Arthropod Fauna of Conventional and Organic Rice Fields in California

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J. Econ. Entomol. 86(1): 149–158 (1993)

ABSTRACT Levels of both pest and nonpest arthropods were compared among four pairs of fields of conventional and organic rice, *Oryza sativa* L., in California. For seven major pests, there were no significant differences in abundance or in level of damage between conventional and organic treatments. However, in two organic fields, the combination of high infestation level (>5% of rice plants infested) by immature *Hydrellia griseola* Fallén, an ephydrid leafminer, and low stand densities (<25 plants per 0.09 m^2) warranted preventive action to avoid economic loss. Collections revealed a high degree of taxonomic similarity between conventional and organic treatments; species richness did not differ significantly between treatments. However, three predatory taxa—*Belostoma flumineum* Say, *Notonecta* spp., and adult *Thermonectus basillaris* (Harris)—were significantly more abundant in the organic than in the conventional treatment.

KEY WORDS Arthropoda, rice field management, species richness

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RICE, *Oryza sativa* L., is grown annually on ≈151,000–174,000 ha in California (USDA 1990). Most rice is produced with conventional farming practices that include the use of synthetic fertilizers and pesticides (Rutger & Brandon 1981); however, a small minority of farmers in California produce rice organically (Altieri et al. 1983). Organic rice farmers rely on various cultural practices (e.g., rotations with cover crops, floodwater management) for maintaining soil fertility and managing pests.

Throughout the production season in California (late April to early September), rice fields are colonized by a variety of aquatic arthropods that are commonly associated with other ephemeral freshwater habitats (Usinger 1956, Zalom 1981). Some of these arthropods are considered to be pests (Grigarick 1984); others are predators (Lange & Grigarick 1970, Veneski & Washino 1970, Zalom & Grigarick 1980, Oraze & Grigarick 1989). Because studies in other agroecosystems have shown that arthropod abundance and community structure can differ between conventional and organic fields or orchards (Dritschilo & Wanner 1980, Madsen & Madsen 1982), we undertook a two-part study to compare the arthropod fauna of conventional and organic rice production systems in California. This study involved an assessment of the arthropod pest complex and a comparison of the composition and abundance of nonpest arthropods inhabiting both systems.

Materials and Methods

Study Sites. The study was conducted during 1988–1989 in four pairs of conventional and organic rice fields located in the Sacramento Valley of California. In 1988, three pairs were studied: one was located ≈2 km NW of Pleasant Grove (Sutter County), a second (designated hereinafter as the Erickson fields) was ≈4 km E of Nelson (Butte County), and a third was ≈6 km NW of Willows (Glenn County). At each location, the conventional and organic fields were <2 km apart. In 1989, a pair of adjacent fields ≈4 km E of Nelson was studied (hereinafter designated as the Gage fields). Individual pairs of fields were managed by the same grower; the four fields at Nelson were managed by one grower. Further details of all eight fields are given in Table 1.

Conventional and organic fields differed principally with respect to the use of synthetic chemicals and to seedbed preparation. "Conventional" rice fields were defined as those in which synthetic fertilizers and pesticides were applied; "organic" fields were defined as those in which no synthetic agrochemicals were used on the land 12 mo before or during the production of the

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Table 1. Profiles of rice fields studied at four locations in the Sacramento Valley, CA, 1988–1989

Variable	Pleasant Grove (1988)		Erickson (1988)		Willows (1988)		Gage (1989)	
	Conventional	Organic	Conventional	Organic	Conventional	Organic	Conventional	Organic
Size, ha	140	56	138	24	161	72	40	24
Rice variety	S201	S201	C101	C101	C101	S201	S201	C101
Planting date	10 May	17 May	18 May	14 May	23 May	23 May	19 May	19 May
Seeding[a]	Aerial	Aerial	Aerial	Drill	Aerial	Aerial	Aerial	Drill
Fertilizer	Ammonium sulfate, 27 kg/ha	None	Aqueous ammonia, 18 kg/ha	None	Aqueous ammonia, 18 kg/ha	Chicken manure, 735 kg/ha	Aqueous ammonia, 18 kg/ha	None
Previous crop	Rice	Vetch	Rice	Vetch	Alfalfa	Rice	Rice	Vetch
Last in rice	1987	1986	1987	1985	1984	1986	1988	1986
Pesticides[b]	Carbofuran 5G 92 g (AI)/ha; copper sulfate 1.84 kg (AI)/ha; fungicide (seed treatment; name and rate unspecified)	None	Carbofuran 5G 92 g (AI)/ha; copper sulfate 1.84 kg (AI)/ha; fungicide (seed treatment; name and rate unspecified); MCPA 4E, 0.16 kg (AI)/ha	None	Carbofuran 5G 92 g (AI)/ha; copper sulfate 1.84 kg (AI)/ha; fungicide (seed treatment; name and rate not specified); molinate 10G, 0.74 kg (AI)/ha	None	Carbofuran 5G 92 g (AI)/ha; copper sulfate 1.84 kg (AI)/ha; fungicide (seed treatment; name and rate not specified); MCPA 4E, 0.16 kg (AI)/ha; molinate 10C, 0.74 kg (AI)/ha	None
Water depth	25 cm first 5 wk, then 13 cm	25 cm first 5 wk, then 13 cm	8 cm first 8 wk, then 13 cm	8 cm upon permanent flood	10 cm	25 cm first 5 wk, then 10 cm	5–11 cm	5–14 cm upon permanent flood
Yield, kg/ha	8,949	7,112	7,728	6,160	Not available	Not available	Not available	Not available

[a] In aerial seeding, rice is sown from an airplane into flooded paddy; in drill-seeding, rice is injected 1–2 cm deep into soil before flooding paddy.

[b] MCPA, 2-methyl, 4-chlorophenoxyacetic acid.

rice crop, in accordance with state regulations for organic food (California Health & Safety Code, secs. 26569.11–17). Further, seedbed preparation in conventional fields included standard tillage practices for California rice fields (cf. Davis 1950, Rutger & Brandon 1981), whereas seedbeds in organic fields underwent less intensive disk plowing and harrowing. The reduced tillage in organic fields resulted in greater amounts of coarse plant material that was not as extensively incorporated into the seedbed; in the Erickson and Gage organic fields, this plant material formed a mulch layer. Stubble from the previous rice crop was burned only in the Willows organic field.

Fields also differed in cropping history. Three conventional fields (Pleasant Grove, Erickson, Gage) were planted in rice the previous production season. The three organic fields with which they were paired were not planted in rice for the previous one or two seasons; instead, they were planted continuously to purple vetch, *Vicia* sp., during the intermittent period. At Willows, the conventional field was planted to alfalfa, *Medicago sativa* L., the previous season, whereas the organic field was fallow for 1 yr.

We noted the composition and relative abundance of weeds in each field and identified particular species using the guide by Bayer et al. (1983). Fields differed among one another in weed composition and abundance. At Pleasant Grove, weeds were sparse in the conventional field and were limited primarily to sedges (smallflower umbrellaplant, *Cyperis difformis* L., and bulrush, *Scirpus* spp.) in the interior of basins and to arrowhead, *Sagittaria* spp., along levees. In the organic field, weeds were also sparse and included arrowhead, barnyard grass, *Echinochloa crus-galli* (L.) Beauv., common water plantain, *Alisma* sp., and filamentous algae. At Erickson, basins within the conventional fields had pockets in which growth of barnyard grass was rank; naiad, *Najas* sp., and bulrush were also present in low densities. Except for small amounts of filamentous algae, basins within the Erickson organic field were almost devoid of weed growth. At Willows, the conventional field was virtually free of weeds, whereas the Willows organic field had great amounts of filamentous algae early in the season and sparse growth of arrowhead and watergrass later. In the Gage conventional field, weed growth was sparse and was limited primarily to sedges; in the organic field, there was rank growth of barnyard grass and bearded sprangletop, *Leptochloa fasicularis* [Lam.] A. Gray.

All fields were subdivided by levees into six or more discrete basins. Sampling was restricted to three basins within the interior of each field.

Arthropod Pest Complex. Rice fields were sampled for the major arthropod pests (except mosquitoes) listed by Grigarick & Washino

(1983). In California, the pest complex may be divided into three categories based on the stage of rice that is attacked (Grigarick 1984). First, three pests attack rice in the early seedling stage: tadpole shrimp, *Triops longicaudatus* LeConte (Notostraca: Triopsidae); chironomid midge larvae (Diptera: Chironomidae; see Clement et al. [1977b] for particular species); and crayfish (e.g., *Procambarus clarki* (Girard) (Decapoda: Astacidae). Rice-stand establishment can be reduced by the feeding activity of all three pests and by the burrowing activity of tadpole shrimp and crayfish. Second, rice is attacked in the late seedling or early tillering stage by *Hydrellia griseola* (Fallén) (Diptera: Ephydridae) and the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae). Larvae of *H. griseola* feed between the epidermal layers of a rice leaf, and their feeding can result in leaf loss and a reduction in photosynthesis (Manandhar & Grigarick 1983). Larvae of the rice water weevil feed on rice roots, causing stunting of the rice plant, reduction in tillering, and subsequent yield loss (Grigarick 1984). The third category of pests includes those that attack rice plants just before or during the reproductive phase: aster leafhopper, *Macrosteles fascifrons* Stål (Homoptera: Cicadellidae), and two species of armyworms (armyworm, *Pseudaletia unipuncta* (Haworth), and western yellowstriped armyworm, *Spodoptera praefica* (Grote) [both Lepidoptera: Noctuidae]). When aster leafhoppers occur at high densities on rice plants, their feeding can lead to a reduction in the number of panicles per plant and yield loss (Way et al. 1984). Armyworms can cause yield loss indirectly by feeding on rice leaves and directly by feeding on panicles (Rice et al. 1982).

During the early seedling stage, pests and their damage to rice plants were monitored in three different ways. First, in the Pleasant Grove, Erickson conventional, and Willows organic fields, we collected seedlings from 10 collection sites along a diagonal transect that ran across three basins in each field; at least 75 seedlings were collected per field. Seedlings were pooled, taken to the laboratory, and examined under a compound microscope. Damage was assessed and attributed to specific pests based on descriptions and illustrations given by Clement et al. (1977a) and Grigarick & Washino (1983).

Second, at Pleasant Grove, we determined seedling density and checked for the presence of tadpole shrimp and chironomid larvae 10 d after seeding in each field. To do this, we examined 10 areas (0.09 m^2) per field using the method described by Grigarick & Washino (1983). Each sampling area was delimited by a four-sided polyacetate box (0.3 by 0.3 m, open on top and bottom) that was gently pushed 3–4 cm deep into the soil. Samples were taken along a diagonal transect that cut across three basins in each field. The numbers of rice seedlings were counted, and the presence of tadpole shrimp and chironomid larvae was noted within each area.

In addition, chironomid larvae were sampled 1–3 wk after seeding in fields at Pleasant Grove and Willows with a modified version of the Kellen dredge (Kellen 1954, Clement et al. 1977b). The dredge removes a 0.023-m^2 sample of soil and can be used to collect chironomid larvae occurring on the surface and top 4–5 cm of the soil (Clement et al. 1977b). On each sampling date, three samples were removed per field, one per basin along a field margin about midway between levees. The contents of the dredge samples were pooled, then washed and screened through three graded brass sieves of 5- (4 mm), 20- (0.85 mm), and 40- (0.425 mm) mesh to remove dirt and debris. Midge larvae in the contents of the 40-mesh screen were counted and identified using keys by Darby (1962).

Infestation levels of *H. griseola* and the rice water weevil were determined when ≈50% of the rice plants emerged above water. Sampling for *H. griseola* was restricted to the Pleasant Grove and Erickson fields. To determine infestation levels, we examined 10 samples (0.09 m^2) and counted the number of plants that were infested with immature stages of the leafminer (Grigarick & Washino 1983). Samples were taken along a diagonal transect that cut across three adjacent basins. The mean percentage of plants infested per 0.09-m^2 area was compared between conventional and organic fields using a paired t test following transformation of the data by arcsine square-root (Zar 1984).

Infestation levels of the rice water weevil were estimated by counting the number of plants having leaves with longitudinal scars produced by feeding of adult weevils, although feeding by adult rice water weevils rarely causes economic damage, the number of scarred leaves is indicative of larval infestation levels and potential yield loss (Grigarick & Way 1978, 1980). Sampling was performed along a line that was ≈5 m from and parallel to a levee margin. The line started ≈100 m from one end of the levee and ran ≈150 m toward the other. We examined 100 randomly selected plants along the line and recorded the number that had scars from weevil feeding on the two newest unfurled leaves. We sampled plants along six levee margins in the Pleasant Grove and Erickson fields and three margins in the Gage fields. Sampling in the Erickson and Gage organic fields (both drill-seeded) occurred after a permanent flood was established in each. The mean percentage of scarred plants was compared between conventional and organic fields using a paired t test after arcsine-square-root transformation of data. In the Gage fields ≈4 wk after counting scarred plants, we removed three sets of soil cores (10 by 10 cm, five cores per set) per field to compare infestation levels of immature weevils on the roots of rice plants. Cores were removed along a diagonal transect that cut across three adjacent basins within each field.

The abundance of aster leafhoppers was estimated at two times: first in mid-July before panicles had begun developing (Pleasant Grove and Erickson fields) and then in early August once panicles had formed (Pleasant Grove, Erickson, and Willows fields). Aster leafhoppers were sampled using a transparent polyacetate cylinder (Way et al. 1984). The cylinder (30.5 cm diameter, 121.9 cm height) was coated on the inside with petroleum jelly and placed over rice plants during sampling. Plants were then agitated, causing leafhoppers to jump or fly onto the cylinder, whereupon they were trapped, counted, and removed. Three samples were taken along a diagonal transect per basin (nine samples per field). Because the number of plants within the sampling area can vary, leafhopper density was calculated on both a per-area and a per-plant basis. The mean numbers of aster leafhopper were compared between conventional and organic fields using a paired *t* test; data were transformed by square root of observed value plus 0.5 to reduce heterogeneity of variances (Zar 1984).

Levels of armyworms and their damage were assessed concurrently while sampling for aster leafhoppers. In the early sample, we counted the number of armyworms (both species) on 30 plants and visually estimated the percentage of rice leaf area defoliated by them. Care was taken to distinguish defoliation caused by armyworms from that caused by grasshoppers (Orthoptera: Acrididae) (Grigarick & Washino 1983). In the late sample, we counted the number of armyworms on 30 plants and the number of plants (of the 30) that had white panicles or parts of panicles, which indicate armyworm feeding damage (Grigarick & Washino 1983). The 30 plants per sample were selected randomly along a diagonal transect running across three adjacent basins (10 plants per basin). The mean number of armyworms, the mean percentage of defoliation, and the number of white-panicle plants per field were compared between conventional and organic treatments by using paired *t* tests; percentage data were arcsine-square-root transformed before analysis.

Other Fauna. Additional species were sampled with Gee minnow traps (Cuba Speciality, Fillmore, NY) that were lined with 1.6-mm-mesh aluminum screening for improved retention of small individuals (Takahashi et al. 1982). By positioning these traps with apertures just below the water surface, organisms that move laterally through the water column (nekton) or across the water surface (neuston) are intercepted. This type of trap has been used in previous studies to provide a relative measure of the abundance and activity of aquatic arthropods in rice fields (cf. Smith & Grigarick 1990). In our study, traps were in place in the fields on 3 d at Pleasant Grove (1 July, 4 and 24 August), 2 d at Erickson (1 and 7 July), and 5 d at Gage (13 and 18 July; 2, 16, and 22 August). On each date, three traps were used per field (one per basin), and they remained in the field for 24 h. Upon collection, insects were identified using keys of Leech & Chandler (1956), Pritchard & Smith (1956), Usinger (1956), Westfall (1978), and White et al. (1978). Other taxa were identified using keys in Edmundson (1959) and Pennak (1978).

For each field, the trap catches for specific taxa were summarized by calculating individual days, which were defined as the sum across sampling dates of the product of the average trap catch and the amount of time between the midpoints of the intervals between the sampling date and the preceding and the following sample dates. The mean numbers of individual days were compared between conventional and organic treatments by using paired *t* tests. Also, the mean numbers of individual days per field summed across all taxa were compared between treatments with paired *t* tests. All tests were performed after the transformation, natural logarithm of observed value plus 1.0.

Similarity in the faunal composition between conventional and organic treatments was measured in two ways. First, the total numbers of taxa in conventional and organic treatments were compared by using a paired *t* test. Second, the degree of taxonomic overlap between treatments was measured by using the quotient of similarity, $Q = 2S_c/(S_a + S_b)$, where Q is the value of similarity, S_c represents the number of taxa common to both treatments, and S_a and S_b represent the number of taxa collected in the conventional and organic treatments, respectively (Huhta 1979). Values of the index range from 0 (no taxa in common) to 1 (all taxa in common).

Results and Discussion

Pest Complex. At Pleasant Grove, total seedling damage was slightly greater in the organic field, but damage in the organic field at Willows was similar to that in the conventional field at Pleasant Grove (Table 2). At Pleasant Grove, <5% damage was attributed to tadpole shrimp in either field, whereas this damage was negligible in the Erickson conventional field and not detected in the Willows organic field. Damage from chironomid larvae was <10% in all fields sampled; the difference in percentage damage attributed to chironomid larvae was greatest between the conventional and organic fields at Pleasant Grove. Crayfish damaged <1.0% of the seedlings sampled from each field.

Area samples (0.09 m^2) confirmed the presence of tadpole shrimp and chironomid larvae in the Pleasant Grove fields. Live shrimp, their cast

Table 2. Damage attributed to various pests during early seedling stage in conventional and organic rice fields in California, 1988

Pest	Pleasant Grove		Erickson, conventional[c]	Willows, organic[d]
	Conventional[a]	Organic[b]		
Tadpole shrimp	2.7 ± 1.9	4.7 ± 0.8	0.1 ± 0.1	0.0 ± 0.0
Chironomid larvae	2.7 ± 1.9	7.5 ± 1.0	2.3 ± 0.4	3.9 ± 1.7
Crayfish	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.8 ± 0.8
Undet. cause	1.3 ± 1.3	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0
Total damage	6.7 ± 2.9	12.2 ± 1.3	2.7 ± 0.4	4.7 ± 1.9

Values are mean ± SE of percentage damage, p, where SE = $[p\ (1 - p)/n]^{1/2}$ for samples of size n.

[a] n = 75.

[b] n = 642.

[c] n = 1,446.

[d] n = 128.

exoskeletons, or both were present in all samples from the organic field. Only dead shrimp and exoskeletons were found in samples from the conventional field; this was expected as sampling took place in the conventional field 2 d after copper sulfate pentahydrate was applied for shrimp control.

We also estimated rice plant density in the area samples. Mean plant densities (± SD) in the conventional and organic fields were similar (19.3 ± 6.0 and 21.8 ± 7.1 plants per 0.09 m^2, respectively). A density of 20 plants per 0.09 m^2 is desirable for grain maturity and maximum yield. To achieve this density, growers are advised to implement control measures when tadpole shrimp or chironomid larvae are present and a stand density of <25 plants per 0.09 m^2 is found (Grigarick & Washino 1983). Standard seeding rates, which were used by growers in our study, typically result in an initial density of ≈ 40 plants per 0.09 m^2. Based on the percentage of seedling damage attributed to arthropod pests (Table 2), stand density was reduced by three to five plants per 0.09 m^2 in the Pleasant Grove fields. Activity by tadpole shrimp and crayfish that uproots seedlings may have caused additional loss that we did not account for in our samples. Also, factors other than arthropods may have been significant in reducing stand establishment (e.g., cool, windy weather; seedling diseases).

Several taxa of larval chironomids were recovered in dredge samples. In the Pleasant Grove conventional field, counts combined from samples taken 11 and 14 d after flooding contained 61 *Chironomus,* 1 *Paralauterborniella,* 7 *Tanytarsus,* and 6 unidentified chironomid specimens. In contrast, samples taken from the Pleasant Grove organic field 7 and 13 d after flooding contained a total of only 4 *Chironomus*. At Willows, samples collected from the conventional field 21 d after flooding contained 14 *Chironomus,* 1 *Paralauterborniella,* and one unidentified specimen. Samples collected at the same time from the Willows organic field contained 805 *Chironomus* and one unidentified specimen. The large number of larvae in the Willows organic field was associated with the heavy infestation of algae there. The samples indicate that species richness of chironomid larvae was greater in the conventional fields; i.e., we recovered at least three distinct chironomid genera from the conventional fields but were able to confirm the presence of only one or two taxa from the organic fields.

Chironomus was the dominant larval chironomid genus in each field. However, this taxon is not associated with damage to seedling rice in California (Darby 1962, Clement et al. 1977a), but members of the genus *Chironomus* are known to damage rice plants in other geographical areas (Way & Wallace [1989] and references therein). The numbers of larvae collected in the Pleasant Grove fields (regardless of whether *Chironomus* are included) were not proportionate to the percentage of damage attributed to chironomid larvae in our seedling samples (Table 2). The discrepancy between damage and dredge counts of larvae may have occurred because larvae were sampled near the margins of a field, whereas seedlings were collected from several locations along a transect that ran into the interior of each field.

Although we did not sample for crayfish, they were more conspicuous in conventional rice fields. Live (and some dead) crayfish were occasionally seen below the water surface in conventional fields but not in organic fields. Also, characteristic burrow holes (particularly near inlet boxes) and carcasses of crayfish were common on the levees and field margins of conventional rice fields but were rare in organic rice fields. These observations suggest that crayfish were more abundant in conventional rice fields, that their distribution in organic fields was limited primarily to flooded basins, or that both were true.

Hydrellia griseola infested a greater percentage (mean ± SD) of plants in the Pleasant Grove (8.4 ± 9.3%) and Erickson organic fields (5.9 ± 4.6%) than in their paired conventional fields (1.2 ± 1.9% and 1.8 ± 4.6%, respectively). However, the mean percentage of leaves infested did

Table 3. Infestation levels of rice water weevil in rice fields in California

Site	Treatment	% Plants scarred by weevil feeding[a]	No. immatures per plant[b]
Pleasant Grove	Conventional	16.8 ± 9.4	—
	Organic	6.0 ± 7.3	—
Erickson	Conventional	8.2 ± 4.7	—
	Organic[c]	1.8 ± 1.5	—
Gage	Conventional	3.7 ± 5.5	0.2 ± 0.3
	Organic[c]	8.7 ± 5.1	2.9 ± 1.7

[a] Values are means ± SD based on six 100-plant samples each at Pleasant Grove and Erickson and on three 100-plant samples at Gage.

[b] Values are means ± SD based on three sets of five core samples per field.

[c] Sampling occurred after fields (both drill-seeded) were permanently flooded.

not differ significantly between organic and conventional treatments ($t = -3.37$, df = 1, $P > 0.05$). In addition, we recorded rice plant densities (mean ± SD) of 16.6 ± 5.5 and 23.9 ± 7.2 plants per 0.09 m^2 in the Pleasant Grove and Erickson organic fields, respectively, at the time of sampling for *H. griseola*. When infestation levels exceed 5% and stand densities are <25 plants per 0.09 m^2, growers are advised to lower water levels in their fields to reduce the potential for further damage and possible yield loss by *H. griseola* (Grigarick & Washino 1983). In some instances, lowering water levels could conflict with the use of deep-water culture by organic growers to suppress weed growth.

Infestation levels of the rice water weevil are shown in Table 3. The mean percentage of plants with scarred leaves did not differ significantly between conventional and organic treatments ($t = 0.83$, df = 2, $P > 0.05$). At the Gage site, the mean number of immature rice water weevils in the organic field was >14 times that in the conventional field.

Aster leafhopper densities in conventional and organic fields are given in Table 4. At Pleasant Grove and Erickson, aster leafhopper densities were greater in conventional fields than in organic fields, but the differences between treatments were not significant (per area, $t = 3.23$; per plant, $t = 1.09$; df = 1, $P > 0.05$). In late samples, differences in densities of aster leafhopper between treatments were not as marked as in early samples, and these differences also were not significant (per area, $t = 1.55$; per plant, $t = 1.35$; df = 2, $P > 0.05$).

Data regarding the abundance of armyworms and their damage are shown in Table 5. Armyworms occurred in low numbers, and the mean density did not differ significantly between conventional and organic treatments (early, $t = 1.01$, df = 1, $P > 0.05$; late, $t = -0.30$, df = 2, $P > 0.05$). Similarly, damage to rice plants from armyworm feeding was minimal. The mean percentage defoliation did not differ significantly between conventional and organic treatments ($t = 0.76$, df = 1, $P > 0.05$); and whitening of panicles of rice plants from armyworm feeding was absent in our samples.

Other Fauna. In total, 5,356 specimens representing 21 arthropod taxa were collected in minnow traps from three pairs of rice fields. A list of the taxa, their abundance, and the frequency at which they were collected from each field is shown in Table 6. The majority of specimens was collected from the organic fields. At Pleasant Grove, 163 individuals representing 18 taxa were collected from the conventional field, whereas 311 individuals from 14 taxa were collected from the organic field. In the Erickson fields, 255 individuals representing 10 taxa were collected from the conventional field compared with 3,760 individuals from 13 taxa in the organic field. At the Gage site, 201 individuals representing 11 taxa and 666 individuals from 11 taxa were collected from the conventional and organic fields, respectively. The number of taxa collected did not differ significantly ($t = 0.16$, df = 2, $P > 0.05$) between conventional and organic treatments. A quotient of similarity of 0.923 indicated considerable overlap in the taxa inhabiting conventional and organic rice fields. The diversity of taxa collected in our study is typical of that collected in minnow traps from California rice fields (Takahashi et al. 1982, Smith & Grigarick 1990, Hesler & Grigarick 1992).

The numbers of individual days for three taxa—*Belostoma flumineum* Say ($t = -4.89$), *No-*

Table 4. Aster leafhopper densities in conventional and organic rice fields in California, 1988

Site	Treatment	No. aster leafhoppers			
		Early sample		Late sample	
		No. per 0.073 m^2	No. per plant	No. per 0.073 m^2	No. per plant
Pleasant Grove	Conventional	6.78 ± 4.20	0.49 ± 0.51	3.67 ± 3.54	0.45 ± 0.48
	Organic	1.11 ± 1.44	0.12 ± 0.18	0.56 ± 1.32	0.14 ± 0.39
Erickson	Conventional	15.78 ± 10.65	2.75 ± 1.71	0.44 ± 0.72	0.03 ± 0.06
	Organic	1.22 ± 1.71	0.28 ± 0.39	0.44 ± 1.32	0.04 ± 0.12
Willows	Conventional	—	—	0.44 ± 0.54	0.13 ± 0.18
	Organic	—	—	0.33 ± 0.51	0.05 ± 0.08

Values are means ± SD ($n = 9$). Data transformed, $(x + 0.5)^{1/2}$, before analysis, but untransformed data are shown.

Table 5. Abundance and damage levels of armyworms in conventional and organic rice fields in California, 1988

Site	Treatment	Early sample		Late sample	
		No. per plant	% Defoliation	No. per plant	% With white panicles
Pleasant Grove	Conventional	0.03 ± 0.18	0.1 ± 0.4	0.00	0.0
	Organic	0.03 ± 0.18	0.2 ± 0.9	0.03 ± 0.18	0.0
Erickson	Conventional	0.10 ± 0.31	1.9 ± 2.9	0.03 ± 0.18	0.0
	Organic	0.03 ± 0.18	0.2 ± 0.8	0.03 ± 0.18	0.0
Willows	Conventional	—	—	0.00	0.0
	Organic	—	—	0.03 ± 0.18	0.0

Values are means ± SD based on a 30-plant sample per field. Percentage data arcsine-square-root transformed before analysis, but untransformed data are shown. Two species of armyworms were sampled but not differentiated: armyworm, *Pseudalaetia unipuncta* (Haworth), and western yellowstriped armyworm, *Spodoptera praefica* (Grote).

tonecta spp. ($t = -5.54$), and adult *Thermonectus basillaris* (Harris) ($t = -8.69$)—were significantly greater (df = 2, $P < 0.05$) in organic fields. There were no significant differences between conventional and organic treatments ($|t| < 2.92$, df = 2, $P > 0.05$) in the numbers of individual days for each of the remaining taxa nor in the total number of individual days summed across all taxa. *B. flumineum*, *Notonecta* spp., and *T. basillaris* are predators, and their greater abundance in organic fields may have been because of increased prey levels there. Because they are mid- and late-season predators of mosquito and chironomid larvae (Veneski & Washino 1970, Zalom & Grigarick 1980), further work is necessary to determine the causes and implications of their greater abundance in organic fields.

The large number of arthropods collected from the Erickson organic field (Table 6) was primarily because of the preponderance of the corixid, *Corisella decolor* Say. In some instances, when the abundance of corixids is great, their ovipositing in the leaf sheaths of rice seedlings causes economic damage (Lange & Grigarick 1970). However, at the time of sampling in the Erickson organic field, rice plants were large and, therefore, not vulnerable to corixids.

Conclusions. The results of our study generally agree with the findings of other studies involving comparisons of arthropod population levels between conventional and organic cropping systems. Generalizations about conventional versus organic methods should be considered tentative because of the low numbers of fields compared per study (one to four pairs) and the relatively short duration of each study (1–2 yr). Nevertheless, some trends are apparent. First, levels of most pest species remain below treatment thresholds, although occasional outbreaks of pests occur in both conventional and organic fields (Madsen & Madsen 1982, Goh & Lange 1989, Gliessman et al. 1990, Hendricks 1990; but see Mansour 1990). Second, the abundance of nonpest arthropods is often greater in organic fields or in orchards (Dritschilo & Wanner 1980, Madsen & Madsen 1982, Goh & Lange 1989, Gliessman et al. 1990, Hendricks 1990, Werner & Dindal 1990). In contrast to our finding that species richness was comparable between conventional and organic rice fields, other studies have shown that organic agroecosystems have a greater richness of arthropod species (Dritschilo & Wanner 1980; Brown & Adler 1989; Goh & Lange 1989; Kromp 1989, 1990; but see Mansour 1990).

According to Lockeretz & Madden (1987), many growers who currently farm conventionally are interested in, but skeptical about, organic production practices. Altieri et al. (1983) reported that some farmers in California produce all of their rice organically, but the organic farmers who cooperated in our study and others of which we are aware grow some percentage (often >50%) of their rice conventionally. From discussions with rice farmers, we ascertained that they have not adopted organic management practices on all of their land for the following reasons: (1) a lack of markets and consumer demand for organically produced rice, and (2) imperfections with their present organic production techniques, including pest management practices (or the lack thereof). These reasons are typical of organic farming in general in the United States (USDA 1980, Baker & Smith 1987, Lockeretz & Madden 1987). Although market and consumer demand matters are subjects for agricultural economists to address, the development of pest management strategies applicable to organic rice production in California would appear to be a particularly useful area of research for entomologists and other agricultural scientists involved in developing pest management strategies. For instance, we are unaware of any specific management practices used by organic rice growers in California to prevent or control economically damaging infestations of rice water weevil, aster leafhopper, or armyworms. Some research that addresses problems with rice water weevil has recently been conducted and is potentially applicable in both conventional and organic rice production systems in California: use of tolerant varieties (Tseng et al. 1987), draining fields (Hesler et al. 1992), disking of grassy levees and other overwintering habitat, and delaying the

Table 6. Numbers of individuals per trap per sample date and number of sample dates with nonzero captures of various arthropod taxa collected in minnow traps from conventional and organic rice fields in California, 1988–1989

Taxon	Stage[a]	Site					
		Pleasant Grove		Erickson		Gage	
		Conventional	Organic	Conventional	Organic	Conventional	Organic
Crustacea							
Decapoda							
Astacidae							
Procambarus clarki (Girard)	I	1.0 ± 1.7 (1)	0.0	1.5 ± 2.1 (1)	0.0	0.0	0.4 ± 0.9 (1)
Arachnida							
Araneae							
Lycosidae							
Pardosa ramulosa (McCook)	A, I	3.7 ± 2.9 (3)	4.7 ± 2.1 (3)	0.0	2.0 ± 0.0 (2)	1.0 ± 1.2 (3)	0.0
Linyphiidae							
Undet sp.	A, I	1.0 ± 1.7 (1)	0.0	0.0	0.0	0.0	0.0
Insecta							
Ephemeroptera							
Baetidae							
Callibaetis sp.	I	0.3 ± 0.6 (1)	4.3 ± 7.5 (1)	0.0	10.5 ± 12.2 (2)	0.0	0.0
Odonata							
Aeshnidae							
Anax junius Drury	I	0.3 ± 0.6 (1)	1.0 ± 1.7 (1)	0.0	0.0	0.0	0.2 ± 0.5 (1)
Libellulidae							
Pantala sp.	I	0.3 ± 0.6 (1)	0.0	2.5 ± 3.5 (1)	15.0 ± 4.2 (2)	1.0 ± 1.2 (4)	2.8 ± 3.6 (3)
Hemiptera							
Belostomatidae							
Belostoma flumineum Say	A, I	0.3 ± 0.6 (1)	1.3 ± 0.6 (3)	0.0	0.5 ± 0.7 (1)	1.0 ± 1.2 (3)	1.6 ± 1.1 (4)
Corixidae							
Corisella decolor Say	A, I	4.0 ± 6.1 (2)	8.0 ± 8.5 (2)	2.0 ± 0.0 (2)	1637.0 ± 301.2 (2)	4.2 ± 4.0 (4)	5.6 ± 8.8 (4)
Sigara sp.	A, I	0.0	0.0	0.0	0.5 ± 0.7 (1)	0.0	0.0
Notonectidae							
Buenoa spp.	A, I	0.0	0.0	0.0	11.5 ± 14.8 (2)	0.0	0.2 ± 0.5 (1)
Notonecta spp.	A, I	3.0 ± 4.4 (2)	12.0 ± 15.7 (3)	3.5 ± 0.7 (2)	32.0 ± 8.5 (2)	2.2 ± 2.4 (4)	16.0 ± 10.3 (5)
Veliidae							
Microvelia sp.	I	4.7 ± 8.1 (1)	10.7 ± 17.6 (2)	0.5 ± 0.7 (1)	0.0	0.0	0.0
Coleoptera							
Curculionidae							
Lissorhoptrus oryzophilus Kuschel	A	4.7 ± 6.4 (2)	0.0	0.0	0.0	0.2 ± 0.5 (1)	0.0
Dytiscidae							
Laccophilus spp.	A	13.7 ± 16.7 (3)	10.7 ± 14.1 (3)	28.5 ± 13.4 (2)	29.0 ± 2.8 (2)	3.0 ± 2.0 (4)	27.0 ± 13.6 (5)
Thermonectus basillaris (Harris)	A	2.3 ± 2.5 (2)	5.0 ± 5.0 (2)	8.5 ± 3.5 (2)	25.5 ± 5.0 (2)	7.2 ± 4.5 (4)	17.0 ± 11.7 (5)
	I	0.3 ± 0.6 (1)	4.7 ± 3.1 (3)	0.0	9.5 ± 6.4 (2)	2.4 ± 2.1 (4)	0.0
Hydrophilidae							
Enochrus sp.	A	0.3 ± 0.6 (1)	3.0 ± 2.6 (3)	0.5 ± 0.7 (1)	0.5 ± 0.7 (1)	0.2 ± 0.5 (1)	0.0
Hydrophilus triangularis Say	A	0.0	1.3 ± 2.3 (1)	0.5 ± 0.7 (1)	1.5 ± 2.1 (1)	0.6 ± 1.3 (1)	8.6 ± 8.7 (5)
	I	0.7 ± 1.2 (2)	3.7 ± 5.5 (2)	3.0 ± 4.2 (1)	5.5 ± 5.0 (2)	3.4 ± 2.5 (5)	3.4 ± 4.2 (3)
Rhantus hoppingi (Wallis)	A	0.7 ± 1.2 (1)	0.3 ± 0.6 (1)	0.0	0.0	0.0	0.0
Tropisternus lateralis (F.)	A	12.0 ± 6.1 (3)	30.0 ± 24.2 (3)	7.5 ± 1.4 (2)	97.5 ± 20.5 (2)	11.6 ± 6.3 (5)	49.6 ± 42.5 (5)
	I	0.3 ± 0.6 (1)	0.7 ± 0.6 (2)	1.5 ± 0.7 (2)	2.0 ± 2.8 (1)	2.4 ± 2.8 (3)	0.8 ± 0.8 (3)
Diptera							
Chironomidae							
Chironomus spp.	I	0.7 ± 1.2 (2)	2.3 ± 2.5 (2)	0.0	0.0	0.0	0.0

Values are means ± SD based on n = 3, 2, and 5 sampling dates for Pleasant Grove, Erickson, and Gage, respectively, for pooled catch in three traps. Values in parentheses denote the number of sample dates that members of a taxon were nonzero in a field.

[a] A, adult; I, immature.

time of planting rice (personal observations). Populations of aster leafhopper and armyworms can be limited indirectly by proper weed control (Grigarick & Washino 1983, Way et al. 1984); thus, management of aster leafhopper in organic fields depends largely on the success of nonchemical methods of weed control. We are unaware of any control for tadpole shrimp in aerially seeded organic rice fields; however, in drill-seeded rice, the practice of delaying a permanent flood until plants are established could minimize problems with this pest. The loss of several pesticides (e.g., carbofuran, bentazon, parathion) previously available to California rice growers, and the increasing concern about the environmental impact of agricultural practices, will further stimulate interest in nonchemical management practices.

Acknowledgments

R. C. Hernandez (University of California, Davis) and L. A. Hesler provided capable technical assistance in the field. K. Dagel, A. K. Lenander, and D. A. Tolk (USDA, Brookings, SD) assisted in data tabulation. H. Lundberg, J. Polit, and E. Sills graciously allowed the use of their fields in this research. C. M. Wick, S. Scardaci, and J. F. Williams (University of California Extension Service) made initial arrangements with these growers. R. L. Bugg and L. E. Ehler (University of California, Davis), L. A. Hesler (California Department of Food and Agriculture), and L. T. Wilson (Texas A&M University) reviewed drafts of the manuscript. The California Rice Research Board provided funds for this research. This paper partially fulfills a doctoral dissertation requirement for L.S.H.

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Received for publication 6 January 1992; accepted 17 August 1992.