Ground-Surface Arthropods of an Old-Field Habitat in the Delta of Mississippi, with Emphasis on the Cicindelidae (Coleoptera)[1]

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Abstract Ground-surface arthropods were captured by barrier pitfall traps over a 15-month period in an old-field habitat adjacent to a cotton field. Members of the Coleoptera, Orthoptera, and Araneae constituted 89% of the 11,496 captures. The most abundant species group was *Gryllus* sp. (Orthoptera: Gryllidae). The most abundant predator species was *Megacephala carolina* L. (Coleoptera: Cicindelidae), present in atypically large numbers. The peak abundance of nymphal *Gryllus* sp. (July-October) overlapped the peak abundance period (August) of *M. carolina*. Feeding experiments indicated *M.carolina* adults were active predators on *Gryllus* sp. nymphs. As a potential biocontrol agent, methods to encourage *M. carolina* adults to move each season from old-field habitats into adjacent crop fields should be considered.

Key Words old-field, arthropod, predation, Cicindelidae

Old-field habitats do not occur frequently in areas under intensive agricultural management. This is particularly true in the Delta area of Mississippi, where approximately 61% of the land area is under cultivation and another 22% is in bottomland timber, with most of the rest in roads, home sites, commercial areas, standing water, marshes, and pastures (Gunn et al. 1980). The importance as reservoirs of natural enemies of such undisturbed habitats as old fields is becoming more well known as pest management programs mature (Bottrell and Adkisson 1977, Landis et al. 2000). Old-field habitats, defined as areas in the early stages of succession (2 - 5 ys) from an abandoned pasture, previously plowed crop field, or other disturbed habitat, have the potential to be nurseries for generalist predators (Lockley and Young 1987), and specific groups such as spiders (Altieri and Whitcomb 1979), preying mantids (Young 2009), carabid beetles (Allen 1979), and hemipterans (Morris and Plant 1983), as well as for numerous parasites (Marino and Landis 1996). Crop pests that spend part of their time in habitats adjacent to crop fields can be negatively impacted by the natural enemies occurring in such habitats, particularly if there is a diversity of invertebrates in those habitats (Harwood et al. 2009). Natural enemies also can disperse into adjacent crop fields and consume additional crop pests (Geiger et al. 2009). Vegetated field borders, however, as opposed to old-field habitats, contribute little to the control of crop pests in adjacent fields (Outward et al. 2008).

During the years 1983 - 1989, the Southern Field Crop Insect Management Laboratory (U.S. Dept. Agriculture) investigated in the Stoneville, MS (Washington Co.),

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area the role of adjacent habitats in the ecology of the tarnished plant bug, *Lygus lineolaris* (Palisot) (Hemiptera: Miridae) (Young 1986a, b). In the course of those investigations, one particular old-field site was sampled intensively for more than a year, with several of the taxonomic groups subjected to detailed analysis [i.e., spiders (Young and Lockley 1994), beetles (Young 1995a, b), mites (Young and Welbourn 1987, 1988)]. This report documents the spatial and temporal occurrence in pitfall traps of the major ground-surface arthropod groups of that old-field site adjacent to cotton in the Delta of Mississippi. These data are then used as background information relative to a more exhaustive analysis of the occurrence of a major cursorial predator group, the Cicindelidae (Coleoptera).

Materials and Methods

Site description. The study site was a 2.5-ha old-field habitat 3 km SSE of Leland, MS (Washington Co.), (Site 1 of Young and Welbourn 1987, 1988). This fenced area had been a pasture for horses and was routinely mowed once a year in the autumn. It was last mowed in 1983, and horses were removed in late 1984. The site was bordered on the east by a narrow paved road and adjacent 32-ha cotton field, on the north by a residence in a woodlot, on the west by a deciduous tree-lined creek, and on the south by old-field habitat. There were 3 distinct zones of vegetation and soil in this field. Nearest the road (east) was a north-south strip 20 m wide, sparsely covered with clovers and grasses. The soil was a heavy clay/loam mixture, and when very dry in mid and late-summer the surface contained many wide and deep cracks. Scattered clumps of *Erigeron strigosus* Willd. and *Anthemis cotula* L. were the principal flowering forbs in early and midsummer, with *Erigeron canadensis* L., *Aster pilosus* Willd., and *Helenium amarum* (Rafin.) dominant in late summer and autumn. Nearest the creek (west) and its associated trees was a north-south strip 10 m wide and shaded daily beginning in midafternoon. Horses had extensively trampled and fed in this area, and the vegetation was mostly *Cynodon dactylon* (L.) and *Sorghum halepense* (L.). Scattered clumps of *E. canadensis* and *Carduus* L. spp. bloomed in late summer, with senescence of all plants by late October. The soil was sandy loam, but was well-packed and drained somewhat better than the clay/loam section. The center section of the field was porous sandy loam with a dense cover of forbs, which included *Amaranthus* L. sp., *Oenothera* L. spp., and *Solidago altissima* L. Senescence occurred in late November, and in the spring of 1986 *Vicia sativa* L. over-grew much (50%) of the vegetation in this and the eastern sections.

Trap description. Six pitfall traps were placed in the field, 2 in each of the sections (east, center, west). Metal oil cans (946 ml, 10 cm diam, 14 cm high) with the tops removed were placed in the ground with the top rim protruding approx. 6 mm above the soil surface. Soil was packed around the can to form a low cone up to the rim. Inserted in each can was a removable plastic cup (473 ml, 10 cm diam, 13 cm high) containing approx. 100 ml of a 50% solution (in water) of commercial auto antifreeze (ethylene glycol). Traps were placed in pairs 1 m apart and connected by a sheet metal barrier 10 cm high, embedded 2.5 cm into the soil, and oriented north-south. Supported 5 cm over each trap by 3 wood dowels was an aluminum pie plate (20 cm diam) spray-painted dark green.

Field procedures. Pitfall traps were emptied and refilled with preservative at weekly or biweekly intervals (depending on temperature and associated arthropod activity levels) from March 1985 to May 1986. Contents of each pair of traps were

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pooled as one sample. Material from pitfall traps were brought into the laboratory and refrigerated for an indefinite period. Samples were subsequently sorted, identified, and tabulated. Unidentified material and voucher specimens were stored in alcohol for further processing.

Laboratory procedures. The body length of all cicindelids was measured to the nearest millimeter. Dissections were performed on the females of the 2 adult *Megacephala* species to determine their reproductive status. The abdomen of females was classified as either (1) containing eggs, (2) containing a large empty space where eggs had been stored (postegg), or (3) neither of the previous conditions. Individuals of *M. carolina* were determined to be either teneral or adult by applying pressure with a fingernail to the middle of an elytra; a teneral flexing and an adult remaining stiff and inflexible .

Experiment procedures. A follow-up experiment was conducted between *M. carolina* and nymphal crickets, *Gryllus* sp. (Orthoptera: Gryllidae), in large laboratory terraria. Live individuals for this experiment were obtained from an old field adjacent to the study plot, using the same barrier pitfall trap method. Traps were maintained without fluid and checked hourly when open, usually in early morning and late afternoon. Individual crickets and tiger beetles were brought into the laboratory, placed in individual containers, and held for 24 h before placement in the terraria. The 2 glass terraria used were 30x75x30H cm and packed level with soil from the study plot to a depth of 10 cm, then maintained throughout the experiment on an outside balcony protected from rain but exposed to ambient conditions. Beginning on 8 August, in each terrarium was placed 20 *Gryllus* sp. nymphs and either 2 male or 2 female *M. carolina*. After each succeeding 24 h, the status of all occupants was determined and the experiment terminated after 3 days. The procedure was repeated on 15 and 22 August, keeping the same number of *Gryllus* sp. (20) but increasing the number of *M. carolina* to 4 and then to 6 of each sex.

Results

Field collections

General arthropods. A total of 11,496 individuals was collected by pitfall traps in 39 sampling periods during 15 consecutive months (Table 1). Two taxonomic groups dominated the soil surface arthropod collections - Coleoptera and Orthoptera. These 2 groups comprised 74.4% (Coleoptera – 37.6%; Orthoptera – 36.8%) of all individuals captured. The Araneae represented an additional 14.7% of the total capture. This predator group along with members captured by sweep-net sampling has been considered previously (Young and Lockley 1994). Acari (4.6%) and Hemiptera (2.8%), combined with the first 3 groups, represented 96.5% of the total captures.

Coleoptera. Within the Coleoptera (Table 2), the Carabidae were the largest family present (1377 individuals). Though some carabids are seed consumers, most are predaceous on other arthropods. If the Cicindelidae (sometimes considered a subfamily within the Carabidae) are included, this composite group (1904 individuals) represents 44% of all Coleoptera captured. Members of the Staphylinidae (predaceous, 386), Scarabaeidae (phytophagous, detritivore, 308), and Curculionidae (mostly seed phytophages, 106) together represent another 18% of the Coleoptera population. Of the 4,327 Coleoptera captured, 3,317 were adults (77%) and 1010 (23%) were immatures. The largest group of immature Coleoptera (40%) was the triungulin larvae of *Meloe americanus* Leach (Meloidae), previously discussed in Young

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Table 1. Arthropods of an old-field habitat captured (mean # per month) in barrier pitfall traps, 25 March 1985 to 27 May 1986, Washington Co., MS *.

Taxon	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total no. Individuals
Chilopoda	1	<1	6	4	<1	<1	1	1	1		<1	<1	1	<1	1	50
Milipoda			<1							<1		<1				3
Isopoda			1	1		3	3	3	1	1		<1		<1	4	49
Acari		5	18	19	36	24	10	17	10	2	25		4	10	8	526
Araneae	73	55	37	43	54	59	44	30	17	25	24	26	68	45	58	1689
Coleoptera larva	1	8	10	13	40	21	39	56	30	9	1	1	<1	82	46	1010
Coleoptera adult	37	46	56	114	106	181	51	80	70	36	18	33	45	163	236	3317
Lepidoptera larva	2	<1	6		2	<1	2	<1		1		<1	<1	3	3	55
Orthoptera nymph		<1	7	169	86	151	172	184	255	27	25	8	8		7	3140
Orthoptera adult	2	3	1	4	27	122	80	36	11	1		1		<1	4	1086
Blatteria			1	1	<1	1	<1	2	1						1	21
Hemiptera nymph			5	7	11	<1	<1	<1	<1						3	68
Hemiptera adult	2	5	13	10	14	10	8	5	4	2		1	1	7	11	257
Neuroptera larva		<1	4				1	1						5	15	63
Mecoptera larva							2	39	8							173
Total monthly mean number	118	122	165	385	376	572	411	454	408	104	93	70	127	315	397	11,496
# sample periods	1	4	4	1	3	4	4	4	2	2	2	2	2	2	2	39

*Monthly intervals, 1 - 4 sample periods each month, sample period = 1 week, 6 pitfall traps per period.

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Table 2. Coleoptera of an old-field habitat captured (mean # per month) in barrier pitfall traps, 25 March 1985 - 27 May 1986, Washington Co., MS *.

Taxon	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total no. adults
Anthicidae	2		2				1	4	3		2			8		53
Carabidae	12	18	11	72		62	35	69	29	12	5	16	27	69	54	1376
Chrysomelidae	1	2	4	1		<1		<1	<1	<1	1		2	2	<1	40
Cicindelidae				8		93	10	3								521
Curculionidae	7	5	8			1	<1	2	1	<1	4	5	4	3	3	106
Elateridae		1	1			1			1			<1			<1	20
Histeridae				1		2			13	<1			3	66	121	414
Meloidae						<1				5	2	2	4	3		32
Nitidulidae		1	2				<1							1		13
Ptilidae		5	<1													18
Scarabaeidae	6	3	10	13		19	2	7	7				<1	3	20	298
Staphylinidae	9	13	19	17		4	3	3	16	17	5	10	7	10	38	411
Tenebrionidae			1	2		<1								<1		10
Miscellaneous **		<1	<1			<1										5
Total mean # adults	37	46	56	114	107	181	52	80	70	36	18	33	45	163	235	3317
Total mean # immatures		8	10	13	41	21	39	56	30	9	1	1	<1	82	46	1010
No. sample periods	1	4	4	1	3	4	4	4	2	2	2	2	2	2	2	39
No. dead vertebrates †						1	2		6			3		3	4	20

*Monthly intervals, 1 - 4 sample periods each month, sample period = 1 week, 6 pitfall traps.

**One individual each from Cantharidae, Lampyridae, Languridae, Mordellidae, and Silphidae.

†Includes frogs, toads, shrews, and mice, all of which became carrion and attractive to the histerids and some staphylinids and scarabs.

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(1995a). Another large group of immatures (10%) was the larvae of *Cotinus nidita* (L.) (Scarabaeidae), discussed in Young (1995b). An unanticipated group of Coleoptera captured were members of the Histeridae (414 individuals), almost all of which were associated with the vertebrates (frogs, toads, mice, shrews) that fell into the pitfall traps and upon decomposition became attractive for the carrion-frequenting histerids.

Orthoptera. All members of this group were herbivorous. The most abundant arthropod species at this site, occurring in every month of the year, were field crickets, *Gryllus* spp. (Gryllidae) (Table 2). Nymphs (3,104) and adults (964) represented 35% of the entire captured arthropod population. Nymphs reached peak numbers in the July-to-October period. Other orthopterans included cone-headed (*Neoconocephalus* sp.) and round-headed (*Amblycorypha* sp) katydids (Tettigoniidae), spur-throated grasshoppers (*Melanoplus* spp.; Acrididae), mole crickets (*Neocurtilia* sp.; Gryllotalpidae), and camel crickets (*Ceuthophilus* sp.; Rhaphidophoridae)

Araneae. As documented by Young and Lockley (1994), 1689 spider individuals of 53 species were captured by pitfall traps at this old-field site in every month of the year, 47.1% immature and 52.9% adult. Members of the Lycosidae represented 68% of the captures, with species in the genera *Lycosa*, *Pardosa*, and *Schizocosa* most frequently captured. The largest-sized ground spiders captured were the 8 species of *Lycosa* and *Schizocosa*, all greater than 10 mm in length and numbering 539 individuals.

Acari. An analysis of the 511 mite individuals captured is in preparation (Welbourn and Young). Discussion of a unique mite from this site is presented in Young and Welbourn (1987, 1988).

Hemiptera. Included in this group were the herbivorous planthoppers (Delphacidae), burrowing bugs (Cydnidae), seed bugs (Lygaeidae), and squash bugs (*Euschistus* sp., Pentatomidae:). Predators included *Podisus* sp. (Pentatomidae), *Geocoris* sp. (Lygaeidae.), *Phymata* sp. (Phymatidae), and *Reduviolus* sp. (Reduviidae). The most frequently collected of the hemipterans were burrowing bugs (*Pangaeus* sp.), 142 adults (March to November) and 34 nymphs (June and July).

Cicindelidae. At the study site were captured 3 cicindelid (tiger beetle) species. *Megacephala virginica* L., *M. carolina* L., and *Cicindela punctulata* Olivier (Table 3), all of which are typically voracious and very active predators. Larvae are tunnel-dwellers, catching arthropods that pass by the tunnel opening. No larvae of these species were collected or observed. Adult cicindelids are typically bright colored and fast runners on ground and quickly fly when disturbed (Knisley and Schultz 1997). All 3 species showed the consistent pattern of decreasing activity (captures west to east) as they moved further from the stream and the adjacent moist soil (Tables 4, 5, 6). During the month of August, cicindelids reached their highest proportion (49%) of all Coleoptera adults (Table 3). Comparing the number of cicindelid adults each month with the monthly number of their potential prey (larval Coleoptera, larval Lepidoptera, nymphal Orthoptera), August also represents the period with the lowest ratio (1:1.8) of cicindelid predator-to-arthropod prey (Table 3). Individual adults of the diurnal *Cicindula punctulata* occurred from the last week of June to the fourth week of September, with 47% captured closest to the stream (west) and 58% females overall (Table 4). *Megacephala virginica* adults (8 males, 4 females) occurred only in 4 consecutive sampling periods in July and August (Table 5). *Megacephala carolina* was the most abundant beetle species captured, with the 404 nocturnally-active individuals composed of 235 males (58%) and 169 females (42%) occurring for 16 consecutive weeks, from late June to late October (Table 6). Most of the adult beetles probably emerged in the first 4 wks of that

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Table 3. Cicindelidae (Coleoptera) of an old-field habitat captured (mean # per month) in barrier pitfall traps, 25 March 1985 - 27 May 1986, Washington Co., MS *.

Taxon	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total # adults
Cicindela punctulata East			1		4.8					20
Center			4	4.3	4.8					36
West				2	9.3	1.5				49
Total			5	6.3	18.9	1.5				105
Megacephala virginica East				0.3	0.5					3
Center				0.7	1					6
West				0.7	0.3					3
Total				1.7	1.8					12
Megacephala carolina East				0.7	3.8					17
Center				11.7	34.3	3.3				186
West			4	10	34.8	5	2.3			202
Total			4	22.4	72.9	8.3	2.3			404
Total mean # adult cicindelids			9	30.4	93.6	9.8	2.3			521
Cicindelid Ad as % of Coleoptera Ad	0	0	7	25	49	21	3	0	0	
Total mean # of potential prey **	9	23	182	132	172	213	240	285	37	
Ratio of cicindelid predator (1:x) to prey			1:22	1: 4.3	1: 1.8	1: 22	1: 104			
# sample periods	4	4	1	3	4	4	4	2	2	

* Monthly intervals, 1 - 4 sample periods each month, sample period = 1 week, 6 pitfall traps.

** Potential prey = larval Coleoptera, larval Lepidoptera, nymphal Orthoptera

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Table 4. Captures of *Cicindela punctulata* in barrier pitfall traps in an old field-habitat, 25 March 1985 - 27 May 1986, Washington Co., MS.

	Location-East		Location-Center		Location-West		Totals	
Date	M	F	M	F	M	F	M	F
24 Jun - 1 Jul	1	-	1	3	-	-	2	3
1 - 8 Jul	-	-	-	-	-	1	-	1
8 - 16 Jul	-	-	1	1	-	1	1	2
16 –26 Jul	-	-	3	8	-	4	3	12
26 Jul - 8 Aug	2	7	5	6	5	10	12	23
8 - 15 Aug	4	5	3	4	14	2	21	11
15 - 22 Aug			-	1	2	2	2	3
22 - 29 Aug	-	1	-	-	-	2	-	3
29 Aug - 5 Sep	-	-	-	-	1	1	1	1
5 - 12 Sep	-	-	-	-	1	2	1	2
12 - 19 Sep	-	-	-	-	-	-	-	-
19 - 26 Sep	-	-	-	-	1	0	1	-
Totals	7	13	13	23	24	25	44	61
	20		36		49		105	

period, as no teneral adults were captured after the period from 16 - 26 July (Table 6). Only 4% of the total captures of *M. carolina* were in the section furthest from the stream; whereas, 51% of the captures were in the section adjacent to the stream. A seasonal shift in population toward the stream was particularly pronounced when listing

Table 5. Captures of *Megacephala virginica* in barrier pitfall traps in an old-field habitat, 25 March 1985 - 27 May 1986, Washington Co., MS.

Date	Location	Sex	Female status
1 - 8 Jul	West	1-F	
8 - 16 Jul	West	1-F	
16 –26 Jul	Center	1-M	
	Center	1-F	Eggs (7)
	East	1-M	
26 Jul – 8 Aug	West	1-F	Eggs (4)
	Center	4-M	
	East	2-M	
Totals	3–East 6–Center 3–West	8 - M 4 - F	

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Table 6. Captures of *Megacephala carolina* in barrier pitfall traps in an old-field habitat, 25 March to 27 May 1986, Washington Co., MS.

Date	Location	Number teneral (%)	No. each sex		Female reproductive status (%)
			M	F	
25 Mar – 28 May (9 sample periods)	All sites	Absent	Absent		Absent
24 Jun – 1 ul	West	4 (100%)	1	3	
1 - 8 Jul	West	1 (100%)	1	-	
8 - 16 Jul	East	1 (100%)	-	1	
	Center	9 (100%)	2	7	2 w/eggs (29%)
	West	5 (100%)	3	2	
16 –26 Jul	East	0	1	-	
	Center	11 (42%)	13	13	1 postegg (8%)
	West	1 (4%)	14	10	1 w/eggs; 1 postegg (20%)
26 Jul – 8 Aug	East	0 (0%)	8	3	3 postegg (100%)
	Center	0	36	33	6 w/eggs; 9 postegg (45%)
	West	0	33	25	9 postegg (36%)
8 - 15 Aug	East	0	1	1	
	Center	0	17	12	1 w/eggs; 2 postegg (25%)
	West	0	19	8	
15 - 22 Aug	East	0	- 1		
	Center	0	14	16	4 w/eggs; 4 postegg (50%)
	West	0	27	15	2 w/eggs; 9 postegg (73%)
22 - 29 Aug	East	0	1	-	
	Center	0	6	3	2 w/eggs; 1 postegg (100%)
	West	0	9	3	2 w/eggs (68%)
29 Aug – 5 Sep	Center	0	4	4	1 w/eggs; 2 postegg (75%)
	West	0	5	1	1 w/eggs (100%)

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Table 6. Continued

Date	Location	Number teneral (%)	No. each sex M	No. each sex F	Female reproductive status (%)
5 - 12 Sep	Center	0	4	-	
	West	0	6	2	
12 - 19 Sep	Center	0	-	1	
	West	0	2	1	1 postegg (100%)
19 - 26 Sep	West	0	-	3	2 w/eggs (68%)
26 Sep - 3 Oct	West	0	3	-	
3 - 10 Oct	West	0	3	1	
10 - 17 Oct	West	0	1	-	
17 - 24 Oct	West	0	1	-	
24 Oct - 27 May (14 sample periods)	All sites	Absent	Absent		Absent
Totals	East—17 Center –185 West—202 Total–404	Before 27 VII 32 / 71 = 45% After 26 VII 0%	M–235 F–169 Sex ratio (M:F) = 1.4: 1		24 w/eggs; 42 postegg 66 / 169 = 39% F reproductives

the last time period when *M. carolina* was captured in a section: East section - 29 August, Center section - 19 September, West section (nearest stream) - 17 October (Table 6).

Other taxonomic groups. A total of 173 scorpionfly larvae (Mecoptera) was captured, all in a 7-wk period from September to November. These caterpillar-like larvae stay on the ground and consume dead insects and other organic material. The adults are scavengers. The 50 predatory centipedes (Chilopoda) were collected in every month of the year, as were the 49 detritivore pill bugs (Isopoda).

Laboratory observations

Measurements of adult cicindelids. *Cicindela punctulata* – 105 individuals: length range- 9 - 14 mm. *Megacephala virginica* – 12 individuals; length range-16 - 21 mm. *M. carolina* – 404 individuals; range- 12 - 18 mm.

Dissections of female *Megacephala*. Of the 4 females of *M. virginica* that were captured and then dissected, 2 were carrying eggs, 1 with 7, 1 with 4, during the late July to early August period (Table 5). Dissections of the 169 captured *M. carolina* females produced 24 with eggs and 42 with empty abdominal space where the eggs had been, indicating that at least 39% of the females were reproductive, occurring from mid-July to late September (Table 6).

Determination of age of *M. carolina*. Teneral adults were the first to appear, and by the 26 VII – 8 VIII period all adults were hardened and nonteneral (Table 6).

Feeding experiment with *M. carolina*. Under the conditions of the experiment, both male and female *M. carolina* were able to capture and consume nymphal *Gryllus* sp. (Table 7). Males were able to kill more prey than females, though the differences

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Table 7. Response of male and female *Megacephala carolina* to *Gryllus* sp. nymphs in laboratory containers, August 1985, Washington Co., MS.*

Week performed	No. *Megacephala carolina* **	No. *Gryllus* sp. nymphs †	First 24 h post exposure	Second 24 h post	Third 24 h post	Total §	Reproductive F status after 72 h
8 Aug	2 M	20	4	6	5	15/20	
8 Aug	2 F	20	3	4	3	10/20	1 – w/eggs
15 Aug	4 M	20	8	5	7	20/20	
15 Aug	4 F	20	6	6	5	17/20	2 – w/eggs
22 Aug	6 M	20	12	8	0‡	20/20	
22 Aug	6 F	20	8	7	5	20/20	2 – w/eggs 2 – post eggs

*30x75x30h cm
**mean length = 16mm
†mean length = 21mm
‡2 *M. carolina* killed & partly consumed
§number killed / number offered

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may be due to the reproductive status of some of the females and their apparent associated reduction in feeding. Cannibalism was detected with males when *Gryllus* prey was depleted after 2 days, but was not detected with females after 3 days (Table 7).

Discussion

Most old-field studies involve plant succession analyses (e.g., Squiers and Wistendahl 1977, Myster and Pickett 1994). Studies that examine the arthropods in old-fields typically are examining either (1) their impact on plant diversity (e.g., Brown et al. 1988, Schmitz 2003), (2) their functional groupings, such as herbivore, carnivore, etc. (e.g., Dowdy 1944, Teraguchi et al. 1977), (3) their interrelationships (e.g., Moran et al. 1996), or (4) their possible role in suppression of pests in adjacent crops (e.g., Allan et al. 1975, Altieri and Schmidt 1986). Research at the current site was particularly interested in the arthropod predators and their potential impact on other arthropods both in the old-field and in the adjacent cotton field. The major predator groups at this old-field site were spiders (Young and Lockley 1994) and Coleoptera. Within the Coleoptera, predatory groups (Staphylinidae, Histeridae, most of the Carabidae, and the Cicindelidae) comprised over 70% of the adults captured.

Previous investigators have demonstrated that larger areas adjacent to crop fields have higher predator-prey ratios than smaller areas (e.g., Thomas et al. 1991, Denys and Tscharnike 2002). This is particularly important when comparing field margin strips versus large fallow areas such as old-fields, where in addition older fallows have higher predator-prey ratios than young fallows (Denys and Tscharnike 2002). The high predator-prey ratio in August of cicindelid predators (1:1.8) in this 2.5-ha old field is in agreement with that research. Adult ground spiders are most common in the March to May period; whereas, immature spiders are more common in the June to September period (Young and Lockley 1994). As potential predators of cicindelids, the large adult lycosid spiders are most abundant when most cicindelid adults are absent.

The occurrence of the large population of nymphal orthopterans coincided with the occurrence of an unusually large population of cicindelids, a known predator on adult and nymphal crickets and grasshoppers (Larochelle 1974). Field studies with some species of wood crickets have demonstrated a daily movement from woodland to field and return (Beugnon 1980). Such movement through the 3 zones in this old field of the resident crickets would expose them to many individuals of the 3 cicindelid species. The feeding experiment conducted with *M. carolina* indicated that nymphal *Gryllus* sp. were readily captured and consumed, providing support for a relationship between a high *Gryllus* sp. population and a concurrent high *M. carolina* population. If abundant *Gryllus* sp. were not present, it is unlikely that the *M. carolina* (and *C. punctulata*) populations could be maintained at their present levels. Perhaps not coincidentally, a *Megacephala* species in South America is an extremely common predator in riverine habitats and is the major predator of *Scapteriscus* mole crickets (also found in USA) (Fowler 1987).

The pattern of late-season appearance of adult cicindelids, and egg laying at that time, suggests that the 3 species are univoltine, with adults dying after the late-summer reproductive period, with eggs probably hatching either late summer or early the following spring. If egg hatching occurs in the late summer, larvae establish their soil tunnels and develop until necessary winter hibernation. In the spring, either overwin-

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tering eggs hatch or overwintering early-stage larvae appear, with subsequent development through the larval and pupal stages and adult appearance by midsummer.

Concurrent with the pitfall sampling in the old-field habitat, sampling also was conducted in the adjacent cotton field. Unfortunately, when the first cotton pests appeared in late May, the grower decided to abandon his no-pesticide pledge and began a weekly program of aerial spraying. Not surprisingly, after several pesticide applications there were essentially no arthropods to sample (Young and Lockley 1994). Although there are no data from the adjacent cotton field, several comparisons between the 2 sites can be made. Because most of the spider species found at this old-field site also have been captured in cotton and other field crops (Young and Edwards 1990), and because many of those species are known predators on cotton pests (Lockley and Young 1987, Young 1989a, b), there is little doubt that this particular old-field site was contributing spider predators to the adjacent cotton field. It is less obvious whether other predators in the old-field may be contributing to that adjacent population. Although some of the nonspider predators are potential consumers of cotton pests (Young 1989c, d, Young and Lockley 1990), there seemed to be very few species and individuals of those predators on the ground in the old-field. The surprise was the substantial population of predatory cicindelids (tiger beetles) in the old field. This group of 3 species (*Megacephala carolina*, *M. virginica*, and *Cicindela punctulata*) is a known inhabitant of cotton and other crops in the southeastern U. S., though typically in low numbers (Whitcomb and Bell 1964, Neal 1974, House and All 1981, Goyer et al. 1983). There apparently are no published studies of *Megacephala* populations in old-field habitats.

Tiger beetles as a group are becoming a favorite research subject of students of ecology, behavior, and evolution (review in Pearson and Vogler, 2001). The biology of *C. punctulata* is relatively well known, whereas the biology of the 2 *Megacephala* species is relatively unknown (Knisley and Schultz 1997). *Cicindela punctulata* exhibits a 1-year life cycle with adults active during the daytime in summer, emerging in June and reaching a peak in July when oviposition occurs. Larvae feed throughout the summer and reach the 3rd instar by September; after overwintering, 3rd instars feed in spring and pupate in late May or June. Adults occur as scattered individuals or at moderate densities (Knisley and Schultz 1997). It is probably the most common tiger beetle in North America, occurs in a wide range of habitats, and is probably less restricted ecologically than any other tiger beetle in North America (Graves and Pearson 1973). The current study documents this species at 'moderate' densities and in proximity with the 2 *Megacephala* species in a riverine habitat, though due to diel separation there may be minimal contact. Perhaps because it is common in many agricultural areas, this species has developed pesticide resistance in some populations (Pearson et al. 2006)

Megacephala virginica occurs nocturnally in a variety of habitats with a wide geographic distribution. Adults are typically solitary and usually found at low densities and may be active during the day, but only after a rain shower or when overcast (Knisley and Schultz 1997). This study indicates minimal spatial and temporal association of this species with *M. carolina*.

Megacephala carolina is gregarious, nocturnal, a rare flier, widespread across the southern U.S., most often found in water-edge habitats, particularly river floodplains, and also in habitats away from water such as unsprayed (chemical) agricultural fields and roadsides (Knisley and Schultz 1997). It has been found in Baltic amber from the Oligocene (25 - 40 mil yrs BP) and is perhaps the only amber species of insect that

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has survived up to the present time (Thiele 1977). The present study documents an unusually large population of this species, but typically in proximity with the other 2 cicindelid species, a situation similar to that described for Florida and Louisiana soybeans (Neal 1974, Goyer et al. 1983). This species may be the principal adult beetle predator at the site, capable of attacking most every other ground arthropod present during mid to late summer, particularly the large population of ground crickets. Though not documented, what must have been numerous predaceous larvae of this species should also have been a significant predator in spring and early summer. It is intriguing to contemplate what a large population of adult *M. carolina* would do to the various arthropod pests in a crop field. Finding methods of encouraging this predator to move each summer from an old-field habitat to an adjacent crop field would be a worthy avenue of research.

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