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Planthopper (Hemiptera: Fulgoroidea) Diversity in the Great Smoky Mountains National Park

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ABSTRACT

Planthoppers from Malaise traps (22 traps operated continuously over 3 years at 11 sites) were investigated as a component of an ongoing all-taxon biotic inventory of the Great Smoky Mountains National Park. The Malaise samples contained 2,195 specimens representing 55 species from 7 families. Elevation patterns and seasonality of planthoppers from the Malaise traps are also presented. Based on Malaise trap data, species accumulation curves and 9 estimators of species richness anticipated 57-81 species, a higher number than predicted in our previous study (Bartlett & Bowman 2004), but lower than the cumulative species list, currently including 97 species in 10 families based on 6,860 specimens. None of the data sets based on single sample methods produced estimates of species richness that were greater than the observed diversity from the compiled species list. Species richness estimates between 95-124 were obtained by combining the Malaise trap sample data with Bartlett and Bowman's (2004) sweep sample data and additional data from 2006, although two estimators still remained below the observed richness of 97 species for the Park. Implications of these findings are discussed.

Planthoppers (Hemiptera: Fulgoroidea) were investigated as a component of the Great Smoky Mountain National Park (GSMNP) All Taxon Biological Inventory (ATBI) (Sharkey 2001), sponsored by Discover Life In America (DLIA) and the National Park Service (NPS). Preliminary work based on sweep samples from 28 locations in the Park was presented by Bartlett and Bowman (2004), who recorded 37 planthopper species and predicted approximately 50 species to be present. Here we extend our observations using 3 years of Malaise trap data and additional field collecting, present new predictions of planthopper species richness based on the combined dataset, including a compiled species list for the Park from all information sources, including our data, specimens from the GSMNP collection at Sugarland's Visitor's Center, near Gatlinburg, Tennessee, and all known published records.

Our primary objectives in the present study were to use the Malaise trap samples from the ATBI structured sampling (Sharkey 2001) and any other available data to evaluate observed planthopper species richness and predict the number of species not observed; and to evaluate these predictions against planthopper species richness observed from all available data sources. An abundance-based species list from all sources of information is presented. A secondary objective was to characterize elevation patterns and seasonality of occurrence for planthoppers in the Park using the Malaise trap data.

MATERIALS AND METHODS

DLIA and the NPS conducted structured sampling, including Malaise traps, at 22 locations throughout GSMNP (Sharkey 2001). These 22 Malaise traps consisted of 2 traps each at 11 sample sites, chosen to vary widely in habitat, strata, and geographic location (Table 1). Park Service volunteers collected samples from the traps at regular two-week intervals through the entire year. We received Homoptera (Hemiptera excluding Heteroptera) from Malaise trap samples collected from April 1999 through September 2002. All adult planthoppers were mounted and labeled using standard taxonomic techniques (e.g., Wilson & McPherson 1980) then identified and inventoried (delicate or abundant taxa retained in alcohol). For some taxa (particularly Cixiidae, most Delphacidae, and certain Derbidae), definitive identification features reside on the male, and unassociated females could not be identified with confidence. Specimens not confidently identified were excluded from analyses, unless the specimen represented a taxon not otherwise recorded. We retained all specimens as vouchers at the University of Delaware Insect Reference Collection (UDCC), with a synoptic collection at the natural history collection at the Great Smoky Mountains National Park (GSMP) Sugarland's Visitor's Center (collection abbreviations follow Arnett et al. 1993).

Seasonality of species in the Park was assessed by plotting the number of specimens observed per month from the Malaise trap data. Similarly, elevation distributions of species were estimated based on the lowest and highest elevation that each species was observed in the Malaise traps, supplemented by reference to specimens collected by other methods whenever the elevation could be assessed. For specimens collected at sites with Malaise traps, the elevation of the Malaise trap was used; for specimens with GPS coordinates, the elevation was estimated by plotting on USGS 7.5 minute topographic maps. For the Malaise trap data alone, linear regression (PROC REG, SAS ver. 9.1, SAS Institute Inc.) was used to examine the relationships between species richness and specimens collected against the independent variable elevation.

A species by sample abundance matrix was created for the Malaise trap data for species richness analyses, and calculated species richness using 9 estimators with the EstimateS (v7.5) software (Colwell 2005) on default settings. These estimators of species richness (described by Colwell & Coddington 1994, Colwell 2005 et cit.) included the Abundance-based Coverage estimator (ACE), the Incidence-based Coverage estimator (ICE), Chao 1 and Chao 2 richness estimators ("classic" and bias-corrected formulae presented in Table 4, see Colwell 2005, "classic" formula used in Figures 4 & 5), the First and Second order Jackknife richness estimators (Jack1 and Jack2), the Bootstrap richness estimator (Bootstrap), and the runs- and means-based Michaelis-Menton richness estimators (MMRuns and MMMean) (Colwell 2005). We also plotted a species accumulation curve for the observed and estimated species richness.

During 2003 and 2006 we collected additional diversity data. In mid July 2003, field work was limited by weather conditions and not adequately systematic to include with the diversity estimation data. In 2006, sweep and light samples were obtained June 19-22 (by Gonzon and Bartlett). Eighteen sweep samples were obtained using methods similar to those described in Bartlett and Bowman (2004), except that we targeted species rich areas (viz. Cades Cove, Clingman's

Dome Road, and Purchase Knob), and exceptionally common delphacid species (viz. *Liburniella ornata* and *Delphacodes puella*) were not always collected. Four light collections of all target taxa were performed using a 15-watt ultra violet light operated from a battery (4 nights) and a 175-watt mercury vapor light, operated from a gas-powered generator (3 nights), against white sheets.

In attempt to improve the estimate of species richness, the Malaise trap data were combined first with the sweep sample data from Bartlett and Bowman (2004), then also with data from 2006 field work (see below). While combining these data probably violates assumptions of sample homogeneity (see Colwell & Coddington 1994), these sample techniques individually produced estimates of species richness well below the observed cumulative species list for the Park. The cumulative species list for the Park (Table 2) was compiled from the species observed in the present study with those observed by Bartlett and Bowmen (2004), the GSMP collection at Sugarland's Visitors Center, additional collecting by the authors in 2003 and 2006, and all published records of which we are aware.

RESULTS

Species richness estimation

From the Malaise trap samples, 2,195 specimens from 7 families, 29 genera, and 55 species were recovered (Table 2, Figure 1), of which 2,096 were identified to species. We identified 99 specimens to the lowest practicable level, generally because they were females of taxa that required males for species confirmation.

Specifically, we excluded specimens of 6 *Haplaxius* spp., (Cixiidae), 2 *Kelisia* spp., and 91 Delphacini (Delphacidae) from all analyses. Of 1,848 possible Malaise trap samples, 194 (10%) contained target taxa.

The sample sites varied widely in their species composition, richness and target specimen abundance (Table 3). Samples from Andrew's Bald (elev. 1756 m, Malaise Trap 11) contained the greatest number of specimens, totaling 1,087 (representing 13 species); but the highest diversity was observed at Twin Creeks (elev. 594 m, MT01 with 26 species, 280 specimens; and MT02, with 25 species, 126 specimens). The fewest specimens were observed from Purchase Knob traps (elev. 1,531 m, MT07 and MT08) collectively representing only 9 specimens and 4 species (Table 3). The number of specimens exhibited no relationship to elevation (with outlier removed, MT12 Table 3; n=21, Adj. R2 = 0.0486, F = 2.02, P = 0.171). Species richness exhibited a weakly significant decreasing trend with elevation (Figure 2, n=22, Adj. R2 = 0.1252, F = 4.01, P = 0.059). Species composition at higher elevations, however, is evidently not an attenuated fauna from lower elevation; rather the higher elevations contained faunistic elements not found elsewhere in the Park.

The overall seasonal distribution of planthoppers from the Malaise traps, driven largely by delphacids, showed an unexpected pattern of being most abundant in alternate months (i.e., May, July, September, and November) through the non-winter season. Delphacids are generally multivoltine, whereas other planthoppers are primarily univoltine (O'Brien & Wilson 1985, Denno & Roderick 1990). For the delphacid species for which life history characteristics are known, the period of time required to compete a generation is about one month, e.g., 23 days for *Delphacodes nigrifacies* and *Stobaera concinna* (Calvert et al 1987a, b), 25 days for *Megamelus davisi* (Wilson & McPherson 1981), 29 days for *Javesella*

pellucida (Raatikainen 1967), 34 days for *Delphacodes lutulenta* (Giri & Freytag 1983), and 35 days for *Toya propinqua* (Raatikainen & Vasarainen 1990); suggesting, at least empirically, some degree of population synchrony. The two most abundant delphacids in the Park, *Delphacodes puella* and *Liburniella ornata*, show the cyclic pattern most distinctly, and when removed from consideration the pattern is evident among the species remaining, although dampened (Figure 3).
Estimates of richness based on Malaise trap samples alone ranged from 57 to 81 species (Table 4, average ~67). The species accumulation curve (Figure 4) approaches its asymptote, although the individual estimators of species richness provide rather divergent results. Both the actually obtained species richness and the estimates of species richness are higher than those presented in Bartlett and Bowman (2004). We observed, however, that 17 of the 37 species reported in Bartlett & Bowman (2004) did not occur in the Malaise traps (for a species list of 72 taxa, with *Haplaxius* sp., *Kelisia* sp. excluded). The compiled species list from all available data (Table 2) has 97 species; thus we observed greater species richness than predicted based on sweep samples or Malaise trap samples alone. Single sampling method richness estimates (in this case sweeping or Malaise traps) predict the number of species that can be efficiently collected by that particular method, and provide an underestimate of the true number of species. Because we are interested in estimating the true number of species for the Park, and not the number of species that can be obtained by any particular sampling method, we combined data from the various sampling methods in an attempt to obtain a better estimate of the true species richness.

From 18 sweep and 4 light samples collected in June, 2006, 1,745 target specimens were obtained, representing 4 families and 45 species. Only the two *Otiocerus* species (Derbidae) were unique to the light samples (i.e., not also found in the sweep samples). We recorded 10 species not previously observed in the Park (including from the Malaise traps and prior field work). Based on these samples alone, diversity estimators ranged between 53 – 74, averaging ~63 species.

A combined dataset utilizing the Malaise samples combined with Bartlett and Bowman's (2004) sweep data and the 2006 field work has 244 samples with 87 observed taxa. Estimates of species richness with this combined data range from 95 to 124 (Table 4, average ~105). The species accumulation curve (Figure 5) has reached its asymptote and the estimators of species richness exhibit less variation. Two of the estimates remain below the actually observed number of species in the compiled species list.

Compiled Species List

The compiled species list (Table 2) includes 97 species in 10 families (including Caliscelidae, raised to familial status by Emeljanov (1999)). Of these species, 14 are new records for North Carolina, 33 are new for Tennessee, and 52 are new for the Park. While this list probably accounts for the majority of planthopper species in the Park, undoubtedly additional species have yet to be observed. The most commonly encountered species observed in the Park are the delphacids *Liburniella ornata* (1,854 specimens) and *Delphacodes puella* (1,717 specimens), collectively representing 52% of the 6,860 specimens observed. Less abundant were 13 species represented only by a single specimen each, plus *Acanalonia bivittata* var. *rosa* (which is a color form, not a valid subspecies, and not included in species counts). The least abundant 50 species (51% of the observed richness) represent only 2.3% of the observed specimens.

The differing techniques used for the samples generated substantially different species lists. Most brachypterous species (e.g., *Bruchomorpha oculata, Delphacodes andromeda,* and *D. lutulenta*) were collected sweeping, but not found in the Malaise traps. The Malaise traps performed better at sampling richness of Derbidae, Achilidae and Cixiidae than sweep samples, although a greater abundance of cixiids were found by sweeping. The 2006 sweep samples, taken 3 weeks earlier in the season than previous samples, contained 23 species not reported by Bartlett and Bowman (2004), including 10 new Park records. In the GSMP collection, *Alphina glauca* (Fulgoridae) was collected at lights and *Thionia* (Issidae) specimens were collected by tree fogging. No single method is uniformly effective, and species composition varies seasonally and spatially.

The compiled species list includes four species evidently new to science: *Melanoliarus* nr *sablensis* (Cixiidae), and three delphacids - *Delphacodes* n. sp. nr *mcateei* (Delphacidae), *Muellerianella* n. sp., and a stenocranine delphacid, now described as *Kelisicranus arundiniphagus* Bartlett (Bartlett 2006). Four specimens of *Kelisicranus arundiniphagus* were collected from giant cane, *Arundinaria gigantea,* from Cade's Cove in June 2006, confirming the host asserted by Bartlett (2006). *Delphacodes* n. sp. nr. *mcateei* remains known from a single specimen, while the undescribed *Muellerianella* is known from additional specimens from outside the Park. The species reported in Bartlett and Bowman (2004) and here as *Ribautodelphax* sp. remains enigmatic, as 246 females have been observed, but we have not found males that are clearly attributable to this species. We have observed this species only at higher elevations.

DISCUSSION

Elevation

The ATBI project involved many habitats at different elevations (Table 1). One of the goals of the ATBI is to collect georeferenced species data so that species and community level biological information can be evaluated descriptively (e.g., what is the range of a particular species in the Park, or discerning biotic or abiotic elements associated with particular species), and predictively (locations where species might be found in the Park where it has not been previously detected; or how changes in environmental conditions may impact the range of a species). Of particular interest is to identify biotic elements that are associated with higher elevations, since these are more likely to be endemic to the Park and influenced by various environmental perturbations. In this study, we assigned a range of elevations to most species based on the range of elevations that they were found to occur in a preliminary attempt to identify species associated with higher elevations (Table 2). We based elevation range primarily on the Malaise trap data, and included specimens collected by other methods whenever elevation could be assigned to specimens. While the data for rarely collected species remains sparse, species potentially associated only with high elevations in the GSMNP include *Epiptera variegata* (Achilidae), *Cixius nervosus* (Cixiidae), *Delphacodes bifurca*, *D. pacifica*, *Javesella pellucida*, *Pissonotus aphidioides*, *P. tumidus*, and *Ribautodelphax* sp. (Delphacidae) (Table 2). We expect other species presently known from the Park only at high elevations (e.g., *Nothodelphax* *lineatipes*, *Saccharosydne saccharivora* [both Delphacidae], and *Scolops perdix* [Dictyopharidae]), to be more broadly distributed in the Park, as suggested by known ranges. For example, *Saccharosydne saccharivora* was collected on Clingman's Dome road at 1,506 m and at Andrew's Bald at about 1,700m. This species was originally described from Grenada as a sugarcane pest (Westwood 1833), and has become widely distributed in the New World in association with the sugarcane industry. Evidently, native *Andropogon* grasses are hosts for *Saccharosydne* (Metcalfe 1969), and its published North American range consists of Georgia and Florida (Metcalf 1943), although Bartlett has collected this species in Raleigh, NC and Cecil Co., MD. Although this species was only detected at high elevation in the Park, sampling *Andropogon* at lower elevations would likely produce new records.

Seasonality

The peaks in seasonal abundance of planthopper species collected in the Park (Figure 3) suggest that most species are univoltine, except delphacids, which appear to be multivoltine wherever there are sufficient numbers collected to suggest a pattern. Seasonal abundance patterns do suggest, however, that *Cixius pini* (Cixiidae) and *Cedusa vulgaris* (Derbidae) may be bivoltine. Although several species were collected in surprisingly large numbers in November and December, very few specimens were collected in the January to March timeframe, suggesting either that most of these species overwinter as adults, as expected (Denno & Roderick 1990), possibly excepting *Isodelphax basivitta* and *Stenocranus lautus* (Delphacidae), or egg laying continues into the late fall.

Species Richness

The observed planthopper species richness for the Park now stands at 97 species. The upper bound of species diversity for the Park might be set by observing that the cumulative species list for North Carolina and Tennessee is approximately 179 species (Table 5), although many of these occur only in habitats not found in the Park (such as coastal plain).

Species richness estimates based on data from individual sample methods uniformly underestimate the observed species richness when all sources of information are considered. The observed planthopper richness from the Malaise traps exceeded the predicted diversity from sweep samples made by Bartlett & Bowman (2004), and in turn, the predicted richness values based on the Malaise trap samples was exceeded by the observed species richness from all methods combined. By combining data from Bartlett and Bowman (2004), the Malaise data, and the 2006 data, 2 estimators (MMRuns and MMMeans) still provided estimates below the observed richness of the cumulative species list. While combining the datasets may violate assumptions of sample homogeneity, it is clearly necessary to use multiple sample methods to estimate planthopper species richness, the intended goal of the data collection. If multiple sample methods are integrated into the initial study design then sample homogeneity will not be violated. Biodiversity estimators based on any single planthopper collection method will only estimate the richness of that species subset efficiently obtained by a particular sample method. Malaise traps are more likely to detect dispersal (macropterous) forms then they are brachypters (wing polymorphism is common in the Delphacidae, see, e.g., Denno & Grissell 1979); thus all 10 specimens of

Delphacodes campestris from the Malaise traps were macropters, but only 14 of the 145 specimens collected by sweeping was a macropter. Similarly *Delphacodes andromeda*, a species that is usually brachypterous, had 156 individuals in the sweep samples, but only 6 individuals in the Malaise traps. Even with our combined data, the accuracy of the estimators remains to be seen. Additional samples (different localities for Malaise traps, a wider timeframe for the sweep samples), or samples using additional methods (light trapping or vacuum sampling), would be required to provide an accurate estimate of species richness for the Park; however, an important function of the biodiversity estimators is to obviate need for intensive sampling efforts. Our data suggest that significant sampling efforts using multiple techniques are needed to produce tenable estimates of species richness.

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Table 1. List of ATBI plots and their corresponding Malaise trap numbers, elevation and plant community types (modified from Sharkey 2001 and NPS unpublished data).

Malaise Trap Numbers	ATBI Plot Name	North Latitude	West Longitude	Approximate Elevation (in meters)	Vegetation Type
1, 2	Twin Creeks	35.6859	83.4995	594	Tulip Poplar - Hemlock
3, 4	Cades Cove	35.5920	83.8380	592	Successional Field
5, 6	Indian Gap	35.6108	83.4437	1,673	Beech gap
7, 8	Purchase Knob	35.5918	83.0602	1,531	Northern Hardwood
9, 10	Cataloochee	35.5863	83.0816	1,381	Mesic Oak
11, 12	Andrew's Bald	35.5388	83.4942	1,756	Grassy Bald
13, 14	Brushy Mountain	35.6766	83.4308	1,466	Heath Bald
15, 16	Clingman's Dome	35.5603	83.4954	1,945	Spruce-Fir
17, 18	Albright Grove	35.7333	83.2806	1,033	Montane Cove
19, 20	Snakeden Ridge	35.7434	83.2199	994	Hemlock
21, 22	Goshen Prong	35.6106	83.5427	896	Cove Hardwood

Table 2. Compiled planthopper species list and abundance of specimens collected for Great Smoky Mountains National Park, with highest and lowest recorded elevations. Numbers within totals column in **bold** indicates not previously recorded in state [North Carolina (NC) and Tennessee (TN)]; "0" in *italics* indicates recorded from state, but not found in study; species names followed by a "*" are new Park records. Elevation data is primarily from Malaise traps with additional information from other specimens where elevation could be determined. (Note: *Bruchomorpha minima*, reported by Wray, 1967, and *Haplaxius glyphis* reported by Kramer (1979) are listed here but specimens not found in this study).

	Elevation		Malaise trap samples		July 2003 Field Work		June 2006 Field Work		GSMNP collection		Bartlett & Bowman 2004		Totals	
Species	Low	High	NC	TN	NC	TN	NC	TN	NC	TN	NC	TN	NC	TN
Acanaloniidae														
Acanalonia bivittata	594	—	0	0	0	3	0	0	6	2	0	21	6	26
Acanalonia bivittata var *rosa*	594	—	0	0	0	0	0	0	0	1	0	0	0	1
Achilidae														
*Catonia carolina**	994	—	0	1	0	0	0	0	0	0	0	0	0	1
*Catonia cinctifrons**	594	1466	1	8	0	0	0	0	2	0	0	0	3	8
*Catonia nava**	994	—	0	1	0	0	0	0	0	0	0	0	0	1
*Epiptera variegata**	1381	1756	3	2	0	0	0	0	0	0	0	0	3	2
*Synecdoche dimidiata**	594	1756	7	16	0	0	0	0	1	0	0	0	8	16
Synecdoche grisea	594	994	0	91	0	0	0	0	0	0	1	0	1	91
Synecdoche impunctata	594	—	0	3	0	0	0	0	3	0	0	2	3	5
Caliscelidae														
Bruchomorpha minima	—	—	0	0	0	0	0	0	0	0	0	0	0	0
Bruchomorpha oculata	510	1517	0	0	1	0	14	13	0	4	0	7	15	24
Cixiidae														
*Cixius coloepeum**	510	1517	1	57	0	0	4	2	0	0	0	0	5	**5**9
Cixius misellus	994	1756	7	21	2	0	0	0	0	0	0	0	9	21
Cixius nervosus	1381	1756	25	0	0	0	7	0	3	0	0	0	35	0

Cixius pini	994	1756	11	39	0	0	0	0	0	0	0	0	11	39
Cixius sp.			0	0	1	0	4	0	2	1	0	0	7	1
Haplaxius fulvus			0	0	0	0	0	19	0	0	0	0	0	19
Haplaxius glyphis			0	0	0	0	0	0	0	0	0	0	0	0
Haplaxius pictifrons	592	594	0	25	0	0	1	5	0	16	1	9	2	55
*Haplaxius radicus**	594		0	0	0	0	0	1	0	2	0	0	0	3
Haplaxius sp.			0	6	0	0	0	0	2	0	0	0	2	6
Melanoliarus chuliotus	594		0	0	0	0	0	0	0	0	2	12	2	12
*Melanoliarus quinquelineatus**	1220		0	0	0	0	0	0	0	2	0	0	0	2
Melanoliarus nr *sablensis**	592		0	18	0	0	1	82	1	6	0	0	2	106
Melanoliarus sp.			0	0	0	1	1	6	0	5	0	1	1	13
*Monorachis sordulentus**	547	557	0	0	0	0	0	21	0	0	0	0	0	21
Pintalia vibex	547	594	0	0	0	0	0	13	0	1	0	2	0	16
Delphacidae														
Delphacodes acuministyla *	551	—	0	0	0	0	0	1	0	0	0	0	0	1
*Delphacodes alexanderi**	592	1499	0	3	0	0	0	0	1	6	0	0	1	9
Delphacodes andromeda	594	1756	1	5	128	0	4	0	0	4	14	6	147	15
*Delphacodes atralabis**	577	1857	0	0	3	0	29	3	0	0	0	0	32	3
Delphacodes bifurca	1508	1756	0	0	0	0	0	0	0	0	2	1	2	1
Delphacodes campestris	592	1945	7	3	39	0	91	0	3	0	11	7	151	10
*Delphacodes fulvidorsum**	1500	1945	0	0	6	0	0	0	0	0	0	0	6	0
*Delphacodes idonea**	594	—	2	0	0	0	0	0	0	0	0	0	2	0
Delphacodes lutulenta	594	1706	0	0	34	0	64	0	0	5	2	1	100	6
Delphacodes n. sp. nr. *mcateei* *	1381	—	1	0	0	0	0	0	0	0	0	0	1	0
Delphacodes nitens	510	1417	0	0	0	3	7	6	0	15	0	25	7	49
*Delphacodes pacifica**	1381	1945	1	0	2	0	0	0	0	0	0	0	3	0
Delphacodes perusta	594	1500	0	0	3	0	0	0	0	0	0	1	3	1
Delphacodes puella	547	1945	376	97	521	16	423	25	33	4	123	99	1476	241
*Delphacodes rotundata**	557	1795	0	0	0	0	2	3	0	0	0	0	2	3
Delphacodes sagae	594	1945	0	0	0	0	0	0	0	1	1	0	1	1
*Delphacodes trimaculata**	594	—	0	1	0	0	0	0	0	0	0	0	0	1
*Delphacodes truncata**	551	594	0	1	0	0	0	1	0	0	0	0	0	2
*Delphacodes waldeni**	594	—	0	1	0	0	0	0	0	0	0	0	0	1
Euides sp.*	1945	—	0	0	1	0	0	0	0	0	0	0	1	0
Isodelphax basivitta	557	1945	99	34	155	7	215	8	14	8	60	25	543	82
Javesella pellucida	1593	1857	0	0	0	0	7	0	1	0	0	0	8	0
Kelisia curvata	526	1517	0	0	0	0	1	4	0	0	0	19	1	23
*Kelisia spinosa**	557	1756	0	3	0	0	0	1	1	0	0	0	1	4
Kelisia sp.			1	1	0	0	0	0	1	0	0	0	2	1
Kelisicranus arundiniphagus	526	594	0	0	0	0	0	4	0	14	0	0	0	18
Liburniella ornata	547	1945	641	231	204	23	272	39	56	9	232	147	1405	449
Megamelus sp. (prob. *distinctus*)*	551		0	0	0	0	0	1	0	0	0	0	0	1
Muellerianella laminalis	594	1756	2	3	0	0	11	1	2	1	3	10	18	15
*Muellerianella n. sp.**	598	—	0	0	0	0	0	1	0	0	0	0	0	1
Nothodelphax lineatipes	1707	1756	0	0	0	0	1	0	0	0	0	112	1	112
Pareuidella spatulata	594	—	0	0	0	0	0	0	0	0	0	5	0	5
Pissonotus aphidioides	1100	—	0	0	0	0	0	0	0	0	1	0	1	0
*Pissonotus binotatus**	1466	1706	0	1	9	0	1	0	0	0	0	0	10	1
Pissonotus brunneus	915	1756	2	1	1	0	5	0	1	2	13	1	22	4
*Pissonotus concolor**	526	1415	0	0	0	0	1	2	0	0	0	0	1	2
*Pissonotus flabellatus**	—	1500	0	0	5	0	0	0	0	0	0	0	5	0
Pissonotus guttatus	557	1381	1	0	1	0	0	1	0	0	0	1	2	2
Pissonotus marginatus	594	1415	1	1	0	1	4	1	0	0	0	1	5	4
Pissonotus piceus *	594	1945	2	6	0	0	0	0	1	0	0	0	3	6
Pissonotus tumidus *	1517		0	0	0	0	2	0	0	0	0	0	2	0
Ribautodelphax sp.	1415	1857	0	0	18	8	87	0	6	0	127	0	238	8
Saccharosydne saccharivora	1506	1700	0	0	0	0	1	0	2	0	1	0	4	0
Sogatella kolophon *	592	1756	1	3	1	0	0	0	0	1	0	0	2	4
Stenocranus brunneus *	547	594	0	0	0	0	0	45	0	0	0	3	0	48
Stenocranus lautus	526	1945	4	2	0	4	10	27	11	3	1	39	26	75
Stenocranus pallidus	547	594	0	0	0	1	0	3	9	0	0	4	9	8
Stenocranus similis *	594	—	0	0	0	3	0	0	0	0	0	0	0	3

Stenocranus sp	—	—	0	0	0	0	1	0	0	0	0	0	1	0
Stobaera tricarinata *	594	1945	5	9	0	0	0	0	1	1	2	0	8	10
Toya propinqua	592	1756	20	12	34	1	1	0	0	0	3	1	58	14
Delphacini			89	0	0	0	97	3	3	0	0	0	189	3
Derbidae														
Anotia uhleri *	594		0	15	0	0	0	0	2	0	0	0	2	15
Anotia westwoodi	551	592	0	5	0	1	0	1	8	3	0	24	8	34
Apache degeerii *	594		0	4	0	0	0	0	1	1	0	0	1	5
Cedusa gedusa *	510		0	0	0	0	0	2	0	0	0	0	0	2
Cedusa kedusa *	594	—	0	0	0	0	0	0	0	1	0	0	0	1
Cedusa maculata *	594	896	0	43	0	0	0	0	2	0	0	0	2	43
Cedusa obscura	594	—	0	0	0	25	0	0	0	0	0	93	0	118
Cedusa olseni *	547	557	0	0	0	0	0	23	0	0	0	0	0	23
Cedusa vulgaris *	594	—	0	32	0	0	0	0	0	3	0	0	0	35
Cedusa sp			0	0	0	0	0	3	1	8	0	0	1	11
Omalicna mcateei *	594		0	2	0	0	0	0	0	0	0	0	0	2
Otiocerus coquebertii *	577		0	0	0	0	0	2	1	1	0	0	1	3
Otiocerus wolfii *	577	594	0	7	0	0	0	3	1	0	0	0	1	10
Patera vanduzeei *	594	1673	4	13	0	0	0	0	1	0	0	0	5	13
Shellenius ballii *	594	—	0	3	0	0	0	0	0	0	0	0	0	3
Sikiana hartii *	594	—	0	1	0	0	0	0	0	0	0	0	0	1
Dictyopharidae														
Scolops angustatus *	592	—	0	1	0	0	0	0	0	0	0	0	0	1
Scolops perdix	1756		0	0	0	0	0	0	0	0	0	2	0	2
Scolops sulcipes	594	—	0	0	0	0	0	0	0	4	0	0	0	4
Flatidae														
Anormenis chloris	594	—	0	7	0	2	0	0	6	2	0	1	6	12
Metcalfa pruinosa	594	1033	0	24	0	2	0	0	8	6	1	3	9	35
Ormenoides venusta	594	—	0	1	0	0	0	0	4	1	0	9	4	11
Fulgoridae														
Alphina glauca *	550	—	0	0	0	0	0	0	1	1	0	0	1	1
Issidae														
Thionia bullata *	808	896	0	1	0	0	0	0	0	2	0	0	0	3
Thionia elliptica *	730	808	0	0	0	0	0	0	1	6	0	0	1	6
Thionia simplex *	592	896	0	9	0	0	0	0	3	2	0	0	3	11
—**Totals**			1315	874	1169	101	1369	376	206	157	602	694	4660	2200

Table 3. Number of planthopper specimens and species diversity by Malaise trap.

Malaise Trap	Number of specimens	Species Richness
1	280	27
2	126	26
3	40	10
4	31	9
5	32	6
6	25	7
7	2	2
8	7	3
9	37	11
10	19	10
11	86	12
12	1080	17
13	109	12
14	57	12
15	42	6
16	45	5
17	45	7
18	6	4
19	44	13
20	40	8
21	17	5
22	21	9

Table 4. Estimates of planthopper species richness in GSMNP with standard deviation as appropriate.—Chao's estimators are reported both as "bias corrected" (BC), and "classic" (C) formulae (Colwell 2005). See methods for acronyms and references.

	Reported Bartlett & Bowman 2004	Malaise trap	Malaise traps + Bartlett & Bowman 2004	2006 Sample	All samples
Estimator	Result	Result	Result	Result	Result
ACE	47.61	63.61	87.11	55.80	102.84
ICE	49.99	64.29	90.14	68.02	108.82
Chao1 mean (C)	49.57	81.17	97.60	69.00	103.06
Chao1 mean (BC)	—	72.50	92.00	61.50	100.60
Chao1 95% CI lower bound (C)	—	59.88	79.43	50.72	92.10
Chao1 95% CI lower bound (BC)	—	59.26	79.06	50.05	91.78
Chao1 95% CI upper bound (C)	—	168.24	160.18	145.72	137.57
Chao1 95% CI upper bound (BC)	—	113.75	128.62	98.92	125.68
Chao2 mean (C)	51.07	85.67	94.22	70.79	113.18
Chao2 mean (BC)	—	75.63	90.91	65.40	109.91
Chao2 lower bound (C)	—	61.16	79.53	53.35	96.65
Chao2 lower bound (BC)	—	60.58	79.28	52.74	96.54
Chao2 upper bound (C)	—	183.72	137.55	124.62	158.01
Chao2 upper bound (BC)	—	120.60	121.16	98.79	141.98
Jack1	51.50	66.93	91.91	63.14	110.90
Jack2	58.24	77.83	102.85	74.35	123.84
Bootstrap	44.08	58.93	80.93	53.00	97.83
MMRuns	51.58	58.93	79.78	59.45	94.94
MMMean	48.78	57.45	78.55	58.55	94.63
—Average (C)	50.27	68.31	89.25	63.57	105.56
— Average (BC)	—	66.23	88.25	62.13	104.92

Table 5. Comparison of numbers of planthopper taxa recorded from North Carolina and Tennessee and those now recorded from the GSMNP. Sources: Brimley (1938), Wray (1967), Kramer (1979, 1981, 1983), Wilson & McPherson (1980), Wilson (1982), Mead & Kramer (1982), Flynn & Kramer (1983), O'Brien (1985), Bartlett & Deitz (2000), Bartlett & Bowman (2004).

	Published Records				Observed GSMNP Species			
	NC		TN		NC		TN	
	genera	species	genera	species	Genera	Species	Genera	Species
Acanaloniidae	1	4	1	2	1	1	1	1
Achilidae	3	14	3	4	3	5	3	7
Caliscelidae[1]	1	7	1	1	1	24	1	1
Cixiidae[2]	7	23	5	15	3	7	5	115
Delphacidae	23	63	13	26	15	39	15	39
Derbidae	8	31	4	9	5	7	8	15
Dictyopharidae	3	11	2	2	0	0	1	3
Flatidae	5	5	3	3	3	3	3	3
Fulgoridae	3	4	1	1	1	1	1	1
Issidae	1	4	1	2	1	2	1	3
Tropiduchidae	1	1	0	0	0	0	0	0
—	56	167	34	65	33	67	39	84

[1] Includes *Bruchomorpha minima* reported by Wray (1967).

[2] Includes *Haplaxius glyphis* reported by Kramer (1979).

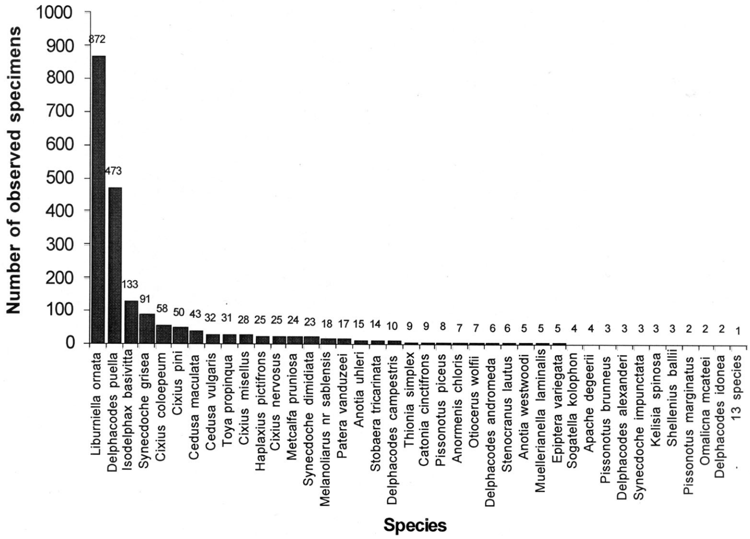

Figure 1. Frequency distribution for planthopper species collected in Malaise traps at GSMNP.

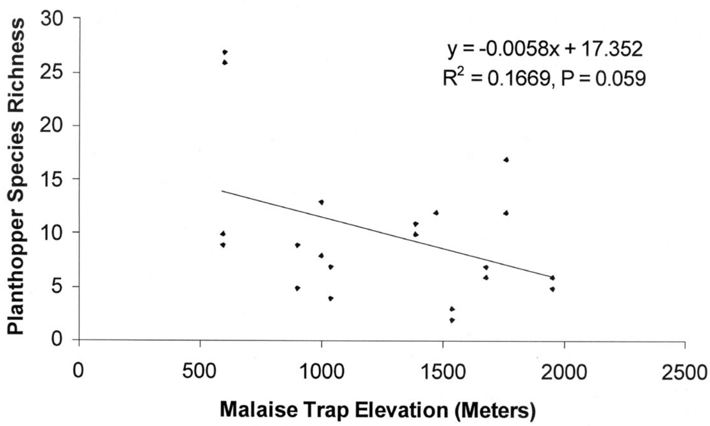

Figure 2. Regression of planthopper species richness and malaise trap elevation.

Figure 3. Seasonal distribution of planthoppers from Malaise traps with number of traps and structured sample sites found (#MT = number of malaise traps found, Sites = number of structured sample sites).

Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Range	#MT	sites
Catonia carolina	0	0	0	0	0	0	0	0	0	1	0	0	Oct.	1	1
Catonia cinctifrons	0	0	0	0	0	0	0	1	2	5	0	1	Aug.-Dec.	7	5
Catonia nava	0	0	0	0	0	0	0	0	0	1	0	0	Oct.	1	1
Epiptera variegata	0	0	0	0	0	0	0	0	0	0	5	0	Nov.	3	3
Synecdoche dimidiata	0	0	0	0	0	0	0	5	18	0	0	0	Aug.-Sept.	8	7
Synecdoche impunctata	0	0	0	0	0	0	2	1	0	0	0	0	July-Aug.	1	1
Synecdoche grisea	0	0	0	0	0	2	33	36	18	2	0	0	June-Oct.	4	3
All Achilidae	0	0	0	0	0	2	35	43	38	9	5	1	June-Nov.		
Cixius coloepeum	0	0	0	8	43	2	5	0	0	0	0	0	Apr.-July	4	3
Cixius misellus	0	0	0	0	0	0	1	7	15	5	0	0	July-Oct.	6	4
Cixius nervosus	0	0	0	0	0	0	18	7	0	0	0	0	July-Aug.	3	2
Cixius pini	0	0	0	0	25	5	20	0	0	0	0	0	May-July	6	4
Haplaxius pictifrons	0	0	0	0	0	8	15	2	0	0	0	0	June-Aug.	3	2
Melanoliarus nr *sablensis*	0	0	0	0	0	13	5	0	0	0	0	0	June-July	2	1
All Cixiidae	0	0	0	8	68	28	64	16	15	5	0	0	Apr.-Oct.		
Delphacodes alexanderi	0	0	0	0	0	1	2	0	0	0	0	0	June-July	3	2
Delphacodes andromeda	0	0	0	0	0	0	1	0	6	0	0	0	July-Sept.	4	3
Delphacodes campestris	0	0	0	0	0	1	4	0	0	0	5	0	June-Nov.	5	4
Delphacodes idonea	0	0	0	0	0	0	0	2	0	0	0	0	Aug.	1	1
Delphacodes pacifica	0	0	0	0	0	0	0	0	1	0	0	0	Sept.	1	1

Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Range	#MT	sites
Delphacodes pacifica	0	0	0	0	0	0	0	0	1	0	0	0	Sept.	1	1
Delphacodes puella	0	0	0	3	25	6	300	9	49	15	60	6	Apr.-Dec.	18	10
Delphacodes trimaculata	0	0	0	0	0	0	1	0	0	0	0	0	July	1	1
Delphacodes truncata	0	0	0	0	0	0	1	0	0	0	0	0	July	1	1
Delphacodes waldeni	0	0	0	0	0	0	0	0	1	0	0	0	Sept.	1	1
Isodelphax basivitta	0	1	0	2	14	2	59	8	2	4	37	4	Feb.-Dec.	15	9
Kelisia spp.	0	0	0	0	0	0	1	1	1	0	1	1	July-Dec.	2	2
Liburniella ornata	0	0	0	2	135	14	536	40	63	18	61	3	Apr.-Dec.	21	11
Muellerianella laminalis	0	0	0	0	0	0	1	0	1	2	1	0	July-Nov.	3	2
Pissonotus binotatus	0	0	0	0	0	0	0	0	1	0	0	0	Sept.	1	1
Pissonotus brunneus	0	0	0	0	0	0	2	1	0	0	0	0	July-Aug.	2	2
Pissonotus guttatus	0	0	0	0	0	0	0	0	0	0	0	1	Dec.	1	1
Pissonotus marginatus	0	0	0	0	0	0	1	0	0	0	1	0	July-Nov.	2	2
Pissonotus piceus	0	0	0	0	0	0	2	1	2	2	1	0	July-Nov.	6	5
Sogatella kolophon	0	0	0	0	0	1	1	0	0	0	1	2	June-Dec.	3	3
Stenocranus lautus	0	0	1	0	0	0	1	0	0	0	2	1	Mar.-Dec.	2	2
Stobaera tricarinata	0	0	0	3	0	0	0	0	0	0	6	5	Apr.-Dec.	9	7
Toya propinqua	0	0	0	0	0	0	0	1	2	1	21	6	Aug.-Dec.	12	7
All Delphacidae	0	1	1	10	174	25	913	63	129	42	197	29	Feb.-Dec.		
w/o *L. ornata, D. puella*	0	1	1	5	14	5	77	14	17	9	76	20	Feb.-Dec.		
Anotia westwoodi	0	0	0	0	0	0	2	2	1	0	0	0	July-Sept.	2	1

Species	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Range	#MT	sites
Anotia uhleri	0	0	0	0	0	0	3	9	3	0	0	0	July-Sept.	2	1
Apache degeerii	0	0	0	0	0	0	0	1	0	0	0	0	Aug.	1	1
Cedusa maculata	0	0	0	0	0	0	0	13	26	7	0	0	Aug.-Oct.	3	2
Cedusa vulgaris	0	0	0	0	1	10	13	1	6	1	0	0	May-Oct.	2	1
Omalicna mcateei	0	0	0	0	0	0	0	1	0	1	0	0	Aug.-Oct.	1	1
Otiocerus wolfii	0	0	0	0	0	0	3	2	1	1	0	0	July-Oct.	2	1
Patera vanduzeei	0	0	0	0	0	0	2	7	7	1	0	0	July-Oct.	7	5
Shellenius ballii	0	0	0	0	0	0	1	1	1	0	0	0	July-Sept.	1	1
Sikiana hartii	0	0	0	0	0	0	0	1	0	0	0	0	Aug.	1	1
All Derbidae	0	0	0	0	1	10	24	38	45	11	0	0	May-Oct.		
Scolops angustatus	0	0	0	0	0	0	1	0	0	0	0	0	July	1	1
Anormenis chloris	0	0	0	0	0	0	1	0	2	0	3	0	July-Nov.	2	1
Metcalfa pruinosa	0	0	0	0	0	0	0	6	7	11	1	0	Aug.-Nov.	6	4
Ormenoides venusta	0	0	0	0	0	0	0	0	1	0	0	0	Sept.	1	1
Thionia bullata	0	0	0	0	0	0	0	0	0	1	0	0	Oct.	1	1
Thionia simplex	0	0	0	0	0	0	0	3	4	1	1	0	July-Nov.	4	3
Totals	0	3	3	41	500	135	2151	343	485	156	485	80			

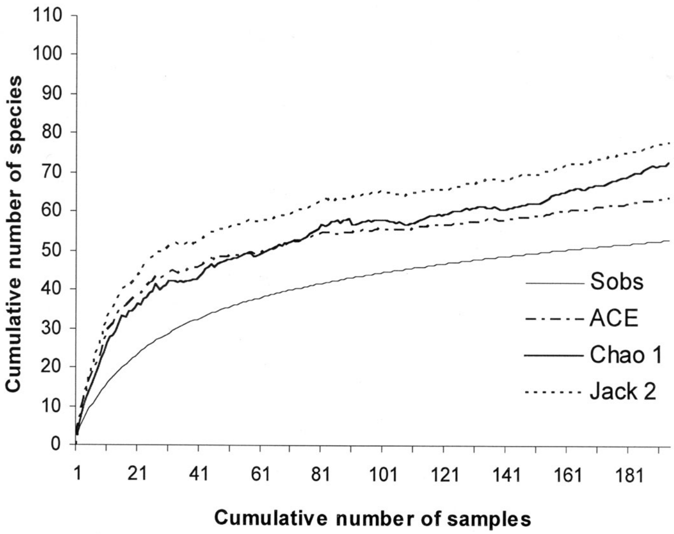

Figure 4. Species accumulation curve and selected richness estimators for GSMNP planthoppers from Malaise trap data (Sobs = Species observed, species richness estimator abbreviations as indicated in Methods).

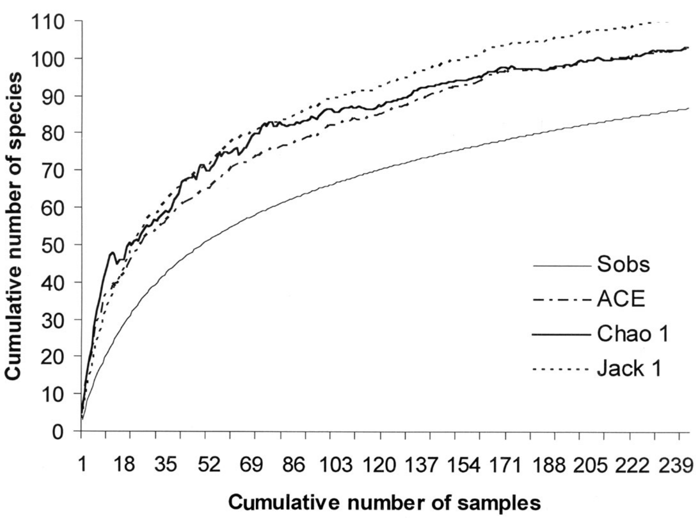

Figure 5. Species accumulation curve and selected richness estimators for GSMNP planthoppers from combined Malaise trap, 2003 sweep and 2006 sweep and light data (Sobs = Species observed, species richness estimator abbreviations as indicated in Methods).