimulated by the summer rains. Counts of overwintered beetles in the same field in the foothills for the six summers showed that the largest population of old beetles was present from July 8 to 20, with July 14 as the average date. The developmental period from egg to adult ranges from 40 to 45 days during the summer. When the killing frost occurs early and destroys the bean, which is the only host plant in the valley, a large percentage of the newly

[5] Howard, N. F., and English, L. L. STUDIES OF THE MEXICAN BEAN BEETLE IN THE SOUTHEAST. U. S. Dept. Agr. Bul. 1243, 51 p., illus. 1924.
[6] Thomas, F. L. LIFE HISTORY AND CONTROL OF THE MEXICAN BEAN BEETLE. Ala. Agr. Expt. Sta. Bul. 221, 99 p., illus. 1924.
[7] Data from correspondence with C. F. Linner, U. S. Weather Bureau, Santa Fe, N. Mex.

emerged beetles are forced into hibernation in a weakened condition, and the hibernation period is lengthened. On the other hand, a late killing frost prolongs the feeding period and shortens the hibernation period. It is therefore evident that a variation of 38 days in the occurrence of the killing frost in autumn is indirectly a factor in the successful hibernation of the insect.

PROXIMITY OF HIBERNATION QUARTERS AND SEASONAL RAINFALL

In the West the Mexican bean beetle is not a major pest in any bean-growing district which does not have suitable hibernation quarters comparatively close to the bean area (within 50 to 70 miles) and which does not have a seasonal rainfall of at least 5 inches rather evenly distributed over the hibernation period. Furthermore, this beetle has never been reported as a serious pest where a well-defined dry hibernation season occurs, especially when the dry season is coincident with high temperatures. In the dry-farmed area in eastern Colorado, for example, the beetle is not known to occur, and in Union County, N. Mex., it has never been a pest of economic importance.

HIBERNATION IN RELATION TO ALTITUDE

Considered independently of all other factors, and within certain limits, there seems to be no close relation between altitude and successful hibernation of the bean beetle, as is shown by the results for cages 4 and 7, located in the ponderosa pine zone. (Table 3.) In cage 4 a small quantity of juniper needles was used with oak leaves instead of pine needles as was the case in cages 7 and 11.

TABLE 3.—*Effect of altitude on hibernation of Mexican bean beetles*

Cage No.	Elevation	Beetles surviving					
		1923–24	1924–25	1925–26	1926–27	1927–28	1928–29
	Feet	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
4	8,400	4.15	0.45	2.40	16.53	0.30	6.88
7	7,000	23.50	7.26	36.24	16.22	2.30	3.58
11	6,100	----------	----------	21.80	2.06	.92	1.12

The data for 1923–24, 1924–25, 1925–26, and 1927–28 show that a larger percentage of the insects survived at the lower elevation than at the higher. The figures for 1926–27 and 1928–29, on the other hand, show a greater survival at the higher elevation. In the case of cage 11, at a still lower elevation, the survival was smaller for these two seasons, but larger in 1925–26 and 1927–28 than in cage 4 at the highest elevation.

These conflicting data indicate that elevation alone has no real significance within the zone of successful hibernation. It is known that the altitude of the ponderosa pine zone ranges from 6,850 to 8,400 feet on the eastern exposure and from 8,000 to 9,000 feet on the western exposure, with a great variation on the northern and southern exposures in the Manzano Mountain Range. Pearson [8] has found that temperature and moisture, not elevation, are the limiting factors in the distribution of trees in the Southwest.

[8] PEARSON, G. A. FOREST TYPES IN THE SOUTHWEST AS DETERMINED BY CLIMATE AND SOIL. U. S. Dept. Agr. Tech. Bul. 247, 144 p., illus. 1931.

RELATION OF EXPOSURE TO SURVIVAL OF BEETLES

The results of six seasons' work, as shown in Table 4, justify the conclusion that exposure, at least so far as locations on eastern, southeastern, and northern slopes are concerned, affects the survival of beetles under mountainous conditions in New Mexico. The important factor in this connection seems to be the topography of the locality as it governs the intensity or degree of shade. Where the hills are low and the slope is comparatively short, as is the case with the situation of cages 5 and 7, exposure considered apart from other factors seems to have no real significance within the zone of hibernation, but it has an important bearing upon beetle mortality in hibernation during certain seasons. The locations of cages 5 and 7 were similar as to topography, drainage, elevation, flora, soil, and hibernation material, and their close proximity permitted precipitation stimulus to affect the beetles in the two cages similarly.[9] The only important difference was in exposure.

TABLE 4.—*Effect of elevation and exposure on hibernation of Mexican bean beetles*

Cage No.	Elevation	Exposure	Beetles surviving					
			1923–24	1924–25	1925–26	1926–27	1927–28	1928–29
	Feet		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2	8,400	North	----------	0	0	1.12	0	0
4	8,400	Southeast	4.15	0.45	2.40	16.53	0.30	6.88
5	7,050	North	----------	10.03	22.24	28.29	.75	2.95
7	7,000	East	23.50	7.26	36.24	16.22	2.30	3.58
8	6,975	North	----------	----------	1.83	10.32	1.80	.04

There was no cage in operation on the northern slope during the season of 1923–24. During the winters of 1925–26, 1927–28, and 1928–29 more insects survived in cage 7 on the eastern slope than in cage 5 on the northern. In 1924–25 and 1926–27, however, more beetles hibernated successfully on the northern slope. The average survival for the five winters shows no significant difference for the two exposures, being 12.24 per cent for the northern and 11.55 per cent for the eastern. When each year is considered separately, however, and such other factors as sunlight, evaporation, temperature, and soil moisture are taken into consideration, it is evident that exposure has a direct influence on the beetle during its dormant period. It will be shown later that in 1924–25 and 1926–27, when more beetles survived on the northern than on the eastern slope, the winters were followed by mild, dry springs, whereas in 1925–26, 1927–28, and 1928–29, when more beetles hibernated on the eastern slope, the springs were cold and wet. A study of beetle hibernation on any one exposure will therefore not give a true index of winter mortality from season to season, as is indicated in Figure 11.

Where the slope is steep and the distance from the cage to the top of the slope is comparatively great, as in cages 2 and 4, exposure considered apart from other factors seems to have a real significance. These two cages were located at the same elevation less than 300 yards

[9] DOUGLASS, J. R. PRECIPITATION AS A FACTOR IN THE EMERGENCE OF EPILACHNA CORRUPTA FROM HIBERNATION. Jour. Econ. Ent. 21: 203-213, illus. 1928.

apart on an eastern spur of Bosque Mountain. Cage 2 was near the lower edge of the fir-spruce association and cage 4 at the upper edge of the ponderosa pine zone, as in this vicinity the Canadian and Transition Zones dovetail into each other on account of the topography and slope exposure. The general air temperature and the precipitation occurring over the two cages were obviously very nearly the same. Cage 4, located on the southeastern slope, was exposed to the sun's rays longer than cage 2 on the northern slope; consequently, the evaporation was greater and the temperature of the duff higher on the southeastern slope. Because of the lower temperature the snow lasts longer on the northern slope, which makes it appear to have more

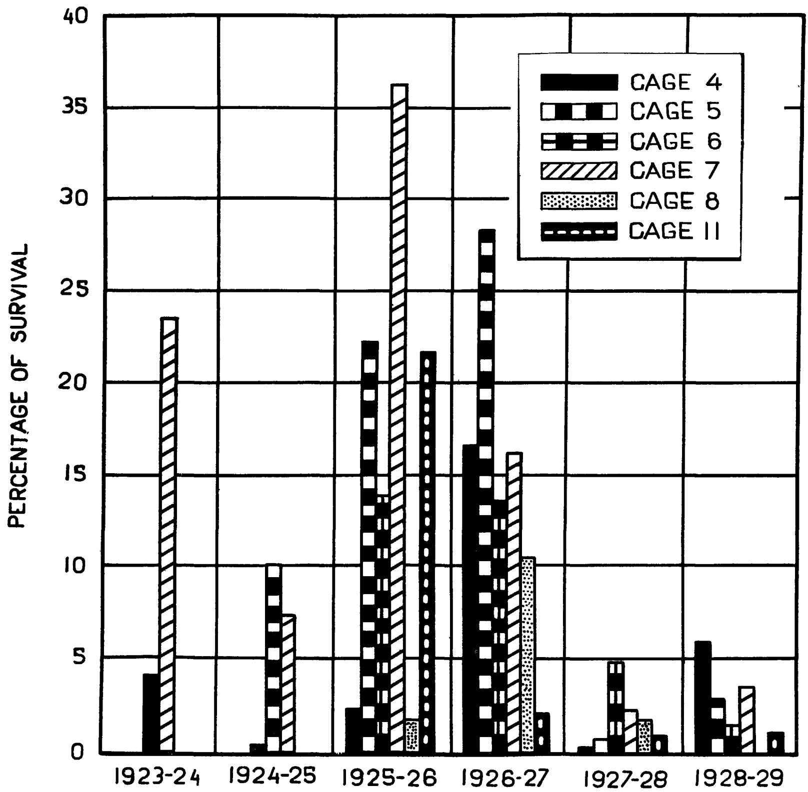

FIGURE 11.—Percentage of beetles surviving hibernation in different cages

moisture than the warmer slopes of the mountain. During the last five seasons of the experimental work 14,000 beetles were introduced into cage 2 and 8,500 into cage 4. In cage 2, 28 beetles survived and in cage 4, 468. (Table 2.) From these results it is apparent that at the same elevation in cages 300 yards apart more beetles may survive in one exposure than in the other.

The important part played by slope exposure and topography in winter mortality may be shown in still a different way by comparing the data given in Tables 1 and 2 for cage 8 with those for the neighboring cage 7. During the four seasons beginning with 1925–26, the average survival of the 40,000 beetles in cage 7 on the eastern slope was 12.08 per cent as compared with 3.16 per cent for the 25,000 beetles in cage 8 on the northern slope. These data indicate that within the lower part of the ponderosa pine zone, the beetle's natural hibernation quarters in the West, there are certain localized areas that are not suitable for successful overwintering on account of the topography and slope exposure.

HIBERNATION IN RELATION TO TEMPERATURE

A study of the monthly minimum temperatures at Estancia and Tajique (Table 5) for the hibernation seasons under discussion, in connection with Table 2, shows that the lowest temperatures occurred in years that were favorable to hibernation. During the winter of 1924–25, when −17° F. was recorded for Tajique, 10.03 per cent of the beetles introduced into cage 5 overwintered. Again during the season of 1925–26, −24° was recorded at Estancia and 21.8 per cent of the beetles survived in cage 11. The lowest temperature (−26°) occurred at Estancia and yet beetles survived this low air temperature, while in the fir-spruce association on Bosque Mountain (Rea's ranch), where the lowest temperature recorded in five years was −15°, there was 100 per cent mortality in the cages in four out of five years of the investigational period.

TABLE 5.—*Monthly minimum temperatures at Estancia and Tajique, N. Mex., and the lowest monthly temperatures recorded at Rea's ranch, 1923–24 to 1928–29*

Station	Season	October	November	December	January	February	March	April	May	June
		°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Estancia	1923–24	23	1	−16	−2	−2	8	15	27	33
	1924–25	17	2	−26	−11	8	3	21	27	30
	1925–26	11	4	−5	−24	5	0	20	23	39
	1926–27	18	12	−16	−1	12	10	19	28	31
	1927–28	17	4	−10	−5	−5	11	1	29	35
	1928–29	21	13	−1	−4	−22	8	15	17	36
Tajique	1923–24	12	−2	−2	2	−1	3	13	24	31
	1924–25	20	10	−17	−4	14	10	22	32	33
	1925–26	24	4	0	−4	10	0	24	23	38
	1926–27	15	15	−10	12	13	5	20	26	36
	1927–28	20	13	−13	−4	−3	8	−4	30	34
	1928–29	19	10	−1	−2	−13	1	13	13	34
Estancia	Lowest	11	1	−26	−24	−22	0	1	17	30
Tajique	do	12	−2	−17	−4	−13	0	−4	13	31
Rea's ranch [a]	do	14	0	−6	−8	−15	−1	10	12	23

[a] Temperatures for period 1913 to 1917; no weather station in operation during the investigational period.

The weekly thermograph records showing the temperatures of the air and of the hibernation material, as presented in Figure 12, illustrate why beetles under the cover of hibernation materials are able to survive during periods when the air temperatures above the materials are extremely low. During periods of subzero weather the ground is usually covered with snow, the protection of which is discussed elsewhere in this paper. The records for April 9, 1928, and May 2, 1929, show that the high mortality occurring during the seasons of 1927–28 and 1928–29 was not caused by low air temperature on these dates, as the temperature of the hibernation material did not go below 30° F.

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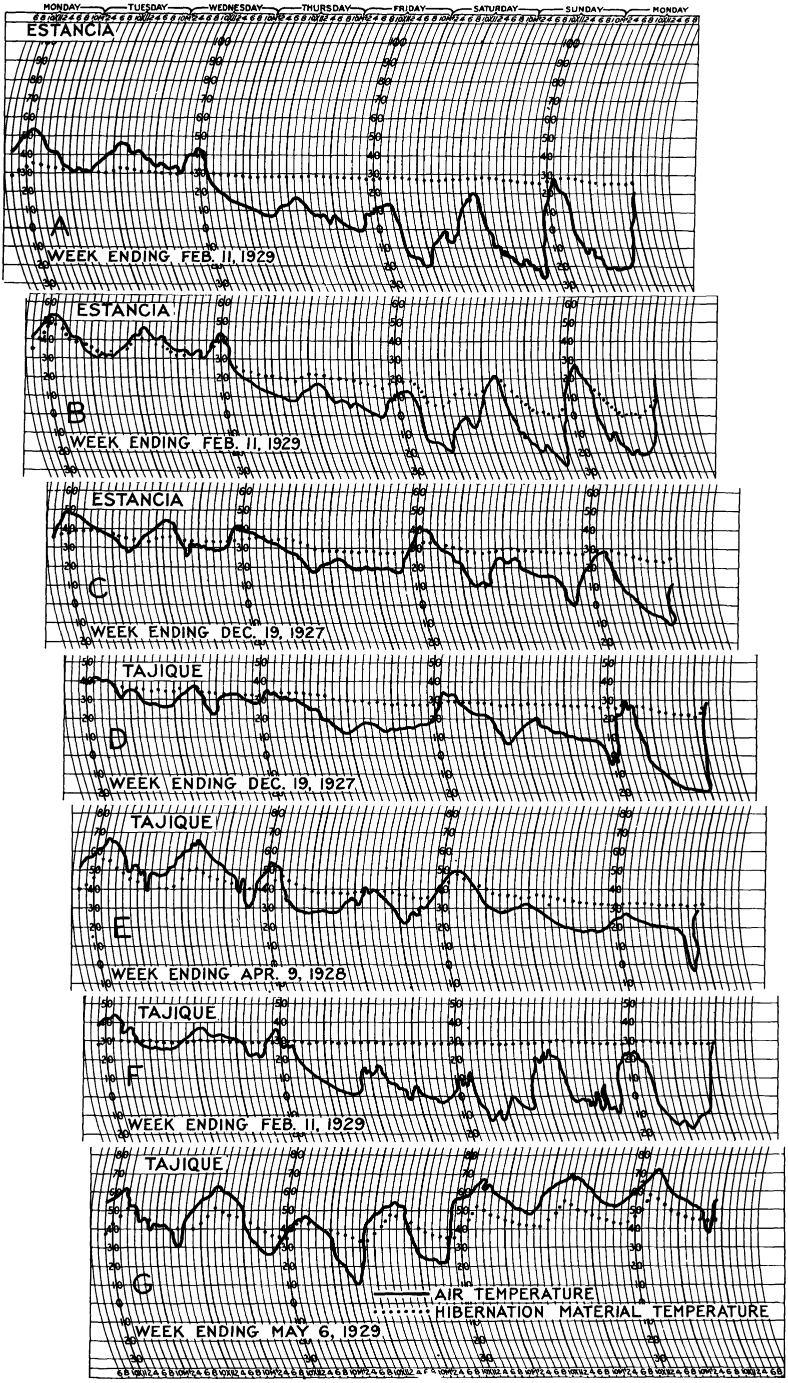

FIGURE 12.—Weekly thermograph records showing the temperatures of the air and of the hibernation material. A is a record taken in cage 11, in which the hibernation material consisted of oak leaves and pine needles, whereas B is a record for the same period in adjacent cage 10, where Russian thistles were used. In all other cases the hibernation material consisted of oak leaves and pine needles

In Table 6 and Figure 13 it is found that the mean minimum temperatures for November, December, and January are lower at Estancia than at Rea's ranch on Bosque Mountain or in the foothills (Tajique), while from February to June, inclusive, these temperatures are lower on the mountain than in the foothills or valley. Of the beetles introduced over a period of five years into cages located on the mountain (Nos. 1, 2, and 3), none survived except during the season of 1926–27, when the monthly mean minimum temperature from January to April, inclusive, at Estancia and Tajique rose 19.3° and 15.5° F., respectively, above the average mean for this period. This mild season, which prevailed generally over the area, permitted successful hibernation even at the higher elevations. This is best illustrated by the results obtained in cage 4 at 8,400 feet elevation, where the average survival for the mild season of 1926–27 was 16.53 per cent as compared with 3.57 per cent for the other five seasons. In cage 8 also during the mild season 10.32 per cent of the beetles survived as compared with an average of 1.38 per cent for the season preceding and the two seasons following the mild winter. It will therefore be seen that the temperatures of the latter part of the hibernating period have the greatest influence on survival.

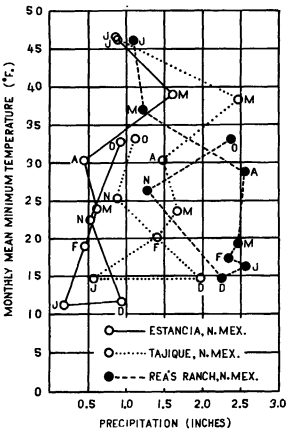

FIGURE 13.—Climograph showing mean monthly minimum temperatures at Estancia, Tajique, and Rea's ranch, N. Mex.

TABLE 6.—*Monthly mean minimum temperatures at Estancia and Tajique, N. Mex., and the mean of the monthly mean minimum temperatures there and at Rea's ranch, 1923–24 to 1928–29*

Station	Season	October	November	December	January	February	March	April	May	June
		°F.	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*
Estancia	1923–24	32.8	23.3	15.8	12.1	18.4	21.7	29.2	39.4	47.1
	1924–25	30.3	19.4	7.2	8.8	20.6	22.4	30.2	39.8	46.2
	1925–26	33.3	17.1	9.2	−2.1	18.3	22.1	30.8	36.0	45.8
	1926–27	33.8	24.0	9.8	21.8	25.5	24.2	32.1	37.5	45.6
	1927–28	28.2	25.6	11.3	11.3	19.6	26.0	30.1	40.7	46.9
	1928–29	37.5	25.0	15.6	15.1	11.9	26.4	29.4	40.4	47.2
Tajique	1923–24	31.1	22.6	16.6	13.0	19.6	20.3	27.8	38.0	46.9
	1924–25	30.8	24.4	13.2	11.1	23.8	26.8	32.6	41.6	47.1
	1925–26	35.3	23.4	16.6	10.9	23.0	22.0	33.0	26.6	44.2
	1926–27	35.3	27.2	14.2	21.4	26.3	23.9	32.8	37.4	43.2
	1927–28	31.1	30.8	12.9	19.1	16.7	25.4	28.6	38.8	50.4
	1928–29	35.3	22.5	15.1	13.4	11.2	23.1	27.8	37.9	46.0
Estancia	Mean	32.7	22.4	11.5	11.2	19.0	24.0	30.3	39.0	46.5
Tajique	do	33.2	25.2	14.8	14.8	20.1	23.6	30.4	38.4	46.3
Rea's ranch [a]	do	33.0	26.4	14.8	16.3	17.3	19.3	28.9	37.0	46.0

[a] Data recorded between 1913 and 1917.

A further study of Table 6 shows that for Estancia during the hibernation season of 1925–26 the sum of the monthly mean minimum temperatures for November to March, inclusive, decreased 23.5° F. from the sum of the means for the same period. During this season

21.80 per cent of the beetles introduced into cage 11 survived as compared with an average survival of 1.54 per cent for the three succeeding years. (Table 2.) These conflicting data show that other important factors besides air temperature are exerting an influence upon the winter mortality of bean beetles.

HIBERNATION IN RELATION TO TEMPERATURE AND PRECIPITATION

The moisture requirements of the beetles vary directly with the temperature, as is indicated in Table 7, which gives the relation between beetle survival and the average seasonal temperature and precipitation at stations in various parts of the range of the beetle in this country.

TABLE 7.—*Average seasonal temperature, precipitation, and beetle survival at several stations*

Station	Period	Hibernation period	Temperature	Precipitation	Beetle survival
			°*F.*	*Inches*	*Per cent*
Tajique, N. Mex.	1923 to 1929	October to June	40.35	12.47	[a] 12.60
Rea's ranch, N. Mex.	1924 to 1929	do	35.94	18.08	.11
Columbus, Ohio	1925 to 1929	October to May	42.71	23.76	[b] 1.43
Amesville, Ohio	do	do	43.94	[c] 24.64	[b] 2.38
Birmingham, Ala.	1920 to 1928	November to April	52.83	30.36	[b] 15.41
Clemson College, S. C.	1924 to 1929	do	50.12	27.43	[d] 15.76

[a] For cages 5 and 7.
[b] From unpublished data by N. F. Howard, Bureau of Entomology.
[c] For Athens, Ohio.
[d] Calculated from data given by EDDY, C. O., and CLARKE, W. H. THE MEXICAN BEAN BEETLE, 1927–1928. S. C. Agr. Expt. Sta. Bul. 258, 42 p., illus. 1929.

The climographs for these stations, presented in Figure 14, show the average monthly temperature and precipitation during the hibernation period under discussion.

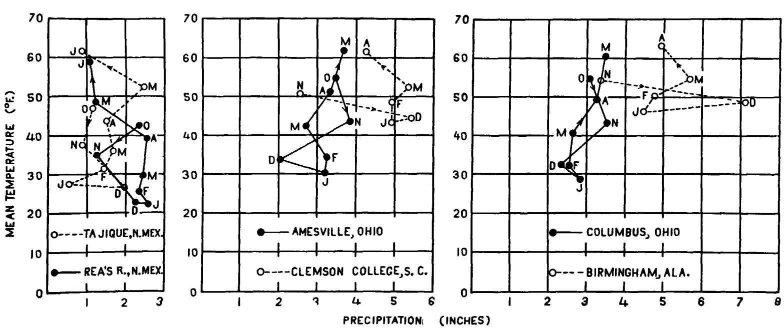

FIGURE 14.—Climograph showing mean monthly temperatures and precipitation in different parts of the range of the Mexican bean beetle in the United States

The average temperature at Tajique, N. Mex., is 2.36° F. lower than at Columbus, Ohio. From the standpoint of temperature, therefore, Columbus is more favorable for winter survival, but excessive moisture combined with low temperature makes it unfavorable for successful hibernation. Tajique, on the other hand, with 11.29 inches less moisture, is favorable for survival. There is little difference in the percentage survival at Birmingham, Ala., and Tajique, N. Mex.; yet the latter station is 12.48° colder and has 17.89 inches less precipitation.

A few beetles have lived 3 days submerged in running water, although the mortality was high on the first and second days. Beetles in perforated salve boxes containing oak leaves placed under a dripping faucet lived from 1 to 12 days, but heavy mortality occurred between the first and fourth days.

HIBERNATION AS AFFECTED BY CLIMATIC FLUCTUATIONS

SEASONAL FLUCTUATIONS

The data in Table 8 and the climographs for Estancia and Tajique (fig. 15) show large variations, from season to season, in temperature and precipitation for corresponding months during the hibernation

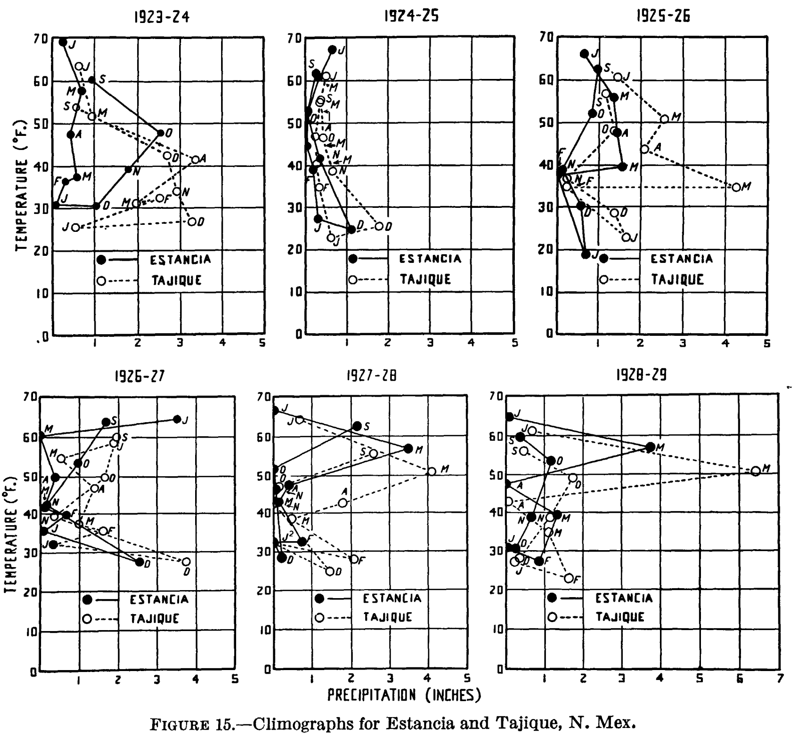

FIGURE 15.—Climographs for Estancia and Tajique, N. Mex.

period. This fluctuation in climatic conditions seems to be the most important factor affecting hibernation in the same cage. A single departure from the normal is not always important, but the combination or the sequence of such departures is important.

TABLE 8.—*Climatic data for Estancia and Tajique, N. Mex., 1923–24 to 1928–29*

MONTHLY MEAN TEMPERATURES

Station	Hibernation season	Sept.	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
		° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Estancia	1923–24	60.3	47.8	39.3	30.2	30.7	36.2	37.1	47.5	57.8	69.1	69.7
	1924–25	61.8	52.1	41.6	24.8	27.2	39.0	44.7	52.9	60.7	67.1	72.6
	1925–26	62.3	52.0	38.9	30.1	18.8	37.6	39.5	47.7	55.7	66.0	67.4
	1926–27	63.9	53.6	42.1	27.3	35.6	39.8	41.3	50.0	60.2	64.5	70.4
	1927–28	62.5	51.8	45.6	28.2	32.5	32.4	42.9	47.1	56.8	66.6	68.4
	1928–29	59.7	53.2	38.4	30.3	30.5	27.1	39.2	47.5	56.8	64.7	68.5
Tajique	1923–24	53.6	42.4	33.8	26.8	25.2	32.0	31.0	41.4	51.8	63.6	62.4
	1924–25	55.4	46.2	38.7	25.4	22.8	34.2	40.2	46.6	54.8	61.0	64.8
	1925–26	56.7	48.0	36.5	28.5	22.8	34.6	34.2	43.6	50.8	60.6	61.8
	1926–27	60.0	49.5	39.1	27.1	33.5	35.2	37.2	46.4	54.6	58.6	64.2
	1927–28	55.6	46.8	42.4	24.9	32.4	27.9	38.1	42.2	50.9	64.4	64.3
	1928–29	56.0	49.0	34.3	28.0	26.9	22.9	34.8	42.8	50.7	61.0	62.9

MONTHLY PRECIPITATION

Station	Hibernation season	Sept.	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Estancia	1923–24	0.91	2.51	1.78	1.02	0.07	0.30	0.59	0.42	0.70	0.26	1.88
	1924–25	.24	.05	.32	1.09	.30	.20	.04	.08	.33	.65	2.03
	1925–26	.99	.82	.13	.58	.70	.02	1.54	1.43	1.37	.63	2.20
	1926–27	1.65	.97	.15	2.54	.06	.64	.05	.37	([a])	3.50	2.30
	1927–28	2.13	([a])	.02	.20	0	.73	.13	.39	3.47	([a])	.74
	1928–29	.36	1.14	.67	.23	.03	.88	1.31	([a])	3.75	.07	5.47
Tajique	1923–24	.57	2.66	2.90	3.23	.53	2.49	1.98	3.35	.92	.62	5.41
	1924–25	.40	.43	.65	1.77	.61	.44	.26	.24	.38	.51	2.62
	1925–26	1.14	1.37	.23	1.39	1.69	.23	4.24	2.09	2.55	1.47	2.14
	1926–27	1.95	1.63	.35	3.77	.32	1.60	.99	1.38	.51	1.86	1.70
	1927–28	2.57	.11	0	1.43	0	2.06	.44	1.80	4.08	.05	2.98
	1928–29	.47	1.72	1.13	.31	.21	1.63	2.09	.05	6.42	.68	6.50

TOTAL MONTHLY SNOWFALL (UNMELTED)

Station	Hibernation season	Sept.	Oct	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
			Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*		
Estancia	1923–24	------	4.5	4.5	13.5	1.0	3.9	10.2	2.2	0	------	------
	1924–25	------	0	0	13.2	7.2	1.5	0	([a])	0	------	------
	1925–26	------	([a])	.5	5.0	10.0	.2	10.5	0	0	------	------
	1926–27	------	2.0	0	9.3	([a])	1.0	.2	1.0	0	------	------
	1927–28	------	0	0	4.8	0	12.0	.5	4.5	([a])	------	------
	1928–29	------	0	3.0	1.0	([a])	18.0	10.0	0	1.0	------	------
Tajique	1923–24	------	25.5	21.0	46.5	7.0	29.0	19.7	20.7	.5	------	------
	1924–25	------	.5	0	27.2	11.3	3.3	.5	0	0	------	------
	1925–26	------	([a])	3.0	13.5	24.6	2.7	37.8	([a])	([a])	------	------
	1926–27	------	5.5	.8	39.3	3.0	8.1	8.0	13.0	1.0	------	------
	1927–28	------	0	0	21.2	0	31.2	([a])	17.1	19.4	------	------
	1928–29	------	.2	9.5	4.8	3.9	26.6	19.0	([a])	2.0	------	------

[a] Trace.

The departures from the normal of temperature and precipitation at Tajique are shown in Table 9.

During the season of 1923–24 the fall was relatively cold and wet, and it was followed by a cold, damp winter with the heaviest snowfall on record. May was nearly normal in temperature, but far below normal in precipitation. June was hot and dry, so that emergence from hibernation was delayed until the July rains. As a whole the hibernation season was the coldest and wettest recorded. However, the winter was favorable for hibernation because the beetles were well protected by a heavy blanket of snow during the cold months, and a mild dry spring followed which was unfavorable for the parasitic fungus *Beauveria globulifera*. In cage 7, on an eastern slope, 23.5 per cent of the beetles survived. It is thus apparent that certain determining factors (in the present instance temperature and precipitation as they affect the development of parasitic fungi) may be so influenced by other determining factors, such as form of precipitation (snow instead of rainfall) or the time of occurrence of the precipitation, as to counteract the unfavorable effects of the first factors.

TABLE 9.—*Departures from the normal of temperature and precipitation, at Tajique, N. Mex., 1923–24 to 1928–29*

[7,100 feet elevation]

TEMPERATURE

Month	1923–24	1924–25	1925–26	1926–27	1927–28	1928–29
	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
October	−4.2	−0.4	+1.4	+2.9	+0.2	+2.4
November	−3.3	+1.6	−.6	+2.0	+5.3	−2.9
December	−1.8	−3.2	−.1	−1.5	−3.7	−.6
January	−3.1	−5.5	−5.5	+5.2	+4.1	−1.5
February	+1.0	+3.2	+3.6	+4.2	−3.1	−8.1
March	−4.8	+4.4	−1.6	+1.4	+2.3	−1.0
April	−1.8	+3.4	+.4	+3.2	+1.0	+.6
May	−.4	+2.6	−1.4	+2.4	−1.3	−1.5
June	+2.7	+.1	−.3	−2.3	+3.5	−.1
Seasonal average	−1.8	+.7	−.5	+2.0	+.9	−1.4

PRECIPITATION

Month	1923–24	1924–25	1925–26	1926–27	1927–28	1928–29
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
October	+1.34	−0.87	+0.05	+0.31	−1.21	+0.40
November	+2.11	−.14	−.56	−.44	−.79	+.34
December	+1.75	+.29	−.09	+2.29	−.05	−1.17
January	−.39	−.31	+.77	−.60	−.92	−.71
February	+1.24	−.81	−1.02	+.35	+.81	+.38
March	+.55	−1.17	+2.81	−.44	−.99	+.66
April	+1.85	−1.26	+.59	−.12	+.30	−1.45
May	−1.15	−1.69	+.48	−1.56	+2.01	+4.35
June	−.53	−.64	+.32	+.71	−1.10	−.47
Seasonal average	+.76	−.73	+.37	+.05	−.21	+.26

The season of 1924–25 was mild and dry, except for December and January, which were cold, with a good protection of snow. The precipitation was well distributed throughout the hibernation period, but the deficiency was too great for favorable hibernation. On the eastern slope (cage 7) 7.26 per cent and on the northern exposure (cage 5) 10.03 per cent of the beetles hibernated, indicating that the deficiency of moisture in the hibernation material was greater on the eastern than on the northern exposure.

During the season of 1925–26 the fall temperature was moderate with a slight deficiency in moisture. The winter was variable, with a good blanket of snow during the cold months and an excess of moisture in March. The spring was slightly above normal in precipitation, which stimulated emergence in June. The season as a whole was nearly normal and favorable for overwintering. In the cage on the eastern slope 36.24 per cent and in that on the northern slope 22.24 per cent of the insects overwintered, indicating that the northern exposure received a slight excess of moisture above the optimum.

The season of 1926–27 was the warmest on record, with a slight excess of precipitation. December was the wettest month and May the driest. The spring was hot and dry, which conditions increased mortality on the eastern slopes and decreased the death rate on the northern. On the eastern exposure 16.22 per cent of the beetles hibernated as compared with 28.29 per cent on the northern exposure. The excess rainfall in June stimulated emergence and thus decreased the length of the hibernation period.

The season of 1927–28 was comparatively warm, with two winter months below normal in temperature and six of the nine months deficient in precipitation. January was warm, clear, and exceedingly dry, the driest on record. May was below normal in temperature, and above normal in precipitation. Snow fell during December, February, April, and May; the amount falling in May was the largest recorded for that month. (Table 8.) June was hot and dry, and emergence of the beetles was delayed until the July rains. The season as a whole was slightly above normal in temperature, with a small decrease in precipitation. On the eastern exposure 2.30 per cent of the beetles survived the winter, and on the northern exposure 0.75 per cent.

For the winter of 1928–29 October and April were above normal in temperature, October being one of the warmest on record. The other months were below normal in temperature, February being the coldest—in fact, it was the coldest February recorded. March was cold and wet, with a heavy, wet snowfall on the 27th and 28th. Five of the nine months had an excess of precipitation, that for May being the greatest on record. June was warm and dry, with a slight precipitation which occurred at the close of the month. Emergence from hibernation was delayed until the July rains. The season as a whole was cold with a slight excess of precipitation. It was unfavorable for hibernation. In the cage on the northern slope 2.95 per cent of the beetles survived as compared with 3.58 per cent on the eastern slope.

Figure 11 shows that the seasons of 1923–24, 1925–26, and 1926–27 were favorable for winter survival, that 1924–25 was fair in this respect, and that 1927–28 and 1928–29 were the least favorable. The seasonal average departures from normal temperature and precipitation, as given in Table 9, show no correlation with winter survival. They do, however, fall within the seasonal variations in survival for the good winters. The only significant relationship is shown between the comparatively uniform seasons of 1923–24 and 1924–25, the cool, damp winter being more favorable for survival than the warm, dry season.

EFFECT OF A COVERING OF SNOW IN RELATION TO TEMPERATURE FLUCTUATIONS

Tables 8 and 9 show a great variation in monthly temperatures from season to season at Tajique. For example, the temperatures in January, 1926 and 1927, showed a variation of 10.7° F. The snowfall for these months (Table 8) was 24.6 and 3.0 inches, respectively. In 1925–26, 36.24 per cent of the beetles survived in cage 7, as compared with 16.22 per cent in the same cage in 1926–27. March in 1924 and 1925 varied 9.2° in temperature, with 19.7 and 0.5 inches, respectively, of snowfall. In cage 7, 23.54 per cent of the beetles survived in 1923–24 as compared with 7.26 per cent in 1924–25.

The mean temperature at Tajique for January, 1925, and for January, 1926, was 22.8° F., with 11.3 and 24.6 inches of snowfall, and in 1924–25 and 1925–26, 7.26 and 36.24 per cent of the beetles, respectively, survived in cage 7. Of the beetles in cage 11 (at Estancia), 21.80 per cent survived during the winter of 1925–26, when the monthly mean temperature decreased to 18.8° for January with a 10-inch snowfall. The mean minimum temperature for this month was −2.1°. (Table 6.)

These data show that during the coldest months of the year the beetles are usually well protected by a blanket of snow and that when there is sufficient covering of snow very few are killed. The lowest temperature recorded in the last three seasons by distant thermographs measuring temperature of natural hibernation material of oak leaves and pine needles was 16° F. In the Southwest the coldest periods follow snowfalls and are accompanied by clear weather.

PRECIPITATION FLUCTUATIONS

During the season of 1923–24, October, November, and December had an excess of precipitation of 1.34, 2.11, and 1.75 inches (Table 9), and during the season of 1925–26 March had an excess of 2.81 inches. In 1926–27 December had an excess of 2.29 inches. This excess precipitation during the months mentioned had little effect on mortality, which indicates that these are not the critical months in the hibernation of the beetle. During the season of 1923–24 April had an excess of 1.85 inches of moisture without any great effect on the mortality of beetles in hibernation. In 1927–28 May was apparently the critical month in the hibernation of the insect. The heavy snowfall during April and May (Table 8) was evidently the cause of the high mortality, especially that in May, when precipitation occurred on 14 days. This conclusion is supported by the fact that 4.92 per cent of the beetles survived in cage 6, from which precipitation was excluded after May 10, as compared with 2.30 per cent survival in cage 7 near by.

During the season of 1928–29 May was cool and the precipitation recorded was the greatest, indicating that this was the critical month of the season. In cage 7, 3.58 per cent of the beetles survived as compared with 1.52 per cent in cage 6. The greatest mortality must have occurred before May 10, when natural precipitation was excluded from cage 6. This indicates that heavy precipitation in the form of rain in May, 1929, was not so detrimental as the heavy snowfall in May, 1928. The critical period must therefore have been subsequent to the heavy snowfall on March 27 and 28. Following this period there were 10 days in which the mean temperature averaged 42.7° F. as compared with 45° for the 10-day period subsequent to the heavy snowfall on May 11 and 12, 1928. The weather conditions during these periods were very favorable for the fungus *Beauveria globulifera*, which caused high mortality among the hibernating beetles. Cage examination during the latter part of April, 1929, showed that many had died before that time.

Cage examinations during the period of hibernation showed that very few beetles are killed during complete dormancy in the natural hibernation zone and that the period of heavy mortality occurs with and immediately following the melting of the accumulated snow, when the beetles are becoming semiactive and are absorbing moisture. For example, during the 1925–26 season beetles in cage 8 were in fine condition until the snow began to melt, and cage examination on April 8 indicated that a large percentage of them would survive. At this time the beetles were becoming semiactive, as five of them were up on the cage, evidently to avoid the excess moisture. After the snow began to melt on the northern slope, where this cage was located, the hibernation material was saturated with moisture for a long time. Later examinations showed that the beetles were being killed by *Beauveria globulifera*, and on May 9 very few live ones were found. Only 1.83 per cent survived. During the warm, dry spring of 1927, 10.32 per cent of the beetles survived in this cage, whereas in the wet springs of 1928 and 1929 only 1.80 and 0.04 per cent survived.

SUMMARY AND CONCLUSIONS

The hibernation of the Mexican bean beetle in the Upper Sonoran, Transition, and Canadian Life Zones has been studied in relation to the plant associations found therein. In the fir-spruce association of the Canadian Zone only 42 insects survived out of a total of 38,500 placed in hibernation during the five seasons 1923–24 to 1928–29, inclusive. This survival occurred during an abnormally warm winter with nearly normal precipitation. In the ponderosa pine, or Transition, zone, 133,340 beetles were used in six years (1923–24 to 1928–29, inclusive), with a total survival of 13,114, or 9.84 per cent. In the Upper Sonoran Zone 44,500 beetles were employed, with a survival of 1,210 adults, or 2.72 per cent. Under natural conditions hibernation is confined to oak mottes found along canyon streams near the upper edge of this zone. The comparison of these results shows a consistent relationship between the zones and the percentage survival. The results indicate that the ponderosa pine forest zone is the natural hibernation quarters of the beetle in the Southwest and becomes more favorable when oak trees are present in the association.

The accumulation of dust, the character of the hibernation material, and snow coverage during subzero weather have been found to affect mortality in hibernation. Drainage is also an important factor in hibernation, mountainous or hilly country being more favorable for winter survival than a low, flat country when other conditions are similar.

Elevation considered alone seems to have no significance within the zone of successful hibernation. The determining factors at high elevations are temperature, precipitation, and exposure.

In the ponderosa-pine forest zone during winters followed by mild, dry springs, the largest percentage of beetles survived in cages on a northern exposure, whereas during winters followed by cold, wet springs survival was greatest on an eastern exposure. A sunny exposure may make hibernation possible in a location otherwise too cold or damp.

Winter temperature is an important limiting factor in the distribution of the Mexican bean beetle. Unless other factors are favorable, such as a covering of snow and the character of the hibernation material, the temperatures in many sections of the northern part of the United States and in Canada are rather low for successful hibernation.

Precipitation is a major factor in successful hibernation. As the temperature decreases, so does the moisture requirement or toleration of the insect. The seasonal distribution of precipitation seems to be more important than the quantity. Spring is the critical period in hibernation. Rain is not so detrimental as snow in the spring, especially if the snow is wet and heavy.

The parasitic fungus *Beauveria globulifera* is capable of causing a high death rate among overwintering beetles. The optimum conditions for growth and reproduction of this fungus follow heavy snowfalls or damp, rainy weather in the spring when the mean temperature is between 42° and 45° F.

Very few beetles are killed during complete dormancy; the period of heavy mortality occurs when the beetles become semiactive.