

# BUDDLEJA DAVIDII (SCROPHULARIACEAE) NATURALIZED POPULATIONS IN TENNESSEE (U.S.A.) AND ITS WOODY ASSOCIATES

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## ABSTRACT

*Buddleja davidii* Franch. (orange-eye butterfly bush), an introduced Chinese shrub in the Scrophulariaceae, is categorically naturalized at seven sites in four new Tennessee counties from field reconnaissance in 2012–2014. *Buddleja davidii* was previously documented by herbarium specimens as escaping from cultivation in Washington County (1952), Cumberland County (1975), and Hamilton County (2010). *Buddleja davidii* has limited naturalization in Anderson, Davidson, DeKalb, and Knox counties in ruderal habitats from field observations and relative abundance values. In Tennessee, orange-eye butterfly bush was confined to culturally-disturbed habitats and was not present in natural secondary forest communities. A total of 51 woody associated species (32 native, 19 non-native) were also documented among these seven populations to obtain descriptive site data. Fifteen of 19 non-native woody associates were classified as state-listed invasive taxa, which affect the colonization of *B. davidii* populations.

KEY WORDS: *Buddleja davidii*, woody associated species, distribution, naturalized, orange-eye butterfly bush, Scrophulariaceae, invasives, Tennessee counties

## RESUMEN

*Buddleja davidii* Franch. (arbusto mariposa de ojos naranja), un arbusto chino introducido de Scrophulariaceae, está naturalizado categóricamente en siete sitios en cuatro nuevos condados de Tennessee a partir de estudios de campo realizados en 2012–2014. *Buddleja davidii* fue previamente documentada por especímenes de herbario como escapada de cultivo en los condados de Washington (1952), Cumberland (1975) y Hamilton (2010). *Buddleja davidii* tiene una naturalización limitada en los condados de Anderson, Davidson, DeKalb y Knox en base a observaciones de campo y valores de abundancia relativa. En Tennessee, el arbusto mariposa de ojos naranja se limitaba a los hábitats perturbados por cultivo y no estaba presente en las comunidades forestales secundarias. También se documentaron un total de 51 especies asociadas leñosas (32 nativas, 19 no nativas) entre estas siete poblaciones para obtener datos descriptivos de los sitios. Quince de las 19 especies asociadas leñosas no nativas fueron clasificadas como taxones invasivos registrados en el estado, que afectan a la colonización de las poblaciones de *B. davidii*.

PALABRAS CLAVE: *Buddleja davidii*, especies leñosas asociadas, distribución, naturalizado, arbusto mariposa de ojos naranja, Scrophulariaceae, invasivos, condados de Tennessee

## INTRODUCTION

*Buddleja davidii* Franch. (orange-eye butterfly bush, butterfly bush, or summer lilac) are unarmed, multiple-stemmed, deciduous to semi-deciduous, shade-intolerant, pioneer shrubs placed in the Scrophulariaceae of the Lamiales (Norman 2012). Orange-eye butterfly bush is native to 13 mountainous provinces in southwest and central China (Zheng et al. 2006; Tallent-Halsell & Watt 2009). *Buddleja* is comprised of 90–100 species worldwide (Stuart 2006; Dirr 2009). *Buddleja davidii* has been the most extensively planted ornamental of the ca. 25 cultivated species. At least 150 cultivars and hybrids of *B. davidii* have been recognized (Stuart 2006; Dirr 2009). *Buddleja davidii* has been selected for ornamental horticulture due to its growth hardiness in many anthropogenic habitats, attractive dark green and grayish-white foliage, fragrant white, lilac-lavender, lilac-rose, red-violet to purple flowers, and high nectar content for the attraction of butterfly, moth, bee, and wasp pollinators (Stuart 2006; Dirr 2009; Tallent-Halsell & Watt 2009).

*Buddleja davidii* (herein, *B. davidii*, butterfly bush, or orange-eye butterfly bush), has a broad ecological amplitude for propagation, establishment, colonization, and naturalization in a diversity of open, insolated and weedy disturbed habitats through means of wind-dispersed seeds (Tallent-Halsell & Watt 2009; Trueblood 2009; Thompson & Abbott 2013). Butterfly bush is a fast growing, semi-cold-tolerant shrub that readily establishes populations in full sun in a wide range of nutrient poor soil types (Tallent-Halsell & Watt 2009; Trueblood 2009). *Buddleja davidii* thrives best in well-drained alkaline soils but regardless of adaptations, it is rather a short-lived shrub mostly of less than 30 years (Smales 1990; Brunel 2006; Tallent-Halsell & Watt 2009; Trueblood 2009). The presence of endophytic arbuscular mycorrhizae in *B. davidii* enhances its establishment and survival (Camargo-Ricalde et al. 2003; Dickie et al. 2007).

In Kentucky, *Buddleja davidii* was reported naturalized in five counties from active and abandoned railroad right of ways, weedy disturbed urban areas, roadside ditch thickets, lake floodplains, and severely-burned national forest lands (Thompson & Abbott 2013). In 2014, butterfly bush was documented as naturalized for a sixth Kentucky county distribution along a grassy road shoulder and guard rail in Leslie County within the Cumberland Plateau [R.L.Thompson & K. Rivers Thompson 14-377 (BEREA, EKY)].

Our definitions of non-native “naturalized” species and “invasive” species are modified from Nesom (2000) and Richardson et al. (2000) by subjective degree of colonization, establishment, and migration. A “naturalized” plant is a non-native plant that grows naturally in ruderal or culturally-derived habitats, and is able to maintain itself for at least 10 years without anthropogenic assistance. An “invasive” plant is an aggressive, non-native naturalized plant that tends to readily spread and displace the native flora and vegetation over time. Thompson & Abbott (2013) described orange-eye butterfly bush as naturalized in Kentucky from field reconnaissance, herbarium searches, and pertinent literature. Furthermore, Thompson and Abbott (2013) determined that *B. davidii* should not be classified as an invasive species in Kentucky. Butterfly bush in six Kentucky counties was closely restricted to those ruderal habitats where it was found with little evidence of additional propagation, spread, or migration into contiguous natural vegetation.

Our major objectives were to conduct field reconnaissance searches for Tennessee populations of *Buddleja davidii*, pursue an in-depth herbarium specimen examination, review relevant literature, and compile descriptive data of the woody associated species at naturalized population sites.

#### BUTTERFLY BUSH NON-NATIVE STATUS

Regarding non-native origin status, *Buddleja davidii* has been classified as naturalized in Australia, Canada, Central America, Europe, New Zealand, Puerto Rico, South America, and the United States (Tallent-Halsell & Watt 2009; Norman 2012). It has been recorded as an invasive shrub in Australia, England, France, New Zealand, and in the USA states of Hawaii, Oregon, and Washington (Tallent-Halsell & Watt 2009; Young-Mathews 2011; Norman 2012; USDA, ARS 2014). In Oregon, *B. davidii* is designated as a Class “B” noxious weed; and, it is listed as a Class “C” noxious weed along riparian floodplains in Washington (Young-Mathews 2011; USDA, NRCS 2014). *Buddleja davidii* grows without cultivation in a variety of temperate habitats that include limestone quarries, coal surface-mined lands, active and abandoned railways, fallow fields, successional woodland ecotones, roadside thickets and ditch margins, riparian corridors, streambeds, floodplains, and lake shores, among numerous other disturbed habitats (Tallent-Halsell & Watt 2009; Norman 2012).

Orange-eye butterfly bush has been reported from 21 states (Kartesz 2014; USDA, NRCS 2014) to 24 states in the United States (EDDMapS 2014). Distribution maps for these states do not clarify whether the non-native status of *B. davidii* is cultivated, introduced, persisting, a waif, naturalized, or invasive among the non-native classifications of Nesom (2000). Map distributions likely represent a grouping of all those non-native categories from herbarium vouchers and literature reports.

Recent literature contains several discrepancies and inconsistencies on the invasiveness of butterfly bush within the eastern United States. *Buddleja davidii* was not listed as an invasive species in AL, FL, GA, KY, MS, NC, SC, nor TN by the SE-EPPC (2014). In contrast, the MA-EPPC (2008) reported butterfly bush as an invasive in CA, KY, NC, NJ, OR, PA, WA, and WV. Swearingen et al. (2010) listed it as a “Plant to Watch” in DE, MD,

NJ, PA, VA, and WV. The KY-EPPC (2013) listed *B. davidii* for the first time, as a “Moderate Threat,” an exotic plant that can spread into disturbed corridors although not readily invading natural areas. Butterfly bush has been updated to an “Alert” rank for Tennessee, an exotic plant that possesses invasive characteristics in habitats similar to those found in Tennessee (TN-EPPC 2009). Jones and Wofford (2013) indicated *B. davidii* to be a non-native escaped species of disturbed sites in Kentucky and Tennessee; and, it was expected to become more problematic in the future. Chester et al. (2015) noted that *B. davidii* is “a landscaping species, rarely naturalized in ruderal areas statewide...shows strong invasive potential.”

Nevertheless, Trueblood (2009) developed an Invasive Species Assessment System data form and score sheet for *Buddleja davidii* in North Carolina. She determined *B. davidii* to have limited ecological impact, distribution, and invasive potential in natural areas. In her assessment summary, orange-eye butterfly bush was considered to be a non-invasive, shade-intolerant, short-lived pioneer shrub that tended to be controlled or eliminated mainly through processes of natural plant succession by native woody vegetation. In brief, *Buddleja davidii* has not been shown to have negative ecological impact in North Carolina natural areas.

#### METHODS

Field reconnaissance was conducted from 2012–2014 toward discovering naturalized populations of *Buddleja davidii* in Tennessee. Descriptive data were also recorded for woody associated species for seven populations in Knox, Anderson, DeKalb, and Davidson counties. “Associated woody species” are those characteristic or indicator taxa often found with certain other non-native and/or native species that have similar phenological life cycles, plant durations, ecological adaptations, and habitat requirements.

Relative abundance values (frequency of occurrence) for orange-eye butterfly bush and interspersed woody associates were based on the scale of Thompson (2007): Rare (R) = 1–4 individuals; Scarce (S) = 5–10 individuals; Infrequent (I) = 11–30 individuals; Occasional (O) = 31–100 individuals; Frequent (F) = 101–1000 individuals; and Abundant (A) = 1000s of individuals.

Relative frequency percentages were determined from absolute frequency by the presence of a native or non-native woody associate within each *Buddleja davidii* population site (Table 1). Relative frequency is a qualitative measure of the abundance and distribution of each associated species’ occurrence within the seven *B. davidii* population sites.

Nomenclature, classification, and identification for associated woody taxa follow Jones and Wofford (2013). Herbarium acronyms for voucher specimens follow Index Herbariorum of Thiers (2014). Herbarium searches were made of the regional Tennessee university herbaria (APSC, ETSU, HTTU, MTSU, TENN, and UCHT) and other state and national herbaria (BRIT, EKY, KY, MO, NCU, and VDB).

#### RESULTS AND DISCUSSION

##### Tennessee Butterfly Bush Herbarium Collections

From herbarium specimen label data, *Buddleja davidii* was first documented growing without cultivation in Washington County on July 28, 1952 [R.L. James 16885 (TENN)]; and, it was also documented as an escape at another site in Washington County in 1999 [Mark Dugger 27 (ETSU)]. In 1975, *B. davidii* was reported as escaped at two locations in Cumberland County [*B. Eugene Wofford 51846* (NCU, TENN); *R. Kral 56489* (MO, VDB)]. The Washington and Cumberland counties “escaped” populations are likely the basis of *B. davidii* being classified as “naturalized” in *A Fifth Checklist of Tennessee Vascular Flora* by Chester et al. (2009). In Hamilton County, a 2010 specimen was also labeled as “commonly escapes from cultivation” [Gary H. Morton 9203 (UCHT)]. Orange-eye butterfly bush distribution was initially mapped for Tennessee in Cumberland, Knox, and Washington counties (Chester et al. 1997; USDA, NRCs 2014), while Cumberland, Grainger, Knox, Shelby, and Washington counties were mapped by TENN (2014) and EDDMapS (2014). *Buddleja davidii* has been documented as a planted ornamental from herbarium specimens and field work in seven Tennessee counties as listed: Blount (BEREA), Bradley (UCHT), Grainger (TENN), Knox (BEREA, TENN), Putnam (BEREA), Sevier (TENN), and Shelby (TENN). Thirteen Tennessee counties have been documented by naturalized or planted butterfly bush specimens (Fig. 1).

TABLE 1. Woody associates for seven *Buddleja davidii* populations in four Tennessee counties.

County Species	Knox Site 1	Knox Site 2	Knox Site 3	Ander. Site 4	Ander. Site 5	DeK. Site 6	Dav. Site 7	No. Sites	Frequency %
<i>Acer negundo</i>	+	+	+	+	+	+	+	7	100
** <i>Ailanthus altissima</i>	+	+	+	+	+	+	+	7	100
** <i>Ligustrum sinense</i>	+	+	+	+	+	+	+	7	100
** <i>Lonicera japonica</i>	+	+	+	+	+	+	+	7	100
** <i>Lonicera maackii</i>	+	+	+	+	+	+	+	7	100
<i>Parthenocissus quinquefolia</i>	+	+	+	+	+	+	+	7	100
<i>Platanus occidentalis</i>	+	+	+	+	+	+	+	7	100
** <i>Albizia julibrissin</i>	+	+	+	+	+	+		6	85.71
** <i>Pyrus calleryana</i>	+	+	+	+	+	+		6	85.71
** <i>Rosa multiflora</i>	+	+	+	+	+	+		6	85.71
<i>Rubus occidentalis</i>	+	+		+	+	+	+	6	85.71
<i>Toxicodendron radicans</i>	+	+	+		+	+	+	6	85.71
** <i>Celastrus orbiculatus</i>	+	+	+	+			+	5	71.43
<i>Cercis canadensis</i>	+	+		+	+	+		5	71.43
<i>Juniperus virginiana</i>	+	+		+	+	+		5	71.43
<i>Liriodendron tulipifera</i>	+	+		+	+	+		5	71.43
** <i>Paulownia tomentosa</i>	+	+	+	+	+			5	71.43
<i>Robinia pseudoacacia</i>	+	+	+		+	+		5	71.43
<i>Ulmus rubra</i>	+	+			+	+	+	5	71.43
<i>Vitis vulpina</i>		+	+		+	+	+	5	71.43
<i>Celtis occidentalis</i>	+	+	+				+	4	57.14
** <i>Elaeagnus umbellata</i>	+	+		+	+			4	57.14
** <i>Euonymus fortunei</i>		+	+		+		+	4	57.14
<i>Fraxinus americana</i>		+	+	+		+		4	57.14
<i>Salix nigra</i>			+			+	+	4	57.14
<i>Acer saccharum</i>		+	+	+				3	42.86
<i>Ampelopsis cordata</i>					+	+	+	3	42.86
<i>Campsis radicans</i>		+			+		+	3	42.86
<i>Fraxinus pennsylvanica</i>			+		+		+	3	42.86
<i>Rhus glabra</i>	+	+			+			3	42.86
<i>Rubus pensilvanicus</i>	+	+			+			3	42.86
<i>Acer saccharinum</i>			+				+	2	28.57
<i>Carya cordiformis</i>			+				+	2	28.57
<i>Clematis virginiana</i>		+			+			2	28.57
<i>Cornus amomum</i>			+	+				2	28.57
<i>Frangula caroliniana</i>	+		+					2	28.57
<i>Gleditsia triacanthos</i>	+				+			2	28.57
** <i>Morus alba</i>					+		+	2	28.57
<i>Quercus muhlenbergii</i>			+				+	2	28.57
* <i>Ulmus pumila</i>	+			+				2	28.57
<i>Catalpa bignonioides</i>							+	1	14.29
** <i>Elaeagnus pungens</i>			+					1	14.29
** <i>Ligustrum vulgare</i>						+		1	14.29
** <i>Nandina domestica</i>					+			1	14.29
* <i>Prunus persica</i>					+			1	14.29
** <i>Pueraria montana</i>		+						1	14.29
<i>Rhus copallinum</i>					+			1	14.29
<i>Sambucus canadensis</i>	+							1	14.29
<i>Smilax rotundifolia</i>							+	1	14.29
<i>Ulmus americana</i>			+					1	14.29
* <i>Yucca filamentosa</i>					+			1	14.29
<b>Totals:</b> 51 taxa	27	30	28	21	34	22	24		

**Ander.** = Anderson County; **DeK.** = DeKalb County; **Dav.** = Davidson County.

(\*) = a naturalized taxon, (\*\*) = an invasive pest plant for Tennessee (TN-EPPC 2009).

The four new counties with naturalized butterfly bush are discussed separately. Tennessee specimen label data on naturalized or planted shrubs from Tennessee counties are as follows:

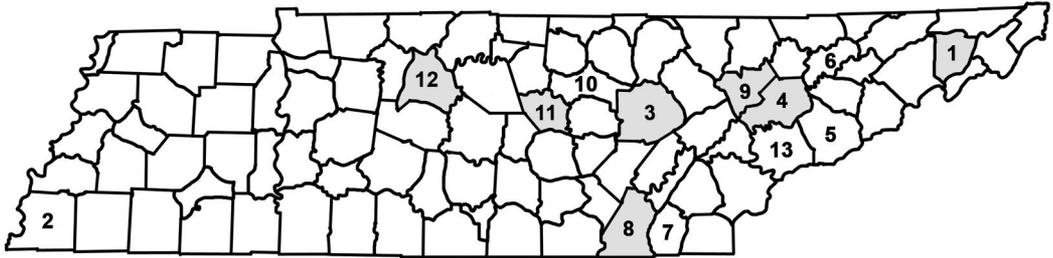


FIG. 1. Tennessee counties documented with *Buddleja davidii* specimens by collection year(s). Gray-numbered counties indicate naturalized populations; white-numbered counties represent cultivated ornamental individuals or populations: 1 = Washington (1952, 1999), 2 = Shelby (1972), 3 = Cumberland (1975), 4 = Knox (1991, 2012, 2013, 2014), 5 = Sevier (1998), 6 = Grainger (1999), 7 = Bradley (2002), 8 = Hamilton (2010), 9 = Anderson (2014), 10 = Putnam (2014), 11 = DeKalb (2014), 12 = Davidson (2014), 13 = Blount (2014). (Tennessee map adapted by Melanie G. Bentley, Eastern Kentucky University)

**TENNESSEE. Blount Co.:** Maryville, Maryville College, E side of Bartlet Hall Student Center lawn off Circle Drive and Morningside Lane, cultivated shrub with lilac-lavender flowers; 35.75053°N, 83.96429°W, 448 m, 29 July 2014, R.L. Thompson & K. Rivers Thompson 14-341 (BEREA, TENN); Townsend, Great Smoky Mountain Heritage Center, 123 Cromwell Drive, off TN 73, one surviving shrub with purple flowers planted by flagpoles in front, one dead from April freeze, 35.67472°N, 83.722292°W, 344 m, 29 July 2014, R.L. Thompson & K. Rivers Thompson 14-342 (BEREA, TENN). **Bradley Co.:** Cleveland, growing at the S side of gymnasium at Cleveland State Community College, adjacent to parking lot approximately 9 m from Adkisson Drive; shrub about 1.5 m tall, mint green color, few dark purple flowers, 220 m, 17 Mar 2002, Anna Lea Griffith 15 (UCHT). **Cumberland Co.:** Crab Orchard, roadside along Highway 70, just W of I-40 E, Exit 329, 30 Jul 1975, B. Eugene Wofford 51846 with W. Michael Dennis (TENN); escape by roadside rip-rap near creek, 28 Aug 1975, R. Kral 56489 (MO, VDB). **Grainger Co.:** Rutledge, planted on Tampico Road, 6 Sep 1999, H.R. DeSelm s.n. (TENN). **Hamilton Co.:** Apison, along fence row at 4312 Bill Jones Road, commonly escapes from cultivation, 9 Jul 2010, Gary H. Morton 9203 (UCHT). **Knox Co.:** Knoxville, planted at Woodland Drive, Sequoyah Hills, 20 Oct 1991, H.R. DeSelm s.n. (TENN); Knoxville, Jjams Nature Center, 2915 Island Home Avenue at NW corner of William O. Miller Education Building (the Home Site), a single shrub planted in 1983, not spreading, 35.95758°N, 83.86961°W, 282 m, 29 Nov 2012, R.L. Thompson & S. Brobst 12-1157 (BEREA, TENN); 18 May 2014, R.L. Thompson & K. Rivers Thompson 14-120 (BEREA, TENN). **Putnam Co.:** Cookeville, two shrubs planted at 2675 Lakeland Drive off I-40 E at Exit 290, US 70 (TN 24), 36.13151°N, 85.44244°W, 291 m, 15 Apr 2014, R.L. Thompson & S.J. Stedman 14-25 (BEREA, TENN); white flowers, evident branch die-back freeze damage, 12 Jul 2014, R.L. Thompson & G.N. Douglas 14-340 (BEREA, TENN). **Sevier Co.:** Sevierville, planted on Section Springs Road, 17 Aug 1998, H.R. DeSelm s.n. (TENN). **Shelby Co.:** Memphis, cultivated, Helene Griffith's home, 568 St. Nick Drive, corolla white, 21 Jul 1972, Edward T. Browne, Jr. & Elizabeth M. Browne 72 FH.3 (TENN). **Washington Co.:** Johnson City, escaped from cultivation off Knob Creek Road near Snow Chapel Memorial Baptist Church, 28 Jul 1952, R.L. James 16885 (TENN); Johnson City, East Tennessee State University, escaped at forest edge of the hiking trail across from Central Receiving, 20 Nov 1999, Mark Dugger 27 (ETSU).

### Reconnaissance of Tennessee Butterfly Bush Populations

Field investigations for seven naturalized *Buddleja davidii* populations and their woody associates were expedited through the assistance of six Tennessee naturalists (S. Brobst & D. Estes, pers. comm. 2012; D. Bruce, T. Crabtree, M. Smith, & S. Stedman, pers. comm. 2014). The seven population sites were discovered in Knox County (3), Anderson (2), DeKalb (1), and Davidson (1) counties; these are new county naturalized Tennessee populations. Orange-eye butterfly bush and the woody associates at each of seven sites are discussed in regards to their location, habitat, physical site characteristics, relative abundance, relative frequency, woody associated species status, and effects of *B. davidii* toward the native flora and vegetation.

### *Buddleja davidii* naturalized in Knox County

Three naturalized populations of *Buddleja davidii* were discovered and studied in Knoxville, Knox County, Tennessee, during 2012–2014 (Fig. 2; Fig. 3). Knoxville and vicinity are situated within the Southern Limestone/Dolomite Valleys and Rolling Hills Ecoregion of the Ridge and Valley Province. Potential vegetation is a mosaic of Appalachian Oak and Mesophytic Forest often with *Juniperus virginiana* L. (Griffith et al. 1997). Forested terrain typically consists of undulating to rolling, rounded hills comprised of underlying bedrock strata from the Ordovician Holston Limestone Formation (Griffith et al. 1997).

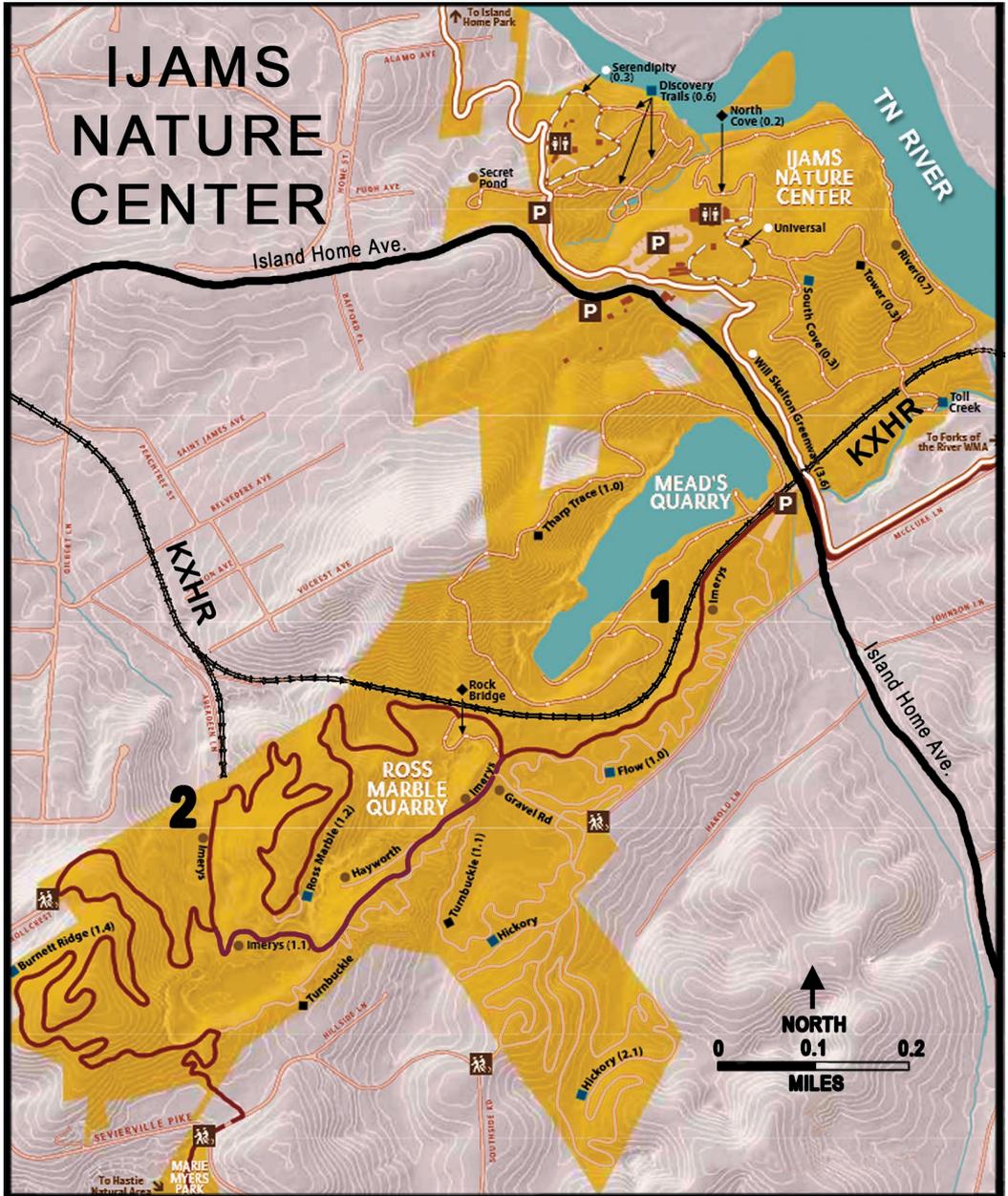


Fig. 2. *Buddleja davidii* (Sites 1, 2) at Ijams Nature Center, Knox County, Tennessee: 1) Mead's Quarry at limestone kiln wall adjacent to railroad tracks (Sites 1), and 2) Imery's Trail end near Aberdeen Lane (Site 2). [Map modified from Knoxville's Urban Wilderness, South Loop Trails: Ijams Nature Center, Ross & Mead's Quarry (Legacy Parks Foundation 2009)].

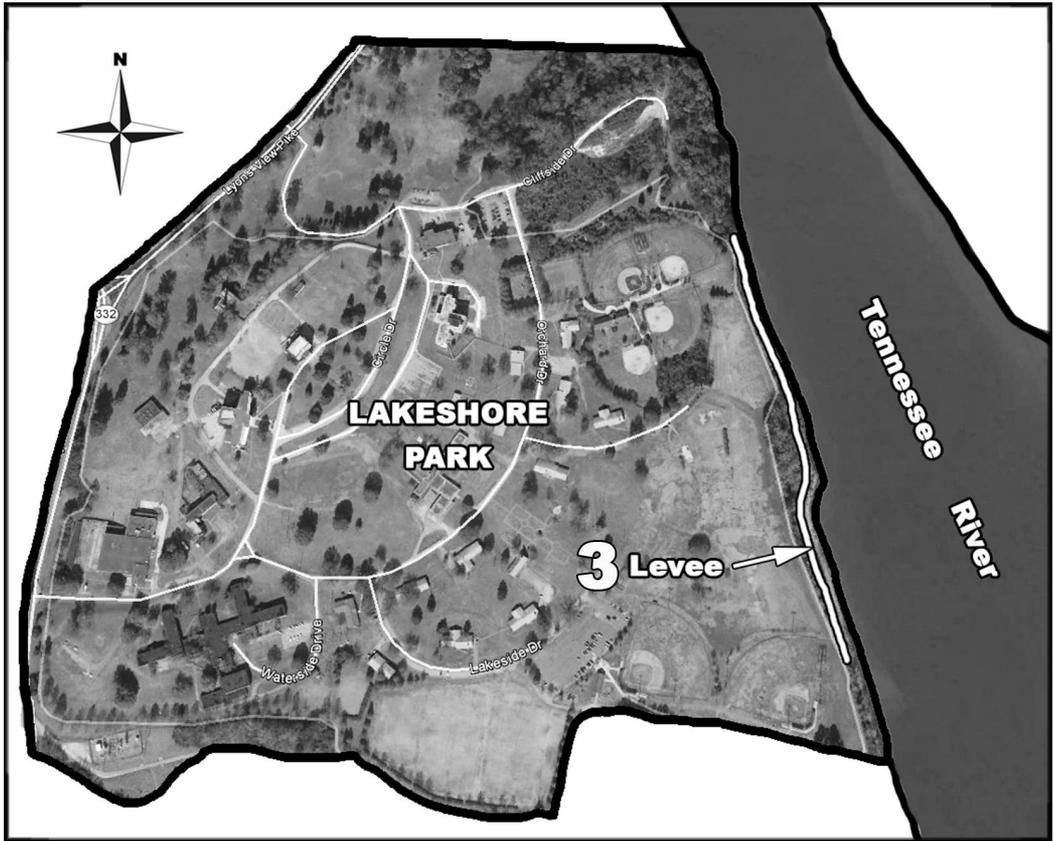


Fig. 3. Lakeshore Park levee (Site 3) designated by narrow white line adjacent to the west side of the Tennessee River, Knox County, Knoxville. [Map modified from Knoxville 2013 Master Plan. ([www.cityofknoxville.org/lakeshore/masterplanupdate121613.pdf](http://www.cityofknoxville.org/lakeshore/masterplanupdate121613.pdf))]

Ijams Nature Center, a 111.3-ha (275-acre) wildlife sanctuary and wildlife environmental learning center, under the management of the Knox County Department of Parks and Recreation, Knoxville, is comprised of lands mainly from two abandoned marble quarries, Ross Quarry and Mead's Quarry (James 2010). From these two quarries, Tennessee marble, a pink to cedar-red coarse crystalline limestone rock from the Ordovician Holston Limestone Formation was excavated (James 2010). Mead's Quarry, the larger quarry, was in operation from 1881–1945 for large marble stone blocks. After 1945–1978, limestone was crushed, kiln-extracted and transported as agriculture lime for commerce by the Knoxville and Holston Railway (KXHR) K Line. Mead's Quarry Lake, a 10.1-ha (25-acre lake) subsequently was formed when water pooled in the quarry pit after Mead's Quarry closed for the last time in 1978 (Fig. 2). The KXHR railway is situated parallel to Mead's Quarry and is still in operation as a short-line spur twice a month for transporting commerce to the Tennessee River. The quarry lake and its environs became a part of Ijams Nature Center in 2001 (James 2010). In 2005, three limestone kilns were demolished with a stone wall and three lime chute openings as the only remnants today of the agricultural lime operation (Paul James, Director, Ijams Nature Center, pers. comm. 2012).

#### Site 1: Ijams Nature Center, Meads Quarry and Railroad Population

On November 21, 2012, a preliminary reconnaissance located the first naturalized *Buddleja davidii* population along the KXHR tracks adjacent to Mead's Quarry Lake (Site 1); 12 herbaceous and 13 woody associates were recorded (Thompson & Abbott 2013). This butterfly bush population was noted in 2003 by Dwayne Estes,

Austin Peay State University, but vouchers were not taken (D. Estes, pers. comm. 2012). At this location, orange-eye butterfly bush is infrequent in relative abundance. *Buddleja davidii* consisted of 20–25 plants comprised of a few mature shrubs, smaller volunteering shrubs, and seedlings that colonized a 75 m extension of the KXHR railroad tracks parallel to the limestone wall and kiln chutes. Butterfly bushes were embedded in a thick crust of slag agriculture lime with typical seasonal vegetation cover of non-native and native woody and herbaceous species. Unseasonally late April and early May freezes in conjunction with herbicide spraying by the KXHR railway personnel between May and June 2014, killed much of the right-of-way vegetation including two adjacent large and several smaller orange-eye butterfly bushes.

The original seed source was undoubtedly derived from a few *Buddleja davidii* between the limestone kilns and the railroad tracks initially planted by a troop of Boy Scouts in 1983 as part of an ornamental planting project near Mead's Quarry (Sally Mirick, Former Director, Ijams Nature Center, pers. comm. 2012). The dispersal of the tiny wind-carried seeds has probably been partly enhanced by the "slipstreaming" wake action by the short-spur railroad freight cars and locomotives. Slipstreaming of *B. davidii* seeds was discussed in a recent descriptive study of butterfly bush dispersal, colonization, and naturalization in Kentucky (Thompson & Abbott 2013).

Twenty-seven tree, shrub, and woody vine associated species (16 native, 11 non-native) were interspersed among 68 herbaceous (28 native, 40 non-native) taxa. Mead's Quarry habitats were open, sunny, ruderal areas (hiking and biking trails, mowed and unmowed areas, parking lots, railroad track right-of-way) where many opportunistic native and non-native naturalized taxa have thrived.

The 16 native trees, shrubs, and vines were documented. Scarce native woody taxa were *Frangula caroliniana* (Walter) A. Gray and *Sambucus canadensis* L. Infrequent to occasional native woody species were *Acer negundo* L., *Celtis occidentalis* L., *Cercis canadensis* L., *Gleditsia triacanthos* L., *Juniperus virginiana* L., *Liriodendron tulipifera* L., *Parthenocissus quinquefolia* (L.) Planch., *Platanus occidentalis* L., *Rhus glabra* L., *Robinia pseudoacacia* L., *Rubus occidentalis* L., *R. pensilvanicus* Poir., *Toxicodendron radicans* (L.) Kuntze, and *Ulmus rubra* Muhl. (Table 1). Eleven naturalized woody taxa documented were infrequent *Celastrus orbiculatus* Thunb., *Ulmus pumila* L.; occasional *Ailanthus altissima* (Mill.) Swingle, *Albizia julibrissin* Durazz., *Elaeagnus umbellata* Thunb., *Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud., *Pyrus calleryana* Decne, *Rosa multiflora* Thunb ex Murray; and frequent *Ligustrum sinense* Lour., *Lonicera japonica* Thunb., *L. maackii* (Rupr.) Maxim. (Table 1). All naturalized species, except *Ulmus pumila*, are classified as woody invasives by the Tennessee Exotic Pest Plant Council (TN-EPPC 2009).

Label data from the Mead's Quarry kiln wall and railroad site, Knox County, are summarized as follows: **TENNESSEE. Knox Co.:** Knoxville, Ijams Nature Center, adjacent to Mead's Quarry Lake, between the remaining limestone kilns wall and the railroad track bed; naturalized Chinese shrubs, infrequent relative abundance, 15–30 shrubs, 35.95066°N, 83.86744°W, 272 m, 20 Nov 2012, R.L. Thompson & K. Rivers Thompson 12-1153 (APSC, BEREA, MO, NCU, TENN); 8 Jul 2013, R.L. Thompson & K. Rivers Thompson 13-375 (APSC, BEREA, NCU); 5 Oct 2013, R.L. Thompson, K. Rivers Thompson, & P.F. Threadgill 13-708 (BEREA, TENN).

## Site 2. Ijams Nature Center, Imery's Trail Population

On November 29, 2012, a larger second naturalized population of *Buddleja davidii* was discovered at the extreme south-southwest portion of Ijams Nature Center near the end of Imery's Trail (Site 2) near Aberdeen Lane (Fig. 2). Orange-eye butterfly bush had occasionally spread into an open sunny area where old limestone kilns and concrete block foundations were dismantled in 2008 (Paul James, Director, Ijams Nature Center, pers. comm. 2012). Butterfly bush in various phenological stages was growing among brick and concrete block debris and limestone slag wastes by Imery's Trail. The butterfly bush population was enclosed by a secondary successional mesophytic hardwood forest of frequent codominant *Acer saccharum* Marshall and *Liriodendron tulipifera* L. with a dense shrub and vine thicket. During May 2014, active bulldozing destroyed many butterfly bush shrubs when Imery's Trail to Aberdeen Lane was widened. Furthermore, the atypical late April-early May freezes caused severe die-back of butterfly bush branches.

Thirty woody associates (18 native, 12 naturalized) were recorded from this open disturbed forest edge (Table 1) scattered among 60 herbaceous (36 native, 24 non-native) taxa. Twenty-three of these woody taxa were also recorded at the Mead's Quarry (Site 1), which included frequent invasive *Ligustrum sinense*, *Lonicera*

*japonica*, and *L. maackii* (Table 1). Six additional woody species (four native, two non-native) at Imery's Trail were infrequent to occasional *Campsis radicans* (L.) Seem. ex Bureau, *Clematis virginiana* L., *Euonymus fortunei* (Turcz.) Hand.-Mazz., *Fraxinus americana* L., *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & Almeida, and *Vitis vulpina* L. Four woody plants present at Mead's Quarry, but not recorded at Imery's Trail (Site 2) were *Frangula caroliniana*, *Gleditsia triacanthos*, *Sambucus canadensis*, and *Ulmus pumila* (Table 1). Of these 12 naturalized woody taxa, all except *U. pumila*, are listed as invasives by the TN-EPPC (2009).

The *Acer saccharum*-*Liriodendron tulipifera* woodland has progressed to a later seral stage of secondary succession than the Mead's Quarry site with fewer ruderal and more native herbaceous and woody taxa. The encroachment of a dense understory shrub thicket and tree canopy confines the expansion of butterfly bush colonization at the Imery's Trail site. This observation supports further the conclusions of Trueblood (2009): the migration of *Buddleja davidii*, a shade-intolerant pioneer shrub, is being controlled by competition through natural secondary plant succession.

A total of 125 herbaceous and woody associated species (91 herbaceous, 34 woody) were recorded from the two naturalized *Buddleja davidii* populations at Ijams Nature Center (Sites 1, 2). The woody species were composed of 22 native and 12 naturalized taxa. Twenty-four (14 native, 10 naturalized) of the 34 woody associates were common to both *B. davidii* population sites (Table 1). The 34 woody taxa (17 trees, 8 shrubs, 9 vines) at the two Ijams Nature Center sites were comparable to the 34 woody taxa (19 trees, 7 shrubs, 8 vines) documented at a drastically disturbed 13-year-old abandoned limestone quarry in central Kentucky (Thompson & Green 2010).

The Ijams Nature Center Imery's population (Site 2) label data are as follows: **TENNESSEE. Knox Co.:** Knoxville, Ijams Nature Center property, 230 m S of 2515 Aberdeen Lane SE beside Imery's Trail, occasional relative abundance, 60–80 naturalized shrubs among rubble, 35.94627°N, 83.87642°W, 286 m, 29 Nov 2012, R.L. Thompson & S. Brobst 12-1160 (APSC, BEREA, MO, TENN); 8 Jul 2013, R.L. Thompson & K. Rivers Thompson 13-376 (APSC, BEREA, BRIT, NCU, TENN); 5 Oct 2013, R.L. Thompson, K. Rivers Thompson, & P.F. Threadgill 13-701; 13-702 (APSC, BEREA, TENN)

### Site 3: Lakeshore Park Tennessee River Rip-rap Levee Population

On January 10, 2014, a third population of *Buddleja davidii* was investigated at Lakeshore Park, Knoxville, a 78.9-ha (195-acre) park also managed by the Knox County Department of Parks and Recreation. Forty-eight orange-eye butterfly bush plants occasional in relative abundance, were established on the rounded apex of a 0.53 km limestone rip-rap levee (Site 3). The levee adjoins Lakeshore Park on the riparian west shoreline of the Tennessee River, 17.2 km downstream from Ijams Nature Center (Fig. 3). Orange-eye butterfly bush colonization on the levee was probably due to the combination of wind-and-water seed dispersal. Twenty-eight woody associates (17 native, 11 non-native) were documented. Infrequent to occasional associated species on the levee crest were *Ailanthus altissima*, *Albizia julibrissin*, *Ligustrum sinense*, *Lonicera maackii*, *Paulownia tomentosa*, *Platanus occidentalis*, *Rosa multiflora*, and *Salix nigra* Marshall. Eight woody associates (7 native, 1 non-native) not present at Ijams Nature Center (Sites 1, 2) were the infrequent *Acer saccharinum* L., *Carya cordiformis* (Wangenh.) K. Koch, *Cornus amomum* Mill., *Euonymus pungens* Thunb., *Fraxinus pennsylvanica* Marshall, *Quercus muhlenbergii* Engelm., *Salix nigra*, and *Ulmus americana* L. (Table 1).

Label data for Lakeshore Park (Site 4), Knoxville are as follows: **TENNESSEE. Knox Co.:** Knoxville, Lakeshore Park, along the top of a limestone boulder rip-rap levee, 48 naturalized shrubs, occasional relative abundance, 35.92372°N, 83.98660°W, 253 m at apex, 249 m at shoreline, 10 Jan 2014, R.L. Thompson & D.M. Bruce 14-02 (APSC, BEREA, TENN).

### *Buddleja davidii* naturalized in Anderson County

Orange-eye butterfly bush was documented from two naturalized populations in Anderson County on April 5, 2014. Both population sites are entirely located within the Southern Limestone/Dolomite Valleys and Low Rolling Hills Ecoregion within the Ridge and Valley Province of potential Appalachian Oak and Mesophytic Forest (Griffith et al. 1997).

### Site 4: Grassy Road Shoulder and Highwall Population

A *Buddleja davidii* population was situated within the city limits of Clinton, Tennessee, beside the Charles G. Seivers Boulevard (TN 61W). A mature butterfly bush, 4 m x 3 m, was growing within a mixed tall fescue (*Fes-*

*tuca arundinacea* Schreb.) road shoulder adjacent to an Ordovician limestone highwall road cut (Site 4). This single shrub has undoubtedly served as the seed source to the 8–9 scarce volunteering shrubs embedded within limestone fractures of a 7–9 m vertical highwall.

Twenty-one woody associates (10 native, 11 non-native) on the road shoulder and highwall were recorded (Table 1). No new native or non-native woody taxa were recorded for Site 4. Among 11 state-listed invasive species, *Ligustrum sinense* and *Lonicera maackii* were frequent codominant shrubs. The unusual freezes of late April and early May killed most of the new leafing branches of the large “parent” butterfly bush, and three small butterfly bushes embedded in the limestone highwall crevices died from the spring freezes as well. Little or no freeze effects were noted on the 11 invasive taxa. Some root collar sprouting was evident on May 18, 2014, and by late June and July, lilac-lavender inflorescences appeared on the surviving parent and surviving high-wall plants. Senescence occurred by late September.

Label data for the Anderson County roadside and highwall (Site 4) are as follows: **TENNESSEE. Anderson Co.:** Clinton, TN 61 W adjacent to Clinch River, tall fescue road shoulder between limestone highwall talus, scarce relative abundance, ca. 8–9 small shrubs established in crevices of a 5–7 m highwall from a large parent shrub, infrequent relative abundance, 36.08231°N, 84.161154°W, 211 m, 5 Apr 2014, R.L. Thompson & D.R. Bruce 14-23 (APSC, BEREA, TENN); severe leaf frost damage, 18 May 2014, R.L. Thompson & K. Rivers Thompson 14-111 (BEREA, TENN); lilac-lavender flowers on new or undamaged branches of parent shrub, 21 Aug 2014, R.L. Thompson & G.N. Douglas 14-520 (APSC, BEREA, TENN).

### Site 5: Abandoned Asphalt, Concrete, and Gravel Landfill

The second Anderson County population was located in Oak Ridge east of Southern Illinois Avenue (TN 62) on Union Valley Road contiguous to the east side of the Oak Ridge Golf Center, 119 Union Valley Road (Site 5). Two rare orange-eye butterfly bushes were growing in different areas 40 m apart in an open, nearly level abandoned asphalt, concrete, and aggregate gravel landfill. A smaller shrub had only a single shoot regenerating from the rootstock, while a second larger shrub had several basal shoots rejuvenating from the rootstock although most of the shrub branches exhibited severe dieback.

This abandoned landfill (Site 5) had the highest species richness of the seven sites with 34 associated woody plants (20 native, 14 non-native) within the immediate vicinity of these two shrubs (Table 1). This landfill ruderal habitat site promoted wide-spread seed dispersal and establishment of both native and non-native woody taxa from various anthropogenic refuse sources. *Ligustrum sinense*, *Lonicera japonica*, *L. maackii*, and *Pyrus calleryana* were the frequent dominant taxa. Three additional native taxa at the landfill site not present at the other four sites were occasional in relative abundance: *Ampelopsis cordata* Michx., *Fraxinus pennsylvanica* Marshall, and *Rhus copallinum* L. Four non-native scarce naturalized taxa present were *Morus alba* L., *Nandina domestica* Thunb., *Prunus persica* (L.) Batsch, and *Yucca filamentosa* L. (Table 1).

Label data for the abandoned landfill (Site 5) in Anderson County are as follows: **TENNESSEE. Anderson Co.:** Oak Ridge, Oak Ridge Highway (TN 170) to Southern Illinois Avenue (TN 62) to Union Valley Road east to a disused city landfill adjacent to Oak Ridge Golf Center, 119 Union Valley Road, rare relative abundance, small solitary shrub embedded in fractured asphalt-concrete layer, 36.00203°N, 84.22006°W, 284 m, 5 Apr 2014, R.L. Thompson & D.R. Bruce 14-24 (APSC, BEREA, TENN); small shrub with a single surviving basal branch and lilac-lavender flowers, 21 Aug 2014, R.L. Thompson & G.N. Douglas 14-537 (BEREA); larger shrub with lilac-lavender inflorescences from several basal shoots from rootstock, remainder of shrub dead, 36.00166°N, 84.21981°W, 282 m, 21 Aug 2014, R.L. Thompson & G.N. Douglas 14-538 (APSC, BEREA, TENN).

### *Buddleja davidii* naturalized in DeKalb County

On April 15, 2014, a naturalized population of *Buddleja davidii* was discovered off TN 83 north of Smithville to Holmes Creek Road for 3.8 km north across from the concrete remains of Hidden Harbor Marina at Center Hill Lake. The abandoned roadside thicket (Site 6) is located entirely within the Outer Nashville Basin Ecoregion of the Interior Plateau Province. Major vegetation is comprised of Oak-Hickory Forest (Griffith et al. 1997).

### Site 6: Abandoned Gravel Road by Center Hill Lake

A total of 9–12 infrequent seed-producing shrubs in various growth stages were rooted in scattered limestone aggregate near an exposed herbicide-sprayed power line cut. Twenty-two woody associates (14 native, 8 naturalized) were recorded at Site 6 (Table 1). This population of orange-eye butterfly bush has been heavily shaded

by the dense forest edge thicket by the frequent Asian invasives, *Ligustrum sinense*, *L. vulgare* L., and *Lonicera maackii* (Table 1). The health of the butterfly bush population was also severely affected by late April and early May freezes with a majority of the larger shrub branches killed back to the rootstock. Likewise, this population appeared to be restricted to the abandoned gravel road due to herbicide spraying of the nearby power line corridor.

Label data at the DeKalb County disused roadside thicket (Site 6) are as follows: **TENNESSEE. DeKalb Co.:** Smithville, on Holmes Creek Road, 3.8 km N of TN 83 along Center Hill Lake on an abandoned limestone aggregate road near power line cut near the Hidden Harbor Marina foundation, scarce relative abundance, ca. 9–10 shrubs present, 36.700175°N, 85.26480°W, 203 m, 15 Apr 2014, R.L. Thompson & S.J. Stedman 14-26 (APSU, BERA, TENN); lilac-rose flowers, severe die-back from spring freezes, 11 Jul 2014, R.L. Thompson & G.N. Douglas 14-330 (APSU, BERA, TENN)

### ***Buddleja davidii* naturalized in Davidson County**

Shelby Park, a 136-ha (336-acre) urban multi-use park located in downtown Nashville adjacent to the Cumberland River, is located in Davidson County (Nashville Parks & Recreation 2014). The city park lies entirely within the Outer Nashville Basin Ecoregion of the Interior Plateau Province and consists of potential Oak-Hickory Forest (Griffith et al. 1997).

#### **Site 7: Steep Cumberland River Rip-rap Bank Population**

Two mature *Buddleja davidii* shrubs were growing out of large limestone rip-rap along the steep embankment thicket of the Cumberland River (Site 7) near a chain link fence separating the Shelby Park lawn from Davidson Street (Music City Bikeway). The thrysoid inflorescence was composed of lilac-lavender perfect, 4-merous flowers (Fig. 4) as all *B. davidii* shrubs were within the seven populations. Twenty-four woody associates (17 native, 7 naturalized) were recorded from this Cumberland River riparian thicket (Table 1). The two butterfly bushes were totally surrounded by a dense thicket of *Euonymus fortunei*, *Ligustrum sinense*, *Lonicera japonica*, *L. maackii*, and various occasional native woody vines, *Ampelopsis cordata*, *Parthenocissus quinquefolia*, *Toxicodendron radicans*, and *Vitis vulpina*. Two additional rare native species reported for the seven sites were *Catalpa bignonioides* Walter and *Smilax rotundifolia* L. (Table 1). Frost damage was not evident mainly due to the temperature buffer from the close proximity to the Cumberland River. No seedlings or evidence of butterfly bush colonization were found.

Label data for these two shrubs on the bank of the Cumberland River are as follows: **TENNESSEE. Davidson Co.:** Nashville, Shelby Park, Davidson Street (Music City Bikeway) across chain link fence on a steep open embankment in limestone rip-rap by Cumberland River; rare relative abundance, first naturalized shrub, 36.16505°N, 86.73046°W, 130 m, 16 Apr 2014, R.L. Thompson 14-30 (APSC, BERA, MO, TENN); lilac-lavender flowers, slight branch frost damage, 11 Jul 2014, R.L. Thompson & G.N. Douglas 14-336 (APSU, BERA, TENN); second shrub adjacent lower down, lilac-lavender inflorescence, 36.164972°N, 86.73070°W, 129 m, 11 Jul 2014, R.L. Thompson & G.N. Douglas 14-338 (BERA, TENN).

### **Synopsis of Naturalized *Buddleja davidii* Populations and Woody Associates**

*Buddleja davidii* was documented as locally naturalized from field reconnaissance at seven population sites in four Tennessee counties as follows: Knox (3), Anderson (2), DeKalb (1), and Davidson (1) during 2012–2014 (Table 1).

Ruderal or culturally disturbed sites and relative abundance values for the seven *B. davidii* populations were as follows: Knox County, Ijams Mead's Quarry Railroad (Site 1) = Scarce; Knox County, Ijams Imery's Trail (Site 2) = Occasional; Knox County, Lakeshore Park Rip-rap Levee, Tennessee River (Site 3) = Occasional; Anderson County, Highway Road Shoulder and Highwall (Site 4) = Scarce; Anderson County Disused Landfill (Site 5) = Rare; DeKalb County, Abandoned Road Thicket at Center Hill Lake (Site 6) = Infrequent; and Davidson County, Cumberland River rip-rap embankment (Site 7) = Rare. These naturalized *B. davidii* populations locally confined to culturally-derived and disturbed habitats have not volunteered or colonized any natural thickets or forest edges.

A summary of descriptive site characteristics and woody associated species from the seven *B. davidii* population studies include the following:



FIG. 4. *Buddleja davidii* inflorescence of lilac-lavender perfect flowers from Cumberland River rip-rap embankment population (Site 7), by Shelby Park, Nashville. (Photo taken by Michael R. Smith, 8 July 2013).

- 1) Fifty-one woody species [32 native (62.75%), 19 non-native (37.25%)] in 41 genera from 26 plant families were documented among the study sites.
- 2) These 51 woody taxa consisted of 26 trees (19 native, 7 exotic), 14 shrubs (7 native, 7 exotic), and 11 woody vines (7 native, 4 exotic).
- 3) Fifteen invasives of the 19 naturalized woody taxa (78.95%) classified by the Tennessee Exotic Pest Plant Council (TN-EPPC 2009) are listed as follows: Severe Threat (10), Significant Threat (2), Lesser threat (1), and Alert (2).
- 4) Eleven woody non-native invasives with a Relative Frequency (frequency of occurrence) of 57% or greater (4 of 7 sites) are listed in order: *Ailanthus altissima*, *Ligustrum sinense*, *Lonicera japonica*, *L. maackii*, *Albizia julibrissin*, *Pyrus calleryana*, *Celastrus orbiculatus*, *Paulownia tomentosa*, *Rosa multiflora*, *Elaeagnus umbellata*, and *Euonymus fortunei* (Table 1).
- 5) These 11 opportunistic woody invasives are inclined to have a greater ecological amplitude and tolerance to volunteer, colonize, compete, thrive, and invade natural habitats in early seral stages of progressive secondary succession than *Buddleja davidii*.
- 6) Most of these invasives have greater relative abundance values than *Buddleja davidii* populations.
- 7) Some non-native invasive adaptations include direct and indirect insolation, variation in moisture-soil requirements and varied pH, strong intraspecific and interspecific competition, better acclimation to cold and herbicides, and a length of establishment over 10 years in the case of typical woody non-native species (Pyšek et al. 2004).
- 8) No Tennessee special concern, threatened, or endangered herbaceous or woody taxa on the Rare Plant List (Crabtree 2014) were recorded within or near proximity to the seven study sites.

## CONCLUSION

We determined *Buddleja davidii* to be locally naturalized in Tennessee based on observations from field reconnaissance, voucher documentation from extant populations in Knox, Anderson, DeKalb, and Davidson counties, and by label information from examination of Tennessee herbarium specimens from Cumberland, Hamilton, and Washington counties. *Buddleja davidii* definitely did not exhibit the widespread invasive adaptations displayed by most non-native woody invasives in this study. Butterfly bush relative abundance values for the seven populations ranged from rare, scarce, infrequent, to occasional. These seven populations have not expanded their range beyond ruderal and culturally-derived areas. At an optimal classification, *B. davidii* populations observed in this study are sparingly and locally naturalized. Similarly in a Kentucky study, *Buddleja davidii* was reported naturalized, but was not determined to be invasive (Thompson & Abbott 2013).

As observed from this study, *Buddleja davidii* is a shade intolerant, short-lived pioneer species established in ruderal habitats of Tennessee that is eliminated through natural plant succession in absence of disturbance. Butterfly bush continues to be restricted to those disturbed habitats rather than secondary forested areas. Other contributing factors observed toward limited naturalization include poor competition among native and especially aggressive invasive woody taxa, low adaptability to unseasonably cold temperatures, and a high sensitivity to herbicides.

Trueblood (2009) evaluated the impact of *Buddleja davidii* on natural vegetation in North Carolina and reported that it has a tendency to be eliminated through natural plant succession. Moreover, orange-eye butterfly bush exhibited little ecological impact, distribution expansion, or invasive potential. These premises also appear to be applicable to Tennessee and Kentucky naturalized *B. davidii* populations. We propose the limited naturalization of *Buddleja davidii* in Tennessee at this present time clearly does not imply any invasive status beyond its current "Alert" rank from the TN-EPPC (2009). Exotic pest plant council personnel in Tennessee, Kentucky, and other southeastern states could benefit from evaluating *B. davidii* with a rational assessment system, such as developed for North Carolina.

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