PRELIMINARY INVENTORY OF THE PLANTHOPPERS (HEMIPTERA: FULGOROIDEA) OF THE GREAT SMOKY MOUNTAINS NATIONAL PARK, NORTH CAROLINA AND TENNESSEE, U.S.A.[1]

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ABSTRACT: The Fulgoroidea of the Great Smoky Mountains National Park was investigated in July 2002 as part of an ongoing all-taxa biotic inventory. Sweep samples were taken by three investigators from 28 localities throughout the Park with all specimens of the target taxon retained. This preliminary inventory obtained 1,290 specimens, representing 8 families, 23 genera and 37 species. Species accumulation curves and nine estimators of species richness were explored, all of which predicted a species richness of approximately 50 species (range of estimates 44-58 species). This approximation probably underestimates the true species richness of planthoppers because of seasonal, spatial and methodological limitations of this initial estimate.

KEY WORDS: Auchenorrhyncha, Fulgoromorpha, All Taxa Biodiversity Inventory (ATBI), species richness estimation.

In late 1997, an all-taxon biodiversity inventory (ATBI) was initiated in the Great Smoky Mountain National Park (GSMNP) (Sharkey 2001). This study represents the first effort to inventory the Fulgoroidea (planthoppers) of the GSMNP. Brimley (1938) and Wray (1967) provide a list of insect species for North Carolina, but there does not appear to be a similar publication for Tennessee. Published species records for the Park appear to be limited to two species: *Haplaxius pictifrons* (Cixiidae) and *Bruchomorpha minima* (Issidae) (Wray 1967, see Holzinger et al. 2002 for recent generic nomenclature for cixiids). Unpublished Park records include 5 species: *Acanalonia bivittata* (Acanaloniidae), *Bruchomorpha oculata* (Issidae), *Anormenis chloris* (as septemtrionalis, Flatidae), *Scolops perdix* (Dictyopharidae), and *Liburniella ornata* (Delphacidae). The objectives of the study were to produce a preliminary inventory of the fulgoroid species and to estimate richness through a species accumulation curve and a series of sample-based richness estimators.

METHODS

Three investigators conducted sweep samples at 28 widely dispersed locations (Figure 1) in the GSMNP during July 8-12, 2002. The samples were generally taken in readily accessible portions of the Park, and were loosely stratified by elevation and general region of the Park. The length of time spent at individual sample locations was not uniform, but it was recorded as a measure of sampling

[1] Received on March 3, 2004. Accepted on May 18, 2004.

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Mailed on September 30, 2004

"effort." All specimens of target taxa were aspirated and retained from the samples in the field. Specimens were layered and stored dry in a freezer until they could be processed.

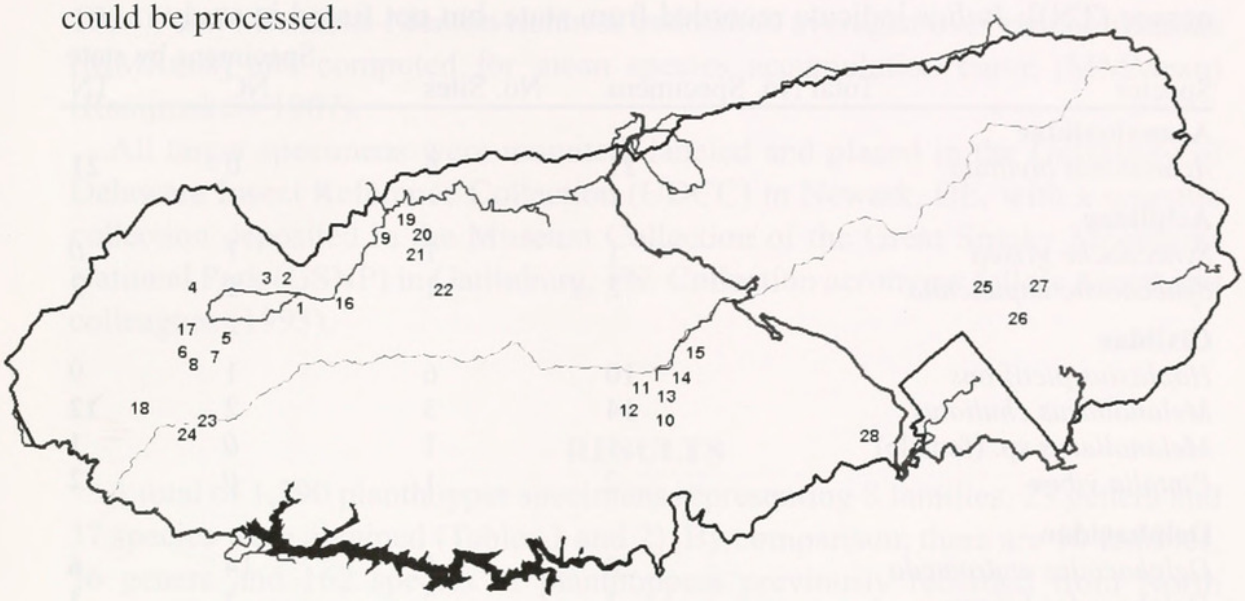

Figure 1. Map of Great Smoky Mountains National Park with sample locations: 1) Cades Cove House in Cades Cove campground; 2) Cades Cove loop road, north side, woods; 3) Cades Cove loop road, north side, field; 4) Cades Cove loop road, Cooper Road and Wet Bottom Trail; 5) Cades Cove, Forge Creek Road, north end roadside, wet meadow; 6) Cades Cove, Forge Creek Road, roadside, woods; 7) Cades Cove, Forge Creek Road, Henry Whitehead cabin, lawn and adjacent herbs; 8) Cades Cove, Forge Creek Road, wet meadow; 9) Laurel Creek Road, at underpass, roadside; 10) Andrew's Bald, North Side; 11) Andrew's Bald, South Side; 12) Forney Ridge Trail, south of Andrew's Bald; 13) Forney Ridge Trail, north of Andrew's Bald; 14) Clingman's Dome Road pullout, near Noland's Divide Trail, roadside; 15) Clingman's Dome Road pullout past Noland's Divide Trail, roadside; 16) Laurel Creek Road, Crib Gap Trail; 17) Forge Creek Road, Wet Meadow; 18) Parson Branch Road, woods, roadside; 19) Laurel Creek Road near jct. Rt 73; 20) Road to GSM institute at Tremont at bridge over Middle Prong, Little River, roadside; 21) GSM Institute at Tremont, fields; 22) Middle Prong Trailhead, woods understory; 23) Gregory Ridge Trail ca. 2 mi from Gregory Bald, woods; 24) Gregory Bald; 25) Hyatt Ridge Trail ca. 1.5 mi from Straight Fork Road, woods understory; 26) Straight Fork Road at Hyatt Ridge Trail trailhead, woods understory at roadside; 27) Horse Camp on Straight Fork Road, grass and woods understory; 28) Mingo's creek trail, trailside

All adult fulgoroids were identified and counted to produce a species-by-sample abundance matrix. A species accumulation curve (e.g. Colwell and Coddington 1994, Hayek and Buzas 1996) and estimates of species richness were created using the EstimateS (v6.0b1) software program using 50 randomizations (Colwell 1997). A series of estimators of species richness are presented because there has yet to be a clear indication of which estimator is statistically and empirically superior. The reported species richness estimates (and standard deviations as appropriate) are as follows: Abundance-based Coverage Estimator (ACE) (Chao et al. 1993, Chazdon et al. 1998), Incidence-based Coverage Estimator (ICE) (Lee and Chao 1994, Chazdon et al. 1998), Chao 1 richness estimator (Chao 1) (Chao 1984, 1987), Chao 2 richness estimator (Chao 2) (Chao 1987), First and Second order Jackknife Richness estimators (Jack 1, Jack 2) (Burnham

Table 1. Species found at Great Smoky Mountains National Park. Numbers in **bold** indicate not previously recoded in state [North Carolina (NC) and Tennessee (TN)]; *Italics* indicate recorded from state, but not found in study.

Species	Total No. Specimens	No. Sites	Specimens by state NC	TN
Acanaloniidae				
Acanalonia bivittata	21	6	0	**21**
Achilidae				
Synecdoche grisea	1	1	1	*0*
Synecdoche impunctata	2	1	*0*	2
Cixiidae				
Haplaxius pictifrons	10	6	1	9
Melanoliarus chuliotus	14	3	2	**12**
Melanoliarus sp. (female)	1	1	*0*	**1**
Pintalia vibex	2	1	*0*	**2**
Delphacidae				
Delphacodes andromeda	20	5	14	**6**
Delphacodes bifurca	3	2	**2**	**1**
Delphacodes campestris	18	3	11	7
Delphacodes laminalis	13	6	3	**10**
Delphacodes lutulenta	3	2	2	**1**
Delphacodes nitens	25	4	0	**25**
Delphacodes perusta	1	1	0	**1**
Delphacodes puella	222	18	123	99
Delphacodes sagae	1	1	**1**	0
Isodelphax basivitta	85	15	60	25
Kelisia curvata	19	5	*0*	**19**
Liburniella ornata	379	25	232	147
Nothodelphax lineatipes	112	1	*0*	**112**
Pareuidella spatulata	5	2	*0*	**5**
Pissonotus aphidioides	1	1	**1**	0
Pissonotus brunneus	14	6	13	1
Pissonotus guttatus	1	1	*0*	1
Pissonotus marginatus	1	1	*0*	1
Ribautodelphax sp. (female)	127	2	**127**	0
Saccharosydne saccharivora	1	1	**1**	0
Stenocranus lautus	40	7	1	**39**
Stenocranus pallidus	4	2	0	**4**
Toya propinqua	4	2	3	**1**
Derbidae				
Anotia westwoodi	24	2	*0*	**24**
Cedusa obscura	93	5	*0*	**93**
Dictyopharidae				
Scolops perdix	2	1	*0*	**2**
Flatidae				
Anormenis chloris	1	1	*0*	1
Metcalfa pruinosa	4	4	1	3
Ormenoides venusta	9	1	*0*	9
Issidae				
Bruchomorpha oculata	7	4	*0*	**7**
Total Specimens	1290	—	599	691

and Overton 1978, 1979; Smith and van Bell 1984, Heltshe and Forrester 1983, Palmer 1991), Bootstrap richness estimator (Bootstrap) (Smith and van Belle 1984), and Michaelis-Menton richness estimators averaged over randomizations (MMRuns) and computed for mean species accumulation curve (MMMean) (Raaijmakers 1987).

All target specimens were mounted, labeled and placed in the University of Delaware Insect Reference Collection (UDCC) in Newark, DE, with a synoptic collection deposited in the Museum Collection of the Great Smoky Mountains National Park (GSNP) in Gatlinburg, TN. Collection acronyms follow Arnett and colleagues (1993).

RESULTS

A total of 1,290 planthopper specimens representing 8 families, 23 genera and 37 species were obtained (Tables 1 and 2). By comparison, there are 10 families, 56 genera and 162 species of planthoppers previously recorded from North Carolina (viz. Brimley 1938, Wray 1967, Wilson and McPherson 1980, Kramer 1981, 1983; Wilson 1982, Bartlett and Deitz 2000). There were 25 new state records (Table 1): 5 for NC and 20 for TN. Eight taxa had not been previously recorded from either state, 31 had not previously been reported from the Park.

The species accumulation curve (Figure 2) appears to have approximately reached its asymptote. The estimators of species richness generally predicted a richness of approximately 50 species, with a range between 44 (Bootstrap) to 58 (Jack2) species (Table 3, Figure 2).

Table 2. Comparison of numbers of taxa recorded from North Carolina and found in the present study. Sources: Brimley (1938), Wray (1967), Wilson and McPherson (1980), Kramer (1981, 1983), Wilson (1982), O'Brien (1985), and Bartlett and Deitz (2000).

	Taxa recorded from NC[4]		Taxa found in GSMNP	
Family	Genera	Species	Genera	Species
Delphacidae	20	61	11	23
Cixiidae	8	23	3	4
Derbidae	10	28	2	2
Dictyopharidae	3	11	1	1
Achilidae	3	14	1	2
Issidae	2	11	1	1
Flatidae	5	5	3	3
Acanaloniidae	1	4	1	1
Fulgoridae	3	4	0	0
Tropiduchidae	1	1	0	0
Total	56	162	23	37

Table 3. Estimates of planthopper species richness in GSMNP, with standard deviation as appropriate. See methods for acronyms and references.

Estimator	Result (± SD)
ACE	47.61 (± 1.99)
ICE	49.99 (± 0.02)
Chao1	49.57 (± 12.46)
Chao2	51.07 (± 9.90)
Jack1	51.50 (± 4.05)
Jack2	58.24 (± 3.59)
Bootstrap	44.08
MMRuns	51.58
MMMean	48.78

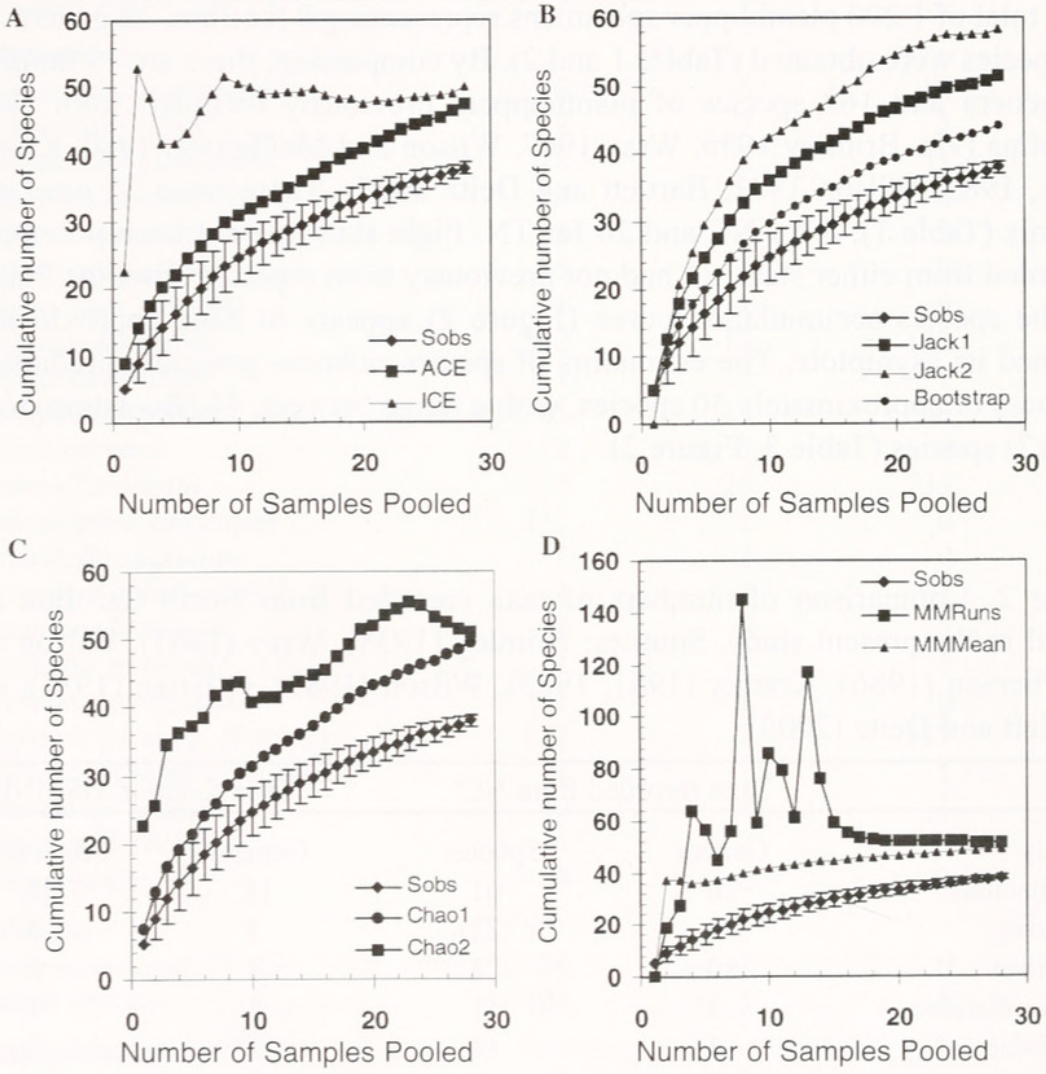

Figure 2. Species accumulation curves and estimated species richness based on 9 estimators. (A) Species observed (Sobs) with standard deviation and Abundance-based (ACE) and Incidence-based (ICE) Coverage Estimator of species richness, (B) Species observed, first and second order Jacknife Richness estimators (Jack1, Jack2), and Bootstrap richness estimator (Bootstrap), (C) Species observed, Chao 1 and Chao 2 richness estimators (Chao, Chao2), (D) Species observed, Michaelis-Menton richness estimators averaged over randomizations (MMRuns) and computed for mean species accumulation curve (MMMean).

Among the species collected, the most abundant 6 species *(Liburniella ornata, Delphacodes puella, Ribautodelphax* sp., *Nothodelphax lineatipes, Isodelphax basivitta* [all Delphacidae], and *Cedusa obscura* [Derbidae]), or 16% of the species collected, represented 79 percent of the individuals collected (Figure 3). Conversely, there were 9 species (29 percent) represented only by a single specimen. This result is similar to that obtained by Wilson and colleagues (1993) at the Paintbrush Prairie, Missouri, who found the top 8 common species (17 percent) representing 79 percent of the total specimens collected (n=1,676), and 10 species represented by a single specimen each.

Two of the 6 most abundant species were collected in very few locations; *Nothodelphax lineatipes* was collected only at Gregory Bald, and the *Ribautodelphax* species was collected only at two sites on Clingman's Dome Road. A patchy distribution of species was expected given that many species are thought to have limited host ranges (Wilson 1992, Wilson *et al.* 1994). The top two most abundant species, however, were also widely distributed in the Park, with *Liburniella ornata* found at 25 of 28 sample sites, and *Delphacodes puella* found at 18 sites (Table 1). The *Ribautodelphax* species represents an unusual record in part because this genus (as currently understood) has not before been reported in the eastern United States south of Michigan (*Ribautodelphax pusilla* Emeljanov, by Wilson 1992), but also because all 127 specimens collected were females, thus its specific identity could not be determined.

Figure 3. Frequency distribution for each planthopper species collected at the GSMNP. Number of individuals provided in Table 1.

DISCUSSION

The estimators of species richness indicate that the true species richness, based on the samples presented here, should be approximately 50. This estimate, however, is limited by the methods used (only sweeping), season, and geographic distribution of the samples. It was necessary, however, to use a single sampling method to meet the species richness estimator's assumption of sample homogeneity. Early July was chosen for this study because it is a period of time when planthopper richness and abundance is relatively high (e.g., Davis and Gray 1966, Wilson et al. 1993), although seasonality varies species by species. This study does appear to have been conducted early relative to the life history of some planthopper taxa, for example flatid nymphs were commonly observed, but adults were scarce and found only at low elevations. Also, the habitats sampled in this study may have disproportionately represented relatively open, grassy areas (roadsides, fields, and balds) because many fulgoroid species feed on herbaceous hosts, leaving woody plant feeders poorly represented in this study. Therefore, the estimate of species richness presented here is more carefully circumscribed as the number of species that can be collected at GSMNP in mid-July by sweeping in relatively accessible locations. It seems extremely likely that additional sampling methods (especially light collecting and vacuum sampling), and a broader spatial and temporal scale of collecting will ultimately produce more than 50 species for the Park.

Many of the species found in this study are taxa that are relatively widespread in occurrence. A few taxa were only collected at high elevations, and some of these represent unusual taxa or records. A *Ribautodelphax* species was collected at two locations on Clingman's Dome Road. The total collection represented 127 specimens, all female, and mostly (121 specimens) brachypterous. The reason for the unusual sex ratio requires further investigation (parthenogenesis is known from delphacids [de Vrijer 1986, den Bieman and de Vrijer 1987], but it is exceedingly unusual). Three *Ribautodelphax* species have been reported in the New World (*R. pusilla* Emeljanov, *R. albostriata* (Fieber), and *R. bidentatus* Anufriev), whose known New World distribution consists mostly of Canada and Alaska, but both also are distributed widely in the Palearctic (Wilson 1988, 1992, 1997; Maw et al. 2000). *Ribautodelphax bidentatus* was reported from Canada by Maw and colleagues (2000), however the correct combination for this species appears to be *Megadelphax binotatus* (Anufriev) (Vilbaste 1980).

There is a series of species where GSMNP represents the southernmost point within the known distribution. These species, in addition to *Ribautodelphax,* include *Delphacodes bifurca, D. sagae, D. nitens, D. perusta,* and *Stenocranus pallidus* (all Delphacidae). *Delphacodes bifurca,* for example, was described from Kansas (Beamer 1946), and later found in Missouri on tallgrass prairie (with *D. sagae,* Wilson et al. 1993). *Delphacodes bifurca* was collected at both Andrew's and Gregory Bald, but nowhere else. *Delphacodes bifurca, D. sagae* (found only on Clingman's Dome Road), *Ribautodelphax* and possibly *Nothodelphax lineatipes* (Gregory's Bald only, but reported from Raleigh, NC; Wray 1967), may be restricted to high elevation in the southern Appalachians.

ACKNOWLEDGMENTS

I would particularly like to thank my field assistants Jeremy Brodt and Mike Cacciapaglia, both students at the University of Delaware, and Keith Langdon, Jean Hilton, and Becky Nichols (National Park Service, Gatlinburg, TN). This study was conducted under the support of a Discover Life In America (DLIA) grant.

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