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By Tim B. Graham, Anne M.D. Brasher, and Rebecca N. Close

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Cover: Female Mormon cricket (*Anabrus simplex*); U.S. Geological Survey photograph by Tim Graham.

Contents

Figures

Tables

Mormon Cricket Control in Utah's West Desert—Evaluation of Impacts of the Pesticide Diflubenzuron on Nontarget Arthropod Communities

By Tim B. Graham[1], Anne M.D. Brasher[2], and Rebecca N. Close[3]

Executive Summary

Grasshopper and Mormon cricket (Orthoptera) populations periodically build to extremely high numbers and can cause significant economic damage in rangelands and agricultural fields of the Great Plains and Intermountain West. A variety of insecticides have been applied to control population outbreaks, with recent efforts directed at minimizing impacts to nontarget fauna in treated ecosystems. A relatively new insecticide for control of Orthoptera is diflubenzuron, which acts to inhibit chitin production, ultimately causing death during the molt following ingestion of the insecticide. All arthropods, including insects, mites, and crustaceans, use chitin to build their exoskeletons and will die if they are unable to produce it during the next molt. Diflubenzuron is not taxon specific—it affects all arthropods that ingest it, except adult insects, which do not molt. Consequently, application of this pesticide has the potential to significantly reduce not only target populations but all terrestrial and aquatic arthropods within treatment zones.

Some research has been done in the Great Plains on the impact of diflubenzuron on nontarget arthropods in the context of grasshopper-control programs, but no work has been done in the Great Basin in Mormon cricket-control areas. This study was instigated in anticipation of the need for extensive control of Orthoptera outbreaks in Utah's west desert during 2005, and it was designed to sample terrestrial and aquatic arthropod communities in both treated and untreated zones. Three areas were sampled: Grouse Creek, Ibapah, and Vernon. High mortality of Mormon cricket eggs in the wet, cool spring of 2005 restricted the need to control Mormon crickets to Grouse Creek. Diflubenzuron was applied (aerial reduced agent-area treatment) in May 2005. Terrestrial and aquatic arthropod communities were sampled before and after application of diflubenzuron in the Grouse Creek area of northwestern Utah in May and June of 2005. In July 2005, U.S. Geological Survey scientists sampled areas in Ibapah and Vernon that had been treated with diflubenzuron in 2004, along with adjacent untreated areas. Pitfall traps at four treated and four untreated sites were used to collect ground-dwelling terrestrial arthropods. Semiquantitative sweep surveys of aquatic habitats were made before treatment, 2 weeks after treatment, and 4 months after treatment (after leaf fall) at Grouse Creek. One-year post-treatment samples were collected by using the same methods for terrestrial and aquatic arthropods at Ibapah and Vernon in July 2005 (treatments applied in June 2004).

More than 124,000 terrestrial arthropods were collected from the three study areas, and more than 200,000 aquatic invertebrates were collected in the aquatic samples. Direct effects of diflubenzuron on aquatic and terrestrial arthropod communities were not apparent in our data from Grouse Creek. The treatment was designed to avoid spraying pesticide on water bodies, and no measurable effects on aquatic communities from either springs or streams were observed, with the exception of the reduction of taxa richness at Vernon (a result confounded by elevational differences in the treatment and nontreatment zones). Some trends indicate diflubenzuron may affect some terrestrial taxa. Ant communities showed some differences, with possible lag effects at Ibapah and Vernon. *Forelius* was more abundant, while *Tapinoma* and, perhaps, *Formica* declined in treated zones in these two study areas. *Solenopsis* also was more numerous at treated Ibapah sites but varied without pattern at Vernon. Scorpions were abundant at Grouse Creek and Ibapah but rare at Vernon. Numbers did not change during several weeks at Grouse Creek, but at Ibapah, numbers at treated sites were much lower than at untreated sites. The Lygaeidae (in the order Hemiptera) were more abundant in the untreated zones at Ibapah and Vernon, although significantly so only at Ibapah. Lygaeidae were absent from the treated zone at Grouse Creek (before and after treatment) but were present after treatment in the untreated zone. Additional research is recommended to determine more explicitly whether these taxa are sensitive to diflubenzuron applications in the Great Basin.

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Introduction

In rangeland ecosystems of the United States, populations of Orthoptera (including grasshoppers and Mormon crickets) can rapidly build to levels that cause economic damage. Despite efforts to prevent outbreaks, grasshopper (multiple species) and Mormon cricket (*Anabrus simplex*) populations (fig. 1) were at large levels for 5 to 6 years preceding this study in the west desert of northern Utah (U.S. Department of Agriculture, 2002). Although much of the area of outbreak was outside of cultivated lands, State and Federal agencies and private landowners were concerned about consumption of crops and range forage during these infestations. The need for rapid and effective suppression of Orthoptera when an outbreak occurs limits the control options available, and the application of an insecticide within all or part of the outbreak area has been the primary response for rapid suppression or reduction of Orthoptera populations to effectively protect rangeland. Control efforts have been implemented in Utah's west desert since 2002 in areas of particularly large Orthoptera populations.

The primary chemicals used for control of grasshoppers and crickets are carbaryl, applied as bran bait, and diflubenzuron, applied as an aerial spray. However, because the use of carbaryl in Utah's west desert has been greatly curtailed and is more localized, we focused on diflubenzuron treatments. Diflubenzuron is a chitin-inhibiting agent, causing arthropods to die during the molting process. Arthropods (including insects, arachnids, and crustaceans) have a hard exoskeleton made of chitin. Since diflubenzuron is a chitin-inhibitor, it affects nontarget arthropods, as well as grasshoppers and crickets. Previous studies have shown that although diflubenzuron is not directly toxic to vertebrates, birds can be indirectly affected when this pesticide reduces availability of key prey items (Sample and others, 1993). Consequently, a major concern in the west desert is that by killing nontarget arthropods, the food base for sensitive, rare, or threatened vertebrates, such as sage grouse and spotted frogs, will be depleted.

Figure 1. Mormon crickets on the road at Grouse Creek study site in May 2005, Utah (U.S. Geological Survey photograph by Tim Graham).

Studies on the Great Plains have shown diflubenzuron to have minimal impacts on nontarget arthropods and their vertebrate predators (Wilcox and Coffey, 1978; McEwen and others, 1996), reinforcing the decision to use diflubenzuron in a reduced agent-area treatment design (using less pesticide in alternating swaths) instead of carbaryl or malathion. Some nontarget arthropods were affected by diflubenzuron, at least in the short term, in some studies (Catangui and others, 2000; Smith and others, 2006). The generality of previous work has not been established. Information directly applicable to the environment of Utah's west desert is required for assessing potential impacts of diflubenzuron on nontarget arthropods in the Great Basin.

Objectives

This study was designed to help managers improve Orthoptera-control programs by increasing the understanding of how diflubenzuron affects both target and nontarget arthropods. The specific objectives of this study were to (1) compare aquatic and terrestrial arthropod community structure (abundance and species composition) in treated and untreated sites in the west desert to determine whether there were changes in either target or nontarget arthropod populations, (2) compare responses at three study areas to determine whether response was similar across the landscape, and (3) compare terrestrial and aquatic arthropod community structure over time at each study area following insecticide treatment. The study also yields valuable baseline data on both aquatic and terrestrial arthropod communities in west desert rangeland ecosystems.

Scope

Three areas of Utah's west desert—Grouse Creek, Ibapah, and Vernon—were chosen for 2005 sampling based on Orthoptera outbreaks in preceding years. However, in 2005, the only area significantly infested, and therefore sprayed with diflubenzuron, was Grouse Creek. We modified our objectives to account for the reduced control effort. We sampled for short-term effects of diflubenzuron at Grouse Creek; at the other two study areas, we tested for lag effects of diflubenzuron application by sampling in untreated zones and zones treated in 2004. Without prespray data or several years of postspray data, our analysis was limited. In addition, water bodies are rare in this semiarid environment; consequently, it was difficult to locate a large number of comparable types of aquatic systems within and outside the treated zone in a given study area. Topography also proved to be an issue, particularly at Vernon, for both terrestrial and aquatic sampling because the treatment zone was on the valley floor and sites outside of the treatment zone were approximately 60–65 m higher in elevation.

Study Area

Grouse Creek (fig. 2), Ibapah (fig. 3), and Vernon (fig. 4) in Utah's west desert were chosen for sampling due to large Mormon cricket populations in previous years and large expected populations for 2005. Ibapah and Vernon had large Mormon cricket populations for a number of years but were not treated with diflubenzuron prior to 2004 (G. Abbott, Animal and Plant Health Service, written commun., 2007). Grouse Creek had not been treated before 2005. Patchy application of carbaryl bran bait in previous years was done in all three areas (G. Abbott, Animal and Plant Health Service, written commun., 2007), including some areas we considered untreated relative to diflubenzuron application for this study. Diflubenzuron was applied to the Grouse Creek treatment zone in May 2005. Grouse Creek is in the extreme northwestern part of the State. We sampled terrestrial sites in four vegetation associations (table 1) according to the Southwest Regional Gap analysis (Prior-Magee and others, 2007). Ibapah sites, near the Utah-Nevada border, were all in the same vegetation association, although there was some variability on the ground in abundance of different vegetation components. The Vernon study area, south of Vernon, Utah, was more diverse, encompassing five vegetation communities.

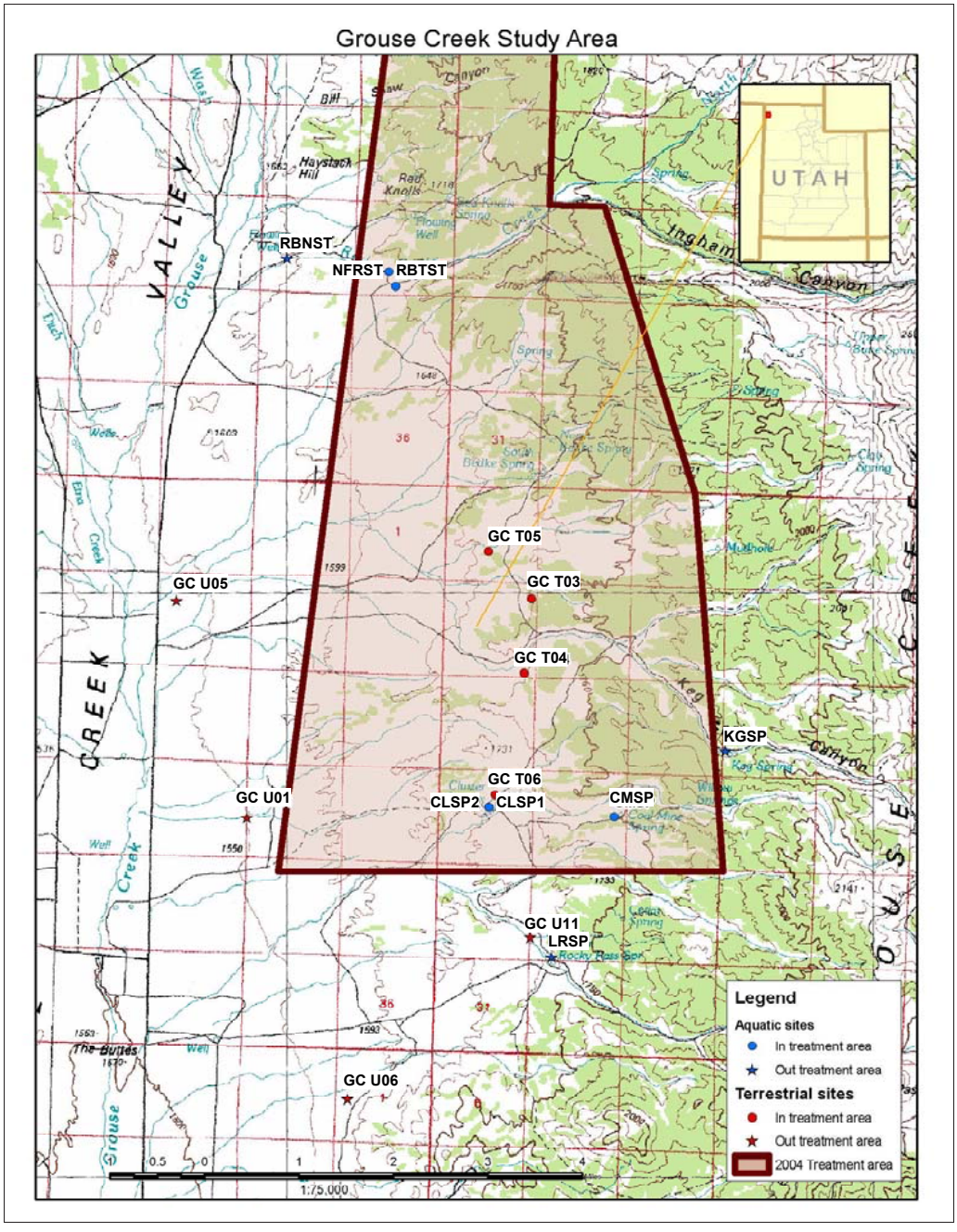

Figure 2. Grouse Creek study area with treated zone shaded; terrestrial (red) and aquatic (blue) sampling sites are shown within treated and untreated zones.

Terrestrial Sampling

Study Sites

Terms for the different spatial scales of this study were defined as follows: study area is defined as one of the three major geographic areas studied [that is, Grouse Creek (GC), Ibapah (IB) or Vernon (VE)]; treatment zone refers to the area within a study area that was treated (T) or untreated (U) with diflubenzuron (that is, treated zone, untreated zone); site refers to the individual locations sampled using pitfall traps within a treatment zone in a study area (for example, GC U06, IB T22, and VE U09). In 2005, Mormon cricket-control efforts were concentrated in the mountains east and west of Grouse Creek valley. We established four sites in the eastern Grouse Creek treatment zone; four untreated sites also were established to the west and south of this treated zone (fig. 5). At the other two study areas, Ibapah (fig. 6) and Vernon (fig. 7), we sampled both zones that had been treated with diflubenzuron in 2004 and adjacent untreated zones. Here we also established four pitfall sites in each of the treated and untreated zones. All pitfall sites were established at locations randomly

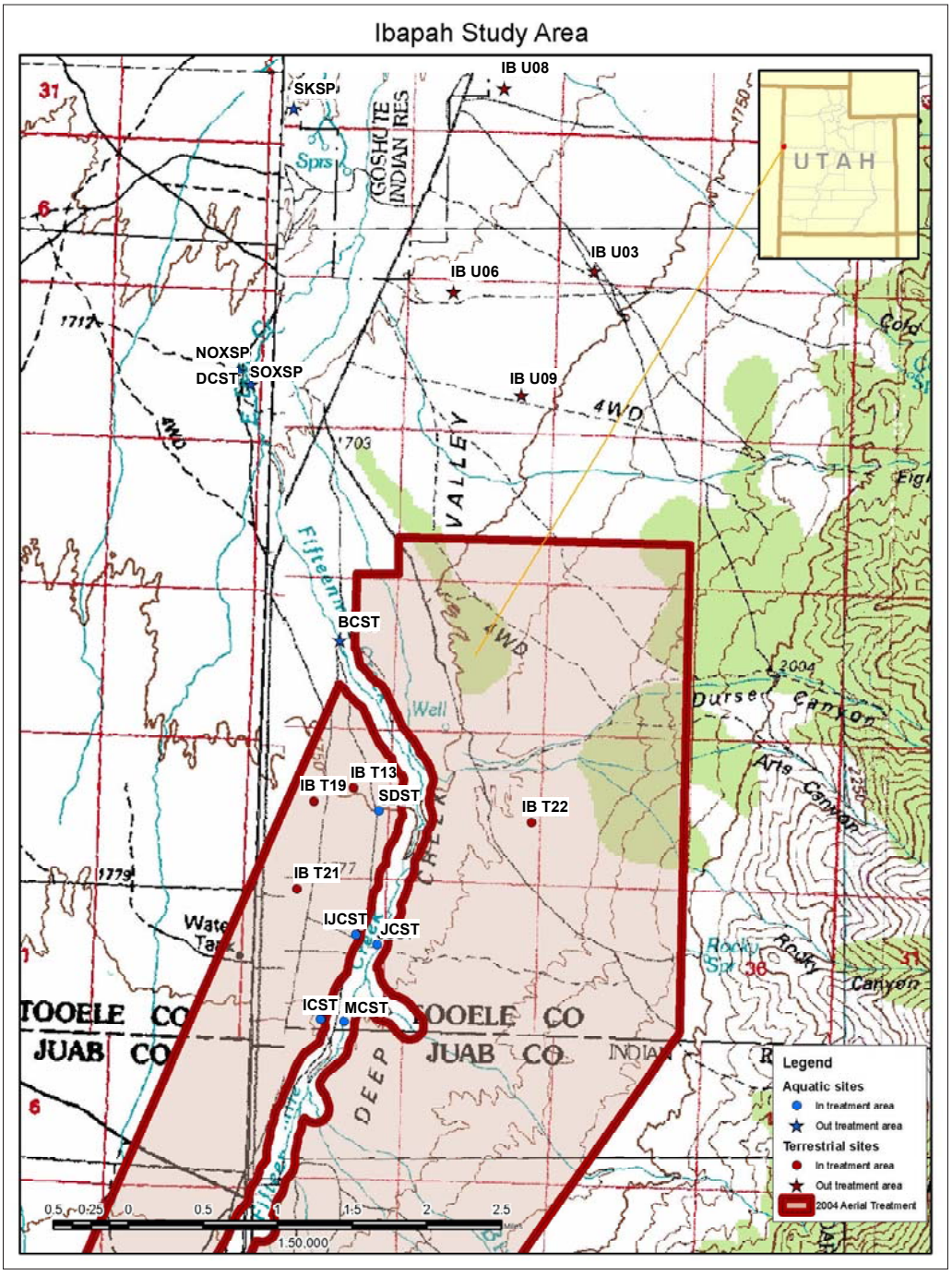

Figure 3. Ibapah study area with treated zone shaded; terrestrial and aquatic sampling sites are shown within treated zone and untreated zones.

selected with a geographic information system. General site characteristics, site-code designations, and sampling dates are shown in table 1.

Sampling Design

Terrestrial arthropods were sampled by using pitfall traps arranged in a pattern that allowed capture data to be used with DISTANCE software (Buckland and others, 2001) to estimate density of total arthropods and of individual taxa (Lukacs and others, 2004). Pitfall traps at each site were arranged to meet the assumptions of DISTANCE sampling, which are that all invertebrates on the center line are detected (that is, caught) and that distances from the center line are accurately measured. We used 60 traps at each site in the arrangement shown in figure 8. This pattern was generated by using WebSim (Lukacs, 2001, 2002) to simulate a hazard-rate model of invertebrate captures that resulted in estimates with small confidence intervals, and matched trapping results in a pilot study of invertebrate pitfall trapping in Colorado (Lukacs, oral commun., 2005).

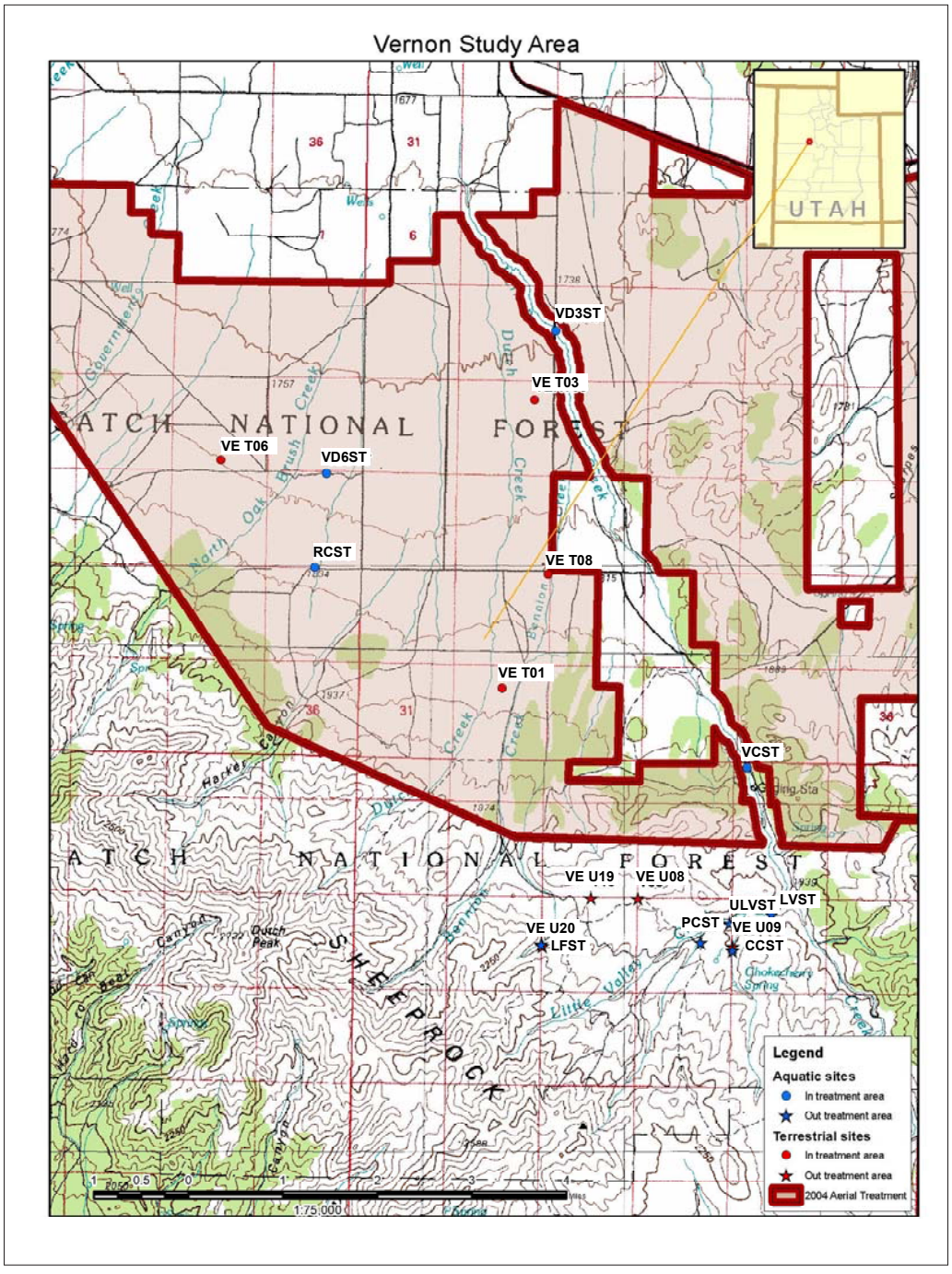

Figure 4. Vernon study area with treated zone shaded; terrestrial and aquatic sampling sites shown within treated zone and untreated zones.

Table 1. Terrestrial site and sampling information, west desert study sites, Utah.

Site code	Treatment zone	Elevation, in meters	GAP vegetation classification	Sample dates	Sample period	Number of days traps were open
			Grouse Creek			
GC U01	Untreated	1,549	Inter-Mountain Basin Mixed Salt Desert Scrub	6/3/2005	pre-treatment	2
				6/20/2005	post-treatment	4
GC U05	Untreated	1,542	Invasive Perennial Grassland	6/3/2005	pre-treatment	2
				6/22/2005	post-treatment	2
GC U06	Untreated	1,573	Inter-Mountain Basin Semi-Desert Grassland	6/6/2005	pre-treatment	3
				6/21/2005	post-treatment	4
GC U11	Untreated	1,669	Inter-Mountain Basin Big Sagebrush Shrubland	5/27/2005	pre-treatment	2
				6/22/2005	post-treatment	5
GC T03	Treated	1,705	Inter-Mountain Basin Big Sagebrush Shrubland	5/26/2005	pre-treatment	2
				6/23/2005	post-treatment	2
GC T04	Treated	1,701	Inter-Mountain Basin Big Sagebrush Shrubland	5/27/2005	pre-treatment	3
				6/21/2005	post-treatment	4
GC T05	Treated	1,665	Inter-Mountain Basin Big Sagebrush Shrubland	5/30/2005	pre-treatment	4
				6/23/2005	post-treatment	2
GC T06	Treated	1,665	Inter-Mountain Basin Big Sagebrush Shrubland	5/26/2005	pre-treatment	2
				6/20/2005	post-treatment	4
			Ibapah			
IB U03	Untreated	1,734	Inter-Mountain Basin Big Sagebrush Shrubland	7/14/2005	1 year post-treatment	3
IB U06	Untreated	1,707	Inter-Mountain Basin Big Sagebrush Shrubland	7/15/2005	1 year post-treatment	3
IB U08	Untreated	1,670	Inter-Mountain Basin Big Sagebrush Shrubland	7/14/2005	1 year post-treatment	3
IB U09	Untreated	1,747	Inter-Mountain Basin Big Sagebrush Shrubland	7/15/2005	1 year post-treatment	3
IB T13	Treated	1,756	Inter-Mountain Basin Big Sagebrush Shrubland	7/15/2005	1 year post-treatment	3
IB T19	Treated	1,769	Inter-Mountain Basin Big Sagebrush Shrubland	7/15/2005	1 year post-treatment	3
IB T21	Treated	1,784	Inter-Mountain Basin Big Sagebrush Shrubland	7/14/2005	1 year post-treatment	3
IB T22	Treated	1,826	Inter-Mountain Basin Big Sagebrush Shrubland	7/15/2005	1 year post-treatment	3

Table 1. Terrestrial site and sampling information, west desert study sites, Utah—Continued.

Site code	Treatment zone	Elevation, in meters	GAP vegetation classification	Sample dates	Sample period	Number of days traps were open
			Vernon			
VE U08	Untreated	2,082	Southern Rocky Mountain Montane-Subalpine Grassland	7/23/2005	1 year post-treatment	3
VE U09	Untreated	1,998	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	7/22/2005	1 year post-treatment	3
VE U19	Untreated	1,879	Great Basin Piñon-Juniper Woodland	7/22/2005	1 year post-treatment	3
VE U20	Untreated	2,117	Inter-Mountain Basin Montane Sagebrush Steppe	7/22/2005	1 year post-treatment	3
VE T01	Treated	1,829	Great Basin Piñon-Juniper Woodland	7/21/2005	1 year post-treatment	3
VE T03	Treated	1,771	Inter-Mountain Basin Big Sagebrush Shrubland	7/23/2005	1 year post-treatment	3
VE T06	Treated	1,801	Inter-Mountain Basin Big Sagebrush Shrubland	7/22/2005	1 year post-treatment	3
VE T08	Treated	1,829	Great Basin Piñon-Juniper Woodland	7/21/2005	1 year post-treatment	3

Figure 5. Typical terrestrial site at Grouse Creek study site, Utah, showing pitfall traps (U.S. Geological Survey photograph by Tim Graham).

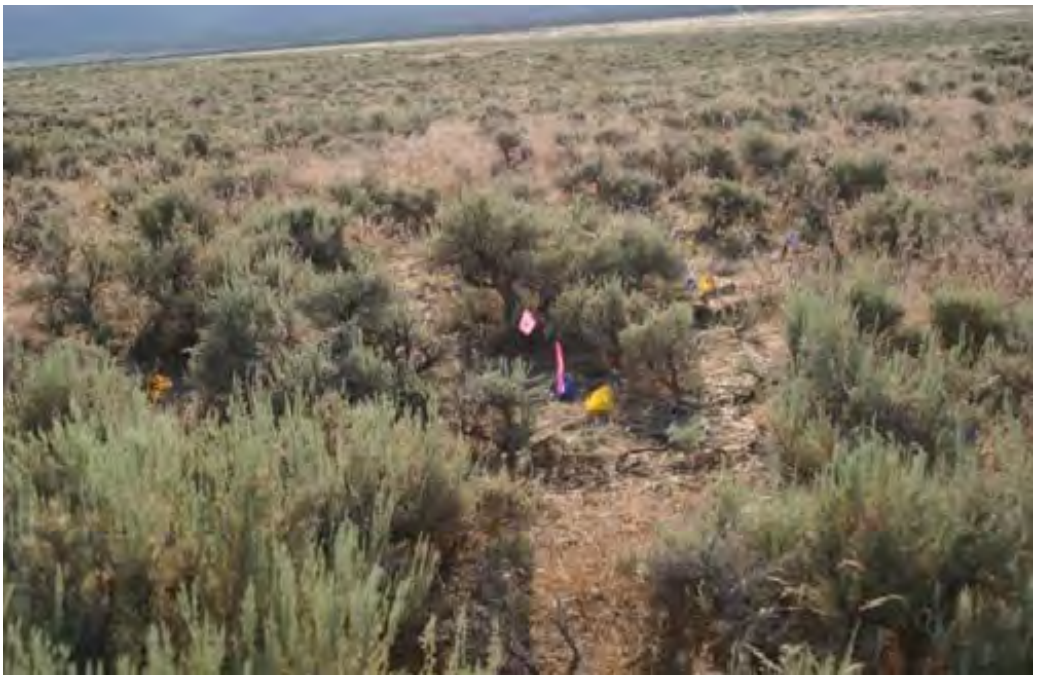

Figure 6. Typical terrestrial site at Ibapah study site, Utah (U.S. Geological Survey photograph by Tim Graham).

Figure 7. Typical terrestrial site at Vernon study site, Utah, showing pitfall traps (U.S. Geological Survey photograph by Becky Close).

Sample Collection and Processing

Pitfall traps were placed by carefully measuring and marking correct locations with flags, then digging in the traps (fig. 9). Pitfall traps were constructed as described by New (1998). For each trap, a 1.5-L plastic jar was buried below ground level and a 500-mL cup containing 125 mL of soapy water was placed in the jar. A 15-cm-diam funnel was placed over the jar, centered over the cup, with the top of the funnel at ground level.

At Grouse Creek, we sampled in late May/early June, just prior to application of diflubenzuron in both the zone to be treated and in the zone to remain untreated (pre-treatment samples). Traps at all sites in both treated and untreated zones were opened again in late June, about 3 weeks after diflubenzuron application (post-treatment samples). By comparing treated and untreated zones before and after treatment, differences between pre- and post-treatment communities associated with the phenology of the arthropods can be separated from those changes that may be due to exposure to diflubenzuron.

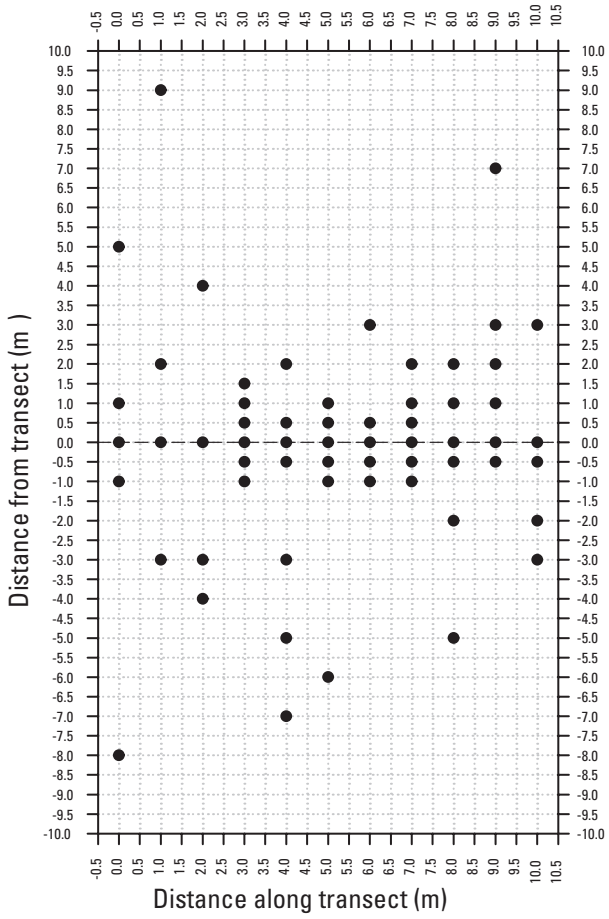

Figure 8. Arrangement of pitfall traps at each terrestrial arthropod sampling site of the study.

Ibapah and Vernon sampling occurred in July 2005, roughly a year following treatment of the treated zones; there was no temporal component to the study in these two areas.

Traps were kept open from 2 to 5 days (table 1); the time period eventually was standardized at 3 days, but different timeframes were used in early sampling periods due to logistical constraints.

Each trap's contents were washed in the field through a 0.5-mm mesh net three times; everything remaining in the net was placed in a 35-mL vial containing about 25 mL isopropyl alcohol (fig. 10). A paper label with site, date, and trap number was placed inside each vial, and a stick-on label with the same information was affixed to the outside of each vial. Vials were kept in the shade in the field, as cool as possible, and stored at room temperature once they were returned to the lab.

Sample Sorting and Identification

All terrestrial invertebrates were sorted to order. Specimens in the orders Hemiptera and Orthoptera were identified to family; ants (Formicidae) were identified to genus (fig. 11). Taxa were identified following Triplehorn and Johnson (2005), and we followed the taxonomic nomenclature of this source (that is, the order Hemiptera includes Heteroptera and the Homoptera; Thysanura has been split into Microcoryphia and Thysanura). Differences in abundance, or presence/absence of particular taxa that correlated with treatment patterns, were used to identify potential indicator species.

Data Analysis

To allow comparisons among individual sites, treatment-zones, and study-areas, data are reported as numbers per day

Figure 9. Putting in pitfall traps (U.S. Geological Survey photograph by Tim Graham).

Figure 10. Processing terrestrial arthropods from pitfall trap in the field (U.S. Geological Survey photograph by Becky Close).

Figure 11. Sorting pitfall trap samples, removing debris, and identifying specimens to order (U.S. Geological Survey photograph by Tim Graham).

(abundance) by taxon, and as relative abundance. Because traps were not kept open for the same number of days during all sampling events, all arthropod numbers were adjusted to average number per day by dividing the number of individuals (both total arthropods and individual taxa) caught in each trap by the number of days the traps at that site were open. Abundance data of terrestrial insects and other arthropods in treated versus untreated zones within a study area were tested for normality and equal variance, then compared using t-tests or Mann-Whitney rank sum tests, using SigmaStat (Systat, 2004). Statistical significance was assigned at $\alpha<0.05$; however, several of the observed differences in abundance were large, indicating the potential for biological significance even when statistical tests did not show them to be significant at $\alpha=0.05$. More sampling will tell whether these effects are real (they are masked by high variability, given our sample sizes); for the record, we note these cases with $\alpha<0.20$. Data used for nonmetric multidimensional scaling (NMS) consisted of the average number of individuals per day per taxon for each sampling event. NMS was performed in PC-ORD (McCune and Mefford, 2005) using Sorensen's distance measure. Fifty iterations were run with the data, then 250 iterations of a Monte Carlo test were used to estimate the best-fit (least-stress) solution.

Terrestrial Results

In May, June, and July 2005, 1,920 pitfall traps were set at the three study areas. More than 124,000 specimens have been identified to order. The total number of arthropods caught at a single site ranged from 853 at GC T06 (pre-treatment collection) to 36,043 at GC U05 (post-treatment collection). Relative abundance of the 13 orders varied considerably in space and time. The most common taxa were typically Diptera (flies), Hemiptera (true bugs), and Formicidae (ants), with Araneae (spiders), non-ant Hymenoptera (bees and wasps), and Orthoptera (grasshoppers, crickets, and such) fairly common at some sites. The three study areas had very different communities. Additionally, the variability among sites at each study area, even among the "replicate" sites of treated or untreated zones, was considerable. Few indications of the short-term effect of diflubenzuron at Grouse Creek on the relative abundance of any taxon except the Orthoptera (the object of control efforts) were discernible.

Comparison of Proportional Abundance

Grouse Creek

Flies were most abundant at the Grouse Creek untreated sites in late May and early June, with ants codominant at GC U11 and GC U06 (fig. 12). Spiders, beetles, bees, wasps,

Hemiptera, and Lepidoptera also were common at one or more sites. By late June, communities at all sites had changed dramatically. At three sites, Hemiptera were by far the most abundant taxon. Ants and flies were still common at most sites but proportionately less abundant given the increase in numbers of Hemiptera. Spiders and Orthoptera increased at GC U11.

Hemiptera, Diptera, and ants were the most abundant groups at treated sites of Grouse Creek prior to treatment. The three groups accounted for more than 70 percent of all the arthropods caught at the four sites (fig. 13). GC T04 had the lowest proportion of Hemiptera, the highest proportion of ants, and larger numbers of beetles and Orthoptera than at the other sprayed sites prior to treatment. GC T04 had the most Mormon crickets during sampling in late May and early June.

After treatment, Hemiptera were much more abundant at the treated sites, showing a pattern similar to that of untreated sites. Ants and flies accounted for most of the other captures. Numbers of Orthoptera declined following treatment, as expected, showing the largest decline at GC T04. Most differences between pre- and post-treatment communities at the treated sites were similar to the changes observed among the untreated sites, indicating that the differences were likely due to seasonal changes, not treatment effects.

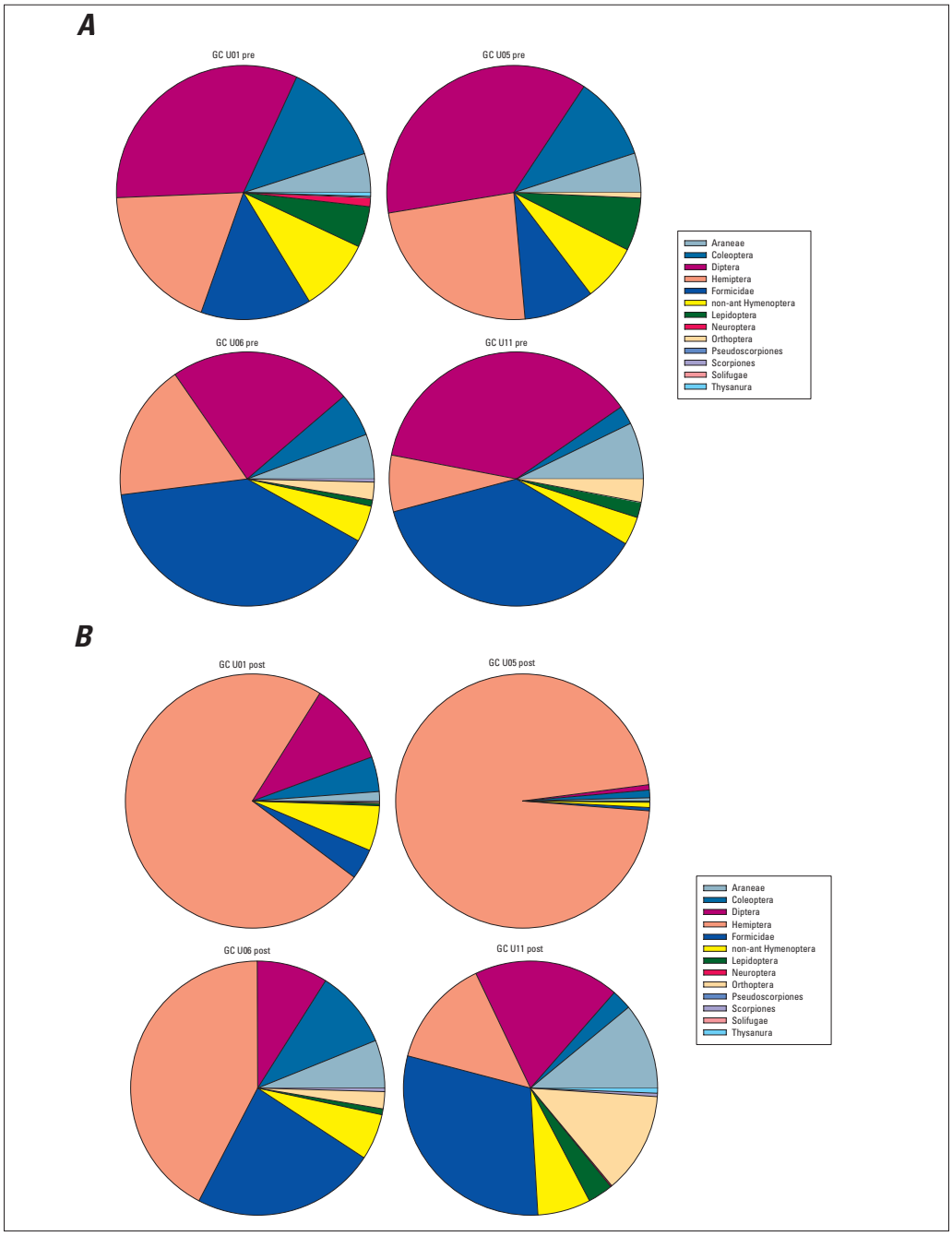

Figure 12. Proportional representation of taxa at the four sites in the Grouse Creek untreated zone. *A*, Pretreatment communities in late May or early June. *B*, Post-treatment communities in late June.

Ibapah

Ibapah sites were sampled only once, in mid-July 2005 (table 1). All communities had large Hemipteran components (fig. 14). Two sites, one treated (IB T13, 68 percent) and one untreated (IB U08, 92 percent), were heavily dominated by Hemiptera. Ants and flies also were abundant at all Ibapah sites; spiders were more prevalent than flies in traps at IB T19 and IB T22 (both treated in 2004). Flies were less common at Ibapah than at Grouse Creek, both in treated and untreated sites. Ants dominated all sites if Hemiptera were excluded from the dataset, constituting more than half the individuals at each site. Spider abundance also became more apparent if Hemiptera were excluded.

Vernon

Vernon was sampled only once in July 2005. At three of four untreated sites and three of four treated sites, about 25–40 percent of all the arthropods caught were Hemiptera; fewer than 15 percent of the arthropods caught at the other two sites (VE U20 and VE T01) were Hemiptera (fig. 15). Compared to Ibapah and Grouse Creek, Hemiptera and flies at Vernon were proportionately less abundant, and the Hymenoptera were relatively more abundant. Specifically, ants and the combined bee and wasp fractions of the Hymenoptera were better represented at Vernon. The non-ant Hymenoptera were more abundant at the untreated sites than

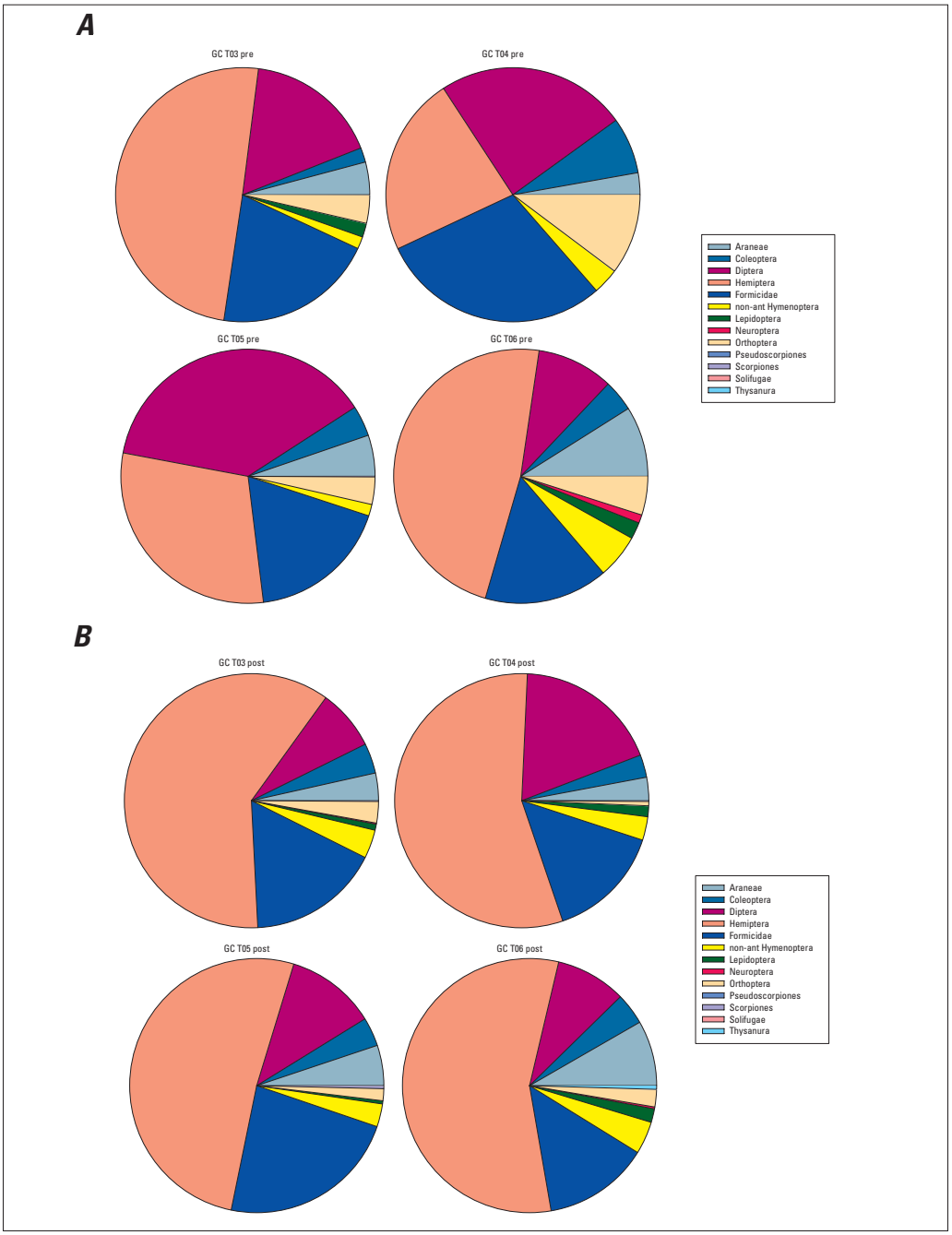

Figure 13. Proportional representation of taxa at the four sites in the Grouse Creek treated zone. *A*, pretreatment communities in late May and early June. *B*, Post-treatment communities in late June.

at the treated sites, although there was no statistical difference in proportional abundance.

Comparisons of Abundance by Orders in Treated and Untreated Zones

Average abundance (numbers per day) for each taxon was calculated for the four sites within a treatment zone in each study area (fig. 16). A t test was used if the data passed normality and equal variance tests; the test statistic is represented as a t. If data failed normality or equal variance tests, comparisons were made with the Mann-Whitney rank sum test; the test statistic is represented as T.

Within each study area, abundance for each taxon in the treated zone was compared to abundance in the untreated zone. Data from different study areas were not compared to each other. At Grouse Creek, we also tested whether changes in arthropod abundance following application of diflubenzuron were related to the insecticide, or merely to phenology (seasonal changes in species composition) of the arthropod community. This test was conducted in two ways; the first approach was to compare average abundance before and after treatment within each treatment zone (for example, GC U pre-

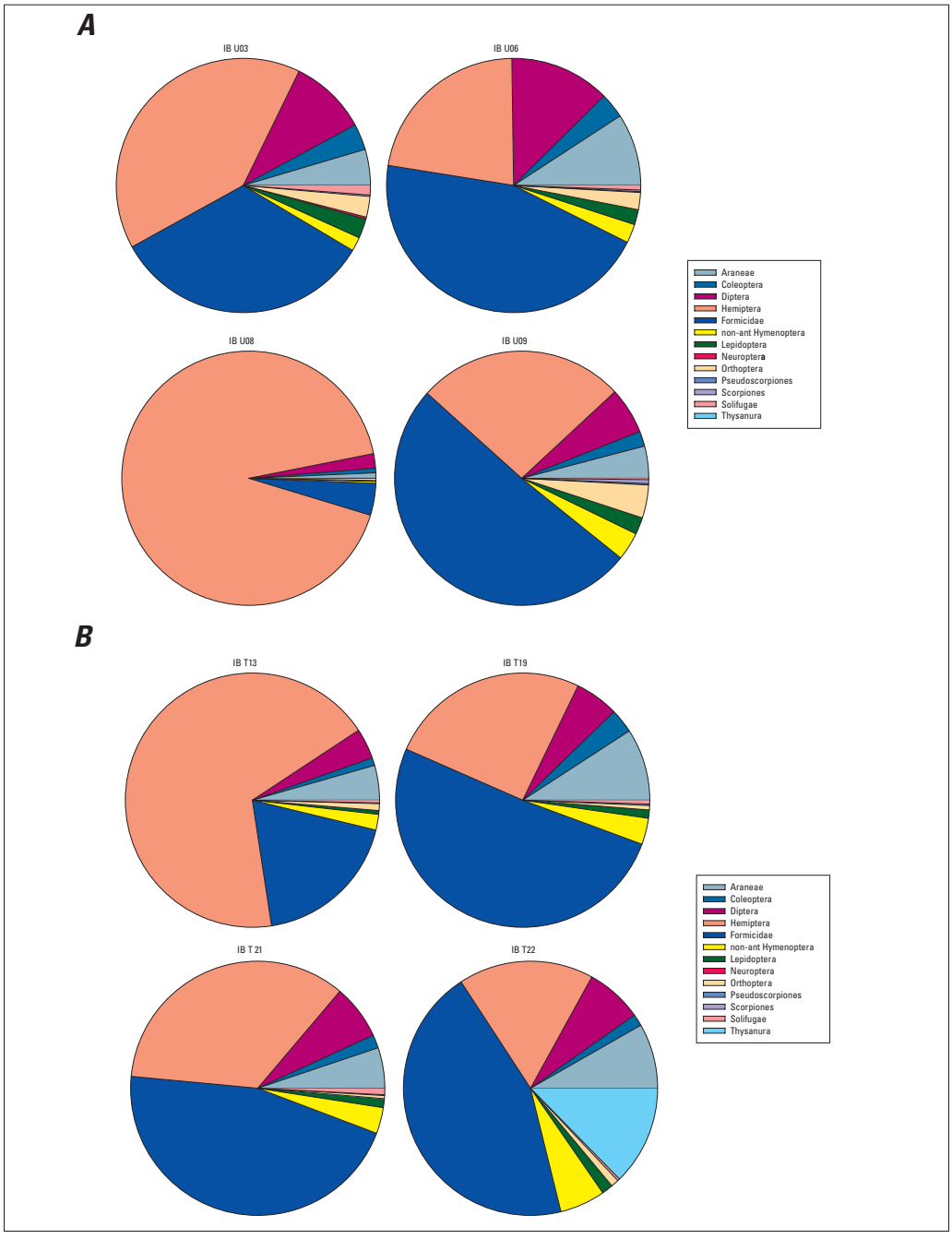

Figure 14. Proportional representation of taxa at the eight Ibapah sites. Communities in the untreated (*A*) and treated (*B*) zones.

treatment compared to GC U post-treatment, and GC T pre-treatment compared to GC T post-treatment). Significant differences for a given taxon in pre- and post-treatment numbers in the treated zone were interpreted as indicating a possible effect of diflubenzuron application. The second approach was to compare taxon abundance in the sprayed and unsprayed zones prior to treatment and again with the data collected 3 weeks after treatment. If there were no differences prior to treatment but treated and untreated average taxon abundance differed following treatment, we assumed diflubenzuron affected that taxon.

Grouse Creek

Pre- versus Post-Treatment Changes in Untreated Zone

Most taxa exhibited an increase in abundance from pre- to post-treatment sampling in the unsprayed zone at Grouse Creek (fig. 16 *A–L*). Spiders ($T_{d.f.\ 6}$=10; P=0.029), non-ant Hymenoptera ($T_{d.f.\ 6}$=10; P=0.029), and total arthropods ($T_{d.f.\ 6}$=10; P=0.029) were significantly more abundant in

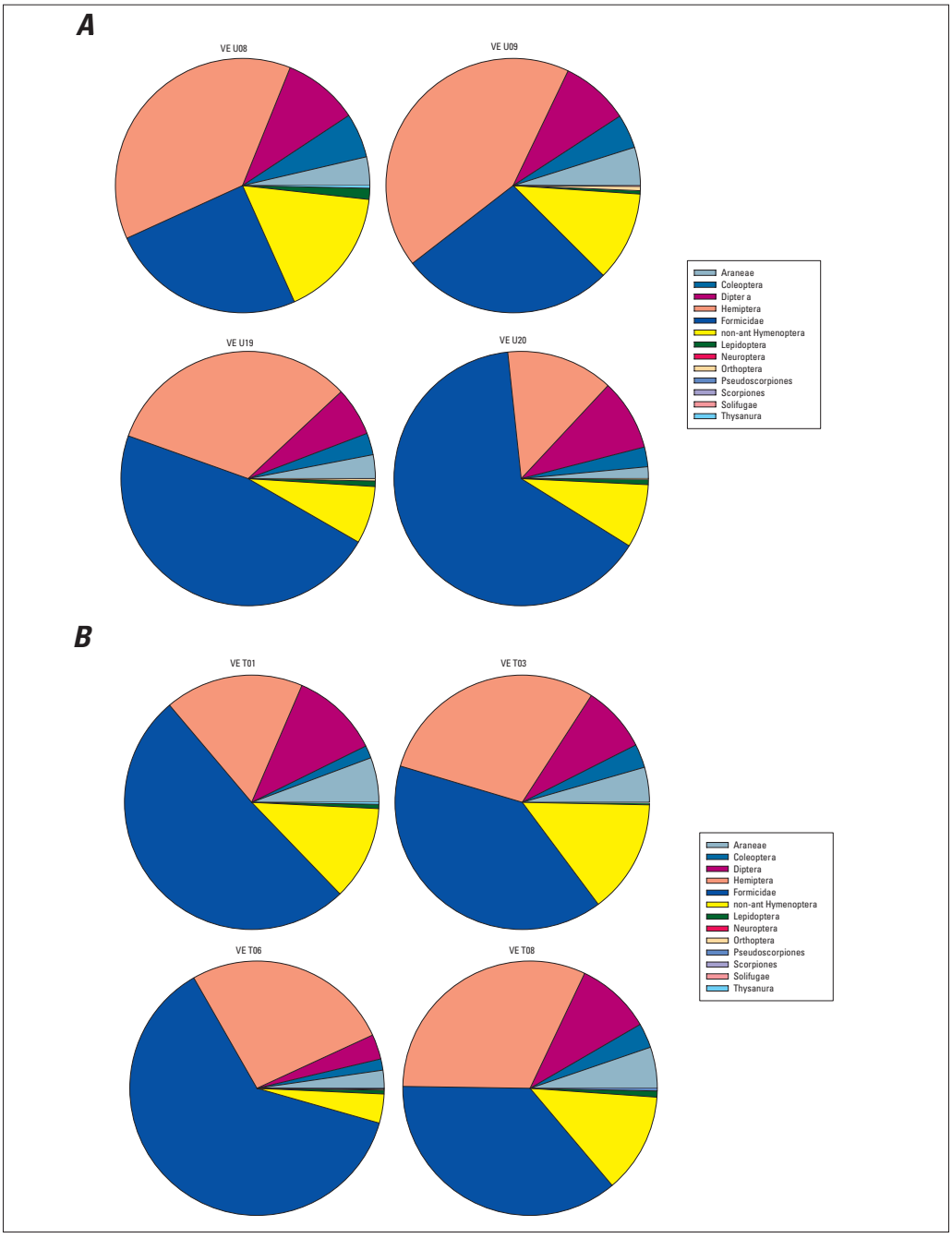

Figure 15. Proportional representation of taxa at the eight Vernon sites. Communities in the untreated (*A*) and treated (*B*) zones.

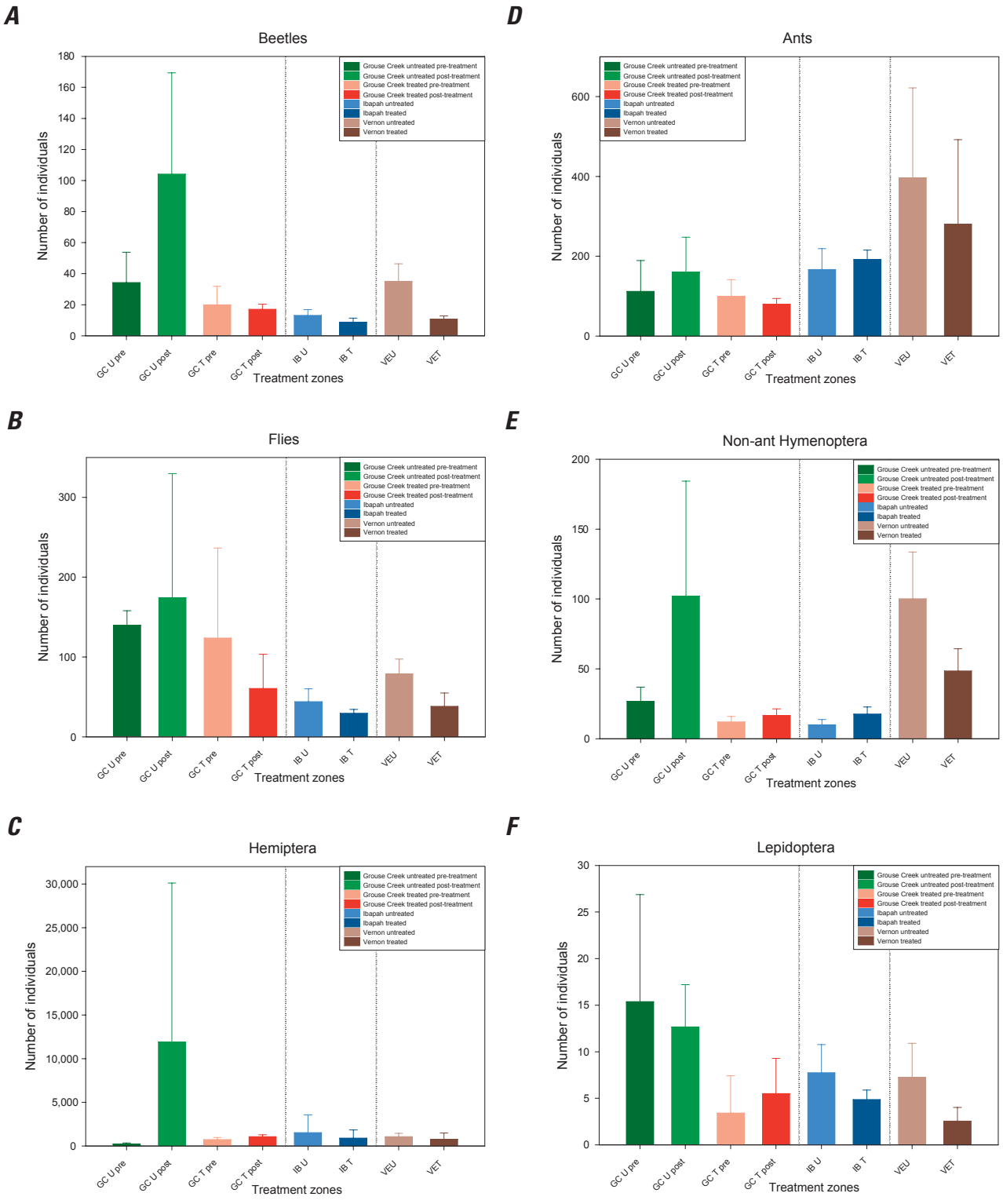

Figure 16 *A*–*L*. Average number of individuals (by taxon) in untreated (GC U pre- and post-treated, IB U, VE U) and treated (GC T pre- and post-treated, IB T, VE T) zones at the three study areas.

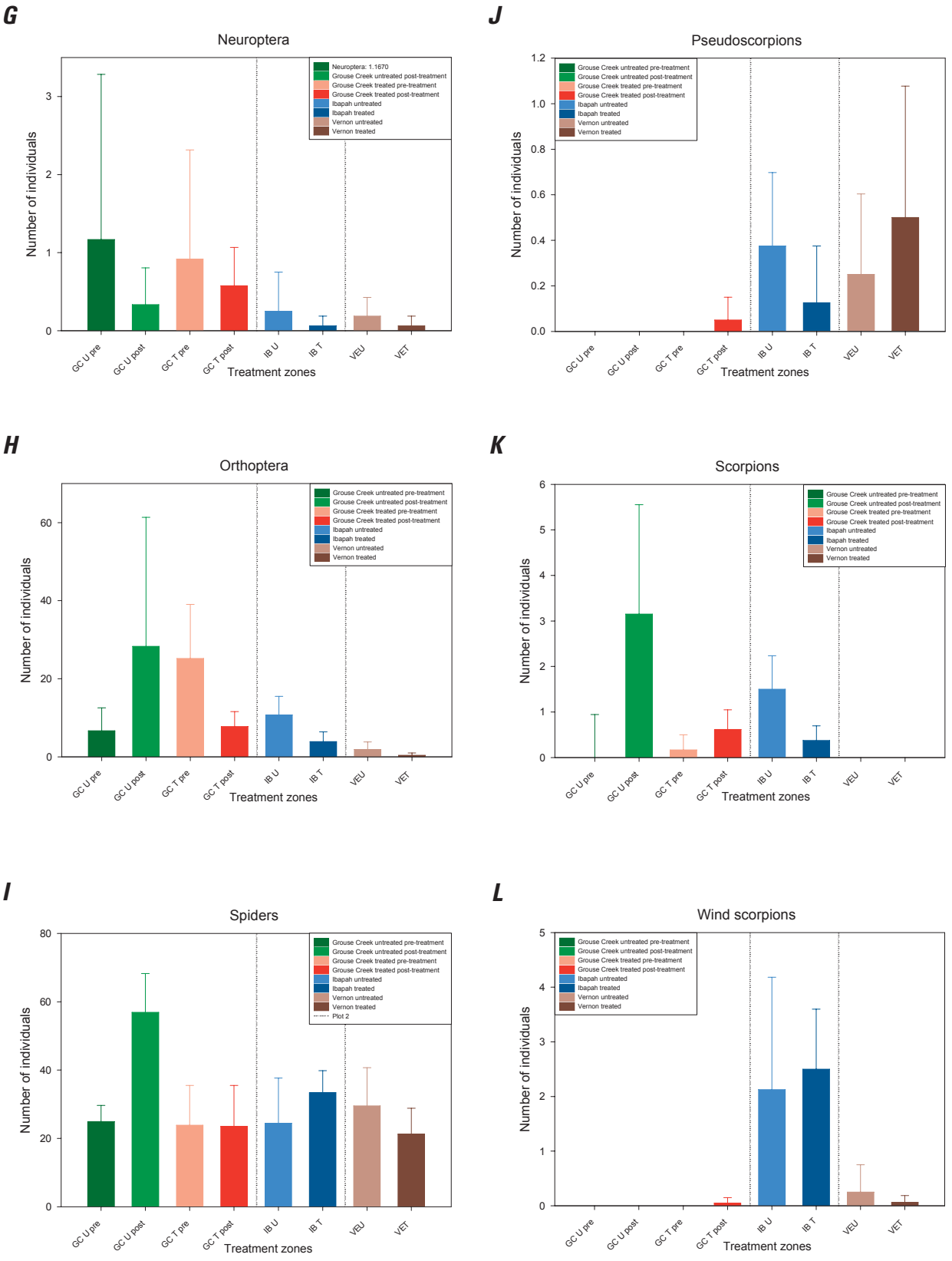

Figure 16 *A*–*L*. Average number of individuals (by taxon) in untreated (GC U pre- and post-treated, IB U, VE U) and treated (GC T pre- and post-treated, IB T, VE T) zones at the three study areas—Continued.

the post-treatment collections at unsprayed sites. Coleoptera ($t_{d.f.\ 6}$=–2.053; P=0.086), Hemiptera ($T_{d.f.\ 6}$=12; P=0.114), and Scorpiones ($t_{d.f.\ 6}$=–1.926; P=0.102) also showed large increases in average abundance from pre- to post-treatment collections but the differences were not statistically significant.

Pre- versus Post-Treatment Changes in Treated Zone

No significant differences in pre- and post-treatment numbers occurred within the sprayed zone, although Hemiptera ($t_{d.f.\ 6}$=–1.992; P=0.093), non-ant Hymenoptera ($t_{d.f.\ 6}$=–1.482; P=0.189), Orthoptera ($t_{d.f.\ 6}$=2.419; P=0.052) and Scorpiones ($T_{d.f.\ 6}$=12.5; P=0.114) all had average abundance differences that were almost significant statistically. Total arthropods did not differ in the sprayed zone. Only Orthoptera showed a decrease from pre- to post-treatment numbers in the sprayed zone, indicating that diflubenzuron did accomplish the management goal of decreasing Orthoptera numbers in the sprayed zone.

Pre-Treatment Changes in Untreated versus Treated Zones

Most taxa did not differ between unsprayed and sprayed zones prior to application of diflubenzuron. There were statistically significant differences in average abundance for the Hemiptera ($t_{d.f.\ 6}$=–2.726; P=0.034), non-ant Hymenoptera ($T_{d.f.\ 6}$=24.5; P=0.035), and Orthoptera ($t_{d.f.\ 6}$=–2.455; P=0.049). Lepidoptera numbers ($T_{d.f.\ 6}$=23.5; P=0.114) also differed between zones but not to the point of being statistically significant. Hemiptera and Orthoptera were more abundant in the sprayed zone prior to treatment; non-ant Hymenoptera and Lepidoptera were more numerous in the unsprayed zone at the same time.

Post-Treatment Changes in Untreated versus Treated Zones

Post-treatment comparisons of unsprayed and sprayed zones showed that spiders ($t_{d.f.\ 6}$=4.042; P=0.007) and non-ant Hymenoptera ($T_{d.f.\ 6}$=26; P=0.029) were significantly more abundant in the unsprayed zone following application of diflubenzuron. Average numbers of Lepidoptera ($t_{d.f.\ 6}$=2.425; P=0.052), Scorpiones ($t_{d.f.\ 6}$=2.077; P=0.083), and total arthropods ($T_{d.f.\ 6}$=25; P=0.057) also differed markedly in the sprayed and unsprayed zones but not to the point of statistical significance. In all cases, post-treatment numbers were greater in the unsprayed zone. The Lepidoptera decreased somewhat from pre-treatment levels in the unsprayed zone and increased slightly during the same timeframe in the sprayed zone, but Lepidoptera still were more abundant in the unsprayed zone. This post-treatment difference is likely the result of inherent differences in the Lepidoptera communities of the two zones.

Ibapah

Numbers of Orthoptera ($t_{d.f.\ 6}$=2.569; P=0.042) and Scorpiones ($T_{d.f.\ 6}$=25; P=0.029) were significantly lower in the sprayed zone at Ibapah compared to the unsprayed zone. Differences in average abundance that were almost significant were recorded for other taxa, including Coleoptera ($t_{d.f.\ 6}$=1.880; P=0.109), Diptera ($t_{d.f.\ 6}$=1.701; P=0.140), non-ant Hymenoptera (t=–2.432; P=0.051), and Lepidoptera ($t_{d.f.\ 6}$=0.801; P=0.122). For all taxa showing large differences, more individuals were caught at the unsprayed sites than at sprayed sites.

Vernon

Vernon data from this study provided the strongest indication of diflubenzuron effects on nontarget arthropods. Beetles ($T_{d.f.\ 6}$=26; P=0.029), flies ($t_{d.f.\ 6}$=3.274; P=0.017), Hemiptera ($t_{d.f.\ 6}$=2.458; P=0.049), non-ant Hymenoptera ($t_{d.f.\ 6}$=2.790; P=0.032), and total arthropods ($t_{d.f.\ 6}$=2.650; P=0.038) were all significantly more abundant in the unsprayed zone than in the sprayed zone. Lepidoptera ($t_{d.f.\ 6}$=2.380; P=0.055) and Orthoptera ($t_{d.f.\ 6}$=1.485; P=0.188) also had greater average numbers in the unsprayed zone than in the sprayed sone, although the differences were not quite significant.

Terrestrial Community Structure

Multivariate analysis (NMS) showed no useful ordination solution using either raw data (average numbers caught per day), or log-transformed data. There was no apparent structure in the data; most of the sites were in a single, large cluster with a few (primarily those with very high or very low numbers of Hemiptera) separated individually from the main grouping. Final stress values for the dataset did not differ from analysis with randomized data, indicating that community structure was weak (McCune and Grace, 2002). This result may have been due to the influence of particular taxa (for example, Hemiptera) at individual sites. Examination of the data indicated that GC U05 post-treatment and IB U08 were outliers in the raw-numbers dataset, and VE U08 and VE T01 were outliers after the data were transformed, based on the PC-ORD outlier test (McCune and Grace, 2002). GC U05 post-treatment and IB U08 were heavily dominated by Hemiptera, with more than 90 percent of all specimens in this order (figs. 12*B* and 14*A*). It is not clear why VE U08 was identified as an outlier because no group seemed particularly over- or under-represented. VE T01 had fewer Hemiptera than any other site, with the exception of the GC U11 pre-treatment collection, and was dominated by ants but not by a higher proportion than at other sites. Removing these outliers did not improve ordination results using either raw numbers or transformed data.

Ordination with the Hemiptera removed from all sites provided a very strong two-axis solution that explained 95.5 percent of the variation in the dataset. This solution left IB T22 isolated from the other sprayed sites at Ibapah, despite what appeared to be very similar communities among the sites. The one significant difference between IB T22 and the other sprayed sites was that no Microcoryphia (silverfish) were found at any Ibapah site except IB T22, where 219 silverfish were collected (no other site in the study had more than 19 silverfish). Ordination (NMS) was then performed, excluding both Hemiptera and Microcoryphia data for all sites (fig. 17).

Ordination with the reduced dataset resulted in a good two-dimensional solution (final stress=10.0747) that explained 92.6 percent of the variation in the dataset. Very little change occurred in the position of the sites, except that IB T22 was brought into close proximity with the other three sprayed sites at Ibapah, and additional separation was achieved between treated and untreated sites at Vernon. The first axis was defined primarily by ant abundance, with some influence from non-ant Hymenoptera numbers. Flies and beetles provided most of the structure on the second axis.

Ibapah and Vernon sites were largely separated from Grouse Creek sites based on abundance of beetles and flies (greater numbers at Grouse Creek) and ants (fewer numbers at Grouse Creek); the former two taxa influenced the position along the second axis, while ants structured sites along the first axis. Abundance of solifugids at Ibapah, beetles and pseudoscorpions at Vernon, and beetle numbers at Grouse Creek also influenced the location of sites in the ordination.

Grouse Creek

Grouse Creek community data indicated a consistent temporal shift for both sprayed and unsprayed sites from pre-treatment (late May and early June) communities to post-treatment (late June) communities, except for GC U05, GC T03, and GC T05 (fig. 17). The basic pattern of data change consisted in a shift to the left and a weak-to-moderate shift down in ordination space. Community structure changed with increases in total arthropod abundance, Coleoptera (beetles), Formicidae (ants), and non-ant Hymenoptera (bees and wasps) from pre- to post-treatment collections. Flies (Diptera) increased at all unsprayed sites and at GC T04 and GC T06 but declined at GC T03 and GC T05. Beetle numbers increased from pre- to post-treatment collections at all sites except GC T05. Sites GC U01 and GC U05 were separated at the bottom of the ordina-

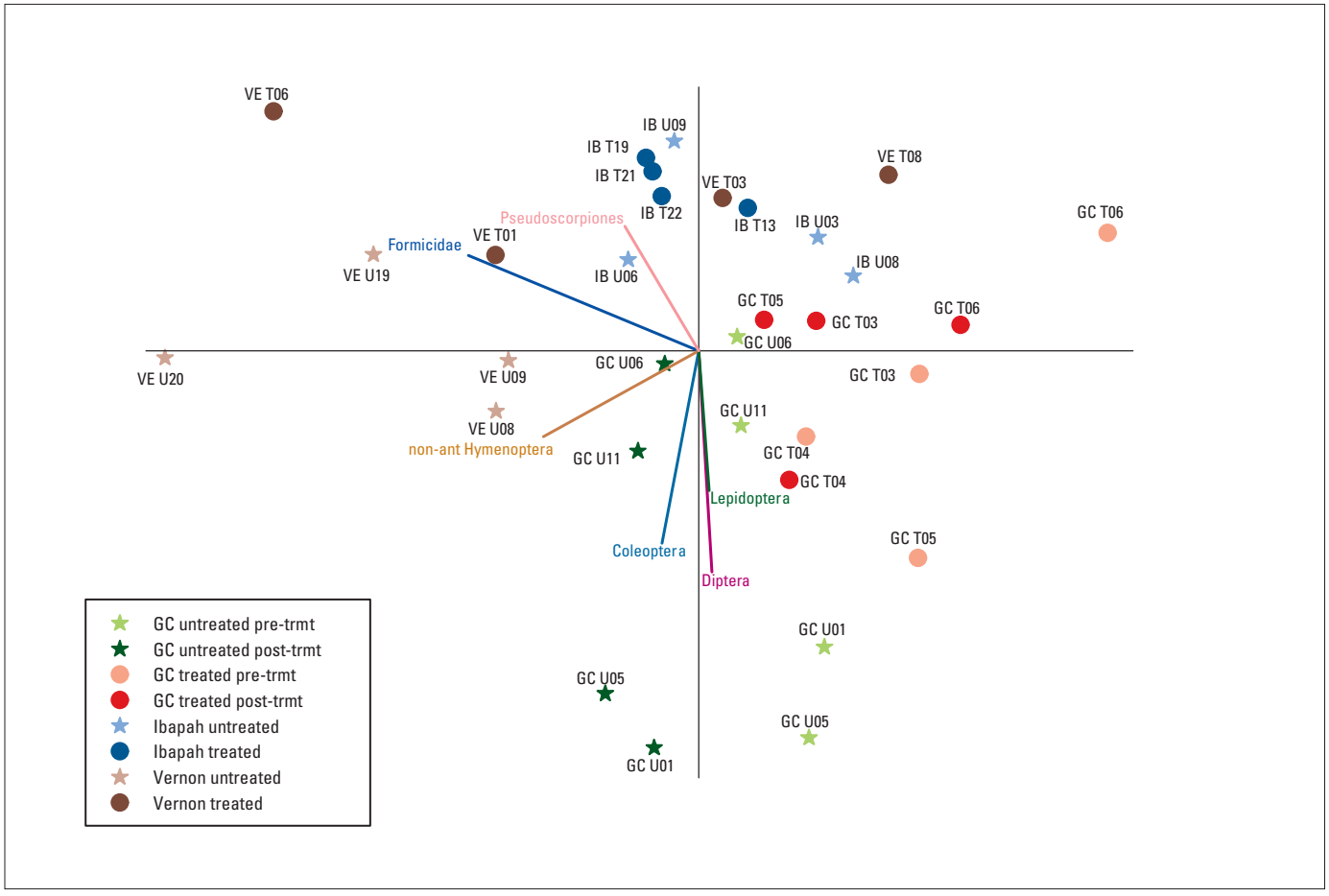

Figure 17. Nonmetric multidimensional scaling ordination for all sites, excluding Hemiptera and Microcoryphia. Vectors represent taxa significantly influencing the spread of sites along the two axes.

tion space and changed primarily along the first axis from pre- to post-treatment collections; these two sites had more beetles than any other site, especially in pre-treatment collections.

The magnitude of increase in abundance differed between sprayed and unsprayed sites, with many more arthropods being caught at unsprayed sites after treatment than at sprayed sites (appendix A1a and A1b). The variation among sites, even within a treatment zone or collection period, kept many of these differences from being statistically significant, but the trend is evident when all 16 sampling events are examined (appendix A1a and A1b). Additional work is needed to determine whether application of diflubenzuron reduces arthropod abundance, or whether observed differences are related to inherent site differences.

Ibapah

Community structure of Ibapah sites was based primarily upon ant abundance. Without Hemiptera (true bugs and leafhoppers) and Microcoryphia (silverfish), the four sprayed sites at Ibapah formed a tight cluster along the second axis, along with IB U09; these five Ibapah sites had similar numbers of ants. The IB U09 ant community resembled communities at the sprayed sites as well, though genus-level data were not included in the dataset used in this ordination. Similarities between IB U09 and the sprayed sites at Ibapah underscore the influence of inherent site properties in structuring arthropod communities. Two of the unsprayed sites (IB U03 and IB U08) were shifted to the right relative to the sprayed sites; these two sites had fewer ants than any other Ibapah site. IB U06, the fourth unsprayed site, had ant numbers similar to the sprayed sites but had more flies, separating it from the sprayed cluster along the second axis. There was little variation along the second axis among the eight Ibapah sites, but what differences did occur were due essentially to differences in abundance of Diptera at each site.

Vernon

As was the case at Ibapah, ant abundance structured the Vernon sites, with more ants at the unsprayed sites than at most of the sprayed sites. Proximity in the multivariate plot to other sites from any study area appeared to be dictated by similar ant numbers. The sprayed sites were scattered across ordination space on the first axis but within a narrow belt on the second axis; large variation in ant abundance at sprayed sites (418 to 2,306 total ants) caused this spread on the first axis. The range of ants collected at unsprayed sites overlapped sprayed sites (870 to 2,826 ants), but the trend was for more ants at unsprayed sites, which accounts for their shift to the left along the first axis (fig. 17). Unsprayed sites also had more beetles and flies than did sprayed sites, and a greater variation in these taxa. The increased numbers of beetles and flies and their greater variation in taxa is reflected in the spread in unsprayed site locations along the second axis and in the small variation in second axis ordination scores for the sprayed sites, which showed less variation in numbers of flies or beetles (appendix A1d).

Range in ordination space was greater for Vernon sites than for Ibapah or Grouse Creek sites, due at least in part to the greater spatial and elevational spread among the sites of the Vernon study area. For example, VE T06 was isolated from all other sites on the ground, being farther west, and was identified as an outlier by using the PC-ORD outlier analysis routine. VE T06 had more beetles and ants, but fewer flies, than the other treated sites. The other outlier identified (of all 32 communities included in the analysis) was VE U20, which was higher in elevation and slightly farther south than the other unsprayed Vernon sites (fig. 4, table 1). More ants were collected at VE U20 than at any other site in the study (2,826 ants); flies also were more abundant, and spiders were less common than at other unsprayed sites. Although data on Hemiptera were not included in the ordination analysis, these two sites also differed from the other Vernon sites in numbers of Hemiptera; VE T06 had more Hemiptera than any other sprayed site, and VE U20 had only about half as many Hemiptera as the other unsprayed sites.

Formicidae

Eighteen genera of ants were collected across the three study areas (table 2). Untreated sites at Grouse Creek had 15 genera; 16 genera were found at sites in the treated zone. Ibapah untreated sites had 11 genera; 14 genera were found at sites in the treated zone. This trend was reversed at Vernon, where 13 genera were found at sites in the untreated zone, and 10 genera were found at sites in the treated zone. Vernon ant communities were slightly less genera rich, but ants were more abundant at Vernon (10,711 ants total) than at the other two study areas. At the eight Ibapah sites, 4,968 ants were collected. Grouse Creek unsprayed sites accounted for 3,622 ants from both collection periods, while 2,887 ants were collected from sprayed sites during the two sampling periods.

Grouse Creek

Ant communities differed in composition among sampling events and sites in the treated and untreated zones at Grouse Creek (fig. 18). Differences appeared to be due to ant phenology and intrinsic site differences, not the application of diflubenzuron. *Formica* were particularly abundant at Grouse Creek, except at GC T03 and GC T05. These two sites were the rockiest sites; GC T03 was on a hillside, GC T05 was at the nose of a small ridge. There were more *Pogonomyrmex* at untreated sites and more *Pheidole* at treated sites, but these differences, which existed prior to treatment, were not related to the insecticide. Seed-harvester numbers increased at nearly every Grouse Creek site from pre- to post-treatment collections. *Forelius* was found only at GC U11 and GC T03; *Forelius* increased at GC U11 from late May to late June but declined over the same period at GC T03.

Table 2. Ant genera found in each west desert treatment zone and during each sampling period, Utah.

[Functional group designations assigned from Nash and others (2001, 2004). G, generalist; P, predator; HT, Homoptera tender; SH, seed harvester; LF, liquid feeder; SM, slave maker.]

Ant genera	Functional group	Grouse Creek untreated pre-treatment zone	Grouse Creek untreated post-treatment zone	Grouse Creek treated pre-treatment zone	Grouse Creek treated post-treatment zone	Ibapah untreated zone	Ibapah treated zone	Vernon untreated zone	Vernon treated zone
Aphaenogaster	G	X	X	X	X		X	X	X
Camponotus	G	X	X	X	X	X	X	X	X
Cardiocondyla	P			X			X		
Crematogaster	G			X	X		X		
Forelius	HT	X	X	X	X	X	X	X	X
Formica	HT	X	X	X	X	X	X	X	X
Lasius	HT	X	X	X	X	X		X	
Leptothorax	G	X	X	X	X	X	X	X	X
Messor	SH	X			X				
Monomorium	SH							X	X
Myrmecocystus	LF	X	X	X	X	X		X	
Myrmica	P	X	X	X	X	X	X	X	X
Pheidole	SH	X	X	X	X	X	X	X	X
Pogonomyrmex	SH	X	X	X	X	X	X	X	X
Polyergus	SM		X	X	X		X		
Prionopelta	P		X						
Solenopsis	G	X	X	X	X	X	X	X	X
Tapinoma	G	X	X	X	X	X	X	X	

Ibapah

Ants at Ibapah differed from site to site, but there were some patterns correlated with whether or not the sites had been treated with diflubenzuron in 2004. Untreated sites showed a large proportion of the community composed of ants in the genera *Formica*, *Leptothorax*, and *Tapinoma*, while *Forelius*, *Pheidole*, and *Pogonomyrmex* dominated collections from treated sites (fig. 19). IB U09 was unusual for an untreated site because of the high numbers of *Forelius* found there. It is not clear what features of IB U09 were more similar to the treated sites than to the other untreated sites, except that IB U09 was closer to the treatment zone than the others. Numbers of *Tapinoma* and *Leptothorax* at IB U09 were comparable to the other untreated sites but *Formica* was rare.

Vernon

Community composition of ants at Vernon also was different at each site, but structure again appeared to be correlated with treatment history (fig. 20). *Tapinoma* was found at three of the four untreated sites but not at any treated sites. *Forelius* was present at all four treated sites; one ant found at VE U20 was the only *Forelius* found at any untreated site. *Pogonomyrmex* was rare at Vernon, occurring at only two sites (one treated and one untreated). *Pheidole*, an important seed harvester, also was relatively uncommon at Vernon sites. *Monomorium*, another seed-harvesting ant, was found only at Vernon, occurring at all eight sites. On average, *Formica* was more abundant at untreated sites, although numbers varied considerably; it occurred at only two treated sites and ranged from common to uncommon at those sites.

Comparisons Among Study Sites

Most Grouse Creek ant communities were dominated by *Formica* or *Pogonomyrmex* (fig. 18). Ibapah ant communities were characterized by *Tapinoma* and *Formica* at untreated sites and *Forelius* at treated sites (fig. 19). The ant communities at Vernon were distinguished by the presence of *Monomorium* at all eight sites (fig. 20). There were some similarities between Vernon and Ibapah communities that were consistent with treated and untreated zones at both study areas. *Formica* and *Tapinoma* were common to abundant at untreated sites at

Vernon and Ibapah, and ants of the genus *Forelius* were very common at most of the treated sites at both study areas.

Ant Community Structure

Ordination (NMS) resulted in a three-dimensional solution providing the best fit and lowest stress (final stress=10.762) and explaining approximately 87 percent of the variation within the dataset. For the sake of graphic simplicity, we present the two-dimensional depiction of axes two and three, which explain about 67 percent of the variation (fig. 21). Axis one was defined primarily by the inverse relationship between *Pogonomyrmex* and *Monomorium*, with some influence from *Solenopsis*. *Monomorium* was found only at the eight sites of the Vernon study area, while *Pogonomyrmex* was common at Grouse Creek and Ibapah but was present at Vernon in small numbers at only two sites. The second axis was structured by the abundance of *Formica*, with *Tapinoma* and *Leptothorax* influencing structure as well. The presence of *Crematogaster*, which occurred at only three sites (GC T03 before and after treatment, IB T19, and IB T22), also influenced scores for NMS axis two and helped separate the latter sites to the left side of the ordination space. Abundance of *Forelius* defined the third axis, with the Vernon and Ibapah

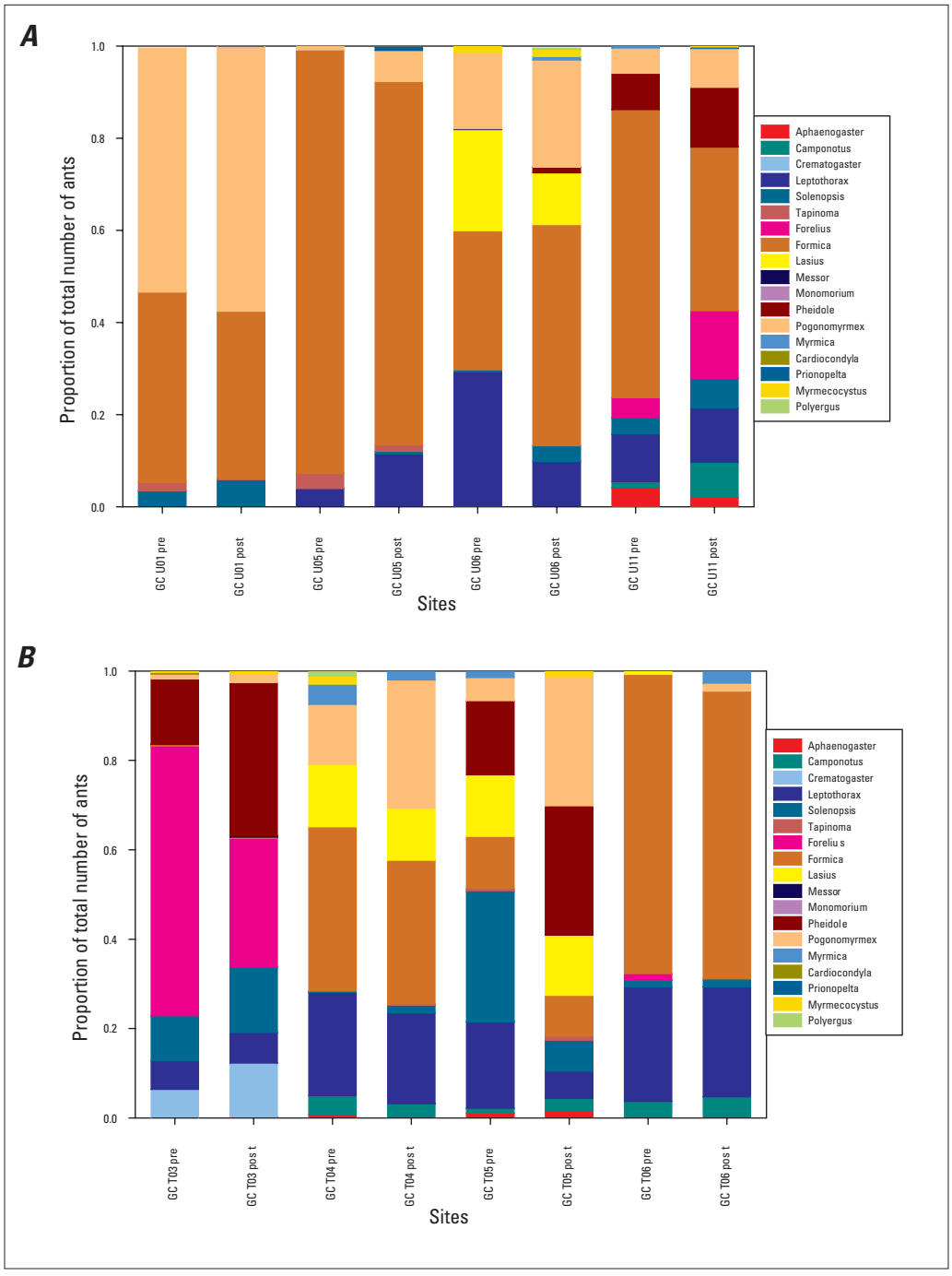

Figure 18. Relative abundance of ant genera at Grouse Creek. Untreated (*A*) and treated (*B*) zones before and after treatment.

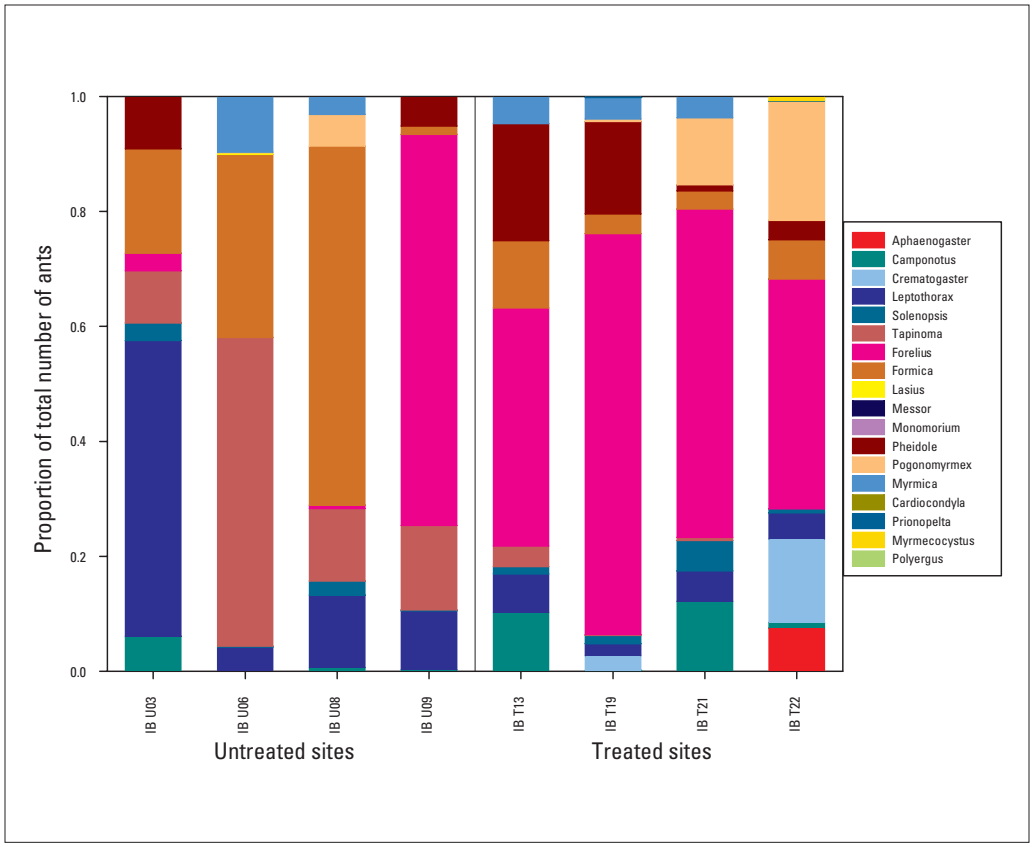

Figure 19. Relative abundance of ant genera at Ibapah untreated and treated zones.

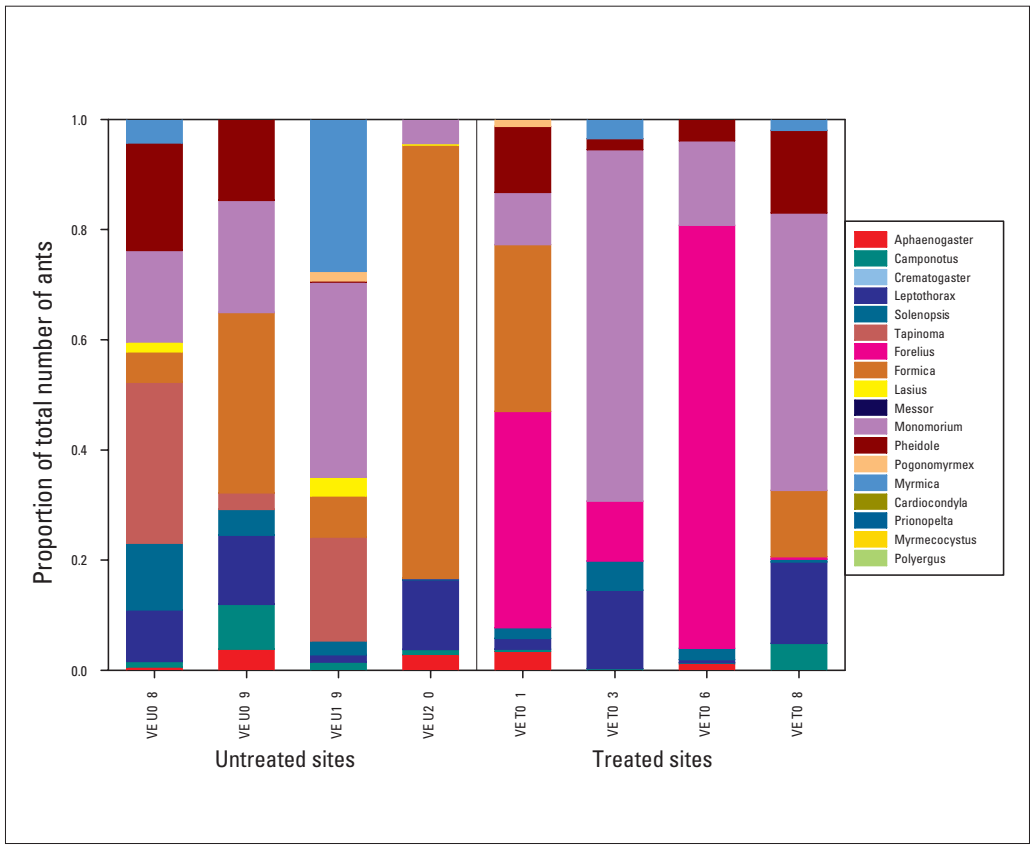

Figure 20. Relative abundance of ant genera at Vernon untreated and treated zones.

treated sites stretched along the third axis primarily according to abundance of *Forelius*. This genus was largely absent from Grouse Creek, being found at only three sites (and rare at two of the three sites) (appendix A2). *Forelius* was abundant only at GC T03, and this Grouse Creek site was the only site with positive axis-three scores. Most Grouse Creek unsprayed-zone ant communities were defined by relatively high numbers of *Formica*, *Pogonomyrmex*, and *Leptothorax* and the absence of *Tapinoma*, *Monomorium*, and *Forelius*. Temporal shifts for the Grouse Creek sites did not show any pattern relative to diflubenzuron application, or any other factor that was examined.

Ibapah ant communities separated into sprayed and unsprayed communities primarily on the abundance of *Forelius* at the sprayed sites. IB U09 was near the sprayed-zone sites because it also had a high abundance of *Forelius* (appendix A2). The unsprayed sites at Ibapah were scattered throughout the ordination space; each of the four sites had a different ant genus as the most abundant taxon.

The sprayed Vernon sites showed almost no variation along the second axis; their locations were almost entirely based on abundance of *Forelius*. The unsprayed sites had essentially no *Forelius* (one individual at VE U20) and were separated from the sprayed sites on this basis. Abundance of *Formica*, *Tapinoma,* and *Leptothorax* influenced the location of the unsprayed sites at Vernon. All the unsprayed Vernon sites were in the upper right quadrat due to the presence of *Monomorium*, which was found only at Vernon.

The ordination was strongly influenced by the presence of *Forelius*; the location of IB U9 and GC T03 in the same region of ordination space as Ibapah and Vernon sprayed sites strengthens this conclusion. Other than dominance by *Forelius*, there was considerable variation among sites; however, some other genera appear to exhibit trends.

Total numbers of ants differed somewhat between sprayed and unsprayed sites at all three study areas, but the average number of ants in each treatment zone at a study area were not significantly different. However, the abundance of the various genera that made up the "ant" category in the statistical analyses was sometimes quite different among sites and between sprayed and unsprayed zones (table 3).

Hemiptera

Immature Hemiptera are difficult to identify, even to family, especially by nonexperts. Because most individuals were nymphs, we had large numbers of unidentified Hemiptera in some samples. To address this problem, we estimated total numbers of Hemiptera in each family. The total number of Hemiptera identified in each family and the total of all Hemiptera excluding unknowns were calculated, and the total for each family was divided by the grand total to generate the proportion of identified Hemiptera in each family. The proportion of Hemiptera in each family was multiplied by the total number of unknown Hemiptera caught to estimate the number of nymphs in each family. This value was added to the number of adults to estimate the total number in each family. We recognize that this approach has inherent problems, especially based on the phenology of the different taxa, and that some

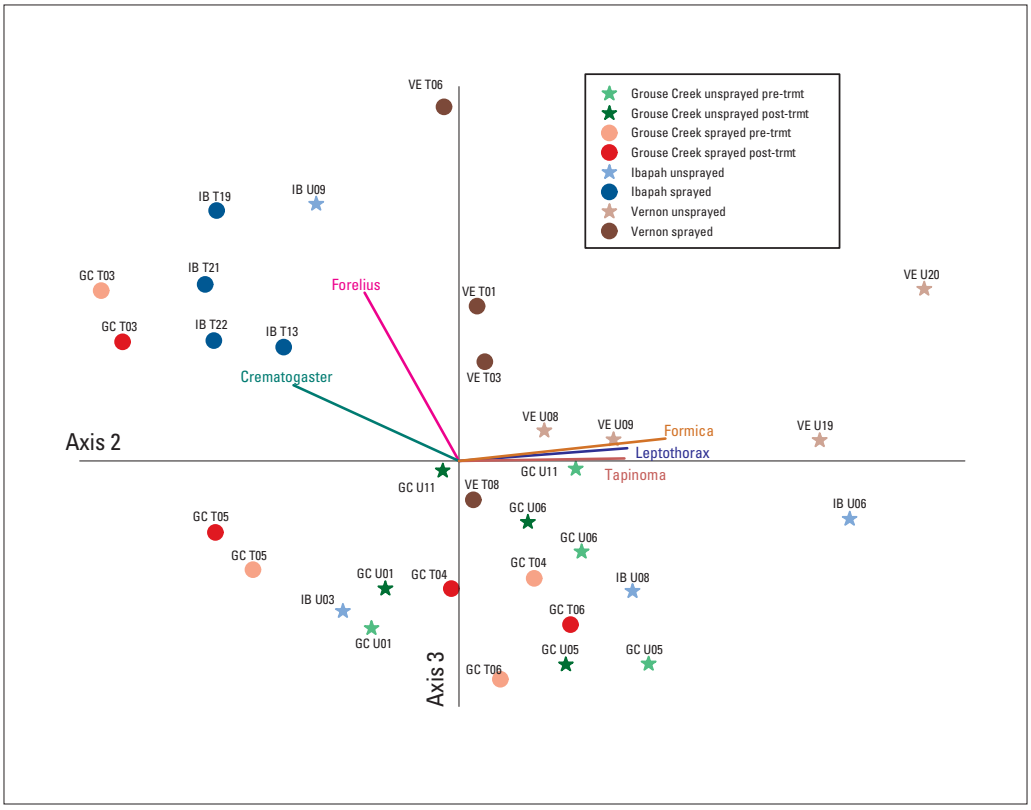

Figure 21. Nonmetric multidimensional scaling joint plot of ant genera as number of ants per day at Grouse Creek, Ibapah, and Vernon. Includes data from before and after treatment at Grouse Creek and the treated and untreated sites of all three areas. Lines indicate genera strongly influencing separation of sites along one or both axes.

Table 3. Total number of ants of the nine most common genera collected in treated and untreated zones at Grouse Creek, Ibapah, and Vernon study sites after treatment with diflubenzuron.

[*IB U9 accounted for 541 of the *Forelius* in untreated traps].

Genus	Grouse Creek after treatment		Ibapah after treatment		Vernon after treatment	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
Forelius	127	442	544	1,396	1	2,239
Formica	963	101	536	158	2,700	396
Leptothorax	197	251	273	101	581	181
Monomorium	0	0	0	0	1,055	1,043
Myrmica	7	24	92	103	497	29
Pheidole	122	238	57	257	314	297
Pogonomyrmex	535	300	19	256	29	14
Solenopsis	109	95	44	42	198	102
Tapinoma	3	5	647	24	597	0
Totals	2,063	1,456	2,212	2,337	5,972	4,301

families might have been represented only by adults, or only by nymphs, at the time of collections. Because the samples at each study area were collected at the same time, we believe any inaccuracies will be consistent across that sampling period.

Grouse Creek

Pre- versus Post-Treatment Changes in Untreated Zone

Community composition of Hemiptera varied from site to site and over time at Grouse Creek (figs. 22*A* and *B*). Cicadellidae were the most abundant Hemiptera at most sites, but GC U01 and GC U05 sites were dominated by the Alydidae in late June (post-treatment period), representing a dramatic increase in this family from the early June sampling event. Most other families were relatively rare at Grouse Creek sites; Miridae were uncommon to abundant at some untreated sites and increased from pre- to post-treatment collections. The only other family that occurred with any frequency was the Aphididae. The GC U11 Hemipteran community appeared to differ from communities at the other untreated sites.

Pre- versus Post-Treatment Changes in the Treated Zone

The treated sites at Grouse Creek also were dominated by the Cicadellidae, even more strongly than in the untreated zone, during both sampling periods (fig. 22*B*). The Alydidae were absent from all treated sites prior to treatment; they were captured in post-treatment samples but in much lower numbers than at post-treatment unsprayed sites. Aphids were again present in all collections and increased across the two collection periods. The Miridae were less frequent in the treated zone and showed only a slight increase from pre- to post-treatment collections, while the increase in Miridae abundance in the untreated zone was large.

The Lygaeidae were absent from both untreated and treated zones prior to treatment at Grouse Creek. No Lygaeids were detected in the treated zone 3 weeks after treatment, but low numbers (averaging 1.9 individuals per day) were detected at each untreated site in the post-treatment collection period. Although there was no difference in numbers of Lygaeidae in the treated zone before and after treatment (no individuals were detected), the comparison between post-treatment untreated and treated zones was significantly different ($T_{d.f.\ 6}$=26; P=0.029). The phenology of the Lygaeidae may account for the lack of any individuals being detected in pre-treatment samples from either treatment zone; they may emerge later in the season and were not active during the early sampling period.

Ibapah

Zones Treated in 2004 versus Untreated Zones

Cicadellidae dominated six of eight Ibapah sites, with the Alydidae most numerous at IB U08 and IB T13 (fig. 23). The Alydidae were present at all eight Ibapah sites, but each treatment zone had one site where the Alydidae dominated the collection of Hemiptera. IB U08 and IB T13 appeared to have finer soils; greasewood, saltbush, and other shrubby Chenopodeaceae made up a significant portion of the shrub component of the vegetation at these two sites. Sagebrush was relatively scarce at IB U08 but common at IB T13. The Lygaeidae had significantly more individuals in untreated sites than treated sites ($T_{d.f.\ 6}$=26; P=0.029).

Vernon

Sites Treated in 2004 versus Untreated Sites

Vernon hemipteran communities differed among sites and were more diverse than Ibapah or Grouse Creek communities (fig. 24), with Cicadellidae dominating some sites; other families, such as the Lygaeidae, Miridae, Nabidae, and Psyllidae, were common. As at Ibapah and Grouse Creek, no pattern in the community structure appeared to be associated with the treatment history at Vernon. The Lygaeidae, which showed indications of sensitivity to diflubenzuron at Grouse Creek and Ibapah, were highly variable at Vernon, but total numbers hinted at sensitivity to diflubenzuron (63 caught in the untreated zone, 32 caught in the treated zone).

Community Structure of Hemiptera

Ordination of numbers per day for hemipteran families did not provide a good solution because the Cicadellidae (at most sites) and the Alydidae (at a few sites) overwhelmed the variation among other families. Data were adjusted by adding 0.01 to each value to eliminate zeros and then log transformed in PC-ORD (McCune and Mefford, 2005) to compress high values (as suggested by McCune and Grace, 2002) of the Cicadellidae and Alydidae; the Euclidean distance measure

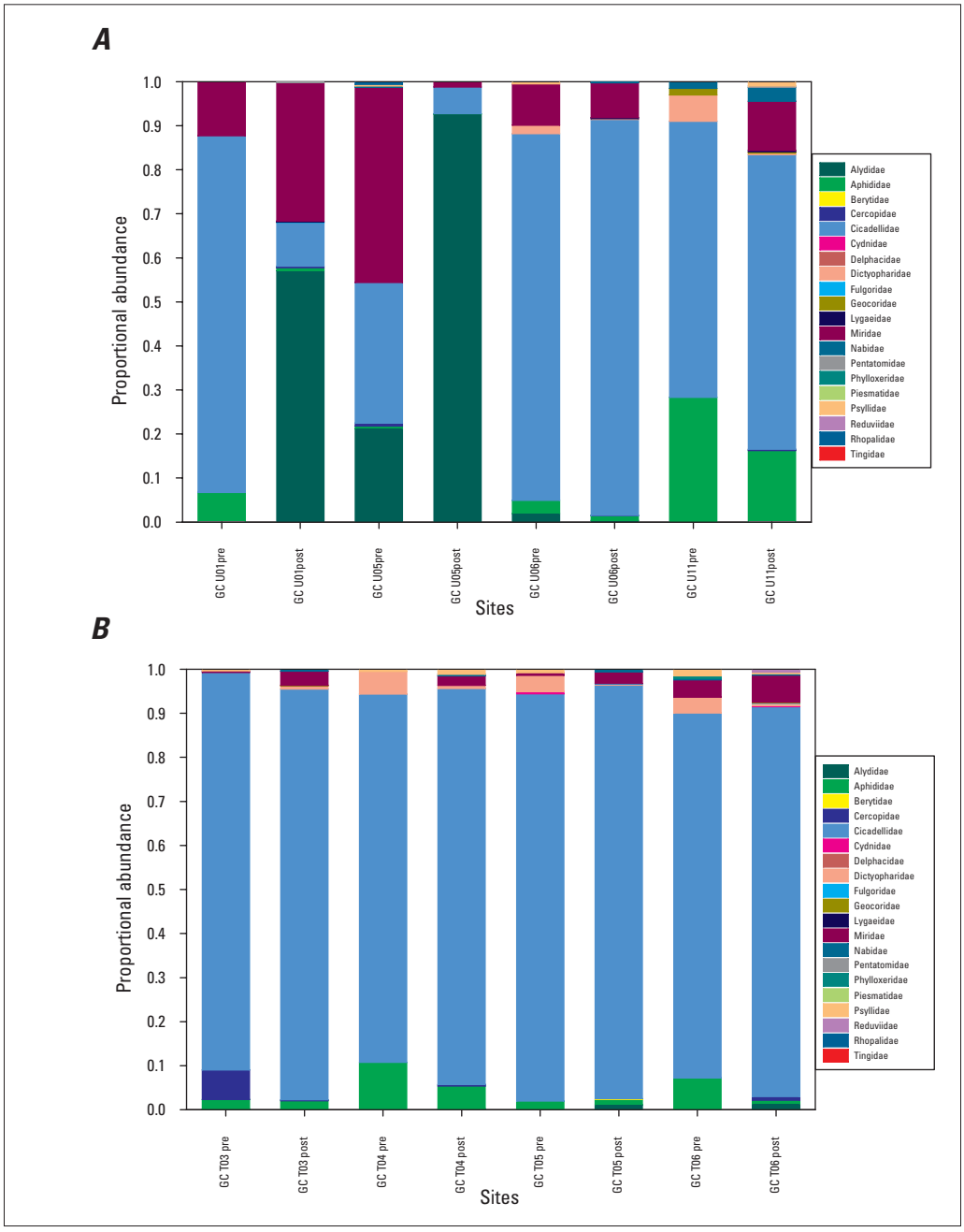

Figure 22. Relative abundances of Hemiptera families at Grouse Creek untreated (*A*) and treated (*B*) zones before and after treatment with diflubenzuron.

was used. Ordination of transformed data resulted in a three-axis solution that explained 89.2 percent of the dataset variation; we present the first two axes, which explain 69.9 percent of the variation, for graphic simplicity (fig. 25). The Alydidade, Cercopidae, Miridae, and Nabidae influenced the first axis structure; the second axis was structured by the Aphididae and Psyllidae (negative values) and the Alydidae (positive values). Grouse Creek sites were spread across ordination space with no differences correlated with insecticide application. Seven of the eight Grouse Creek sites showed similar shifts in pre- to post-treatment community structure that were correlated with large increases in Miridae and Cicadellidae. GC U11 had only modest increases in these families (appendix A3), and it moved in ordination space differently than the other seven sites (fig. 25). The Ibapah sites were relatively isolated from most Vernon and Grouse Creek sites by the abundance of the Cicadellidae. Within the Ibapah cluster, three treated sites and two untreated sites formed a tight group. IB T13 and IB U08 were somewhat isolated on the basis of abundant Alydidae. The Vernon sites were scattered throughout ordination space with no apparent pattern (fig. 25).

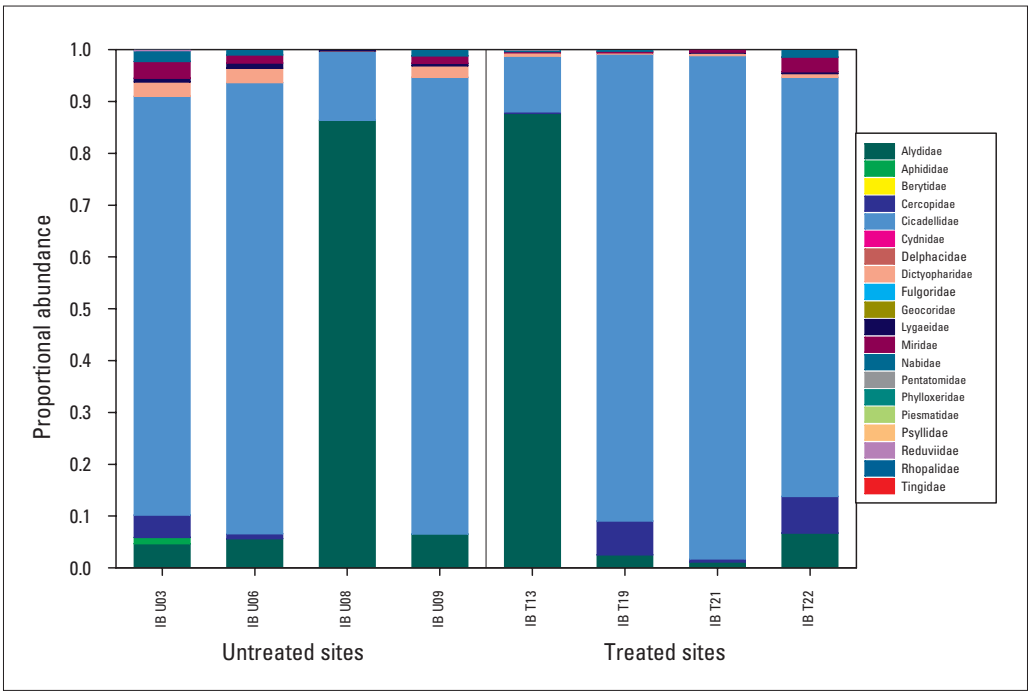

Figure 23. Relative abundances of Hemiptera families at Ibapah treated and untreated sites.

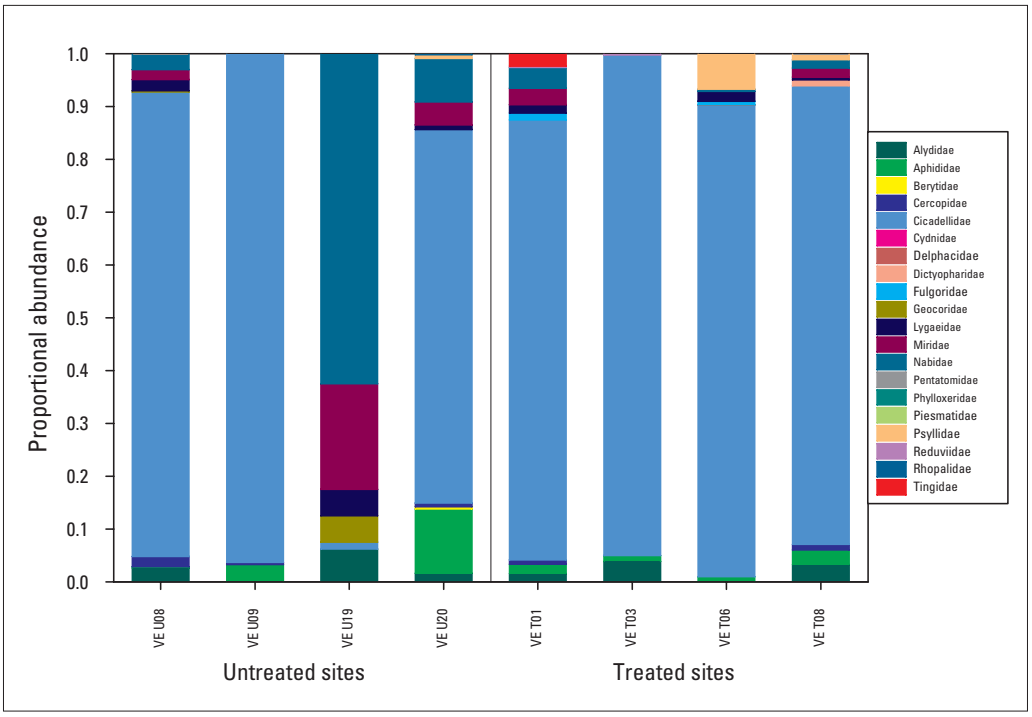

Figure 24. Relative abundances of Hemiptera families at Vernon untreated and treated sites.

The abundant Hemiptera in this study are phloem-feeding herbivores, such as Alydidae, Cicadellidae, and Aphididae. Many species of Cicadellidae and Aphididae are tended by ants (Buckley, 1987; Fischer and Shingleton, 2001; Offenberg, 2001) in commensal to symbiotic relationships. The Geocoridae and Nabidae consist mostly of generalist predators, but some species may specialize on particular taxa or a particular habitat, spider webs, for example (Readio and Sweet, 1982; Schuh and Slater, 1995). The abundance of Nabidae at some Vernon sites is surprising since predators are usually less abundant than potential prey. Total numbers of arthropods captured at Vernon sites were not particularly high (appendix A1d).

Solifugae and Scorpiones

Solifugae were rare at Grouse Creek (1 individual in 960 traps) and Vernon (7 individuals in 480 traps) but were common at Ibapah (74 individuals in 480 traps) and occurred at all 8 sites. Four species of Solifugae (wind scorpions) were recorded in this study. The single specimen at Grouse Creek was *Eremobates ascopulatus*; Vernon's seven specimens included two species, *Hemerotrecha handfordana* and *Eremobates actenidia*. Fifty-five of the wind scorpions from Ibapah were sent for identification, and three species were identified: *H. handfordana* (41), *E. ascopulatus* (10), and *E. corpink* (1), with three immature specimens that could not be identified. The remaining 19 specimens have been sent to Jack Brookhart (Denver Museum of Natural Sciences) for identification.

Scorpions, another large, cursorial predator, were common at both Grouse Creek and Ibapah (66 individuals found in 960 traps at Grouse Creek and 30 individuals found in 480 traps at Ibapah) but rare at Vernon (1 individual found in 480 traps). Captures at Ibapah indicated that the association between scorpions and solifugids differed in treated and untreated zones. Regression of the average number of solifugids caught per day compared to the mean number of scorpions caught per day showed a highly significant negative relationship at the untreated sites and a strong positive relationship, though not significant, among the sites treated in 2004 (fig. 26).

Aquatic Sampling

Study Sites

We collected aquatic invertebrates at 27 sites (table 4). Sites ranged in elevation from 1,597 m to 2,113 m, with the most variation in elevation at Vernon, and included nine vegetation classification zones. There were eight sampling sites at Grouse Creek (fig. 27), ten at Ibapah (fig. 28), and nine at Vernon (fig. 29). Sampling sites within these three areas were located first by an indication of water on the map. We would then travel to the site and determine whether it was suitable. To the extent possible, we attempted to find similar water bodies in and outside of the treatment zone in each of the study areas. Water was rare in the study areas, and we sampled as many aquatic sites as we could locate within the three study areas.

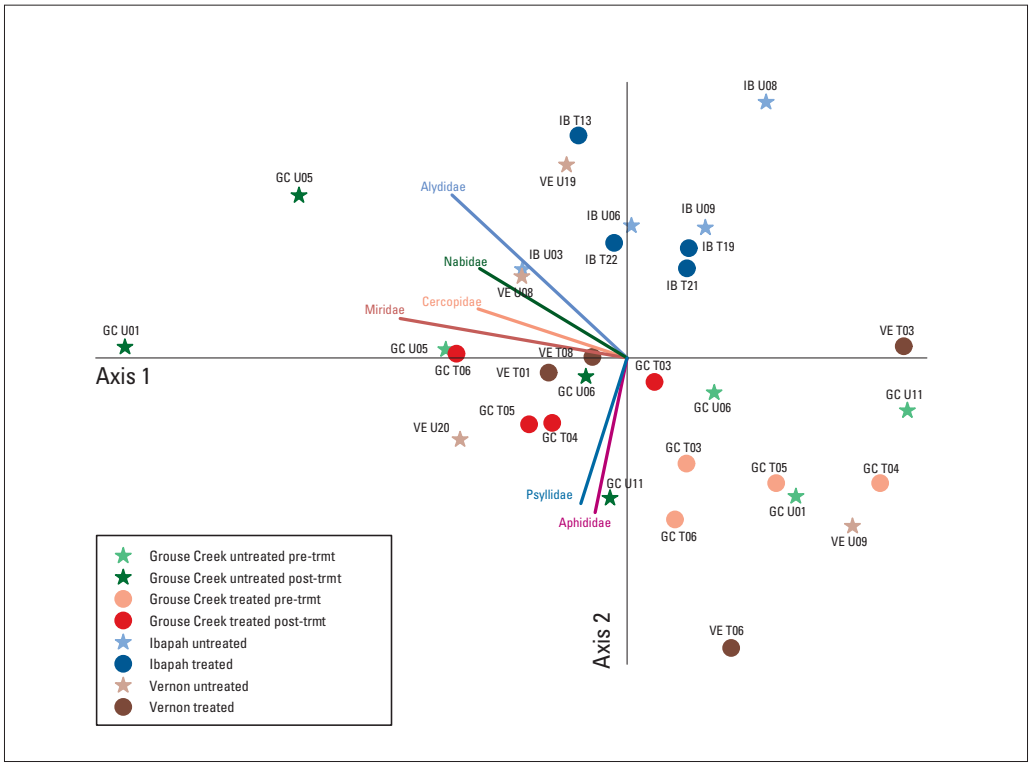

Figure 25. Nonmetric multidimensional scaling ordination of Hemiptera families at the three study areas.

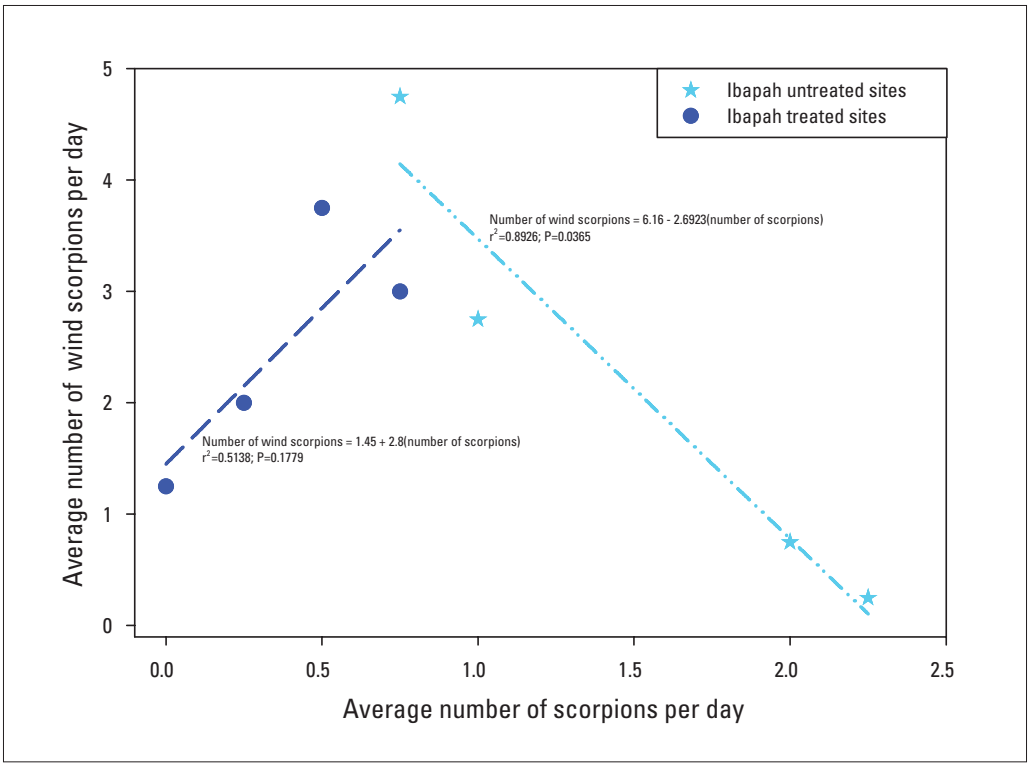

Figure 26. Number of wind scorpions per day versus number of scorpions per day at Ibapah study site.

Figure 27. Aquatic site at Grouse Creek (U.S. Geological Survey photograph by Anne Brasher).

Table 4. Aquatic site information, west desert study area, Utah.

Site	Spray zone	Code	Elevation, in meters	GAP vegetation classification
		Grouse Creek		
Coal Mine Spring	In	CMSP	1,742	Great Basin Pinyon-Juniper Woodland
Cluster Spring no. 1	In	CLSP1	1,661	Inter-Mountain Basins Big Sagebrush Shrubland
Cluster Spring no. 2	In	CLSP2	1,661	Inter-Mountain Basins Big Sagebrush Shrubland
Red Butte Creek—inside treatment	In	RBTST	1,633	Inter-Mountain Basins Big Sagebrush Shrubland
N. Fork Red Butte Creek	In	NFRST	1,629	Inter-Mountain Basins Big Sagebrush Shrubland
Keg Spring	Out	KGSP	1,839	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland
Lower Rocky Pass Spring	Out	LRSP	1,692	Inter-Mountain Basins Big Sagebrush Shrubland
Red Butte Creek—outside treatment	Out	RBNST	1,597	Inter-Mountain Basins Big Sagebrush Shrubland
		Ibapah		
Mike's Crossing	In	MCST	1,796	Inter-Mountain Basins Big Sagebrush Shrubland
Spray Ditch	In	SDST	1,757	Inter-Mountain Basins Big Sagebrush Shrubland
Jason's Crossing	In	JCST	1,780	Inter-Mountain Basins Big Sagebrush Shrubland
Irrigation Ditch at Jason's Crossing	In	IJCST	1,781	Inter-Mountain Basins Big Sagebrush Shrubland
Indian Crossing	In	ICST	1,803	Inter-Mountain Basins Big Sagebrush Shrubland
Oxbow N. End	Out	NOXSP	1,689	Inter-Mountain Basins Big Sagebrush Shrubland
Oxbow S. End	Out	SOXSP	1,689	Inter-Mountain Basins Big Sagebrush Shrubland
Skinner Springs	Out	SKSP	1,653	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland
Bobcat Crossing	Out	BCST	1,720	Inter-Mountain Basins Big Sagebrush Shrubland
East Deep Creek	Out	DCST	1,691	Agriculture
		Vernon		
VE T03 Ditch	In	VD3ST	1,744	Inter-Mountain Basins Big Sagebrush Shrubland
Roger's Crossing	In	RCST	1,836	Inter-Mountain Basins Big Sagebrush Shrubland
Vernon Creek	In	VCST	1,888	Great Basin Pinyon-Juniper Woodland
VE T06 Ditch	In	VD6ST	1,787	Inter-Mountain Basins Big Sagebrush Shrubland
Chokecherry Stream	Out	CCST	2,002	Inter-Mountain Basins Montane Sagebrush Steppe
Left Fork Bennion Creek	Out	LFST	2,113	Inter-Mountain Basins Montane Sagebrush Steppe
Little Valley Creek	Out	LVST	1,956	Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland
Upper Little Valley Creek	Out	ULVST	1,983	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
Private Creek	Out	PCST	2,023	Inter-Mountain Basins Montane Sagebrush Steppe

Figure 28. Aquatic site at Ibapah (U.S. Geological Survey photograph by Anne Brasher).

Figure 29. Aquatic site at Vernon (U.S. Geological Survey photograph by Becky Close).

Table 5. Aquatic site characteristics and sampling information, west desert study areas, Utah.

[m, mud; sl, silt; sa, sand; smr, small rocks; g, gravel; c, cobble; r, rocks; b, boulder]

Code	Sample dates	Spray zone	Stream/spring	Temperature, in degrees Celsius	Depth, in meters	Width, in meters	Substrate
CMSP	5/25/05	In	Spring	23.5	NA	30 by 34	sa,m,sl
	6/24/05			14	1	30 by 35	NA
	10/7/05			12	NA	43 by 30	m,sl
CLSP1	5/26/05	In	Spring	18	NA	5 by 5	NA
	10/7/05			10	NA	10 by 6	NA
CLSP2	6/23/05	In	Spring	18.5	NA	15 by 5	M
	10/7/05			9	NA	4 by 5	NA
RBTST	5/27/05	In	Stream	7	NA	2.3	Sa
	6/22/05			14	NA	NA	NA
NFRST	10/7/05	In	Stream	4	NA	NA	sl to c
KGSP	5/25/05	Out	Spring	NA	.45	21 by 16	m,s
	6/23/05			9	.15	15 by 10	sl
	10/7/05			11.5	.45	18 by 12	Sl
LRSP	6/2/05	Out	Spring	17	.13	15 by 9	sa,sl,m
	6/22/05			NA	NA	NA	sl
	10/7/05			15	.6	20 by 10	Sl
RBNST	6/2/05	Out	Stream	15	.75	2.5	G
	6/22/05			NA	NA	NA	NA
MCST	7/12/05	In	Stream	18	.15	4	g,c,r
SDST	7/13/05	In	Irrigation ditch	16	.3	1.5	G
JCST	7/13/05	In	Stream	19	.2	5	sa,g,c
IJCST	7/13/05	In	Irrigation ditch	14.5	.15	1.75	c,g,smr
ICST	7/14/05	In	Irrigation ditch	15	.15	1.5	sa,g,c
NOXSP	7/13/05	Out	Spring	15	.3	90 by 20	NA
SOXSP	7/13/05	Out	Spring	15	.3	90 by 20	NA
SKSP	7/13/05	Out	Spring	9	.45	15 by 10	NA
BCST	7/13/05	Out	Stream	18	.2	3	sa,g,c
DCST	7/14/05	Out	Stream	20.5	.3	2.5	sa,m,g
VD3ST	7/20/05	In	Irrigation ditch	19	.05	.3	m,sl
RCST	7/21/05	In	Stream	27	.1	1	c,g,smr
VCST	7/21/05	In	Stream	NA	.5	2	NA
VD6ST	7/21/05	In	Irrigation ditch	23	.1	1.75	g,c
CCST	7/20/05	Out	Stream	11	.4	2.5	g,m,sa
LFST	7/20/05	Out	Stream	11	.1	1	c,b,g
LVST	7/20/05	Out	Stream	15	.3	2.5	c,g
ULVST	7/20/05	Out	Stream	15	.5	2.5	c,g
PCST	7/21/05	Out	Stream	11	.1	2	sl,sa

Aquatic sites consisted of both streams (including actual streams and irrigation ditches) and springs (table 5). There were five sites in the treatment zone at Grouse Creek and three sites outside of the treatment zone. At one of the sites in the treatment zone, Cluster Springs, there were two different springs (CLSP1 and CLSP2). CLSP1 was sampled during the first sampling event. During the second sampling event, CLSP1 was inadvertently overlooked, and CLSP2 was sampled. During the third sampling event, both CLSP1 and CLSP2 were sampled. At Ibapah, there were five sites inside and five sites outside of the treatment zone. At Vernon, there were four sites inside and five sites outside of the treatment zone. The sites in pesticide treatment zones were surrounded by a buffer zone extending 150 m from both sides of the water body. Some sites at Ibapah (ICST, IJCST, SDST) and Vernon (VD6ST, RCST) were not buffered because they are irrigation ditches and, therefore, were directly in the spray zone. The sites at Grouse Creek and Ibapah consisted of both springs and streams. All the sites at Vernon were classified as streams. Because the lower elevation sites at Vernon were areas that are ranched or farmed, these lower elevation areas also were the sites that were sprayed. Upper elevation sites at Vernon were not sprayed, potentially confounding the effects of spraying versus elevation on aquatic communities. Basic habitat characteristics were recorded at most sites. Water temperatures ranged from 4°C to 27°C. Spring pools ranged in size from small (20 m^2) to relatively large (1,800 m^2). Streams were generally similar in size to each other, with wetted widths of 0.3 to 2.5 m.

Sampling Design

We collected samples in three timeframes at Grouse Creek—before treatment, 2 weeks after treatment, and 4 months after treatment. Grouse Creek was the only area treated with diflubenzuron in 2005. Samples were collected only once, 1 year after treatment, at both Ibapah and Vernon.

Sample Collection and Processing

We collected macroinvertebrate samples by using a D-frame net (fig. 30). We targeted as many different habitat types as possible within each water body. These samples are semiquantitative, based on sampling effort. We recorded the amount of time spent sampling at each location and tailored the time to the size of the water body (that is, at the larger springs, such as Coal Mine Springs, we sampled for 10 minutes; but at Cluster Springs no. 1, which is much smaller, we sampled for 3 minutes). The samples were presorted in the field and preserved in ethanol.

Sample Sorting and Identification

All samples were sent to Rhithron Associates for identification and enumeration. Subsamples of a minimum of 300 organisms were obtained by using Caton subsampling devices, divided into 30 grids (each approximately 5 by 6 cm). The organisms were identified to the lowest practical level con-

Figure 30. Collecting an aquatic macroinvertebrate sample using a D-frame net (U.S. Geological Survey photograph by Anne Brasher).

sistent with Montana Department of Environmental Quality (DEQ) data requirements by using appropriate published taxonomic references. Quality-control procedures for taxonomy involved checking taxonomic accuracy and precision and enumeration accuracy.

Data Analysis

We used the Invertebrate Data Analysis System (Cuffney, 2003) for data management. Macroinvertebrate data were resolved for taxonomic ambiguities (by site) at the genus level, lifestages were combined, and coarser taxonomic levels were distributed to finer taxonomic levels. Rare taxa were retained. Standard metrics, including abundance, richness, and Shannon diversity were computed, and this dataset was used for subsequent analyses. This dataset was used for subsequent analyses. Multivariate procedures were conducted by using the statistical package PC-ORD (McCune and Mefford, 2005) to evaluate associations among species composition and sampling sites. Relative abundance data were used for NMS, which is a conglomerative technique that groups sites based on species composition (McCune and Grace, 2002). Results are presented as a bi-plot. In NMS, sites that are grouped more closely together have more species in common than sites that are distant from each other. Key species influencing the spread of sites along the axes are indicated on the bi-plot as vectors. The nonparametric Kruskall Wallis test was used with relative abundance and richness data to compare taxa from treated and untreated zones at each study area by using the statistical package S-PLUS (2000).

Aquatic Results

Aquatic Macrofauna by Study Area

We collected 169 different taxa at the three study areas (table 6), including 17 orders and 59 families. Appendix B provides a comprehensive taxa list (including abundances) at each sampling site. Grouse Creek was dominated by Tubificidae (tubificid worms), Cladocera (water fleas), Ostracoda (seed shrimp), *Callibaetis* mayflies, *Enallagma* damselflies, *Pseudochironomus* sp., *Apedilum* sp., and *Micropsectra* sp. midges, as well as *Simulium* sp. (blackfly larvae). Ibapah also was dominated by Tubificidae, Ostracoda, *Callibaetis* sp., *Enallagma* sp., and *Simulium* sp. In addition, *Physa* sp. snails, copepods (Maxillopoda/ Copepoda), amphipods, the mayflies *Baetis tricaudatus* and *Epeorus longimanus*, and midges *Tvetenia bavarica* gr. and *Micropsectra* sp. were abundant at Ibapah. One sampling site at Ibapah had more than 2,000 *Fluminicola* sp. snails. At Vernon, Ostracoda, *Fluminicola* sp., Pisidiidae (pea clams), the stonefly *Zapada cinctipes, Baetis tricaudatus*, *Optioservus* sp. (a beetle), *Simulium* sp., and the midges *Micropsectra* sp., *Tvetenia bavarica* gr., *Orthocladius* sp., and *Eukiefferiella claripennis* gr. were the dominant taxa.

Figure 31. Cluster Spring 2 (CLSP2) at Grouse Creek, within the treated zone (U.S. Geological Survey photograph by Anne Brasher).

Figure 32. Aquatic macroinvertebrate sampling at one of the study streams (U.S. Geological Survey photograph by Anne Brasher).

Water bodies at Grouse Creek and Ibapah consisted of both springs (fig. 31) and streams (fig. 32); only streams were sampled at Vernon. Overall, the macroinvertebrate fauna at springs was different than at streams. Crustaceans (Cladocera, Amphipoda, Maxillopoda, and Ostracoda) dominated springs, and mayflies (Ephemeroptera) and true flies (Diptera) dominated streams.

Approximately two-thirds of the taxa in springs at Grouse Creek (fig. 33*A*) and Ibapah (fig. 34*B*) consisted of crusta-

Table 6. Aquatic taxa collected at the three west desert study areas, Utah.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
Annelida	Clitellata	Arhynchobdellida	Erpobdelliformes	Erpobdellidae		*Mooreobdella* sp.	MOORE		X	X
					Erpobdellinae	*Erpobdella* sp.	ERPOB		X	
		Haplotaxida		Enchytraeidae			ENCHY	X	X	X
				Naididae			NAIDI	X		X
				Tubificidae			TUBIF	X	X	X
		Rhynchobdellida		Glossiphoniidae	Haementeriinae	*Helobdella stagnalis*	HELOB		X	
Mollusca	Bivalvia	Veneroida		Pisidiidae			PISID	X	X	X
	Gastropoda	Basommatophora		Lymnaeidae			LYMNA	X		
						Fossaria sp.	FOSSA	X		X
						Stagnicola sp.	STAGN	X	X	X
				Physidae		*Physa* sp.	PHYSA	X	X	
				Planorbidae		*Gyraulus* sp.	GYRAU		X	X
		Neotaenioglossa		Hydrobiidae		*Fluminicola* sp.	FLUMI	X	X	X
Nematoda							NEMAT	X	X	X
Platyhelminthes	Turbellaria						TURBE	X		X
		Tricladida		Planariidae		*Polycelis coronata*	POLYC			X
Arthropoda	Arachnida	Trombidiformes					TROMB	X	X	X
	Branchiopoda	Diplostraca	Cladocera				CLADOC	X	X	
	Malacostraca	Amphipoda		Gammaridae		*Gammarus* sp.	GAMMA		X	X
				Hyalellidae		*Hyalella* sp.	HYALE	X	X	X
	Maxillopoda/ Copepoda						COPEP	X	X	X
Copepoda	Ostracoda						OSTRA	X	X	X
	Insecta	Ephemeroptera	Furcatergalia	Caenidae		*Caenis* sp.	CAENI	X		
				Ephemerellidae		*Drunella* sp.	DRUNE	X		
						Drunella grandis	DRUGR	X	X	
						Ephemerella inermis	INERM	X		X
					Ephemerellinae	*Serratella tibialis*	SERRAT	X		

Table 6. Aquatic taxa collected at the three west desert study areas, Utah—Continued.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
			Schistonota	Leptophlebiidae		*Paraleptophlebia* sp.	PARAL			X
				Siphlonuridae			SIPHLO	X		
			Pisciforma	Ameletidae		*Ameletus* sp.	AMELE	X	X	
				Baetidae		*Acentrella* sp.	ACENT	X		
						Baetis tricaudatus	BAETI	X	X	X
						Callibaetis sp.	CALLI	X	X	X
						Centroptilum sp.	CENTR	X	X	
						Diphetor hageni	DIPHE		X	X
			Setisura	Heptageniidae		*Cinygmula* sp.	CINYG	X		
						Epeorus grandis	EGRAND		X	
						Epeorus deceptivus	EDECEPT		X	
						Epeorus longimanus	ELONGIM	X	X	
		Odonata	Anisoptera	Aeshnidae			AESHN	X		
						Aeshna sp.	AESHNSP	X		
						Anax sp.	ANAXSP	X		
				Libellulidae			LIBEL	X		
						Erythemis sp.	ERYTHEM	X		
						Libellula sp.	LIBELSP	X		
						Sympetrum sp.	SYMPE	X	X	
			Zygoptera	Calopterygidae		*Hetaerina* sp.	HETAER		X	
				Coenagrionidae			COENAGR	X		
						Amphiagrion sp.	AMPHIAG	X		
						Enallagma sp.	ENALLAG	X	X	
				Lestidae		*Lestes* sp.	LESTES		X	
		Plecoptera	Euholognatha	Capniidae			CAPNII	X		
				Nemouridae			NEMOU	X		
					Amphinemurinae	*Malenka* sp.	MALENKA		X	
					Nemourinae	*Zapada* sp.	ZAPAD			X

Table 6. Aquatic taxa collected at the three west desert study areas, Utah—Continued.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
						Ochrotrichia sp.	OCHROT	X	X	X
				Rhyacophilidae		*Rhyacophila* sp.	RHYACO			X
		Coleoptera	Adephaga	Dytiscidae			DYTISCI	X	X	X
						Agabus sp.	AGABU	X	X	
						Colymbetes sp.	COLYMB	X		
						Rhantus sp.	RHANTU	X		
						Liodessus sp.	LIODESS		X	
						Hygrotus sp.	HYGROTU		X	
						Stictotarsus sp.	STICTOT	X	X	X
						Laccophilus sp.	LACCOPH	X		
				Haliplidae		*Peltodytes* sp.	PELTODY	X		
			Polyphaga	Elmidae		*Cleptelmis* sp.	CLEPTEL			X
						Optioservus sp.	OPTIOSE	X	X	X
				Hydraenidae		*Ochthebius* sp.	OCHTHEB	X		
				Hydrophilidae			HPHILID	X	X	
						Hydrobius sp.	HYBIUS	X		
						Laccobius sp.	LACCOB	X		
						Tropisternus sp.	TROPIST	X		
		Diptera	Nematocera	Blephariceridae	Blepharicerinae	*Agathon* sp.	AGATH	X		
				Ceratopogonidae	Ceratopogoninae		CERATOP	X	X	X
				Chironomidae	Chironomini	*Apedilum* sp.	APEDILU	X	X	
						Chironomus sp.	CHIRONO	X		
						Chironomus sp.	CHIRONO	X		
						Parachironomus sp.	PARACHI			X
						Paracladopelma sp.	PARACLA			X
						Paratendipes sp.	PARATEN	X	X	
						Phaenopsectra sp.	PHAENOP	X	X	X
						Polypedilum sp.	POLYPED	X	X	X

Table 6. Aquatic taxa collected at the three west desert study areas, Utah—Continued.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
					Pseudochironomini	*Pseudochironomus* sp.	PSEUDOC	X	X	
					Tanytarsini		TARSINI	X		
						Cladotanytarsus sp.	CLADOT		X	
						Micropsectra sp.	MICROPS	X	X	X
						Rheotanytarsus sp.	RHEOTAN	X		
						Stempellinella sp.	STEMPEL	X		
						Tanytarsus sp.	TANYTAR	X		X
					Diamesinae	*Pagastia* sp.	PAGAS	X	X	X
						Pseudodiamesa sp.	IAMESA			X
						Diamesa sp.	DIAMES	X		
					Orthocladiinae	*Acricotopus* sp.	ACRICOT	X		
						Brillia sp.	BRILLIA	X		X
						Chaetocladius sp.	CHAETOC	X		X
						Corynoneura sp.	CORYNON	X	X	X
						Cricotopus (Cricotopus)	CRICOTO	X	X	X
						Cricotopus (Isocladius)	ISOCLAD	X		
						Eukiefferiella brehmi gr.	EUKBREH	X	X	X
						Eukiefferiella devonica gr.	EUKDEVO		X	X
						Eukiefferiella gracei gr.	EUKGRAC		X	X
						Eukiefferiella claripennis gr.	EUKCLAR		X	X
						Limnophyes sp.	LIMNOP	X	X	X
						Orthocladius sp.	ORTHOC	X	X	X
						Parakiefferiella sp.	PARAKI			X
						Parametriocnemus sp.	PARAME	X		X

Table 6. Aquatic taxa collected at the three west desert study areas, Utah—Continued.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
						Paraphaenocladius sp.	PARAPH	X		
						Psectrocladius sp.	PSECTRC	X	X	
						Pseudosmittia sp.	PSEUDOS	X		
						Rheocricotopus sp.	RHEOCRI			X
						Thienemanniella sp.	THIENEM		X	
						Tvetenia bavarica gr.	TVETE	X	X	X
						Metriocnemus sp.	METRIOC	X	X	X
					Podonominae	*Parochlus* sp.	PAROC			X
					Prodiamesinae	*Odontomesa* sp.	ODONTO		X	X
						Prodiamesa sp.	PRODIA			X
					Tanypodinae		TANYPOD	X		
						Apsectrotanypus sp.	APSECTR		X	X
						Psectrotanypus sp.	PSECTRT		X	
						Radotanypus sp.	RADOTA		X	X
						Pentaneura sp.	PENTA	X	X	
						Thienemannimyia gr.	NIMYIA	X	X	X
						Zavrelimyia sp.	ZAVRELI	X	X	
						Tanypus sp.	TANYPUS		X	
				Culicidae			CULICI	X	X	X
				Dixidae			DIXID		X	
						Dixa sp.	DIXASP			X
						Meringodixa sp.	MERINGO	X		
				Psychodidae			PSYCHOD	X		X
				Simuliidae		*Prosimulium* sp.	PROSIMU	X	X	
						Simulium sp.	SIMULIU	X	X	X
				Tipulidae	Limoniinae	*Molophilus* sp.	MOLOPH		X	
						Pedicia sp.	PEDICI			X
						Dicranota sp.	DICRAN			X

Table 6. Aquatic taxa collected at the three west desert study areas, Utah—Continued.

Phylum	Class	Order	Suborder	Family	Subfamily/Tribe	Genus/Species	Code	Grouse Creek	Ibapah	Vernon
					Tipulinae	*Tipula* sp.	TIPULA	X		
			Brachycera	Dolichopodidae			DOLICHO	X		
				Empididae			EMPIDI		X	
						Neoplasta sp.	NEOPLAS			X
						Clinocera sp.	CLINOCE	X	X	X
				Ephydridae			EPHYDR	X		
				Muscidae			MUSCIDA	X	X	X
				Sciomyzidae			SCIOMYZ	X	X	

ceans. Diptera and noninsect taxa (mites, nematodes, and oligochaetes) made up about one quarter of the noncrustacean taxa in springs at Grouse Creek. Insects (Ephemeroptera, Diptera, and other insects) made up a little more than one-fifth of the taxa in springs at Ibapah, with molluscs accounting for an additional tenth. Diptera in springs at Grouse Creek and Ibapah were almost entirely Chironomidae.

Streams at Grouse Creek (fig. 33*B*), Ibapah (fig. 34*B*), and Vernon (35) had fairly similar relative abundances of different taxa at the order level. Diptera was the most abundant, followed by Ephemeroptera. Together, these two orders accounted for 95 percent, 82 percent, and 80 percent of the taxa in streams at Grouse Creek, Ibapah, and Vernon, respectively. More than three-quarters of the Diptera in streams at Grouse Creek were Simulidae; most of the remaining Diptera were Chironomidae. The opposite pattern was observed at Ibapah and Vernon, with approximately three-quarters of the Diptera consisting of Chironomidae. Crustaceans and molluscs contributed little to the overall abundance at Grouse Creek and Ibapah streams (less than 5 percent), while 12 percent of the abundance in Vernon streams consisted of crustaceans and molluscs. Vernon streams had half as many mayflies as streams in Grouse Creek and Ibapah.

Richness, Abundance, and Diversity at Sampling Sites in the Three Study Areas

Grouse Creek

Grouse Creek was the only study area sprayed in 2005. There was no significant difference in abundance (Kruskall Wallis chi-square=0.4176; *P*=0.5181) or richness (Kruskall Wallis chi-square=1.5578; *P*=0.212) between sites inside and outside the treatment zones after treatment. Because water bodies were buffered (no pesticide was sprayed closer than about 150 m from a water body), the lack of difference between sprayed and unsprayed sites was not unexpected. At Grouse Creek, abundance (number of individuals) was highly variable among sites, with no clear pattern between the treated and untreated zones (fig. 36). Richness (number of taxa) was less variable among sites. The diversity index mirrors the richness values. Since there was no statistically significant difference in macroinvertebrate abundance or richness between the treated and untreated zones after treatment, all sampling dates (before and after treatment) were plotted for further commu-

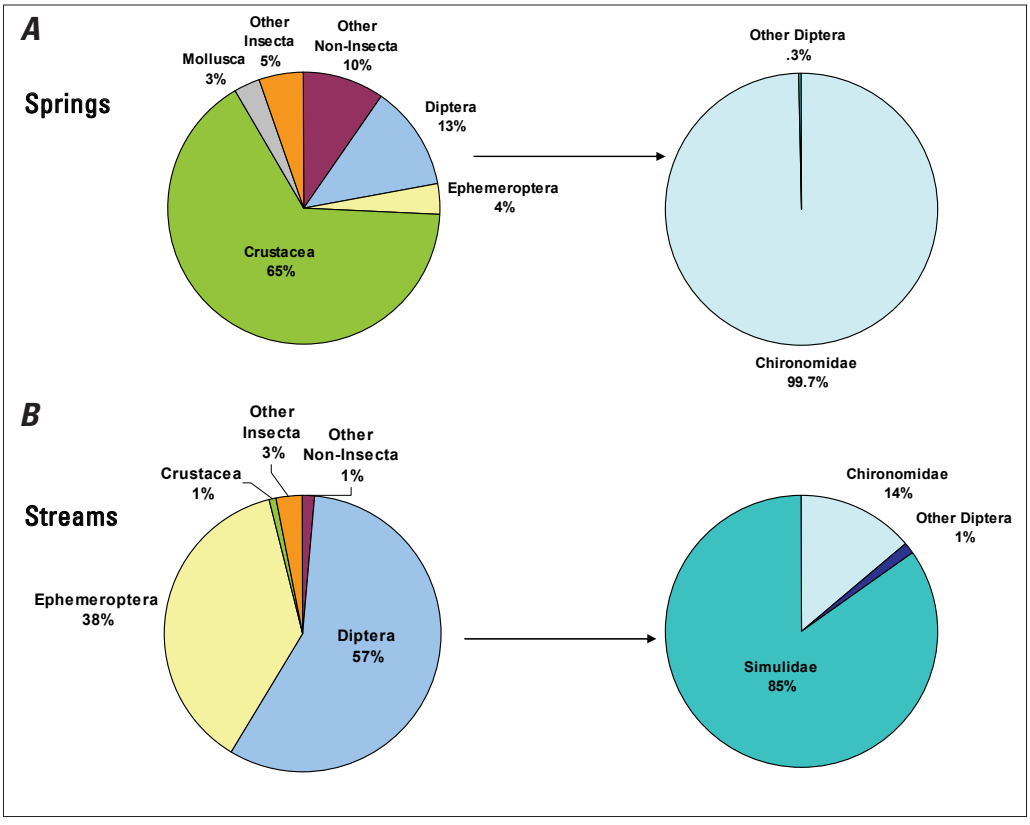

Figure 33. Relative abundances of aquatic taxa in springs (*A*) and streams (*B*) at the Grouse Creek study area.

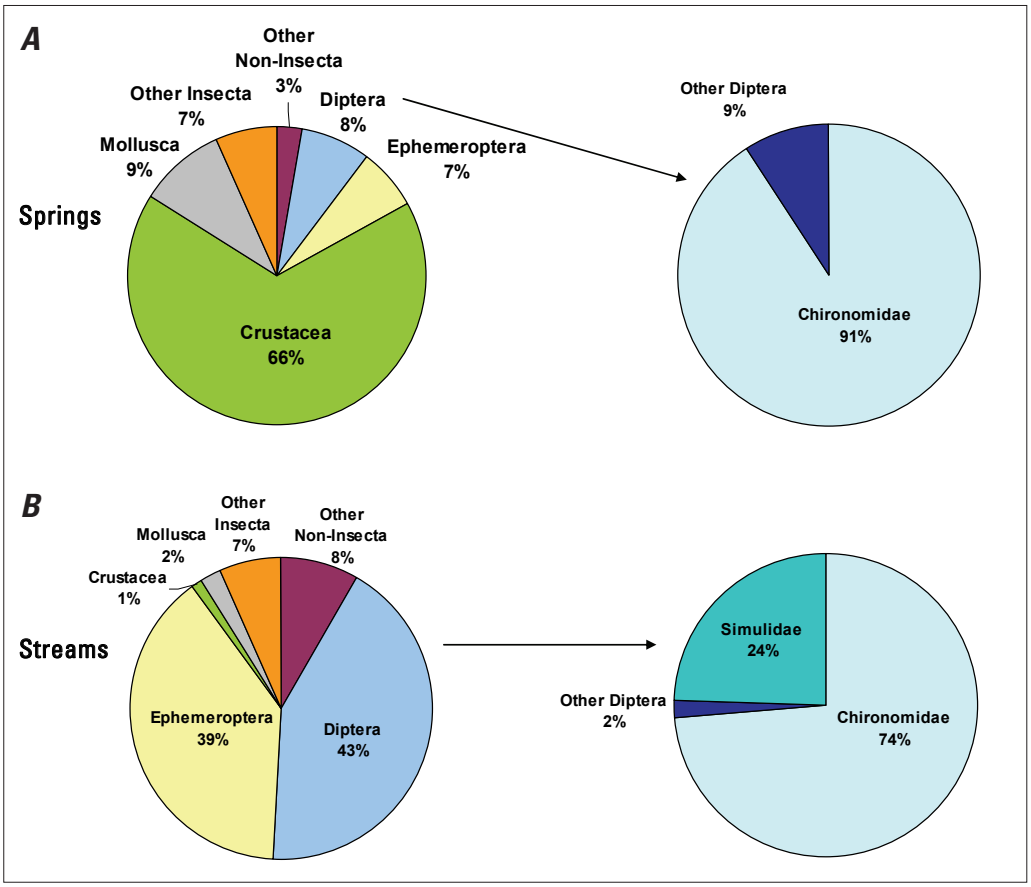

Figure 34. Relative abundances of aquatic taxa in springs (*A*) and streams (*B*) at the Ibapah study area.

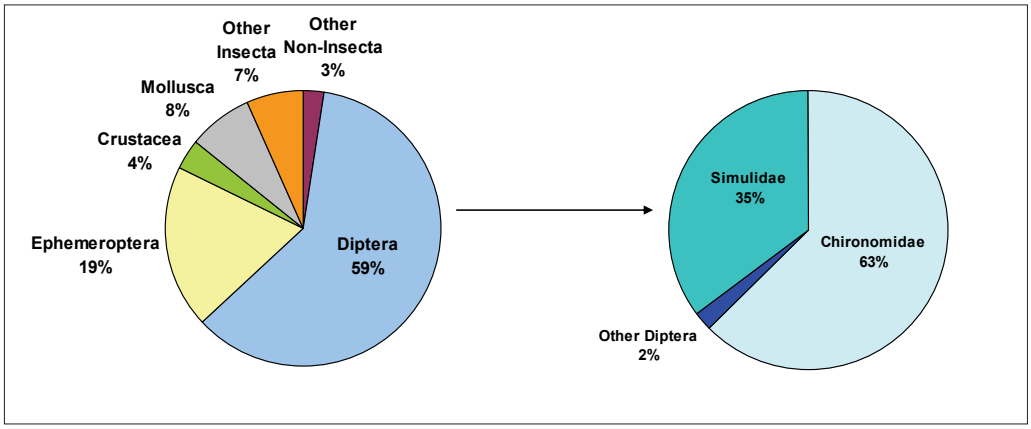

Figure 35. Relative abundances of aquatic taxa in streams at the Vernon study area.

nity analysis (fig. 37). The lowest abundance in the untreated zone was at Keg Springs, which was sampled in May 2005; and the highest abundance in the untreated zone was at this same sampling site in October 2005. This high abundance was in large part due to the presence of 7,306 individual Cladocera in the sample. Seasonal changes in species composition and abundance are further addressed in the section discussing pre- and post-treatment aquatic communities.

Ibapah

Ibapah was sprayed in 2004 but not 2005 (the year we sampled). There was no significant difference in abundance (Kruskall Wallis chi-square=0.5345; P=0.4647) or richness (Kruskall Wallis chi-square=1.866; P=0.1719) between sites inside and outside of the treatment zone. Richness was fairly consistent across all sites (fig. 38). Sites outside the treatment zone at Ibapah included two streams and three springs; inside the treatment zone, we were able to locate and sample streams but no springs. The difference in habitat type may confound the analysis of pesticide effect on abundance because the three springs (all outside of the treatment zone) had substantially higher abundance than any of the streams. One spring site (SKSP) had more than 27,000 individuals (of these, 21,086 were Ostracoda), a second spring site (SOXSP) had almost 10,000 individuals (with no taxa particularly dominant), and

a third spring site (NOXSP) had more than 5,000 individuals (with no taxa particularly dominant). The next most abundant sample was 2,550 individuals at a stream site within the treatment zone. The remaining stream sites had less than 1,700 individuals.

Vernon

Vernon also was sprayed in 2004 but not in 2005. All sampling sites at Vernon were classified as streams for this study. However, some sites were streams (and, thus, were buffered from spraying) and some were ditches (and were not buffered from spraying). There was no significant difference in abundance (Kruskall Wallis chi-square=1.5; P=0.2207) between sites inside and outside of the treatment zone, even considering ditches versus streams. Again, abundance was highly variable among sites in both the treated and untreated zones (fig. 39). Two sites outside the treatment zone each had approximately 20,000 individuals. More than half of the individuals at LFST (11,743) were *Micropsectra* sp. midges. Abundance was fairly evenly distributed among taxa at PCST, with the two most dominant taxa being *Simulium* sp. and *Micropsectra* sp. The next largest abundances were approximately 10,000 individuals each at one treated site and one untreated site.

Richness was significantly higher (Kruskall Wallis chi-square=6.0504; P=0.0139) in the untreated zone than in the treated zone, and higher in the actual streams than in the ditches. This may indicate an effect of pesticide spraying, but the difference in elevation again confounds this interpretation. Sites in untreated zones at Vernon had elevations ranging from 597 to 644 m, and sites in treatment zones ranged in elevation from 532 to 576 m. This elevation gradient also represents a gradient in habitat quality that would influence community composition.

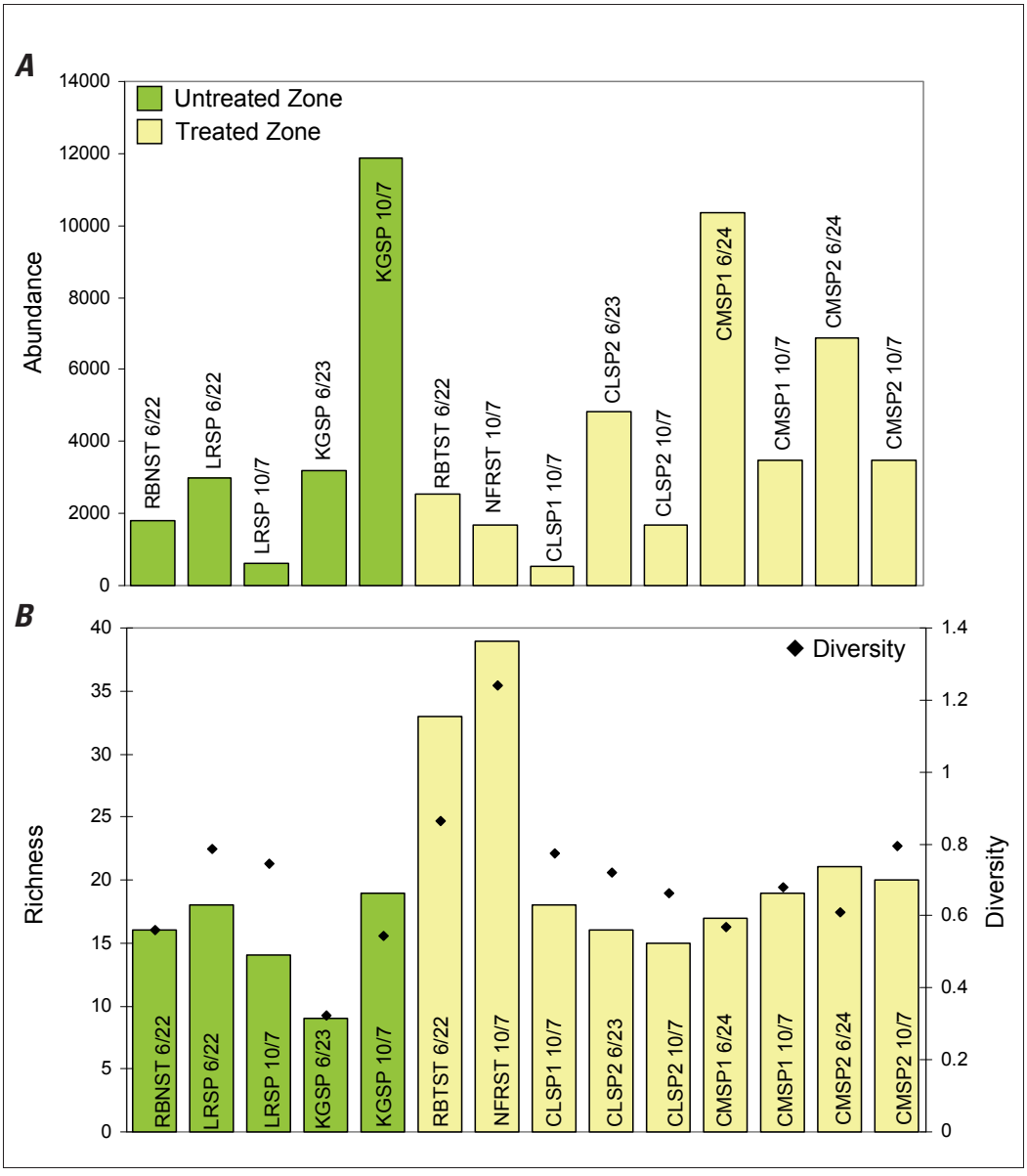

Figure 36. Taxa abundance (*A*) and richness and diversity (*B*) inside and outside diflubenzuron treatment zones at Grouse Creek, only after treatment.

Macroinvertebrates in the Grouse Creek Treatment Zone

Grouse Creek, the only study area treated in 2005, was sampled three times during this study. We sampled before treatment, 2 weeks after treatment, and 4 months after treatment. Sampling site RBTST was dried up 3 months after treatment, so we were unable to sample there. We also did not sample at CLSP1 2 weeks after treatment. Generally, abundance and richness increased from pre-treatment samples to 2-week post-treatment samples, and decreased from 2-week post-treatment samples to 3-month post-treatment samples (fig. 40). This pattern of changing abundance and richness is most likely due to natural temporal variation, whereby aquatic invertebrate populations peak in the month of June and their populations decrease again with colder weather in October. Consequently, evaluation of any effects of diflubenzuron application is confounded by temporal phenology (change during the season) in aquatic communities.

Aquatic Community Structure

We used NMS to evaluate community structure at the three study areas. The NMS was run on relative abundance data using the Sorensen distance measure, allowing a maximum number of 6 axes (dimensions). A two-dimensional solution was selected as the best-fit model.

In an NMS plot, sites with similar taxa plot close to each other. Results of the NMS analysis generated two major groupings, stream communities and spring communities (fig. 41). Cladocera, *Callibaetis* sp., *Enallagma* sp., *Sympetrum* sp., *Notonecta* sp., *Erythemis* sp., and Ostracoda are characteristic of springs. *Baetis tricaudatus, Pagastia* sp., *Ameletus* sp., *Micropsectra* sp., and *Simulium* sp. are characteristic of streams. Ostracoda grouped the Grouse Creek spring samples taken in May and June with one Ibapah spring (SKSP), while the other spring-driven species listed above grouped the Grouse Creek springs collected in October with the other two Ibapah springs, NOXSP and SOXSP. Ibapah streams grouped separately from Grouse Creek and Vernon streams.

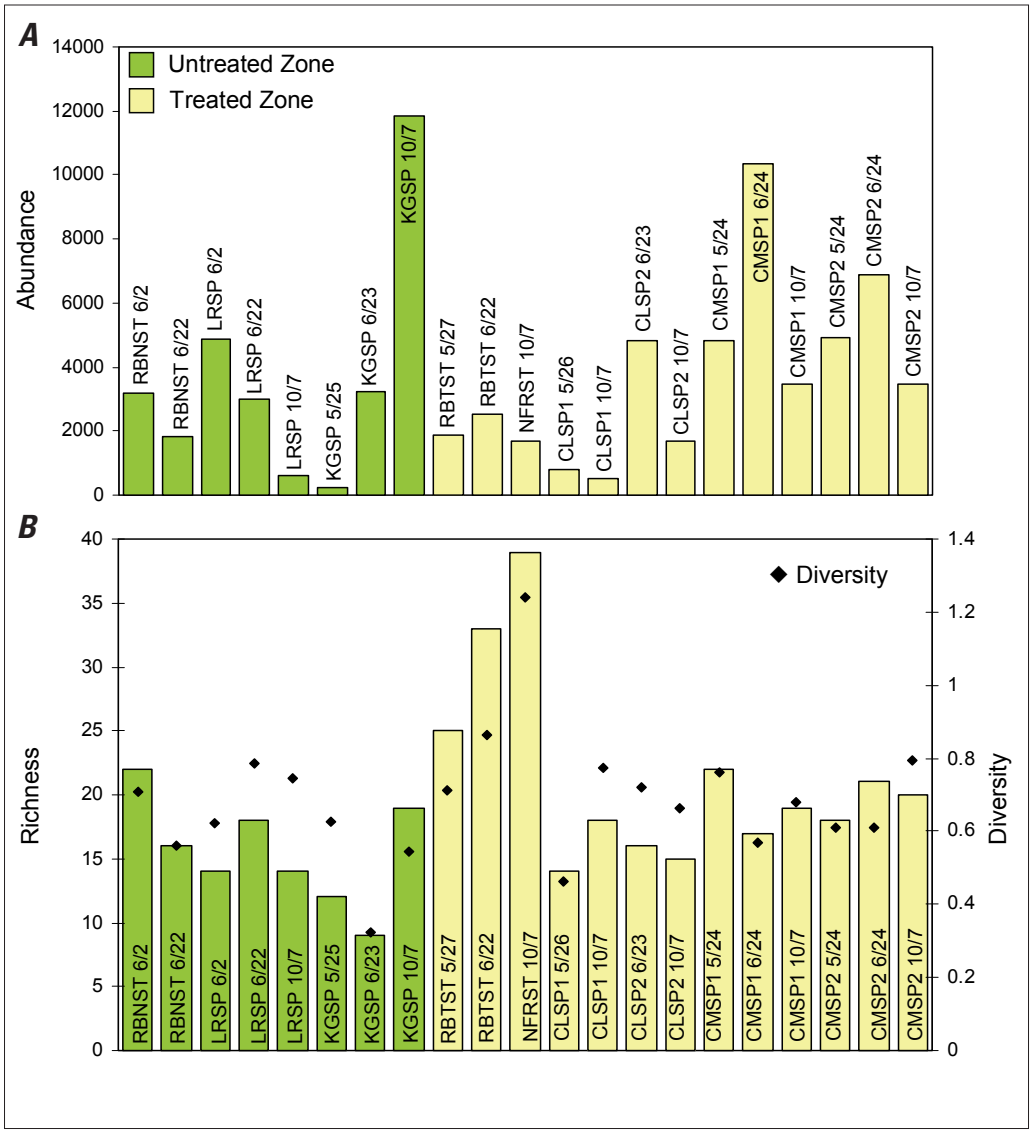

Figure 37. Taxa abundance (*A*) and richness and diversity (*B*) inside and outside diflubenzuron treatment zones at Grouse Creek, all sampling dates included.

Discussion

Terrestrial Study

Our results indicate that nontarget arthropods vary considerably in susceptibility to diflubenzuron when used to control Mormon cricket populations in the Great Basin. Sensitivity to diflubenzuron is not necessarily predictable on a taxonomic basis or on an assessment of life history traits. Our data indicate that some taxa assumed not to be susceptible did have population differences that correlated with treatment zones. The importance of identifying specimens to the lowest possible taxonomic level in analyzing results should be emphasized, as conclusions may be very different depending on how the arthropods are classified (for example, counts at family versus genus level). A total of 42 comparisons of untreated abundance versus treated abundance were possible for the three study areas. Nine of these comparisons showed significant differences between treatment zones; another nine comparisons indicated large, but not statistically significant, differences. In all 18 instances, more individuals were collected in the untreated zone.

At the order level, no consistent patterns of difference in proportional representation between treated and untreated sites at any of the three study areas indicate that treatment with diflubenzuron affects nontarget arthropods. Our results are not conclusive, however, because there is tremendous variation between individual sites within each treatment type, and because order-level resolution may mask changes in communities at lower taxonomic levels. For example, shifts between genera or from one family to another may not be detected if one taxon replaces another with a similar number of individuals. In addition, there may have been confounding effects from

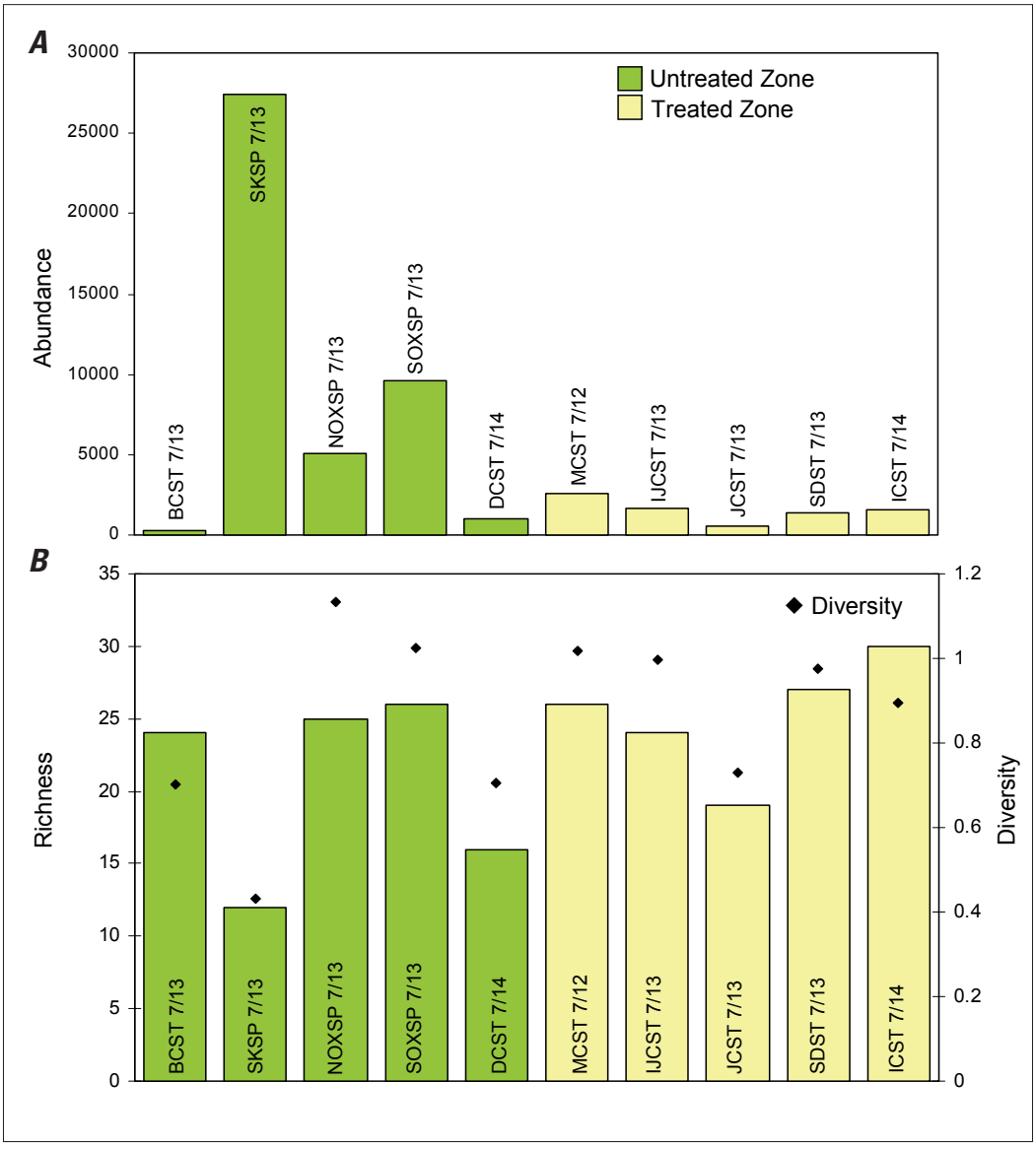

Figure 38. Taxa abundance (*A*) and richness and diversity (*B*) inside and outside diflubenzuron treatment zones at Ibapah.

topography and other issues with the spatial distribution of treated and untreated sites due to the nature of Mormon cricket treatment applications in general.

Studies conducted in South Dakota and Wyoming found diflubenzuron had minimal impacts on nontarget arthropods and their vertebrate predators (Wilcox and Coffey, 1978; McEwen and others, 1996), indicating that use of diflubenzuron in a reduced agent-area treatment design (by using less pesticide in alternating swaths) would have less environmental impact than carbaryl or malathion. However, some taxon-specific effects have been recorded. Catangui and others (2000) reported temporary declines in ants, "flying predators," and "parasites." Weiland and others (2002) reported that Diptera increased significantly and spider numbers were reduced in treated plots in a Wyoming study. Smith and others (2006) found that for some applications, numbers decreased at low pesticide-application rates, but abundance was greater at higher pesticide-application rates. Studies indicating diflubenzuron had limited impacts on nontarget arthropods and was effective at low-application rates were conducted in the Great Plains, but additional information that is directly applicable to the environment of Utah's west desert is needed.

Catangui and others (2000) found that ants in pitfall traps declined by 43 percent 49 to 55 days after treatment, but subsequent sampling periods showed a rebound to pre-treatment numbers. Smith and others (2006) reported that Formicidae as a family showed mixed responses in a Wyoming study of nontarget arthropod responses to treatments of carbaryl and diflubenzuron at different dose rates and carrier oils. Ants were reduced in diflubenzuron treatments relative to carbaryl treatments using the same carrier oil in 2001, but no significant differences between the two treatments were found in 2002. Weilund and others (2002) reported no response at the order level by Hymenoptera to diflubenzuron applications in Wyoming.

Grouped at the family level, ants did not show declines in treated zones at any of our study areas. In fact, more ants were collected at Ibapah sprayed sites than at unsprayed sites, and at Grouse Creek more ants were collected in the sprayed zone 3 weeks after diflubenzuron application than were col-

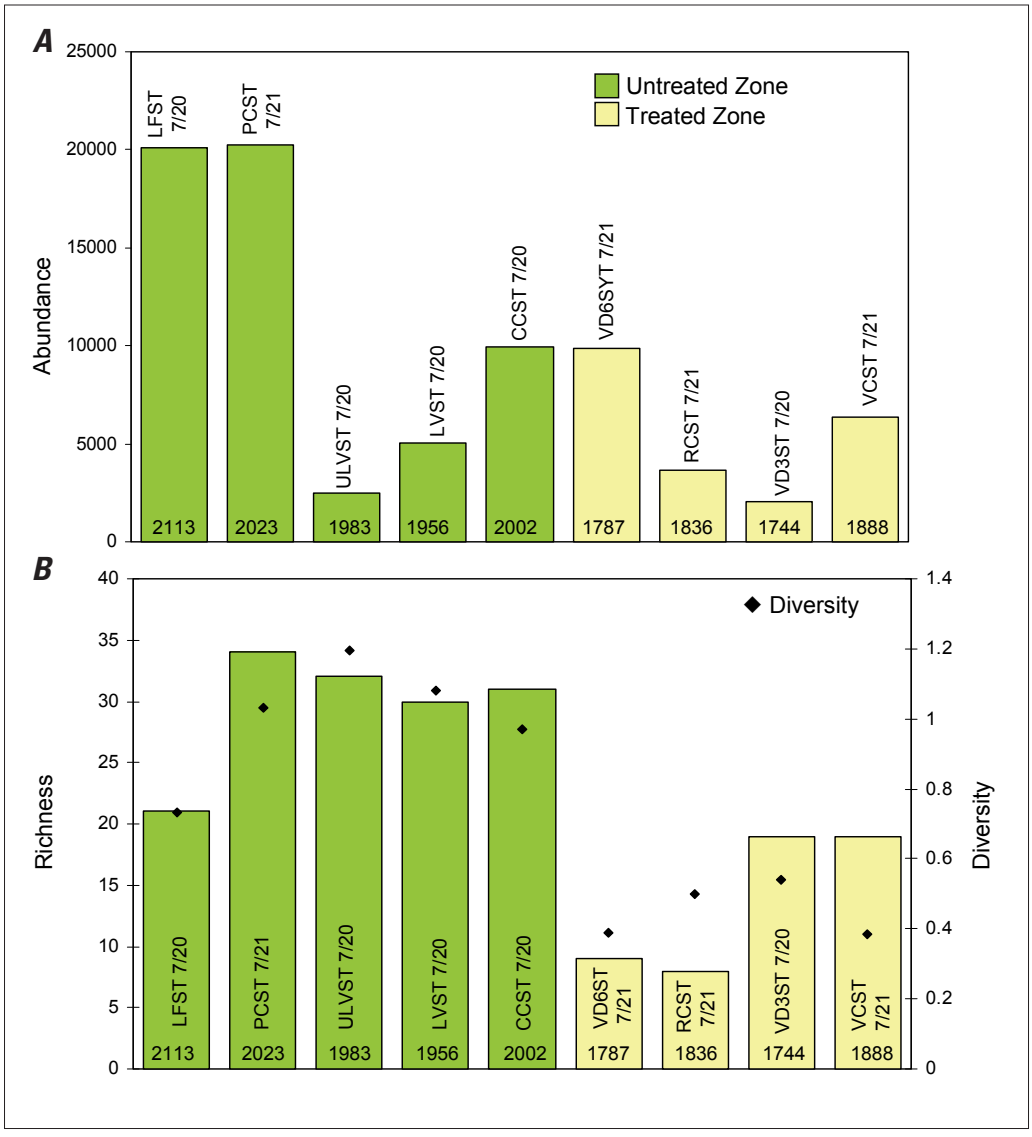

Figure 39. Taxa abundance (*A*) and richness and diversity (*B*) inside and outside diflubenzuron treatment zones at Vernon.

lected prior to treatment. However, when examined at the genus level, differences in abundance were correlated with diflubenzuron treatment. Some genera (for example, *Forelius*) had higher numbers in sprayed zones, while the abundance of other genera (for example, *Tapinoma*) was lower in sprayed zones. Potential indicators in the ant communities we sampled include genera that appear to decrease in response to diflubenzuron treatment and those that increase. *Formica* and *Tapinoma* tended to have lower numbers in treated zones, while *Forelius* and perhaps *Pheidole* tended to increase in treated zones.

Ants perform a number of important ecological functions, especially in arid and semiarid ecosystems (Greenslade, 1976; Risch and Carroll, 1982; Lobry de Bruyn and Conacher, 1990; Lobry de Bruyn and Conacher, 1994; Nash and others, 1998; Whitford and others, 1999). Predictions of the sensitivity of ants to environmental perturbations and restorations and, thus, their value as bioindicators have not been consistently supported (Bestelmeyer and Wiens, 1996; Whitford and others, 1999; Read and Andersen, 2000; Nash and others, 2001; Andersen and others, 2002; Andersen and Majer, 2004; Nash and others, 2004). Because ants perform significant functions in ecosystems, it is important to understand how individual species and collective units at functional group and community levels respond to disturbance, and how they recover from perturbation in the short and long term.

Diflubenzuron may be a factor in developing ant community structure at Ibapah and Vernon. However, pesticide treatments could be correlated with other environmental factors we did not measure that made these sites favorable for *Forelius* and, perhaps, less favorable for *Formica* and *Tapinoma*. There are potential confounding effects of topography based on where and how diflubenzuron was applied. Ibapah treated sites were all south of untreated sites, and most were a little higher in elevation. These conditions were reversed at Vernon, however, where untreated sites were higher and south of the treated area; elevation differences were greater at Vernon than at Ibapah. Similarities among ant communities from treated zones at Ibapah and Vernon, despite environmental differences between them, suggest a role for diflubenzuron in structuring ant communities in the treated zones. Untreated-zone communities at Ibapah and Vernon study areas differed; each untreated site within the Ibapah and Vernon study areas had different ant communities (fig. 21). Convergence of

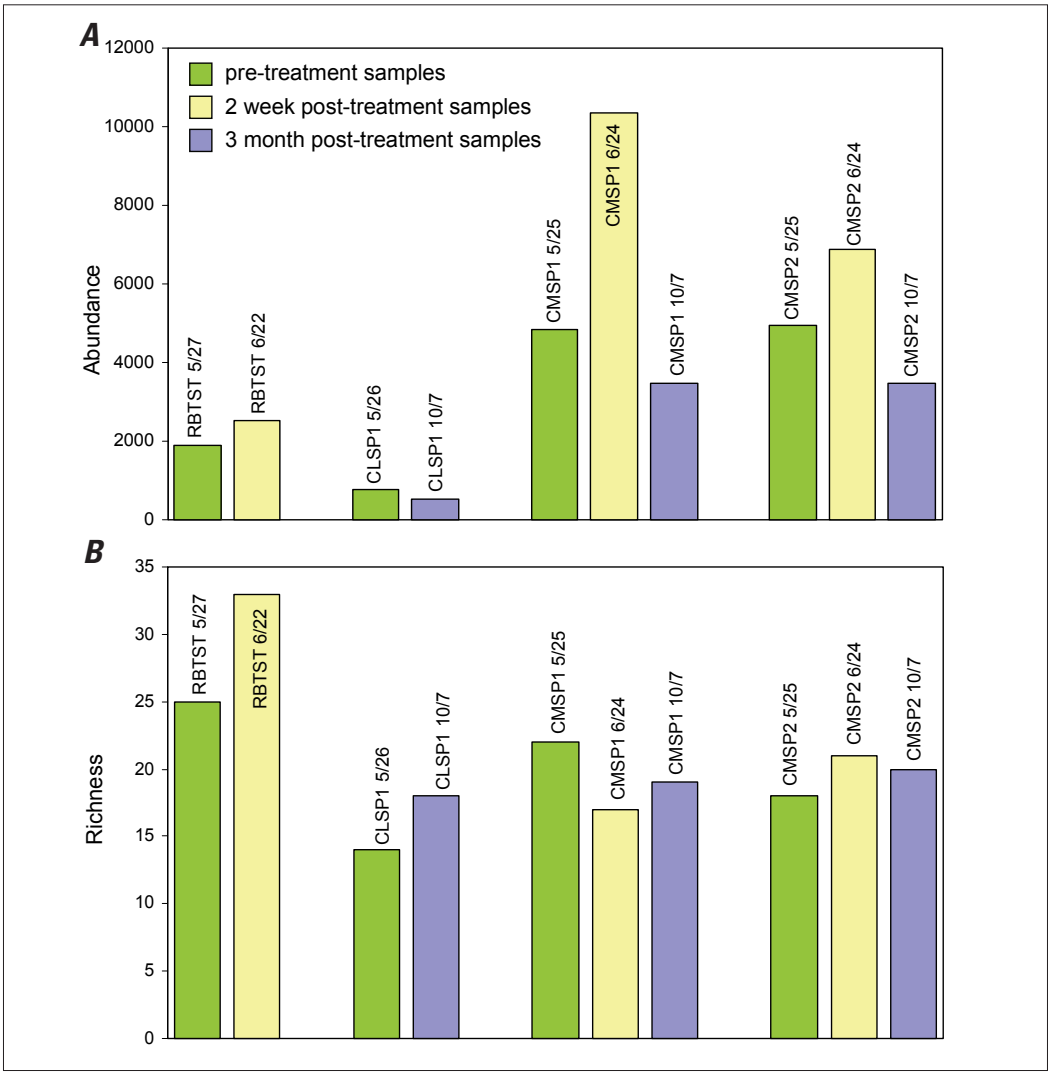

Figure 40. Taxa abundance (*A*) and richness (*B*) before diflubenzuron treatment, 2 weeks after treatment, and 4 months after treatment, at the Grouse Creek study area.

communities in the treated zones indicates a possible link to diflubenzuron treatment. Additional research is needed, especially a study designed to address the possibility of lag effects of diflubenzuron on the ant communities, and ants should be identified to species level to elucidate ecological functions that might be affected by changes in ant community structure in response to diflubenzuron application.

Non-ant Hymenoptera (including bees and predatory and parasitic wasps) were significantly lower in treated zones at Grouse Creek and Vernon. Coleoptera demonstrated the same pattern as non-ant Hymenoptera, with significantly fewer beetles at treated sites at Vernon and a trend toward more beetles at untreated sites in the Ibapah study area. Flies also were significantly reduced at Vernon and showed a trend toward declining numbers at treated sites at Ibapah. Catangui and others (2000) reported that diflubenzuron reduced the number of flying predators by 59 percent 15 to 20 days after treatment, however, numbers rebounded in subsequent samples. Parasite numbers also were reduced (by about 18 percent) 35 to 41 days after treatment, but abundance returned to near-control levels after 41 days (Catangui and others, 2000). Flying insects classified as parasites included both Hymenoptera and Diptera; flying insects classified as predators included Hymenoptera, Diptera, and Coleoptera (Catangui and others, 2000).

Hemiptera showed large differences in abundance among sites, and large changes over time were observed at Grouse Creek. Some differences were correlated with treatment zone; more Hemiptera and more of particular families were found in the untreated zones in all three study areas. Smith and others (2006) found the Hemiptera had mixed responses to various treatments, but some diflubenzuron treatments did reduce Hemiptera numbers.

Within the Hemiptera, there was some indication that the Lygaeidae (seed bugs), in particular, were sensitive to diflubenzuron treatments. Lygaeidae were absent at Grouse Creek from all late May and early June samples, probably because of phenology. No seed bugs were found in any traps from treated sites during the late June collection period, but they were caught consistently, albeit at low numbers, in the untreated zone during this sampling period. The seed bugs at Grouse Creek and Ibapah showed a trend toward reduced numbers in the treated zones; differences in numbers of seed bugs between zones were significant at both study areas. There were large differences in total numbers of seed bugs at Vernon (63 in the untreated zone, 32 in the treated zone), but the differences were not significant because of high variability among sites. Seed bugs represented a relatively small component of the arthropod community at all three study areas. The

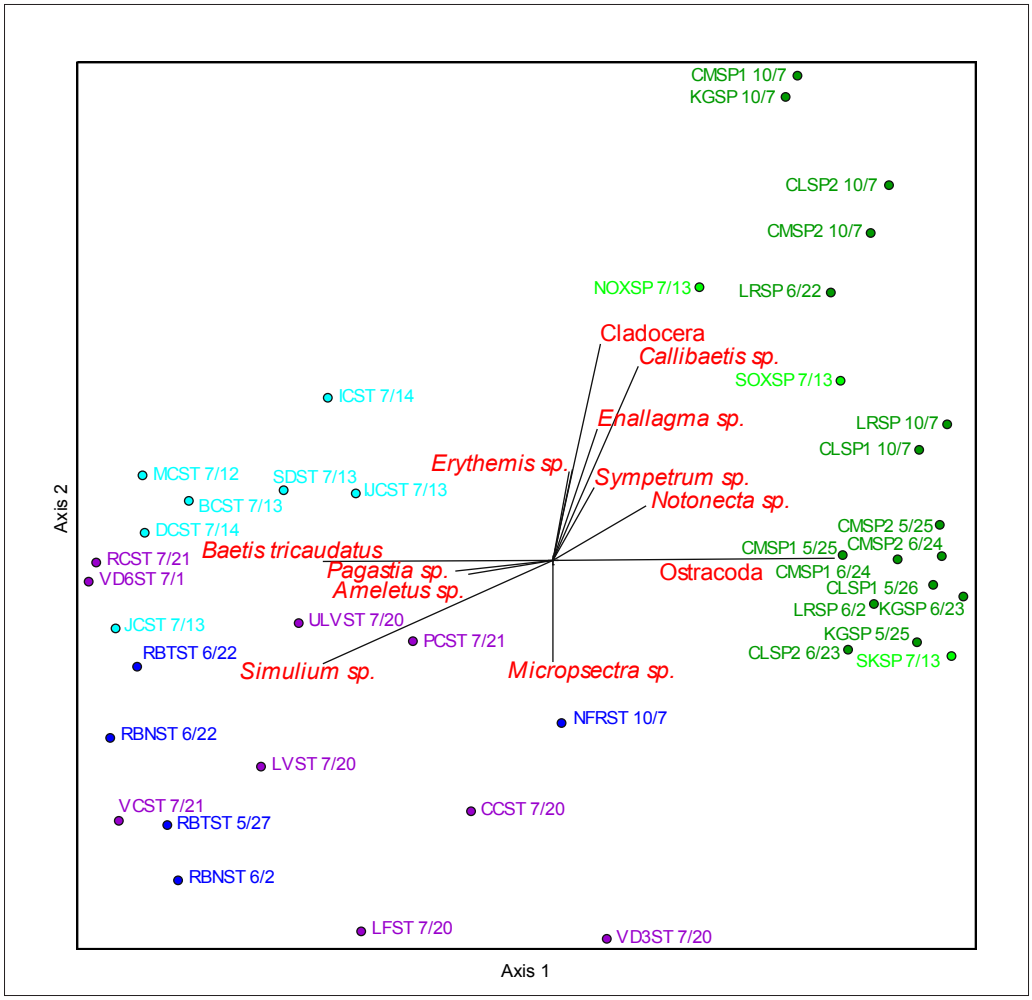

Figure 41. Nonmetric multidimensional scaling joint plot with aquatic macroinvertebrate relative taxa abundances. Dark green, Grouse Creek springs; light green, Ibapah springs; dark blue, Grouse Creek streams; light blue, Ibapah streams; purple, Vernon streams.

ecological impact of changes in Lygaeidae numbers, if they are affected by diflubenzuron, is probably relatively minor given the small population of bugs that will be affected.

Scorpions and solifugids are large, nocturnal predators that forage on the ground. Scorpions and solifugids compete for food (Polis and McCormick; 1986a, Polis and others, 1989). Polis and McCormick (1986a) found that scorpions and solifugids also prey on each other. Thus, it is not surprising to find an inverse correlation between scorpion and solifugid abundance. This correlation was seen among the untreated sites at Ibapah. The association is reversed among plots treated with diflubenzuron in 2004. The data indicate that, rather than some interaction between scorpions and solifugids in the presence of diflubenzuron, scorpions may simply be more sensitive to diflubenzuron than solifugids. There was a dramatic decline in scorpion numbers in treated sites compared to untreated sites, while solifugid abundance remained unchanged. In the 4 untreated areas, 34 solifugids were found in traps, and 40 solifugids were caught in the traps in the treated zone. Only 6 scorpions were caught within the treated zone, while 24 scorpions were trapped in the untreated zone.

Scorpion life histories may make them more susceptible to exposure to diflubenzuron. Young scorpions molt more frequently than older individuals (Polis and McCormick, 1986b); if more young individuals are present during treatment periods, the numbers could be affected. Another possibility is that scorpions' prey may have been affected more than the solifugids' prey. Thus, scorpion numbers declined, but solifugid numbers remained relatively unchanged in the treatment zone. At least one group of large, potential prey showed concomitant declines at the treated sites at Ibapah; Orthoptera were roughly one-third as abundant at treated sites as at untreated sites (62 total at the 4 treated sites compared to 172 total at the 4 untreated sites, fig. 16*H*). The relative importance of Orthoptera in scorpion and solifugid diets should be explored to test this hypothesis.

Scorpions eat solifugids and solifugids eat scorpions. In the Coachella Valley of California, Polis and McCormick (1986a) found the diet of the scorpion *Paruroctonus mesaensis* consisted of up to 14.4 percent solifugids and up to 65.4 percent intraguild prey (spiders, scorpions, and solifugids). However, in an experiment in which scorpions were removed from experimental plots and the numbers of solifugids and spiders were sampled spring and fall for 2 years, no significant increases in numbers or size of solifugids were observed in the removal plots compared to the control plots where scorpions were not removed (Polis and McCormick, 1986b). In our study, solifugid numbers did not differ in treated and untreated zones despite a fourfold difference in scorpion numbers, which is consistent with the findings of Polis and McCormick (1986b) that indicate solifugids do not show a numerical response to reduction or removal of a potential competitor/predator.

The importance of scorpions in Great Basin sagebrush communities has not been well studied, but they can be extremely abundant in some systems (Polis and McCormick, 1986a) and may play a significant role in population regulation of other arthropods in arid and semiarid ecosystems. Research is needed to clarify the impact of scorpions on the arthropod community, especially experiments in which scorpions are removed from large plots and other arthropods are monitored.

Numbers of beetles in the families Carabidae and Tenebrionidae were reduced shortly after diflubenzuron treatment (Catangui and others, 2000). Smith and others (2006) reported that tenebrionid beetles (collected in pitfall traps) and Coleoptera (collected with sweep nets) showed some differences in response to a variety of carbaryl and diflubenzuron treatments. Coleoptera collected in sweep nets had the most consistent response to diflubenzuron and carbaryl, with fewer beetles caught in all insecticide applications compared to the control plots. We found significant reductions in beetles at Vernon and markedly fewer beetles at Ibapah, indicating there may be long-term effects on beetles from diflubenzuron application in the Great Basin.

Ants and beetles are major components of sage grouse chick diets, as are many Orthoptera (Klebenow and Gray, 1968; Peterson, 1970; Pyle and Crawford, 1996; Drut and others, 1994). Few food-habit studies of sage grouse chicks have been done, and many lump invertebrates found in bird stomachs into very basic categories (for example, "beetles" or "worms"); thus, it is difficult to assess from these studies the potential effect of changes in arthropod communities from diflubenzuron application on sage grouse population dynamics. Because chicks concentrate on insects and other arthropods during the first month after hatching, even a temporary decline in numbers, such as those reported by Catangui and others (2000), could have a significant impact on sage grouse chick survival. Sample and others (1993) found that five species of songbirds in diflubenzuron-treated sites had significantly different and potentially less nutritious diets compared to songbirds in untreated sites, and two species in treated sites had significantly less invertebrate biomass in their stomachs. Whitmore and others (1993) found seven of nine bird species tested on diflubenzuron-treated plots had lower fat levels than those on untreated plots due to reductions in invertebrate prey populations, increased foraging costs, reduction in food quality, or some combination of the three. Bell and Whitmore (1997) reported lower numbers of birds of most species in plots that had been treated with diflubenzuron, and they attributed this to a reduction in habitat quality related to prey availability in treated forest plots.

Our temporal comparisons, while covering the critical insectivore phase of sage grouse chick life history (Drut and others, 1994), did not yield definitive results because of the extreme variability in sites and taxa response to diflubenzuron and the uncertainty of sage grouse chick food preferences. However, diflubenzuron application to control Orthoptera has the potential to affect sage grouse chick foraging by altering prey-species composition and/or abundance. Survival of chicks has been shown to be critical for sustainable sage grouse populations (Johnson and Boyce, 1990). Additional work is needed to clarify whether diflubenzuron affects sage grouse chick

survival and, thus, sage grouse population dynamics in areas where Mormon cricket or grasshopper control occurs.

Aquatic Study

This study provides one of the first quantitative, comprehensive assessments of aquatic invertebrates in these areas of Utah's west desert and, consequently, will provide valuable baseline data for future studies. Within the three study areas, 169 different aquatic taxa were collected, including 17 orders and 59 families. Taxa varied among study areas and between streams and springs. Crustaceans dominated springs, while mayflies (Ephemeroptera) and true flies (Diptera) dominated streams.

Although the pesticide-spraying program was specifically designed with buffers to avoid direct spraying of aquatic habitats, we included sampling of aquatic habitats and identification of aquatic macroinvertebrates as part of this study to confirm that there was no impact on the aquatic systems. In general, our results showed no significant differences in community composition, richness, or abundance between the treated and untreated zones. In some instances, it is possible that differences caused by pesticide spraying were masked by large environmental differences; and in the one case where there was a statistically significant difference between the treated and untreated zone, the results were confounded by elevational differences between the two zones.

Grouse Creek was the only study area treated in 2005. There was no significant difference in abundance or richness between sites inside and outside the treatment zones after treatment, and because water bodies were buffered (no pesticide was sprayed within about 150 m of a water body), this result is not unexpected. The initial study design called for collection of water samples to be tested for diflubenzuron but this was not possible given the timing of the first, and only, spraying at Grouse Creek. Future studies should collect and analyze water samples to confirm that the buffer zones are indeed areas that are not being sprayed.

Ibapah was sprayed in 2004 but not in 2005 (the year we sampled). Again, there was no significant difference in species abundance or richness between sites inside and outside the treatment zone. Sites outside the treatment zone at Ibapah included three springs and two streams. We were able to locate and sample only streams inside of the treatment zone. This difference in habitat type may mask a pesticide effect on abundance because the three springs (all located outside of the treatment zone) had substantially higher abundance than any of the streams.

All sampling sites at Vernon were classified as streams for this study. However, some sites were actual streams (which were buffered from spraying) and some were ditches (which were not buffered). There was no significant difference in abundance between sites inside and outside the treatment zone, even considering ditches versus streams. However, taxa richness was significantly higher in the untreated zone than the treated zone and higher in the actual streams than in the ditches. This finding may indicate an impact of pesticide spraying, but the difference in elevation confounds this interpretation. Sites at the lower elevations (treated zone) tended to be irrigation ditches, and sites at the higher elevations (untreated zone) were relatively pristine streams. This elevation gradient also represents a gradient in habitat quality, which would have an influence on community composition. The significant differences observed between treated and untreated sites at Vernon may be due to the inherent variation among the sites rather than from diflubenzuron. Nevertheless, it is possible that pesticide treatment contributed to the observed significant differences. Future studies designed to separate environmental differences between sites and treatment effects could provide a clearer assessment of the effects of diflubenzuron on aquatic communities in these areas.

Temporal phenology (change during the season) in aquatic communities also confounded our ability to detect the effects of diflubenzuron. Grouse Creek, the only study area treated in 2005, was sampled three times during this study. We sampled before treatment, 2 weeks after treatment, and 4 months after treatment. Generally, abundance and richness increased from pre-treatment samples to 2-week post-treatment samples, and decreased from 2-week post-treatment samples to 3-month post-treatment samples. Changes in abundance and richness are most likely due to natural temporal variation, whereby aquatic-invertebrate populations peak in June, and their populations decrease again with colder weather in October. Consequently, evaluation of any effects of diflubenzuron application is confounded by temporal phenology in aquatic communities. Future studies will be able to use baseline data collected during this study to separate changes in community composition associated with temporal phenology from those associated with diflubenzuron.

Conclusions

Our study design included several treated and untreated zones to facilitate statistical comparisons. Because a limited outbreak of Orthoptera occurred in 2005, only one area was treated with diflubenzuron, thus, severely limiting our ability to detect the effects of the pesticide spraying.

The effects of diflubenzuron on aquatic and terrestrial arthropod communities are not apparent in our data from Grouse Creek, the only area treated in 2005. The treatment was designed to avoid spraying pesticide on water bodies, and no measurable impacts on aquatic community composition, richness, or abundance on either springs or streams were observed, with the exception of reduced taxa richness at Vernon (a result confounded by elevational differences in the treatment and nontreatment zones). Our study did indicate that treatment with diflubenzuron was correlated with changes in abundance for some terrestrial taxa, notably some ant genera, the Lygaeidae (Hemiptera), non-ant Hymenoptera, beetles (Coleoptera), and scorpions (Scorpiones).

Important ecosystem functions (for example, seed predation and pollination) are performed by the arthropods showing reduced abundance during this study, and, thus, ecological function could be adversely affected by declines caused by diflubenzuron application. Many of these taxa are used by sage grouse chicks at a critical stage in their development; sustainability of sage grouse populations could be indirectly affected by use of diflubenzuron in sage grouse brood habitat. Differences between sprayed and unsprayed zones were greater at Ibapah and Vernon when sampled a year after diflubenzuron application, suggesting that the effect may lag behind application. Although direct effects may still occur, the potential for indirect effects increases greatly. Differences in abundance may not be observed at higher taxonomic levels (for example, order or family) for some taxa; thus, work to evaluate the effects of diflubenzuron on nontarget arthropods should include identification of arthropods to at least family, and for ecologically or taxonomically diverse groups (for example, ants), identification should be to genus and species when possible.

Although few apparent short-term effects of diflubenzuron on terrestrial arthropods at Grouse Creek were observed that were statistically significant, mean abundances of some taxa at Ibapah and Vernon were significantly different at untreated sites than at sites treated with diflubenzuron the previous year, and nearly significant differences were observed at all three study areas. The same taxa differed over several study areas. Sometimes the differences were statistically significant and sometimes they were not. These taxa, which included Coleoptera, Diptera, Hemiptera, non-ant Hymenoptera, Lepidoptera, Orthoptera, and Scorpiones, may be more susceptible to diflubenzuron. Additional research targeting these taxa would be informative. Funding should be sought to identify specimens of the taxa collected in this study to the lowest taxonomic level possible (at least to genus, preferably to species). This finer resolution may show which taxa are actually affected by pesticide spraying. For example, the mean number of ants (as a group) did not differ for any comparison of the treated and untreated zones, but there were significant differences for some genera. The same could be true for Coleoptera, Diptera, or other taxa.

In the aquatic community analyses, species composition, richness, and abundance were highly variable among sites. This high variability, combined with the fact that only one pesticide treatment had occurred in only one area, made it difficult to assess treatment effects. Replicate sampling within sites or an increase in the number of sampled sites could reduce this variability. Because it may be difficult to add more sites (we sampled at all of the water bodies we could find), additional habitat characterization could allow for better comparisons among similar groups of sites.

To determine whether diflubenzuron application caused the observed differences in either terrestrial or aquatic arthropod communities, a study should be designed to control for environmental differences. Ideally, an area where Mormon cricket-control is judged to be needed should be divided into randomly assigned treatment and nontreatment blocks and sampled extensively the year prior to treatment to provide quantitative baseline data. Sampling should also occur just before treatment and at several intervals after treatment from about 3 weeks to at least 18 months.

Control efforts will continue to affect nontarget arthropods as long as diflubenzuron is the insecticide of choice; the current application methods are likely the most effective for Orthoptera control and do not lend themselves to avoiding particular patches in the treated areas. Although additional research is needed to clarify the suspected relationships identified in this study, we recognize that efforts to control Orthoptera on rangelands in the Intermountain West will continue. We suggest that the potential impacts of diflubenzuron treatment discussed here be considered in future decisions regarding control efforts. The value of Orthopteran population control must be weighed against the potential direct and indirect effects on ecosystem structure and functioning that may result from changes in arthropod community structure through shifts in sensitive taxa.

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Appendix A: Terrestrial Taxa Collected—Total Number of Arthropods Caught During Each Sampling Event at Each Site

Table A1a. Number of arthropods, by order, captured at each site in the untreated area at Grouse Creek, before and after treatment.

	GC U01 pre-treatment	GC U01 post-treatment	GC U05 pre-treatment	GC U05 post-treatment	GC U06 pre-treatment	GC U06 post-treatment	GC U11 pre-treatment	GC U11 post-treatment
Coleoptera	162	516	181	355	84	333	29	76
Diptera	400	1,220	626	240	352	303	457	549
Hemiptera	233	8,581	404	34,856	262	1,420	88	410
Formicidae	173	453	151	150	602	786	456	869
non-ant Hymenoptera	115	669	123	240	70	197	44	200
Lepidoptera	64	33	114	37	12	25	23	95
Mantodea								
Neuroptera	13			1			1	5
Orthoptera	1	18	12	20	34	73	36	381
Microcoryphia	6	3				1		19
Trichoptera	1	1						1
Araneae	61	139	85	144	86	205	88	325
Scorpiones	2	16			6	14		13
Solifugae								
Pseudoscorpiones								
Chilopoda		1					2	2
Diplopoda								
Total arthropods	1,231	11,650	1,696	36,043	1,508	3,357	1,224	2,945

Table A1b. Number of arthropods, by order, captured at each site in the treated area at Grouse Creek, before and after treatment.

	GC T03 pre-treatment	GC T03 post-treatment	GC T04 pre-treatment	GC T04 post-treatment	GC T05 pre-treatment	GC T05 post-treatment	GC T06 pre-treatment	GC T06 post-treatment
Coleoptera	25	80	93	114	88	65	34	100
Diptera	230	161	314	747	858	204	83	223
Hemiptera	671	1,268	295	2,264	676	914	407	1,401
Formicidae	276	351	381	597	407	408	134	334
non-ant Hymenoptera	21	76	42	121	33	52	48	103
Lepidoptera	23	16		53		7	18	43
Mantodea	1	1						1
Neuroptera	1	3	1	3			9	6
Orthoptera	48	57	133	22	79	27	42	53
Microcoryphia	1							12
Trichoptera	1			1			2	
Araneae	56	73	36	120	118	91	76	206
Scorpiones	2	2		4	2	6		1
Solifugae						1		
Pseudoscorpiones								1
Chilopoda	1			2		1		1
Diplopoda								
Total arthropods	1,357	2,088	1,295	4,048	2,261	1,776	853	2,485

Table A1c. Number of arthropods, by order, captured at each site in Ibapah.

	IB U03 untreated	IB U06 untreated	IB U08 untreated	IB U09 untreated	IB T13 treated	IB T19 treated	IB T21 treated	IB T22 treated
Coleoptera	52	62	64	31	33	50	31	26
Diptera	155	246	206	96	130	90	128	125
Hemiptera	632	428	10,289	429	2,287	414	638	298
Formicidae	525	868	452	825	631	823	841	773
non-ant Hymenoptera	28	46	27	58	67	54	61	100
Lepidoptera	39	37	13	35	16	17	20	25
Mantodea	1	1			1		2	
Neuroptera	4						1	
Orthoptera	40	42	22	68	29	9	7	17
Microcoryphia								219
Trichoptera								
Araneae	72	177	76	66	148	148	95	143
Scorpiones	3	4	9	8	3	1	2	
Solifugae	19	11	1	3	12	8	15	5
Pseudoscorpiones	1	2		3		2		
Chilopoda								
Diplopoda								
Total arthropods	1,571	1,924	11,159	1,622	3,357	1,616	1,841	1,731

Table A1d. Number of arthropods, by order, captured at each site in Vernon.

	VE U08 untreated	VE U09 untreated	VE U19 untreated	VE U20 untreated	VE T01 treated	VE T03 treated	VE T06 treated	VE T08 treated
Coleoptera	198	154	99	110	36	46	53	36
Diptera	336	310	220	397	253	129	117	110
Hemiptera	1,326	1,516	1,162	598	397	453	978	366
Formicidae	870	963	1,679	2,826	1,148	610	2,306	418
non-ant Hymenoptera	580	406	261	355	270	222	137	146
Lepidoptera	49	14	25	28	12	3	17	9
Mantodea	4	3	1	1			1	
Neuroptera		1		2			1	
Orthoptera		18	8	4		1	5	
Microcoryphia	12				6			
Trichoptera				1				
Araneae	127	173	107	65	128	68	84	60
Scorpiones			1					
Solifugae		4				1		
Pseudoscorpiones		1	3				4	4
Chilopoda								
Diplopoda		1,107		2				
Total arthropods	3,504	4,670	3,566	4,389	2,256	1,533	3,703	1,162

Table A2. Total numbers of ants by genus collected in pitfall traps at each site and sampling event in the three study areas.

Ants	*Aphaenogaster*	*Camponotus*	*Cardiocondyla*	*Crematogaster*	*Forelius*	*Formica*	*Lasius*	*Leptothorax*	*Messor*	*Monomorium*	*Myrmecocystus*	*Myrmica*	*Pheidole*	*Pogonomyrmex*	*Polyergus*	*Prionopelta*	*Solenopsis*	*Tapinoma*	Totals
GC U01pre						72								91			6	3	172
GC U05pre						138		6						1				5	150
GC U06pre						200	123	165	1		8			93			2		592
GC U11pre	19	6			20	285		47				2	36	25			16		456
GC T03pre			1	18	164	1		18			1		41	3			28		275
GC T04pre	3	16				139	53	88			7	17		51	4		1		379
GC T05pre	4	5				47	56	78			5		67	21			119	2	404
GC T06pre		5			2	88	1	34				1					2		133
GC U01post						155		1						270			25	1	452
GC U05post						118		17						10		1	1	2	149
GC U06post						380	88	77			12	6	10	182	2		27		784
GC U11post	18	64			127	310		102			1	1	112	73		2	56		866
GC T03post	1			42	101	1		24	1		2		120	7			51		350
GC T04post		19				189	69	120			1	11		169	1		10	1	590
GC T05post	6	12				37	55	25			5		118	118			28	4	408
GC T06post		16				215		82			3	13		6			6		341
IB U03		27			1	34		107					15				33	44	261
IB U06						279	2	44			1	81		1			2	448	858
IB U08		2			2	212		44				11		18			8	43	340
IB U09		2			541	11		78					42				1	112	787
IB T13		57			250	71		37				50	117				7	20	609
IB T19		1		42	527	24		14				25	112	7	1		10	1	764
IB T21		46			322	12	2	16				28	3	95			20	3	547
IB T22	56	7	5	108	297	51		34					25	154	1		5		743
VE U08	5	9				48	15	81		144		37	169				105	253	866
VE U09	37	78				315		121		196			141				45	29	962
VE U19		25				125	57	22		592	1	460	4	29			42	315	1,672

Table A2. Total numbers of ants by genus collected in pitfall traps at each site and sampling event in the three study areas—Continued.

Ants	*Aphaenogaster*	*Camponotus*	*Cardiocondyla*	*Crematogaster*	*Forelius*	*Formica*	*Lasius*	*Leptothorax*	*Messor*	*Monomorium*	*Myrmecocystus*	*Myrmica*	*Pheidole*	*Pogonomyrmex*	*Polyergus*	*Prionopelta*	*Solenopsis*	*Tapinoma*	Totals
VE U20	80	26			1	2,212	8	357		123							6		2,813
VE T01	39	5			448	345		22		108			137	14			22		1,140
VE T03		2			66			86		386		21	12				32		605
VE T06	26	5			1,723			13		344			87				46		2,244
VE T08		20			2	51		60		205		8	61				2		409
Totals	294	455	6	210	4,594	6,165	529	2,020	2	2,098	47	772	1,429	1,438	9	3	764	1,286	22,121

Table A3. Total numbers of Hemiptera by family collected in pitfall traps at each site and sampling event in the three study areas.

	Alydidae	Aphididae	Berytidae	Cercopidae	Cicadellidae	Cydnidae	Delphacidae	Dictyopharidae	Fulgoridae	Geocoridae	Lygaeidae	Miridae	Nabidae	Pentatomidae	Phylloxeridae	Piesmatidae	Psyllidae	Reduviidae	Rhopalidae	Tingidae	Totals
GC U01pre		16			192							29									237
GC U05pre	83	2		2	126							174	1				1		2		391
GC U06pre	4	5			152			4				17					1				183
GC U11pre		35			77			7		2			2								123
GC U01post	4,485	53		28	767			3	13		19	2,470	1	1			11			1	7,852
GC U05post	35,852	40		3	2,349						1	450	15			1					38,711
GC U06post	3	9		1	749			1			2	66	1	1			1				834
GC U11post		36		1	147			1		1	1	24	7	1			2				221
GC T03pre	2	24		73	979							4					4				1,086
GC T04pre		59			462			28									3				552
GC T05pre		13			610	3		25				4					5				660
GC T06pre		45			515			22				24	2		4		9				621
GC T03post		25		3	1,149			9		1		40	5								1,232
GC T04post	3	65		4	1,143			9				27	4				15				1,270
GC T05post	11	12	1		909			2	1			25	5				1				967
GC T06post	11	7		7	734	2		4	1	1		51	3				3	5			829
IB U03	29	8		27	510			17			4	21	13					1			630
IB U06	24			4	371			12			4	7	4								426
IB U08	3,958				612			1			5		5					1			4,582
IB U09	29				391			10			2	6	5								443
IB T13	2,006			8	245			16				5	6	1							2,287
IB T19	11			27	372			1				1	1								413
IB T21	7			4	614			3			1	2	1								632
IB T22	20			21	240			2			1	8	4								296
VE U08	29	3		21	971					3	23	21	33								1,104
VE U09		50		6	1,458												2				1,516
VE U19	69				14					55	55	221	689								1,103

Table A3. Total numbers of Hemiptera by family collected in pitfall traps at each site and sampling event in the three study areas—Continued.

	Alydidae	Aphididae	Berytidae	Cercopidae	Cicadellidae	Cydnidae	Delphacidae	Dictyopharidae	Fulgoridae	Geocoridae	Lygaeidae	Miridae	Nabidae	Pentatomidae	Phylloxeridae	Piesmatidae	Psyllidae	Reduviidae	Rhopalidae	Tingidae	Totals
VE U20	10	71	2	4	412						5	25	48				4		1		582
VE T01	6	7		3	324				5		6	12	15					1		3	382
VE T03	17	5			422													1			445
VE T06		19			1,659		2		11		35		8				125				1,859
VE T08	12	10		4	317			4			2	6	6				4				365
Totals	46,681	619	3	251	19,992	5	2	181	31	63	166	3,740	884	4	4	1	191	9	3	4	72,834

Appendix B: Aquatic Taxa Collected

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
MOORE	Annelida	Clitellata	Arhynchobdellida	Erpobdelliformes	Erpobdellidae		*Mooreobdella* sp.
ERPOB						Erpobdellinae	*Erpobdella* sp.
ENCHY			Haplotaxida		Enchytraeidae		
NAIDI					Naididae		
TUBIF					Tubificidae		
HELOB			Rhynchobdellida		Glossiphoniidae	Haementeriinae	*Helobdella stagnalis*
PISID	Mollusca	Bivalvia	Veneroida		Pisidiidae		
LYMNA		Gastropoda	Basommatophora		Lymnaeidae		
FOSSA							*Fossaria* sp.
STAGN							*Stagnicola* sp.
PHYSA					Physidae		*Physa* sp.
GYRAU					Planorbidae		*Gyraulus* sp.
FLUMI			Neotaenioglossa		Hydrobiidae		*Fluminicola* sp.
NEMAT	Nematoda						
TURBE	Platyhelminthes	Turbellaria					
POLYC			Tricladida		Planariidae		*Polycelis coronata*
TROMB	Arthropoda	Arachnida	Trombidiformes				
CLADOC		Branchiopoda	Diplostraca	Cladocera			
GAMMA		Malacostraca	Amphipoda		Gammaridae		*Gammarus* sp.
HYALE					Talitridae		*Hyalella* sp.
COPEP		Maxillopoda/ Copepoda					
OSTRA		Ostracoda					
CAENI		Insecta	Ephemeroptera	Furcatergalia	Caenidae		*Caenis* sp.
DRUNE					Ephemerellidae		*Drunella* sp.
DRUGR							*Drunella grandis*
INERM							*Ephemerella inermis*
SERRAT						Ephemerellinae	*Serratella tibialis*
PARAL				Schistonota	Leptophlebiidae		*Paraleptophlebia* sp.
SIPHLO					Siphlonuridae		
AMELE				Pisciforma	Ameletidae		*Ameletus* sp.
ACENT					Baetidae		*Acentrella* sp.

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
BAETI							*Baetis tricaudatus*
CALLI							*Callibaetis* sp.
CENTR							*Centroptilum* sp.
DIPHE							*Diphetor hageni*
CINYG				Setisura	Heptageniidae		*Cinygmula* sp.
EGRAND							*Epeorus grandis*
EDECEPT							*Epeorus deceptivus*
ELONGIM							*Epeorus longimanus*
AESHN			Odonata	Anisoptera	Aeshnidae		
AESHNSP							*Aeshna* sp.
ANAXSP							*Anax* sp.
LIBEL					Libellulidae		
ERYTHEM							*Erythemis* sp.
LIBELSP							*Libellula* sp.
SYMPE							*Sympetrum* sp.
HETAER				Zygoptera	Calopterygidae		*Hetaerina* sp.
COENAGR					Coenagrionidae		
AMPHIAG							*Amphiagrion* sp.
ENALLAG							*Enallagma* sp.
LESTES					Lestidae		*Lestes* sp.
CAPNII			Plecoptera	Euholognatha	Capniidae		
NEMOU					Nemouridae		
MALENKA	.					Amphinemurinae	*Malenka* sp.
ZAPAD						Nemourinae	*Zapada* sp.
ZAPACI							*Zapada cinctipes*
ZAPACOL							*Zapada columbiana*
ZAPAOR							*Zapada oregonensis*
TAENIOP					Taeniopterygidae	Taeniopteryginae	*Taeniopteryx* sp.
CHLORO				Systellognatha	Chloroperlidae		
ISOPER					Perlodidae	Isoperlinae	*Isoperla* sp.
PTERON					Pteronarcyidae	Pteronarcyinae	*Pteronarcella* sp.
CORIXID			Heteroptera		Corixidae		
CENOCOR							*Cenocorixa* sp.

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
HCORIXA						Corixinae	*Hesperocorixa* sp.
SIGARAS							*Sigara* sp.
NOTONE					Notonectidae		*Notonecta* sp.
HPSYCHI			Trichoptera	Annulipalpia	Hydropsychidae		
HPSYCSP						Hydropsychinae	*Hydropsyche* sp.
AMIOCE				Integripalpia	Brachycentridae		*Amiocentrus aspilus*
BRACHYC							*Brachycentrus americanus*
MICRAS							*Micrasema* sp.
LEPIDO					Lepidostomatidae	Lepidostomatinae	*Lepidostoma* sp.
LEPTO					Leptoceridae		
YLODE							*Ylodes* sp.
LIMNE					Limnephilidae		
ECCLISO					Limnephilidae	Dicosmoecinae	*Ecclisomyia* sp.
PHILAR						Limnephilinae	*Philarctus quaeris*
HESPER							*Hesperophylax* sp.
LIMNEP							*Limnephilus* sp.
HPTILID				Spicipalpia	Hydroptilidae		
HPTILSP						Hydroptilinae	*Hydroptila* sp.
OCHROT							*Ochrotrichia* sp.
RHYACO					Rhyacophilidae		*Rhyacophila* sp.
DYTISCI			Coleoptera	Adephaga	Dytiscidae		
AGABU							*Agabus* sp.
COLYMB							*Colymbetes* sp.
RHANTU							*Rhantus* sp.
LIODESS							*Liodessus* sp.
HYGROTU							*Hygrotus* sp.
STICTOT							*Stictotarsus* sp.
LACCOPH							*Laccophilus* sp.
PELTODY					Haliplidae		*Peltodytes* sp.
CLEPTEL				Polyphaga	Elmidae		*Cleptelmis* sp.
OPTIOSE							*Optioservus* sp.
OCHTHEB					Hydraenidae		*Ochthebius* sp.

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
HPHILID					Hydrophilidae		
HYBIUS							*Hydrobius* sp.
LACCOB							*Laccobius* sp.
TROPIST							*Tropisternus* sp.
AGATH			Diptera	Nematocera	Blephariceridae	Blepharicerinae	*Agathon* sp.
CERATOP					Ceratopogonidae	Ceratopogoninae	
APEDILU					Chironomidae	Chironomini	*Apedilum* sp.
CHIRONO							*Chironomus* sp.
PARACHI							*Parachironomus* sp.
PARACLA							*Paracladopelma* sp.
PARATEN							*Paratendipes* sp.
PHAENOP							*Phaenopsectra* sp.
POLYPED							*Polypedilum* sp.
PSEUDOC						Pseudochironomini	*Pseudochironomus* sp.
TARSINI						Tanytarsini	
CLADOT							*Cladotanytarsus* sp.
MICROPS							*Micropsectra* sp.
RHEOTAN							*Rheotanytarsus* sp.
STEMPEL							*Stempellinella* sp.
TANYTAR							*Tanytarsus* sp.
PAGAS						Diamesinae	*Pagastia* sp.
IAMESA							*Pseudodiamesa* sp.
DIAMES							*Diamesa* sp.
ACRICOT						Orthocladiinae	*Acricotopus* sp.
BRILLIA							*Brillia* sp.
CHAETOC							*Chaetocladius* sp.
CORYNON							*Corynoneura* sp.
CRICOTO							*Cricotopus (Cricotopus)*
ISOCLAD							*Cricotopus (Isocladius)*
EUKBREH							*Eukiefferiella brehmi* gr.
EUKDEVO							*Eukiefferiella devonica* gr.
EUKGRAC							*Eukiefferiella gracei* gr.

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
EUKCLAR							*Eukiefferiella claripennis* gr.
LIMNOP							*Limnophyes* sp.
ORTHOC							*Orthocladius* sp.
PARAKI							*Parakiefferiella* sp.
PARAME							*Parametriocnemus* sp.
PARAPH							*Paraphaenocladius* sp.
PSECTRC							*Psectrocladius* sp.
PSEUDOS							*Pseudosmittia* sp.
RHEOCRI							*Rheocricotopus* sp.
THIENEM							*Thienemanniella* sp.
TVETE							*Tvetenia bavarica* gr.
METRIOC							*Metriocnemus* sp.
PAROC						Podonominae	*Parochlus* sp.
ODONTO						Prodiamesinae	*Odontomesa* sp.
PRODIA							*Prodiamesa* sp.
TANYPOD						Tanypodinae	
APSECTR							*Apsectrotanypus* sp.
PSECTRT							*Psectrotanypus* sp.
RADOTA							*Radotanypus* sp.
PENTA							*Pentaneura* sp.
NIMYIA							*Thienemannimyia* gr.
ZAVRELI							*Zavrelimyia* sp.
TANYPUS							*Tanypus* sp.
CULICI					Culicidae		
DIXID					Dixidae		
DIXASP							*Dixa* sp.
MERINGO							*Meringodixa* sp.
PSYCHOD					Psychodidae		
PROSIMU					Simuliidae		*Prosimulium* sp.
SIMULIU							*Simulium* sp.
MOLOPH					Tipulidae	Limoniinae	*Molophilus* sp.
PEDICI							*Pedicia* sp.

Code	Phylum	Class	Order	Suborder	Family	Subfamily/tribe	Genus/species
DICRAN							*Dicranota* sp.
TIPULA						Tipulinae	*Tipula* sp.
DOLICHO				Brachycera	Dolichopodidae		
EMPIDI					Empididae		
NEOPLAS							*Neoplasta* sp.
CLINOCE							*Clinocera* sp.
EPHYDR					Ephydridae		
MUSCIDA					Muscidae		
SCIOMYZ					Sciomyzidae		

Grouse Creek sites

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP			RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
MOORE																					
ERPOB																					
ENCHY	90								15			30	10				30	20			
NAIDI													90				180	390			
TUBIF	1,185	1,484	70	1,395	40	20	7		30			8		5	320		960	330			
HELOB																					
PISID					20						6										
LYMNA	15	32		15					75								30				
FOSSA							14							1				10			
STAGN			10		80			48		110			30						26		
PHYSA																					
GYRAU																			90		
FLUMI	315			15	680	80															
NEMAT	60										11	8	10	13			615	130			
TURBE							5			5											
POLYC																					
TROMB										5		15	10							10	
CLADOC	60	63	1,820	90	100	1,070	58		15	240		8	5			7,306	45	1150	32	10	
GAMMA																					
HYALE	15				20								10								
COPEP			10		40		14	72	180			8	165								
OSTRA	2,235	6,821	110	2,715	4,560	630	595	243	2,310	230	6		35	150	2,620	671	2,655	700	276	20	
CAENI			10			10															
DRUNE												60									5
DRUGR													30								
INERM											11	98	10							50	48
SERRAT											6										
PARAL																					
SIPHLO																				10	
AMELE											29	30								10	

Grouse Creek sites—Continued.

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP		RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
ACENT											217	195								212	21
BAETI								2			109	773									380
CALLI	30	411	820	30	340	1,010		88	225	875	6		160			2,718		10	105		
CENTR																				268	16
DIPHE																					
CINYG											11										
EGRAND																					
EDECEPT																					
ELONGIM												8									
AESHN																		10			
AESHNSP		32	20		20																
ANAXSP						10													4		
LIBEL	15								45									20	6		
ERYTHEM			60		20	35															
LIBELSP		32																			
SYMPE		32		15		35										35					
HETAER																					
COENAGR									30												
AMPHIAG	15			15	60			20								71			11		
ENALLAG	15	189	110	30	40	220				145						282			15		
LESTES																					
CAPNII													5								
NEMOU												30									
MALENKA																					
ZAPAD																					
ZAPACI													60								5
ZAPACOL																					
ZAPAOR																					
TAENIOP												15									
CHLORO											6										

Grouse Creek sites—Continued.

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP			RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
ISOPER																					
PTERON																					
CORIXID	15	95			200				45								15	60			
CENOCOR								2													
HCORIXA			20			10									30	35					
SIGARAS										5											
NOTONE	15	32	10	120	20	10		7		5					20	35		60	2		
HPSYCHI																					
HPSYCSP												8									
AMIOCE											11	8								10	
BRACHYC																					
MICRAS																					
LEPIDO																					
LEPTO											6										
YLODE												8								20	
LIMNE			10			10		2													
ECCLISO																					
PHILAR												8									
HESPER												8									
LEPHILU													20								
HPTILID																				10	
HPTILSP																					
OCHROT																					5
RHYACO																					
DYTISCI		63					7		105		6			14							11
AGABU			20		50								5								
COLYMB																35					
RHANTU			20					7		5			10			35	15	30	2		
LIODESS																					
HYGROTU																					

Grouse Creek sites—Continued.

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP			RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
STICTOT												30	10		40						
LACCOPH				15	50			2		5			5			71					
PELTODY		32			40																
CLEPTEL																					
OPTIOSE													10								
OCHTHEB													10								
HPHILID																		10			
HYBIUS															20						
LACCOB													10				15				
TROPIST		63	10			10								1							
AGATH											6										
CERATOP	30			45								8								20	
APEDILU	15					10	2	5	459	8	6		77	3		318					
CHIRONO	15			62		10			126						110		60	10			
PARACHI																					
PARACLA																					
PARATEN																				11	
PHAENOP													41								
POLYPED						10														33	
PSEUDOC	45	411	257	109	400	40				17						35					
TARSINI								2										10			
CLADOT																					
MICROPS	135	474		31			14		1,123		12		429	2		35	195		4	22	
RHEOTAN											6		5							11	
STEMPEL												20									
TANYTAR											12	10	47							65	
PAGAS											6		5								6
IAMESA																					
DIAMES											54	79								76	
ACRICOT	385			117						17									30		

Grouse Creek sites—Continued.

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP			RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
BRILLIA																				11	
CHAETOC							38	11	32					40	40		45	25			
CORYNON			82			230							36			35		25			
CRICOTO													7								
ISOCLAD	35							6													
EUKBREH																					6
EUKDEVO																					
EUKGRAC																					
EUKCLAR																					
LIMNOP			10	17		20							14								
ORTHOC											42	20	121			35				282	133
PARAKI																					
PARAME													78								
PARAPH											6										
PSECTRC	105			100	60			15	16	8						35			2		
PSEUDOS																	15				
RHEOCRI																					
THIENEM																					
TVETE								2				30	14								11
METRIOC								2													
PAROC																					
ODONTO																					
PRODIA																					
TANYPOD																35					
ASPECTR																					
PSECTRT																					
RADOTA																					
PENTA												20									
NIMYIA					20							10	10								
ZAVRELI		95																			
TANYPUS																					

Grouse Creek sites—Continued.

	CMSP1			CMSP2			CLSP1		CLSP2		RBTST		NFRST	KGSP			LRSP			RBNST	
Code	5/25	6/24	10/7	5/25	6/24	10/7	5/26	10/6	6/23	10/6	5/27	6/22	10/7	5/25	6/23	10/7	6/2	6/22	10/7	6/2	6/22
CULICI							19														
DIXID																					
DIXASP																					
MERINGO												8									
PSYCHOD							2														
PROSIMU											223	9								141	38
SIMULIU											1,074	958	40			35				1,869	1,103
MOLOPH																					
PEDICI																					
DICRAN																					
TIPULA													10								
DOLICHO							5							5							
EMPIDI																					
NEOPLAS																					
CLINOCE														2							
EPHYDR												8	10	20							5
MUSCIDA												8	30		10						11
SCIOMYZ							2														

Ibapah sites

Code	MCST 7/12	SDST 7/13	JCST 7/13	IJCST 7/13	ICST 7/14	NOXSP 7/13	SOXSP 7/13	SKSP 7/13	BCST 7/13	DCST 7/14
MOORE						30				
ERPOB								86		
ENCHY	60	47							9	52
NAIDI										
TUBIF				140	55	435	450			6
HELOB		4								
PISID		176		21		60	60			
LYMNA										
FOSSA										
STAGN						15				
PHYSA						555	300	857		
GYRAU	8					210				
FLUMI								1,971		
NEMAT	8	103		181	65	15	30		1	
TURBE										
POLYC										
TROMB		4			10	105			2	6
CLADOC						270	540			
GAMMA								943		
HYALE						825	360			
MAXIL						120	360	600		
OSTRA		26		36	30	315	2,850	21,086	4	
CAENI										
DRUNE										
DRUGR	143	9	23	5	5				5	
INERM										
SERRAT										
PARAL										
SIPHLO										
AMELE	23	4	2	5	5					
ACENT										
BAETI	615	459	201	403	365				196	474
CALLI						585	2,190			
CENTR	8	9							5	
DIPHE		9		5					3	
CINYG										
EGRAND					60					
EDECEPT					5					
ELONGIM	338	9	41	26	75					
AESHN										

Ibapah sites—Continued.

Code	MCST 7/12	SDST 7/13	JCST 7/13	IJCST 7/13	ICST 7/14	NOXSP 7/13	SOXSP 7/13	SKSP 7/13	BCST 7/13	DCST 7/14
AESHNSP										
ANAXSP										
LIBEL										
ERYTHEM										
LIBELSP										
SYMPE						15	30			
HETAER							30			
COENAGR										
AMPHIAG										
ENALLAG						780	810			
LESTES						15				
CAPNII										
NEMOU										
MALENKA			2		5				1	
ZAPAD										
ZAPACI										
ZAPACOL										
ZAPAOR										
TAENIOP										
CHLORO										
ISOPER										
PTERON										
CORIXID										
CENOCOR										
HCORIXA							240			
SIGARAS						105	240			
NOTONE					5	15	90			
HPSYCHI			2							
HPSYCSP				10	5					
AMIOCE										
BRACHYC			3							
MICRAS	285		5						1	
LEPIDO										
LEPTO										
YLODE										
LIMNE										
ECCLISO	8		2							
PHILAR										
HESPER										
LEPHILU								171		
HPTILID										

Ibapah sites—Continued.

Code	MCST 7/12	SDST 7/13	JCST 7/13	IJCST 7/13	ICST 7/14	NOXSP 7/13	SOXSP 7/13	SKSP 7/13	BCST 7/13	DCST 7/14
HPTILSP		4		31	5					9
OCHROT	8								3	
RHYACO										
DYTISCI		47	11	5		75				
AGABU	53				10					
COLYMB										
RHANTU										
LIODESS							150			34
HYGROTU									4	
STICTOT									12	
LACCOPH										
PELTODY										
CLEPTEL										
OPTIOSE					15					
OCHTHEB										
HPHILID		4		10						
HYBIUS										
LACCOB										
TROPIST										
AGATH										
CERATOP	15		2		5	45			1	
APEDILU	8					46	90			3
CHIRONO										
PARACHI										
PARACLA										
PARATEN					16					
PHAENOP									1	3
POLYPED								86		
PSEUDOC						46				
TARSINI										
CLADOT	8									
MICROPS	8	10		17		309	120	343	1	
RHEOTAN										
STEMPEL										
TANYTAR										
PAGAS	16	15	5	6	5					17
IAMESA										
DIAMES										
ACRICOT							103			
BRILLIA										
CHAETOC										

Ibapah sites—Continued.

Code	MCST 7/12	SDST 7/13	JCST 7/13	IJCST 7/13	ICST 7/14	NOXSP 7/13	SOXSP 7/13	SKSP 7/13	BCST 7/13	DCST 7/14
CORYNON							34			
CRICOTO										3
ISOCLAD										
EUKBREH	39	20	5	91	5				1	30
EUKDEVO		5								
EUKGRAC					71					
EUKCLAR	31	5		12						3
LIMNOP					11					
ORTHOC	24	40	10	193	5		34		2	
PARAKI										
PARAME										
PARAPH										
PSECTRC							69			
PSEUDOS										
RHEOCRI										
THIENEM	71				5			171		
TVETE	401	227	5	326	666				27	177
METRIOC								1,029		
PAROC										
ODONTO	39		5		11					
PRODIA										
TANYPOD										
ASPECTR		5								
PSECTRT							240			
RADOTA				6				86	2	
PENTA	8				8					
NIMYIA		10		11	25				1	
ZAVRELI			10			108				
TANYPUS										3
CULICI						15	150			
DIXID							30			
DIXASP										
MERINGO										
PSYCHOD										
PROSIMU									2	
SIMULIU	323	90	187	83	30				34	182
MOLOPH		9		5						
PEDICI										
DICRAN										
TIPULA										
DOLICHO										

Ibapah sites—Continued.

Code	MCST 7/12	SDST 7/13	JCST 7/13	IJCST 7/13	ICST 7/14	NOXSP 7/13	SOXSP 7/13	SKSP 7/13	BCST 7/13	DCST 7/14
EMPIDI			3							
NEOPLAS										
CLINOCE				5						
EPHYDR										
MUSCIDA	8	9			5				2	3
SCIOMYZ							30			

Vernon sites

Code	VD3ST 7/20	RCST 7/21	VCST 7/21	VD6ST 7/21	CCST 7/20	LFST 7/20	LVST 7/20	ULVST 7/20	PCST 7/20
MOORE			38				60		
ERPOB									
ENCHY		33		90	150				
NAIDI	18				30	60			
TUBIF	18				90			60	
HELOB									
PISID					450		15	38	480
LYMNA									
FOSSA								8	
STAGN	6								
PHYSA	6								
GYRAU									
FLUMI				30	4,140		30	210	600
NEMAT	66		19		90		30	8	
TURBE					510				120
POLYC								113	
TROMB		11	113		60		180	23	60
CLADOC									
GAMMA								75	
HYALE					210				840
MAXIL	12								60
OSTRA	60		19		180		15		1,440
CAENI									
DRUNE									
DRUGR									
INERM			56		30		435	135	
SERRAT									
PARAL								8	
SIPHLO									
AMELE									
ACENT									

Vernon sites—Continued.

Code	VD3ST 7/20	RCST 7/21	VCST 7/21	VD6ST 7/21	CCST 7/20	LFST 7/20	LVST 7/20	ULVST 7/20	PCST 7/20
BAETI		2,182	300	6,480	960	1,860	225	458	2,040
CALLI	12								
CENTR									
DIPHE					60			23	120
CINYG									
EGRAND									
EDECEPT									
ELONGIM									
AESHN									
AESHNSP									
ANAXSP									
LIBEL									
ERYTHEM									
LIBELSP									
SYMPE									
HETAER									
COENAGR									
AMPHIAG									
ENALLAG									
LESTES									
CAPNII									
NEMOU									
MALENKA									
ZAPAD	6								
ZAPACI		524	19	210	660		270	45	480
ZAPACOL						180			
ZAPAOR						60			
TAENIOP									
CHLORO									
ISOPER			38		60		30	8	
PTERON								15	
CORIXID	84								
CENOCOR									
HCORIXA									
SIGARAS									
NOTONE									
HPSYCHI									
HPSYCSP			75				75	38	
AMIOCE									
BRACHYC									
MICRAS									

Vernon sites—Continued.

Code	VD3ST 7/20	RCST 7/21	VCST 7/21	VD6ST 7/21	CCST 7/20	LFST 7/20	LVST 7/20	ULVST 7/20	PCST 7/20
LEPIDO							15	30	
LEPTO									
YLODE									
LIMNE									
ECCLISO									
PHILAR					45				
HESPER			113		135		120	45	60
LEPHILU								45	
HPTILID									
HPTILSP									
OCHROT							30		
RHYACO					30				
DYTISCI		22		30		60		15	
AGABU									
COLYMB									
RHANTU									
LIODESS									
HYGROTU									
STICTOT	6								
LACCOPH									
PELTODY									
CLEPTEL			19				75		
OPTIOSE			75		150		480	210	540
OCHTHEB									
HPHILID									
HYBIUS									
LACCOB									
TROPIST									
AGATH									
CERATOP					30			15	
APEDILU									
CHIRONO									
PARACHI	6								
PARACLA							16		
PARATEN									
PHAENOP	43				62		93		
POLYPED					31	60			
PSEUDOC									
TARSINI									
CLADOT									
MICROPS	1488				1,246	11,743	264	38	4,689

Vernon sites—Continued.

Code	VD3ST 7/20	RCST 7/21	VCST 7/21	VD6ST 7/21	CCST 7/20	LFST 7/20	LVST 7/20	ULVST 7/20	PCST 7/20
RHEOTAN									
STEMPEL									
TANYTAR						60			
PAGAS						241		8	61
IAMESA						723			122
DIAMES									
ACRICOT									
BRILLIA								8	
CHAETOC							17		
CORYNON						60			
CRICOTO			19						
ISOCLAD									
EUKBREH			19		70	181		8	63
EUKDEVO							33		63
EUKGRAC					35		17		
EUKCLAR			56		35	542	66	61	254
LIMNOP						60			
ORTHOC	43		38			602	83	30	63
PARAKI	62								
PARAME				90	70				63
PARAPH									
PSECTRC									
PSEUDOS									
RHEOCRI						482			
THIENEM						60			
TVETE	49	65	56	60	70	1,445	531	312	2,412
METRIOC									63
PAROC						181			
ODONTO							109	8	61
PRODIA							16		61
TANYPOD									
ASPECTR									61
PSECTRT									
RADOTA							31		61
PENTA									
NIMYIA									61
ZAVRELI									
TANYPUS									
CULICI	6								
DIXID									
DIXASP					30			45	120

Vernon sites—Continued.

Code	VD3ST 7/20	RCST 7/21	VCST 7/21	VD6ST 7/21	CCST 7/20	LFST 7/20	LVST 7/20	ULVST 7/20	PCST 7/20
MERINGO									
PSYCHOD									60
PROSIMU									
SIMULIU	30	764	5,250	2,820	180	1,020	1,665	368	4,860
MOLOPH									
PEDICI									60
DICRAN					30				60
TIPULA									
DOLICHO									
EMPIDI									
NEOPLAS							15		
CLINOCE									60
EPHYDR									
MUSCIDA		65	19	60		420			60
SCIOMYZ									

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