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The Use of *Bacillus thuringiensis kurstaki* for Managing Gypsy Moth Populations under the Slow the Spread Program, 1996-2010, Relative to the Distributional Range of Threatened and Endangered Species

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Abstract

The Slow the Spread (STS) Program operates along the expanding population front of the gypsy moth, from Minnesota to North Carolina. The primary objective of the program is to eliminate newly-founded colonies that form ahead of the leading edge to reduce the gypsy moth's rate of spread and delay the costs associated with infestation and outbreaks. Although the majority of areas under the STS Program are treated with control methods specific to the gypsy moth, commercial formulations of *Bacillus thuringiensis* var. *kurstaki* (*Btk*) are the second most used tactic. *Bacillus thuringiensis kurstaki* can directly affect other Lepidoptera, as well as indirectly affect species that depend on Lepidoptera for pollination services or as a food source. Because of these nontarget effects, proposed treatment areas are always reviewed by the U.S. Department of Interior – Fish and Wildlife Service as well as state agencies that are responsible for the conservation of threatened and endangered species to ensure that government programs to control gypsy moth are not likely to have an adverse effect. In this report, we used a variety of sources to compile a spatial database of the historical distributional ranges of 21 threatened and endangered species that occur within the STS management area. We then quantified the area of overlap between areas treated with *Btk* under the STS Program from 1996 to 2010 and the distributional ranges of these species to evaluate the use of *Btk* with regard to federal and state management guidelines. The percentage of overlap between the distributional ranges for each of the 21 nontarget species was <1 percent in any year, while the cumulative percent overlap (1996 to 2010) was generally <3.34 percent. Species with the greatest overlap between their respective range and *Btk* treated areas were most often those species for which distributional data were rare. Although *Btk* can affect nontarget species, its prudent use in combination with the existing review process reduces the adverse effects on threatened or endangered species.

Cover:

(A) Eastern prairie fringed orchid (*Platanthera leucophaea*). Paul Pratt, Ojibway Nature Centre (www.ojibway.ca/orchids.htm)

(B) Karner blue butterfly (*Lycaeides melissa samuelis*) adult. Catherine Herms, The Ohio State University, Bugwood.org

(C) Indiana bat (*Myotis sodalis*). Jerry A. Payne, USDA Agricultural Research Service, Bugwood.org

(D) Unexpected cycnia (*Cycnia inopinatus*) larva. Sam Houston, BugGuide.net

Cover design by Laura Blackburn (USDA Forest Service, Northern Research Station).

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INTRODUCTION

The gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), was introduced into North America in 1869 near Boston, Massachusetts (Liebhold et al. 1989). Gypsy moth larvae are polyphagous folivores that can exploit more than 300 species of deciduous and coniferous host trees; oak, aspen, willow, apple, and larch species are among the highly preferred hosts (Elkinton and Liebhold 1990, Liebhold et al. 1995). Larvae hatch from overwintering egg masses in spring, proceed through five (male) or six (female) instars, pupate, and emerge as adults in mid-summer. In North America, gypsy moth adult females cannot fly and they emit a sex pheromone to attract males, which are capable of flight. Since its introduction into North America, the gypsy moth has generally spread at mean rates of 6-18 km yr^{-1} (Tobin et al. 2007) and is considered to be established over 863,334 km^2 in North America (Fig. 1, U.S. Code of Federal Regulations, Title 7, Chapter III, Section 301.45), an area that represents only one-fourth of the habitat considered to be susceptible to gypsy moth infestation (Morin et al. 2005).

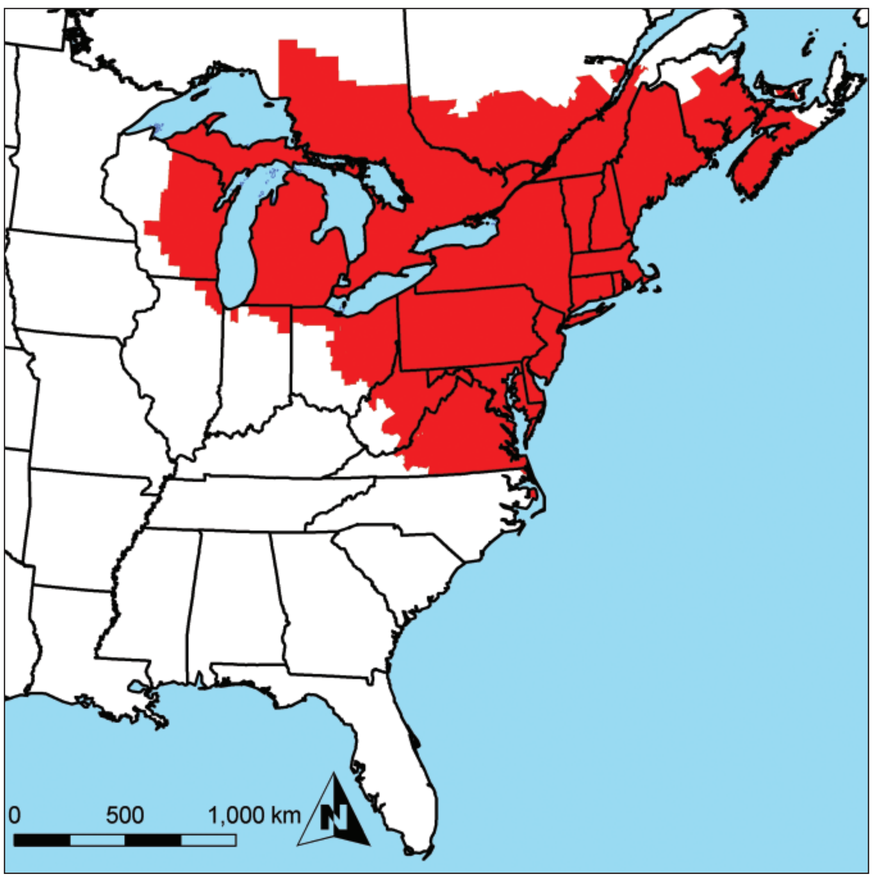

Figure 1.—Gypsy moth generally infested area in North America, 2010 (U.S. Code of Federal Regulations, Title 7, Chapter III, Section 301.45-3; Canadian Food Inspection Agency, Plant Health Division, Policy Directive D-98-09).

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Management strategies to reduce gypsy moth damage and spread fall into one of three programs: (1) outbreak suppression in areas where gypsy moth is established; (2) eradication in areas where populations are not established, such as the west coast of North America; and (3) barrier zone management along the leading population front in an effort to slow the rate of gypsy moth spread and delay the costs associated with infestation and outbreaks (Leuschner et al. 1996, Sharov and Liebhold 1998a, Sharov et al. 2002). Barrier zone management is accomplished through the gypsy moth Slow the Spread (STS) Program, undertaken jointly by the U.S. Department of Agriculture (USDA), Forest Service, and cooperating states (Gypsy Moth Slow the Spread Foundation, Inc. 2011, Tobin and Blackburn 2007). Across all three management programs, several treatment options are deployed against gypsy moth populations, depending on the population density, spatial extent of the target population, and management objective. One treatment tactic that is used in all three management programs is the biopesticide *Bacillus thuringiensis* var. *kurstaki* Berliner (*Btk*) (Reardon et al. 1994).

Bacillus thuringiensis is a gram positive, naturally occurring soil microbe that has been used in management programs against multiple insect species across several taxa, including Coleoptera, Diptera, Hymenoptera, and Lepidoptera (Schnepf et al. 1998). More than 360 products manufactured from *B. thuringiensis* spores and toxins or toxins alone are registered for use in the United States (Garczynski and Siegel 2007). In recent decades, several agricultural crops have been genetically modified by insertion of *B. thuringiensis* toxin genes into plants as a means of pest control (Gould 1998, Hutchison et al. 2010, Shelton et al. 2000). Sporangia of *B. thuringiensis* contain a spore and a toxin crystal that must be ingested by the insect for infection to occur. The toxin produces lesions in the gut cells of a susceptible host, usually causing death within 2 days (Broderick et al. 2006). Different subspecies and strains of *B. thuringiensis* carry different toxins that are specific to different insect hosts; the *kurstaki* strain is specific to Lepidoptera. The use of *Btk* against gypsy moth populations has been studied extensively (reviewed by Hajek and Tobin 2010, Solter and Hajek 2009). Aerial and ground applications of *Btk* are targeted against early gypsy moth instars, which are the most susceptible life stages (Reardon et al. 1994).

Although *Btk* is more host-specific than chemical-based insecticides, its application can deleteriously affect many species of Lepidoptera (Peacock et al. 1998, Wagner et al. 1996), one of the largest insect orders, with more than 11,000 species in the United States and Canada alone (Borror et al. 1992). Studies that have considered the nontarget effects of *B. thuringiensis*, including the use of *Btk* against gypsy moth populations, number in the hundreds (see Garczynski and Siegel 2007 for a review). Nontarget effects from the use of *Btk* in gypsy moth management programs are broadly considered to be direct and indirect. Direct nontarget effects are caused by direct exposure to applications of *Btk*; the toxin is ingested and lepidopteran larvae consequently die or show sub-lethal effects that often have fitness consequences. Indirect effects occur when direct effects on some species affect other trophic levels; for example, decreases in abundance of Lepidoptera can negatively affect plant populations that depend on lepidopteran pollinators, as well as species that depend on Lepidoptera as a food source.

To ensure that adverse impacts to federally protected species are not likely to occur as a result of government programs to manage gypsy moth populations, proposed treatment areas are reviewed by the U.S. Department of the Interior – Fish and Wildlife Service as well as state agencies that are responsible for the conservation of protected species (U.S. Department of Agriculture 1995). The STS Program is thus unlikely to use *Btk* in areas where a threatened or endangered species, or critical habitat, is known to occur and therefore be impacted by *Btk*.

In this report, we examined the extent to which *Btk* treatments against gypsy moth populations managed under the STS Program were applied within the ranges of nontarget species from 1996 to 2010 to evaluate the use of *Btk* with regard to federal and state management guidelines. We specifically addressed threatened and endangered species that are putatively both directly and indirectly affected. Although *Btk* is used in all three gypsy moth management programs, we focused on its use in the STS Program for three reasons. First, spatially referenced *Btk* treatment areas are archived by the STS Program and thus are readily available from 1996 to 2010, which facilitates a robust exploratory analysis through time. Second, *Btk* treatments implemented in the STS management area encompass a large geographic area (>190,000 km^2) across 10 states, from North Carolina to Minnesota (Fig. 2), and thus potentially overlap with the distributional range of several nontarget species. Third, unlike in eradication and suppression programs, *Btk* treatments are consistently used in the STS Program each year, enabling exploration of year-to-year patterns in the use of this biopesticide.

Btk Treatment Areas under the Gypsy Moth Slow the Spread Program

The framework, scientific rationale, objectives, organization, and implementation of the gypsy moth STS Program are described in Tobin and Blackburn (2007). Briefly, the STS Program was a pilot program from 1992-1999, with the bulk of management activities beginning in 1996. In 2000, the program became fully operational as a principle component of a USDA strategy to manage the gypsy moth. The management plan includes the deployment of pheromone-baited traps to detect incipient colonies that form ahead of the leading edge of the expanding gypsy moth population front. Upon detection and

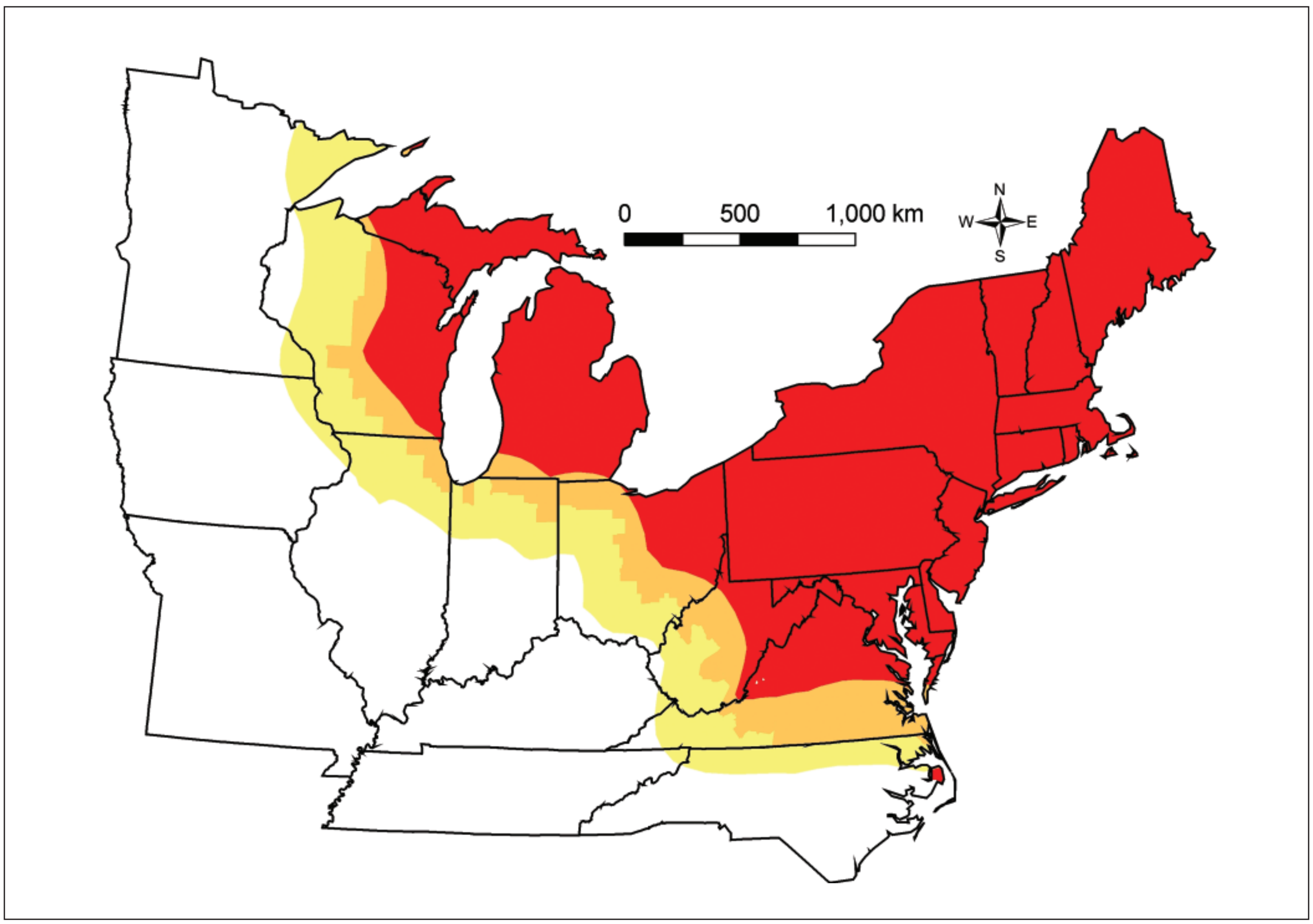

Figure 2.—Area (orange and yellow) managed under the gypsy moth Slow the Spread Program, 2010. The red area is considered to be generally infested by gypsy moth, the orange area represents a monitoring zone where trapping is used to estimate spread rates, and the yellow area represents the active management zone where treatments are deployed (Tobin and Blackburn 2007).

delimitation, one of several treatment tactics is used to eliminate smaller populations before they expand and coalesce with the expanding front. This approach thereby reduces the rate of gypsy moth range expansion (Sharov and Liebhold 1998b).

The biopesticide *Btk* was the most commonly used STS tactic from 1996 to 2000, and is currently the second most used tactic after mating disruption (Roberts et al. 2010, Tobin and Blackburn 2007). Mating disruption is the use of products impregnated with synthetic pheromone that are aerially applied to foliage to chemically interfere with male moths' ability to locate females (Thorpe et al. 2006). At higher gypsy moth population densities, mating disruption is not effective because some males are still able to locate females. In this case, *Btk*, which is density-independent, is often used. It is generally applied aerially to foliage when early instars are feeding (Reardon et al. 1994). The treatment of choice against higher density populations is *Btk* unless the treatment area occurs in an environmentally sensitive habitat where the gypsy moth-specific nucleopolyhedrovirus, *Ld*NPV, commercially produced as Gypchek® (Reardon et al. 1996), is used. However, *Ld*NPV is not easily mass-produced because it must be produced *in vivo* (Hajek and Tobin 2010). Spatially-referenced areas treated with *Btk* are maintained by and available from the STS Program (Roberts et al. 2010). The area treated annually from 1996 to 2010 is listed in Table 1, and the general location of treated areas is presented in Figure 3.

Table 1.—Area treated with the biopesticide *Bacillus thuringiensis kurstaki* (*Btk*), and the percentage of area treated with *Btk* relative to the entire area treated under the gypsy moth Slow the Spread Program, 1996-2010

Year	Area treated (km^2)	Percent of all area treated
1996	97.6	64.2
1997	270.0	86.1
1998	283.7	74.4
1999	216.0	53.3
2000	344.0	47.8
2001	268.7	23.7
2002	142.3	5.9
2003	305.6	11.7
2004	499.9	25.8
2005	439.5	26.2
2006	518.4	17.7
2007	303.0	13.5
2008	219.7	10.9
2009	168.0	24.1
2010	267.4	12.4

METHODS

Compilation of Distributional Ranges of Threatened and Endangered Species

Records of the historical and current distributional ranges of threatened and endangered species that could be potentially affected by the use of *Btk* were obtained from a variety of sources, including the gray and peer-reviewed literature, websites, universities, field guides, and state and federal agencies (Agriculture and Agri-food Canada 2009; Bartlett 2010; Bess 2005; Bowles 1999; Butchkoski 2010; Crosson et al. 1999; Cuthrell et al. 1999; Garner and Gardner 1992; Hilty 2010; Iowa Department of Agriculture and Land Stewardship 2010; Johnson et al. 1995; Lienk et al. 1991; NatureServe 2010; New York State Department of Environmental Conservation 2010; North Carolina Natural Heritage Program 2010; Opler et al. 2010; Peacock et al. 1998; Penskar and Higman 2000; Pruitt and TeWinkel 2007; Pyle 1992; Rings et al. 1992; Scott 1986; Sheviak and Bowles 1986; U.S. Fish and Wildlife Service 2009, 2010; University of Alberta 2010; Virginia Department of Game and Inland Fisheries 2004; Wagner 2005; Wagner et al. 1997, 2001, 2011; Warren et al. 2010). We focused specifically on 18 Lepidopteran species with larval stages that are reasonably synchronized with the larval stage of the gypsy moth and would therefore be exposed to *Btk*. We included species that are active as feeding larval stages from April to June, the period over which *Btk* is applied under STS. We also considered three species that could be indirectly affected through the application of *Btk*: two species of threatened and endangered bats that feed on Lepidoptera, and one species of a threatened and endangered plant that depends on lepidopteran pollinators in the family Sphingidae.

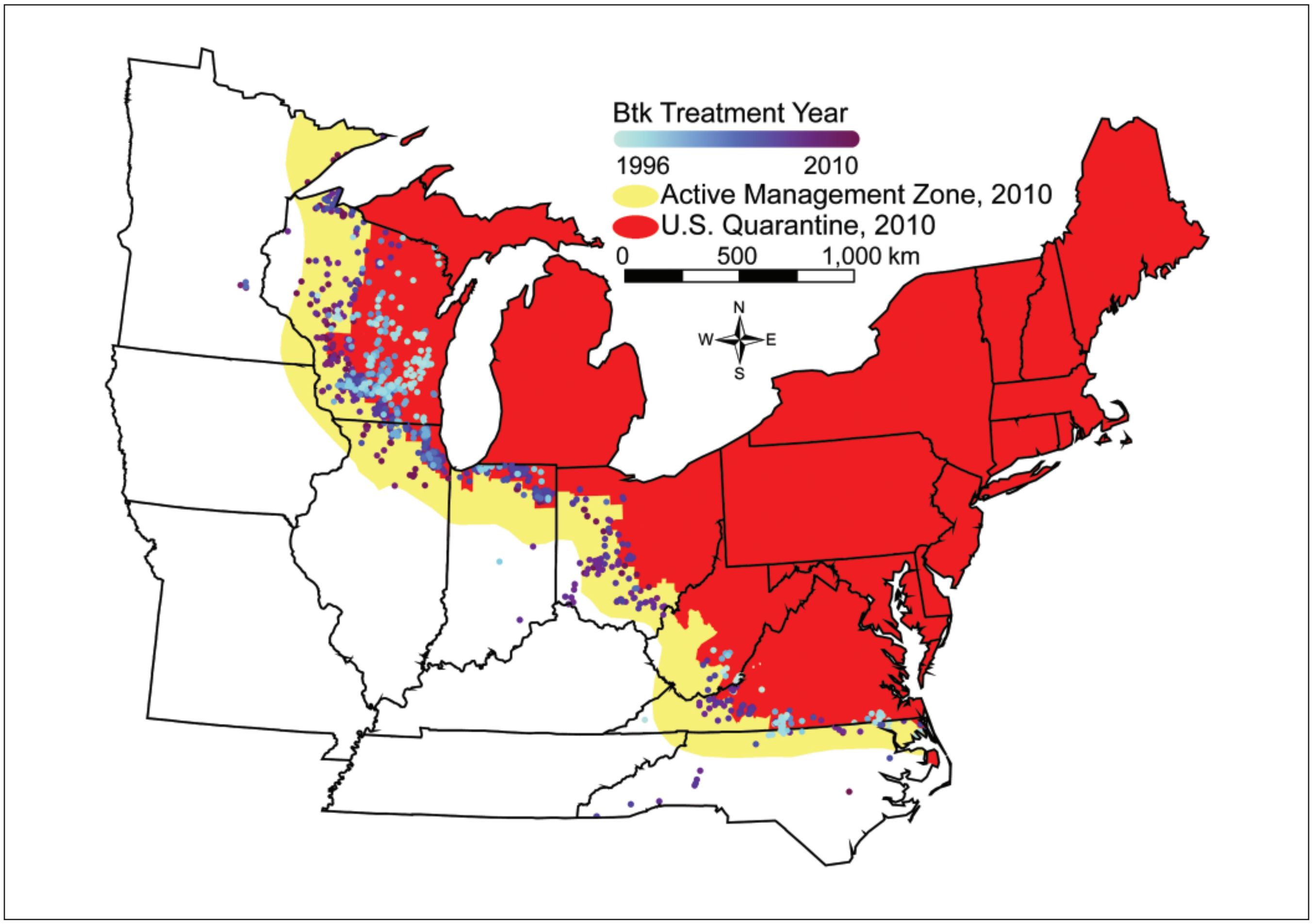

Figure 3.—Spatial representation of *Btk* treatment areas (not drawn to scale) deployed under the Slow the Spread Program, 1996-2010.

All species considered in this report are listed in Table 2. The distributional ranges for these species should be considered as a conservative estimate for several reasons. First, we considered the historical distribution of threatened and endangered species, as opposed to currently known distributions or critical habitats to assess the overlap between applications of *Btk* and ranges. Second, in cases for which specific point locations of threatened and endangered species were available from our sources, we included the entire county when compiling distributional ranges. Distributional ranges were spatially compiled in ArcGIS 9.3 (ESRI, Redlands, CA), and are presented for each species in Figure 4.

Table 2.—List of threatened and endangered species considered in this report

Species (common name; Family)	Distributional range (km²)
Species Potentially Directly Affected	
Atrytone arogos (Boisduval & Leconte) (Arogos skipper; Hesperiidae)	516,215
Boloria selene (Denis & Schiffermüller) (silver-bordered fritillary; Nymphalidae)	757,620
Catocala antinympha (Hübner) (sweetfern underwing; Noctuidae)	8,518[a]
Catocala gracilis Edwards (graceful underwing; Noctuidae)	9,435[a]
Cycnia inopinatus (Hy. Edwards) (unexpected cycnia; Arctiidae)	61,619[a]
Erynnis persius (Scudder) (Persius duskywing; Hesperiidae)	318,948
Fagitana littera (Guenée) (marsh fern moth; Noctuidae)	4,052[a]
Hesperia metea Scudder (cobweb skipper; Hesperiidae)	645,553
Hesperia ottoe Edwards (ottoe skipper; Hesperiidae)	360,594
Incisalia irus (Godart) (frosted elfin; Lycaenidae)	415,409
Incisalia polios Cook & Watson (hoary elfin; Lycaenidae)	345,730
Lycaeides melissa samuelis Nabokov (Karner blue butterfly; Lycaenidae)	254,479
Lycaena helloides (Boisduval) (purplish copper; Lycaenidae)	566,437
Neonympha mitchellii (French) (Mitchell's satyr; Nymphalidae)	59,580
Photedes enervata (Guenée) (many-lined cordgrass moth; Noctuidae)	2,703[a]
Pyrgus wyandot (Edwards) (Appalachian grizzled skipper; Hesperiidae)	228,369
Speyeria idalia (Drury) (regal fritillary; Nymphalidae)	715,220
Tricholita notata Strecker (marked noctuid; Noctuidae)	8,048[a]
Species Potentially Indirectly Affected	
Corynorhinus townsendii virginianus Handley (Virginia big-eared bat; Vespertilionidae)	65,351
Myotis sodalis Miller & Allen (Indiana bat; Vespertilionidae)	558,551
Platanthera leucophaea (Nuttall) (Eastern prairie fringed orchid; Orchidaceae)	351,811

[a]Distributional data were rare and uncertain.

Use of *Btk* within Ranges of Threatened and Endangered Species

For each year, from 1996 to 2010, we considered the spatial extent of the area treated using *Btk* relative to the distributional ranges of the threatened and endangered species we evaluated to estimate the area of overlap for each year and species. We also used a more conservative approach to quantify the potential overlap between *Btk* applications and the range of each species. In this case, we used a grid of 1 × 1-km cells and selected any cells that overlapped with the *Btk* treatment area. We then considered this enlarged area as the *Btk* treatment area when assessing the overlap with the distributional range of each species. An example of this process is shown in Figure 5. The grid of 1 × 1-km cells buffers the treated areas so that the area potentially affected by the application of *Btk* would include, for example, application overspray or drift.

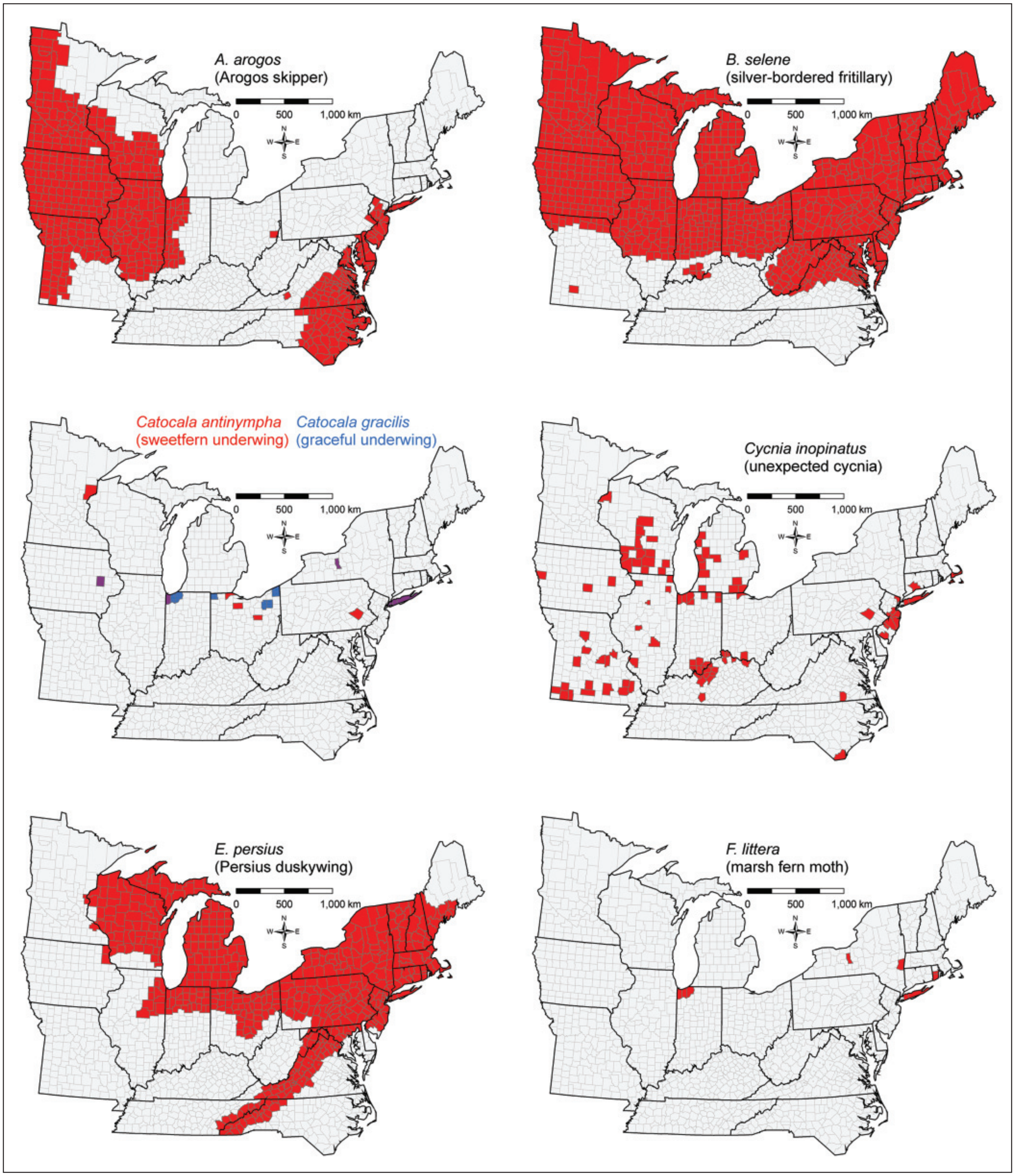

Figure 4.—Known distributional ranges of threatened and endangered species considered in this report. (Figure 4 continues on the next page.)

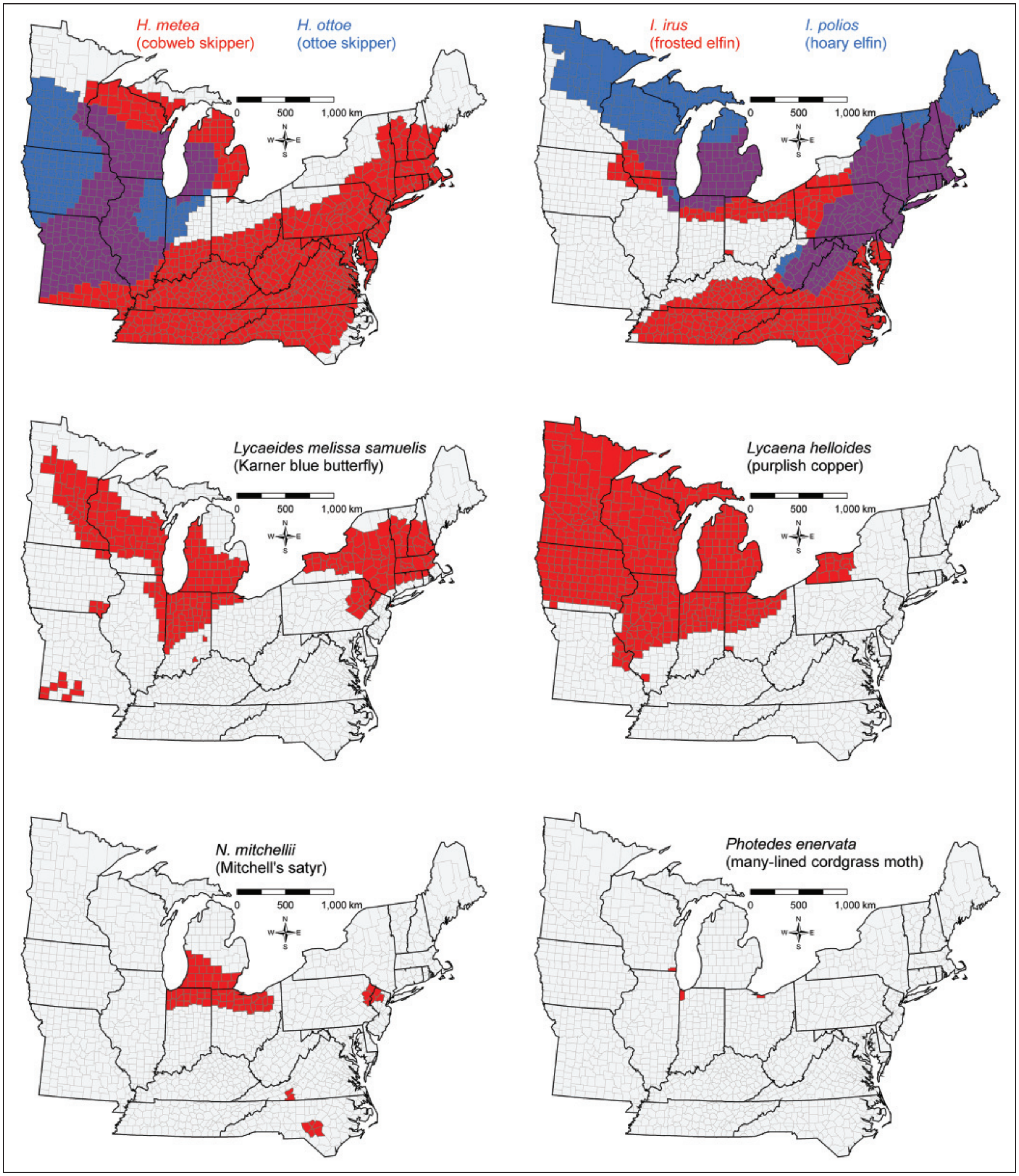

Figure 4 (continued).—Known distributional ranges of threatened and endangered species considered in this report. (Figure 4 continues on the next page.)

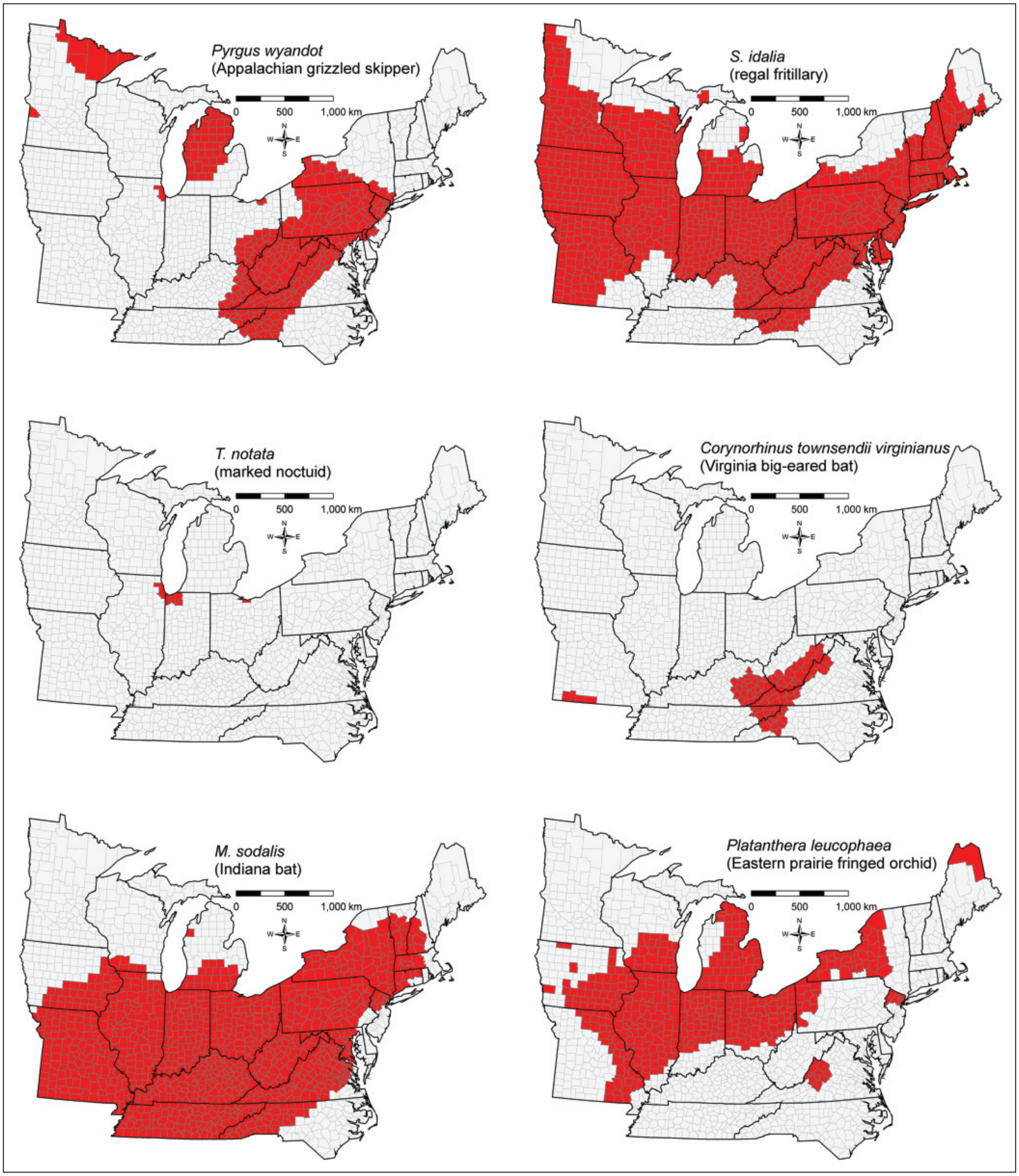

Figure 4 (continued).—Known distributional ranges of threatened and endangered species considered in this report.

Figure 5.—Two spatial scales were used to quantify the overlap between Btk treatment areas and the distribution ranges of threatened and endangered species: the actual treatment area (red), and the treated area plus any 1 × 1-km cells overlapping the treatment area (yellow).

RESULTS

The amount of distributional range of each species that overlaps areas treated with *Btk* under STS is listed by year in Table 3. Overlap areas vary considerably, in part due to the irregularity in the extent of the historical distributional ranges for each species (Fig. 4). The total amount of overlapping area, from 1996 to 2010, ranged from 2.6 km^2 (many-lined cordgrass moth, *Photedes enervata*, a species for which distribution data were rare and uncertain; see Table 2) to 3,946.7 km^2 (cobweb skipper, *Hesperia metea* Scudder).

Year-to-year trends in the overlap of distributional ranges and areas treated with *Btk* are presented in Figure 6. In this case, the area of overlap is presented as a proportion of the total known distributional range for each species (Table 2). We also included the overlapped area when considering the *Btk* treated area expanded over a network of 1 × 1-km cells (Fig. 6b). The percentage of overlap in any year, from 1996 to 2010, and across all species is <1 percent, even when the *Btk* treatment areas are expanded (Fig. 6). The overall mean (95-percent confidence intervals) of the percent overlap across species and years is 0.05 percent (0.04-0.05 percent) for the actual treated areas and 0.11 percent (0.10-0.13 percent) for the 1 × 1-km scale.

Table 3.—Area (km^2) of the known distributional range of species overlapping *Btk* treatment areas deployed under the Slow the Spread Program

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
A. arogos	41.9	121.2	11.4	134.4	221.7	161.2	74.4	219.9	276.4	238.1	112.0	109.3	96.5	103.8	172.7
B. selene	57.0	188.3	148.2	173.4	326.2	255.7	123.2	231.1	475.2	556.2	376.9	264.6	204.7	162.4	249.4
Catocala antinympha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.2	2.6	0.0	0.0	0.0	0.0	0.0
Catocala gracilis	0.0	0.0	0.0	8.1	2.9	0.0	3.3	1.2	2.4	0.3	5.7	3.0	8.4	4.5	0.0
Corynorhinus townsenddii virginianus	56.0	22.3	0.0	3.5	71.3	0.0	0.0	0.0	18.0	127.3	86.8	43.0	3.8	0.0	0.0
Cycnia inopinatus	0.0	23.2	88.6	109.2	162.2	153.2	98.0	172.7	286.4	356.9	95.4	84.1	30.2	44.3	48.1
E. persius	7.5	175.3	117.0	76.6	144.0	189.8	99.6	170.1	238.2	443.8	278.7	157.2	167.6	129.5	202.8
F. littera	0.0	0.0	0.0	8.1	2.9	0.0	3.3	1.2	2.4	0.3	5.7	3.0	8.4	4.5	0.0
H. metea	98.9	259.6	148.2	188.6	345.6	258.0	93.0	229.8	446.3	650.3	448.8	255.3	174.9	133.4	216.0
H. ottoe	0.0	143.4	141.6	161.1	241.2	171.0	117.0	209.5	355.8	423.1	135.2	120.5	122.4	118.8	174.4
I. irus	98.9	142.1	80.1	155.9	313.2	161.6	91.9	280.3	470.1	621.7	270.2	182.9	104.9	111.3	136.7
I. polios	50.5	188.3	145.5	133.8	264.3	220.8	104.2	209.0	229.1	256.3	143.3	77.2	162.0	78.9	110.6
Lycaeides melissa samuelis	0.0	167.2	110.5	72.4	141.3	151.3	111.2	150.7	139.0	245.2	91.4	92.7	124.7	119.3	161.8
Lycaena helloides	0.0	176.1	148.2	169.9	254.9	255.7	117.7	231.1	453.7	505.1	224.9	189.8	204.3	154.3	230.0
M. sodalis	76.2	57.6	100.5	75.6	140.2	51.4	39.9	52.4	222.4	445.7	414.0	220.5	66.1	56.3	89.4
N. mitchellii	0.0	0.0	0.0	15.3	3.5	0.1	4.0	2.8	20.7	41.9	78.0	28.7	23.3	29.0	20.8
Photedes enervata	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Platanthera leucophaea	1.0	54.5	80.1	130.1	214.8	145.5	79.1	207.2	342.9	466.2	213.3	162.8	63.5	51.2	83.1
Pyrgus wyandot	57.0	22.3	0.0	3.5	71.3	0.0	8.0	7.1	21.6	177.5	294.7	87.3	32.4	11.0	25.5
S. idalia	57.0	198.4	145.5	169.2	323.6	249.0	123.2	211.8	403.1	653.4	434.5	268.9	147.8	152.4	221.5
T. notata	0.0	0.0	0.0	8.1	2.9	0.0	5.7	6.3	3.6	4.3	14.7	8.1	16.5	4.5	8.1

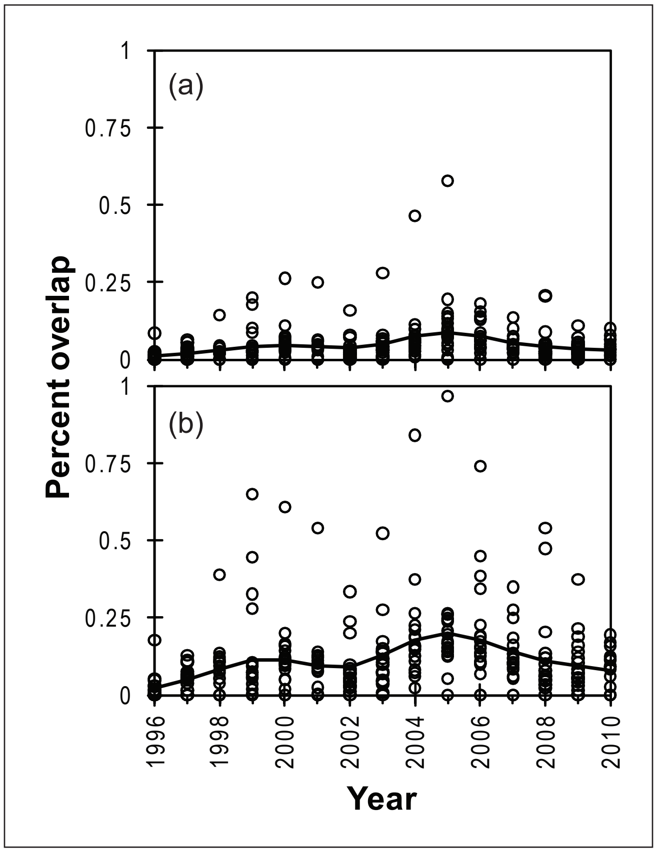

Figure 6.—The percentage of overlap between each species' known distributional range and (a) the actual area treated with *Btk* and (b) the actual treated area including 1 × 1-km overlapping cells for each year, 1996 to 2010. Within each year, each symbol represents a species. The general trend line over time is shown, and was estimated using locally weighted polynomial regression in R (R Development Core Team 2011).

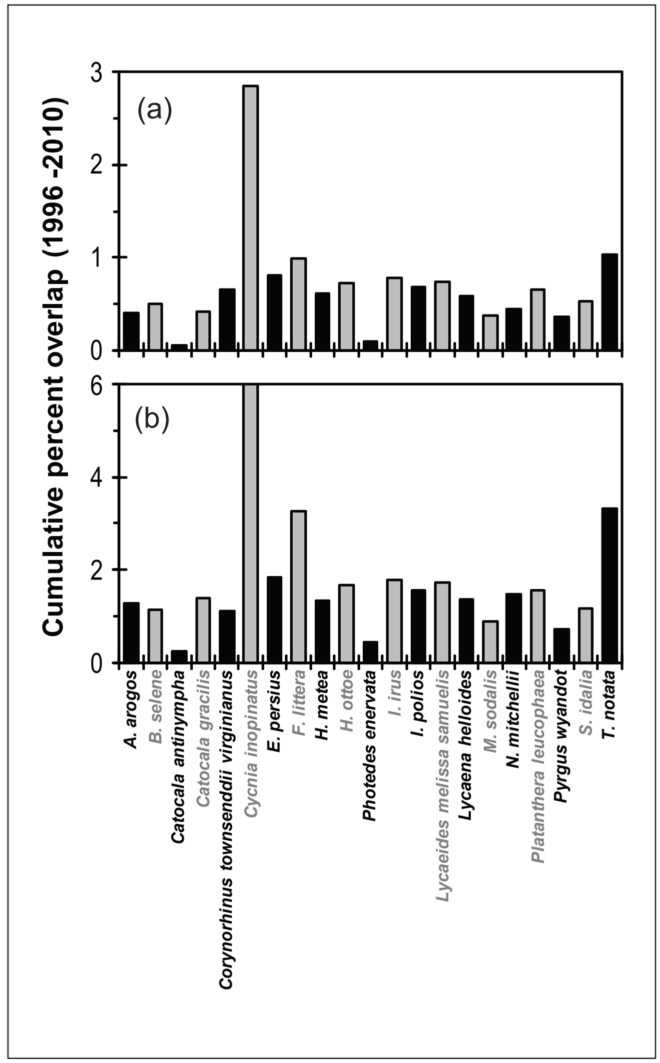

Figure 7.—Cumulative percentage of overlap between each species' known distributional range and (a) the actual area treated with *Btk* and (b) the actual treated area including 1 x 1-km overlapping cells.

The cumulative percentage of overlap across all years (1996 to 2010) between the historical distributional range of each species, and the actual area treated with *Btk* and the area of treatment expanded to a 1 × 1-km scale, is shown in Figure 7. The cumulative percentage of overlap is <1 percent for the actual treatment area and <3.5 percent at the 1 × 1-km scale for all species except for *Cycnia inopinatus* (unexpected cycnia), for which distributional data were scarce (Table 2). The percentages for this species were 2.84 percent for the actual treated area (Fig. 7a) and 6.04 percent for the 1 × 1-km scale (Fig. 7b).

The relationship between distributional ranges of nontarget species and the use of *Btk* to manage gypsy moth populations under the STS Program is highlighted for three species: *Lycaeides melissa samuelis* (Karner blue butterfly, Fig. 8), *Cycnia inopinatus* (unexpected cycnia, Fig. 9), and *Platanthera leucophaea* (eastern prairie fringed orchid, Fig. 10). Karner blue butterfly and eastern prairie fringed orchid represent nontarget species that generate much concern in the STS Program due to the number of treatments in the midwestern United States, where these two species are distributed. They also represent species that are directly (*L. melissa samuelis*) and indirectly (*P. leucophaea*) affected by the use of *Btk*. Unexpected cycnia is also highlighted because it represents a species with scarce distributional data (Table 2) and the highest cumulative area of overlap between its range and *Btk* applications when actual treatment areas and areas extrapolated at the 1 × 1-km scale are used (Fig. 7).

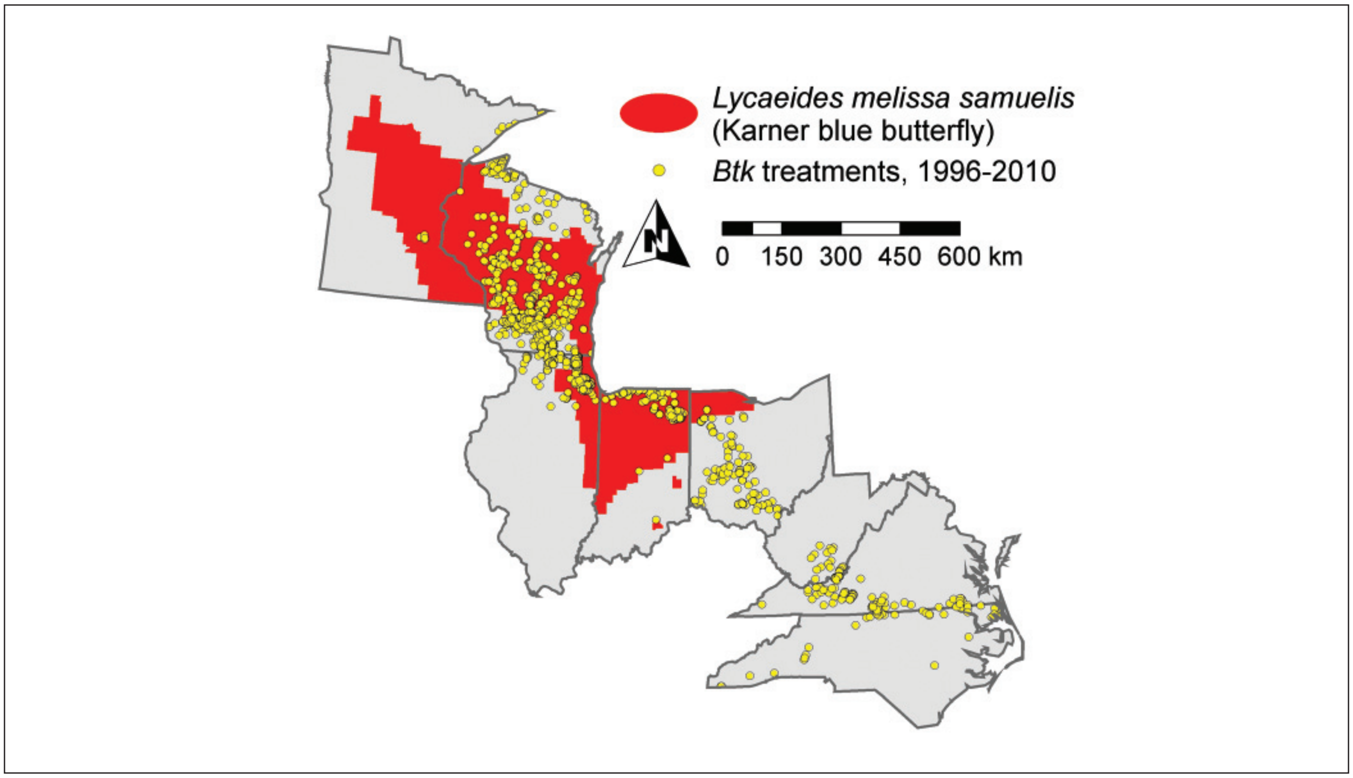

Figure 8.—The historical distributional range of *Lycaeides melissa samuelis* and the locations of *Btk* treatment blocks under the Slow the Spread Program, 1996-2010.

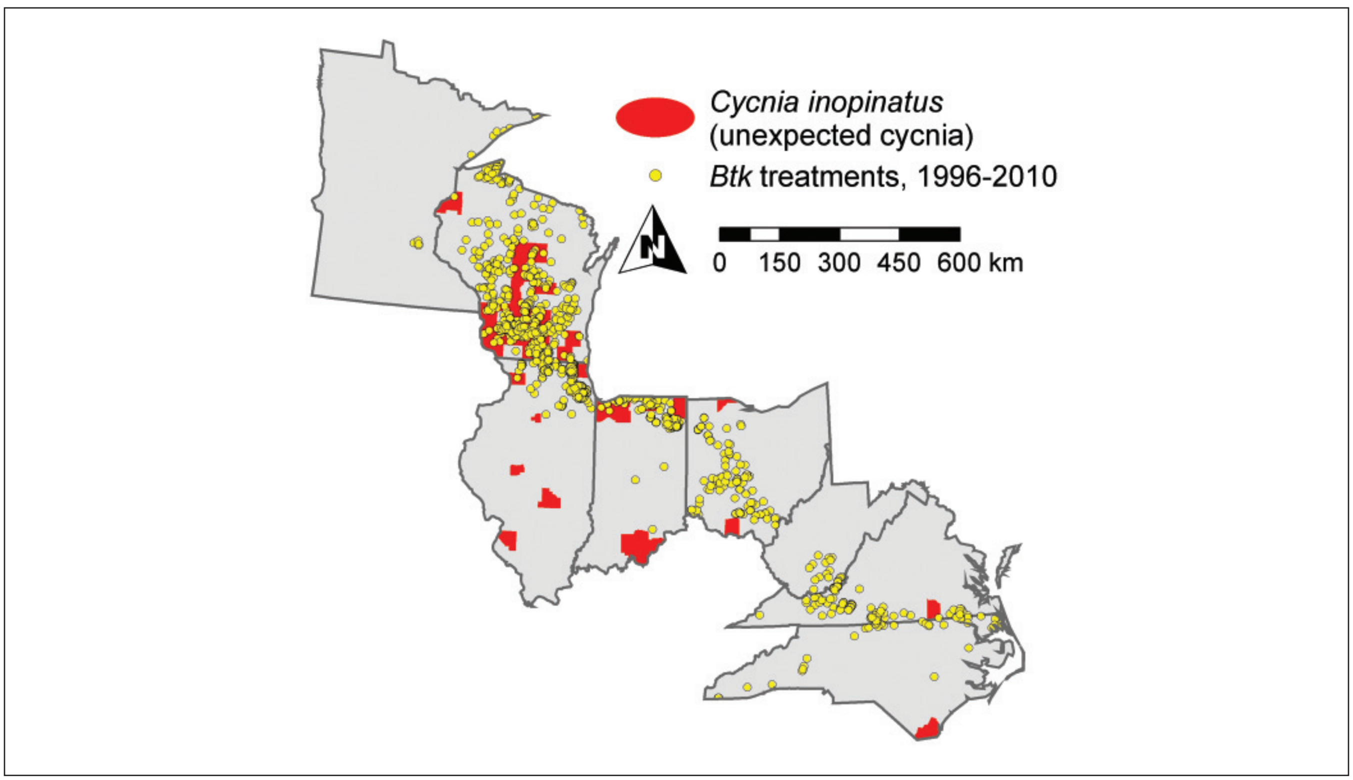

Figure 9.—The distributional range of *Cycnia inopinatus* and the locations of *Btk* treatment blocks under the Slow the Spread Program, 1996-2010.

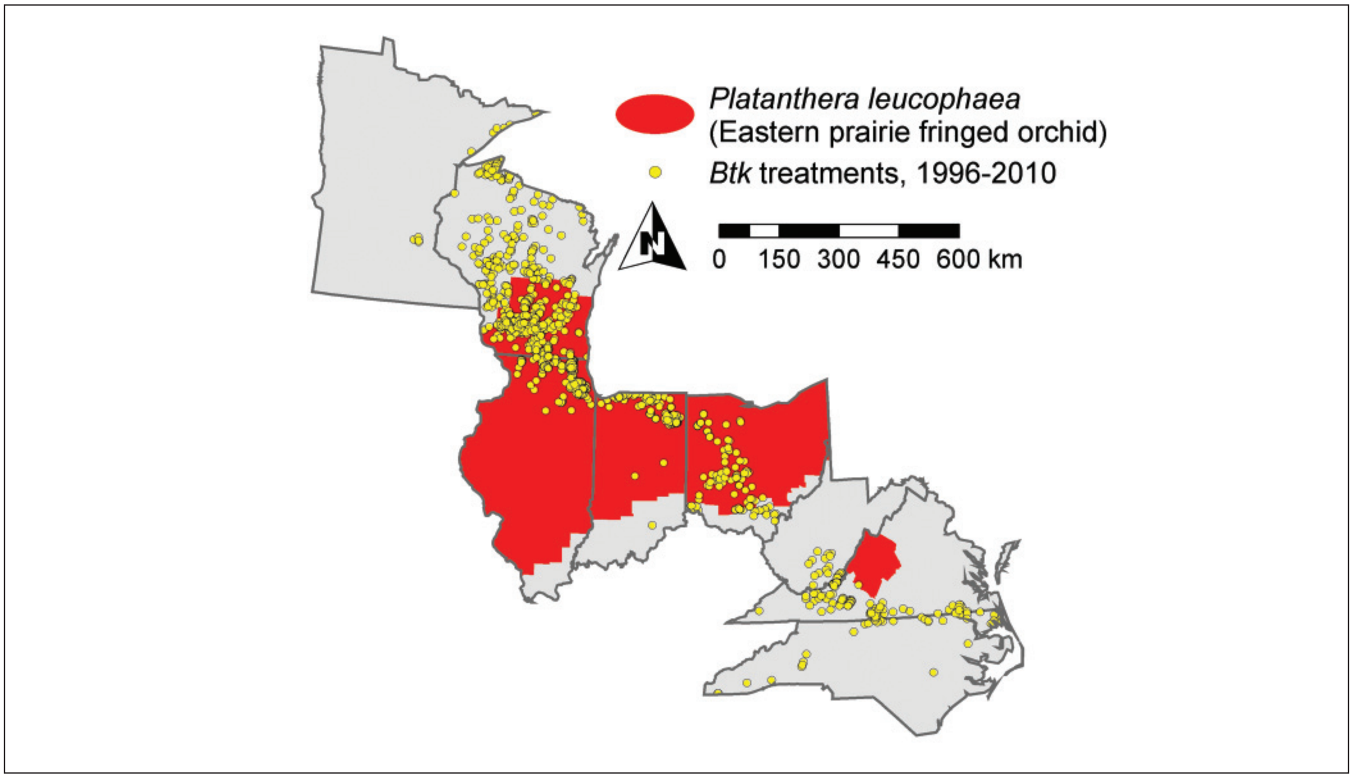

Figure 10.—The distributional range of *Platanthera leucophaea* and the locations of *Btk* treatment blocks under the Slow the Spread Program, 1996-2010.

In all cases, we relied on available information regarding the distributional ranges of the threatened and endangered species used in this report. Current data on the distributional ranges of threatened and endangered species are particularly rare, and thus the distributional ranges considered here represent the historical ranges, which are a conservative estimate of the currently known ranges. In the case of *L. melissa samuelis*, however, the Wisconsin Department of Natural Resources, in cooperation with the U.S. Fish and Wildlife Service and several public and private land managers, has developed a Karner blue butterfly Habitat Conservation Plan (Wisconsin Department of Natural Resources 2010). As part of this plan, state and federal agencies have identified specific areas for conservation of *L. melissa samuelis*. This managed distributional range in Wisconsin is 7,527.9 km^2, considerably smaller than the historical range of 96,245.5 km^2. Thus, we compared the overlap of *Btk* applications with both the historical and currently managed range of *L. melissa samuelis* in Wisconsin (Fig. 11) and summarize the area of overlap in Table 4. The maximum percent overlap of the currently managed range of *L. melissa samuelis* in Wisconsin and *Btk* treatments for any year from 1996 to 2010 was 0.46 percent when the actual treated areas were used, while the mean across all years was 0.05 percent. When the treatment areas were expanded to the 1×1-km scale, the maximum percent overlap for any year was 0.83 percent while the mean across all years was 0.12 percent. Thus, the use of *Btk* in areas actively managed for the conservation of Karner blue butterfly in Wisconsin is rare and limited to the edges of the conservation area (Fig. 11).

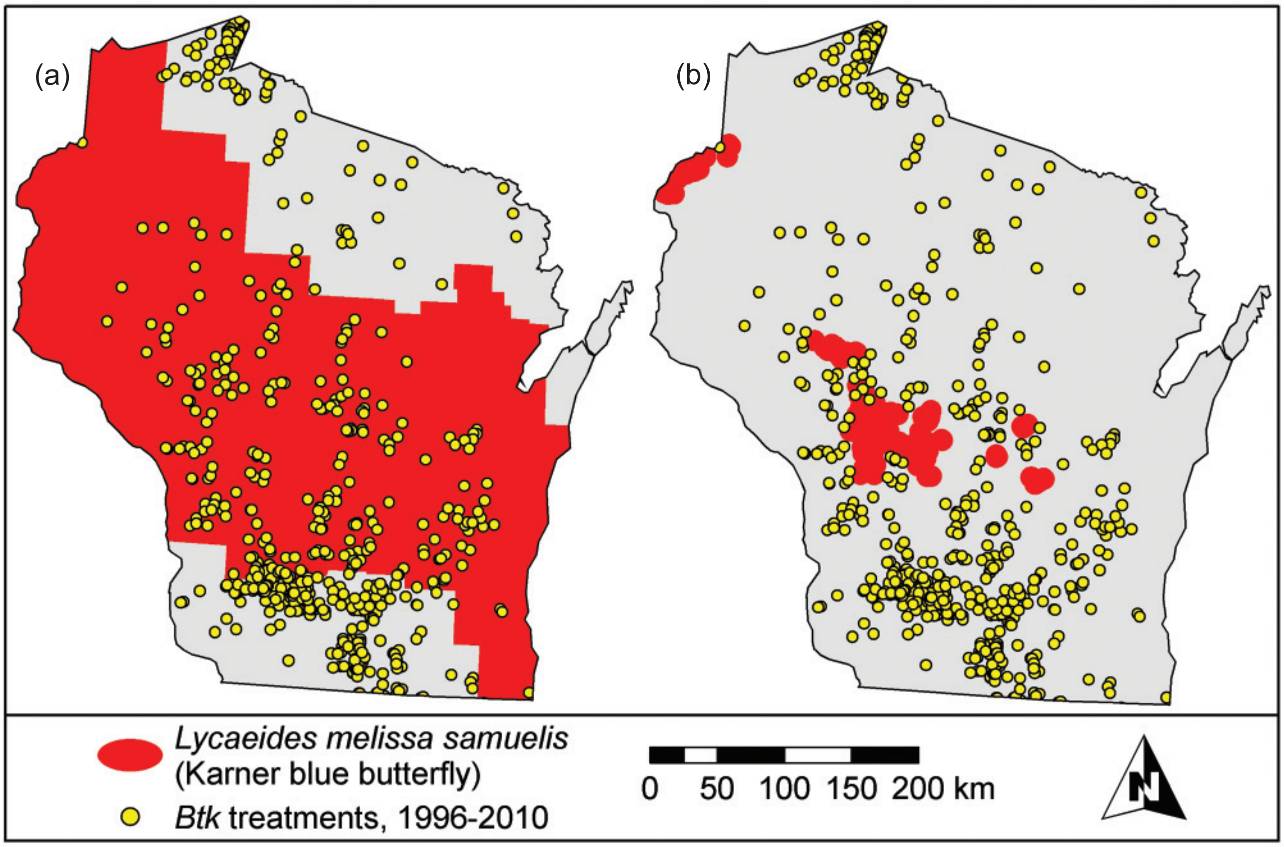

Figure 11.—*Lycaeides melissa samuelis* in Wisconsin: (a) the historical distribution and (b) its currently managed range under the Karner blue butterfly habitat conservation plan (Wisconsin Department of Natural Resources 2010). Areas treated with *Btk* under the Slow the Spread Program are shown in both (a) and (b).

Table 4.—Area of overlap (km^2) between actual *Btk* treated areas or areas when extrapolated to a 1 × 1-km scale, with the historical and currently managed distributional range of *L. melissa samuelis* in Wisconsin

	Actual treated area		1×1-km Scale	
Year	Historical range	Current range	Historical range	Current range
1996	0.0	0.0	0.0	0.0
1997	167.2	34.5	327.8	62.7
1998	142.2	2.6	282.3	8.1
1999	57.2	1.7	129.5	5.1
2000	136.1	0.0	297.4	0.0
2001	148.6	0.0	316.7	0.0
2002	71.5	0.0	134.6	0.0
2003	133.9	0.0	207.4	0.0
2004	100.9	0.0	229.7	0.0
2005	196.6	0.0	334.9	0.0
2006	29.4	0.0	69.8	0.0
2007	52.8	11.2	117.4	19.2
2008	88.7	7.1	189.2	15.2
2009	87.6	3.4	211.4	18.2
2010	129.9	0.3	294.4	2.0

SUMMARY

We found that the percentage of overlap between the distributional ranges of 21 nontarget species likely to be affected by *Btk* and the area of *Btk* treatments was <1 percent for all species in any year, whether calculations included the actual *Btk* treated area (Fig. 6a) or treated areas expanded to a 1×1-km scale (Fig. 6b). Furthermore, the cumulative percent overlap from 1996 to 2010 was <1.03 percent for the actual treated areas (Fig. 7a) and <3.34 percent at the 1×1-km scale (Fig. 7b) for all but one species. Species with the greatest overlap between their respective range and *Btk*-treated areas, *F. littera*, *T. notata*, and *C. inopinatus* (Fig. 7), were most often those for which distributional data were particularly rare (Table 2). The low cumulative percent overlap of the managed range of *L. melissa samuelis*, for which there is a state-level management plan in Wisconsin (Fig. 11), highlights the rarity of *Btk* use in areas that are actively managed for species conservation. Moreover, these estimates for *L. melissa samuelis* underscore how conservative the estimates are for the other threatened and endangered species considered in this report for which only historical—as opposed to the currently known—distributions were available.

The increased use of mating disruption against gypsy moth populations managed under the STS Program, particularly since 2000 (Table 1), has relegated *Btk* to a secondary tactic. However, *Btk* will continue to be an important tool to manage gypsy moth populations in the STS Program because mating disruption is not effective against higher density populations (Thorpe et al. 2006), and because Gypchek®, which specifically targets gypsy moth, can be manufactured only in limited quantities (Hajek and Tobin 2010). Although *Btk* can affect nontarget species, its prudent use in combination with the existing review process reduces the adverse effects on threatened or endangered species.

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The Slow the Spread Program operates along the expanding population front of the gypsy moth, from Minnesota to North Carolina. The primary objective of the program is to eliminate newly-founded colonies that form ahead of the leading edge to reduce the gypsy moth's rate of spread and delay the costs associated with infestation and outbreaks. Although the majority of areas under the STS Program are treated with control methods specific to the gypsy moth, commercial formulations of *Bacillus thuringiensis* var. *kurstaki* (*Btk*) are the second most used tactic. *Bacillus thuringiensis kurstaki* can directly affect other Lepidoptera, as well as indirectly affect species that depend on Lepidoptera for pollination services or as a food source. Because of these nontarget effects, proposed treatment areas are always reviewed by the U.S. Department of Interior – Fish and Wildlife Service as well as state agencies that are responsible for the conservation of threatened and endangered species to ensure that government programs to control gypsy moth are not likely to have an adverse effect. In this report, we used a variety of sources to compile a spatial database of the historical distributional ranges of 21 threatened and endangered species that occur within the STS management area. We then quantified the area of overlap between areas treated with Btk under the STS Program from 1996 to 2010 and the distributional ranges of these species to evaluate the use of *Btk* with regard to federal and state management guidelines. The percentage of overlap between the distributional ranges for each of the 21 nontarget species was <1 percent in any year, while the cumulative percent overlap (1996 to 2010) was generally <3.34 percent. Species with the greatest overlap between their respective range and *Btk* treated areas were most often those species for which distributional data were rare. Although *Btk* can affect nontarget species, its prudent use in combination with the existing review process reduces the adverse effects on threatened or endangered species.

KEY WORDS: *Bacillus thuringiensis kurstaki*, biological invasions, biopesticide, invasive species management, gypsy moth, *Lymantria dispar*, nontarget effects, threatened and endangered species

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