

Ephemeroptera, Plecoptera, Megaloptera, and Trichoptera of Great Smoky Mountains National Park

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Abstract - Great Smoky Mountains National Park (GSMNP), situated on the mountainous border of North Carolina and Tennessee, is recognized as one of the most highly diverse protected areas in the temperate region. In order to provide baseline data for the scientific management of GSMNP, an All Taxa Biodiversity Inventory (ATBI) was initiated in 1998. Among the goals of the ATBI are to discover the identity and distribution of as many as possible of the species of life that occur in GSMNP. The authors have concentrated on the orders of completely aquatic insects other than odonates. We examined or utilized others' records of more than 53,600 adult and 78,000 immature insects from 545 locations. At present, 469 species are known from GSMNP, including 120 species of Ephemeroptera (mayflies), 111 species of Plecoptera (stoneflies), 7 species of Megaloptera (dobsonflies, fishflies, and alderflies), and 231 species of Trichoptera (caddisflies). Included in this total are 10 species new to science discovered since the ATBI began.

Introduction

Great Smoky Mountains National Park (GSMNP) is situated on the border of North Carolina and Tennessee and is comprised of 221,000 ha. GSMNP is recognized as one of the most diverse protected areas in the temperate region (Nichols and Langdon 2007). GSMNP contains more than 3400 km of streams (Parker and Pipes 1990). Virtually all of these streams originate within the Park (Fig. 1), arising as springs fed by groundwater from the higher elevations and ultimately derived from abundant rainfall. Very few kilometers of some low-elevation streams flow into GSMNP from outside its boundaries. This circumstance results in the waters of GSMNP being of high quality, with little or no direct industrial, commercial, or residential inputs to the system. This is offset to an uncertain, but probably significant, extent by the extremely high levels of atmospheric pollutants that the Park receives (Shaver et al. 1994, Smoot et al. 2000). In addition, much of the south side of GSMNP borders Fontana Lake, a large Tennessee

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Valley Authority reservoir. The southern Appalachian mountains, among the oldest in the world, were never glaciated (Flint 1971), which, when combined with rugged topography, abundant rainfall, and mild climate, results in a rich fauna of aquatic insects.

Morse et al. (1993, 1998) reviewed the status of Ephemeroptera, Plecoptera, and Trichoptera (EPTs) and Odonata in the southern Appalachian Mountains, and found that components of the fauna are vulnerable and at risk. They considered species potentially at risk based on whether they were rare, inhabited isolated or sensitive habitats, and were subject to identifiable threats. They listed 74 species of EPTs as potentially rare and vulnerable to range loss, regional extirpation, or extinction. The primary threats to the fauna were considered to be from human activities, both historical and current. These threats included the clearing of land for agriculture and development, logging, pollution from industrial activity, road and dam building, and the introduction of exotic species. Examples of the latter include chestnut blight over a century ago and *Adelges tsugae* Annand (hemlock woolly adelgids) in recent years. *Castanea dentate* (Marshall) Borhk (American chestnut) was the dominant forest overstory tree at mid elevations in GSMNP until *Cryphonectria parasitica* (Murrill) M.E. Barr (chestnut blight fungus) killed virtually all of them by the 1950s (Schlarbaum et al. 1999). The American chestnut was replaced largely by various *Quercus* spp. (oak species). Smock and MacGregory (1988) examined processing rates, feeding preferences, and growth of aquatic insects and found significantly higher leaf breakdown, consumption, and growth rates among species fed American chestnut leaves compared with

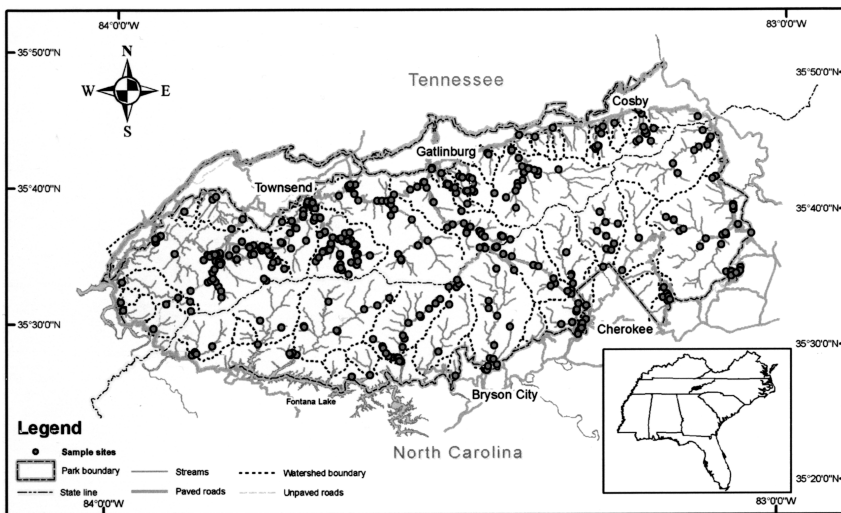


Figure 1. Great Smoky Mountains National Park showing second-order and higher streams with aquatic insect sampling locations represented as circles. Major watersheds are indicated by black dashed lines.

oak leaves. They suggested that, especially in headwater streams, the loss of American chestnut may have resulted in subtle changes at the population, community, and ecosystem levels. Recently hemlock woolly adelgid has infested GSMNP (Johnson et al. 2005). Snyder et al. (2002, 2005) found that hemlock decline may result in long-term changes in headwater streams, particularly in terms of alteration of the thermal and light regimes of the streams, leading to loss of biodiversity within and among stream reaches. Morse et al. (1993, 1998) also discussed the sensitivity of “island” populations of spring-inhabiting species that are threatened by drought, acid precipitation, or development.

In order to further the science-based management goals of GSMNP, an All Taxa Biodiversity Inventory (ATBI) was initiated in 1998 (Nichols and Langdon 2007, White and Langdon 2006). Among the goals of this effort are to discover the identity and distribution of the myriad species that inhabit the park. To assist the Park Service in conducting the ATBI, a non-profit organization—Discover Life in America (DLIA)—was created (Nichols and Langdon 2007). DLIA has provided organization, volunteers, and funding to help with the ATBI, including help with surveys of aquatic insects. In this report we focus on the Ephemeroptera (mayflies), Plecoptera (stoneflies), Megaloptera (dobsonflies, fishflies, and alderflies), and Trichoptera (caddisflies). We refer to these collectively as the EPMT orders, or the EPMTs. The EPMTs comprise those orders of insects whose species are primarily aquatic as immatures, except Odonata, which are discussed separately by Muise et al. (2007). These insects are ubiquitous in freshwater habitats and are found on all the continents except Antarctica. The rich aquatic habitats of GSMNP and the southern Appalachian Mountains have drawn aquatic entomologists to the region for decades to describe and study the aquatic insect life. We have built upon the foundation laid by previous workers and have attempted to fill gaps in coverage both spatially and taxonomically.

Methods

Aquatic insects were surveyed primarily by traditional sampling methods, including light trapping, sweep-netting, and hand collecting. We also took advantage of the work of others, gleaning aquatic specimens from the by-catches of various “bio-blitzes” that have been held in GSMNP as part of the ATBI. Bio-blitzes are intense 1- or 2-day collecting efforts, usually targeted at particular taxa (e.g., Lepidoptera and Coleoptera) or habitats (e.g., caves and high elevations) (Nichols and Langdon 2007). Rearing immatures to adults also has been used to confirm the identity of some of the species collected as larvae. Other data came from the GSMNP inventory and monitoring program for aquatic ecosystem health (Becky Nichols, National Park Service, GSMNP, Gatlinburg, TN, pers. comm.). Data also came from the ATBI structured-sampling pilot study, which operated Malaise and other types of traps at 11 plots located throughout GSMNP continuously for 2.5 years (Parker and Bernard 2006). In addition to the collecting done by the

authors, various students, and many DLIA volunteers, much valuable collecting was done by Ed DeWalt and Brian Heinold of the Illinois Natural History Survey, who concentrated their efforts on the west and southwest areas of GSMNP, but did not include Megaloptera (DeWalt and Heinold 2005, DeWalt et al. 2007). David Etnier, University of Tennessee, provided records from numerous studies he has conducted in GSMNP, and the North Carolina Department of Environment and Natural Resources, Division of Water Quality (NCDENR-DWQ), provided important mayfly records. Finally, species records were obtained from the literature.

Specimens are deposited in the collections of Clemson University, Colorado State University, GSMNP, the Illinois Natural History Survey, the NCDENR-DWQ, Purdue University, the Smithsonian Institution, and the University of Tennessee. Details may be obtained from the authors, and the records are available for perusal on-line at http://tremont22.campus.utk.edu/ATBI_start.cfm.

Results

More than 53,600 adult and 78,000 immature insects from 545 locations were examined. At present, 468 species of EPMTs are known from the Park, including 10 species new to science (Appendices 1–4). Four of the new species are mayflies (*Acentrella barbara*e Jacobus & McCafferty 2006, *Heterocloeon davidi* Waltz and McCafferty 2005, *Procloeon* new species, *Centroptilum* new species), two are stoneflies (*Haploperla parkeri* Kirchner and Kondratieff 2005, *Soyedina* new species), and four are caddisflies (*Rhyacophila celadon* Etnier, Stocks, and Parker 2005, *Rhyacophila* new species, *Ceraclea* new species, *Neophylax kolodskii* Parker 2000). Ten of the mayflies (Appendix 1), 12 of the stoneflies (Appendix 2), and 15 of the caddisflies (Appendix 4) were listed by Morse et al. (1993, 1998) as rare and vulnerable to extirpation. The new species and those considered vulnerable by Morse et al. are indicated in the tables.

Ephemeroptera

GSMNP contains a very diverse fauna of Ephemeroptera. The eastern Nearctic species of the Baetidae genera *Acentrella*, *Acerpenna*, and *Baetis*; the Ephemerellidae genera *Attenella*, *Dannella*, *Drunella*, and *Ephemerella*; the Heptageniidae genera *Epeorus* and *Maccaffertium*; and the Isonychiidae genus *Isonychia* are especially well represented in the Park. One-hundred twenty species have been documented to date (Appendix 1).

Most of the species found in GSMNP are relatively widespread throughout eastern or southeastern North America. Some species (e.g., *Ameletus tertius* McDunnough and *Attenella margarita* (Needham); DeWalt et al. 2007; Eric Fleek, NCDENR-DWQ, Raleigh, NC, pers. comm.) are better known from northeastern North America and have their southernmost records from the Park. One seldom-reported southeastern species, *Isonychia hoffmani* Kondratieff and Voshell, is known outside GSMNP only from a

few locales in Virginia and West Virginia (Kondratieff and Kirchner 1991, Kondratieff and Voshell 1984).

Two new species of small minnow mayflies have been described recently based on material from GSMNP (Jacobus and McCafferty 2006, McCafferty et al. 2005). *Heterocloeon davidi* Waltz and McCafferty is known from the Oconaluftee River system and a few other North Carolina locales (McCafferty et al. 2005). *Acentrella barbarae* has been collected only from GSMNP. It is surprising that this species had not been discovered previously, considering that larvae have distinctive morphological features, such as dorsal abdominal projections, and that adults are attracted to lights and emerge throughout the year (Jacobus and McCafferty 2006).

In addition to the discovery of new species and extended geographic distributions, the ATBI has helped further our understanding of the life histories of many species. Previously unknown life stages and biological attributes have been discovered as a direct result of habitat observations and specimen-rearing of several *Ephemerella* species, for example (Jacobus and McCafferty 2001, Jacobus et al. 2002). Studies by Jacobus and McCafferty (2003b, 2004) and Webb and McCafferty (2006) have documented previously unknown morphological variation based on series of specimens that have been collected from GSMNP over a period of several years. The discovery of this variation led to revisions in the concepts of several species from the genera *Drunella*, *Epeorus*, *Ephemerella*, and *Serratella*. Jacobus and McCafferty (2003a, 2005) gave two ATBI research updates, providing general introductory information about the biology and taxonomic diversity of mayflies from GSMNP and efforts made to study them.

Plecoptera

Currently, 111 species of stoneflies (Appendix 2) have been confirmed from GSMNP including five new GSMNP records and two new species. The Plecoptera species in GSMNP are primarily southern Appalachian or widespread eastern North American taxa, and represent approximately 95% of the regional fauna of mountainous North Carolina, South Carolina, Tennessee, and Virginia. This supports the concept that national parks are often remarkable “islands” of biodiversity (Ruiter et al. 2005). Morse et al. (1993, 1998) considered several species of stoneflies found in the Park to be rare and vulnerable throughout their range. They indicated that *Beloneuria georgiana* (Banks) (“fairly common in a restricted area of North Carolina and Georgia, but at low densities”) and *Megaleuctra williamsae* Hanson and *Oconoperla innubila* (Needham and Claassen) (each known from only a few scattered locations) were especially vulnerable, being restricted to isolated springbrooks that are subject to threats of drought, acid precipitation, and development. *Zapada chila* Ricker (Smokies forestfly) is of special note, originally described from a single male and two female adults from Walker Camp Prong and the Newfound Gap area (Ricker 1952). Subsequently, only about 150 additional specimens, mostly immatures, have been collected from 12 localities. Currently, of the nine North

American species of *Zapada*, *Z. chila* is the most geographically restricted, still apparently known only from GSMNP.

Other uncommon regional endemics that have major known populations in GSMNP include: *Allocapnia fumosa* Ross, *A. stannardi* Ross, *Leuctra mitchellensis* Hanson, *L. monticola* Hanson, *L. nephophila* Hanson, *M. williamsae*, *Soyedina kondratieffi* Baumann and Grubbs, *Strophopteryx limata* (Frison), *Alloperla neglecta* Frison, *Sweltsa urticae* (Ricker), *Tallaperla elisa* Stark, *Acroneuria petersi* Stark and Gaufin, *B. georgiana*, *B. stewarti* Stark and Szczytko, *Cultus decius isolatus* (Banks), *O. innubila*, *Yugus arinus* (Frison), *Isoperla bellona* Banks, and *I. distincta* Nelson. The above species are not commonly collected outside of GSMNP, with *T. elisa* apparently restricted to GSMNP. Additionally, an undescribed species of *Soyedina* is known only from the Park.

Megaloptera

This is a small order, with fewer than 300 species known worldwide, and fewer than 50 species known from North America (Anderson 2003, Poole and Gentili 1996). Seven species have been collected in GSMNP (Appendix 3). One, *Sialis joppa* Ross, was described from specimens collected in the Newfound Gap area of the Park. Each of these species is widespread in eastern North America (Flint 1964, Hazard 1960, Ross 1937). Brigham (1982) listed 18 species of Megaloptera from North Carolina and South Carolina, but it is likely that only two or three additional species of this order will be found in GSMNP.

Trichoptera

To date, 230 species of caddisflies have been recorded from GSMNP (Appendix 4). Seventy-two of these are new records, and at least five are new to science. One species, *Beraea nigratta* Banks (Beraeidae), is known only as larvae from a literature record (Stoneburner 1977), and has not been recollected recently. Other than this record from the North Carolina side of GSMNP, *B. nigratta* is known from Delaware, New Jersey, New York, and Pennsylvania (Morse 1993). It is possible that the record actually refers to another species, *B. gorteba* Ross, which is known from Georgia (Hamilton 1985). Until it can be confirmed, we consider the record for *B. nigratta* in the Smokies to be provisional.

Only one caddisfly species is apparently restricted solely to Great Smoky Mountains National Park. The recently described *Neophylax kolodskii* is known from just a few streams deep in the interior of GSMNP (Parker 2000). Other species are known from GSMNP and nearby areas, notably along the Blue Ridge Parkway. These include *Rhyacophila accola* Flint, *R. montana* Carpenter, *R. mycta* Ross, *R. celadon*, *Cheumatopsyche halima* Denning, *Theliopsyche corona* Ross, *T. epilonis* Ross, *Goera* new species, *Goerita flinti* Parker, *G. semata* Ross, *Wormaldia mohri* (Ross), and *Cera-clea* new species. Another 15 species are restricted to the Southeast, and the remaining species are more widely distributed in eastern North America.

Fifteen species known from GSMNP were regarded by Morse et al. (1998) as potentially rare or vulnerable to extinction (Appendix 4). The occurrence of these species within the confines of a national park is heartening for their prospects of survival, as the probability of the extirpation of local populations of these species is lowered because of the protected status afforded by the federal statutes that established the Park. For example, *R. montana*, which was described in 1933 from specimens collected in the Smoky Mountains, was not seen again until 55 years later. The larvae of *R. montana* live in films of water flowing over near-vertical rock faces, in crevices, or in wet moss. Since the discovery of the habitat of this species, additional populations outside of GSMNP were discovered along the Blue Ridge Parkway in similar habitats. It is likely that the protected status of the national parks where these high-elevation madicolous habitats occur helps keep *R. montana* safer from potential threats to its survival than it would be in the absence of this protection.

Discussion

The aquatic insect fauna of GSMNP is a rich subset of the fauna of the Southeast, which includes widespread elements of the North American fauna. The Southeast was never glaciated and represents one of the large southern refugia from which species spread northward as the last glaciers retreated (Flint 1971).

When the ATBI began, authorities with expertise in the flora and fauna of the southern Appalachians and GSMNP were asked to provide their best scientific estimates of the total number of species that might be expected to occur in GSMNP for the groups in which they had expertise. For the EPMTs, the consensus estimate was 650 species. The current total of 468 species represents 72% of the experts' earlier estimate. In addition to the 72 new GSMNP records and 10 new species reported here, several additional undescribed species are known to us or have been reported among specimens being examined by others (R.E. DeWalt pers. comm.). These taxa have not been reported here because studies are continuing. DeWalt et al. (2007) found 169 species of EPTs in the southwest drainages they sampled. Using species-accumulation curves and statistical techniques, they estimated that an additional 80 to 120 species of EPTs would eventually be found in the sections of GSMNP where they concentrated their efforts. Estimating how many more species are to be expected Park-wide is difficult. Our current knowledge of the fauna is based on numerous types of sampling efforts over many years, most of which were not designed as inventories of species diversity. Traditional insect survey techniques such as light-trapping and sweep-netting are extremely difficult to quantify. Because of these considerations, we are unable to perform a statistical analysis of the Park-wide data.

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Literature Cited

- Anderson, N.H. 2003. Megaloptera. Pp. 700–703, *In* V.H. Resh and R.T. Cardé (Eds.). *Encyclopedia of Insects*. Academic Press, San Diego, CA. 1266 pp.
- Brigham, W.U. 1982. Megaloptera. Pp. 7.1–7.12, *In* A.R. Brigham, W.U. Brigham, and A. Gnilka (Eds.). *Aquatic Insects and Oligochaetes of North and South Carolina*. Midwest Aquatic Enterprises, Mahomet, IL. 837 pp.
- DeWalt, R.E., and B.D. Heinold. 2005. Summer emerging Ephemeroptera, Plecoptera, and Trichoptera of Abrams Creek, Great Smoky Mountains National Park. *Proceedings of the Entomological Society of Washington* 107:34–48.
- DeWalt, R.E., L.M. Jacobus, and W.P. McCafferty. 2007. Summer Ephemeroptera, Plecoptera and Trichoptera from southwestern drainages in Great Smoky Mountains National Park, with additional Ephemeroptera records. *Proceedings of the Entomological Society of Washington* 109:136–154.
- Flint, O.S., Jr. 1964. New species and new state records of *Sialis* (Neuroptera: Sialidae). *Entomological News* 75: 9–13.
- Flint, R.F. 1971. *Glacial and Quaternary Geology*. John Wiley and Sons, New York, NY. 892 pp.
- Hamilton, S.W. 1985. The larva and pupa of *Beraea gorteba* Ross (Trichoptera: Beraeidae). *Proceedings of the Entomological Society of Washington* 87(4): 783–789.
- Hazard, E.E. 1960. A revision of the genera *Chauliodes* and *Nigronia* (Megaloptera: Corydalidae). M.Sc. Thesis. Ohio State University, Columbus, OH. 53 pp.
- Jacobus, L.M., and W.P. McCafferty. 2001. Adult description and commentary for two species of southeastern Nearctic *Ephemerella* (Ephemeroptera: Ephemerellidae). *Entomological News* 112:294–298.
- Jacobus, L.M., and W.P. McCafferty. 2003a. An introduction to the Smoky Mountain mayflies (Insecta: Ephemeroptera). *Southeastern Biology* 50:358–360.
- Jacobus, L.M., and W.P. McCafferty. 2003b. Revisionary contributions to North American *Ephemerella* and *Serratella* (Ephemeroptera: Ephemerellidae). *Journal of the New York Entomological Society* 111:174–193.
- Jacobus, L.M., and W.P. McCafferty. 2004. Revisionary contributions to the genus *Drunella* (Ephemeroptera: Ephemerellidae). *Journal of the New York Entomological Society* 112:127–147.
- Jacobus, L.M., and W.P. McCafferty. 2005. Mayfly (Ephemeroptera) diversity in the Great Smoky Mountains. *Southeastern Biology* 52:45–46.
- Jacobus, L.M., and W.P. McCafferty. 2006. A new species of *Acentrella* Bengtsson (Ephemeroptera: Baetidae) from Great Smoky Mountains National Park, USA. *Aquatic Insects* 28: 101–111.
- Jacobus, L.M., W.P. McCafferty, and S. Spichiger. 2002. First adult description for *Ephemerella hispida* (Ephemeroptera: Ephemerellidae). *Entomological News* 113:342–343.
- Johnson, K., T. Remaley, and G. Taylor. 2005. Management strategies for the hemlock woolly adelgid and the balsam woolly adelgid in the Great Smoky Mountains National Park. *In* B. Onken and R. Reardon (Compilers), *Third Symposium on Hem-*

- lock Woolly Adelgid in the Eastern United States. Asheville, NC, February 1–3, 2005. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia. FHTE-2005–01. Available online at http://na.fs.fed.us/fhp/hwa/pub/2005_proceedings/index.shtml. Accessed June 2006.
- Kondratieff, B.C., and R.F. Kirchner. 1991. Mayflies, Class Insecta: Order Ephemeroptera, Subphylum Tracheata. Pp. 194–197, *In* K. Terwilliger (Ed.). Virginia's Endangered Species: Proceedings of a Symposium. McDonald and Woodward Publishing Company, Blacksburg, VA. 672 pp.
- Kondratieff, B.C., and J.R. Voshell, Jr. 1984. The North and Central American species of *Isonychia* (Ephemeroptera: Oligoneuriidae). Transactions of the American Entomological Society 110:129–244.
- McCafferty, W.P., M.D. Meyer, J.M. Webb, and L.M. Jacobus. 2004. New state and provincial records for North American small minnow mayflies (Ephemeroptera: Baetidae). Entomological News 115:93–100.
- McCafferty, W.P., R.D. Waltz, J.M. Webb, and L.M. Jacobus. 2005. Revision of *Heterocloeon* McDunnough (Ephemeroptera: Baetidae). Journal of Insect Science [serial online] 5(35). Available online at <http://www.insectscience.org/5.35>. Accessed 2005 Dec 9.
- Morse, J.C. 1993. A checklist of the Trichoptera of North America, including Greenland and Mexico. Transactions of the American Entomological Society 119(1):47–93.
- Morse, J.C., B.P. Stark, and W.P. McCafferty. 1993. Southern Appalachian streams at risk: Implications for mayflies, stoneflies, caddisflies, and other aquatic biota. Aquatic Conservation: Marine and Freshwater Ecosystems 3:293–303.
- Morse, J.C., B.P. Stark, W.P. McCafferty, and K.J. Tennessen. 1998. Chapter 2. Southern Appalachian and other southeastern streams at risk: Implications for mayflies, dragonflies and damselflies, stoneflies, and caddisflies. Pp. 17–42, *In* G.W. Benz and D.E. Collins (Eds.). Aquatic Fauna in Peril: The Southeastern Perspective. Special Publication 1, Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA. 554 pp.
- Muise, C., K.R. Langdon, R.P. Shifflett, D. Trently, A. Hoff, P. Super, A. Mayor, and B.J. Nichols. 2007. Preliminary odonate checklist of the Smokies. Southeastern Naturalist (Special Issue 1):207–214.
- Nichols, B.J., and K.R. Langdon. 2007. The Smokies ATBI: History and progress. Southeastern Naturalist (Special Issue 1):27–34.
- Parker, C.R. 2000. *Neophylax kolodskii* (Trichoptera: Uenoidae), a new species from the Great Smoky Mountains National Park, USA. Aquatic Insects 22(4):271–274.
- Parker, C.R., and E.C. Bernard. 2006. The science approach to the Smokies All Taxa Biodiversity Inventory. The George Wright Forum 23(3):26–36.
- Parker, C.R., and D.W. Pipes. 1990. Watersheds of Great Smoky Mountains National Park: A geographical information system analysis. US Department of the Interior, National Park Service, Atlanta, GA. Research/Resources Management Report SER-91/01. 126 pp.
- Poole, R.W., and P. Gentili. 1996. Nomina Insecta Nearctica: A checklist of the insects of North America, Vol. 2. Entomological Information Services, Rockville, MD. 793 pp.
- Ricker, W.E. 1952. Systematic studies in Plecoptera. Indiana University Publications, Science Series 18:1–200.
- Ross, H.H. 1937. Studies of Nearctic aquatic insects I. Nearctic alder flies of the genus *Sialis* (Megaloptera, Sialidae). Illinois Natural History Survey Bulletin 21(3): 57–87.

- Ruiter, D.E., B.C. Kondratieff, R.A. Lechleitner, and R.E. Zuellig. 2005. An annotated list of the caddisflies (Trichoptera) of Mount Rainier National Park, Washington, USA. *Transactions of the American Entomological Society* 131: 159–187.
- Schlarbaum, S.E., R.L. Anderson, and F.T. Campbell. 1999. Control of pests and pathogens. Pp. 291–306. *In* J.D. Peine (Ed.). *Ecosystem Management for Sustainability, Principles and Practices Illustrated by a Regional Biosphere Reserve Cooperative*. Lewis Publishers, Boca Raton, FL. 500 pp.
- Shaver, C.L., K.A. Tonnessen, and T.G. Maniero. 1994. Clearing the air at Great Smoky Mountains National Park. *Ecological Applications* 4(4):690–701.
- Smock, L.A., and C.M. MacGregory. 1988. Impact of the American chestnut blight on aquatic shredding macroinvertebrates. *Journal of the North American Benthological Society* 7(3):212–221.
- Smoot, J., B. Robinson, M. McCann, G. Harwell, and J. Shubzda. 2000. Assessment of stream water quality and atmospheric deposition rates at selected sites in the Great Smoky Mountains National Park. Report prepared for the US National Park Service. Department of Civil and Environmental Engineering, The University of Tennessee, Knoxville, TN.
- Snyder, C.D., J.A. Young, D.P. Lemarié, and D.R. Smith. 2002. Influence of eastern hemlock (*Tsuga Canadensis*) forests on aquatic invertebrate assemblages in headwater streams. *Canadian Journal of Fisheries and Aquatic Sciences* 59: 262–275.
- Snyder, C.D., J.A. Young, R.M. Ross, and D.R. Smith. 2005. Long-term effects of hemlock forest decline on headwater stream communities. Pp. 42–55. *In* B. Oknen and R. Reardon (Compilers). *Third Symposium on Hemlock Woolly Adelgid in the Eastern United States*. USDA, Morgantown, WV. Forest Health Technology Enterprise Team report FHTET-2005-01. 384 pp.
- Stoneburner, D.L. 1977. Preliminary observations of the aquatic insects of the Smoky Mountains: Altitudinal zonation in the spring. *Hydrobiologia* 56(2): 137–143.
- Webb, J.M., and W.P. McCafferty. 2006. Contribution to the taxonomy of Eastern North American *Epeorus* Eaton (Ephemeroptera: Heptageniidae). *Zootaxa* 1128: 57–64.
- White, P., and K. Langdon. 2006. The ATBI in the Smokies: An overview. *The George Wright Forum* 23(3):18–25.

Appendix 1. Ephemeroptera of Great Smoky Mountains National Park. V = species considered vulnerable to extirpation by Morse et al. (1998). * = new species discovered since 1998.

Ameletidae

- Ameletus cryptostimulus* Carle
A. lineatus Traver
A. tertius McDunnough

Baetidae

- * *Acentrella* new species
A. parvula (McDunnough)
A. turbida (McDunnough)
Acerpenna macdunnoughi (Ide)
A. pygmaea (Hagen)
Baetis brunneicolor McDunnough
B. flavistriga McDunnough
B. intercalaris McDunnough
B. pluto McDunnough
B. tricaudatus Dodds
* *Centroptilum* new species
C. triangulifer (McDunnough)
Diphetero hageni (Eaton)
Heterocloeon curiosum (McDunnough)
H. davidi Waltz and McCafferty
H. frivolum (McDunnough)
Paracloeodes minutus (Daggy)
Plauditus dubius (Walsh)
P. punctiventris (McDunnough)
P. virilis (McDunnough)
Procloeon new species
P. rivulare (Traver)
P. viridoculare (Berner)
Pseudocentroptiloides usa Waltz and McCafferty
Pseudocloeon frondale (McDunnough)
P. propinquum (Walsh)

Baetiscidae

- Baetisca carolina* Traver
B. gibbera Berner

Caenidae

- Brachycercus nitidus* (Traver)
Caenis anceps Traver
C. hilaris (Say)
C. latipennis Banks
C. maccafferti Provonsha

Ephemereillidae

- Attenella attenuate* (McDunnough)
A. margarita (Needham)
Dannella lita (Burks)
D. simplex (McDunnough)
D. provonshai (McCafferty)
Drunella allegheniensis (Traver)
V *D. lata* (Morgan)
D. tuberculata (Morgan)
D. walkeri (Eaton)

- Ephemerella catawba* Traver
E. dorothea dorothea Needham
E. excrucians Walsh
E. hispida Allen and Edmunds
E. invaria (Walker)
E. septentrionalis McDunnough
E. subvaria McDunnough
Eurylophella aestiva (McDunnough)
E. funeralis (McDunnough)
E. minimella (McDunnough,)
E. verisimilis (McDunnough)
Serratella deficiens (Morgan)
S. molita (McDunnough)
S. serrata (Morgan)

Ephemeridae

- Ephemera blanda* Traver
E. guttulata Pictet
E. varia Eaton
Hexagenia limbata (Serville)

Heptageniidae

- Cinygmula subaequalis* (Banks)
Epeorus dispar (Traver)
E. fragilis (Morgan)
E. pleuralis (Banks)
V *E. subpallidus* (Traver)
E. vitreus (Walker)
Heptagenia julia Traver
H. marginalis Banks
Leucocuta aphrodite (McDunnough)
L. hebe (McDunnough)
L. junio (McDunnough)
L. maculipennis (Walsh)
L. thetis (Traver)
V *Maccaffertium carlsoni* (Lewis)
M. exiguum (Traver)
M. ithaca (Clemens and Leonard)
M. mediopunctatum mediopunctatum (McDunnough)
M. meririvulanum (Carle and Lewis)
M. modestum (Banks)
M. mexicanum integrum (Ulmer)
M. pudicum (Hagen)
M. pulchellum (Walsh)
M. sinclairi (Lewis)
M. terminatum terminatum (Walsh)
M. vicarium (Walker)
Nixe perfida (McDunnough)
N. spinosa (Traver)
Rhithrogena amica Traver
R. exilis Traver
R. fasciata Traver

- R. fuscifrons* Traver
R. uhari Traver
Stenacron carolina (Banks)
S. interpunctatum (Say)
S. pallidum (Traver)
- Isonychiidae**
- Isonychia bicolor* (Walker)
 V *I. georgiae* McDunnough
I. hoffmani Kondratieff and Voshell
I. obscura Traver
I. rufa McDunnough
I. sayi Burks
I. similis Traver
I. tusculanensis Berner
- Leptophlebiidae**
- Habrophlebia vibrans* Needham
Habrophlebiodes americana (Banks)
- Leptophlebia johnsoni* McDunnough
Paraleptophlebia adoptiva
 (McDunnough)
P. assimilis (Banks)
P. guttata (McDunnough)
P. moerens (McDunnough)
P. mollis (Eaton)
P. swannanoa (Traver)
P. volitans (McDunnough)
- Neophemeridae**
- Neophemera purpurea* (Traver)
- Potamanthidae**
- Anthopotamus distinctus* (Traver)
- Siphonuridae**
- Siphonurus mirus* (Eaton)
S. typicus (Eaton)

Appendix 2. Plecoptera of Great Smoky Mountains National Park. V = species listed as vulnerable to extirpation by Morse et al. (1998). * = new species discovered since 1998.

Capniidae

- Allocapnia aurora* Ricker
A. frisoni Ross and Ricker
 V *A. fumosa* Ross
A. granulata (Claassen)
A. recta (Claassen 1924)
A. rickeri Frison
A. stannardi Ross
Paracapnia angulata Hanson

Chloroperlidae

- Alloperla atlantica* Baumann
A. chloris Frison
A. nanina Banks
A. neglecta Frison
A. petasata Surdick
A. usa Ricker
Haploperla brevis (Banks)
H. parkeri Kirchner and Kondratieff
Rasvena terna (Frison)
Suwallia marginata (Banks)
Sweltsa lateralis (Banks)
S. mediana (Banks)
S. urticae (Ricker)

Leuctridae

- Leuctra alexanderi* Hanson 1941
L. biloba Claassen 1923
L. carolinensis Claassen 1923
L. ferruginea (Walker 1851)
L. grandis Banks 1906
L. maria Hanson 1941
L. mitchellensis Hanson 1941
L. monticola Hanson 1941
L. nephophila Hanson 1941
L. sibleyi Claassen
L. tenella Provancher
L. tenuis (Pictet)
L. triloba Claassen
L. truncata Claassen
L. variabilis Hanson
Megaleuctra williamsae Hanson
Paraleuctra sara (Claassen)

Nemouridae

- Amphinemura appalachia* Baumann
A. delosa (Ricker)
A. nigrutta (Provancher)
A. wui (Claassen)

- Prostoia completa* (Walker)
P. similis (Hagen)
Soyedina carolinensis (Claassen)
S. kondratieffi Baumann and Grubbs
Soyedina new species
Zapada chila (Ricker)
- Peltoperlidae**
Tallaperla anna (Needham and Smith)
T. cornelia (Needham and Smith)
V *T. elisa* Stark
T. laurie Ricker
T. maria (Needham and Smith)
Viehooperla ada (Needham and Smith)
- Perlidae**
Acroneuria abnormis (Newman)
A. arenosa (Pictet)
V *A. arida* (Hagen)
A. carolinensis (Banks)
A. filicis Frison
A. frisoni Stark and Brown
A. internata (Walker)
A. perplexa Frison
V *A. petersi* Stark and Gaufin
Attaneuria ruralis (Hagen)
Agnentina capitata (Pictet)
V *Beloneuria georgiana* (Banks)
V *B. stewarti* Stark and Szczytko
Eccoptura xanthenes (Newman)
Hansonoperla appalachia Nelson
Neoperla clymene (Newman)
N. coosa Smith and Stark
N. occipitalis (Pictet)
Paragnetina ichusa Stark and Szczytko
P. immarginata (Say)
P. media (Walker)
Perlesta decipiens (Walsh)
P. frisoni Banks
P. nelsoni Stark
P. placida (Hagen)
Perlinella drymo (Newman)
P. ephyre (Newman)
- Perlodidae**
Clioperla clio (Newman)
Cultus decius isolatus (Banks)
C. verticalis (Banks)
Diploperla duplicata (Banks)
D. robusta Stark and Gaufin
Helopicus subvarians (Banks)
Isogenoides hansonii (Ricker)
V *Isoperla bellona* Banks
I. bilineata (Say)
I. dicala Frison
V *I. distincta* Nelson
I. frisoni Illies
I. holochlora (Klapalek)
I. lata Frison
I. orata Frison
I. similis (Hagen)
Malirekus hastatus (Banks)
Oconoperla innubila (Needham and Claassen)
Remenus bilobatus (Needham and Claassen)
Yugus arinus (Frison)
Y. bulbosus (Frison)
- Pteronarcyidae**
Pteronarcys dorsata (Say)
P. scotti Ricker
- Taeniopterygidae**
Bolotoperla rossi (Frison)
Oemopteryx contorta (Needham and Claassen)
Strophopteryx fasciata (Burmeister)
S. limata (Frison)
Taenionema atlanticum Ricker and Ross
Taeniopteryx burksi Ricker and Ross
T. maura (Pictet)

Appendix 3. Megaloptera of Great Smoky Mountains National Park.

- Corydalidae**
Chauliodes pectinicornis Linnaeus
C. rastricornis Rambur
Corydalus cornutus (Linnaeus)
Nigronia fasciatus (Walker)
N. serricornis (Say)
- Sialidae**
Sialis joppa Ross
S. velata Ross

Appendix 4. Trichoptera of Great Smoky Mountains National Park. V = species listed as vulnerable to extirpation by Morse et al. (1998). “*” = new species discovered since 1998. “+” = new species discovered prior to 1998. “#” = provisional record.

Apataniidae

- Apatania praevolans* (Morse)
A. rossi (Morse)

Beraeidae

- # *Beraea* species

Brachycentridae

- Brachycentrus appalachia* Flint
B. lateralis (Say)
B. nigrosoma (Banks)
B. spinae Ross
Micrasema bennetti Ross
M. burksi Ross and Unzicker
M. charonis Banks
M. rickeri Ross and Unzicker
M. rusticum (Hagen)
M. scotti Ross
M. wataga Ross

Calamoceratidae

- Anisocentropus pyraloides* (Walker)
Heteroplectron americanum (Walker)

Dipseudopsidae

- Phylocentropus auriceps* (Banks)
P. carolinus Carpenter
P. lucidus (Hagen)

Glossosomatidae

- Agapetus crasmus* Ross
A. hessi Leonard and Leonard
A. iridis Ross

V *A. jocassee* Morse

- A. minutus* Sibley
A. pinatus Ross
A. rossi Denning
A. tomus Ross
Glossosoma nigrrior Banks
Matrioptila jeanae (Ross)

Goeridae

- Goera calcarata* Banks
G. fuscula Banks
+ *G. new species*
Goerita betteni Ross
G. flinti Parker

Helicopsychidae

- Helicopsyche borealis* (Hagen)

Hydropsychidae

- Arctopsyche irrorata* Banks
Cheumatopsyche analis (Banks)
C. campyla Ross
C. ela Denning

- C. enigma* Ross, Morse, and Gordon

C. geora Denning

C. gyra Ross

C. halima Denning

C. harwoodi Denning

C. helma Ross

C. oxa Ross

C. pasella Ross

C. speciosa (Banks)

Diptertrona metaqui Ross

D. modesta Banks

Homoplectra doringa (Milne)

Hydropsyche (Ceratopsyche) alhedra Ross

H. (Ceratopsyche) bronta Ross

H. (Ceratopsyche) cheilonis Ross

H. (Ceratopsyche) macleodi Flint

H. (Ceratopsyche) morosa Hagen

H. (Ceratopsyche) slossonae Banks

H. (Ceratopsyche) sparna Ross

H. (Hydropsyche) betteni Ross

H. (Hydropsyche) carolina Banks

H. (Hydropsyche) depravata Hagen

H. (Hydropsyche) franclemonti Flint

Hydropsyche (Hydropsyche) rossi Flint,
Voshell, and Parker

H. (Hydropsyche) scalaris Hagen

H. (Hydropsyche) simulans Ross

H. (Hydropsyche) venularis Banks

Parapsyche apicalis (Banks)

P. cardis Ross

Hydroptilidae

Dibusa angata Ross

Hydroptila amoena Ross

H. armata Ross

H. callia Denning

H. chattanooga Frazer and Harris

H. delineata Morton

H. fiskei Blickle

H. grandiosa Ross

H. hamata Morton

H. oneili Harris

H. remita Blickle and Morse

H. scolops Ross

H. talladega Harris

H. valhalla Denning

H. waubesiana Betten

Leucotrichia pictipes (Banks)

Mayatrichia ayama Mosely

Ochrotrichia graysoni Parker and
Voshell

- Oxyethira michiganensis* Mosely
O. novasota Ross
O. pallida (Banks)
Palaeagapetus celsus (Ross)
Stactobiella delira (Ross)
S. martynovi Blickle and Denning
S. palmata (Ross)
- Lepidostomatidae
Lepidostoma americanum (Banks)
L. bryanti (Banks)
L. carrolli Flint
V *L. compressum* Etnier and Way
L. excavatum Flint and Wiggins
V *L. flinti* Wallace and Sherberger
L. frosti (Milne)
L. griseum (Banks)
L. latipenne (Banks)
V *L. lobatum* Wallace and Sherberger
L. lydia Ross
L. mitchelli Flint and Wiggins
L. modestum (Banks)
L. ontario Ross
L. pictile (Banks)
L. sackeni (Banks)
L. styliferum Flint and Wiggins
L. tibiale (Carpenter)
L. togatum (Hagen)
Theliopsyche corona Ross
T. epilonis Ross
T. grisea (Hagen)
- Leptoceridae
Ceraclea ancylus (Vorhies)
C. cancellata (Betten)
C. diluta (Hagen)
C. flava (Banks)
C. maculata (Banks)
C. nepha (Ross)
* *C. new species*
C. tarsipunctata (Vorhies)
C. transversa (Hagen)
Leptocerus americanus (Banks)
Mystacides sepulchralis (Walker)
Nectopsyche candida (Hagen)
N. exquisita (Walker)
Oecetis avara (Banks)
O. inconspicua (Walker)
O. nocturna Ross
O. persimilis (Banks)
Setodes stehri (Ross)
Triaenodes ignitus (Walker)
T. injustus (Hagen)
T. marginatus Sibley
T. perna Ross
T. taenius Ross
T. tardus Milne
- Limnephilidae
Frenesia difficilis (Walker)
F. missa Milne
Hydatophylax argus (Harris)
Ironoquia punctatissima (Walker)
Platycentropus radiatus (Say)
Pseudostenophylax sparsus (Banks)
P. uniformis (Betten)
Pycnopsyche antica (Walker)
P. conspersa Banks
P. divergens (Walker)
P. flavata (Banks)
P. gentilis (MacLachlan)
P. guttifer (Walker)
P. lepida (Hagen)
P. luculenta (Betten)
P. sonso (Milne)
P. subfasciata (Say)
- Molannidae
Molanna blenda Sibley
M. ulmerina Navas
- Odontoceridae
Pseudogoera singularis Carpenter
Psilotreta amera (Ross)
P. frontalis Banks
P. labida Ross
P. rossi Wallace
P. rufa (Hagen)
- Philopotamidae
Chimarra aterrima Hagen
C. augusta Morse
C. obscura (Walker)
C. socia Hagen
Dolophilodes distinctus (Walker)
D. major (Banks)
D. sisko ()
Wormaldia moesta (Banks)
W. mohri (Ross)
W. shawnee (Ross)
- Phryganeidae
Agrypnia vestita (Walker)
Ptilostomis ocellifera (Walker)
P. postica (Walker)
- Polycentropodidae
Cyrnellus fraternus (Banks)
Neureclipsis crepuscularis (Walker)
Nyctiophylax affinis (Banks)
N. moestus Banks
N. nephophilus Flint
N. uncus Ross
N. banksi Morse
N. celta Denning
N. denningi Morse

Polycentropus blicklei Ross and
Yamamoto

- V *P. carlsoni* Morse
- P. carolinensis* Banks
- P. cinereus* Hagen
- P. colei* Ross
- P. confusus* Hagen
- P. crassicornis* Walker
- P. maculatus* Banks
- P. rickeri* Yamamoto

Psychomyiidae

Lype diversa (Banks)
Psychomyia flavida Hagen
P. nomada (Ross)

Rhyacophilidae

- V *Rhyacophila accola* Flint
- R. acutiloba* Morse and Ross
- V *R. amicus* Ross
- R. appalachia* Morse and Ross
- R. atrata* Banks
- R. banksi* Ross
- R. carolina* Banks
- R. carpenteri* Milne
- * *R. celadon* Etnier, Stocks, and Parker
- R. formosa* Banks
- R. fuscula* (Walker)
- R. minor* Banks
- R. montana* Carpenter
- R. mycta* Ross
- R. nigrita* Banks
- R. glaberrima* Ulmer
- R. ledra* Ross
- R. mainensis* Banks
- R. new species*
- R. teddyi* Ross
- R. torva* Hagen
- R. vibox* Milne

Sericostomatidae

Agarodes tetron (Ross)
Fattigia pele (Ross)

Uenoidae

Neophylax aniqua Ross
N. concinnus MacLachlan
N. consimilis Betten
N. fuscus Banks
N. kolodskii Parker
N. mitchelli Carpenter
N. oligius Ross
N. ornatus Banks