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Distribution of *Lythrum salicaria* L., Purple Loosestrife, in Western Virginia and Northeastern Tennessee

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ABSTRACT

Purple loosestrife (*Lythrum salicaria* L.) is an endemic species of Eurasia and since its introduction in the late 18th century has become a highly invasive weed in North America. This species reportedly displaces native wetland plant species by forming monocultures. The changes in number and size of purple loosestrife infestations at 51 sites in western Virginia and northeastern Tennessee were monitored over an 11-year period. All sites were along riverbanks or in shallow water along the Clinch, James, and Maury rivers. Only two sites could be considered wetlands. At the 43 sites not impacted by biological control agents or human activities, there was no change in purple loosestrife abundance at seven sites (16%), a decrease at 19 (44%), and an increase at 17 sites (40%). More than twice the number of sites that increased were frequently flooded open cobble bars. The flooding disturbance seems to make these areas more susceptible to invasion and persistent infestations. Purple loosestrife infestations responded similarly in all three rivers during the study. There was a significant difference in the change in density during the study between the two major habitat types. Cobble bar sites increased while riverbank sites decreased in density during the study. The presumed age of these infestations varied considerably and may have influenced the size of the infestations. Generally, large infestations were closer to the initial infestation and presumably older than those downstream. However, the most distant site from the initial infestation was one of the largest infestations. This suggests that the size of the infestation is influenced more by habitat suitability than age of the infestation. Seven species of rare plant populations that prefer a similar habitat as purple loosestrife have been recorded or grow in close proximity to the sites recorded in this study. Populations of water willow (*Justicia americana*), a valuable species in the riverine ecosystem, were susceptible to invasion by purple loosestrife. The threat of purple loosestrife to this species and rare plant species warrants continued monitoring throughout this study area.

Key words: purple loosestrife, *Lythrum salicaria*, distribution, invasive species, Virginia.

INTRODUCTION

Purple loosestrife (*Lythrum salicaria* L.) is considered native to Eurasia and occurs in the eastern hemisphere in Eurasia, northern Africa, and Australia (Hultén, 1971). It has a perennial rootstock that annually sends up 4 - 10 stems per root and grows to a height of two meters (Thompson et al., 1987). Dispersal is primarily through seed. Shamsi & Whitehead (1974) reported annual seed production of approximately 100,000. Other estimates range from 300,000 (Teale, 1982) to 2.7 million seeds annually (Thompson et al., 1987). Seeds may also remain viable for several years (Shamsi & Whitehead, 1974; Rawinski, 1982). Since the early 19th century purple loosestrife has become a major weed of wetlands in North America (Stuckey, 1980), infesting over 400,000 acres and displacing native wetland plant species (Thompson et al., 1987). Initial establishment of purple loosestrife is often associated with recently disturbed areas such as industrial, construction, waste, and dump areas (Stuckey, 1980). Water level reduction, and highway construction and maintenance also provide favorable conditions for establishment (Wilcox, 1989). Its efficient use of nutrients and energy (Nagel & Griffin, 2001) plus the absence of host-specific herbivores (Blossey & Notzold, 1995; Galatowitsch et al., 1999) may explain the competitive advantage of purple loosestrife over native plant species in North America.

The introduction of purple loosestrife into North America began in the late 18th and early 19th centuries. Ballast such as sand and rock taken from the harbors of Europe where purple loosestrife was naturally growing was used on ships on their voyage to North America (Thompson et al., 1987). From these harbors purple loosestrife was able to spread inland by dispersal of seeds adhering to migrating birds and wildlife. Over the past two centuries, purple loosestrife has also been planted in cultivated gardens for herbal, aesthetic, and beekeeping purposes (Thompson et al., 1987). Its present distribution in North America extends from southern Canada south to the 36th parallel (Stuckey, 1980; National Agricultural Pest Information System, 2004).

Purple loosestrife was reported at Salt Sulfur Springs resort, Monroe County, West Virginia in 1885 (Stuckey, 1980). It was also reported in Indian Creek in Monroe County, and at Mercer Springs resort in Mercer County, West Virginia (McNeil, 1938). There were no records of establishment of purple loosestrife in Virginia prior to 1900, although it was reported in adjacent states near the border of Virginia. It was planted in fish ponds in Washington D. C. and in waste areas in Wilmington, North Carolina in the late 1800s (Stuckey, 1980). It was reported as rare in marshes in Watuga County, North Carolina (Radford et al., 1968). During the 19th century it was planted as a medicinal and ornamental at health resorts.

In Virginia, Capel (1993) reported purple loosestrife increasing from 15 counties in 1981 to 25 counties in 1992. The Atlas of Virginia Flora (Harvill et al., 1992) documented 24 counties with purple loosestrife; three of these counties (Scott, Wise, and Buchanan) are in southwestern Virginia.

Recognizing the limitations of mechanical and chemical control procedures, biological control was initiated and several insect species were extensively tested and approved for release in 1992 (Kok et al., 1992 a, b; Malecki et al., 1993; Blossey et al., 1994 a, b). Three natural enemies of purple loosestrife, *Galerucella calmariensis* L., *G. pusilla* Duftschmidt (Coleoptera: Chrysomeldiae), and *Hylobius transversovittatus* Goeze (Coleoptera: Curculionidae), were collected in Germany by the International Institute of Biological Control (CABI Bioscience) and releases began in 1992. Establishment of these biological control agents on purple loosestrife in Virginia was reported by McAvoy et al. (1997, 2002) and Kok et al. (2000), and in other parts of North America by Hight et al. (1995), Weibe et al. (2001), Dech & Nosko (2002), and Lindgren (2003).

Since the first release of these exotic agents for biological control of purple loosestrife in 1992, several publications have expressed concern that the adverse impact of purple loosestrife on native vegetation has been overstated and has not been adequately documented (Anderson, 1995; Hager & McCoy, 1998; Treberg & Husband, 1999; Farnsworth & Ellis, 2001; Houlahan & Findlay, 2004). Blossey et al. (2001) provided a summary of the negative impacts caused by purple loosestrife ranging from decline in quality bird habitat and reduction in plant biodiversity to alteration of wetland function.

The purpose of this study was to document infestations of purple loosestrife in western Virginia (and northeastern Tennessee) over an 11-year period. Documenting the location and size of purple loosestrife infestations over an extended period of time will help in determining the threat of purple loosestrife to native riverine plant species. Future workers can use these data to assess the status and long-term impact of purple loosestrife and help determine the effects of this species on wetland and riverine ecosystems.

MATERIALS AND METHODS

Distribution of *L. salicaria* infestations were monitored from 1991 to 2002 along the Clinch, James, and Maury rivers in Virginia. Surveys were made on the Guest River, a tributary of the Clinch River beginning at Coeburn in Wise County and downstream of Dungannon on the Clinch River to Sneedville, Hancock County, Tennessee. Surveys on the James River drainage were from Dunlap Creek near Sweet Chalybeate in Alleghany County through Botetourt and Rockbridge counties to Amherst and Bedford counties at Big Island. The Maury River drainage was surveyed from Cabin Creek in Millboro to Mill Creek, Bath County to the Calfpasture River in Goshen through Rockbridge County to its confluence with the James River at Glasgow.

Surveys were conducted in late July and August when purple loosestrife is in full bloom and the tall magenta inflorescences are highly visible. We drove along roads paralleling the waterways and where access was possible to the waterway. The presence or absence of purple loosestrife was recorded. These sites were usually at bridge crossings or where the road came close enough to the waterway to allow access. The number of purple loosestrife plants was counted at each site. Locations where no purple loosestrife was present but were open and similar to infested sites with respect to plant species and terrain were selected as sites as well.

At large infestations, the number of square meters of purple loosestrife was recorded. The plant species found within 1 to 2 meters of each purple loosestrife infestation were recorded at all sites. Abundance of associated plant species was categorized during the 2000 and 2002 surveys into three classes of percent area covered: uncommon (1-33%), common (34-66%), and abundant (67-100%). Plant species were determined as native or non-native according to Harvill et al. (1992). To document the location of each site the UTM (Universal Transverse Mercator, zone 17, North American Datum 1927) coordinates were recorded using a Magellan GPS315®, global positioning satellite recorder.

A linear regression was done on each site to determine change in loosestrife density with year as the independent variable and plant density as the dependent variable. A negative slope was interpreted as a decrease in density, a positive slope an increase and a slope of zero as no change. Change in density between the cobble and riverbank habitats not influenced by biological control agents or human disturbances was compared using ordinal logistics (SAS, 1985).

RESULTS

Clinch River

Nineteen sites were monitored from 1991 to 2002 (Fig. 1 and Table 1) in the Clinch River drainage. The source of the purple loosestrife infestation in the Clinch River drainage was determined to be 1.5 km upstream of site C1 (Fig. 1). No purple loosestrife was found upstream of this area on Little Toms Creek. This stream flows into the Guest River which flows into the Clinch River 8 km upstream of Dungannon. No purple loosestrife was found in the Clinch River upstream of the confluence of the Guest River. This suggests that the infestation of purple loosestrife along the Clinch River originated in Coeburn. The Coeburn town manager stated that purple loosestrife had been present since the mid-1970s. It was thought to have been planted as an ornamental near the stream. The town had been trying to control purple loosestrife because it aggravates flooding by catching debris that flows downstream during floods. In the past the herbicide Rodeo® (glyphosate) and mowing were used to control purple loosestrife but with little impact. In 1995 the stream was channelized to remove extensive silt build up. The channelizaltion involved removing approximately 0.5 m of the soil in and along the stream. The stream bank was then seeded with a grass seed mixture consisting primarily of *Poa pratensis* L. Purple loosestrife density was reduced but still remained a problem.

The largest infestation was site C1 located between two railroad bridges separated by 0.6 km along Little Toms Creek. Purple loosestrife was found 3 to 4 meters on either side of the stream between the two bridges. *Galerucella calmariensis*, *G. pusilla*, and *H. transversovittatus* were released at this site in 1992 (McAvoy et. al., 1997, 2002). With establishment of the biological control agents, purple loosestrife significantly decreased from approximately 15,000 plants in 1992 to 1,500 plants in 2002 (McAvoy et al., unpublished data). Purple loosestrife density was inversely related to the number of associated plant species based on square meter plots located throughout this infestation. Another factor that may be contributing to its decrease is competition from other plant species such as *Arundinaria gigantea* (Walter) Muhl. (Table 2), a native grass that can grow taller than the shade-intolerant purple loosestrife and forms thick mats preventing seed germination. Non-native and aggressive species such as *Rosa multiflora* Murray and *Lonicera japonica* Thunberg were also present (Table 2) and may have contributed to its decrease. *Galerucella* spp. were observed at site C2 for the first time in 2003 approximately 6 km downstream of the original release site (C1), eleven years after their release (Fig. 1).

The streams and rivers in western Virginia are typically shaded and allow only a narrow expanse of suitable habitat along the riverbank for a shade-intolerant species such as purple loosestrife. Downstream of site C1, much of the riverbank is shaded by woody plants. Purple loosestrife increased at five (31%; C2, C3, C4, C5, and C10) of the 16 sites not impacted by biological control agents or human activities (Tables 1 and 3). Purple loosestrife often grew in disturbed areas at the base of bridge abutments composed of gravel and stream cobble with *Salix nigra* Marshall and *Platanus occidentalis* L. (Table 2). These areas are prone to flooding that causes scouring, providing open areas for germination of purple loosestrife. Purple loosestrife often establishes itself on waste areas, dumps, and construction areas (Stuckey, 1980; Wilcox, 1989). Establishment of purple loosestrife has also occurred on bare soils exposed after lowering of the water level (Harris & Marshall, 1963). Site C4 had the greatest increase from six plants in 1991 to 100 plants in 2002. This infestation was in a rocky area near a bridge abutment associated with *S. nigra* and *P. occidentalis* (Table 2).

The number of purple loosestrife plants decreased at six (C6, C8, C9, C12, C14, and C15) of the nine

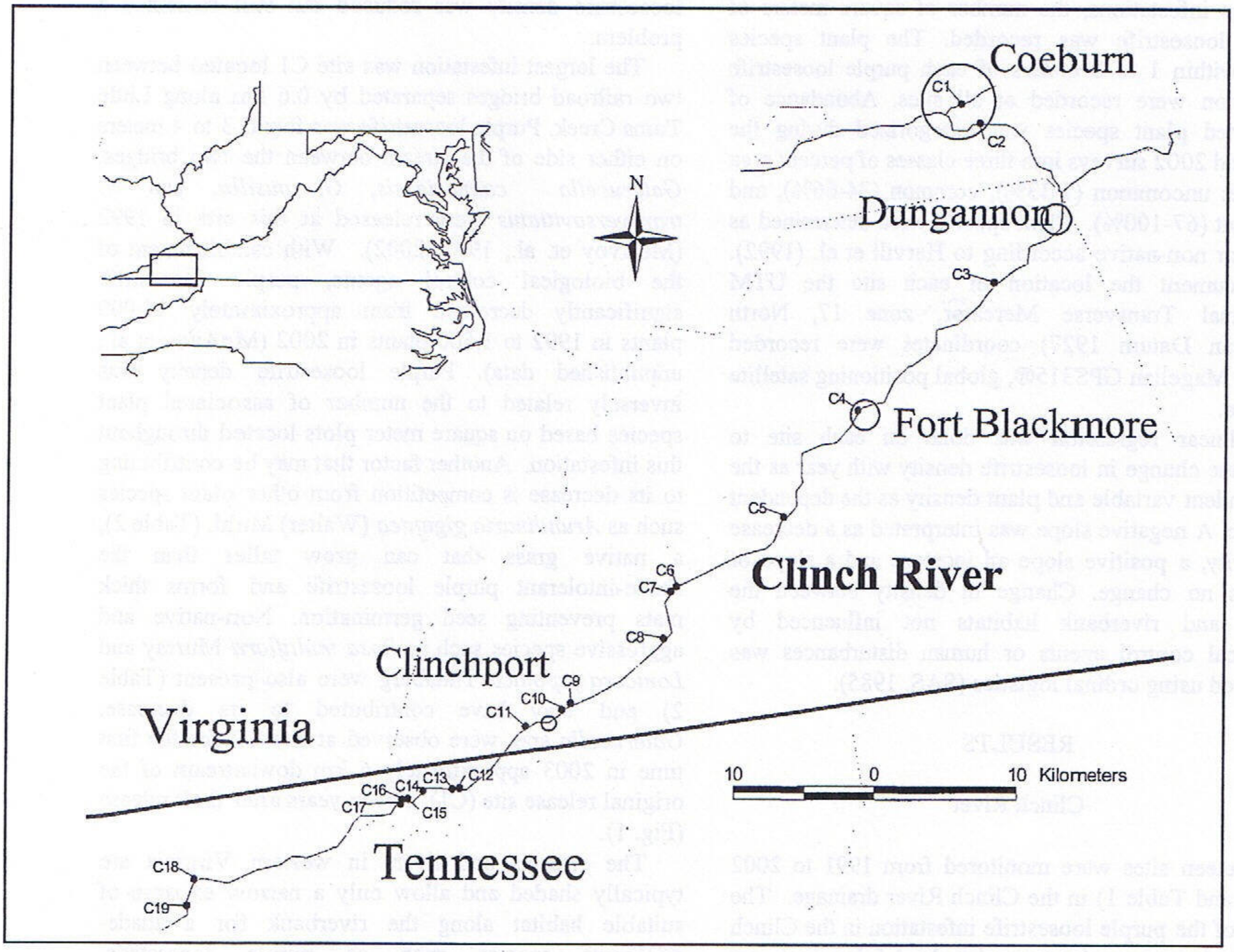

Fig. 1. Purple loosestrife sites in the Clinch River drainage.

riverbank sites unaffected by biological control agents or human activities. These sites were along shaded, undisturbed riverbanks that are not optimal for purple loosestrife growth (Table 1). Of the seven sites that were open cobble bars (C3, C4, C7, C10, C13, C16, and C17), four had decreases in purple loosestrife (C7, C13, C16, and C17). *Justicia americana* (L.) Vahl was the most commonly found species followed by purple loosestrife and *Phalaris arundinacea* L. (Table 2). *Phalaris arundinacea* forms thick monospecific populations similar to *A. gigantea*. Rachich & Reader (1999) reported that removal of *P. arundinacea* was required for purple loosestrife seed germination. No purple loosestrife seeds germinated when they were sown in an existing, undisturbed stand of *P. arundinacea* and thus may be less susceptible to purple loosestrife invasion. Although *P. arundinacea* is considered invasive (Morrison & Molofsky, 1999), it has been reported to support 10 species of insects (Beaulieu et al., 2002) and therefore is a valuable component of the riverine ecosystem as a food source for these insects. *Justicia americana* also produces monospecific populations, but on gravel bars in shallow water below the water level preferred by *P. arundinacea*. It is shorter in height than *P. arundinacea* and may be more susceptible to infestation. However, Carter & Grace (1986) reported that aqueous leachates of decomposing *J. americana* reduced seedling growth of *Polygonum lapathifolium* L, a common annual colonizer of exposed mudflats. This may indicate allelopathy, but the effects of *J. americana* leachate on purple loosestrife is unknown. *Justicia americana* is an important riverine species with respect to biomass production and support of invertebrate species. In the Virginia section of the upper New River it was found to produce 4-5 times more aquatic macrophyte matter than other major aquatic species (Hill, 1981; Hill & Webster, 1982). *Justicia americana* was the only

Table 1. Distribution and abundance of *L. salicaria* along the Clinch River drainage in Virginia and Tennessee.

Site Number	UTM[a] East	North	Estimated distance from source[b] (km)	Habitat	Year	Number of *L. salicaria* plants	Slope	Status
C1[1*]	369225	4089300	0.8	River bank	1992	15,000		
					1998	6,000		
					2000	1,500		
					2002	1,500	-1446	decrease
C2	370240	4087830	6.8	River bank	1992	10		
					1998	15		
					2000	20		
					2002	30	1.79	increase
C3	369592	4076882	29.2	Cobble	1991	20		
					1992	22		
					1993	20		
					1998	10		
					2000	20		
					2002	30	0.30	increase
C4	358820	4069887	44.5	Cobble	1991	6		
					1992	4		
					1993	4		
					1998	7		
					2000	50		
					2002	100	7.13	increase
C5	352423	4063536	57.3	River bank	1991	7		
					1993	4		
					1998	12		
					2000	20		
					2002	20	1.46	increase
C6	344286	4060116	66.1	River bank	1991	5		
					1993	40		
					1998	15		
					2000	20		
					2002	0	-1.14	decrease
C7	343847	4059824	67.4	Cobble	1993	10		
					1998	0		
					2000	6		
					2002	6	-0.44	decrease
C8	342900	4056950	71.3	River bank	1991	1		
					1992	3		
					1994	2		
					1998	0		
					2000	0		
					2002	0	-0.22	decrease
C9	335845	4053511	79.2	River bank	1992	2		
					1994	3		
					1998	0		
					2000	0		
					2002	0	-0.29	decrease

Table 1. (continued).

Site Number	UTM[a] East	North	Estimated distance from source[b] (km)	Habitat	Year	Number of *L. salicaria* plants	Slope	Status
C10	335207	4053130	80.0	Cobble	1994	0		
					1998	0		
					2000	0		
					2002	1	0.10	increase
C11	332490	4052422	83.4	River bank	1994	4		
					1998	4		
					2000	4		
					2002	4	0	no change
C12	327259	4049228	89.5	River bank	1994	3		
					1998	0		
					2000	0		
					2002	0	-0.39	decrease
C13	326747	4049031	92.1	Cobble	1994	25		
					1998	15		
					2000	15		
					2002	12	-1.59	decrease
C14	324650	4049400	92.6	River bank	1994	15		
					1998	2		
					2000	2		
					2002	0	-1.87	decrease
C15	323445	4048816	94.4	River bank	1994	12		
					1998	4		
					2000	0		
					2002	0	-1.60	decrease
C16	323022	4048848	96.0	Cobble	1994	3		
					1998	0		
					2000	2		
					2002	0	-0.30	decrease
C17	322900	4049650	96.5	Cobble	1994	1		
					1998	0		
					2000	0		
					2002	0	-0.13	decrease
C18	307762	4045872	117.6	Cobble	1994	0		
					2000	0		
					2002	0	0	no change
C19	307005	4044370	119.2	Cobble	1994	0		
					2000	0		
					2002	0	0	no change

[a] Universal Transverse Mercator, zone 17, North American Datum 1927.
[b] The source is the purple loosestrife infestation farthest upstream.
[1] *G. pusilla, G. calmariensis,* and *H. transversovittatus* released and established.
*Site impacted by biological control agents or human activities.

Table 2. Relative abundance[a] of plant species associated with *Lythrum salicaria* L. along the Clinch River (2000 and 2002).

Species	# of sites present	Site number[1]															
		C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 13	C 15	C 16	C 17	C 18	C 19
Lythrum salicaria L.[+]	11	C	U	U	C	U	U		C	U	U	U			U		
Justicia americana (L.) Vahl	10			U	U	C	U	U			A	C		U		C	C
Phalaris arundinacea L.	7			C	C	U	A	A				C				U	
Salix nigra Marshall	5			U	U	U				U				C			
Arundinaria gigantea (Walter) Muhl.	2	A	C														
Impatiens sp.	2	U	U														
Carex spp.	1			U													
Eupatorium spp.	1					U											
Lonicera japonica Thunberg [+]	1	U															
Platanus occidentalis L.	1					U											
Poa pratensis L.	1	U															
Polygonum spp.	1												U				
Pueraria lobata (Willd.)Ohwi[+]	1												U				
Rosa multiflora Murray [+]	1	U															
Rumex spp.	1													U			
Verbesina sp.	1	U															

[a]U = uncommon, C = common, and A = abundant.
[+]Exotic species.
[1]No data available for sites C11, C12, and C14.

macrophyte species associated with *Notiphila carinata* Loew (Diptera: Ephydridae) (Deonier et al., 1978). *Eupera cubensis* (Prime) (Bivalvia: Sphaeriidae) was commonly found associated with *J. americana* in Kansas (Mackie & Huggins, 1976). *Justicia americana* and *P. arundinacea* may be threatened if purple loosestrife becomes the dominant species in their habitats. Sites C8 - C10 (Table 4) are less than 0.3 km from the rare plant species *Cimicifuga rubifolia* Kearney which grows in habitats similar to purple loosestrife. This area should be monitored for infestation of purple loosestrife into this rare plant population.

Site C17, which is 96 km downstream of the initial infestation, was the last site where purple loosestrife was observed on the Clinch River. Although no purple loosestrife was found at sites C18 and C19, located 118 and 119 km downstream, respectively, of the source, these two sites are open gravel bars dominated by *J. americana*. Sites similar to these are infested with purple loosestrife and these two sites may become infested in the future.

Excluding purple loosestrife, only three other non-native species were observed in this survey. Two of these species, *L. japonica* and *R. multiflora,* were observed only at site C1, the most disturbed site surveyed (Table 2). The third exotic species, *Pueria lobata* (Willd.) Ohwi was found at site C15.

Sites C2 – C5 were closer to the source and presumably older than the sites downstream. Downstream of C6 the density was much lower, with a maximum of 25 plants at C13, which is 92.1 km from the source. Loosestrife density either did not change or decreased in density at sites downstream of C6 with the exception of C10. If the sites were infested in order of proximity to the initial source, the age of each infestation should decrease with increased distance from the source. These sites were possibly between 10 and 25 years old at the time of this study. Stuckey (1980) indicated that purple loosestrife will begin to aggressively spread 20-40 years after the initial infestation.

Table 3. Status of purple loosestrife infestations in riverbank and cobble habitats not influenced by biological control agents or human activity.

River[1]	Number of sites: Decrease	No change	Increase	Total
Clinch	10	1	5	16
Maury	3	3	4	10
James	6	3	8	17
Total	19	7	17	43
Habitat[2]				
River bank	12	8	4	24
Cobble	5	2	10	17
Total	17	10	14	41

[1] Includes observations from 1991 to 2002.
[2] Includes observations from 1998 to 2002.

Table 4. Purple loosestrife sites within 0.3 km of rare plant populations (J. F. Townsend, pers. comm.).

Family	Species	Common name	Rank[1] Global	Rank[1] Virginia	Sites
Capparaceae	*Polanisia dodecandra* (L.) DC.	Common clammy-weed	G5T?	S2	J11, J19
Melastomataceae	*Iliamna remota* Greene	Kankakee globe-mallow	G1Q	S1	J8, J19, J21
Poaceae	*Elymus canadensis* L.	Nodding wild rye	G5	S2?	J8
Poaceae	*Spartina pectinata* Link	Freshwater cordgrass	G5	S2	M9
Ranunculaceae	*Cimicifuga rubifolia* Kearney	Appalachian bugbane	G3	S2	C8, C9, C10
Rubiaceae	*Spermacoce glabra* Michaux	Smooth buttonweed	G4G5	S1	J19
Vitaceae	*Vitis rupestris* Scheele	Sand grape	G3	S1?	M9

[1] Global and state rankings are categorized as reported by Townsend (2005).

Maury River

Two possible sources of purple loosestrife were found in the James River drainage (Fig. 2). One source was located in the Maury River drainage in the community of Millboro at the head of Cabin Creek where a large infestation of purple loosestrife was found with over 1,000 plants (sites M1 and M2, Table 5). Local community members indicated that a beekeeper may have planted purple loosestrife as a nectar source for honeybees (Pellett, 1966). Pellett (1977), an avid beekeeper, enthusiastically described how purple loosestrife spread down the Raccoon River in Iowa and provided instructions on how to propagate it. Purple loosestrife is present in many drainage ditches along the roads and railroad track in Millboro. In 1996, *G. pusilla* and *G. calmariensis* were released at sites M1 and M2, respectively. Both species were observed at these two sites for several years after their release. In 2000, site M1 was channelized and this may account for the reduction in purple loosestrife. However, purple loosestrife had increased in abundance in the area channelized during visits in 2002. At site M3, it grew among the rocks of Mill Creek and declined from approximately 50 plants in 1994 to five plants in 2002. Cabin Creek enters Mill Creek approximately 4 km upstream of this site (Fig. 2).

The largest site in the Maury River drainage was M5, a 0.5 ha infestation 13.4 km downstream of the source (M1). This site is bordered by a raised railroad track and a highway (Rt. 42). Several springs flow into this site creating a marginal wetland. This site is approximately 0.5 km north of Mill Creek and 3-5 meters above the normal water level of the stream. In November 1985, a major flood occurred in this area and water from Mill Creek inundated this site. Within one or two years, purple loosestrife was observed growing here by the farmer who manages an adjacent field. Thus, this site was probably nine years old at the beginning of this study in 1994.

The biological control agents *G. calmariensis*, *G. pusilla*, and *H. transversovittatus* were released at site M5 beginning in 1994 (Table 5). The latter species is now well established at this site (McAvoy et al., 2002). Both *Galerucella* spp. were observed at this site every year since their release but in very low numbers and no impact has been observed at this site by the biological control agents. Although this site had the greatest number of associated plant species (n = 7) (Table 6), many areas of this site were completely dominated by purple loosestrife and in these areas it had very few associated species. Unfortunately, new owners of this site began mowing this area in 2002.

Another large infestation was found along the Calfpasture River (M4) in a large, rocky cobblestone area along the river. In 2000, a flood scoured much of the loosestrife away, but by 2002 it had reestablished its dominance. Site M6 is similar to site M5, being several feet above the normal river level and not in direct contact with any large water source. Purple loosestrife is found here in open, dry abandoned fields, and along drainage ditches. This area was likely flooded also in 1985, perhaps introducing purple loosestrife seeds. No change in purple loosestrife density has occurred here. Another large infestation is at the Maury Monument wayside in the Goshen Pass (M8), 23.2 km downstream of the source. Purple loosestrife density has increased substantially at this site from 250 plants in 1994 to approximately 1,500 plants in 2002. This is an open rocky area along the river and is often flooded, which may contribute to the dominance of purple loosestrife. Site M9, also in the Goshen Pass, has remained stable with approximately 12 plants. However, this site is less than 0.2 km from *Vitis rupestris* Scheele and *Spartina pectinata* Link (J. F. Townsend, pers. comm.) populations (Table 4). These sites should be monitored for any impact by purple loosestrife on these rare species. Three other sites (M10 - M12) were identified between the Goshen Pass and the Maury River's confluence of the James River. Site M10 increased from

Table 5. Distribution and abundance of *Lythrum salicaria* along the Maury River, Virginia.

Site Number	UTM[a] East	UTM[a] North	Estimated distance from source[b] (km)	Habitat	Year	Number or area of *L. salicaria* plants	Slope	Status
M1*	622746	4203738	0	River bank	1994	>2,000		
					1996[2]	>2,000		
					1998[5]	>2,000		
					2002[5]	1,000	-128.6	decrease
M2	623126	4203878	0.8	River bank	1998	500 m^2		
					1996[3]	500 m^2		
					2000[6]	500 m^2		
					2002[6]	500 m^2	0	no change
M3	628583	4206915	7.6	Cobble	1994	50		
					1998	1		
					2000	0		
					2002	5	-5.94	decrease
M4	632250	4205000	13.2	Cobble	1994	2,000 m^2		
					1998	2,000 m^2		
					2000	500 m^2		
					2002	1,200 m^2	-144.3	decrease
M5	632550	4205550	13.4	wetland	1994[1, 2, 3]	0.5 ha		
					1998[4, 5, 6]	0.5 ha		
					2000[4, 5, 6]	0.5 ha		
					2002[4, 5, 6]	0.5 ha	0	no change
M6	631758	4204411	14.0	River bank	1994	2,000 m^2		
					1998	2,000 m^2		
					2000	2,000 m^2		
					2002	2,000 m^2	0	no change
M7	631350	4203260	15.3	River bank	1994	3		
					1998	4		
					2000	0		
					2002	0	-0.44	decrease
M8	635726	4199136	23.2	Cobble	1994	250		
					1998	1,000		
					2000	1,000		
					2002	1,500	146.4	increase
M9	636157	4199001	23.5	Cobble	1994	12		
					1998	10		
					2000	12		
					2002	12	0.03	increase
M10	641615	4179706	65.2	Cobble	1998	6		
					2000	8		
					2002	40	8.50	increase
M11	637303	4168837	85.7	River bank	1993	1		
					1998	2		
					2000	4		
					2002	12	1.03	increase

[a] Universal Transverse Mercator, zone 17, North American Datum 1927.
[b] The source is the purple loosestrife infestation farthest upstream.
[1] *H. transversovittatus* released. [2] *G. pusilla* released. [3] *G. calmariensis* released.
[4] *H. transversovittatus* established. [5] *G. pusilla* established. [6] *G. calmariensis* established.
* Site impacted by biological control agents or human activities.

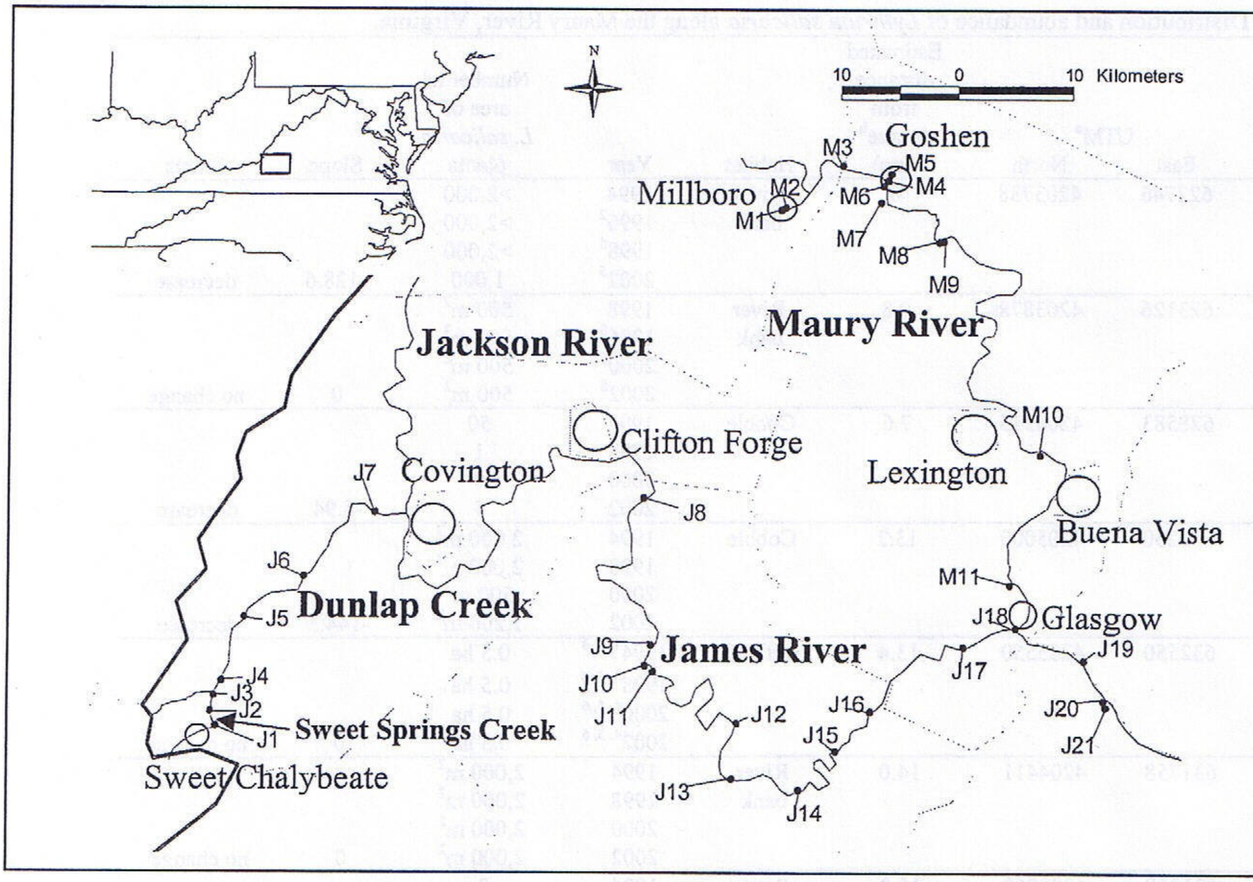

Fig. 2. Purple loosestrife sites in the Maury and James river drainages.

approximately six plants in 1998 to 40 plants in 2002. This infestation is in an open gravel bar and is the only site found in the Maury River with *J. americana*. Site J18 (Table 7) is at the confluence of the Maury and James rivers, 90.5 km downstream of the Maury River infestation source. Purple loosestrife density did not change at three sites, increased in density in four sites, and decreased in three sites (Tables 3 and 5). The decrease at site M1 was manmade.

As in the Clinch River drainage, the sites closest to the original infestation had the highest density of purple loosestrife. However, site M8, 23.2 km downstream of the original infestation had 2,000 m^2 of purple loosestrife. The area of infestation at sites M1, M2, and M4-M6 (Table 5) was greater than at other sites because of the large, open, and level terrain. Susceptibility of these sites to loosestrife infestation probably accounted for the size of infestation rather than age of infestation. Three (M8-M10, Table 5) of the four sites that increased in the Maury River drainage were in cobble areas indicating that these sites are more susceptible to invasion and prolonged infestations than the riverbank habitats. Sites downstream of M8 had a narrower area of potential infestation and subsequently had lower numbers of plants.

Five other exotic species were observed in the Maury River study area (Table 6). *Arthraxon hispidus* (Thund.) was the most common exotic species and was found at sites M4 - M6, M8, M10, and M11. Other exotics species observed were *Dipsacus fullonum* L. (M5 and M6), *Humulus japonicus* Siebold & Zucc. (M11), *Lysimachia nummularia* L. (M2), and *Poa trivialis* L. (M1). No rare plant species that occupy a similar habitat as purple loosestrife has been recorded along the Maury River (J. F. Townsend, pers. comm.).

James River

The James River infestation likely began at health spring resorts located along Sweet Springs Creek (Fig. 2). Site J1 was the farthest site upstream in the Jackson River drainage, a tributary of the James River. This site is 1.6 and 3.0 km downstream from two former health springs, Sweet Springs and Sweet Chalybeate Springs,

Table 6. Relative abundance[a] of plant species associated with *Lythrum salicaria* along the Maury River (2000 and 2002).

Species	# of sites present	Site number[1]										
		M1	M2	M3	M4	M5	M6	M8	M9	M10	M11	M12
Lythrum salicaria L.[+]	11	C	C	U	A	A	C	C	U	U	U	U
Arthraxon hispidus (Thunb.) Makino [+]	6				C	C	U	C		U	U	
Carex spp.	6		U		U	C		U		U		U
Phalaris arundinacea L.	3				C					U	A	
Cyperus spp.	2							U			U	
Dipsacus fullonum L.[+]	2					U	U					
Impatiens sp.	2	U										U
Juncus effusus L.	2		U			U						
Platanus occidentalis L.	2							U			U	
Salix nigra Marshall	2						U	U				
Solidago spp.	2					U	U					
Typha latifolia L.	2				U		U					
Acer negundo L.	1										U	
Apocynum sp.	1					U						
Bidens spp.	1											U
Cardamine rotundifolia Michaux	1	U										
Humulus japonicus Siebold & Zucc.[+]	1										U	
Justicia americana (L.) Vahl	1									U		
Lespedeza sp.	1							U				
Lysimachia nummularia L.[+]	1		U									
Myosotis laxa Lehmann	1					U						
Poa trivialis[+] L.	1	U										
Ranunculus spp.	1		U									
Vernonia noveboracensis (L.) Michaux	1											U

[a] U = uncommon, C = common, and A = abundant.
[+] Exotic species.
[1] No data available for site M7.

respectively (Table 7). Sweet Springs was a resort begun in 1792, and Sweet Chalybeate Springs located in the community of Sweet Chalybeate was begun in 1850 (Morten, 1916). One or both of these resorts may have been the source of the present infestation of purple loosestrife since it was often planted as a medical or ornamental at health springs during the 19th century (Stuckey, 1980). Purple loosestrife was reported from two West Virginia resorts in the 19th century: Salt Sulfur Springs in Monroe County (Stuckey, 1980) and Mercer Springs in Mercer County (McNeil, 1938). Both of these resorts are in the New River drainage. Based on these records, purple loosestrife may have been planted at Sweet Springs and Sweet Chalybeate Springs resorts. However, no purple loosestrife was found in the immediate area of these resorts during this study. The Sweet Springs resort has been unoccupied for many years, but the property is mowed and few weedy areas remain. Sweet Chalybeate Springs and former cottages are now privately owned. This area is also mowed and livestock graze the surrounding fields.

Site J1 is immediately below a culvert under Rt. 311 that drains a small tributary of Sweet Springs Creek (Table 7). Releases of *G. pusilla* and *H. transversovittatus* were made at this site in 1993. *Galerucella pusilla* was found for several years after its release, but in 1999 the stream was dredged and mowed, and very little purple loosestrife remains.

Site J2 at the two Beaverdam Falls is a very large infestation. Purple loosestrife was common 100 m upstream of the upper falls, and 0.5 km downstream of the lower falls. Both falls were heavily infested. The upstream portions of the stream flow through unfenced pastures allowing livestock access to the stream. Grazing by livestock may have reduced or eliminated purple loosestrife from these areas. The stream between the two falls is fenced to restrict livestock and may account for the high density of purple loosestrife. *Galerucella calmariensis* and *H. transversovittatus* were released at this site in 1994. *Galerucella calmariensis* became well established and in 1998 nearly 100% defoliation of purple loosestrife occurred. Purple loosestrife density since then has been greatly reduced and *P. arundinacea* is now the most abundant species at this site (Table 8).

Downstream of site J2 the habitat is similar to that found along the Clinch and Maury rivers, with shaded riverbanks and abundant woody vegetation. Most sites had fewer than 50 plants, except for three sites (J8, J10, and J20) which had over 100 plants each (Table 7).

Table 7. Distribution and abundance of *L. salicaria* along the James River, Virginia.

Site number	UTM[a] East	UTM[a] North	Estimated distance from source[b] (km)	Habitat	Year	Number or area of *L. salicaria* plants	Slope	Status
J1*	567350	4167900	1.6	River bank	1992[1,2]	75		
					1993	75		
					1998	75		
					2000	75		
					2002	0	-4.93	decrease
J2*	567150	4169180	3.1	River bank	1992	2,000		
					1994[1,3]	2,000		
					1998[6]	2,000		
					2000[6]	1,000		
					2002[6]	500	-145.35	decrease
J3	567661	4170269	5.2	River bank	1992	4		
					1998	10		
					2000	3		
					2002	4	-0.04	decrease
J4	568446	4171402	7.3	River bank	1992	0		
					1998	1		
					2000	12		
					2002	1	0.50	increase
J5	571284	4176467	14.2	River bank	1992	0		
					1998	5		
					2000	4		
					2002	0	0.14	increase
J6	576936	4179181	23.9	River bank	1992	0		
					1998	10		
					2000	10		
					2002	8	0.93	increase
J7	583870	4183890	36.9	River bank	1992	0		
					1998	0		
					2000	0		
					2002	0	0	no change
J8	607387	4181286	81.1	Cobble	1992[1,2,3]	100		
					1998	200		
					2000	1,000		
					2002	1,000	96.43	increase
J9	605827	4168544	100.7	Cobble	1991	2		
					1992	0		
					1998	4		
					2000	15		
					2002	3	0.65	increase
J10*	605070	4167118	103.2	River bank	1991	4		
					1992	3		
					1998	4		
					2000	3		
					2002	200	11.13	increase
J11	605657	4166289	103.9	River bank	1991	10		
					1992	2		
					1998	4		
					2000	0		
					2002	4	-0.40	decrease

Table 7. (continued).

Site number	UTM[a] East	UTM[a] North	Estimated distance from source[b] (km)	Habitat	Year	Number or area of *L. salicaria* plants	Slope	Status
J12	612291	4160764	124.8	Cobble	1991	5		
					1998	150		
					2000	30		
					2002	20	2.27	increase
J13	611126	4156140	162.9	Cobble	1991	3		
					1998	20		
					2000	10		
					2002	10	0.72	increase
J14	616692	4154274	170.3	River bank	1993	3		
					1998	3		
					2000	4		
					2002	0	-0.21	decrease
J15	620339	4157051	179.8	River bank	1993	10		
					1998	5		
					2000	0		
					2002	0	-1.20	decrease
J16	623818	4159951	186.1	River bank	1993	2		
					1998	2		
					2000	2		
					2002	2	0	no change
J17	632541	4164121	197.1	River bank	1993	8		
					1998	0		
					2000	0		
					2002	0	-0.94	decrease
J18	637200	4165019	202.6	River bank	1993	8		
					1998	20		
					2000	20		
					2002	6	0.23	increase
J19	642800	4161600	216.9	Cobble	1993	50		
					1998	50		
					2000	50		
					2002	50	0	no change
J20	644000	4157900	221.5	wetland	1998	1500 m^2		
					1999[1, 2, 3]	1500 m^2		
					2000[4, 5, 6]	1500 m^2		
					2002[4, 5, 6]	1500 m^2	0	no change
J21	644100	4157400	221.9	River bank	1993	12		
					1998	4		
					2002	2	-1.13	decrease

[a] Universal Transverse Mercator, zone 17, North American Datum 1927.
[b] The source is the purple loosestrife infestation farthest upstream.
[1] *H. transversovittatus* released. [2] *G. pusilla* released. [3] *G. calmariensis* released.
[4] *H. transversovittatus* established. [5] *G. pusilla* established. [6] *G. calmariensis* established.
*Site impacted by biological control agents or human activities.

Table 8. Relative abundance[a] of plant species associated with *Lythrum salicaria* along the James River (2000 and 2002).

Species	# of sites present	Site number[1]																	
		J1	J2	J3	J4	J5	J6	J8	J9	J10	J11	J12	J13	J15	J16	J17	J18	J19	J20
Lythrum salicaria L.[+]	16	C	C	U	U	U	U	U	U	C	U	U	C		U		U	C	A
Impatiens spp.	7	C	C		U		U			U							U		U
Platanus occidentalis L.	7				U	C	U	C						C	U	U			
Eupatorium spp.	6		C	U	U			U	C			U							
Justicia americana (L.) Vahl	5								U		A	C	A	U					
Salix nigra Marshall	5				U		U	U							U	U			
Phalaris arundinacea L.	4		A	C	U		U												
Vernonia noveboracensis (L.) Michaux	4						U		U			U					U		
Verbesina sp.	4	C		U		U				U									
Uniola latifolia Michx.	3										U	U			U				
Carex spp.	2									U							U		
Dipsacus fullonum L.[+]	2	C	U																
Mentha spicata L.[+]	2		U	U															
Acer negundo L.	1															C			
Bidens spp.	1																U		
Cephalanthus occidentalis L.	1														U				
Equisetum spp.	1					U													
Lysimachia nummularia L.[+]	1																		U
Microstegium vimineum (Trinius)[+]	1																		U
Myosotis laxa Lehmann	1																		U
Oenothera biennis L.	1									U									
Polygonum spp.	1																		U
Polymnia uvedalia (L.) L.	1									U									
Sorghum halepense (L.) Persoon[+]	1								U										
Typha latifolia L.	1																		U

[a] U = uncommon, C = common, and A = abundant.
[+] Exotic species
[1] No data available for sites J7, J14, and J21.

Purple loosestrife increased at eight sites not affected by biological control agents or human influences. Half of these were cobble sites. All three biological control agents were released at site J8 in 1992, but they have not been observed since the release. Site J10 was a small infestation with approximately four plants in 1993 growing in the depression of a canal lock of the former James River and Kanawha Canal (Langhorne, 2000) and remained stable until 2002. In 2000, this site was sprayed with herbicide. In 2002, the number of purple loosestrife plants increased to approximately 200. The increase in purple loosestrife may be a result of the death of competing plants allowing the purple loosestrife to germinate and quickly dominate the site. Gabor et al. (1996) reported that after removal of purple loosestrife with herbicide, native vegetation predominated for a time but subsequently was replaced by purple loosestrife. Site J11 is less than 0.2 km from a population of the rare plant, *Polanisia dodecandra* (L.) DC (Table 4). Eleven more sites were observed downstream of site J10 with 50 or fewer plants. A decrease in purple loosestrife occurred at five of these sites (J11, J14, J15, J17, and J21). No purple loosestrife was observed at three sites (J14, J15, and J17) that were infested before 2002 (Table 7). Purple loosestrife at site J14 was mowed in 2002. Reduction at sites J15 and J17 may be due to the increase in *P. occidentalis* and *S. nigra* (Table 8). Site J19 was within 0.2 km of rare plant populations of *Polanisia dodecandra* (L.) DC., *Iliamna remota* Greene, and *Spermacoce glabra* Michaux (Table 4).

Site J18 is at the confluence of the James and Maury rivers (Fig. 2). Below this point there are two possible original sources of purple loosestrife, one from the Maury River (M1) and the other from the upper James River (J1), 90.5 km and 202.6 km upstream, respectively, of the confluence of these rivers. The possible source is J1. Since it is possible that purple loosestrife was planted at the resorts in the 19th century, it could have a much longer presence in this section of the river and would have reached this point in the river sooner. Currently, seeds from both sources now occur below the confluence because purple loosestrife is found along the Maury River just upstream (M11) of site J18.

The largest infestation on the James River drainage was site J20, 3 km north of Big Island, Virginia and 221.5 km downstream of J1. This infestation grows in a depression formed by the James River and Kanawha Canal (Langhorne, 2000). Several springs flow into this area creating a wetland. The canal in this section of the James River was built during the 1850s. Approximately 1,500 m^2 of purple loosestrife was found in an area approximately 500 m long and 20 m wide in the old canal. In 1999, *G. calmariensis*, *G. pusilla*, and *H. transversovittatus* were released at this site. All three species have been observed since their release and are now established at this site (McAvoy et al., 2002), but no reduction in purple loosestrife has been observed. The exotic species *Microstegium vimineum* (Trinius) and *Lysimachia nummularia* L. were observed at this site (Table. 8). The former was the dominant species in some areas, covering approximately 50 m^2. It is a very aggressive, shade-tolerant species that has restricted native species (Barden, 1987), as well as affected soil properties (Kourtev et al., 1998, 2002). A population of the rare plant *Iliamna remota* Greene (Table 4) has been recorded growing within this site but has not been seen during our surveys. This area should also be monitored for this rare species for any impact by purple loosestrife. Access to the river downstream of site J21 below Big Island was limited and no further sites were investigated.

No change in purple loosestrife density occurred at three (18%) of the 17 sites not affected by biological control agents or human influences. Purple loosestrife decreased in density at six (35%) of the 17 sites and increased in eight (47%) sites (Tables 3 and 7).

DISCUSSION

Based on observations from the 43 sites not impacted by biological control agents or human activities over a nine to 11-year period on the Clinch, James, and Maury rivers, purple loosestrife abundance did not change in 16% of the sites (n =7), decreased in 44% (n = 19) and increased in 40% (n = 17) of the sites (Table 3). No differences were found in the change in purple loosestrife density between the three river systems studied (P = 0.51). Therefore, the sites in the three rivers responded equally and were combined in the analysis to determine if differences occurred between riverbank and cobble habitats. This analysis was conducted using site densities taken in 1998, 2000, and 2002. Site densities recorded before 1998 were sporadic and not used in this analysis. Of the 14 sites where purple loosestrife increased, ten were open cobble bars disturbed by flooding, while only four were riverbank sites (Table 3). A difference (P = 0.02) was found between the two habitats, with the riverbank habitats decreasing (n = 12) and the cobble habitats increasing in density (n = 10) from 1998 to 2002 (Table 7).

The sites that remained open and disturbed by flooding or human activities showed population increases. These types of sites need to be monitored in the future to detect new infestations or expansion of current infestations. Based on the results of this study, purple loosestrife does not appear to be as invasive in undisturbed river banks as in cobble bars. However, *J. americana* stands were susceptible to invasion by purple loosestrife and warrant continued monitoring. Also, populations of seven rare plant species that prefer habitats similar to purple loosestrife occur along the James and Clinch Rivers. These populations may be threatened by purple loosestrife and need to be monitored. Recruitment of purple loosestrife at sites with a long history of infestation will continue to be a source of new plants, especially following disturbance. Welling & Becker (1990) reported over 400,000 seeds per m^2 in a wetland that had been infested for 5 to 10 years. This infestation was not a monospecific stand and covered only 14% of the study area. With the establishment of biological control agents at more sites, purple loosestrife should decline in the future as was evident at several sites. New and small infestations should be given high priority for control to limit the seed bank.

The presumed age of these infestations varied considerably and may have influenced the size of the infestations. Generally, larger infestations were closer to the initial infestation and presumably older than those downstream. However, the most distant site (J20) from the initial infestation was one of the largest infestations. This infestation is more likely affected by habitat suitability rather than the age of the infestation. Wilcox (1989) reported a distinct east-west gradient in purple loosestrife density along an interstate in New York, but it was influenced by a large infestation of purple loosestrife at the Montezuma National Wildlife Refuge. This concurs with our findings that the quality of habitat can influence the size of the infestation.

Treberg & Husband (1999) conducted a one-year study on sites similar to ours, analyzing the impact of purple loosestrife on species richness along the Bar River in Canada. They reported that purple loosestrife had no impact on species richness nor was there a reduction of plant species as purple loosestrife density increased. However, Mal et al. (1997) reported that *Typha angustifolia* L., dominant in the first four years of a wetland replacement study, was displaced by purple loosestrife after five years in a wetland habitat. A one-year study of five wet meadows in Connecticut (Farnsworth & Ellis, 2001) indicated that the total biomass of non-purple loosestrife species was negatively correlated with purple loosestrife biomass while no differences were found using density and diversity metrics. Thus, conflicting conclusions can be deduced depending on the metrics used in the study. Riverine and wetland habitats also offer different plant species associations, and ecosystem dynamics need to be considered in long-term forecasting. While invasion of purple loosestrife may be more destructive to wetland habitats (Blossey et al., 2001), it may not be as threatening to the riverbank habitats. However, seeds released from riverbank infestations could be a source of infestations in wetlands downstream and riverine sites should be managed and new infestations controlled (Mal et al., 1997).

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