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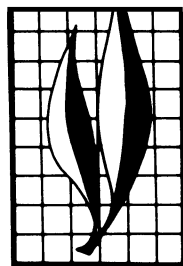
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Effect of Common Knotweed (*Polygonum aviculare*) on Abundance and Efficiency of Insect Predators of Crop Pests

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ABSTRACT

Common knotweed, *Polygonum aviculare* L. (Polygonaceae), a summer annual occurring in agricultural and urban settings in the Sacramento Valley, was attended by numerous predatory and parasitic insects, many of which fed on the exposed floral nectar. Representatives of 36 insect taxa were observed feeding at the flowers; 29 of these groups contain entomophagous species. Other entomophagous insects were associated with a honeydew-producing, host-specific aphid, *Aphis avicularis* Hille Ris Lambers. Among predators frequently observed feeding at the flowers were bigeyed bugs, *Geocoris* spp.

Surveys indicated that common knotweed plants harbored higher densities of bigeyed bugs than did hay alfalfa (*Medicago sativa* L.), prostrate pigweed (*Amaranthus graecizans* L.), or field bindweed (*Convolvulus arvensis* L.). *Geocoris punctipes* (Say) and *Collops vittatus* (Say), two predators which are also nectarivorous, survived longer when caged on common knotweed as opposed to hay alfalfa, as did *G. punctipes* caged on common knotweed as opposed to prostrate pigweed. No difference in longevity was found when *G. punctipes* was caged on common knotweed with flowers and without flowers.

A further study featured replicated monocultural plots of common knotweed, common purslane (*Portulaca oleracea* L.), prostrate pigweed, and control plots of bare ground, arrayed in a completely randomized design. Common knotweed plots harbored the highest densities of bigeyed bugs, aphidophagous ladybeetles, and total numbers of predators. Tests of predation efficiency yielded mixed results. Predator discovery of simulated prey (dead vinegar flies glued to cards) was higher on common knotweed than on prostrate pigweed foliage. Similar studies employing egg masses of beet armyworm (*Spodoptera exigua* Hubner) yielded less definitive results, with rates of discovery by predators being higher on both common knotweed and prostrate

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Effect of Common Knotweed (*Polygonum aviculare*) on Abundance and Efficiency of Insect Predators of Crop Pests¹

INTRODUCTION

VEGETATIONAL DIVERSITY CAN affect arthropod populations in various ways. Some scientists have emphasized the role of diversification in influencing movement and reproduction by pests (Risch, Andow, and Altieri 1983; Kareiva 1983), while the approach has also been explored as a means for enhancing natural enemies (Altieri and Whitcomb 1979; William 1981; Altieri and Letourneau 1982; Sheehan 1986). Root (1973) formalized the "enemies hypothesis," whereby vegetational diversification would provide resources (alternative foods, shelter, etc.), leading to higher densities or efficiencies of biological control agents. However, researchers often fail to investigate or specify which resources are used by important natural enemies. For example, in several previous studies, no specific mechanisms for predator or parasite enhancement were postulated *a priori* (Root 1973; Bach 1980a, 1980b; Horn 1981, 1984; Risch 1980, 1981). In such cases, it can be difficult to develop meaningful conclusions from either positive or negative experimental results.

Generalist predators, which rely to varying degrees on alternative food sources, have been shown to be of major importance in reducing pest levels in temporary agroecosystems (Ehler and Miller 1978). Some workers (Ehler and Miller 1978; Tamaki 1981; Murdoch, Chesson, and Chesson 1985) believe that availability of alternative foods may enable generalist predators to colonize croplands in advance of pests and thereby prevent or retard buildup of high pest densities.

Several generalist predators commonly encountered in various Californian agroecosystems often feed on plant products such as sap, seeds, extrafloral and floral nectar, and pollen. Those that feed on nectar include bigeyed bugs (*Geocoris* spp.; Hemiptera: Lygaeidae) (Yokoyama 1978; Crocker and Whitcomb 1980; De Lima 1980; De Lima and Leigh 1984; Thead, Pitre, and Kellogg 1985), minute pirate bug (*Orius tristicolor* White); Hemiptera: Anthocoridae) (Yokoyama 1978), a brown lacewing (*Hemerobius* sp. [prob. *ovalis* Carpenter]; Neuroptera: Hemerobiidae) (Bugg 1987), and a green lacewing (*Chrysoperla carnea* [Stephens]; Neuroptera: Chrysopidae) (Sundby 1967). The latter species, though predatory in the larval stages, feeds mainly on honeydew, pollen, and nectar during the adult stage. Moreover, DeLima (1980) showed that a bigeyed bug, *Geocoris pallens* Stal, attained maximum longevity, fecundity, and per capita prey consumption rates when cotton extrafloral nectar was available in addition to prey. Thus, nectar and various prey species (including agricultural pests) may serve as complementary resources to certain predatory insects (Leon and Tumpson 1975; Rapport 1980). That is, optimal diets may involve appropriate combinations of the two types of food.

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Despite knowledge that various generalist predators can subsist and indeed may rely in part on nectar and pollen (Rogers 1985), and despite increasing interest in the use of weeds to enhance biological control (Altieri and Whitcomb 1979; William 1981; Altieri and Letourneau 1982; Norris 1986), there have been few field studies designed to test for enhancement of predation through provision of nectar-bearing crop or non-crop plants (Crepps 1980; Agnew, Sterling, and Dean 1982). The present studies concern common knotweed, *Polygonum aviculare* L. (Polygonaceae), a plant found to attract a diversity of predators and parasites which feed on floral nectar or pollen as well as on other arthropods.

During a 1980 survey of insect-weed relationships at Spring Valley Farms, a large organic vegetable farm in La Selva Beach, Santa Cruz County, California, one of us (R. L. B.) discovered that relatively high densities of bigeyed bugs, *Geocoris* spp., were associated with common knotweed. Observations revealed that the bugs commonly probed the flowers of common knotweed, apparently feeding on floral nectar.

Bigeyed bugs are regarded as important predators in various crops (Tamaki and Weeks 1972; Eveleens, van den Bosch, and Ehler 1973; Ehler 1977; Bisabri-Ershadi and Ehler 1981) and have been noted to respond to alternative foods (Tamaki and Weeks 1972; Gonzalez et al. 1982). For example, Tamaki and Weeks (1972) demonstrated buildup of *Geocoris* in areas where alternative food (sunflower seed) was abundant. That experiment also indicated increased bigeyed bug oviposition on sugarbeet plants adjoining concentrations of sunflower seed. It occurred to one of us (R. L. B.) that a nectar source might similarly arrest the movement of bigeyed bugs, leading to local abundance and reproduction, and possibly to improved pest control on nearby crop plants. That is, common knotweed might serve as an insectary plant (Atsatt and O'Dowd 1976). We decided to investigate further.

Common knotweed, a prostrate or low-growing summer annual, is believed to be native to the United States, but there have also been introductions of other strains from Europe (U.S. Department of Agriculture 1970). The species occurs principally in disturbed sites throughout the continental United States and southern Canada, north to Alaska in the West and Newfoundland in the East. In California, it germinates from fall to late spring, and can be a problem in first-year alfalfa (Fischer et al. 1978), sugarbeet, and in some other crops, as well as in lawns. It is common in roadside areas and in vacant lots in cities; in urban and community gardens, it often grows in close proximity to crop plants.

The Polygonaceae comprise several major honey plants, such as domestic and wild buckwheats (*Fagopyrum esculentum* Moench and *Eriogonum* spp., respectively) (Pellett 1976). Many representatives of this family feature exposed floral nectar presented in small flowers. This easily-accessible nectar often prompts heavy visitation by bees, wasps, flies, and other saccharophilic insects. Common knotweed shares the feature of exposed nectar; moreover, because its flowers are usually presented at or very near ground level, they are often encountered by *Geocoris* spp. and ground-dwelling predators. Common knotweed produces flowers indeterminately from April through early winter, when the plants usually senesce and die. Based on observations conducted in northern Europe, Knuth (1908) considered common knotweed flowers to be devoid of nectar, but noted five species of apparent nectar feeders, including three syrphids (Diptera). Allen and Smith (1958) found that *Cotesia medicaginis* (Muesebeck)

(Hymenoptera: Braconidae), a parasite of alfalfa caterpillar, *Colias eurytheme* (Boisduval) (Lepidoptera: Pieridae), fed at the flowers of common knotweed.

The present studies concern common knotweed in relationship to associated entomophagous insects, and the possibility of exploiting these associations to improve biological control of crop pests.

FIELD SURVEYS

In order to document the insect fauna associated with common knotweed, we recorded numerous field observations of both phytophagous and flower-visiting insects. In addition, we conducted field surveys comparing densities of *Geocoris* on common knotweed and on hay alfalfa (*Medicago sativa* L., Leguminosae), a crop known to harbor high densities of bigeyed bugs (Benedict and Cothran 1975). Similar comparisons involved common knotweed and two commonly-associated prostrate weeds, prostrate pigweed (*Amaranthus graecizans* L., Amaranthaceae), and field bindweed (*Convolvulus arvensis* L., Convolvulaceae).

Methods

During 1980-1983, a species list was compiled based on insects observed feeding on the floral resources of common knotweed. These data were collected at Spring Valley Farms, the Student Experimental Farm at the University of California, Santa Cruz, and the Student Experimental Farm and Department of Animal Science fields at the University of California, Davis. Records and collections were also made of phytophagous arthropods associated with common knotweed.

In 1981, we measured *Geocoris* density on common knotweed growing amid hay alfalfa and on nearby alfalfa plants. Similar comparisons were also made between common knotweed and prostrate pigweed and between common knotweed and field bindweed. These comparisons were all made by placing a 20-cm diameter metal hoop over randomly-chosen plants and counting all the adult and nymphal bigeyed bugs found in the circumscribed area.

The common knotweed-alfalfa comparisons were all conducted in the same field (alfalfa cultivar A.S. 13R), located at the University of California, Davis, and managed by the Department of Animal Science. Observations were made on six dates: 27 September; 1, 3, 4, and 23 October; and 18 November, 1981. The observations made on the last two dates involved paired comparisons, whereby a randomly-selected common knotweed plant was paired with the nearest alfalfa plant. The comparisons conducted on the first four dates involved randomized selection of plants occurring on the same irrigation levees. Overall analysis was conducted using a two-way ANOVA of untransformed counts, with date and plant species employed as crossed factors. Given the balanced sampling regime and the preliminary nature of the work, this procedure seemed justified for detecting any effect due to plant species.

Survey data comparing common knotweed and the two other prostrate weeds were also obtained during 1981. Bigeyed bug densities were measured on common knotweed

versus prostrate pigweed on 14 July, 5 and 30 September, and 15 October at sites in and near Davis, in mixed weed communities featuring the two species. These data were analyzed using ANOVA of untransformed counts, with weed species and sampling date employed as crossed factors. Common knotweed versus field bindweed were compared only on 4 September, employing a weed community on a dirt road bordering sugarbeet and alfalfa fields near Dixon (Solano Co.), California. The sampling technique involved randomly-chosen common knotweed plants, each paired with the nearest field bindweed plant. The untransformed counts were analyzed using a paired t-test.

Results

Flower-visiting insects associated with common knotweed are presented in table 1. Representatives of 36 distinguishable taxa were observed feeding at common knotweed flowers, and 29 of these taxa contain entomophagous species. Several pests were also observed feeding at the flowers, such as common housefly, *Musca domestica* L., a bulb fly, *Eumerus* sp., and a plant bug, *Lygus* sp. As the data are qualitative, they do not permit any discussion of diversity beyond species richness. Subsequent observation (R. L. Bugg, *unpub. data*) indicated that halictids and small syrphids were among the most common foragers during summer.

Phytophagous arthropods associated with common knotweed included a scentless plant bug, probably *Arhyssus lateralis* (Say) (Hemiptera: Rhopalidae), spider mites (Acari: Tetranychidae) on foliage, and thrips (Thysanoptera) on flowers. In addition, two apparently host-specific homopterans, an aphid, *Aphis avicularis* Hille Ris Lambers (Homoptera: Aphididae), and a psyllid, *Aphalara curta* Caldwell (Homoptera: Psyllidae), were noted. Both often attained high population densities in late summer and early autumn. The aphid was often tended by several species of honeydew-feeding ants, and various aphidophagous predators were often associated with the aphid colonies. Based on several years of observations by one of us (R. L. B.) common knotweed appears to be among the few summer weeds in California that support high densities of aphids that produce honeydew and attract large numbers of aphidophagous insects.

Common knotweed exhibited significantly higher bigeyed bug densities than did any of the other three plant species assessed. Figures 1 and 2 summarize *Geocoris* densities on common knotweed versus hay alfalfa and versus prostrate pigweed, respectively. The respective overall means (\pm S.E.M.) for common knotweed and alfalfa were 2.97 ± 0.31 and 0.65 ± 0.15 ($P=0.0001$). The corresponding means for common knotweed and pigweed were 6.57 ± 1.24 and 2.87 ± 0.64 ($P=0.001$). The paired t-test for common knotweed versus field bindweed indicates significant differences for the counts obtained ($t = 2.662$; d.f. = 8; $P = 0.0287$), with the respective means (\pm S.E.M.) being 2.9 ± 0.7 and 0.7 ± 0.3 ($n=9$).

LONGEVITY STUDIES

Longevity and fecundity are important in determining the effectiveness of natural enemies, and both have been shown to be enhanced through provision of floral

TABLE 1. INSECTS OBSERVED AS FLOWER VISITORS AT COMMON KNOTWEED IN NORTHERN CALIFORNIA, 1980-1984

Order	Family	Genus, species, and authority
Hemiptera	Lygaeidae	<i>Geocoris atricolor</i> Montandon <i>G. pallens</i> Stal <i>G. punctipes</i> (Say)
	Miridae	<i>Lygus</i> sp.
	Nabidae	<i>Nabis</i> sp.
	Anthocoridae	<i>Orius tristicolor</i> (White)
Coleoptera	Carabidae	Undetermined spp.
	Melyridae	<i>Collops vittatus</i> (Say)
	Coccinellidae	<i>Hippodamia convergens</i> Guerin-Meneville
	Anthicidae	<i>Anthicus</i> spp.
Diptera	Syrphidae	<i>Allograpta</i> sp. <i>Eumerus</i> sp. <i>Paragus tibialis</i> (Fallen) <i>Sphaerophoria</i> sp. <i>Syritta pipiens</i> (L.)
		<i>Musca domestica</i> L.
		Undetermined spp.
		<i>Archytas californiae</i> (Walker)
		Undetermined spp.
	Muscidae	
	Calliphoridae	
	Tachinidae	
Hymenoptera	Braconidae	<i>Chelonus</i> sp. Undetermined microgastrine spp.
	Ichneumonidae	prob. <i>Compsocryptus</i> sp.
		prob. <i>Pristomerus</i> sp.
	Chalcidoidea	Undetermined spp.
	Dryinidae	Undetermined sp.
	Formicidae	<i>Conomyrma bicolor</i> (Wheeler) <i>Conomyrma insana</i> (Buckley) <i>Iridomyrmex humilis</i> (Mayr) <i>Tetramorium caespitum</i> (L.)
		<i>Polistes apachus</i> Saussure
		<i>Polistes fuscatus</i> (Fabricius)
		<i>Euodynerus</i> sp.
		Undetermined spp.
	Pompilidae	<i>Ammophila</i> sp.
	Sphecidae	<i>Tachytes</i> sp. prob. <i>distinctus</i> Smith
		Undetermined spp.
	Halictidae	Undetermined spp.
	Megachilidae	Undetermined sp.
	Apidae	<i>Apis mellifera</i> L.

resources (Leius 1961a, 1961b, 1963, 1967b; Shahjahan 1968; Syme 1975, 1977; Topham and Beardsley 1975; Foster and Ruesink 1984; Treacy et al. 1987). If common knotweed supplies an important alternative food, such as nectar, one might expect to see better survival of predators caged on common knotweed than on other plants not supplying that resource. Therefore, longevity studies were conducted for two nectarivorous predators, *Geocoris punctipes* (Say) and *Collops vittatus* (Say) (Coleoptera: Melyridae).

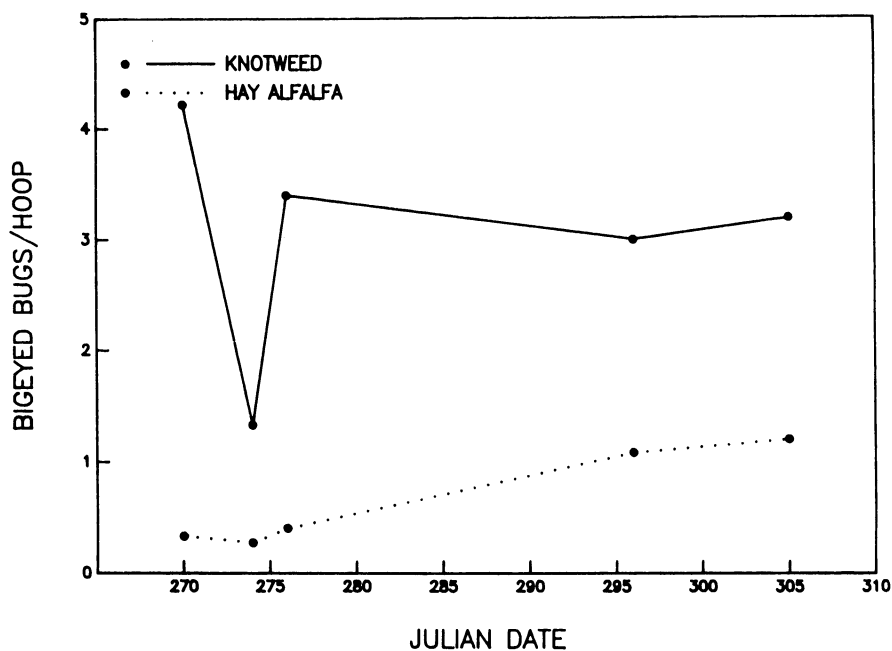


Fig. 1. Mean numbers of bigeyed bugs per hoop sample on common knotweed (growing in alfalfa) and on nearby alfalfa plants, 1981.

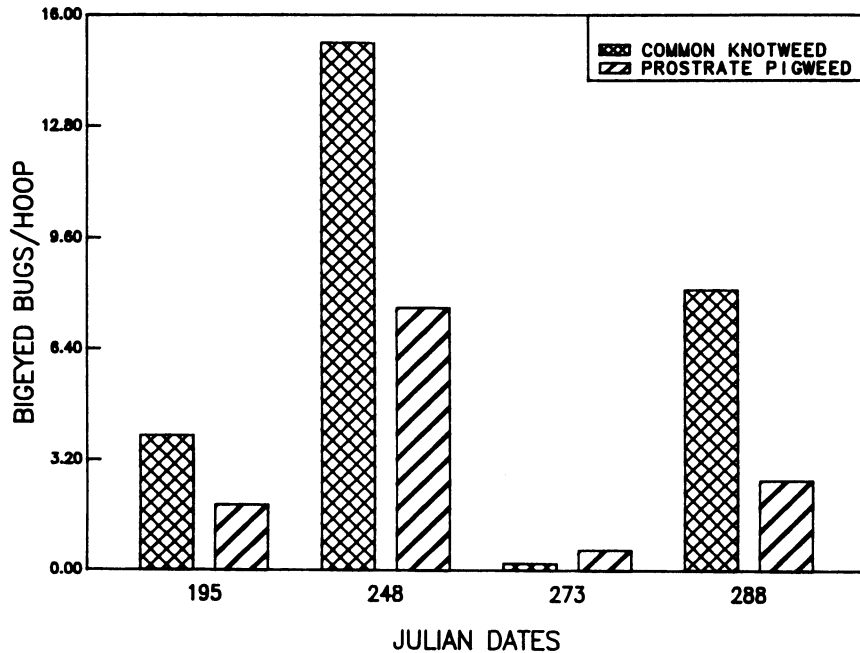


Fig. 2. Mean numbers of bigeyed bugs per hoop sample on common knotweed and on nearby prostrate pigweed, 1981.

Methods

During 1982, field longevity trials were conducted at the border of a hay alfalfa field (cultivar A.S. 13R) which featured stands of common knotweed and other weeds, as well as volunteer alfalfa plants. Late-instar *G. punctipes* nymphs were aspirated from a nearby stand of common knotweed and female-male pairs enclosed in cages constructed of polyester netting (rectangular mesh, 8×20 lines/cm) and Velcro. These cages were designed to enclose strands of vegetation without allowing the bugs to escape. Randomly-chosen 10 to 15 cm sprigs of common knotweed or alfalfa were used in this trial. In this and subsequent longevity trials, no other arthropods were initially observed on the sprigs chosen, but it is probable that thrips and spider mites were present in all cases. Thirteen pairs of bugs were caged on common knotweed sprigs and 12 pairs on alfalfa sprigs. The study began on 1 September, and ended on 31 October. Survivorship was assessed daily. The longevity data were analyzed using two approaches: a two-way ANOVA employed plant species and sex as independent variables, and one-way ANOVA used only the longer-lived individual of each pair, to control for mortality due to cannibalism that occasionally occurred during molting.

A similar study was conducted at the same location from 13 September to 31 October, 1982, employing adult *Collops vittatus*. Beetles were collected from the field, mainly at a commercial organic vegetable farm near Woodland (Yolo Co.), California. Due to the relative abundance of female beetles, we assigned 10 female-male pairs and 10 single females to polyester-Velcro cages, and assigned both groups equally to common knotweed and alfalfa. Survivorship was assessed daily. Analysis was by two separate ANOVA approaches. In one case, longevity of each member of a pair was regarded as a subsample, that is, caged pairs provided two observations per cell, and the mean was taken as the composite value. Singly-caged females provided only one observation per cell. Data for pairs and singly-caged females were analyzed by one-way ANOVA. As cannibalism occurred in all cages initially having two beetles, a two-way ANOVA was also conducted, employing single females and the longer-lived member of each pair. These two categories determined assignment of the second independent variable for a two-way ANOVA.

A greenhouse study of *Geocoris punctipes* longevity was conducted from 16 September to 31 October, 1982. Alfalfa (cultivar W.S. 318) plants were grown from seed in plastic pots (15.24 cm diameter, 1.66 l volume); common knotweed plants were grown from seedlings transplanted from the field to similar pots. In each case, the soil mix employed was 3:2:1 sandy loam to delta peat to sand. Fertilization was with 0.1-strength modified Hoagland's solution (Epstein 1972, 32). Irrigation was provided as needed, approximately every other day. After alfalfa plants had grown 1 month in the greenhouse, the longevity trial was initiated. Nymphal *G. punctipes* were collected as previously noted, sexed, and assigned to cages constructed of fine mesh polyester netting (35×35 lines/cm) and Velcro. Seven female-male pairs were caged on common knotweed and seven on alfalfa, employing 10 to 15 cm sprigs of vegetation in all cases. Longevity was assessed and analyzed as in the field study of *G. punctipes* longevity described above.

From 1 August to 17 September, 1983, we conducted a field study of survivorship of *G. punctipes* caged on common knotweed versus prostrate pigweed. The plots employed were those described later in the section on monocultural weed plots. The nymphal

bugs were collected by aspiration as before, but were not sexed. Pairs were caged in fine mesh polyester-Velcro cages; thirteen pairs were assigned to randomly-chosen 5 to 10 cm sprigs of common knotweed, and thirteen to similar sprigs of prostrate pigweed. Survivorship was assessed daily, and results were analyzed using ANOVA, with the longevity of each individual bug regarded as a subsample from its cage. An additional ANOVA was conducted using the longer-lived individual from each cage.

An additional study was conducted from 19 September to 8 October, 1983 in the greenhouse, and from 8 September to 11 October, 1983 in the field. The greenhouse component involved potted common knotweed plants, grown as above. In the field component, common knotweed plants were randomly selected from the monocultural weed plots described in the next section. *G. punctipes* were caged in pairs on randomly-chosen, 5-cm common knotweed sprigs with flowers and on similar sprigs from which flowers were removed every other day. Five pairs of unsexed late-instar nymphs were assigned to each of four treatments: (1) plants with flowers in field, (2) plants with flowers in greenhouse, (3) plants with flowers removed in field, and (4) plants with flowers removed in greenhouse. The bugs were confined in fine-mesh polyester cages, and survivorship was assessed daily. Data were analyzed using ANOVA, regarding field versus greenhouse as a factor crossed with flowers versus no flowers.

Results

Results of the 1982 longevity studies for predators caged on common knotweed versus alfalfa are summarized in table 2. All four analyses of data for *G. punctipes* yielded significant differences, and longevity was roughly twice as long on common knotweed than on hay alfalfa. Both analyses of field longevity data for *Collops vittatus* indicated significantly enhanced survival on common knotweed as opposed to alfalfa, with the beetle living some four times as long on the former.

Analysis of field data for *G. punctipes* longevity on common knotweed versus prostrate pigweed indicated significantly enhanced survival on the former ($p < 0.001$). The respective means were 42.1 ± 3.9 and 8.5 ± 1.1 , representing a 34-day or nearly fivefold difference.

TABLE 2. LONGEVITY OF *GEOCORIS PUNCTIPES* AND *COLLOPS VITTATUS* CAGED ON COMMON KNOTWEED VS. ALFALFA (1982)

Study site	Species	Mean longevity in days \pm S.E.M. (n)		F ratio (df)	p
		Knotweed	Alfalfa		
Field	<i>G. punctipes</i> *	44.2 ± 4.8 (13)	16.5 ± 3.6 (12)	24.47 (1,23)	0.0001
Field	<i>G. punctipes</i> [†]	55.9 ± 4.1 (13)	25.0 ± 6.4 (12)	17.03 (1,23)	0.0004
Greenhouse	<i>G. punctipes</i> *	19.7 ± 1.5 (7)	9.8 ± 1.7 (7)	19.73 (1,12)	0.0008
Greenhouse	<i>G. punctipes</i> [†]	23.0 ± 0.0 (7)	12.6 ± 2.6 (7)	15.88 (1,12)	0.0018
Field	<i>C. vittatus</i> *	22.0 ± 5.2 (10)	5.9 ± 1.6 (10)	9.26 (1,18)	<0.01
Field	<i>C. vittatus</i> [†]	30.3 ± 5.7 (10)	7.7 ± 2.2 (10)	13.26 (1,18)	0.002

*All insects considered.

[†]Only longer-lived insect considered.

Data for *G. punctipes* caged on common knotweed with versus without flowers failed to indicate any significant difference ($P=0.4996$). Respective means (\pm S.E.M.) for common knotweed with and without flowers were 8.8 ± 2.5 and 7.7 ± 2.3 ($n=10$). The low overall longevities in this study may suggest a systematic problem in the experiment. The sprigs employed were smaller on average than those used in the other studies (5 vs. 5–15 cm), and perhaps not enough flowers were available under the “with flowers” regime. However, this question was not addressed further, due to an injury to the principal investigator (R. L. B.) during late 1983.

MONOCULTURAL WEED PLOTS

The survey results suggested that common knotweed harbored higher densities of bigeyed bugs than did other plant species that frequently grow alongside it. However, these data were obtained at field margins and other sites affording little control of other variables. We therefore decided to test common knotweed against two commonly-associated prostrate weeds, prostrate pigweed and common purslane (*Portulaca oleracea* L., Portulacaceae), under more rigorous experimental conditions.

Prior observation and literature review indicated that these two low-growing weeds each harbored a distinctive entomofauna. Prostrate pigweed featured two bugs: *Chariesterus* (?) sp. (Hemiptera: Coreidae) and *Piesma* (?) sp. (Hemiptera: Piesmatidae). *Piesma* was often abundant during these studies (1981–83). In addition, larval beet armyworm, *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae), were frequently found feeding on the foliage of the weed. Common purslane may be attended by several nectarivorous parasites and predators, including various tachinid flies and sphecoid wasps, which were observed visiting the flowers (R. L. Bugg, *pers. obs.*). Herbivorous insect associates reported from California include two apparently host-specific herbivores: a sawfly, *Schizocerella pilicornis* Holmgren (Hymenoptera: Pergidae); and a weevil, *Hypurus bertrandi* Perris (Coleoptera: Curculionidae) (Clement and Norris 1982). Larvae of both these insects mine the leaves, which can have adverse effects on the plant. Common purslane is also attacked by a fungal pathogen, *Dicotomophthora portulacae* Mehrlich and Fitzpatrick ex M. B. Ellis, which can cause severe damage (Klisiewicz, Clement, and Norris 1983).

Methods

The study was conducted at the Student Experimental Farm at the University of California, Davis, during 1983. The field employed had dimensions 16.5 m in the east-west axis and 20.1 m in the north-south axis. The land was disked in early May, and the experiment was laid out and planted in mid-May. A completely randomized design was employed, featuring five replications of each of the following: (1) common knotweed, (2) prostrate pigweed, (3) common purslane, and (4) bare ground (control plots). The plots were 1.8-m-sided squares, separated by 1.8-m alleys. Overall arrangement of plots was 4×5 . Plots were each initially planted with nine plants of the appropriate species. The common knotweed and common purslane plants had been

raised in the greenhouse, while the prostrate pigweed plants were excavated from the surrounding fields and roadside areas. As the aim was to obtain complete vegetational cover in the treatments featuring weeds, supplemental plantings of prostrate pigweed were made on 24 May to compensate for early mortality and slow growth.

Following planting, the weeds were watered by hand to ensure establishment. Thereafter, the intent was to give them no irrigation, in order to simulate typical roadside and fieldside conditions. Irrigation of adjoining fields on two occasions flooded several of the plots, but this seemed to have no lasting influence on the activity of *Geocoris* or other insect species. Fertilization involved two foliar applications (by atomizer) of diluted fish emulsion. Alleys were initially hoed, and were kept weed free using both hoe and rototiller. The entire experiment was fenced against rabbits in early June.

Proportional weed cover was assessed visually on 16 July and 17 August. Differences were assessed using repeated-measures ANOVA (Winer 1971, 365-6), following transformation of the proportional data ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$) (Neter and Wasserman 1974, 507-8). The above measurements involved data taken from the same plots on successive dates. With these and subsequent repeated measures data from this study, the mean squares for "among plots, corrected for weed regime" served as error terms in the F-tests for effects due to weed regime. When significant F-tests were obtained, Duncan's multiple range test (Duncan 1955) was employed for mean separation. This was also the case in all subsequent ANOVA involving more than two weed regimes.

Abundance of entomophagous insects was assessed by use of a ten-cm-radius hoop, plus whole-plot visual inspection and accompanying enumeration of entomophagous insects. Predator efficiency was assessed by baiting with chunks of oil-based tuna placed on paper cards in the plots, and with egg masses of beet armyworm (*Spodoptera exigua* (Hubner), Lepidoptera: Noctuidae) or dead vinegar flies (*Drosophila* spp., Diptera: Drosophilidae) glued to the weeds in question. Exposed baits were inspected for occupancy, or damage presumably caused, by predators.

The hoop method involved placing the hoop at predetermined sites in each plot. The weed foliage was lifted up gently, and the hoop placed beneath it. Next, the foliage was shaken several times to dislodge clinging arthropods, and the arthropods inside the hoop were enumerated. This sampling method was used on 11 occasions: 21 and 27 June; 5 July; 5, 16 (twice), and 25 August; 1, 3, and 21 September; and 12 October. There was one observation per plot from 21 June through 5 July, and two per plot on subsequent dates. Counts were taken of total predators, *Geocoris* spp., aphidophagous Coccinellidae (all species and postembryonic stages pooled), and pavement ant, *Tetramorium caespitum* (Linnaeus) (Hymenoptera: Formicidae). These data were analyzed using repeated-measures ANOVA, with subsampling on the sampling dates for which there were two observations per plot. Control plots were considered in the analysis of pavement ant data, but were ignored in the other three analyses.

The plots were visually inspected on six dates: 26 July; 7, 14, 23, and 25 August; and 1 September. The procedure involved walking slowly around each plot while enumerating all predators observed. The untransformed data for total predators and *Geocoris* were assessed by repeated-measures ANOVA. Visual inspection provided information on predator densities in entire plots. The method was principally useful in

assessing densities of predators in plain view, for example, running about on the ground or perched on weed foliage. By contrast, the hoop sampling assessed densities of predators occurring under, as well as on, foliage.

Baiting with tuna was conducted on 11 October (1130–1145 [PDT]), 17 October (1350–1400), and 20 October (1252–1312). Tuna chunks, each about 1.3×1.3 cm, were placed singly on pieces of index card (each ca 7.6×5.0 cm) in the plots. Two baits per plot were employed on the first two dates, and four on the last date. After the exposure periods, counts were made to assess number of pavement ants found on each bait and rates of bait discovery by the pavement ant. Discovery rate is here defined as rate of occurrence of baits occupied by at least one pavement ant. These data were analyzed using separate repeated-measures ANOVA for the count and proportional data. In the latter case, proportions were transformed prior to analysis as mentioned above.

Egg masses of beet armyworm were obtained by allowing laboratory-reared moths to oviposit on paper towels. The towels were then cut into small pieces, each containing an egg mass. Egg masses contained approximately 10 to 30 eggs, with the mean being 20. Baiting was done on nine dates: 7 and 11 July; 7, 10, 11, 14, 17, and 29 August; and 6 September. Two baits were used per plot on all of these dates except 17 August, when four were used. On five dates, baiting was restricted to common knotweed and prostrate pigweed. Following exposure periods that were uniform for any one date, baits were inspected, and those occupied or apparently damaged by predators were termed "discovered." Proportions discovered (transformed) were analyzed using repeated-measures ANOVA.

When beet armyworm egg masses became unobtainable late in the season, we switched to dead vinegar flies glued to 1.3×1.3 cm pieces of white index card. These cards were in turn glued to weed foliage, and subsequent inspection revealed whether the flies had been removed or damaged by predators. Such studies were conducted on five dates: 28 August and 9, 15, 17, and 20 September. Two baits per plot were used on each of the dates mentioned, with exposure periods ranging from 0.5 to 6 hours. Predation efficiency was assessed as above.

Results

The proportions of cover among weed regimes are presented in table 3. Analysis indicated significant differences among all means, ranked in descending order: common knotweed, prostrate pigweed, common purslane, and control. All common purslane plots were devastated through the combined action of the two herbivorous insects and the pathogen mentioned previously. Such destruction of common purslane had seldom been seen elsewhere (R. F. Norris, *pers. comm.*). Thus, the results reported here for common purslane should probably be considered atypical.

Data for hoop sampling of total predators are presented in figure 3. Common knotweed harbored significantly higher predator densities than either pigweed or common purslane, while means for the latter two were not significantly different. Overall, common knotweed showed a better than fivefold advantage over common purslane, and a better than fourfold advantage over pigweed. Predators observed included ants, bigeyed bugs, lady beetles, anthicid beetles, and harvestmen (Phalangida). Predators were seldom observed in the control plots.

TABLE 3. VEGETATIONAL COVER IN MONOCULTURAL WEED PLOTS (1983)*

Date	Mean proportion \pm S.E.M. (n = 5)			
	No weeds	Pigweed	Knotweed	Purslane
July 16	0.015 \pm 0.010	0.595 \pm 0.406	0.825 \pm 0.296	0.305 \pm 0.300
Aug. 17	0.005 \pm 0.005	0.660 \pm 0.040	0.850 \pm 0.045	0.280 \pm 0.037
Overall	0.01 \pm 0.01	0.63 \pm 0.04	0.84 \pm 0.03	0.29 \pm 0.03

*ANOVA of overall proportions transformed ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{3,16} = 113.80$; $P = 0.0001$. All overall means are significantly different by Duncan's multiple range test.

Data for *Geocoris* per hoop (11 dates included) are summarized in table 4. Analysis indicated that common knotweed harbored slightly higher densities of *Geocoris* than either pigweed or common purslane, while means for the latter two were not significantly different.

Data for aphidophagous coccinellids are summarized in table 5. Analysis indicated that common knotweed harbored significantly higher mean densities than did either prostrate pigweed or common purslane. No ladybeetles were observed on common purslane or prostrate pigweed. Coccinellid species observed on common knotweed included *Hippodamia convergens* (Guerin-Meneville), *Coccinella novemnotata* Hbst., and an unidentified species near *Scymnus*. All three species were observed in both larval and adult stages.

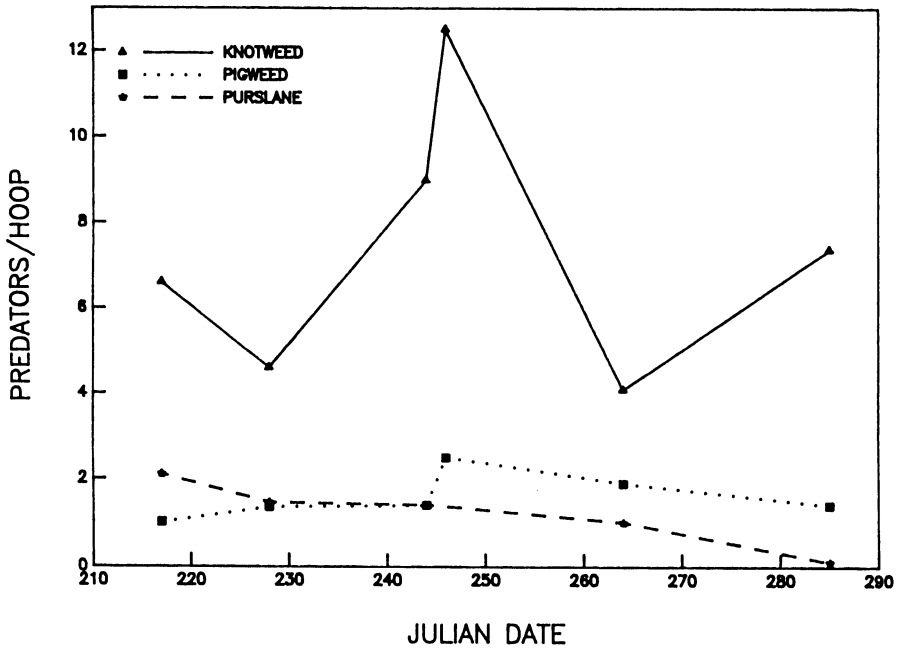


Fig. 3. Mean numbers of total predators per hoop sample in monocultural weed plots, 1983.

TABLE 4. BIGEYED BUGS PER HOOP SAMPLE IN MONOCULTURAL WEED PLOTS*

Date	Mean no. \pm S.E.M. (n = 5)		
	Pigweed	Knotweed	Purslane
June 21	0.00 \pm 0.00	0.00 \pm 0.00	0.20 \pm 0.20
27	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
July 5	0.20 \pm 0.20	0.40 \pm 0.24	0.20 \pm 0.20
Aug. 5	1.00 \pm 0.52	0.70 \pm 0.46	1.40 \pm 0.43
15	1.10 \pm 0.24	1.40 \pm 0.37	0.10 \pm 0.10
16	0.20 \pm 0.20	0.10 \pm 0.10	0.00 \pm 0.00
25	0.30 \pm 0.12	1.40 \pm 0.40	0.40 \pm 0.29
Sept. 1	0.80 \pm 0.12	2.00 \pm 0.45	1.30 \pm 0.25
3	0.80 \pm 0.34	1.00 \pm 0.39	— [†]
21	0.30 \pm 0.12	1.40 \pm 0.46	0.30 \pm 0.12
Oct. 12	0.10 \pm 0.01	0.60 \pm 0.10	0.10 \pm 0.10
Overall	0.61 \pm 0.12a	1.09 \pm 0.15b	0.50 \pm 0.10a

*Overall $F_{2,12} = 5.78$; $P = 0.0174$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

[†] "—" indicates samples not taken.

TABLE 5. APHIDOPHAGOUS COCCINELLIDS PER HOOP SAMPLE IN MONOCULTURAL WEED PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 5)		
	Pigweed	Knotweed	Purslane
June 21	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
27	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
July 5	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
17	0.00 \pm 0.00	0.10 \pm 0.10	0.00 \pm 0.00
Aug. 5	0.00 \pm 0.00	0.10 \pm 0.10	0.00 \pm 0.00
16	0.00 \pm 0.00	0.20 \pm 0.12	0.00 \pm 0.00
25	0.00 \pm 0.00	0.20 \pm 0.12	0.00 \pm 0.00
Sept. 9	0.00 \pm 0.00	0.90 \pm 0.37	0.00 \pm 0.00
3	0.00 \pm 0.00	2.40 \pm 0.94	0.00 \pm 0.00
21	0.00 \pm 0.00	1.40 \pm 0.58	0.00 \pm 0.00
Oct. 12	0.00 \pm 0.00	0.00 \pm 0.00	0.00 \pm 0.00
Overall	0.00 \pm 0.00a	0.71 \pm 0.22b	0.00 \pm 0.00a

*Control plots ignored in this comparison. Overall $F_{2,12} = 14.86$; $P = 0.0006$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

Hoop-sampling of pavement ant (seven dates assessed) yielded a highly significant difference ($P=0.0036$) due to weed regime (fig. 4). Analysis of overall mean densities revealed a significantly higher mean density for common knotweed than for any of the other three regimes; the latter were not significantly different from one another. Pavement ant was observed in the control plots; overall means (\pm S.E.M.) for prostrate pigweed, common purslane, and common knotweed were 0.16 ± 0.15 , 0.04 ± 0.01 , and 3.90 ± 0.31 .

Data for total predators observed during visual inspection of the weed plots (table 6) indicated a significant difference due to weed regime ($P=0.0036$). Mean predator density for common knotweed was significantly higher than for any of the other three regimes, which themselves did not significantly differ. Overall means (\pm S.E.M.) for common knotweed, control, prostrate pigweed, and common purslane were 9.90 ± 1.21 , 1.00 ± 0.70 , 1.03 ± 0.23 , and 2.20 ± 0.86 . Predators observed included ants, bigeyed bugs, adult and larval ladybeetles (*H. convergens* and *C. novemnotata*), and aphidophagous syrphid flies (*Mesograpta* sp. and *Paragus tibialis* [Fallen]).

Table 7 summarizes data for *Geocoris* observed during visual inspection of weed plots. Common knotweed harbored significantly higher densities than did any of the other three regimes, which did not significantly differ from each other. No *Geocoris* were observed in the control plots. Overall means for common purslane, pigweed, and common knotweed were in the ratio 1.00 : 1.54 : 10.61.

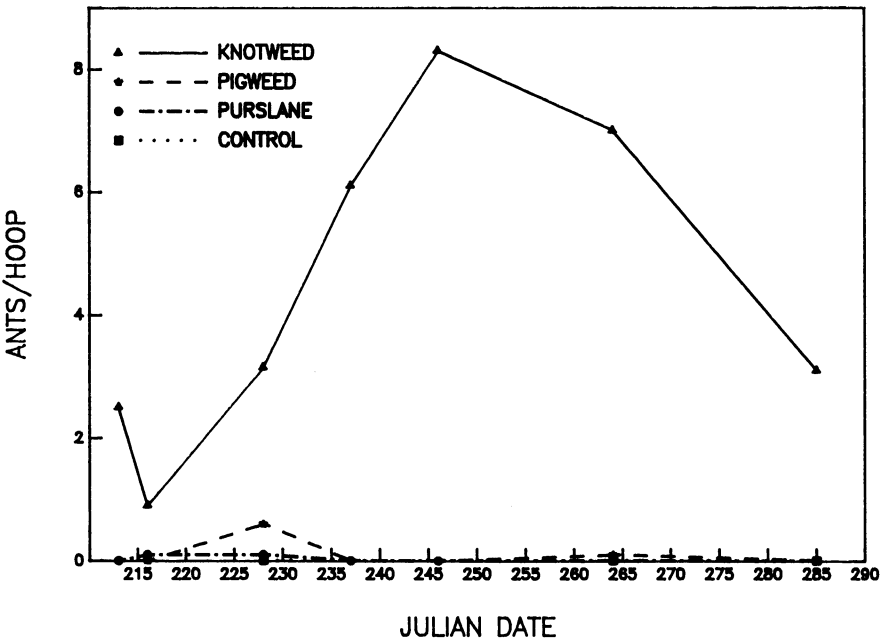


Fig. 4. Mean numbers of pavement ant per hoop sample in monocultural weed plots, 1983.

TABLE 6. TOTAL PREDATORS OBSERVED PER PLOT DURING VISUAL INSPECTION OF MONOCULTURAL WEED PLOTS (1983)*

Date	Mean count \pm S.E.M. (n = 5)			
	No weeds	Pigweed	Knotweed	Purslane
July 26	0.60 \pm 0.40	0.20 \pm 0.20	11.00 \pm 3.19	1.40 \pm 0.24
Aug. 7	1.40 \pm 1.40	0.80 \pm 0.37	9.00 \pm 4.16	0.00 \pm 0.00
14	— [†]	1.00 \pm 0.55	12.00 \pm 3.27	0.80 \pm 0.37
23	—	1.60 \pm 0.81	7.00 \pm 2.55	0.40 \pm 0.24
25	—	1.60 \pm 0.81	12.40 \pm 3.33	1.80 \pm 0.92
Sept. 1	—	1.00 \pm 0.32	8.00 \pm 1.26	—
Overall	1.00 \pm 0.70a	1.03 \pm 0.23a	9.90 \pm 1.21b	2.20 \pm 0.86a

*Overall $F_{3,16} = 9.81$; $P = 0.0036$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

[†]“—” indicates samples not taken.

TABLE 7. MEAN NUMBERS OF BIGEYED BUGS OBSERVED PER PLOT DURING VISUAL INSPECTION OF MONOCULTURAL WEED PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 5)			
	No weeds	Pigweed	Knotweed	Purslane
July 26	0.00 \pm 0.00	0.00 \pm 0.00	3.80 \pm 0.97	0.80 \pm 0.37
Aug. 7	0.00 \pm 0.00	0.40 \pm 0.24	1.60 \pm 0.68	0.00 \pm 0.00
14	— [†]	0.80 \pm 0.37	3.00 \pm 1.05	0.20 \pm 0.20
23	—	0.80 \pm 0.58	2.00 \pm 0.71	0.00 \pm 0.00
25	—	0.00 \pm 0.00	3.80 \pm 1.20	0.40 \pm 0.40
Sept. 1	—	0.60 \pm 0.24	3.60 \pm 0.51	—
Overall	0.00 \pm 0.00a	0.43 \pm 0.13a	2.97 \pm 0.37b	0.28 \pm 0.12a

*Overall $F_{3,16} = 28.21$; $P = 0.0001$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

[†]“—” indicates samples not taken.

Assessment of predator efficiency in the various plots yielded mixed results. Numbers of pavement ants found per tuna bait (table 8) were not significantly different from one another, but when the same data were analyzed for proportions of baits discovered by pavement ants (table 9), the results were deemed significant. This discrepancy is dealt with under “Discussion.” Means for common knotweed and common purslane were both deemed higher than those for control and pigweed, but within both these pairs, means were not significantly different. Predation was slightly higher on egg masses of beet armyworm glued to prostrate pigweed and common knotweed than on egg masses glued to common purslane, but the former two regimes did not differ significantly from each other (table 10). Finally, common knotweed had a slightly but significantly higher proportion of *Drosophila* baits discovered by predators (table 11).

TABLE 8. MEAN NUMBERS OF PAVEMENT ANTS PER TUNA BAIT IN MONOCULTURAL WEED PLOTS (1983)*

Date	Exposure period (min)	Mean no. \pm S.E.M. (n = 5)			
		No weeds	Pigweed	Knotweed	Purslane
Oct. 11	15	0.00 \pm 0.00	1.20 \pm 0.97	2.20 \pm 0.49	3.60 \pm 1.32
17	10	10.40 \pm 5.95	4.40 \pm 1.81	15.00 \pm 4.87	16.10 \pm 3.19
20	20	4.45 \pm 0.94	3.15 \pm 0.83	5.45 \pm 1.32	9.15 \pm 2.04
Overall	— [†]	5.20 \pm 2.83	2.80 \pm 1.22	8.60 \pm 2.86	9.85 \pm 2.40

*Overall $F_{3,16} = 1.73$; $P = 0.201$.[†]“—” indicates samples not taken.

TABLE 9. MEAN PROPORTIONS OF TUNA BAITS OCCUPIED BY AT LEAST ONE PAVEMENT ANT IN MONOCULTURAL WEED PLOTS (1983)*

Date	Baits per plot	Mean proportion \pm S.E.M. (n = 5)			
		No weeds	Pigweed	Knotweed	Purslane
Oct. 11	2	0.00 \pm 0.00	0.20 \pm 0.05	0.60 \pm 0.04	0.60 \pm 0.08
17	2	0.60 \pm 0.08	0.40 \pm 0.08	0.60 \pm 0.08	0.90 \pm 0.04
20	4	0.20 \pm 0.04	0.15 \pm 0.03	0.30 \pm 0.04	0.35 \pm 0.08
Overall	8	0.27 \pm 0.09b	0.25 \pm 0.08b	0.53 \pm 0.07a	0.62 \pm 0.11a

*Overall ANOVA of transformed proportions ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{3,16} = 5.38$; $P = 0.0094$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

TABLE 10. PROPORTIONS OF BEET ARMYWORM EGG MASS BAITS DAMAGED OR OCCUPIED BY AT LEAST ONE PREDACEOUS ARTHROPOD IN MONOCULTURAL WEED PLOTS (1983)*

Date	Exposure period (hours)	Mean proportion \pm S.E.M. (n = 5)		
		Pigweed	Knotweed	Purslane
July 7	2, afternoon	0.10 \pm 0.10	0.00 \pm 0.00	0.00 \pm 0.00
11	2, afternoon	0.10 \pm 0.10	0.00 \pm 0.00	0.20 \pm 0.12
Aug. 8	ca 5, afternoon	0.50 \pm 0.00	0.40 \pm 0.19	0.00 \pm 0.00
10	2, night	0.30 \pm 0.12	0.50 \pm 0.16	— [†]
11	3, night	0.00 \pm 0.00	0.50 \pm 0.22	—
14	9, afternoon	0.30 \pm 0.12	0.70 \pm 0.20	—
17	4, night	0.35 \pm 0.17	0.50 \pm 0.18	0.25 \pm 0.08
29	6, afternoon	0.00 \pm 0.00	0.10 \pm 0.10	—
Sept. 6	14, dusk-morn	0.30 \pm 0.12	0.70 \pm 0.20	—
Overall		0.21 \pm 0.03a	0.39 \pm 0.10a	0.11 \pm 0.11b

*Two baits per plot except Aug. 17, when four were used. Overall ANOVA of transformed proportions ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{2,12} = 3.92$; $P = 0.0489$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.[†]“—” indicates samples not taken.

TABLE 11. PROPORTIONS OF *DROSOPHILA* BAITS DAMAGED OR OCCUPIED BY AT LEAST ONE PREDACEOUS ARTHROPOD IN MONOCULTURAL WEED PLOTS (1983)*

Date	Exposure period (hours)	Mean proportion \pm S.E.M.	
		Knotweed	Pigweed
Aug. 28	0.5, dusk	0.70 \pm 0.15	0.15 \pm 0.10
Sept. 9	ca 6, night	0.60 \pm 0.19	0.60 \pm 0.19
15	ca 4, night	0.80 \pm 0.12	0.60 \pm 0.19
17	ca 5, night	1.00 \pm 0.00	0.60 \pm 0.10
20	ca 3.5, night	0.10 \pm 0.10	0.10 \pm 0.10
Overall		0.64 \pm 0.03	0.41 \pm 0.03

*Two baits were used per plot on all dates. Overall ANOVA of transformed proportions ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{1,8} = 27.13$; $P = 0.008$.

RADISH STUDIES

Tamaki, Weiss, and Long (1981) suggested that *Geocoris* tend to show greater affinity for radish plants, *Raphanus sativus* L. (Cruciferae), than for certain other row crops. Because radish is often grown in urban and community gardens, near common knotweed and other prostrate weeds, it was chosen for the present experiment. As initial observations suggested that roadside patches of common knotweed often featured high densities of bigeyed bugs, the studies were conducted in these habitats. Such patches may recur year after year, and they may be similar to those encountered in many urban and community gardens.

In order to determine whether the associated weed flora might influence densities and efficiencies of bigeyed bugs and other predators on the crop plants, flats of radish were embedded amid almost pure wild stands of common knotweed and in nearby mixed stands of other weeds.

Methods

The study area was situated along the borders of a dirt access road running between two hay alfalfa fields managed by the Department of Animal Science at the University of California, Davis. Along these borders, some zones featured dense, nearly pure common knotweed stands providing nearly complete cover. Other sections featured other weeds, such as *Sonchus* spp. (Compositae), *Linaria* sp. (Scrophulariaceae), and various grasses (Gramineae), as well as volunteer alfalfa plants. The latter areas were generally free from common knotweed, and none of the other species afforded exposed nectar. There had been no recent herbicide application.

Starting in mid-August, 1982, domestic radish (cv "Scarlet Globe" and "Sparkler") was grown from seed in plastic flats (dimensions 17 cm \times 11 cm, and 6 cm high, 1,100 cm³ in volume) containing a soil mix of 2 : 1 sandy loam to peat moss. Approximately 2 weeks after germination, the flats, having 10 plants each, were taken to the field.

On 1 September, 1982, six flats of radish (cv "Sparkler") were placed at randomly-chosen sites amid the stands of common knotweed; six were also placed in nearby sites without common knotweed, but featuring other adjoining broadleaved weeds, grasses, or volunteer alfalfa. Flats were embedded so that the rims were approximately at soil level, and spaced no closer than 2 m from one another. On 20 September, three additional flats (cv "Scarlet Globe") were added to each treatment. Irrigation was provided as needed. At the end of the experiment, no attempt was made to measure radish yields because the flats interfered with normal root growth.

Geocoris and other predators occurring on radish foliage or soil in the flats were sampled 18 times: 11 sampling episodes for the original six replicates, followed by 7 for the nine replicates. Sampling was conducted on 1, 5, 6, 7 (twice), 8 (three times), 9, 11, 13, 20, 21, 22, 23, 26, and 27 September, and 2, 12, and 26 October. Data for the periods of six and nine replicates were analyzed by separate repeated-measures ANOVA. The mean-squares for "among flats, corrected for weed regime" were used as the error terms in all the F-tests for effects due to weed regime.

To gauge predation rates, egg masses of an armyworm, *Pseudaletia unipuncta* (Hayworth) (Lepidoptera: Noctuidae), were used as baits. Laboratory-reared moths were allowed to oviposit in the crevices of pleated pieces of paper towel. After exposure for 12 hours, towel pieces were removed and moistened with distilled water to weaken the layers of adhesive substance applied by the ovipositing moths. The pleats were then teased apart and the towel pieces were cut into rectangular pieces (ca 0.64 cm \times 1.27 cm). The baits averaged 15 eggs (range ca 6 to ca 30), usually in monolayers. Baits were held in cold storage for a maximum 3 days before use.

Randomly-selected baits were stapled to radish foliage in the flats and subsequently inspected for occupancy, or damage presumably caused, by predators. Exposure periods were uniform for any one trial and ranged from three to 24 hours for different trials. Trials were conducted on 2 September (3 h), 11 (24 h), 13 (19.5 h), 22 (24 h), and 27 September (24 h). Rates of discovery by predators were then assessed by one-way ANOVA, using a binomial response variable for discovery versus non-discovery. That is, a bait occupied or apparently damaged by a predator was scored as a "1." Otherwise, it was scored as a "0." Overall analysis was done using proportions of egg masses discovered in each flat, pooled over all dates. Thus, multiple observations from each flat were regarded as subsamples. Proportions pooled over dates were analyzed following transformation ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$) (Neter and Wasserman 1974, 507-8). As with the count data, all F-tests for effects due to weed regime employed the mean square for "among flats, corrected for weed regime" as the error term.

Results

Data for *Geocoris* spp. occurring in radish flats are summarized in figure 5. Densities of bigeyed bug on flats with adjacent common knotweed were significantly higher than on flats with other adjoining weeds. Respective overall means (\pm S.E.M.) were 0.33 ± 0.10 and 0.06 ± 0.03 ($P = 0.0246$) during the first period ($n = 6$), and 1.11 ± 0.15 and 0.06 ± 0.02 ($P = 0.0001$) during the second ($n = 9$).

A number of other predators occurred in the radish flats. These included ants, such as *Conomyrma* sp., *Formica* sp., and *Tetramorium caespitum* (Linnaeus) (Hymenoptera:

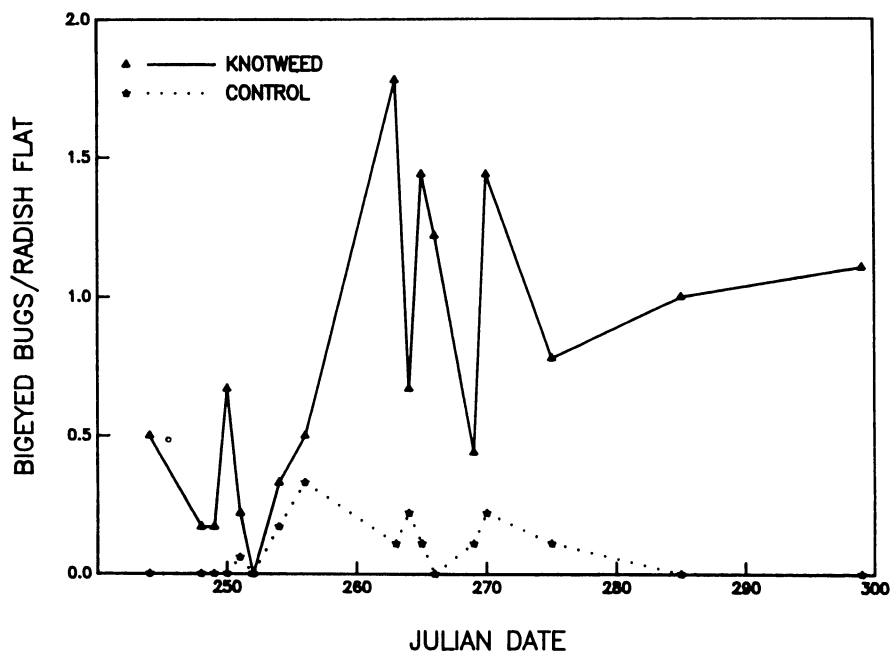


Fig. 5. Bigeyed bugs per radish flat, adults and nymphs of all species pooled, 1982.

Formicidae); harvestmen (Phalangida); *Lygus* sp. (Hemiptera: Miridae); and various ladybeetles (Coleoptera: Coccinellidae). Data obtained for these predators (pooled) are presented in figure 6. Overall analysis of data for the period of six flats per weed regime yielded non-significant differences, with the means for knotweed and control flats being 0.38 ± 0.09 and 0.33 ± 0.10 ($P=0.74$). The corresponding results for $n=9$ were 0.91 ± 0.12 and 0.58 ± 0.10 ($P=0.0521$). The latter results would have been declared statistically significant had a one-tailed t-test been used, based on the hypothesis that flats with adjoining common knotweed should have higher predator densities ($P=0.026$).

Results of the predation studies are presented in figure 7. Overall analysis indicated significant differences in favor of radish with adjoining common knotweed, with respective means (\pm S.E.M.) for knotweed and control flats being 0.54 ± 0.06 and 0.35 ± 0.06 ($P=0.0334$). Although the overall predation rate was ca 1.5 times greater in flats with adjoining common knotweed, predation rate was actually higher in the control on two dates. Of the 68 armyworm egg masses placed in flats surrounded by common knotweed, 37 were damaged or occupied by predators at the times of inspection, compared to 24 of 66 in the control flats (two baits in the control could not be found at time of inspection). If there was a treatment effect, it could hardly be considered a strong one.

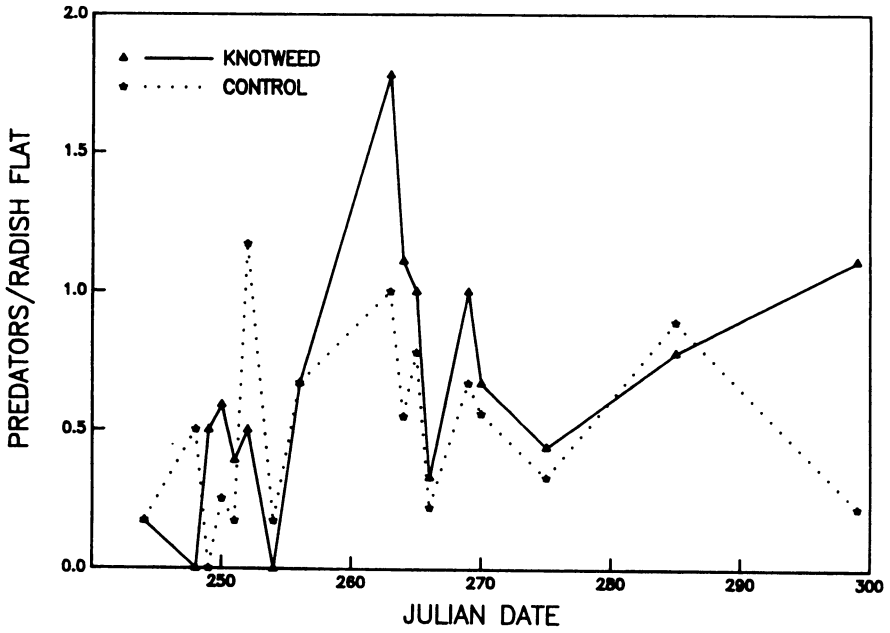


Fig. 6. Total predators (exclusive of bigeyed bugs) per radish flat, 1982.

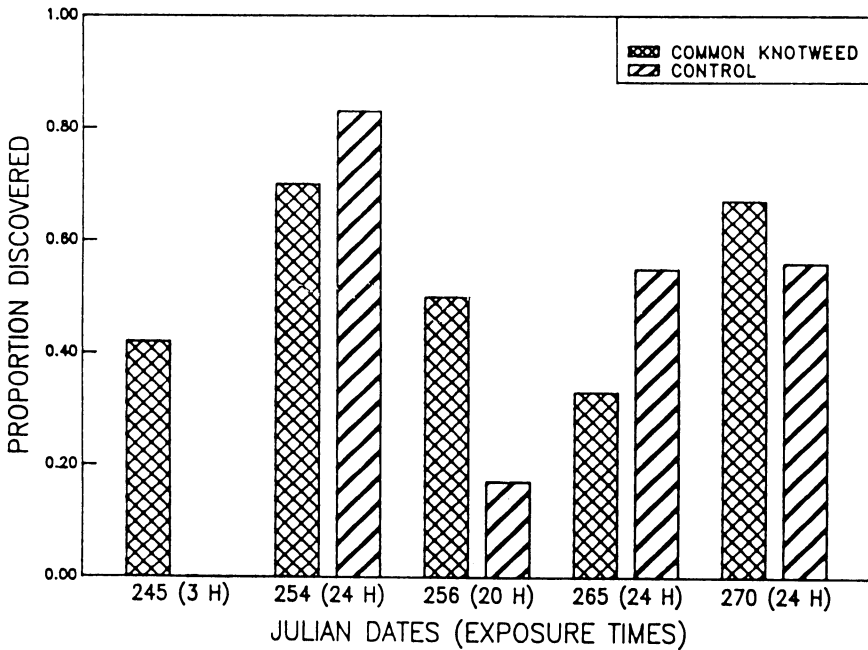


Fig. 7. Proportions of *Pseudaletia unipuncta* egg masses on radish damaged or occupied by predators, 1982. No predators were observed in control plots on Julian date 245.

BELL PEPPER STUDIES

Studies involving bell pepper (*Capsicum annuum* L., Solanaceae) and common knotweed complemented those involving radishes and weeds. However, instead of inserting crop plants into matrices of weed flora, common knotweed was interplanted among commercial, organically-grown bell pepper plants. The aim was to determine what effect nearby common knotweed might have on predator densities and efficiencies on the crop plants.

In California, commercial acreages of bell pepper are located primarily in Santa Clara, San Benito, San Joaquin, Stanislaus, Ventura, and Merced Counties (Sims and Smith 1976). Bell pepper is also commonly grown in home and community gardens in various parts of the state. Common knotweed typically germinates from late winter to mid-spring. Bell pepper is a summer crop and land preparation generally includes spring tillage; therefore, common knotweed is seldom encountered in commercial fields. However, in community gardens, common knotweed often occurs on pathways, near pepper and other crop plants.

In northern California, bell pepper is subject to attack by the following insects: green peach aphid, *Myzus persicae* (Sulzer) (Homoptera: Aphididae); corn earworm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae); beet armyworm, *S. exigua*; saltmarsh caterpillar, *Estigmene acrea* (Drury) (Lepidoptera: Arctiidae); and omnivorous leafroller, *Platynota stultana* Walshingham (Lepidoptera: Tortricidae). Adult spotted cucumber beetle, *Diabrotica undecimpunctata* (Barber) (Coleoptera: Chrysomelidae), is often abundant on pepper plants, but appears to cause little direct damage. At the time of these studies, there was little documentation on the role of biological control in suppressing these pests in the bell pepper agroecosystem, but observations by E. J. Dietrick (*pers. comm.*) suggested that bigeyed bugs may frequently be abundant.

Methods

Common knotweed seedlings were excavated from roadside stands near Davis during the late winter of 1981-82 and transplanted to plastic pots (dimensions ca 20 cm deep and 15 cm in top diameter). Each pot contained a mixture of about 1 part peat moss to 2 parts sandy loam. The potted weeds were housed in a greenhouse and provided with water and 0.1-strength modified Hoagland's Solution (Epstein 1972, 32) as needed, until time for transplanting to the field.

Bell pepper (cv "Yolo Wonder") was seeded on 22 March, 1982; seedlings were grown in a greenhouse until 2 June. At that time the seedlings were transplanted to two, three-row blocks, each extending some 215 m from east to west. Block I bounded the southerly side of the farm, abutting on a dirt access road, with an intervening roadside weed complex featuring grasses but very little common knotweed. On the north side of Block I were rows of melons and cucumbers. Block II was located in the interior of the farm and adjoined rows of eggplant and squash. Pepper plants were transplanted into 112-cm beds having 20- to 25-cm irrigation furrows on each side. Plants were installed at 38-cm intervals, two rows to a bed, on the outer edges of each bed.

Common knotweed plants were transplanted to the field in mid-June. Planting was done during late afternoons, followed by watering, to ensure a good rate of establishment. Each block was assigned 10 plots with common knotweed and 10 clean-cultivated plots. Plot locations were randomly selected from many possible sites in the central bed of each block, and randomly assigned to the two treatments. Successive plots were separated by a minimum distance of 3 m to limit the exchange of *Geocoris* and other predators among plots. A plot with common knotweed comprised two common knotweed plants, separated from one another by ca 38 cm, and the adjoining six bell pepper plants. A control plot simply consisted of six bell pepper plants and the intervening bare ground. After establishment of the weeds, the plots received no special cultural treatment; the farmer provided irrigation to the crop as needed.

Several approaches were used in assessing population densities of various predaceous arthropods found in the plots. In order to gauge densities of *Geocoris*, a 10-cm-radius metal hoop was placed at the centers of the plots. In common knotweed plots, the weed foliage was lifted up and the hoop placed down on the underlying ground. The foliage was shaken lightly, and any *Geocoris* observed in the circumscribed area were counted. In control plots, the hoop was placed on the bare ground at the plot centers, and any *Geocoris* observed were counted. Such counts were conducted on 14 occasions in Block I: 6, 9, 12, 14, and 28 July; 1, 4, 12, 15, 23, and 29 August; 15 and 23 September; and 14 October. Plots in Block II were sampled on nine occasions: 26 June; 7 (twice), 14 (twice), and 28 July; 24 and 29 August; and 11 September. Adult and nymphal *Geocoris* spp. (pooled) were counted and data were analyzed by two-way ANOVA. Weed regime and block were regarded as crossed factors, and repeated measures from the same plots were treated as subsamples. The F-tests for effects due to weed regime employed the mean square for "among plots, corrected for weed regime, block, and interaction" as error term. This was also the case in all subsequently-mentioned instances in which subsamples or repeated measures were taken during this study.

On 14 July and 5 September, predators (including *Geocoris*, all species and post-embryonic stages pooled) occurring on the ground within 5 cm of each pepper plant were counted. These data were analyzed by ANOVA as above; weed regime and block were regarded as crossed factors. Observations from different pepper plants in the same plot were regarded as subsamples, with observations from different dates regarded as repeated measures.

Two-minute observations in each plot of Block I provided data on abundance of pooled entomophaga (including parasitic and predatory species), in crop and non-crop components under both weed regimes. These data were collected only on 9 August, in the early afternoon hours. Each plot was approached stealthily; then, to compensate for any disturbance caused by the observer, 30 seconds were allowed to pass before observation began. Each plot was observed from a standing position for a period of 2 minutes. Counts were recorded for predaceous arthropods observed on the six pepper plants within each plot, and for predators observed on the remainder of each plot (on the common knotweed or on the ground). Separate one-way ANOVA were used to test for effects of weed regime on: (1) cumulative predators in each plot, (2) predators observed on pepper plants in each plot, and (3) predators observed on common knotweed or on the ground in each plot. For each plot, the value obtained by criterion (1) represented the sum of those obtained by criteria (2) and (3).

Samples were obtained on eight occasions for predatory arthropods occurring on foliage of bell pepper plants. Sampling was done by shaking individual pepper plants 10 to 20 times over a sweepnet of 38-cm diameter. Predators caught were then counted after having been classified as minute pirate bug, soft-winged flower beetle (*Collops vittatus*), or other entomophaga (pooled), such as bigeyed bugs, erigonid spiders, or anthicid beetles. Plots in Block I were sampled during the night of 22 July and during the early afternoon on 4, 15, and 23 August. Plots in Block II were sampled on 24 August. Plots in both blocks were sampled on 1 and 17 August. Only one pepper plant per plot was assessed on 4 August and two plants per plot on the remaining 7 dates. Following transformation of the raw data ($y' = \text{SQRT}(y+1)$) (Neter and Wasserman 1974, 507), densities of *Orius*, *Collops*, and total predators were assessed in separate ANOVA. The ANOVA models employed weed regime and block as crossed factors, with sampling of the same plots on successive dates regarded as repeated measures. Measurements taken on multiple plants in the same plot on a given day were regarded as subsamples for that plot-date combination.

Densities of entomophaga, per se, do not provide sufficient information on predator efficiency under differing weed regimes. Therefore, predator efficiency was assessed by baiting with armyworm egg masses (prepared as in the radish study), both at ground level and in the upper foliage of bell pepper plants. Following specified periods of exposure, baits were inspected for characteristic damage and for predators occupying the baits. One might reasonably infer that for an enhancement scheme to be effective in the bell pepper agroecosystem, it should result in enhanced natural enemy efficiency in the foliar strata, where vulnerable stages of the most important pests occur.

Predation efficiencies at ground level were assessed on five occasions: 18 and 21 July; and 9, 13, and 16 August. These trials were all conducted during afternoon hours. Baits were placed on the soil surface at the bases of pepper plants. Two baits per plot, each placed at the base of a different pepper plant, were employed on 21 July and one bait per plot on the other dates. Predation efficiencies were assessed in the upper foliage on four occasions: the afternoon hours of 30 July and 5 and 6 August, and the evening hours of 5 August. Baits were stapled to the plant foliage. Two baits per plot, each stapled to a separate pepper plant, were employed on all dates.

After specified periods of exposure, elapsed times being the same for all baits in any one trial, the baits were inspected for predators or damage to eggs apparently caused by predators. Proportions of baits occupied or damaged in the ground-level and foliar trials were assessed using separate ANOVA. Analysis followed transformation of the proportional data, as in the radish trials. Weed regime and block were regarded as crossed factors, with observations from the same plot on different dates regarded as repeated measures and multiple observations per plot on a given date regarded as subsamples.

Data were also assessed for *Geocoris* and total predators (including *Geocoris*) actually observed on or within 5 cm of the ground-level baits. Analysis was by separate ANOVA, with each data set being assessed both before and after transformation as with earlier count data. Aside from the use of a different transformation, the ANOVA models employed were similar to those mentioned above for the proportional data on egg mass predation. No analyses were conducted for predators discovered on baits stapled to the foliage. Although evidence of predation was detected on those foliar baits, too few predators were actually seen on the baits to render such analyses useful.

If a weed is to be of value in an enhancement scheme, it should not suppress yield through competition, allelopathy, or harborage of pests and diseases. In fact, one could reasonably demand that a weed contribute to improved crop plant vigor and yield, or at least profitability, before it be included in any commercial enhancement program. With this in mind, crop vigor and yield were assessed. Pepper plant height and width were measured on 31 July, from plots in Block I only. Four plants per plot were measured, and plant volumes were estimated by calculating the volume of a cylinder of equal height and diameter (width). This index to plant vigor was then assessed as the response variable in a one-way ANOVA, with weed regime regarded as the independent variable and multiple observations per plot regarded as subsamples.

Yield figures were obtained by weighing fruit picked by the farmer on 12 August. Yields per plant (assuming 6 pepper plants per plot) were analyzed using two-way ANOVA, regarding weed regime and block as crossed factors. Mean weight per pepper under the two weed regimes was assessed by a two-tailed t-test, ignoring the variables block and plot. Cull rates were assessed by sorting out fruit that showed external damage by pests or sun scald. These were scored as "culls"; marketable fruit were scored as such. Ratios of culls to marketable fruit under the two weed regimes were assessed by chi-square analysis of the count data arrayed in a 2×2 contingency table.

Results

Geocoris appeared to be more abundant at the centers of knotweed plots than on the bare ground afforded by control plots. The data for hoop sampling in Block I yielded highly significant differences due to weed regime ($P=0.0001$), the overall means (\pm S.E.M.) being 0.56 ± 0.08 and 0.01 ± 0.01 for knotweed and control plots, respectively (fig. 8). The results from Block II were also highly significant ($P=0.0001$), with overall means for knotweed and control plots being 0.74 ± 0.13 and 0.02 ± 0.02 (fig. 9). By contrast, there was no evidence for enhanced densities of all predators (including *Geocoris*) at the immediate bases of pepper plants (table 12). Predators found included bigeyed bugs; anthicid, carabid, and *Collops* beetles; and lycosid and erigonid spiders.

Figure 10 summarizes the results from 2-minute observations on entomophaga densities in pepper plots. The analyses indicated a significant difference for the whole plots (pepper plants plus bare ground or common knotweed), with the observed mean for plots with common knotweed showing a better than tenfold advantage. Differences were also detected in the non-crop portions of plots (bare ground or common knotweed), again in favor of common knotweed. By contrast, analysis of the counts obtained for entomophaga perched or foraging on the pepper plants failed to indicate any differences due to weed regime. Entomophaga observed included bigeyed bugs, *Collops*, a parasitic wasp (prob. *Chelonus* sp. (Hymenoptera: Braconidae)), and damselflies (Odonata: Coenagrionidae).

Data for *Orius*, *Collops*, and total predators (including the *Orius* and *Collops*) from shake sampling of pepper plants are presented in figures 11, 12, and 13, respectively. Bigeyed bugs, though present, were notably scarce in these samples. Other predators observed included anthicid beetles, ants, and erigonid spiders. Overall analyses of these data detected no significant differences due to weed regime. Overall means for knotweed and control (respectively) were as follows: for *Orius*, 0.56 ± 0.06 and 0.39 ± 0.06

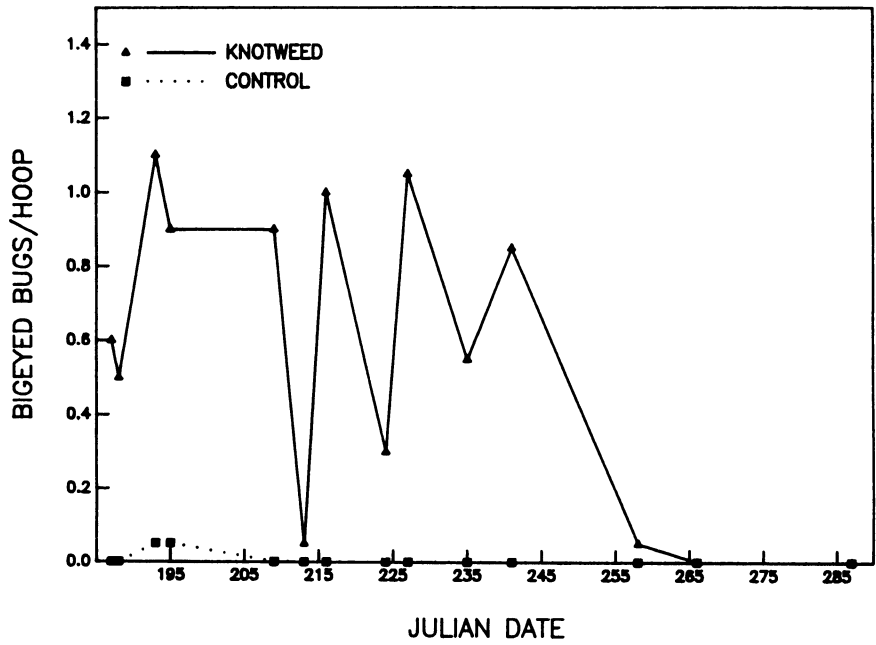


Fig. 8. Mean numbers of bigeyed bugs per hoop sample on ground at centers of bell pepper plots, Block I, 1982.

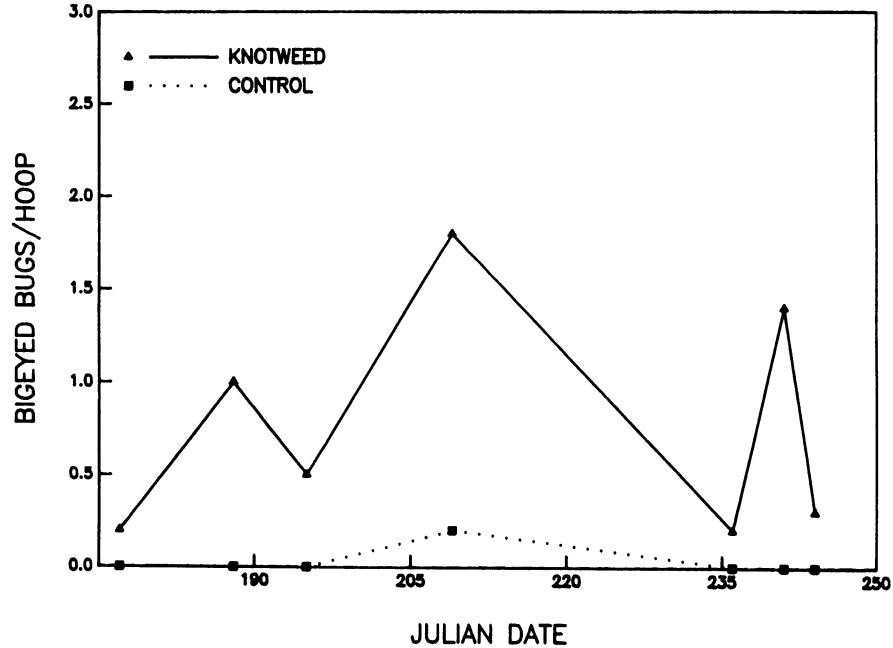


Fig. 9. Mean numbers of bigeyed bugs per hoop sample on ground at centers of bell pepper plots, Block II, 1982.

TABLE 12. ENTOMOPHAGOUS ARTHROPODS (INCLUDING *GEOCORIS*) OBSERVED WITHIN 5 CM OF THE BASES OF PEPPER PLANTS (1982)*

Date	n	Mean no. \pm S.E.M.	
		Knotweed	Control
July 14	15	1.02 \pm 0.19	1.08 \pm 0.22
Sept. 5	20	2.08 \pm 0.53	1.85 \pm 0.67
Overall	20	1.38 \pm 0.24	1.21 \pm 0.26

*Results of ANOVA: $F_{1,39} = 0.22$; $P = 0.6386$.

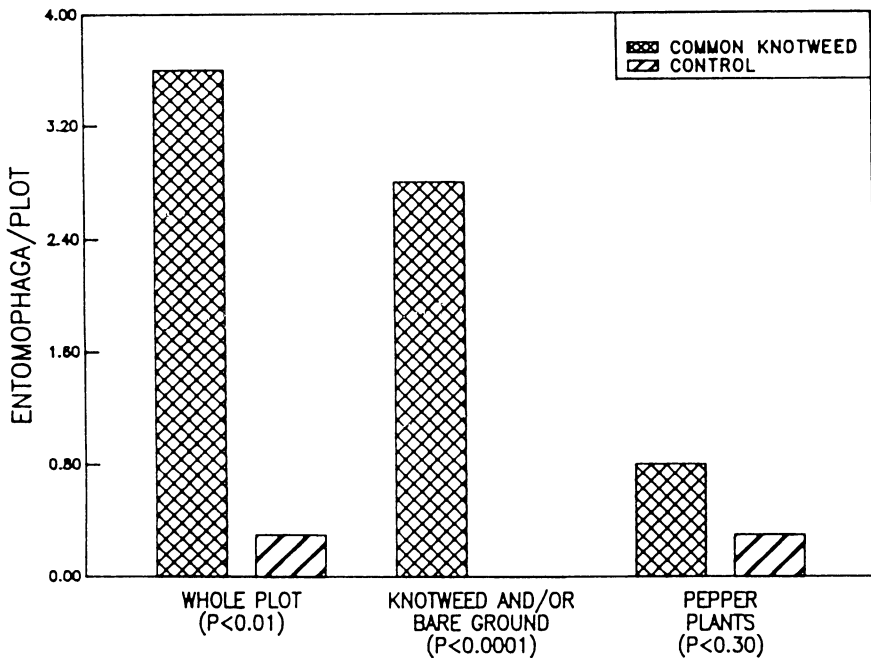


Fig. 10. Mean numbers of entomophagous arthropods observed per 2-min. observation in bell pepper plots, 1982. No entomophaga were observed on bare ground in control plot.

($P = 0.2033$); for *Collops*, 0.18 ± 0.04 and 0.17 ± 0.03 ($P = 0.8742$); and for total predators, 1.97 ± 0.20 and 1.79 ± 0.13 ($P = 0.3020$). It should be noted that although the data do not show significant overall differences due to weed regime, mean densities for minute pirate bug were consistently higher on pepper plants with adjoining knotweed, as indicated in figure 11.

Results were mixed for predation on armyworm egg masses placed at the bases of pepper plants. Analysis of transformed proportions of egg masses discovered showed significantly higher rates of predation in knotweed plots ($P = 0.002$); overall means were 0.77 ± 0.07 and 0.39 ± 0.05 for knotweed and control plots (fig. 14). Figure 15 depicts results for *Geocoris* found on or within 5 cm of egg masses. As *Geocoris*

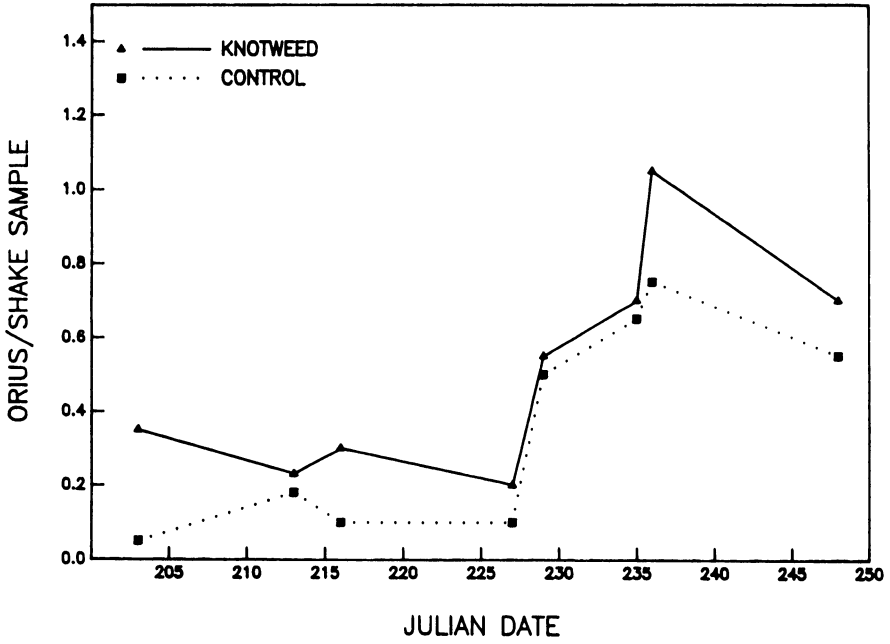


Fig. 11. Mean numbers of *Orius tristicolor* per shake sample from bell pepper plants, 1982.

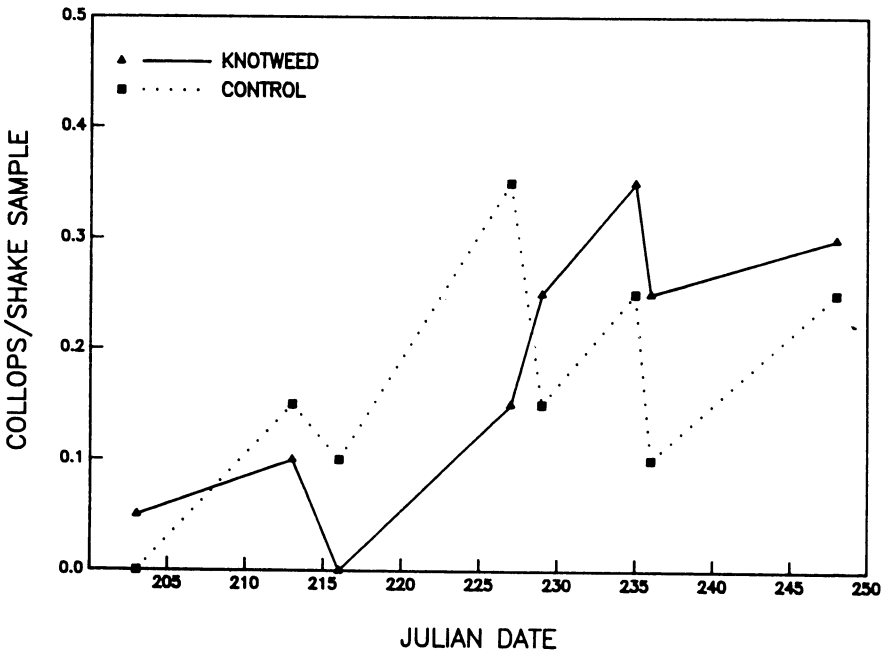


Fig. 12. Mean numbers of *Collops vittatus* per shake sample from bell pepper plants, 1982.

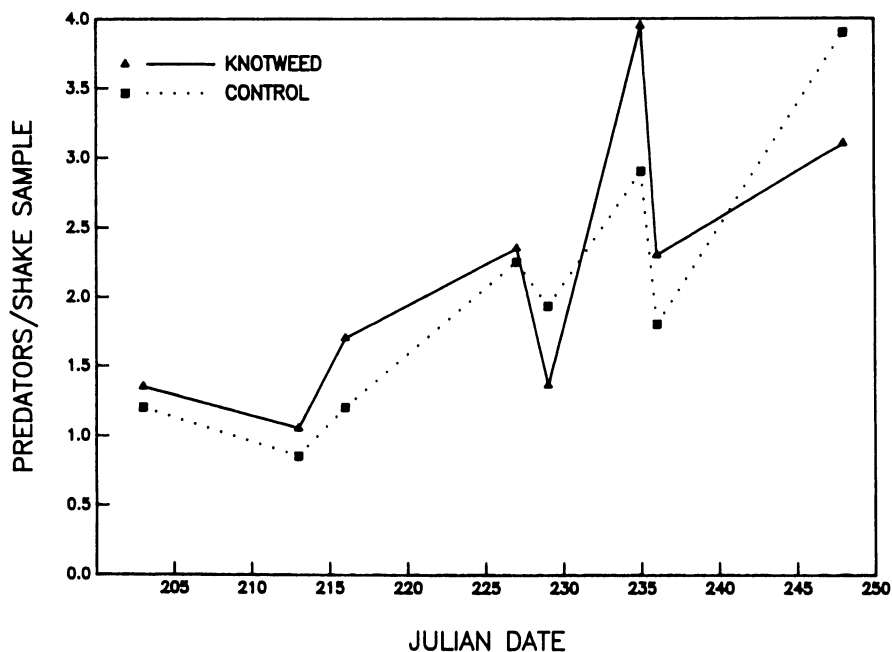


Fig. 13. Mean numbers of total predators per shake sample from bell pepper plants, 1982.

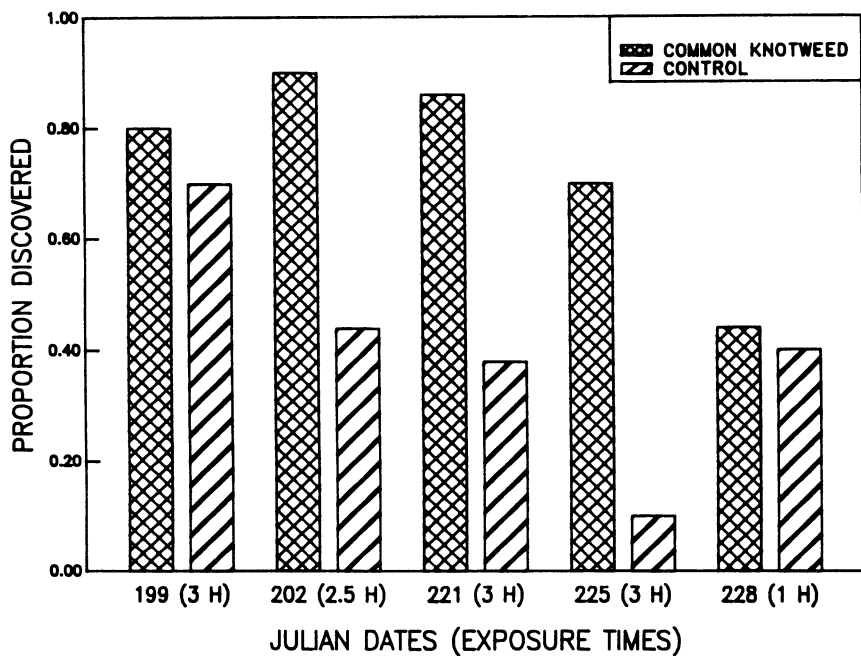


Fig. 14. Proportions of *Pseudaletia unipuncta* egg masses occupied or damaged by predators following placement at bases of bell pepper plants, 1982.

TABLE 13. INDICES TO PEPPER PLANT QUALITY IN PLOTS WITH VERSUS WITHOUT COMMON KNOTWEED (1982)

Variable (per plant)	Mean ± S.E.M. (n = 20)		F _{1,18} (P)
	Knotweed	Control	
Height (cm)	37.88 ± 0.91	38.38 ± 0.76	0.18 (0.678)
Width (cm)	25.00 ± 0.64	23.75 ± 0.63	1.96 (0.179)
Estimated volume (m ³)	0.029 ± 0.001	0.028 ± 0.001	0.23 (0.636)
Number of fruit	3.00 ± 0.34	3.13 ± 0.37	0.06 (0.805)

occurred only on the first three dates, analysis was restricted to those. ANOVA of transformed data indicated significantly higher per-bait densities of bigeyed bugs ($P=0.0481$), while the corresponding analysis for untransformed data yielded a non-significant result ($P=0.0641$). Overall means for knotweed and control plots were 1.11 ± 0.43 and 0.29 ± 0.11 . Figure 16 presents the results for total predators occurring on or near armyworm egg masses placed at the bases of pepper plants. Overall analysis indicated no significant difference due to weed regime ($P=0.5406$), and overall means for knotweed and control plots were 2.24 ± 0.43 and 1.39 ± 0.47 .

None of the plant-quality or yield data indicated suppression of pepper plants by knotweed. Results for ANOVA and descriptive statistics for plant height, width, volume, and number of fruit per plant are expressed in table 13. No significant

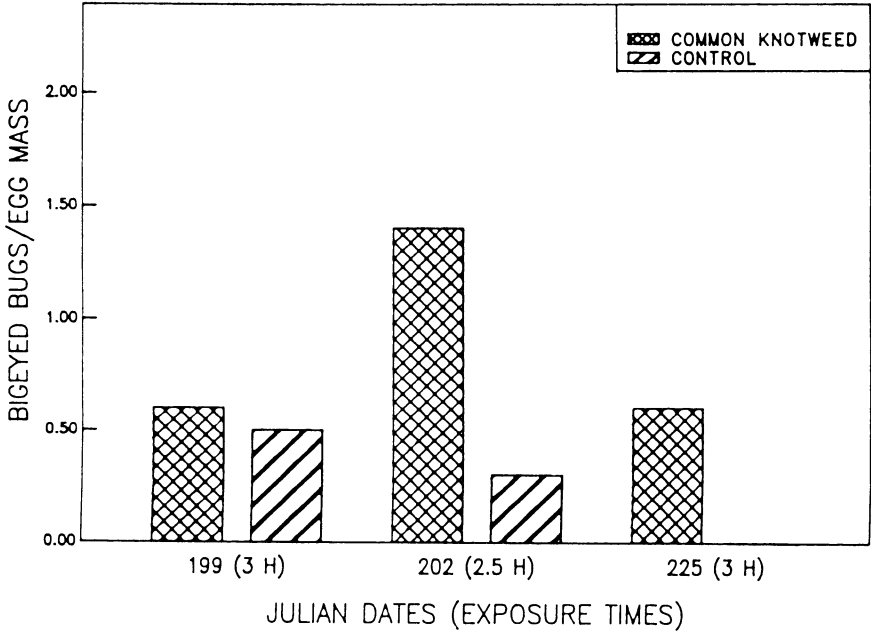


Fig. 15. Mean numbers of bigeyed bugs found on or within 5 cm of *Pseudaletia unipuncta* egg mass baits placed at bases of bell pepper plants, 1982. No bigeyed bugs were observed in control plots on Julian date 225.

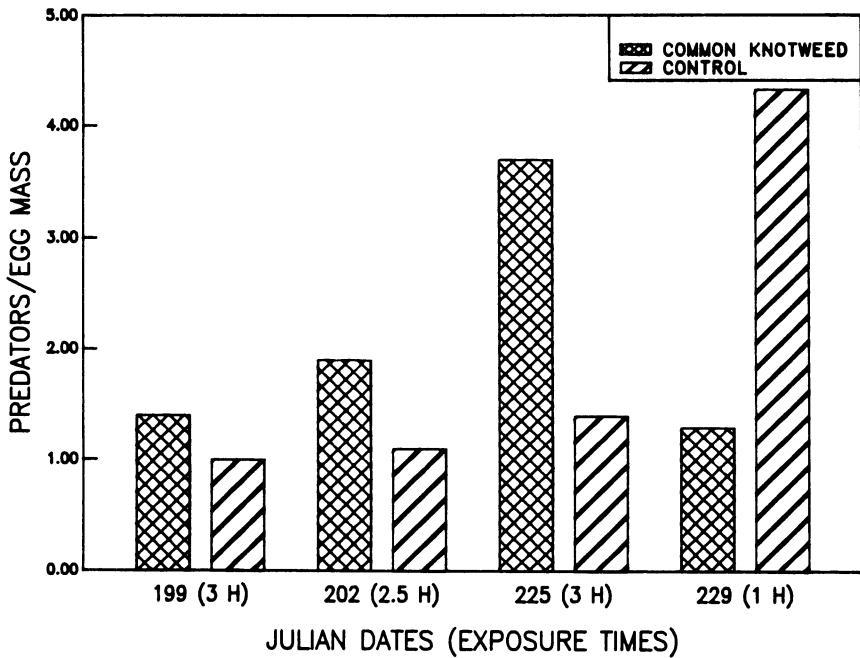


Fig. 16. Mean numbers of total predators found on or within 5 cm of *Pseudaletia unipuncta* egg mass baits placed at the bases of bell pepper plants, 1982.

differences due to weed regime were evident. In addition, analysis of data for fruit yield (grams of saleable fruit per plant) showed no significant differences due to weed regime ($P=0.99$), with means being 29.2 ± 7.3 g for knotweed and 28.0 ± 6.7 g for control. Fruits had higher mean weights in the plots with common knotweed ($t=2.32$; d.f. = 25; $P=0.029$): in plots with knotweed the result was 135.0 ± 4.3 g, while in control plot, it was 120.0 ± 4.5 g. There were 13 saleable peppers and 24 culls from plots with common knotweed, versus 14 saleable and 23 culls from control plots. The Chi-square analysis of data in the 2×2 table failed to indicate significant differences due to weed regime (Chi-square = 0.06; d.f. = 1; $p>0.90$).

ALFALFA STUDIES

Hay alfalfa, *Medicago sativa* L. (Leguminosae), is a crop of several years' duration, harboring such Lepidoptera as yellow-striped armyworm, *Spodoptera praefica* (Grote) (Noctuidae); beet armyworm, *S. exigua*; and alfalfa caterpillar, *C. eurytheme* (Summers, Gilchrist, and Norris 1981). The crop also frequently sustains high densities of various generalist predators, several of which attack at least the first two pests mentioned above (Bisabri-Ershadi and Ehler 1981; Eveleens, van den Bosch, and Ehler 1973). These predators include *Geocoris* spp. Benedict and Cothran (1975) found that, of the three species of bigeyed bugs usually encountered in hay alfalfa, *G. atricolor* Montandon was the most common, followed by *G. pallens* and *G. punctipes*. As common knotweed

frequently occurs in hay alfalfa fields, this weed-crop combination seemed a logical prospect for enhancement of biological control. The following experiments were intended to test this possibility.

Methods

The study was conducted at the Student Experimental Farm at the University of California, Davis, during 1983, in a 2.25-ha field extending 67 m in the east-west dimension and 55 m in the north-south dimension. On 12 May, EPTC, a preemergence herbicide, was applied (3.63 kg/ha) and incorporated into the soil by disking; the next day, alfalfa seed (cv "Amador") was sown at 32 kg/ha. Sprinkler irrigation was employed for the duration of the project. After alfalfa establishment, irrigation was as infrequent as possible, to simulate the arid conditions of levees in commercial fields, where both common knotweed and bigeyed bugs appeared most abundant (R. L. Bugg, *pers. obs.*).

On 27 May, during the early establishment phase of the crop, sites of future plots were marked and cordoned off. The overall layout featured 20 plots in a 4×5 arrangement. Each plot was 6.1×6.1 m, and consecutive plots were separated by 6.1-m alleys. Sixteen of the original 20 plots were employed in the experiment. Four weed regimes were featured in strips 0.61 m wide extending along east and west plot margins: (1) common knotweed, (2) prostrate pigweed, (3) common purslane, and (4) borders of pure alfalfa—that is, no weeds. A 4×4 Latin square was employed.

Earlier, during the winter of 1983, seedlings of common knotweed, common purslane, and prostrate pigweed were grown in the greenhouse in polyvinyl chloride growing trays having cell dimensions 3.81-cm diameter and 6.99-cm depth (produced by Growing Systems, Inc., of Milwaukee, Wisc.). The weeds were grown in a soil mix of 3:2:1, sandy loam:delta peat:sand; as in the bell pepper experiment, water and 0.1-strength modified Hoagland's solution were provided as needed.

On 28 May, the weeds were planted along the west and east borders of the appropriate 12 plots. Each border received 20 plants of the appropriate species, in two offset rows per border. Rows were separated by about 0.46 m, and within-row spacing between consecutive plants was about 0.61 m. The aim was to ultimately obtain complete vegetational cover in all borders. Due to a shortage of prostrate pigweed, additional specimens were transplanted from nearby field sites. Weeds were watered by hand for several days after transplantation. To compensate for mortality, supplemental transplants were added on 13 and 14 June, and on 15 July.

On 10 June, the inter-plot alleys, intended to limit exchange of predators, were cultivated using a tractor-drawn rotovator. All alfalfa and weeds were thus removed between consecutive plots, exclusive of the borders. The preemergence herbicide failed to prevent growth of common purslane, red root pigweed (*Amaranthus retroflexus* L., Amaranthaceae), and various grasses in the alfalfa. Therefore, the plots were hand-weeded, beginning on 11 June and continuing through early July. The field was fenced against rabbits on 28 June.

Plots were mowed only once, in late August; by contrast, most hay alfalfa fields in the area are mowed monthly during the summer. Mowing was minimized because it apparently causes many predators to disperse (Rakickas and Watson 1974). Plots were

mowed using a sickle-bar attachment mounted on a rototiller. Non-border portions of the plots were mowed to a height of 7.6 cm. Plot borders were left intact, including the alfalfa borders of control plots.

Complete vegetational cover in the borders was not always obtained. Interspecific differences in establishment and growth, as well as differing herbivore and pathogen pressures, led to differing proportions of cover among weed regimes. Proportions of cover in the borders were visually assessed on 16 July and 14 August, and ANOVA was performed following transformation as mentioned previously for other proportional data. Weed regime and Latin square row and column were regarded as crossed factors; estimates from the two borders of each plot were regarded as subsamples. The mean square for "among plots, corrected for weed regime, row, and column" was used as the denominator in tests to detect effects due to weed regime (this was the case in all subsequent ANOVA, unless otherwise mentioned).

Predator densities in border vegetation were assessed in common knotweed, pigweed, and control plots. In borders of common purslane, a fungal pathogen and two herbivores caused severe damage, as described earlier, rendering those borders essentially bare by late July, and thus of little interest. Sampling was done by placing a hoop of 10-cm radius at predetermined stations, and counting arthropods found under the foliage. Sampling was conducted on eleven dates: 3, 5, 10, 15, 16, 24, and 25 August; 3, 16, and 23 September; and 11 October. On eight dates, there were three stations in each border: 2 m from edge, center of border, and 2 m from the other edge. On three dates, one or two subsamples were taken per border. The data obtained for *Geocoris* spp. and total predators (including *Geocoris*) were analyzed by separate ANOVA with repeated measures. As plots in only three of the four weed regimes were included, an approximate analytical procedure for the partial Latin square design was employed. Separate analyses were run, alternately using row and column as factors crossed with weed regime. Data from only eight of the eleven sample dates were used in analyzing *Geocoris* counts from the borders. The dates used were those in which three subsamples per border were obtained.

For additional information on densities of entomophaga in borders, visual inspections were made on 11, 14, 16, 19, 29, and 31 July. These inspections entailed walking slowly from north to south along the east and west borders of each plot, and recording the *Geocoris* observed. This was done while waving one hand above the borders in an attempt to flush bigeyed bugs which might otherwise remain still and therefore go unobserved. The vegetation was not physically disturbed. Whereas the hoop method was used to detect *Geocoris* and other predators occurring under border foliage, this technique was useful in detecting *Geocoris* occurring on the soil surface. However, this approach was only feasible early in the season when proportions of vegetational cover were less than 0.50. By early August, cover was so dense in several plots that ground-dwelling arthropods were very difficult to see. The data for *Geocoris* spp. were analyzed by ANOVA for Latin square with the two borders of each plot regarded as subplots, and dates regarded as repeated measures.

Weekly sampling in the alfalfa was conducted from 16 June to 22 September (15 sampling dates), using the U.C. Vac suction device (Summers, Garrett, and Zalom 1984). The aim was to assess densities of four predatory species within the alfalfa: *Geocoris*, *Nabis* spp. (Hemiptera: Nabidae), *Lygus* spp. (Hemiptera: Miridae), and lycosid spiders. Representatives of the first three have been observed to feed at knotweed flowers, whereas high densities of lycosids are often associated with knotweed, perhaps

in response to high densities of prospective insect prey (R. L. Bugg, *pers. obs.*). Each plot was sampled by placing a 33-cm-diameter plastic hoop in the center and four corners. Corner sectors were located ca 61 cm inside the alfalfa. After the hoop was placed, the U.C. Vac was used to vacuum thoroughly the circumscribed alfalfa foliage and underlying soil surface. Sampling was generally started at 1030 (PDT), and required about 1.5 hours to complete. The plots were always sampled in the same sequence. Samples were immediately placed on ice, then kept in cold storage, and cleaned and sorted using a graded series of U.S.A. Standard Testing Sieves. Sample material was placed at the top (the coarsest sieve) of the series, and rinsed with tapwater for several minutes. The material was then transferred to white enamel trays, and the various arthropods were counted. Data for the four arthropod taxa mentioned were analyzed using ANOVA models for Latin square with repeated measures.

Predator densities in alfalfa were also assessed by another method, as a check on the U.C. Vac. Purslane plots were excluded from this comparison. The procedure involved counting *Geocoris* and other predators found within a hoop of 10-cm radius placed down at three stations within the alfalfa along the east and west sides of plots, 61 cm from the borders. These observations were made on 5 and 10 August; sampling regime and analytical approaches were otherwise similar to those employed for hoop samples from the border vegetation.

Shake sampling of border weeds was conducted on 19 August, in an attempt to gauge the densities of bigeyed bugs and minute pirate bugs on the foliage of common knotweed versus prostrate pigweed. The technique involved holding enough of each weed to cover the aperture of a 38.1-cm-diameter fine-mesh insect net; the plant was then given 10 vigorous shakes to dislodge insects. The contents of the net were then inspected and the insects enumerated. All plots devoted to common knotweed or prostrate pigweed were sampled, with two subsampling stations per border. The stations were located approximately 2 m from the north and south ends of each border. Because the latter comparison involved only two of the four weed regimes employed in the Latin square design, several approximate analytical procedures were employed. Untransformed data for *Orius* and *Geocoris*, adults and nymphs pooled in both cases, were analyzed in separate one-way ANOVA. Weed regime was regarded as a factor, and multiple observations per plot were regarded as subsamples; however, row and column were both ignored. In other words, these analyses were conducted as if the plots had been arrayed in a completely randomized design. Four alternate analyses were conducted on each of the two data sets. In these analyses, both transformed and untransformed data were assessed using two-way ANOVA. Weed regime was regarded as a factor in all analyses, while row and column were employed as alternative crossed factors in separate analyses.

To assess possible effects of weed regime on *Orius* densities in adjoining alfalfa, sweep sampling was conducted in all 16 plots on 18 August. This was done using a sweepnet with canvas bag and a diameter of 38.1 cm. Subsamples were taken at four corner stations within each plot. The stations were located 2 m from the north or south borders, and 0.61 m from the inside edges of the east or west borders. Two sweeps were made at each station, and adult and nymphal *Orius* were enumerated. Pooled densities of adult and nymphal bugs were assessed by ANOVA. Weed regime, row, and column were regarded as crossed factors, with multiple observations per plot regarded as subsamples.

On 31 August, nearly 2 weeks after mowing, *Geocoris* densities were again assessed in the alfalfa plots. It was thought that mowing, though a disruptive process, might make the resulting alfalfa habitat more attractive to bigeyed bugs by rendering a stand more open and sunlit. Thus, bugs occurring at high densities in weedy borders might show an increased tendency to move into adjoining alfalfa. This might improve the likelihood of enhanced biological control. Only the 12 plots under the common knotweed, prostrate pigweed, and control regimes were included in this comparison. The sampling procedure involved three east-west transects through each plot: two lateral transects situated 1.5 m from the north and south edges, and a third through the center. Along each transect, there were five subsampling stations, located at intervals of 1.53 m. These stations were located at the weed-alfalfa interfaces on east and west sides, and at the three intervening points within each plot. Thus, there were 15 subsamples taken per plot. The 10-cm-radius metal hoop was placed down at the appropriate sites along the transects, and the predators were enumerated. Per-hoop densities for *Geocoris* (all species and postembryonic stages pooled) were analyzed by ANOVA, both before and after transformation as above. The design employed was that of a partial Latin square, with multiple observations per cell, regarding weed regime, row, and column as crossed factors.

Studies on predation intensity were also conducted, employing baits of either beet armyworm egg masses or chunks of canned tuna, both of which are acceptable to a wide variety of predatory arthropods. Beet armyworm egg masses were employed on nine dates: 10, 16, and 20 June; 1, 6, 12, and 21 July; and 3 and 30 August. Egg masses were obtained as in the above study on monocultural weed plots. Egg masses contained from 10 to 30 eggs, the mean being 20. To simulate the ovipositional habit of beet armyworm, towel pieces containing fresh egg masses were fixed to upper foliage of alfalfa plants (using white glue). Plants used were always located 0.61 m in from the plot borders. Two egg masses were used per plot on each date, except on 30 August, when four were used; thus, a total of 320 baits was employed. Baits were generally placed out during the early afternoon hours and were inspected 24 hours later for occupancy, or damage presumably caused, by predators. Pooled proportions of baits occupied or presumed damaged by predators were obtained for each plot. Following transformation as previously mentioned for proportional data, these data were assessed by ANOVA for Latin square, with row, column, and weed regime regarded as crossed factors.

Chunk light tuna (vegetable oil base) was used in baiting experiments conducted on 4 and 13 October. Pieces of tuna approximately $1.5 \text{ cm} \times 1.5 \text{ cm}$ were placed on pieces of cardboard (dimensions $5 \text{ cm} \times 5 \text{ cm}$). Nine baits were used per plot per date, each bait being assigned to one of nine prescribed stations. Within each plot, these stations were arrayed in three rows, three baits per row. Three were placed in north-south rows along either border, 0.61 m within the alfalfa, and the remaining three were placed in a north-south row down the center of each plot. Intra-row distance between baits was 2 m. Baits were placed on the ground at the specified stations during the late morning, then inspected 1 hour later for occupation by predators. Several kinds of data were obtained, including numbers of *Geocoris* and pavement ant per bait, and proportions of exposed baits found by pavement ant (occupied by at least one worker). Count data were analyzed without prior transformation, while proportional data were analyzed following the transformation mentioned earlier. The Latin-square ANOVA models used in the

separate analyses were otherwise similar, employing weed regime, row, column, and date as crossed factors, with multiple observations per plot.

Crop yields were assessed on 7 November, by placing a wooden frame (0.093 m²) near the corners of each plot, 0.6 m from either edge, and clipping the enclosed alfalfa to 2.5-cm height. These samples were dried and weighed and the results analyzed using ANOVA for Latin square, with subsampling in each plot.

Results

Proportions of vegetational cover obtained in the plot borders are summarized in table 14. Cover was significantly greater for common knotweed and control (borders of pure alfalfa) than prostrate pigweed, and greater for these three than for common purslane. Proportions of cover for common knotweed and control plots were not statistically different, and only in these did the values reach 1.0 by mid-August. As with the studies involving monocultural weed plots, common purslane was severely damaged by herbivorous insects (Clement and Norris 1982) and a fungal pathogen (Klisiewicz, Clement, and Norris 1983).

An effect due to weed regime was detected for hoop samples of *Geocoris* in borders (fig. 17). Overall analysis indicated significant differences among all three weed regimes assessed ($P = 0.0002$ with Latin square columns as blocks, $P = 0.0001$ with Latin square rows as blocks). Prostrate pigweed borders featured the highest mean densities of *Geocoris* (1.29 ± 0.15), followed by common knotweed (0.92 ± 0.07) and the control (0.15 ± 0.04). Overall analysis for total predators (including *Geocoris*) in hoop samples also indicated significant differences ($P = 0.0039$) among weed regimes (fig. 18). In this case, however, common knotweed borders featured the highest mean densities of predators (4.85 ± 0.29), followed by prostrate pigweed (2.74 ± 0.12) and control (1.36 ± 0.15).

Data for visual inspection of *Geocoris* in plot borders also showed significant differences among weed regimes (table 15). Duncan's multiple range test indicated that the overall mean density for common knotweed was higher than for any of the other three regimes, and that means for common purslane and prostrate pigweed were not statistically different from each other, but both higher than those for control.

TABLE 14. PROPORTIONS OF VEGETATIONAL COVER ATTAINED IN THE BORDERS OF ALFALFA PLOTS (1983)*

Date	Mean proportion \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control [†]
July 16	0.38 \pm 0.14	0.79 \pm 0.06	0.47 \pm 0.09	0.72 \pm 0.08
Aug. 14	0.00 \pm 0.00	1.00 \pm 0.00	0.89 \pm 0.03	1.00 \pm 0.00
Overall	0.19 \pm 0.07c	0.90 \pm 0.03a	0.68 \pm 0.06b	0.86 \pm 0.04a

*ANOVA for proportions: $F_{3,6} = 212.28$; $P = 0.0001$; for transformed proportions ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{3,6} = 226.98$; $P = 0.0001$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

[†]Plots, including borders, devoted to pure alfalfa.

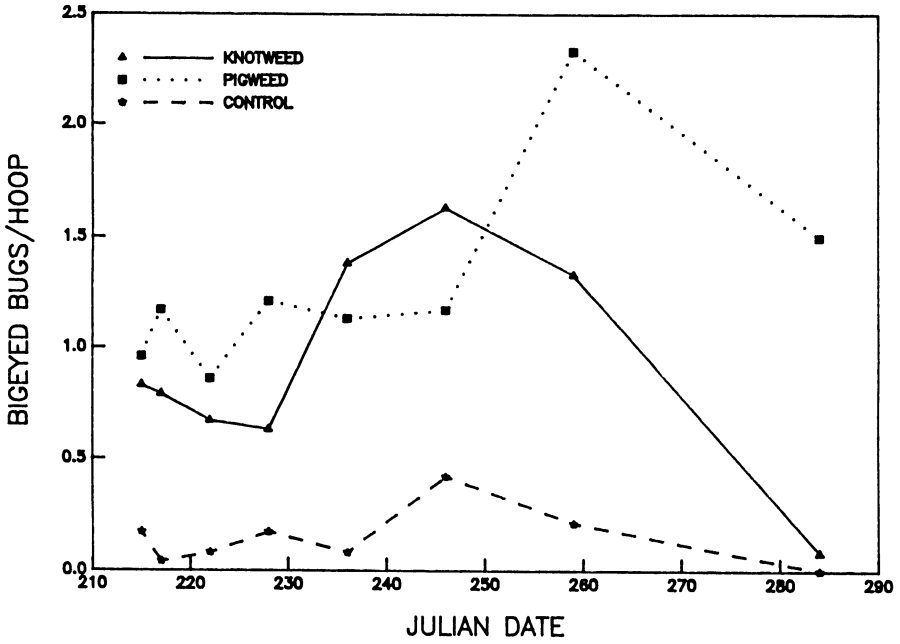


Fig. 17. Mean numbers of bigeyed bugs per hoop sample in borders of alfalfa plots, 1983.

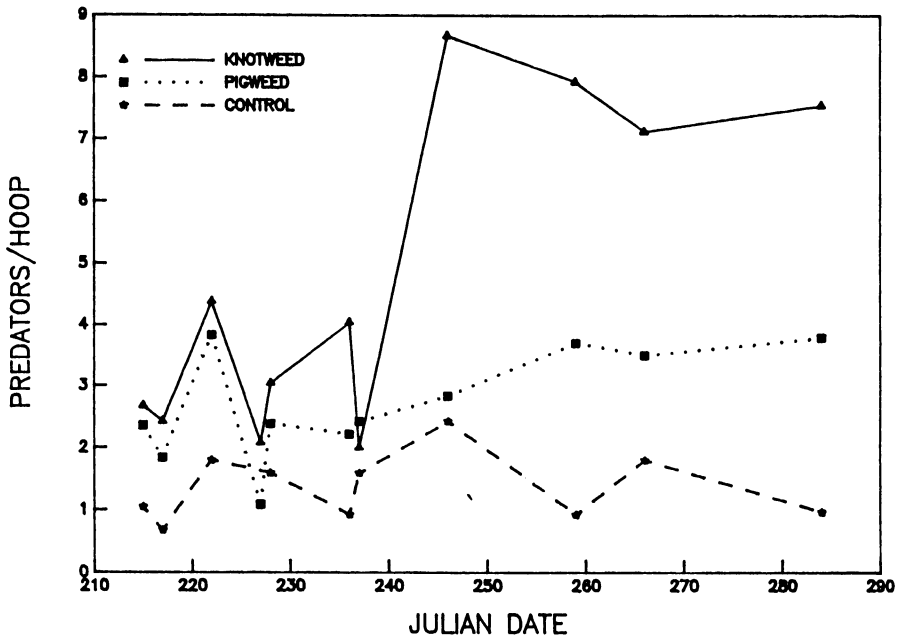


Fig. 18. Mean numbers of total predators per hoop sample in borders of alfalfa plots, 1983.

TABLE 15. BIGEYED BUGS (ALL STAGES) OBSERVED PER BORDERS DURING WALKS ALONG EAST AND WEST EDGES OF ALFALFA PLOTS (1983)*

Date	Mean no. (\pm S.E.M.) per border			
	Purslane	Knotweed	Pigweed	Control
July 11	2.12 \pm 0.88	4.00 \pm 0.35	1.67 \pm 0.93	1.00 \pm 0.61
14	1.75 \pm 0.48	5.00 \pm 1.84	2.63 \pm 1.36	1.00 \pm 0.20
16	1.25 \pm 1.25	1.63 \pm 0.69	0.33 \pm 0.17	0.13 \pm 0.13
19	2.75 \pm 0.85	3.00 \pm 1.02	2.50 \pm 1.17	0.13 \pm 0.13
29	1.75 \pm 0.75	4.88 \pm 1.38	3.25 \pm 0.95	— [†]
31	—	4.63 \pm 1.01	2.25 \pm 0.75	—
Overall	2.29 \pm 0.64b	3.85 \pm 0.53a	2.20 \pm 0.58b	0.56 \pm 0.12c

*ANOVA of transformed data ($y' = \text{SQRT}(y \pm 1)$): $F_{3,6} = 13.75$; $P = 0.004$. Overall means followed by same letter are not significantly different by Duncan's multiple range test.

[†]“—” indicates samples not taken.

TABLE 16. MEAN NUMBERS OF BIGEYED BUGS PER U.C. VAC SAMPLE IN ALFALFA PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control
June 16	0.50 \pm 0.50	0.00 \pm 0.00	0.25 \pm 0.25	0.25 \pm 0.25
23	1.75 \pm 0.75	1.75 \pm 0.25	1.25 \pm 0.48	1.00 \pm 0.41
30	2.50 \pm 0.50	2.50 \pm 1.19	0.75 \pm 0.48	2.75 \pm 1.31
July 7	1.00 \pm 0.71	5.00 \pm 0.91	3.00 \pm 1.15	2.75 \pm 0.85
21	4.50 \pm 1.85	2.75 \pm 0.85	2.00 \pm 0.91	2.75 \pm 1.25
28	3.00 \pm 1.08	2.50 \pm 0.65	1.75 \pm 0.48	2.25 \pm 1.44
Aug. 4	2.50 \pm 1.26	5.00 \pm 1.47	3.50 \pm 1.04	3.75 \pm 1.38
11	2.25 \pm 1.03	2.50 \pm 0.65	1.25 \pm 0.95	3.75 \pm 0.63
18	5.50 \pm 2.18	6.50 \pm 1.85	7.75 \pm 3.77	8.75 \pm 3.22
25	1.00 \pm 0.41	4.25 \pm 0.48	4.00 \pm 0.91	4.00 \pm 1.68
Sept. 1	4.75 \pm 1.65	7.25 \pm 0.75	5.75 \pm 1.03	5.75 \pm 2.10
8	10.50 \pm 3.23	11.00 \pm 3.39	14.75 \pm 3.64	9.75 \pm 2.10
15	8.75 \pm 0.75	11.25 \pm 0.48	7.75 \pm 1.11	7.50 \pm 2.50
22	4.25 \pm 0.95	4.25 \pm 0.95	5.00 \pm 0.82	2.25 \pm 0.63
Overall	3.83 \pm 0.62	4.57 \pm 0.48	4.03 \pm 0.20	3.87 \pm 0.63

*Results for ANOVA $F_{3,6} = 1.33$; $P = 0.3489$.

By contrast, results obtained for U.C. Vac sampling in alfalfa (tables 16 through 19) failed to indicate any significant differences due to weed regime for cumulative *Geocoris* spp., *Nabis* spp., *Lygus* spp., or lycosid spiders. Non-significant results were also obtained for hoop samples of *Geocoris* within the alfalfa ($P = 0.95$, by both analytical approaches). Overall mean per-hoop densities of *Geocoris* for common knotweed, prostrate pigweed, and control plots were 0.21 ± 0.07 , 0.23 ± 0.09 , and 0.25 ± 0.08 . In addition, samples taken within alfalfa plots 2 weeks after mowing failed to indicate effects on *Geocoris* densities due to weed regime ($F_{2,3} = 4.98$; $P = 0.111$), with mean

TABLE 17. MEAN NUMBERS OF *NABIS* SPP. PER U.C. VAC SAMPLE IN ALFALFA PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control
June 16	1.50 \pm 0.65	0.50 \pm 0.29	1.25 \pm 1.25	1.25 \pm 0.25
23	1.50 \pm 0.29	0.75 \pm 0.75	0.50 \pm 0.50	0.75 \pm 0.48
30	0.75 \pm 0.25	1.00 \pm 0.00	1.00 \pm 1.00	1.00 \pm 0.71
July 7	2.50 \pm 1.32	3.25 \pm 0.85	2.50 \pm 0.65	0.75 \pm 0.75
14	0.75 \pm 0.25	1.00 \pm 0.71	1.00 \pm 0.41	0.25 \pm 0.25
21	3.75 \pm 0.85	4.50 \pm 0.65	2.25 \pm 0.85	3.50 \pm 1.55
28	6.25 \pm 1.93	1.75 \pm 0.48	3.50 \pm 1.04	3.50 \pm 1.32
Aug. 4	4.00 \pm 1.22	1.75 \pm 0.85	4.25 \pm 1.31	3.00 \pm 0.91
11	6.75 \pm 0.95	6.50 \pm 2.18	2.50 \pm 0.96	5.50 \pm 1.55
18	4.00 \pm 1.83	4.74 \pm 2.46	3.50 \pm 1.04	3.25 \pm 0.75
25	0.00 \pm 0.00	0.25 \pm 0.25	0.50 \pm 0.29	0.00 \pm 0.00
Sept. 1	0.75 \pm 0.25	0.25 \pm 0.25	1.00 \pm 0.71	0.25 \pm 0.25
8	0.75 \pm 0.48	1.50 \pm 0.65	0.75 \pm 0.48	0.25 \pm 0.25
15	1.75 \pm 0.48	2.00 \pm 0.41	2.25 \pm 0.25	1.25 \pm 0.48
22	3.75 \pm 1.65	7.50 \pm 1.85	2.75 \pm 1.80	2.25 \pm 0.25
Overall	2.58 \pm 0.22	2.48 \pm 0.23	1.97 \pm 0.30	1.78 \pm 0.26

*Results for ANOVA: $F_{3,6} = 1.67$; $P = 0.2720$.TABLE 18. MEAN NUMBERS OF *LYGUS* SPP. PER U.C. VAC SAMPLE IN ALFALFA PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control
June 16	0.50 \pm 0.29	1.25 \pm 0.25	0.75 \pm 0.25	0.25 \pm 0.25
23	1.00 \pm 0.00	1.00 \pm 0.41	0.75 \pm 0.48	1.25 \pm 0.95
30	0.25 \pm 0.25	0.25 \pm 0.25	0.00 \pm 0.00	0.50 \pm 0.50
July 7	0.50 \pm 0.50	0.50 \pm 0.29	0.25 \pm 0.25	1.00 \pm 0.71
14	0.50 \pm 0.50	0.75 \pm 0.48	1.00 \pm 0.71	1.00 \pm 1.00
21	0.75 \pm 0.48	1.25 \pm 0.48	1.25 \pm 0.95	0.75 \pm 0.48
28	1.50 \pm 0.29	2.00 \pm 0.41	0.75 \pm 0.48	1.75 \pm 0.48
Aug. 4	2.50 \pm 1.04	4.00 \pm 1.22	4.00 \pm 1.08	2.75 \pm 0.63
11	4.00 \pm 0.71	1.75 \pm 0.75	3.75 \pm 1.03	3.00 \pm 0.00
18	3.25 \pm 0.75	3.50 \pm 1.26	2.75 \pm 0.85	1.75 \pm 0.25
25	0.00 \pm 0.00	0.50 \pm 0.29	0.00 \pm 0.00	0.00 \pm 0.00
Sept. 1	0.75 \pm 0.48	0.50 \pm 0.29	1.75 \pm 1.11	1.00 \pm 0.41
8	0.75 \pm 0.75	1.25 \pm 0.25	1.00 \pm 0.41	2.00 \pm 0.41
15	2.50 \pm 0.65	1.25 \pm 0.95	1.50 \pm 0.65	1.75 \pm 0.48
22	1.75 \pm 0.63	3.50 \pm 0.65	2.50 \pm 0.65	1.25 \pm 0.75
Overall	1.37 \pm 0.08	1.55 \pm 0.18	1.47 \pm 0.29	1.33 \pm 0.06

*Results for ANOVA: $F_{3,6} = 0.22$; $P = 0.8771$.

TABLE 19. MEAN NUMBERS OF LYCOSID SPIDERS PER U.C. VAC SAMPLE IN ALFALFA PLOTS (1983)*

Date	Mean no. \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control
June 16	0.25 \pm 0.25	0.00 \pm 0.00	1.00 \pm 0.58	0.25 \pm 0.25
23	0.75 \pm 0.48	0.50 \pm 0.50	0.75 \pm 0.75	0.25 \pm 0.25
30	0.75 \pm 0.48	1.00 \pm 0.41	1.75 \pm 0.25	0.25 \pm 0.25
July 7	0.75 \pm 0.48	1.50 \pm 0.65	3.00 \pm 0.41	1.50 \pm 0.65
14	2.50 \pm 0.29	1.00 \pm 0.00	2.50 \pm 1.89	1.50 \pm 0.65
21	1.25 \pm 1.25	1.25 \pm 0.48	1.25 \pm 0.48	0.75 \pm 0.75
28	1.50 \pm 0.29	0.50 \pm 0.29	0.75 \pm 0.48	0.50 \pm 0.50
Aug. 4	1.75 \pm 0.85	1.75 \pm 0.63	3.00 \pm 1.22	1.50 \pm 0.65
11	1.00 \pm 0.58	2.00 \pm 1.08	2.00 \pm 0.71	1.00 \pm 0.71
18	4.25 \pm 1.49	2.75 \pm 0.75	1.00 \pm 0.71	0.75 \pm 0.75
25	0.00 \pm 0.00	0.75 \pm 0.25	1.50 \pm 0.65	0.00 \pm 0.00
Sept. 1	0.00 \pm 0.00	1.00 \pm 0.41	1.25 \pm 0.95	1.00 \pm 0.71
8	2.25 \pm 0.75	1.00 \pm 0.41	1.25 \pm 0.48	1.00 \pm 0.71
15	3.25 \pm 0.85	3.75 \pm 1.93	3.25 \pm 1.03	3.50 \pm 1.85
22	4.25 \pm 1.49	3.75 \pm 0.75	5.25 \pm 1.84	4.25 \pm 1.55
Overall	1.63 \pm 0.28	1.50 \pm 0.27	1.97 \pm 0.39	1.22 \pm 0.10

*Results for ANOVA: $F_{3,6} = 3.69$; $P = 0.0815$.

numbers per hoop for common knotweed, prostrate pigweed, and control plots being 1.11 ± 0.23 ; 0.77 ± 0.20 ; and 0.75 ± 0.24 .

Shake sampling of border vegetation on 19 August yielded the following means for common knotweed and prostrate pigweed: for *Orius*, 16.63 ± 1.32 and 6.75 ± 0.79 ; and for *Geocoris* spp., 0.31 ± 0.24 and 2.25 ± 0.54 . One-way ANOVA of untransformed counts indicated that common knotweed harbored higher densities of minute pirate bug ($P < 0.001$), whereas prostrate pigweed harbored significantly higher densities of bigeyed bugs ($P < 0.025$). Other analytical approaches indicated significant differences in *Orius* counts, but the results for *Geocoris* were mixed. Two-way ANOVA employing column as a factor indicated significant differences for both transformed and untransformed *Geocoris* counts ($F_{1,3} = 38.44$; $P = 0.0085$ (untransformed); $F_{1,3} = 87.79$; $P = 0.0026$ (transformed)). However, the corresponding ANOVA employing row as a factor failed to indicate significant differences due to weed regime ($F_{1,3} = 7.01$; $P = 0.0771$ (untransformed); $F_{1,3} = 7.49$; $P = 0.0716$ (transformed)).

Despite the relatively high densities of minute pirate bug harbored in borders of common knotweed, sweepnet sampling within the alfalfa failed to indicate differences in *Orius* density among the four weed regimes ($F_{3,6} = 0.02$; $P = 0.9944$). As the sampling was conducted a mere 0.6 m from the weedy borders, this method should have been especially sensitive to any real differences. Respective means for common knotweed, prostrate pigweed, common purslane, and control plots were 8.75 ± 4.04 , 8.38 ± 2.04 , 8.75 ± 2.21 , and 8.13 ± 2.05 .

Table 20 summarizes rates of predator discovery of beet armyworm egg masses glued to alfalfa foliage. Overall analyses of transformed and untransformed proportions did

TABLE 20. PROPORTIONS OF *SPODOPTERA EXIGUA* EGG MASS BAITS DAMAGED OR OCCUPIED BY PREDATORS, ALFALFA PLOTS (1983)*

Date	Mean \pm S.E.M. (n = 4)			
	Purslane	Knotweed	Pigweed	Control
June 10	0.00 \pm 0.00	0.00 \pm 0.00	0.50 \pm 0.29	0.67 \pm 0.33
16	0.00 \pm 0.00	0.25 \pm 0.14	0.83 \pm 0.17	0.25 \pm 0.14
20	0.25 \pm 0.25	0.25 \pm 0.25	0.00 \pm 0.00	0.13 \pm 0.13
July 1	0.50 \pm 0.29	0.00 \pm 0.00	0.17 \pm 0.17	0.00 \pm 0.00
6	0.00 \pm 0.00	0.13 \pm 0.13	0.00 \pm 0.00	0.00 \pm 0.00
12	0.25 \pm 0.14	0.50 \pm 0.29	0.38 \pm 0.24	0.38 \pm 0.13
21	0.25 \pm 0.14	0.13 \pm 0.13	0.13 \pm 0.13	0.13 \pm 0.13
Aug. 3	— [†]	0.00 \pm 0.00	0.63 \pm 0.24	0.38 \pm 0.24
Overall	0.19 \pm 0.06	0.26 \pm 0.05	0.38 \pm 0.02	0.31 \pm 0.04

*ANOVA of transformed proportions ($p' = 2 \times \text{ARCSINE}(\text{SQRT}(p))$): $F_{3,6} = 3.83$; $P = 0.076$.

[†] "—" indicates sample not taken.

not indicate significant differences among weed regimes. Of a total of 28 predators observed on or near egg masses during inspection, only six were bigeyed bugs. Others included *Lygus* sp., larvae of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), *Orius tristicolor*, and *Collops vittatus*. Also, no significant differences were detected for *Geocoris* observed on or near tuna baits ($P=0.87$). In this case, overall means for common knotweed, prostrate pigweed, common purslane, and control plots were 0.33 ± 0.21 , 0.96 ± 0.08 , 0.58 ± 0.12 , and 0.32 ± 0.11 . Proportions of tuna baits discovered by pavement ant and mean numbers of ants per bait were not significantly different among weed regimes ($P = 0.34$ and $P = 0.66$, respectively). Overall means for proportions of baits discovered in common knotweed, prostrate pigweed, common purslane, and control plots were 0.47 ± 0.12 , 0.25 ± 0.09 , 0.43 ± 0.07 , and 0.43 ± 0.11 , and the corresponding results for numbers of ants per bait were 9.67 ± 6.57 , 3.07 ± 1.76 , 7.15 ± 2.41 , and 8.96 ± 3.52 .

Analysis of alfalfa yields failed to indicate significant differences due to weed regime ($F_{3,6} = 1.58$; $P = 0.2892$). Mean yields in grams dry weight/m² for common knotweed, prostrate pigweed, common purslane, and control plots were 102.80 ± 10.98 , 99.03 ± 6.67 , 82.34 ± 5.81 , and 87.83 ± 8.83 . Although no difference was detected, alfalfa was excluded from borders except in control plots; thus, the experimental enhancement scheme would lower the per-plot cropped area by 20 percent without a compensatory improvement in yield.

DISCUSSION

Surveys

A survey of flower visitors revealed that representatives of some 36 distinguishable insect taxa made use of the floral resources of common knotweed. These included many principally entomophagous groups. Also, field survey data indicated that *Geocoris* densities were typically higher on common knotweed than on other plants such as hay

alfalfa, prostrate pigweed, and field bindweed. This might have been due to retention of transient bugs by an attractive resource, such as nectar or alternate prey, not present on the other three plant species. The advantage of common knotweed over hay alfalfa was particularly striking, because alfalfa fields are known to harbor high densities of big-eyed bugs.

Longevity

Field longevity studies indicated increased lifespan for *Geocoris punctipes* when caged on common knotweed versus alfalfa or prostrate pigweed, and for *Collops vittatus* when caged on common knotweed as opposed to alfalfa sprigs. Again, there is a noteworthy advantage of common knotweed over hay alfalfa, a crop commonly regarded as an excellent source of beneficial insects (Fye 1972; Ellington et al. 1985). However, our data alone do not necessarily imply that common knotweed nectar caused the difference. In fact, common knotweed may harbor relatively high levels of prey, particularly the host-specific aphid and psyllid.

During greenhouse longevity trials, we tried to eliminate prospective prey; however, spider mites became abundant on common knotweed and alfalfa plants. Moreover, in field-and-greenhouse trial, *Geocoris punctipes* caged on normally flowering common knotweed sprigs demonstrated no better longevity than on sprigs from which flowers were removed.

Naranjo and Stimac (1985) surveyed 10 weed species as substrates for *G. punctipes*, measuring, among other response variables, adult longevity. The weeds included one member of the Amaranthaceae, one from the Chenopodiaceae, four from the Compositae, three from the Leguminosae, and one from the Rubiaceae. The insects were only exposed to vegetative structures of the weeds, and no differences in longevity were detected. Also, in no case was longevity obtained on a weed significantly different from that obtained on water alone. This suggests that the addition of sugar could improve longevity. Nevertheless, the precise mechanism whereby common knotweed contributes to enhanced longevity of predators remains unresolved.

Monocultural Weed Plots

Common knotweed harbored higher densities of several predaceous insects than did prostrate pigweed, common purslane, or bare soil. However, where differences were statistically significant, absolute differences were not consistently great. For example, bigeyed bug densities did not differ greatly among the three regimes assessed. Even when the observed differences were larger, these were not reflected in increased predator efficiency at discovering baits. For example, though hoop sampling indicated that common knotweed plots featured by far the highest densities of pavement ants, experiments failed to indicate enhanced ant predation in common knotweed plots. Honeydew-producing aphids and alternate prey may have occupied the attention of the ants, detracting from "predation" at the tuna baits. In fact, predation by pavement ants may have been so efficient that it obscured any differences in predation by other predators, such as bigeyed bugs. Bigeyed bugs and other predators will feed on tuna, beet armyworm egg masses, and dead *Drosophila* baits, if these remain relatively undisturbed by ants.

Exclusion of ants might have made evaluation of other predators easier. However, a rigorous test for enhancement of ant predation would require a multiyear study involving larger plots separated by considerably wider clean-cultivated alleys, and any colonies initially present should be eliminated. Such an approach would minimize inter-plot interactions, and permit evaluation of cumulative effects that a honeydew source might have on colony strength and predation efficiency over time.

It is not clear how variability in vegetational cover might have affected predator densities and efficiencies. Hoop samples of predator densities were always taken at the immediate bases of plants. The severe damage to common purslane and consequent shrinkage in cover may have actually led to concentration of relatively non-dispersive predators such as *Geocoris* nymphs. Control plots also exhibited decreased cover in the second sampling, but in this case the habitat was virtually bare ground, subject to intense heat during the day, and inhospitable to most diurnal epigeal predators. By contrast, neither common knotweed nor prostrate pigweed exhibited decreases in cover, so such interpretive complications do not arise in these cases.

We do not assume that common purslane on other sites would show responses similar to those observed here. In fact, in experimental plots of common purslane previously protected from herbivores by a systemic insecticide, one of us (R. L. B.) has observed high densities of bigeyed bugs and other predators. Those plots were located at the Student Experimental Farm during 1984.

Radish Study

The results from the radish experiment indicate that common knotweed may contribute to enhanced predator abundance, and possibly efficiency, on adjoining radish. Bigeyed bug numbers were significantly higher on flats with adjoining common knotweed, but other predators evinced little or no enhancement. As radish is commonly grown in urban and community gardens where common knotweed often occurs, and because bigeyed bugs attack a diversity of pests, this relationship may have some practical application. However, evidence for enhanced predation was equivocal: on two of the five dates, predation rates were actually lower for flats with adjoining knotweed.

A large proportion of the bigeyed bugs encountered in this study were *G. punctipes*. This species is common in hay alfalfa, and is believed by some researchers to be especially suitable for biological control in vegetable crops, because it tends to forage on foliage of crop plants (Dunbar 1967; Read and Sweet 1982). However, *G. punctipes* was relatively scarce in most other common knotweed stands that we observed, including those in community gardens. Both *G. pallens* and *G. atricolor* were usually much more common in such settings. Therefore, it is still uncertain whether *G. punctipes* could be enhanced under typical cultural conditions for radish.

As this experiment was conducted amid pre-existing weed stands, there was little opportunity to ensure systematic or random interspersions of flats representing the two treatments. As a result of the configuration of the weed stands, flats with adjoining knotweed were typically nearer to other knotweed flats than to control flats. Thus, the results, though suggestive, should be viewed as preliminary.

Bell Pepper Study

The bell pepper study indicated limited effects of common knotweed on the insect fauna of adjoining pepper plants. At ground level, plots with common knotweed showed increased *Geocoris* densities, whereas total numbers of predators at pepper plant bases appeared unaffected. Baiting experiments with armyworm egg masses indicated increased predation efficiency at ground level. Nevertheless, neither visual inspection nor shake sampling of pepper plants showed significant differences in predator densities on aerial portions of the plants. Plant quality and fruit yield measurements failed to indicate any inhibition of pepper plants by adjoining common knotweed, and fruit cull rates were unaffected by weed regime.

The results obtained by sampling *Geocoris* at the centers of plots were not surprising. The centers of control plots were essentially without cover. By contrast, common knotweed provided partial cover, which seemed to be the sort of habitat favored by *Geocoris*, and lycosid spiders. Several studies have shown that cover afforded by weeds or intercropped legumes can contribute to higher net rates of predator attack on pests on adjoining crop plants (Dempster 1969; Smith 1969; Ryan, Ryan, and McNaeidhe 1980). However, the present research only indicated an effect on predator abundance and efficiency at ground level. Predator density and efficiency were not significantly improved in the upper foliar strata where predation would presumably be more important in suppressing important pests of bell pepper. In summary, common knotweed showed limited value in enhancing biological control for pests of bell pepper plants.

Preferred foraging strata of predators may be an important consideration in assessing results of these and similar studies. The degree of overlap of the strata occupied by opportunistic predators and crop pests may be crucial in determining predator efficacy in a given crop. This concept has thus far received little attention in vegetable crops. However, Wilson and Gutierrez (1980) found that bigeyed bugs occurring on cotton plants were most commonly encountered in the upper foliar strata. In the present study with bell pepper, these predators, though frequently encountered on the ground, were rarely found on crop foliage. It is in this zone that predators would probably be most important in combatting the pests of bell pepper. Subsequent work in Davis (R. L. Bugg and L. T. Wilson, *unpub. data*) indicates that bigeyed bugs may indeed be abundant on bell pepper foliage through late July.

Hay Alfalfa Study

The results from the hay alfalfa experiment indicate that weed regime affected the densities of insects in plot borders, but these differences were not reflected in the adjoining alfalfa. Moreover, the differences in *Geocoris* density in the borders were not always as expected. For example, visual inspection during July indicated that the highest levels of soil-surface *Geocoris* occurred in borders of common knotweed. By contrast, sampling during August, both by the hoop and shake methods, indicated that prostrate pigweed harbored higher densities of bigeyed bugs than did common knotweed. The discrepancy may have been due to the extremely dense, multilayered cover afforded by the end of July in the borders of common knotweed. Moreover, the dense knotweed

stands often resulted in moist conditions at ground level, apparently due to a combination of heavy nightly guttation and deep shade during the day. The more open, sunlit stands afforded in the prostrate pigweed borders may have better met the microclimatic requirements of the principally ground-dwelling *G. atricolor* and *G. pallens* prevalent during this study (Dunbar 1967).

Data from shake samples of common knotweed and prostrate pigweed also highlighted another, possibly related, paradox. Although bigeyed bugs were more abundant in samples from prostrate pigweed, the converse was true for *Orius*, which feeds on many of the same foods as *Geocoris*. The key to this puzzle may lie in the fact mentioned above, that the bigeyed bugs most commonly seen in this study (*G. atricolor* and *G. pallens*) apparently spend most of their time on the ground (Dunbar 1967), while *Orius* occurs primarily among apical foliage, buds, and flowers. Soil-surface moisture might have little direct impact on *Orius*, while prompting bigeyed bugs to disperse. Thus, if the physical environment is inadequate, provision of alternate resources may mean little.

The only evidence suggestive of enhanced *Geocoris* activity in alfalfa came from the transect hoop samples obtained after the alfalfa had been mowed. Further experiments might reveal whether enhancement with common knotweed is more feasible under a regime of regular mowing for both the weed and alfalfa. This might result in the open, sunlit stands apparently favored by *G. atricolor* and *G. pallens*. Soil nutrient levels, in particular, the balance of N:P:K, might also be important in determining floral as opposed to foliar production by common knotweed. This could have important consequences for enhancement.

There was little evidence of predation by *Geocoris* in the upper foliar strata. Bigeyed bugs were seldom seen on the lepidopterous egg masses used as baits. Though bigeyed bugs may be abundant in California hay alfalfa (Benedict and Cothran 1975; Bisabri-Ershadi and Ehler 1981), it may be premature to assume that they therefore play a major role in control of lepidopterous pests of the crop. The vulnerable egg and early larval stages of such pests are located principally in the apical foliage. Bigeyed bugs are much less commonly encountered in this stratum than are other opportunistic predators, such as *Lygus*.

Common knotweed also failed to enhance efficiency of tuna-bait discovery by pavement ant, despite the presence of the honeydew-producing aphid, *Aphis avicularis*.

The predominantly negative results obtained with alfalfa may indicate the difficulty of enhancing predators in an already-rich community of arthropods. However, if cultural conditions had been modified to include regular mowing, or different soil nutrient or water regimes, results might have been different. Perhaps bigeyed bugs are effective predators during the early stages of alfalfa regrowth following mowing. Many other predators appear to depart the hay alfalfa agroecosystem following mowing, but a large proportion of bigeyed bugs may remain (Rakickas and Watson 1974).

SUMMARY AND CONCLUSION

In light of the principally-negative findings of the present studies, it is important to note Naranjo and Stimac's (1987) laboratory trial assessing *Geocoris punctipes* activity on soybean sprigs presented with and without contiguous sprigs of 10 weed species.

The plants used were all in early vegetative phases of growth. Some weed-crop combinations led to decreased searching by *G. punctipes* at the lower prey densities employed. Underlying mechanisms remain unclear, as does applicability to field conditions, but the findings raise the possibility of somehow reducing predator efficiency by permitting weeds to grow alongside crop plants.

Also of interest is Sheehan's (1986) concern that vegetational diversification can lead to increased leaf-surface area per unit of soil area, and that visually- or tactilely-searching natural enemies (such as those emphasized here) may have to search a greater area to find the same number of prey. Thus, these natural enemies may be less effective at reducing pest densities in dense, vegetationally-diverse agroecosystems. Although we did not assess leaf area, it is clear that common knotweed, with its finely-dissected foliage, could greatly increase agroecosystem leaf area when interplanted with crops.

Another problem may have arisen because common knotweed grown in conjunction with irrigated crops may become dense and lush. This results in an unfavorable habitat for *Geocoris pallens* and *G. atricolor*, which are principally ground dwelling and favor more open, sunlit stands. Further research should involve manipulation of knotweed stands, to influence microclimate and general suitability of the habitat to predators.

Common knotweed was selected for these trials because its readily-accessible floral nectar was presumed to be a nutritional complement to the arthropod prey consumed by bigeyed bugs and other predators (Rapport 1980). This may have been an oversimplification, inasmuch as common knotweed also provides pollen and harbors high densities of herbivorous arthropods, several of which serve as prey to bigeyed bugs and other predators. Provided with abundant supplementary as well as complementary resources (alternate prey items as well as nectar), predators may have little tendency to leave the weed and forage on adjoining crop plants, where densities of suitable prey may actually be lower. Such conditions could actually detract from biological control of insect pests on crop plants (Ables, Jones, and McCommas 1978).

Related problems may arise in future attempts to enhance generalist predators through the use of floral resources. For example, various plants having compound inflorescences often harbor minute pirate bug (*Orius tristicolor*), an important predator of several crop pests. Field and laboratory studies indicate that that *Orius* feeds not only on nectar (Yokoyama 1978), but also on pollen and thrips (Thysanoptera) (Salas-Aguilar and Ehler 1977). Salas-Aguilar (1976) suggested that the predator might be enhanced through provision of flowering plants in the agroecosystem. However, as thrips are often abundant in inflorescences, the minute pirate bug might not have any tendency to explore crop plants in search of prey. Counterbalancing this "pessimistic" appraisal are other studies (Hagen and Hale 1974; Gonzalez et al. 1982) stressing the importance of alternate prey in sustaining predators during times of low pest densities.

The use of nectariferous plants to provide complementary resources may prove more feasible in attempts to enhance natural enemies of greater host (or prey) specificity. In such cases, one would presumably be less likely to inadvertently provide supplementary resources. In fact, laboratory and field studies illustrate the importance of dietary nectar or pollen to tachinid parasites (Shahjahan 1968; Topham and Beardsley 1975) and various parasitic Hymenoptera (Leius 1967b; Syme 1975, 1977; Foster and Ruesink 1984; and Treacy et al. 1987). These parasites, by comparison with such generalist predators as *Geocoris* (Crocker and Whitcomb 1980), are only capable of attacking

narrow ranges of arthropods. Thus, one might anticipate a higher likelihood of success through provision of flowering weeds, and, incidentally, their other insect associates.

To date, however, there have been few definitive field studies confirming enhanced parasitization or predation through provision of nectar sources (van Emden 1962, 1965; Leius 1967a; Pollard 1971; Topham and Beardsley 1975; Crepps 1980; Agnew, Sterling and Dean 1982; Treacy et al. 1987). Some of these studies yielded principally negative results; some yielded statistically-significant but relatively-slight differences; others suffered from insufficient control of potentially-confounding variables, lack of true replication, or probable interaction among plots as a result of inadequate spacing. The latter point and related issues of spatial and temporal scale may be of prime importance. That is, long-term, large-scale, well-replicated studies featuring widely-separated plots may prove essential in addressing these issues. There is clearly a need for further experimentation (Sheehan 1986).

As noted, common knotweed produces flowers indeterminately from early spring through late autumn, with alternate prey becoming abundant in late summer and early fall. Thus, normal phenology of the weed during the course of one year would probably not prompt wholesale dispersal of predators to a crop of interest, as the predators involved are not of much use during winter. In the present studies, no cultural practices were used to reduce the availability of these resources. Perhaps timely destruction or seasonal decline of flowering weeds would be useful, so long as undue destruction of predators can be avoided (Altieri and Whitcomb 1979). However, predator dispersal behavior under such conditions is still poorly understood, and it is not clear what benefits might accrue to a nearby crop (Rakickas and Watson 1974). What is clear is that multiyear studies are advisable. In the present case, for example, it is possible that with the advent of spring, overwintered predators might disperse from last year's stands of common knotweed to nearby crops.

Based on these experiments, common knotweed, despite its attractiveness to numerous species of entomophagous insects, appears to have limited use in enhancing biological control on adjoining crops. Nonetheless, fieldside common knotweed appears to provide a very favorable habitat for various predators of known agricultural importance. Pending further research, perhaps the weed should be tolerated in those settings, as it may provide refuge from disruptive agronomic practices in adjoining farmlands, and breeding sites and reservoirs from which these insects might recolonize agricultural fields. Further studies are needed to discover to what extent this potential exists and can be realized.

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ABSTRACT (Continued from inside front cover.)

pigweed than on common purslane, while the former two rates were not significantly different. Recruitment of predatory ants (*Tetramorium caespitum* L.) to tuna baits was not significantly different among plots containing the three weed species, despite high numbers of ants attending aphid colonies in the common knotweed plots.

In the next experiment, flats of radish (cv "Sparkler" and "Scarlet Globe," *Raphanus sativus* L.), maintained amid wild stands of common knotweed harbored higher densities of bigeyed bugs than did flats in nearby stands of other low-growing weeds. No treatment effect on other predators was evident. Egg masses of an armyworm, *Pseudaletia unipuncta* (Hayworth) (Lepidoptera: Noctuidae), stapled to radish foliage, were damaged or occupied by predators in slightly greater proportions on radish grown amid common knotweed stands.

In another experiment, predator densities and efficiencies were assessed amid commercial organically-grown bell pepper (cv "Yolo Wonder," *Capsicum annuum* [L.]) grown in plots with and without common knotweed. Although the weed harbored higher densities of bigeyed bugs than did bare ground afforded by control plots, visual inspection and shake sampling yielded no evidence for increased densities of predators at the immediate bases or on the foliage of pepper plants. On the other hand, studies employing armyworm egg masses showed enhanced predation by bigeyed bugs and other predators at the bases of pepper plants with adjoining common knotweed. Similar studies involving egg masses stapled to foliage of pepper plants failed to indicate a difference. Common knotweed apparently had no effect on crop vigor and yield.

The final experiment involved replicated plots of hay alfalfa (cv "Amador," having borders of either common knotweed, prostrate pigweed, common purslane, or uncut alfalfa (control). Proportions of vegetational cover in plot borders differed among several weed regimes: knotweed and control plots featured denser cover than pigweed, and these three regimes exceeded purslane. Purslane borders were devastated by the combined action of herbivorous insects and a fungal pathogen, rendering that regime of little interest. Samples taken on the ground beneath border vegetational canopies yielded an effect due to weed regime for *Geocoris* densities, with pigweed exceeding knotweed, which in turn exceeded control. Data for total predators, including *Geocoris*, indicated that knotweed exceeded pigweed, which in turn exceeded control. Visual inspection of borders, which detected *Geocoris* running about on exposed ground, showed knotweed surpassing purslane and pigweed, which were indistinguishable, followed by control. Despite differences observed in borders, vacuum samples from alfalfa portions of plots indicated no effect by weed regime on densities of bigeyed bugs, *Nabis* spp., *Lygus* spp., or lycosid spiders.

(Continued)

ABSTRACT *(Continued)*

Similarly, counts of *Geocoris* taken at ground level amid alfalfa, both before and after mowing the crop, failed to show an effect. Based on shake samples, density of *Geocoris* was higher on pigweed than on knotweed, whereas the converse was true for *Orius tristicolor* (White). Nonetheless, based on sweepnetting, *Orius* densities in alfalfa were not different among the four weed regimes. Predation studies involving beet armyworm egg masses glued to apical foliage of alfalfa failed to show differences among weed regimes. Also, studies employing chunks of tuna placed on cards at ground level amid the alfalfa did not yield significant differences in rates of attendance by *Geocoris* or by pavement ant. Weed regime had no effect on yield of adjoining alfalfa.

Common knotweed, despite its attractiveness to numerous species of entomophagous insects, may have limited use in enhancing biological control on adjoining crops. The weed may provide alternate prey as well as floral resources, and thus represent such a hospitable habitat that some predators may have no tendency to forage on nearby crop plants. Thus, a weed originally selected to provide a complementary resource (nectar) may also inadvertently afford supplementary resources (alternate prey). Alternate prey could conceivably detract from biological control of pests on adjoining crops. Nonetheless, fieldside common knotweed appears to provide favorable habitat for various predators of agricultural importance. At this point, perhaps the weed should be tolerated in many settings, as it may provide breeding sites and reservoirs from which predators might colonize agricultural fields. Further research should involve multiyear studies on manipulation of common knotweed stands to influence microclimate, soil nutrient levels, and quality of the habitat. These could clarify whether this weed may yet be useful in the enhancement of biological control of insect pests.

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