Collection of Emerald Ash Borer (Coleoptera: Buprestidae) by *Cerceris fumipennis* (Hymenoptera: Crabronidae) in North Carolina: Case Study at One Nesting Site[1]

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Abstract The buprestid hunting wasp, *Cerceris fumipennis* Say, was detected bringing an emerald ash borer, *Agrilus planipennis* Fairmaire, back to its nest for the first time in North Carolina, USA at a nesting aggregation in Franklin County. We took the opportunity to closely monitor the site to track further collections of the pest and to monitor activity patterns of the wasp. Of the total 271 beetles collected at this site during 14 visits in 2015 (52 h of biosurveillance), just three emerald ash borers were collected from at least two females within 1 h on one date (15 June 2015). None of the three emerald ash borers were paralyzed by the wasps. At least 20 beetle species were collected from the wasp during the flight season: 14 species were represented in the first 57 beetles collected at the site, with 6 additional species identified from later collections. The wasps actively foraged for beetles from 9 June to 6 August, 2015. Until evidence to the contrary is available, this long activity period is best interpreted as the extended emergence of a single generation rather than as a partial second generation of wasps.

Key Words biosurveillance, *Agrilus planipennis*, univoltine, Buprestidae

Since first proposed for this use by Marshall et al. (2005), the buprestid hunting wasp, *Cerceris fumipennis* Say (Hymenoptera: Crabronidae) has been utilized as a tool for detecting beetles in the family Buprestidae that are potential threats to forest health. The method, called 'biosurveillance,' was developed primarily to monitor the establishment and spread of the emerald ash borer, *Agrilus planipennis* Fairmaire in North America (Careless et al. 2014). The technique has been used in North Carolina since 2009 (Swink et al. 2013) and, in June 2015, *C. fumipennis* collected emerald ash borer in the state for the first time. This collection was a new county (Franklin County), but not state, record as at that time emerald ash borer was already known to be in five counties in North Carolina. The *C. fumipennis* collection of the pest did, however, contribute to the decision to institute a state-wide quarantine for emerald ash borer in September 2015. We used this collection of emerald ash borer by *C. fumipennis* to more closely examine activity patterns and foraging behavior of the wasp.

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Table 1. The number of nests present and the number of Buprestidae collected from *Cerceris fumipennis* at Franklinton Park, Franklin County, North Carolina, USA during the summer of 2015.

Date	No. nests[a]	No. beetles collected	Person hours in biosurveillance
9 June	14	1	0.3
15 June	53	56[b]	5.0
22 June	—	76	—
25 June	60	41	9.0
2 July	75	45	9.5
7 July	22	11	6.5
8 July	—	1	—
16 July	89	21	7.5
22 July	35	4	4.5
28 July	31	8	7.0
4 August	23	4	1.3
6 August	15	3	0.5
13 August	5	0	0.5
20 August	3	0	0.7
Total		271	52.3

[a] Dash (—) indicates a casual visit to the site, when dropped buprestids were collected on the field but nests were not counted and no biosurveillance was conducted.
[b] Includes three emerald ash borers.

Materials and Methods

The site of the emerald ash borer collection was a *C. fumipennis* nesting aggregation on a ball diamond in Franklinton Park (N36°06′30.25′′, W78°26′06.48′′) in the central part of the state. The site was visited about once per week between 9 June and 20 August (Table 1) and more often if the opportunity arose (14 visits overall). A total of 52.3 person hours were invested in biosurveillance at the site. In some cases (22 June, 8 July), the field was inspected for the presence of dropped beetles only (see Swink et al. 2013: Fig.1); these 'drops' were gathered but personnel did not remain to collect from foraging wasps. Nest counts were made at most visits, but these were unreliable; the aftermath of ball games and field maintenance activities often obscured active nests. Beetles were identified by W.G.S. and deposited in the Beneficial Insects Laboratory Insect Collection at the North Carolina Department of Agriculture and Consumer Services (Raleigh).

Results and Discussion

Three emerald ash borers were collected on 15 June 2015 between 9:00 and 10:00 a.m. The first borer was found immobile and lying on the turret of a *Cerceris* nest on the pitcher's mound of the ball field. It was collected and placed into a ziplock bag. When examined later, this beetle was active and apparently feigning death when collected. Thirty minutes after the first collection, a wasp returning from a foraging trip carrying an emerald ash borer was captured in an insect net, and 20 min after that another was captured in the same manner. These two foraging wasps were collected near nests at the edge of the grass between first and second bases of the ball field. Neither of the borers these wasps were carrying was paralyzed. No additional emerald ash borers were collected in four subsequent hours at the nesting site on that day.

Adult emerald ash borers are assumed to be active in central North Carolina until early July, as occurs in Tennessee (Klingeman et al. 2015). In the five site visits we made between when the emerald ash borer was initially collected (15 June) and early July (8 July), 174 beetles were collected either from foraging wasps or as drops. No additional emerald ash borers were taken during this period of time. In total, 271 beetles were taken at the site during 52 h of biosurveillance (Table 1), but emerald ash borer was collected only within the span of 1 h on 15 June by at least two different wasp females.

Close monitoring of this site yielded several results that may contribute to the efficient use of the wasp for detecting pest Buprestidae. First, the emerald ash borers were collected by *C. fumipennis* early in the morning, prior to the period when most borer adults are expected to be active (from 11:00 a.m. to 3:00 p.m. [Jennings et al. 2014]). Second, none of the collected emerald ash borers were paralyzed, a common occurrence when *Agrilus* spp. are taken as prey by the wasp (Nalepa and Swink 2015). Consequently, it is possible that an emerald ash borer dropped by the wasp at the nesting site may abscond unless the beetle is discovered quickly. Third, the emerald ash borers were detected as part of the first full day of biosurveillance at the site when 56 beetles were collected. It is thought that the majority of buprestid species in an area are sampled after collecting 50 beetles from an active colony (Careless 2009). However, of a total of at least 20 species taken at this site in 2015, 14 were identified from the first 57 beetles collected, with 6 additional prey species taken in later collections (Table 2: *Acmaeodera pulchella* (Herbst), *Acmaeodera tubulus* (F.), *Actenodes* sp., *Agrilus ruficollis* (F.) (rednecked cane borer), *Brachys ovatus* (Weber), and *Neochlamisus bebbianae* Brown). The collection of *A. pulchella* was the first report of this species being taken as prey by *C. fumipennis* in North Carolina. These findings suggest that our collection of emerald ash borer from the wasp was rather fortuitous and that ceasing to collect at a site after taking the first 50 beetles may be ill-considered, particularly if these were taken on a single day and the wasp aggregation remains active.

The large number of beetles found dropped on the field on 22 June ($n = 76$) is unexplained. Although it had been a week since last visiting the site, the drops were undoubtedly recent, as ants are typically efficient at removing them. It is also unknown as to why the emerald ash borers were detected only within a very short period of time; this result is related to wasp foraging behavior, which is largely

Table 2. Species collected by *Cerceris fumipennis* at Franklinton Park in 2015; species taken after the first 57 beetles were collected appear in bold.

Species	Dates collected
***Acmaeodera pulchella* (Herbst)**	2, 16 July
***Acmaeodera tubulus* (F.)**	2 July
Actenodes sp.	22 June
Agrilus arcuatus (Say)	15, 22, 25 June; 7 July
Agrilus bilineatus (Weber) (twolined chestnut borer)	15, 22 June; 2 July
Agrilus planipennis Fairmaire (emerald ash borer)	15 June
***Agrilus ruficollis* (F.) (rednecked cane borer)**	22 July
***Brachys ovatus* (Weber)**	2, 7 July; 4 August
Buprestis lineata F.	15, 22, 25 June; 2, 7, 16, 28 July; 4, 6 August
Buprestis maculipennis Gory	15, 22, 25 June; 2, 16, 28 July
Buprestis rufipes Olivier	15, 22, 25 June; 2, 7, 16, 22 July
Chrysobothris spp.	9, 15, 22, 25 June; 2, 7, 16, 28 July
Chrysobothris cribraria Mannerheim	15, 22, 25 June; 2, 8, 16 July; 4 August
Chrysobothris dentipes (Germar)	15, 22 June; 2 July
Chrysobothris hubbardi Fisher	15 June
Chrysobothris pusilla Gory & Laporte	15, 22, 25 June
Chrysobothris sexsignata Say	15, 22, 25 June; 16 July
Dicerca asperata (Laporte & Gory)	15 June
Dicerca punctulata (Schönherr)	15, 25 June; 2, 16, 22, 28 July; 4, 6 August
***Neochlamisus bebbianae* Brown**	7, 28 July

unknown. Emerald ash borers were likely present in low densities in this location. The area around the site was searched extensively for declining ash trees; one mature, healthy-looking ash was found ~0.4 km from the ball diamond, but large brush piles and stacks of firewood were common in the neighborhoods surrounding the site.

The 14 visits to the Franklinton site in 2015 made it possible to monitor the activity period of the resident *C. fumipennis* nesting aggregation. Our first visit to the

Table 3. Nesting aggregations of *Cerceris fumipennis* in the same general region as Franklinton Park where activity had ceased prior to 4 August 2015.

Location	County	Location relative to Franklinton Park	Peak number of nests	Last date checked	Results
Luddy Park	Franklin	10.3 k, S-SW	74 on 16 June	4 August	6 end stage nests*
Lake Lynn	Wake	33.9 k, SW	75 on 13 June	4 August	0 nests
Faith Christian Academy	Wayne	81 k, SE	75 on 6 June	5 August	3 end stage nests

* Nests backfilled by the resident wasp.

site was on 9 June, when *C. fumipennis* nests were first becoming active. End stage nests, some guarded by wasp females, were first noted on 2 July. Of the 89 nests present on 16 July, 62% were end stage (no turret, edges of entry hole chewed away and, in some cases backfilled and guarded) and 38% of nests were active and turreted. One female was observed completing the backfill, then flying off in a straight line without orienting to the nest. She did not return in two subsequent hours of observation. This behavior was observed a second time on 28 July. Nests with fresh turret (indicating active excavation) were noted as late as 13 August. The presence of *C. fumipennis* males on the field was noted casually on 2, 7, and 22 July.

Cerceris fumipennis is considered univoltine throughout most of its range in North America, but two generations are thought to occur in south Florida and other Gulf Coast States (Careless et al. 2014). It is unclear at what latitude the switch from being univoltine to bivoltine occurs (Careless 2009). Recently Johnson et al. (2015) indicated that a partial or full second generation occurs in Louisiana, based on an extended period of wasp activity (9 wk) and on the observation of males and new nests late in the season in some sites. By those criteria, the Franklinton site might also have had a partial second generation. Some wasps were still foraging as late as 6 August (Table 1), more than 8 wk after nests began appearing at the site. The Franklinton site, however, was unique. The wasps typically complete foraging activity by about mid-July in central North Carolina (Klingeman et al. 2015), and in 2015 wasp activity had ceased by early August in three nesting sites in the same general region as Franklinton (Table 3).

Delineating a second generation in *C. fumipennis* is complicated by the behavior of the wasp; nest switching, occasional co-occurrence of two wasps in the same nest, immigration into and emigration from the nesting area, and the construction of more than one nest by a single female are all known or suspected to occur. We twice observed healthy-looking females leaving the area after backfilling a nest. Linsley and MacSwain (1956) indicated that, in most studies where a wasp species appears double-brooded, it is found that the insect has but a single generation per

Fig. 1. Dates of collection of adult *Cerceris fumipennis* in Wake County North Carolina ($n = 39$) based on labels of specimens deposited in the North Carolina State University Entomological Collection 1921–1982.

year with a protracted period of adult emergence. Although the duration of the *C. fumipennis* flight period is typically 5–8 wk after adult emergence, cool weather may prolong the season and hot, dry weather curtail it (Careless et al. 2014). Data taken from labels on *C. fumipennis* collected in Wake County, North Carolina, in the North Carolina State University Entomological Collection, indicate that these wasps had been collected as early as 24 May and as late as 30 September between 1921 and 1982 (Fig. 1). Many of these wasps were collected on flowers, however, so it is unknown if the females were still provisioning nests; the wasp lifespan may exceed the nesting season. While males are most-commonly observed during the early, nest-founding stage (Mueller et al. 1992), they are known to persist throughout the nesting season although in ever decreasing numbers (Careless 2009).

It may be that in North Carolina, a partial second generation is limited to sites with favorable microclimates where early emerging females can quickly collect numerous prey. On the other hand, the length of activity of a single wasp generation may depend on the species and activity of buprestids in the immediate vicinity of the nesting area. While the seasonal activities of many buprestid species are complete by late summer, there is a subset of Buprestidae that are active well into the fall season (Klingeman et al. 2015). Partially bivoltine life histories are common in the Hymenoptera but are notoriously difficult to detect without knowing both the egg laying and adult emergence dates for individuals (Brockmann 2004). Until such detailed information is available for *C. fumipennis* in North Carolina, the wasp is best considered univoltine in this state. Emerald ash borer was not found among the 78 beetles collected by *C. fumipennis* at the Franklinton Park site in 2016.

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