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1973 PROGRESS REPORT

DEMOGRAPHIC STUDIES OF SAGEBRUSH INSECTS AS FUNCTIONS OF VARIOUS ENVIRONMENTAL FACTORS

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ABSTRACT

Compared to 1972 data, investigations during 1973 at Curlew Valley showed an overall slower trend of seasonal development in the sagebrush defoliator, *Aroga websteri* Clarke. The population density was very low, less than 100 defoliators per kiligram of fresh sagebrush at the peak of population growth. Defoliator mortality due to parasitism was also rather low, denoting a continued downward trend of the level of parasitism over the past three years. It is apparent that parasitism was not the most important factor in regulating defoliator population at the study site. A survey of the defoliator distribution in Utah established that the southern boundary of the defoliator range probably does not extend into Washington or Kane counties. Some 21 species and varieties of *Artemisia* and 15 other species of Compositae were tested for acceptability and suitability for growth of defoliator larvae in the laboratory. Seven plants belonging to six species of *Artemisia* supported normal feeding and growth. None of the other plants tested were acceptable, indicating a high degree of host-plant specificity by this insect. Findings from oviposition studies indicate that oviposition and feeding preferences appear to be correlated among *Artemisia* species. Those species that received eggs were also those fed upon by the larvae. Evaluation of defoliator impacts on sagebrush productivity and mortality revealed that severely defoliated plants had a drastic reduction of green weight, an increased number of dead branches and a reduction in the percentage of live plants which produced flower stalks. The impact of defoliation on sagebrush production may be much more profound than previously assumed.

INTRODUCTION

The sagebrush defoliator, *Aroga websteri* Clarke, continues to be the major insect pest of the big sagebrush, *Artemisia tridentata*, at the Curlew Valley, Utah-Idaho study site. A major portion of research in 1973 was devoted to the study of the population dynamics of this species. Methods for population sampling of different age groups have been improved. Data from three consecutive years have now been accumulated and analyzed on the seasonal history, population density and natural mortality of the defoliator at the study site.

Several new aspects of the study were initiated in 1973. The host range and feeding habits of the defoliator were investigated in the field and in the laboratory. In the field, the geographic distribution and natural hosts of the species in Utah were determined. A comparison was made of the biology of the defoliators feeding on different *Artemisia* species at several localities in southern Idaho. In laboratory studies, the acceptability and suitability of different *Artemisia* species for the support of growth and reproduction of the defoliator were determined. Data obtained from these studies will provide basic information for assessing the extent of defoliator infestations and potential hosts of the defoliator in the cool desert.

Research on the biology of the defoliator has been extremely helpful in developing meaningful techniques of assessing defoliator impacts on sagebrush defoliation and this phase of the study was expanded considerably in 1973. A large number of heavily defoliated sagebrush plants at the study site have been tagged and the extent of regrowth and survival of the individual plants measured. Continued monitoring of these tagged plants will be carried out in subsequent seasons to determine the long-term effects of defoliator damage on sagebrush mortality and productivity.

Results obtained from these studies are included in the report.

OBJECTIVES

The following objectives have been pursued in 1973:

1. To determine seasonal history and natural mortality of the sagebrush defoliator at the study site.
2. To study the host range, feeding habits and oviposition preferences of the defoliator under field and laboratory conditions.
3. To assess the impact of defoliators on sagebrush mortality and productivity.

METHODS

Population Sampling

Samples of the immature stages of the defoliator were collected at approximately 10-day intervals between April and late May. As the defoliator development proceeded at a more rapid rate in the field, weekly samples were taken from early June to early August. The same 1 ha study plot established in 1972 was used. On each sampling date, 40 individual samples of single branches that extended from the ground level to the height of the plant were selected randomly at the plot. The branch was cut off at ground level, measured, weighed, labeled, and placed in a plastic bag. In the laboratory the samples were examined and the number and instars of the defoliators recorded. The population density was expressed in terms of the number of defoliators per kilogram of fresh sagebrush (DSCODE A3UHL01).

In order to measure the duration of adult activity in the field, a Malaise trap was erected near the study site at the beginning of the adult emergence period and weekly records were kept of the number of moths captured and the adult sex ratio.

Laboratory Rearing

Each age group of the defoliator was reared separately to determine the age-specific parasitism and mortality factors. The early larval instars were reared in groups of 10 individuals per plastic cage confined to potted sagebrush plants. The food plants were changed every 5-7 days. This technique improved the percent of larval survival. Older larvae were reared in plastic containers with excised plants and food was changed every 2-3 days to maintain freshness for the insects. Parasites obtained from these rearings were identified and recorded.

Host Range and Suitability Studies

At the beginning of the season, several field trips were made in Utah and southern Idaho to collect *Artemisia* species and varieties and determine their natural infestations by the defoliator. Some of these species were transplanted into pots and brought back to the laboratory for feeding experiments. To determine the acceptability and suitability of various plants for growth of the defoliator, the same method as described in the laboratory rearing section was used. Fourth and early 5th instar larvae collected from the big sagebrush at the study site were introduced in groups of 10 into a plastic cage on the test plant. Fresh foliage was used for those plant species that were not successfully transplanted to pots. Foods were changed as necessary. Three to four replicates were run on each test plant. The percent survival, pupal weight and rearing duration were used as criteria of acceptability and suitability.

In July, several sites in northern Utah and southern Idaho having mixed stands of *A. tridentata*, *A. arbuscula*, *A. nova*, and *A. tripartita* were visited and 10 samples of plant branches were taken from each species to determine the population density, age distribution and the extent of defoliation by the defoliator. Laboratory rearing of the immature stages of the defoliators from these plants was carried out to determine the various mortality factors.

Oviposition Studies

Three outdoor cages, 1 x 1.5 x 2 m, were erected near campus. Potted plants of 10 *Artemisia* species and varieties were placed in each of these cages. Newly emerged adults were released into the cages during late July and early August. A supply of honey and sugar water was provided in each cage to serve as adult food. During October, the potted plants were cut, weighed and the number of defoliator eggs on each plant was recorded to assess the ovipositional preferences of the female moth toward these plants.

Defoliation Studies

Several general methods of evaluating defoliator damage to sagebrush plants have been devised and tested in previous years. None of these gave consistent results. In 1973, a method of assessing long-term defoliator effects on sagebrush mortality and productivity was developed. During July, when defoliator feeding activity ceased, some 150 completely defoliated sagebrush plants were tagged at the study site. At the end of September and during the first part of October, these plants were checked to determine the size of the plant (plant height and diameter) and the status of growth (number of live branches per plant, number and sizes of flower stalks, etc.). A number of these heavily defoliated plants were destroyed to obtain the biomass of the green and stem weights for assessing the productivity of the plants. A group of healthy sagebrush plants from the study site was also evaluated in the same manner to determine the normal level of plant productivity under minimum insect damage. All of the tagged plants will be checked in subsequent years to determine the incidence of plant mortality due to defoliation.

RESULTS AND DISCUSSION

Seasonal History and Population Trends

Table 1 summarizes the data from field samples of different age groups of the defoliator and the population density throughout the season (A3UHL01). The first set of samples was taken on April 17. Very few defoliators were obtained in these samples and the population density was only about 10% that of the previous year. All the larvae collected from the samples were in the 1st instar, whereas last year's samples of the same time period had many 2nd and 3rd instar larvae (Hsiao and Kirkland, 1973). The same slow trend in development was observed in subsequent field samples, indicating a delay of about 7-10 days in the duration of development. The population density of the defoliator at the study plot was also very low: less than 100 defoliators per kilogram fresh sagebrush at the peak of population growth. There was a rapid decline in population near the period of pupation. This phenomenon had not been observed in previous years and suggested the presence of some unknown mortality factors operating in the population.

Although the defoliator population was low at the study plot, dense defoliator populations with completely defoliated sagebrush plants were observed elsewhere in areas several kilometers east of the plot. This fact suggests that within the north Curlew Valley, defoliator populations shift frequently to different areas according to the prevailing weather conditions during the period of adult dispersal. If this assumption holds true, it could explain the inconsistency existing in the 1972 and 1973 data. We had predicted an increase of defoliator population at the study plot in 1973 from the 1972 population data; however, the reverse population trend was actually recorded at the site. In the absence of any other explanation of overwintering mortality, we are led to believe that adult emigration to adjacent areas might be the cause of the decrease in population at the study plot. It would seem that in future work the selection of samples from a larger area would provide a better measurement of population density of the defoliator.

Adult Activity and Oviposition Period

The duration and activity of adult moths were measured from field sampling (Table 1) and Malaise trap data (Table 2). Pupal cases were observed as early as July 3 and reached a peak number by July 31, indicating that over 90% of adult emergence was completed by this time. The Malaise trap record also showed a peak of adults captured between July 24-31, and this coincided with the period of adult emergence mentioned above. Judging from the significant number of moths captured between July 31 and August 24, it can be assumed that the adult activity was still prevalent during this period. From August 24 to September 18 only about 4% of the season total of moths captured were found in the trap, indicating a very low level of adult population during this period. It is interesting to note that less males than females were found in the trap. Of the 3,984 moths captured during the season, a higher percentage of females (56.4%) than males (43.6%) was recorded.

Table 1. Age structure and population density of *A. websteri* at Curlew Valley site, 1973 (A3UHL01)

Date of sampling	Egg	Larval instar 1st	2nd	3rd	4th	5th	Pupa	Pupal case	Total	Total defoliators per Kg fresh sagebrush
April 17		82							82	12.21
April 30		219	48	3					270	55.34
May 11		168	144	32					344	103.96
May 21		1	46	235	29	1			312	95.27
May 31			3	137	331	52			523	96.10
June 8				25	109	163	1		298	58.16
June 18					16	318	9		343	53.65
June 25					2	299	56		357	54.88
July 3						125	143	4	272	40.65
July 10						16	207	48	271	38.80
July 16						4	89	76	169	21.68
July 23						1	40	76	117	16.26
July 31							7	92	99	16.15
August 7							4	71	75	11.59

Table 2. Record of *A. websteri* moths captured in Malaise trap at Curlew Valley site, 1973

Dates	No. of Adults	♀	♂	Unidentified
July 13-16	232	68	162	2
July 16-24	312	97	196	19
July 24-31	1,508	850	637	21
July 31-Aug. 7	658	427	210	21
Aug. 7-14	568	374	191	3
Aug. 14-24	538	325	208	5
Aug. 24-Sept. 4	91	38	51	2
Sept. 4-18	77	25	47	5
Total	3,984	2,204	1,702	78
%		56.4	43.6	

Sampling of egg populations began on July 31 (Table 3). The first record of egg laying was obtained from the August 14 sagebrush samples. All subsequent samples contained defoliator eggs. Since some of the leaf samples were not examined immediately, but were kept in a cold room, the possibility that some eggs hatched during storage cannot be ruled out. It is also possible that the empty egg shells were the remains of the previous year's population. The fact that most of the eggs found were in the embryonic stage by October 2 indicates that the majority of the defoliators overwinter in the egg stage. Since most of the adult activity ceased by the end of August, it can be assumed that the adult egg laying period would terminate by this time and all subsequent eggs obtained from field samples were laid at an earlier time. Because of the difficulties involved in egg sampling, the data presented here indicate only the timing of egg laying and cannot be used to assess the population level of the overwintering generation.

Table 3. Sampling of *A. websteri* eggs at Curlew Valley site, 1973

Sample date	Sagebrush dry wt (g)	No. Eggs Total	With embryo	Empty shell*
July 31	219.2	0	0	0
August 14	457.4	3	0	3
24	370.7	14	7	7
Sept 4	689.4	20	10	10
18	861.7	18	16	2
Oct. 2	1,299.6	45	34	11
Total		100	67	33

* Some eggs hatched during cold storage of the samples.

Mortality Factors

Defoliators obtained from field samples were reared in separate age groups to determine the various mortality factors. Table 4 summarizes the details of causes of mortality of each life stage. Improved laboratory rearing technique has increased the percent survival to succeeding instars. However, the overall mortality was still rather high when compared to other insect species. For example, larval mortality was about 60% during the first four instars. The highest mortality always occurred during the initial stage of rearing, indicating that this species is difficult to transfer and to induce to feed on their food plants. With the exception of the initial rearing instar, the mortality during subsequent developmental instars varied without showing any patterns of age-specific mortality related to developmental processes. The incidence of protozoan disease was not noticeable in the course of the laboratory rearing.

Pupal mortality was classified under five categories. Incomplete pupal devlopment was the major mortality factor in all age groups. Insects reared beginning with 1st through 4th instars had a rather low overall pupal mortality ranging from 3.4 to 5.8%. Those larvae reared from the 5th instar showed considerably higher percentage of mortality (20.4%). In addition to the mortality due to incomplete pupal development, a significant number of deformed

Table 4. Percent mortality of field-collected *A. websteri* during laboratory rearing

	Stage					
	1st	2nd	3rd	4th	5th	Pupae
Initial number	238	138	291	446	858	548
Larval mortality (non-parasitized)						
1st	21.0					
2nd	6.7	29.0				
3rd	10.9	0.7	38.5			
4th	2.9	2.9	7.9	33.4		
5th	6.7	3.6	8.9	18.2	16.1	
Unidentified	10.5	22.5	5.2			
Total parasitized larvae	1.7	0	5.8	6.5	2.8	
Total dead larvae	60.5	58.7	66.3	58.1	18.9	
Total successfully reared to pupation	39.5	41.3	33.7	41.9	81.1	
Pupal mortality						
Injured				1.1	1.2	1.1
Incomplete pupation	0.8	0.7	1.7	0.7	5.4	1.6
Undeveloped			0.3	1.1	1.9	7.3
Incomplete development	2.5	2.9	3.1	1.8	9.1	11.9
Failed to emerge		1.4	0.7	0.7	2.9	4.7
Parasites failed to emerge						2.0
Parasitized Pupae						14.6
Total dead pupae	3.4	5.1	5.8	5.4	20.4	43.2
Total successfully reared to adult	36.1	36.2	27.8	36.6	60.7	56.8
Total parasitism	4.1	0	14.8	13.4	3.3	20.2

pupae were also recorded. This cause of mortality was probably due to the failure of the larvae to initiate feeding and as a result proper pupal development was not completed. This particular mortality factor was not significant in pupae collected from field samples. Laboratory rearing of field-collected pupae showed the highest percentage of mortality, with a total of 26.6% from the five categories. This figure is higher than that of the total mortality due to parasitism. This fact indicates that the failure to complete pupal development can be regarded as an important age-specific mortality factor for the defoliator.

Detailed records of parasites reared from each age group of the defoliator are summarized in Table 5. Five species, including *Apanteles cacoeiae*, *Temelucha* sp., *Copidosoma bakeri*, *Phaeogenes* sp., and *Spilochalcis leptis*, were recorded in significant numbers. In addition, a hyperparasite, *Catolaccus aeneoviridis*, was also found. The parasite *Orgilus ferus* was not present in 1973's samples. The population of this species was, during 1972, already declining from the high incidence of parasitism of 1971. With respect to individual age groups, the species *Apanteles cacoeiae* and *Copidosoma bakeri* were the only two species which were found to attack 1st instar larvae. These two species have been reported to attack the egg stage of the defoliator. *Temelucha* sp. was found only on 3rd, 4th and

Table 5. Records of *A. websteri* parasites reared from field samples

Date	No. hosts initiated	No. hosts sucessfully reared	No. hosts parasitized	*Apanteles cacoeiae*	*Temelucha* sp.	*Copidosoma bakeri*	*Phaeogenes* sp.	*Spilochalcis leptis*	Other	*Catolaccus aeneoviridis*	Total % parasitism
1st instar											
April 17	5	3	0								0
30	119	41	1			2.4					2.4
May 11	106	54	3	1.9		3.7					5.6
21	8	0	0								0
Total	238	98	4	1.1		3.3					4.1
2nd instar											
April 30	20	0	0								0
May 11	95	53	0								0
21	23	4	0								0
Total	138	57	0								0
3rd instar											
April 30	3	0	0								0
May 11	17	8	0								0
21	160	72	6	1.4	1.4	5.6					8.4
31	99	33	11	27.3	3.0				3.0		33.3
June 8	12	2	0								0
Total	291	115	17	8.7	1.7	3.5			0.9		14.8
4th instar											
May 21	19	8	0								0
31	346	179	17	7.3	1.1	0.6			0.6		9.6
June 8	68	21	6	9.5	4.8	9.5			4.8		28.6
18	13	8	6	75.0							75.0
Total	446	216	29	9.7	1.4	1.4			0.9		13.4
5th instar											
May 31	44	25	0								0
June 8	158	98	0								0
18	314	279	6			2.2					2.2
25	250	195	7		0.5	3.1					3.6
July 3	119	110	8			7.3					7.3
10	13	13	3			30.0					30.0
Total	858	720	24		0.1	3.2					3.3
Pupal stage											
June 18	13	7	1						14.3		14.3
25	59	38	10				10.5	15.8			26.3
July 3	139	105	23				8.6	11.4		1.9	21.9
10	203	153	29				6.5	5.2		7.2	18.9
16	88	62	11				3.2			14.5	17.7
23	39	27	4							14.8	14.8
31	7	5	2							40.0	40.0
Total	548	397	80				6.3	6.5	0.3	7.1	20.2

5th larval instars, indicating that younger hosts may not be suitable for this parasite.

Pheogenes sp. and *Spilochalcis leptis* were pupal parasites and were attacked by the hyperparasite *Catolaccus aeneoviridis*. Another hyperparasite, *Gelis* sp., was not recorded in the 1973 data. Several other minor defoliator parasites, *Diadegma* sp., *Microdontomerus* sp., *Meteorus* sp., and *Microtypus* sp., found in previous years were not observed in significant numbers in 1973.

In general, defoliator parasitism was quite low; none of the age groups had more than 20% mortality from this cause. The data show a continued downward trend of the level of parasitism over the past three years. It appears that parasitism probably is not the most important factor in controlling defoliator population at the study site.

Geographic Range of the Defoliator

The sagebrush defoliator has been reported in seven western states including California, Oregon, Idaho, Montana, Nevada, Utah, Washington, and probably Wyoming (Hall, 1965). Previous studies by other workers have established the northern, western and southwestern boundaries of the defoliator's geographic range of distribution. The eastern and southern limits of defoliator distribution have not been clearly established. Since Utah lies in the southern end of the geographic range, we were anxious to determine the status of the defoliator in this state.

In connection with the study of the host range of the defoliator, we investigated the southern limit of defoliator distribution in Utah during early June by the collection of defoliators at different locations in central and southern Utah and rearing them in the laboratory. Figure 1 and Table 6 summarize the information on collection sites and findings of this study. In our survey, each site was examined for approximately 30 min to 1 hr for evidence of the defoliator. Samples were then taken of defoliator webbings and were later sorted. Therefore, the total number of defoliators collected at each site as shown in Table 6 is not intended to indicate population density. The presence or absence of defoliators at a given site is a more meaningful indicator of defoliator distribution. Of 11 sites investigated, sites 6, 7, 8, and 10 did not yield any defoliators. This fact suggests that the southern boundary of the defoliator range probably does not extend into Washington or Kane counties. In the eastern part of the state, the defoliator has been recorded in Uintah County, but its occurrence in the southeastern part of the state has not yet been surveyed.

The rate of development of the defoliator at the various sites was comparable to that at the north Curlew Valley site. Three adults were reared from samples collected at site 9, two of these apparently belonged to an unidentified species related to *A. websteri*. Several parasites were recorded from the defoliator samples collected at sites 3, 4 and 9. All of these parasites have been recorded previously, with the exception of an unidentified species.

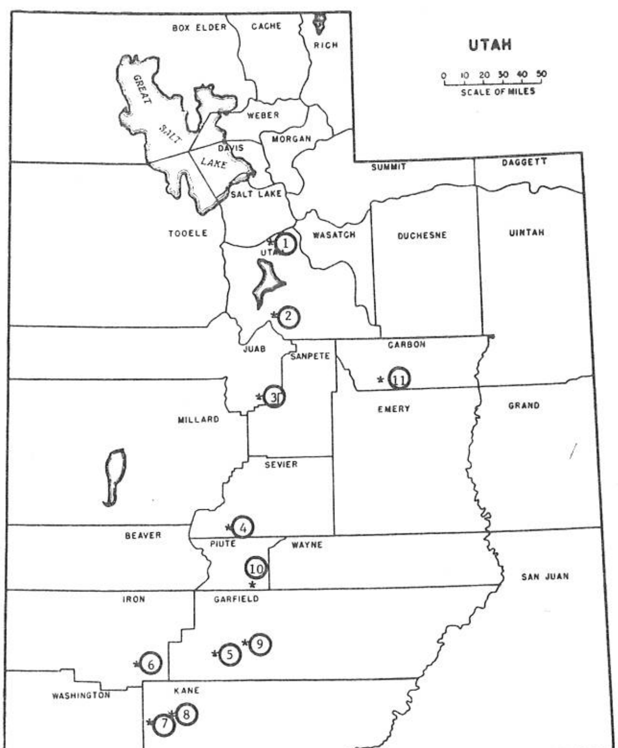

Figure 1. Sites surveyed for *A. Websteri* occurrence in Utah, 1973.

1. 1.6 km east on Utah 80, road to Timpanogas Cave (El. 4,500 ft.).
2. 1.6 km south of Santaquin on Mt. Nebo road (El. 5,000 ft.).
3. 1.6 km north of Sanpete-Juab County line on Utah 28.
4. 1.6 km south of Sevier on Utah 28.
5. 1.6 km west of entrance to Red Canyon campground (El. 6,500).
6. 6.4 km east of Cedar City on Utah 14 (El. about 8,000).
7. 1.6 km east of Zion Park east entrance.
8. 1.6 km south of Glendale on US 89.
9. 11.2 km south of Widtsoe Junction on Utah 22, 9.6 km northeast of junction of Utah 12 and 22, on Utah 22 (El. 7,800).
10. Garfield-Piute county line on Utah 22 (El. about 8,000).
11. 12.8 km south of Price on Utah 10, junction of Utah 10 and Utah 122 (El. about 5,800).

Table 6. Defoliators found on sagebrush at different sites in Utah, 1973. See Figure 1 for site locations

Date	Site #	Total No. Defoliators	Instar 3rd	Instar 4th	Instar 5th	No. Parasites	Remarks
June 1	1	5	0	2	3	0	
June 1	2	3	2	0	1	0	
June 3	3	16	2	11	3	3	*Apanteles*, *Orgilus*, *Diadegma*
June 3	4	11	1	5	5	1	*Orgilus*
June 3	5	1	0	0	1	0	
June 3	6	0	0	0	0	0	
June 4	7	0	0	0	0	0	
June 4	8	0	0	0	0	0	
June 4	9	8*	0	2	6	2	*Copidosoma*, and an unidentified species
June 4	10	0	0	0	0	0	
June 4	11	37	0	25	12	0	

* 1 adult was *A. websteri*, 2 adults were related species not yet identified.

Host-Plant Relationships

The feeding habits of the defoliator are rather restricted. In addition to the big sagebrush, *Artemisia tridentata*, Henry (1961) reported natural infestations on *A. tripartita*, *A. nova*, *A. arbuscula*, *A. cana*, and *A. longiloba* in southern Idaho. Gates (1964) observed positive feeding in the field on *A. tridentata*, *A. arbuscula*, *A. nova*, and *A. cana* in Oregon. Hall (1965) reared the defoliator on *A. tridentata*, *A. arbuscula*, and *A. cana* in California, and included rabbitbrush, *Chrysothamnus nauseosus*, and bitterbrush, *Purshia tridentata*, as hosts. Most investigators observed that the big sagebrush is probably the principal host, with other species utilized only when the primary host has been completely defoliated and if these species are in close proximity to the big sagebrush. Since some 23 species of *Artemisia* and many varieties of these species are known to be present in the intermountain region (Holmgren and Reveal, 1966) it would be desirable to determine the extent of potential and actual infestation so as to evaluate the possible impact by the defoliator. Two types of experiments were conducted toward this end. In the laboratory, the acceptability and suitability of different *Artemisia* species and varieties as well as some related Compositae were assessed. In the field, the extent of infestation of different *Artemisia* species occurring in several localities was surveyed. The results are discussed in the following sections.

Host Rearing and Suitability

Plants of *Artemisia* species and varieties were collected throughout Utah and southern Idaho and established in pots for rearing experiments. A supply of foliage of several *Artemisia* species was obtained from the Forest Service Great Basin Experiment Station in Ephraim, Utah. We have tested 21 species and varieties of *Artemisia* and 15 other Compositae species. Among the *Artemisia* species (Table 7), seven plants supported normal feeding and growth, two species supported moderate feeding and growth, and seven species were accepted slightly, but did not support growth, five species were not accepted by the larvae. Of the seven plants that are suitable for growth, all yielded normal adults. The variation found in mean pupal weight and percent adult yields from these plants may not be taken as a valid indication of the degree of acceptability or suitability, because of the small sample size. Further experiments with

Table 7. Host range of *Aroga websteri* among *Artemisia* species: 4th and 5th instar larvae were used in the tests

Species	No. defoliator	No. pupated	Mean Pupal wt. (mg) ± S.E.	No. Adults	% Yield of Adult	Acceptibility & Suitability*
A. abrotanum	30	0	-	0	0	-
A. absinthium	30	0	-	0	0	-
A. arbuscula	40	23	10.8 ± 0.33	12	30.0	+++
A. bigelovii	40	13	8.9 ± 0.33	8	20.0	+++
A. cana cana	30	9	10.2 ± 1.07	5	16.7	+++
A. cana vigidida	30	0	-	0	0	+
A. carruthii	22	0	-	0	0	+
A. dracunculus	30	0	-	0	0	-
A. filifolia	50	0	-	0	0	+
A. frigida	30	0	-	0	0	+
A. longiloba	30	0	-	0	0	+
A. ludoviciana candicans	30	0	-	0	0	+
A. ludoviciana incompta	40	0	-	0	0	-
A. ludoviciana typica	30	0	-	0	0	-
A. nova	30	7	7.8 ± 0.75	3	10.0	+++
A. pygmaea	30	7	7.5 ± 0.49	1	3.3	++
A. rothrockii	40	0	-	0	0	+
A. spinescens	30	2	7.4 ± 1.90	1	3.3	++
A. tridentata tridentata	30	16	9.9 ± 0.48	8	26.7	+++
A. tridentata wyomingensis	30	10	8.7 ± 0.84	6	20.0	+++
A. tripartita	30	7	9.6 ± 0.33	5	16.7	+++

* +++ Supports normal feeding and growth

++ Moderate feeding and supports growth for 1 larval instar

\+ Slight feeding, but does not support growth

\- No feeding

younger defoliator larvae and more replicates will be needed in order to establish the host preferences of this insect. Among the accepted plants, only *A. bigelovii* has not been reported as a natural host in the field. Although the species *A. pygmaea* and *A. spinescens* supported moderate feeding and growth, they are morphologically and phenologically quite different from other acceptable *Artemisia*. It is doubtful that these species would be utilized as hosts under natural conditions.

In comparing the varietal differences in acceptability in *Artemisia* species, the two *tridentata* varieties were found to be equally suitable. The two *cana* varieties showed diametrically opposed results with *A. cana vigidida* totally unacceptable. These facts indicate the presence of varietal preferences which may be important in considering the host relationship under natural conditions. None of the 15 plants tested outside the genus *Artemisia* were acceptable to the defoliator: *Chrysothamnus viscidiflorus, C. nauseosus, Chaenactis douglasii, Tetradymia canescens, Townsendia scapigera, Senecio canus, Erigeron pumilus, Cirsium undulatum, Tragopogon dubius, Wyethia mulenburgia, Taraxacum officinale, Erigeron* sp. (1), *Erigeron* sp. (2), *Atriplex confertifolia, Purshia tridentata.* Since all of these tested plants grow in the vicinity of *Artemisia*, they can be excluded as potential host plants for the defoliator. Our results did not verify those of Hall (1965) who considered *Purshia tridentata* and *Chrysothamnus nauseosus* as hosts of the defoliator.

Figure 2. Localities surveyed for *A. websteri* population on *Artemisia* species in southern Idaho during 1973.

1. Curlew Valley. 9.6 km north of Holbrook on Idaho 37 (El. 4,800 ft.).
2. Shoshone. 16.6 km north of Shoshone on US 93 (El. 4,400 ft.).
3. Butte City (I). 5.4 km east of Butte City on Idaho 22 and 88 (El. 5,000 ft.).
4. Butte City (II). 8.0 km east of Butte City on Idaho 22 and 88.
5. South Pocatello. On I-15, 6.4 km south of turnoff to Indian Rock State Park and Lava Hot Springs.

Field Survey of Host Range

During the collecting trip within Utah (Fig. 1) the following *Artemisia* species were located but showed no evidence of defoliator infestation: *A. pygmaea, A. carruthii, A. filifolia, A. bigelovii, A. ludoviciana candicans, A. ludoviciana incompta*, and *A. ludoviciana typica.* During July a study was made to determine the extent of defoliator infestation among the different *Artemisia* species found to be acceptable in our laboratory studies. The purpose of the study was to assess the population density on different adjacent *Artemisia* species, thereby to determine the species preferences of the defoliator.

In our survey, localities that contain mixed stands of *Artemisia* species and show a high degree of defoliator damage were examined. At each location, 10 random samples of plant branches extending from ground level were collected from each species and the samples were processed in the same manner as described in the sampling method section. Figure 2 shows the location of sampling sites and Table 8 summarizes the results obtained. Of the five sites sampled, two contained three sagebrush species and the other three sites contained two species. The rate of development of the defoliator varied from site to site depending on local climatic conditions and was less influenced by the species of host utilized. In general, the number of defoliator feeding sites correlates with the number of defoliators per kilogram of sagebrush, but this parameter is not an accurate indicator of population density on the different species of sagebrush.

In general, defoliator population density was higher on *tridentata* than on *A. arbuscula* or *A. tripartita.* Pupal weight followed the same trend, with individuals from *A. tridentata* having the highest mean weight and those from *A. arbuscula* the lowest. This result indicates that big sagebrush is the most suitable host for the defoliator. From our observations in the field, *A. arbuscula* is a low-growing shrub, has less foliage, and the leaves are less succulent than the other two species. Such a host condition may adversely affect growth and development of the defoliator larvae and result in smaller pupal size and higher mortality due to food shortage. This particular aspect of the insect-host plant relationship warrants further investigation.

Several species of parasites were reared from the defoliator samples. Among the larval parasites, *Copidosoma bakeri* was the most common species at all sites, but a few individuals of *Apanteles cacoeiae* species were found at three sites. Fillmore (1965) also listed *C. bakeri* as the most commonly found defoliator parasite in southern Idaho. Two pupal parasites, *Phaeogenes* sp., and *Spilochalcis leptis*, were also recorded. The hyperparasite, *Catolaccus aeneoviridis*, was also present in the samples from all sites. Overall parasitism recorded in the southern Idaho sites was similar, but all were higher than that of the Curlew Valley site (Table 5).

Oviposition Preferences Among Artemisia *Species*

Eight *Artemisia* species and another Compositae, the gum-plant, *Grindelia squarrosa*, were evaluated (Table 9). Approximately 300 individuals were placed in each cage; however, many of them died or escaped from the field cages. Therefore, only a small number of eggs were recovered from the test plants. The gum-plant was originally included to provide nectar for the adults to feed upon. Although this plant provided the most foliage area of the caged plants, no eggs were found on it. Among the eight *Artemisia* species, no eggs were found on *A. carruthii*, *A. frigida*, or *A. ludoviciana*. Eggs were recovered from all three caged plants of *Artemisia tridentata*, from two of three plants of *A. spinescens*, and one of three plants of *A. arbuscula*, *A. bigelovii*, and *A. cana vigidida*. The largest number of eggs (23) was found on *A. bigelovii*. Although the total number of eggs collected was low, preference for oviposition and feeding appears to be correlated among *Artemisia* species. Those species that received eggs were also those accepted by the larvae (Table 7).

Defoliation Studies

The major goal of 1973's work was to develop a method of assessing the long-term defoliator effects on sagebrush productivity and mortality. This study was initiated in July and the assessment of defoliator impacts was conducted on September 18 and October 2 when sagebrush fall growth was nearly complete. Table 10 summarizes the findings obtained from a total of 148 severely defoliated sagebrush plants that were tagged in July when defoliator feeding activity ceased. Among these tagged plants, 18.2% did not show regrowth in the fall and were presumed to be dead. In the surviving plants (81.8%), the most noticeable defoliator impact on the sagebrush was the reduction of plant vigor as shown by the decrease of the mean number of live branches from 4.5 to 2.8 per plant. There was also a drastic reduction in the percentage of live plants which produced flower stalks (53.7% or .95 branches with flower stalks per plant). This fact indicates that defoliator damage can adversely affect the flowering processes of the plant.

Examination of the various height groups of sagebrush for

Table 9. Oviposition preferences of *A. websteri* among *Artemisia* species. Each of three cages contained one plant of each species evaluated

Plant species	Aver. plant height (cm)	Total plant fresh wt. (g)	No. plant with eggs	Total no. eggs collected
A. arbuscula	12.6	26.0	1	8
A. bigelovii	24.0	39.9	1	23
A. cana vigidida	29.7	60.5	1	1
A. carruthii	16.4	49.3	0	0
A. frigida	44.0	56.9	0	0
A. ludoviciana	46.7	30.6	0	0
A. spinescens	13.7	86.6	2	6
A. tridentata tridentata	47.3	38.4	3	9
Grindelia squarrosa	81.0	820.6	0	0

Table 8. Survey of *A. websteri* population on *Artemisia* at different localities in Idaho during 1973

Date of sampling	Location	Plant species	Plant height (cm)	Plant weight (g)	No. feeding sites	Defoliators					
						Total	% larvae	% pupae	% pupal cases	Mean pupal wt. (mg) ± S.E.	No. defoliators/kg plant
July 11	Curlew Valley	*A. tridentata*	49.3	1054.1	150	88	5.7	85.2	9.1	7.8 ± 0.31	85.4
		A. tripartita	56.3	1030.7	80	56	1.8	78.6	19.6	7.6 ± 0.32	58.2
July 18	Shoshone	*A. tridentata*	59.3	725.4	125	39	0	25.6	74.4	7.0 ± 0.59	78.6
		A. tripartita	58.1	567.5	49	25	4.0	24.0	72.0	6.1 ± 0.78	47.6
		A. arbuscula	33.6	499.5	63	36	0	27.8	72.2	5.7 ± 0.33	74.0
July 19	Butte City (I)	*A. tridentata*	46.0	1527.7	54	55	5.5	65.5	29.0	7.0 ± 0.19	45.2
		A. arbuscula	29.1	1255.3	28	50	0	62.0	38.0	5.7 ± 0.20	44.6
July 19	Butte City (II)	*A. tridentata*	39.7	799.1	127	122	5.7	61.5	32.8	8.4 ± 0.15	168.9
		A. tripartita	55.3	556.5	48	74	10.8	56.8	32.4	8.0 ± 0.14	185.1
		A. arbuscula	33.8	758.8	20	31	3.2	74.2	22.6	6.7 ± 0.30	40.9
July 19	South Pocatello	*A. tridentata*	37.1	565.1	123	71	0	45.0	55.0	8.2 ± 0.40	157.5
		A. tripartita	53.1	492.7	46	27	0	37.0	63.0	7.4 ± 0.49	67.0

extent of defoliator damage showed that plants of less than 60 cm in height were most susceptible. These plants had the highest percentage of plant mortality and the lowest percentage of flower stalks produced. All of the taller plants (above 61 cm) were better able to withstand the impact of defoliation; 80 to 87% produced fall growth. The percentage of these plants that produced flower stalks varied from 45 to 100%. There appears to be no predictable correlation between plant height and flower production.

In order to quantify the differences between severely defoliated plants (Table 10, tagged plants) and healthy plants, 10 whole plants were randomly selected from each group and taken on each sampling day. The total plant weight, percent green weight, as well as the number of flower stalks and flower lengths were measured and recorded in the laboratory (Table 11). The data show that although the total biomass of the two plant groups were similar, there was a sizable reduction in the green weight produced by defoliated plants (from 34% down to 4%). The percentage of dead branches per plant was increased from 2.4 to 41.5%. Another noticeable difference was the reduction in the mean number of flower stalks, from 81.1 to 4.5 per plant. The average flower stalk length was also decreased to about half of normal size. These findings illustrate the profound impact of defoliators on sagebrush production and mortality. In order to obtain more quantified data, more plants of various age classes with different levels of defoliator infestation will need to be evaluated. Since our data show that defoliated plants usually can survive more than one year of defoliator infestation, it will also be necessary to monitor the same plants for several consecutive seasons in order to assess the full defoliator impact on sagebrush.

EXPECTATIONS

Considerable biological data have been gathered on the life history and biology of the sagebrush defoliator, *Aroga websteri* Clarke, at the study site. It is now feasible to assess the impact of the defoliator on sagebrush productivity and mortality. In addition to continued monitoring of the population dynamics of the defoliator at the study site, a major portion of 1974's research will be devoted to devising additional techniques for measuring the effects of different

Table 10. Impact of defoliators on sagebrush plant defoliation. Severely defoliated plants evaluated Sept. 18 and Oct. 2, 1973, and data arranged according to plant heights

Plant height group (mean, cm)	No. plants examined	% live plants	% live plants with flower stalks	Mean branches /plant	Mean live branches /plant	Mean branches with flower stalks/plant
41-50 (49.0)	2	0	0	5.0	0	0
51-60 (56.2)	13	69.2	11.1	4.5	2.7	0.11
61-70 (66.4)	20	80.0	68.8	3.9	2.1	1.13
71-80 (76.8)	35	82.9	51.7	4.6	2.7	0.93
81-90 (86.1)	38	86.8	51.5	5.1	3.3	0.94
91-100 (95.9)	23	87.0	45.0	4.5	3.3	0.90
101-110 (105.3)	12	83.3	80.0	4.2	2.3	1.20
111 (119.6)	5	80.0	100.0	4.6	2.3	2.00
All plants (82.3)	148	81.8	53.7	4.5	2.8	0.95

Table 11. Impacts of defoliators on sagebrush plant defoliation. Healthy and severely defoliated plants were marked on July 31, 1973. Ten plants were randomly selected and destroyed on each sampling date

Sampling date	Mean plant height (cm)	Mean plant wt. (kg)	% green wt.	Mean branches/plant	% dead branches /plant	Mean flower lengths (cm)	Mean flower stalks/ plant
Healthy plants							
Sept. 18	82.3	0.668	36.[illegible]	2.1	4.8	13.3	70.5
Oct. 2	82.0	0.771	31.7	2.2	0	12.2	91.7
All plants	82.2	0.720	33.9	2.2	2.4	12.8	81.1
Defoliated plants							
Sept. 18	72.7	0.568	5.3	2.5	40.0	5.5	6.8
Oct. 2	81.5	0.850	2.9	3.5	42.9	8.2	2.1
All plants	77.1	0.709	4.2	3.0	41.5	6.9	4.5

levels of defoliator infestation on sagebrush productivity. Tagged sagebrush plants will be used to follow the growth pattern of the plants, level of defoliator infestation, and extent of plant regrowth and reproduction throughout the growing season. A group of these tagged plants will be treated with a plant systemic insecticide to eliminate all insect infestation and to serve as an insect-free control treatment.

Biology and population dynamics of defoliators infesting several *Artemisia* species in southern Idaho will continue to be investigated to determine the effects of host species on the distribution and outbreaks of this insect. In connection with this study, several environmental variables such as temperature, precipitation, moisture stress of plants, altitude correlation, etc., will be examined to assess their direct and indirect influences on defoliator populations of different localities.

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