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Feeding Fauna and Foraging Habits of Tiger Beetles Found in Agro-ecosystems in Western Ghats, India[1]

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ABSTRACT

Cicindela (Calochroa) whithilli (Hope) and *Cicindela (Calochroa) flavomaculata* Hope (Cicindelidae: Coleoptera) are seasonally dominant predatory insects in the cultivated, and irrigated rice paddy fields of the South Indian peninsula. While studying the feeding ecology of these tiger beetles in rice paddy agro-ecosystems in Sringeri area of the central Western Ghats, we examined their potential as biocontrols on the major rice paddy pest populations available in this region. Earthworms and tadpoles were significant prey organisms during the early cultivation period, while other traditional prey organisms like ants and spiders (mainly wolf and jumping spiders) were more common as prey organisms toward the mid-season. The results showed that the feeding fauna of tiger beetles can extend to prey items beyond arthropods, to include vertebrates. *Cicindela (Calochroa) duponti* Dejean is another common species that occurs abundantly in the *Areca* orchards and on the bunds that separate rice paddy fields from adjacent uncultivated lands. We performed laboratory tests to determine the feeding guild of these beetles, and to investigate their possible role as a predator of the rice paddy pests. Although preliminary in nature, the results suggest that both *C. whithilli* and *C. flavomaculata* are ineffective as biocontrol agents of rice paddy agro-ecosystems. They appear to have only a marginal impact on the larvae of *Leptocorisa acuta*, a major insect pest of paddy rice, but further experimental and observational studies are needed to firmly establish the significance of this observation.

Key words: Cicindela flavomaculata; Cicindela whithilli; feeding guild; generalist predators; rice paddy agro-ecosystems; Western Ghats; India.

AMONG OTHER MAJOR LIMITING RESOURCES, food can play a pivotal role in determining the life cycle, activity, and co-occurrence of animal populations (Lenski 1982); a number of studies have indicated that various biotic factors, such as competition, resource availability, and partitioning, can be important for some insect assemblages, especially predatory insects (Lawton *et al.* 1980, Lawton & Hassell 1981, Tepedino & Stanton 1981, Juliano 1986, Juliano & Lawton 1990). Knisley and Pearson (1981) and Hori (1982) have shown that the availability of prey organisms can be the fundamental limiting factor in maintaining the life cycle and growth rate of tiger beetles (Coleoptera: Cicindelidae). Rainfall is apparently the most important abiotic factor that influences the diversity of tiger beetles in many parts of the world (Pearson & Knisley 1985, Pearson & Ghorpade 1989, Pearson & Carroll 1998).

Overlap in habitat use and resource sharing by closely related species is an alternative to the principle of competitive exclusion proposed by Gause (1934), and has been documented widely among herbivorous insects (Ross 1957, Broadhead 1958). Tiger beetles of various species are among the most widely studied predatory insects that are known to use the same habitat or the same microclimate niche, and sometimes even partition prey organisms (Pearson & Vogler 2001).

Tiger beetles are well-known, voracious insect predators of a range of small arthropods in various ecosystems (Pearson & Mury 1979, Pearson 1988, Pearson & Cassola 1992). Recent reviews, such as Pearson and Vogler (2001) and Pearson (1988), have compiled the extensive biology and foraging behavior of tiger beetles. Although both larvae and adult tiger beetles are assumed to be general hunters, their strategies to capture prey organisms are entirely different; larvae are passive predators that wait at the openings of their tunnels and ambush approaching prey (Hori 1982), while adults are fast hunters and use several iterations of stop-and-go running before they capture the prey (Gilbert 1997). Adults mainly use the familiarity of the shape or size and location of the prey to recognize the victim (Swiecimski 1956). In another study, Kaulbars and Freitag (1993) reported ambush predation of approaching prey by *Cicindela denikei* Brown. On occasion, tiger beetle adults will scavenge large dead or dying organisms, or feed on fruits (Pearson & Vogler 2001).

Although several species of tiger beetles have been proposed as potential biocontrol agents in various agro-ecosystems around the world (Pearson 1988, Pearson & Vogler 2001), these claims are based only on personal observations by researchers. Some experimental studies (Sastry & Appanna 1958, Fowler 1987, Hudson *et al.* 1988) have examined the role of tiger beetles in controlling pest populations. A preliminary observation by a research team in India suggested that *Cicindela flavomaculata* could be a potential biocontrol agent of rice paddy pests in irrigated

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rice fields (Pearson & Vogler 2001). Meanwhile, other observations (Dammerman 1929, Frick 1957) illustrated the potentially negative roles of tiger beetles.

With more than 2600 species worldwide, tiger beetles (Cicindelidae: Coleoptera) occur in a broad range of habitats, except for some oceanic islands and Antarctica (Pearson 1988). *Cicindela* Linnaeus is by far the largest tiger beetle genus with approximately 875 known species worldwide; the Indian subcontinent has 151 species from 24 subgenera (Acciavatti & Pearson 1989). Adults occur in almost all major habitats that include forest grounds, plantations, stream edges, agricultural lands, and ocean beaches. Although some members of this genus occasionally use undergrowth bushes as a temporary substratum, virtually all species are ground dwellers and foragers (Fowler 1912). Most of them are found to prefer open areas, compared to thick evergreen forest floors.

In south India, *Cicindela (Calochroa) whithilli* (Hope) and *Cicindela (Calochroa) flavomaculata* Hope are the two major tiger beetle species that are found together in enormous numbers in cultivated rice paddy fields (Fowler 1912). Another common species, *Cicindela (Calochroa) duponti* Dejean is observed abundantly on the sandy floors of adjacent monoculture plantations, such as *Areca* palm orchards and *Acacia* (wattle) plantations, and also on the bunds that separate these plantations from the cultivated rice paddy fields. Thus, we tested the prediction that these three tiger beetle species were significant predators of several rice paddy pests. To conduct these tests, we chose: (1) to observe the feeding ecology and feeding fauna of *C. whithilli*, *C. flavomaculata*, and *C. duponti*; (2) to understand the feeding strategies of tiger beetles on earthworms and on tadpoles; and (3) to examine the predatory potential of these three species of tiger beetles on major rice paddy pests. The article also discusses the detailed natural history of adult *C. whithilli* and *C. flavomaculata*.

METHODS

Study area.—The study was conducted in Sringeri, the smallest taluk of Chikmagalur district in Karnataka state, India. Situated on the gentle eastern slope of the central Western Ghats between 12°55′–13°54′N and 75°01′–76°22′E, Sringeri is surrounded by cliffs of the Ghats. Seventy-five percent of the area is under forest cover, which consists of two types classified by the forest management—reserve forest (55%) and community-managed forest (20%). The forest in Sringeri is mid-elevation wet evergreen, and the entire landscape is comprised of a mosaic of land use types, such as degraded evergreen forests, *Acacia auriculiformis* (Wattle) plantations (4%), *Areca* orchards (7%), and agricultural lands (rice paddy fields, 6%). The rainfall varies between 3500 and 5000 mm/yr, and during the study year, rainfall was nearly 4000 mm. Sringeri generally has the highest precipitation from June to October, with a distinct dry season from January to May; the elevation ranges from 625 to 750 m. Eight rice paddy fields, one each from eight hamlets (Fig. 1), which were following the traditional farming practice (no pesticide and inorganic fertilizer application happens) for past 5 yr

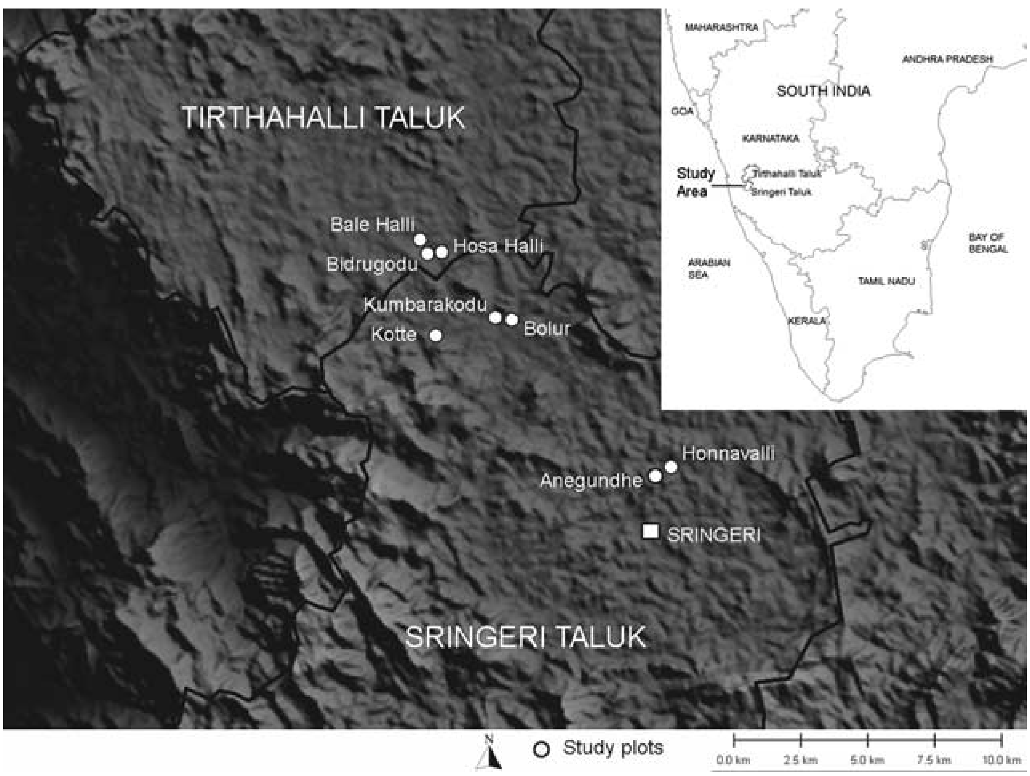

FIGURE 1. Map showing study area and locations.

(prior to the study year), were selected for the field observations. The study was conducted from March 2003 to October 2004.

NATURAL HISTORY OF TIGER BEETLES IN SRINGERI.—We recorded eight species of tiger beetles from various habitats on or adjacent to the study sites. Six species belonged to the genus *Cicindela* Linnaeus, and one species each from the genera *Collyris* Fab. and *Rhytidophaena* Bates. All species, except the arboreal *Collyris* sp., were found on the ground of one or more habitat types; *C. whithilli* and *C. flavomaculata* were the two most abundant species in the area, and the only tiger beetle species encountered in the cultivated rice paddy fields in Sringeri. The species co-occurred and shared food resources. *C. duponti* Dejean was the third common species observed in Sringeri area and occurred in large numbers on sandy floors of *Areca* orchards, other tree-based plantations like *Acacia* plantations, and occasionally in association with *Cicindela (Calochroa) fabriciana* Horn on forest paths. Unlike *C. whithilli* and *C. flavomaculata* that frequently congregated together in large numbers, individuals of *C. duponti* were more solitary in their feeding habitat. Although *C. duponti* was common on bunds that separate *Areca* gardens from paddy fields, they did not move toward paddy fields even when disturbed. *Cicindela (Ancylia) andrewsi* (Horn) was observed rarely on forest paths in Sringeri. *Cicindela (Eugrapha) minuta* Olivier and *Rhytidophaena* sp. are riparian species, and occupy sandy banks of streams and other water bodies. Adult *C. minuta* were active on the banks of streams throughout the year, whereas all other species were highly seasonal. *C. whithilli*, *C. flavomaculata*, and *Collyris* sp. were active from June to December; adults of all the other beetle species were active between June and October (the period with high precipitation). All the tiger beetles were identified using Acciavatti and Pearson (1989), and their identities confirmed by comparison to voucher specimens available at the Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore.

ABUNDANCE OF *C. WHITHILLI* AND *C. FLAVOMACULATA* ACROSS SEASONS.—Eight rice paddy fields were selected in various villages (Fig. 1) of Sringeri taluk, and a single transect of 10 × 5 m was laid from one edge toward the center in each rice paddy field. We estimated the relative abundance of *C. whithilli* and *C. flavomaculata* with a visual census in each of these transects during a 30-min walk. The counts were taken during two different periods of a crop season—immediately after plowing (late May, early season), and 30 d after seedling transplantation (early October, mid-season). The number of individuals of both the species was plotted for each study site and later, the abundance of each species pooled across study sites, and the average value was calculated for both the seasons.

PREY PREFERENCE AND FORAGING STRATEGIES OF ADULT TIGER BEETLES.—The foraging behavior of *C. whithilli*, *C. flavomaculata*, and *C. duponti* from the eight study sites in Sringeri taluk were observed. All three species were most active during forenoon; hence, field observations were restricted in each study site from 0700 to 1300 h. Care was taken not to disturb the natural activities of the adult tiger beetles. A selected number of beetles (*N* in Tables 2 and 3) of both the species were tracked carefully for 1 h to quantify and compare the capture rate (number of prey captured per hour), and consumption time (time required to consume each prey organism) for prey organisms including tadpoles, earthworms, and ants. Nonparametric Mann–Whitney *U* test was conducted to compare the difference in median capture rate of tiger beetle species, and to compare the median consumption time of earthworms and tadpoles between tiger beetle species. Analyses were performed using STATISTICA (Version 5.5, StatSoft Inc., Tulsa, Oklahoma, 1999). Both capture and attempted capture of prey species were recorded and identified to the lowest possible taxon. The predatory actions of the beetles were photographed. The predators of *C. whithilli* and *C. flavomaculata* that were encountered during the course of field survey were recorded.

RESULTS

ABUNDANCE OF *C. WHITHILLI* AND *C. FLAVOMACULATA* ACROSS SEASONS.—The three tiger beetle species started emerging immediately after the first few summer showers in May (81 mm of rainfall in 2003 and 190 mm in 2004), and the emergence peaked with the first few monsoon showers, which fell on Sringeri by 16th June in 2003 (rainfall in June, 758 mm) and 2nd June in 2004 (rainfall in June, 1017 mm). A major decline in the abundance of *C. whithilli* and *C. flavomaculata* was noted toward the latter period of their adult activity in all the study sites (Fig. 2a,b); *C. whithilli* was found to decrease from an average of 23 individuals per transect in the early season to 12.25 toward the mid-season, and *C. flavomaculata* was found to decrease from an average of 8.75 individuals in the early season to 2 toward the mid-season (see Fig. 1 for the distance between study sites).

PREY PREFERENCE OF ADULT TIGER BEETLES.—Both *C. whithilli* and *C. flavomaculata* were active during early monsoon (early July in 2003 and mid-June in 2004), but maximum foraging activity was observed in mid-July in both the years. Earthworms (Annelidae) and frog tadpoles (size 85 mm; Ranidae: Anura) were the very common prey for both species of tiger beetles until late August. *Cicindela whithilli* and *C. flavomaculata* preferred earthworms and tadpoles to other prey organisms like wolf spiders (Family: Lycosidae) and ants during this period. But with the disappearance of exposed earthworms and stranded tadpoles in drying small puddles and shallow ditches in paddy fields late in the season, the tiger beetles were presumed to switch over to more conventional prey organisms like ants and spiders (until early November). A detailed list of organisms observed to be preyed upon by tiger beetles is given in Table 1.

There was a significant difference in the mean capture rate of *Polyrhachis exercita* Walker (Hymenoptera: Formicidae) by *C. whithilli* and *C. flavomaculata*. They were found to feed on an average of 6.3 and 4 individuals, respectively, per hour (Mann–Whitney *U* test, $P = 0.01$). But no significant difference in the capture rate of other prey organisms (see Table 2) was observed between *C. whithilli* and *C. flavomaculata*.

A comparison of mean consumption time by *C. whithilli* and *C. flavomaculata* showed that *C. whithilli* takes relatively less time to consume preys like tadpoles and earthworms than *C. flavomaculata*.

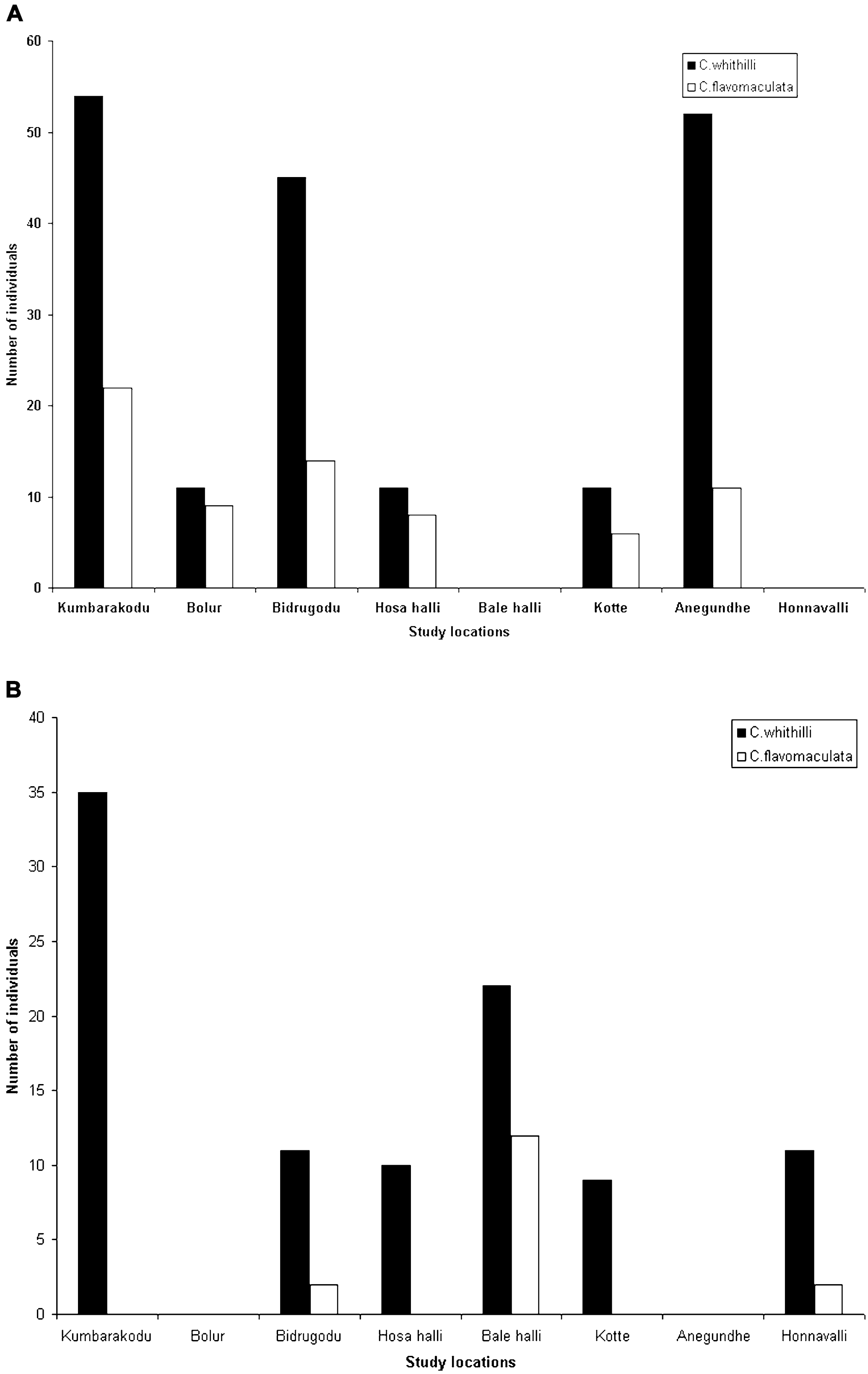

FIGURE 2. (A) Abundance of *Cicindela whithilli* and *Cicindela flavomaculata* in early adult activity period (early cultivation season) across various study sites. (B) Abundance of *C. whithilli* and *C. flavomaculata* in middle adult activity period (mid-season) across various study sites.

TABLE 1. *Prey list of* Cicindela whithilli *(CW),* Cicindela flavomaculata *(CF), and* Cicindela duponti *(CD).*

Class	Order	Family	Species	CW	CF	CD
Oligochaeta	Opisthopora		Earthworms	*	*	
Amphibia	Anura	Ranidae	Tadpoles of *Euphlyctis cyanophlyctis*	*	*	
Arachnida	Araneae	Salticidae	*Bavia* sp.	*	*	
			Bianor sp. 1	*	*	
			Bianor sp. 2	*		
		Lycosidae	*Pardosa sumatrana*	*		
			Pardosa pseudoannulata	*		
		Gnaphosidae	*Zelotus* sp.	*		
Insecta	Hymenoptera	Formicidae	*Polyrhachis exercita*	*	*	
			Polyrhachis hauxwelli	*	*	
			Camponotus angusticollis	*		
			Pheidolegeton diversus	*	*	
			Pachycondyla tesseronoda	*		
			Paratrechina longicornis			*
			Cardiocondyla carbonaria			*
			Tetramorium pacificum			*
			Anoplolepis gracilipes			*
			Oecophylla smaragdina			*
			Tetraponera allaborans			x
			Camponotus parius			x
			Diacamma rugosum	x		
	Diptera	Ephydridae	*Ochthera* sp.	*		
	Coleoptera	Coccinellidae	Sp. 1	*		
		Carabidae	*Clivina* sp.	*		
		Dytiscidae	sub adults	*		
		Scarabaeidae	grub	o	o	
		Cicindelidae	*Cicindela whithilli*	o		
	Isoptera	Termitidae	Sp. 1	*	*	
	Orthoptera	Gryllidae	Sp. 1	o	o	
	Hemiptera	Alydidae	*Leptocorisa acuta*	*	*	

*Preferred prey, [x]fighters, [o]carcasses.

To consume a tadpole, *C. whithilli* took 22–36 sec (mean 27.28 sec), while *C. flavomaculata* took 40–60 sec (mean 52.2 sec). This difference in the mean consumption time between tiger beetle species was significant (Mann–Whitney *U* test, $P = 0.004$). Although the mean consumption time for earthworms (approximate length 3.5 cm) by *C. whithilli* (8.52 min) was shorter than that by *C. flavomaculata* (11.5 min), the difference was not significant (Table 3).

The species composition of ants in *Areca* and *Acacia* plantations is different from that of rice paddy fields, and it is reflected in the feeding differences of *C. duponti* (Table 1). *Cicindella duponti* preyed on several species of ants, including *Paratrechina longicornis* Latreille, *Anoplolepis gracilipes* Smith *(Formicinae)*, *Cardiocondyla carbonaria* Forel, and *Tetramorium pacificum* Mayr *(Myrmicinae)*. *Oecophylla smaragdina* Fab., another common formicine ant in *Acacia* plantations, was captured at a lower rate, possibly due to the aggressiveness of the ant.

FORAGING AND POST-FORAGING BEHAVIOR OF TIGER BEETLES.—Several iterations of stop-and-go running were used by *C. whithilli* and *C. flavomaculata* to locate and capture mobile prey organisms like ants and spiders. Preys that moved by running followed by pause, including ants (particularly noted in *P. exercita*), wolf spiders (Lycosidae), and jumping spiders (Salticidae) alerted the tiger beetles. Immobile preys (Lycosid and Salticid spiders) were not captured even though they were less than 1 cm away from the beetles.

TABLE 2. *Mean capture rate (range, number consumed in every 1 h time) of significant and key prey organisms by* Cicindela whithilli *(CW) and* Cicindela flavomaculata *(CF). Significant difference in the median capture rate between* C. whithilli *and* C. flavomaculata *is compared by Mann Whitney U test, N = number of beetles observed every 1 h.*

	CW				CF				
Prey items	*N*	Range	Mean capture	SD	*N*	Range	Mean capture	SD	*U* Value
Tadpoles	10	7–15	11.4	2.63	7	7–14	11	2.31	30.5 (NS)
Earthworms	5	2.5–4.5	4	1.04	5	2.5–5.5	4	2.29	12 (NS)
P. exercita	10	3.5–8	6.3	1.78	6	2.5–5	4	4.11	8 ($P = 0.01$)
P. diversus	10	7–13	10.2	1.93	5	6–12	9	4.07	17.5 (NS)

FORAGING STRATEGIES OF TIGER BEETLES ON EARTHWORMS AND TADPOLES.—Tadpoles of species *Euphlyctis cyanophlyctis* (Schneider) aggregated in small puddles that are formed during rainy days in paddy fields. The tiger beetles probed the mud with their mandibles and picked out the tadpoles as the puddles dried out. The capture rate of earthworms was high during rainy days, as the earthworms exposed themselves on the substrate surface to escape inundation. Tiger beetles generally attacked the middle portion of the worm first, which reduced the worm activity; this behavior, however, often allowed the worm to escape with half of its body.

DISCUSSION

Emergence times indicate that rainfall is likely to be the signal for terminating the pupal diapause of these beetles. Both *C. whithilli* and *C. flavomaculata* occupy open rice paddy fields and bunds with sparse herb cover and moist soil. In contrast, moderate shade by tall trees (in our study, *Areca* palms of 9- to 12-yr-old and *Acacia mangium* trees of 7-yr-old plantations) appear to be the most important habitat for *C. duponti*, in addition to sparse grassy bunds and sandy water channels. The decline in the number of *C. whithilli* and *C. flavomaculata* in all the study sites, and a simultaneous incidence of tiger beetles in previously uninhabited areas during latter stage of their activity are most likely explained by a high rate of dispersal (Fig. 2a,b).

After a well-defined reproductive period between early August and mid-October, *C. duponti* completely disappeared from the six study sites by mid-October. But *C. whithilli* and *C. flavomaculata* were relatively abundant until late December. Individuals of *C. whithilli* and *C. flavomaculata* spent more than 60 percent of their time in mate finding, and courting from late October onward in both the study years.

Adult tiger beetles are known for their active predation, which includes several iterations of "stop-and-go running" before capturing the prey (Gilbert 1997). In the present study, a similar prey-capturing behavior was observed for all three tiger beetle species, particularly for spiders and ants. But, the feeding strategies of *C. whithilli* and *C. flavomaculata* on prey organisms like earthworms and tadpoles were different from the above described behavior. Although tiger beetles are defined as generalist hunters (but specific to relative size) of various live arthropods (Pearson & Mury 1979, Pearson 1988), this may be the first report that earthworms are among typical prey organisms in their diet. We found that *C. whithilli* and *C. flavomaculata* prey more regularly on tadpoles and earthworms during early stages of their adult activity, even though other conventional prey organisms like ants and spiders were abundant in their vicinity. The beetles were found pressing their abdomen on wet ground while consuming food; this partially is explained as a thermoregulatory action by which beetles can efficiently transfer their excess body heat (Dreisig 1980). Although Pearson and Vogler (2001) reported that *Cicindela sedecimpunctata* in Arizona opportunistically takes advantage of tadpoles as an atypical food resource under special circumstances, no other studies are available on the predatory behavior of tiger beetles on tadpoles. Indeed, *C. whithilli* and *C. flavomaculata* may be the only two tiger beetle species that use tadpoles as a major food source, at least for a part of their adult stage (Tables 2 and 3).

Tiger beetles in general are fluid feeders and use pre-oral digestion by the introduction of midgut enzymes (Evans 1965). Tiger beetles were found to take less time to handle smaller preys than larger ones (Table 3). In one instance, a *C. whithilli* was observed

TABLE 3. *Mean consumption time (in sec) of significant prey organisms by* Cicindela whithilli *(CW) and* Cicindela flavomaculata *(CF). Significance in difference in the median consumption time compared by Mann Whitney U test. N = Number of beetles observed every 1 h.*

	CW				CF				
Prey items	*N*	Range	Mean	SD	*N*	Range	Mean	SD	*U* value
Tadpoles	7	20–36	27.28	5.88	5	40–60	52.2	9.18	0 ($P = 0.004$)
Earthworms	5	252–720	511.2	193.61	5	510–870	690	173.64	6.5 (NS)

to eat termites (approximate size, 30 mm) at an average of 16 individuals per minute, which were emerging from their ground nest. Normally, *C. whithilli* and *C. flavomaculata* were found to take an average of 4.6 and 5 min, respectively, to completely feed on an ant species *P. exercita* (size, 70 mm). However, for another ant species *Pheidolegeton diversus* Jerdon (size, 30 mm), the feeding time was 55–80 sec for *C. whithilli*, and 50–65 sec for *C. flavomaculata*. In another instance, a *C. duponti* was found to take an average of 2 min to feed on another ant species, *Anoplolepis longipes*, in an *Areca* orchard.

Some tiger beetles also scavenge dead organisms and feed on nontypical food resources such as fruits and carcasses (Pearson & Vogler 2001). We found that both *C. whithilli* and *C. flavomaculata* scavenged on dead organisms, including grubs of dung beetles (Scarabaeidae: Coleoptera), ground-dwelling mole crickets (Gryllidae: Orthoptera), and adult *C. whithilli* in field. Some nontypical prey organisms such as live *Clivina* sp. (Carabidae: Coleoptera) and ladybird beetles (Coccinellidae: Coleoptera) were also noted for *C. duponti* on occasions; it took almost 19 min to partly finish the heavily armored *Clivina* sp. and 15 min to completely feed upon the ladybird beetle.

The switching of adult tiger beetles' food resources from the "tadpole–earthworm complex" in early season to various ants and spiders toward the latter foraging periods may be due to the availability of prey organisms as well as field conditions. The presence of loose soil and muddy pools in the plowed paddy fields in the early crop season creates a suitable microenvironment for the occurrence of tadpoles and earthworms as an additional prey for the beetles. But, as the fields dried out, the microclimate became more suitable for ants and spiders, and they were found abundantly.

Robber flies (Asilidae: Diptera), dragonflies (Libellulidae: Odonata), and water scorpions (Nepidae: Heteroptera: Insecta) were found as natural enemies of *C. whithilli* and *C. flavomaculata*. Unlike robber flies and dragonflies that are aerial predators, water scorpions were found ambushing the approaching tiger beetles from muddy puddles in paddy fields during the beetle's search for the tadpoles and earthworms in the muddy substratum. This observation is the first report of an aquatic insect as predator of adult tiger beetles.

The results of our preliminary laboratory experiments show minimal predatory potential of *C. whithilli* and *C. flavomaculata* on major rice paddy pests in Sringeri during the study period. Only observations of their occasional capture of nymphs of *Leptocorisa acuta* indicate some small potential as biocontrols. Although minimal, this observation has great relevance, as the pest is considered to be one of the major pests of rice paddy in South and Southeast Asian countries. Meanwhile, other locally major pests, such as larvae and adults of rice skipper (*Pelopidas mathias* (F.), Hesperidae: Lepidoptera), green-horned caterpillar (*Melanitis leda ismene* (Cram.), Nymphalidae: Lepidoptera), rice army worm (*Spodoptera mauritia* Boisd., Noctuidae: Lepidoptera), and adults of rice case worm (*Nymphula depunctalis* Guen., Pyralidae: Lepidoptera) that were presented to captive tiger beetles went unnoticed by both tiger beetle species.

FIGURE 3. (A) *Cicindela whithilli* consumes an earthworm in rice paddy field; (B) *Cicindela flavomaculata* preys on a major worker of *Polyrhachis exercita* on a paddy bund; (C) *C. whithilli* and *C. flavomaculata* share food resources and scavenge on carcass of Scarab grub in paddy field; (D) Individuals of *C. whithilli* aggregate on rice paddy canopy in a water-logged rice paddy field, in September 2004.

We propose two reasons why *C. whithilli* and *C. flavomaculata* are unlikely to be efficient natural enemies of major rice paddy pests (except *L. acuta*) in Sringeri. First, the beetles are ground dwellers and restrict their feeding to wet, muddy substratum in rice paddy fields, and are not active climbers (either for roosting or feeding). However, during periods of flooding, beetles aggregate on plants; in one instance, more than 300 individuals of *C. whithilli* were found roosting on rice paddy saplings of age 48 d, after transplantation for 4 d without any activity until the water receded (Fig. 3). Second, the other possible and accessible prey organisms such as brown plant hopper (*Nilaparvata lugens*) and yellow stem borers (*Scirpophaga incertulus*) that usually attack the root level of rice paddy saplings were not available in Sringeri region during the study period in 2003 and 2004. A study by Sastry and Appanna (1958), however, found that *C. flavomaculata* forages on rice stem borers (Lepidoptera: Pyralidae), a major rice paddy pest in irrigated paddy fields of South Indian plains. Other researchers (T. A. Shivashankar & A. R. V. Kumar, and G. K. Veeresh, pers. comm.) have illustrated the positive economic importance of *C. flavomaculata* over some other paddy pests.

Our study contributes to a better understanding of the feeding fauna of tiger beetles, which includes arthropods and vertebrates. It also provides some superficial data on the biocontrol potential of tiger beetles, which neither *C. whithilli* nor *C. flavomaculata* meet the criteria to be significant natural enemies of rice paddy pests, at least in Sringeri area. Our experimental findings are based on relatively short-term data, and more research is needed before tiger beetles can be excluded as beneficial natural enemies.

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