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(2001 LCMR- Biological Control of Eurasian Watermilfoil and Purple Loosestrife-Continuation)

Landscape-Scale and Within-Wetland Movement of *Galerucella* spp. Introduced for Management of Purple Loosestrife (*Lythrum salicaria* L.)

BY

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ABSTRACT

In 1992, leaf beetles *Galerucella calmariensis* and *G. pusilla* were introduced from Europe as biological control agents against purple loosestrife, *Lythrum salicaria* L. in the United States. The ability of *Galerucella* spp. to control or reduce purple loosestrife infestations has been well documented. However, there is limited knowledge regarding the ability of this insect to disperse, and a technique often used to study insect spatial distributions is geostatistics. The objectives of this study were to 1) characterize the spatial distribution of *Galerucella* spp. within a wetland, and 2) evaluate the ability of *Galerucella* spp. to disperse to noncontiguous loosestrife infested wetlands on a landscape-scale. *Galerucella* spp. disperse and colonize a wetland habitat shortly after the initial release. In our experiment, apparent reductions in purple loosestrife infestations were often related to high egg mass densities of *Galerucella* spp. egg masses and beetle damage observed in the spring. This trend was present in all four wetlands studied. These beetles appear to be well adapted to changing environments and are capable of dispersing and colonizing large purple loosestrife infestations. On average, beetles dispersed 5 km from established release sites to non-release sites within 3 years. To maximize redistribution efforts, we advise resource managers to select wetlands that are greater than 5 km from known release sites. *Galerucella* spp. is capable of colonizing new purple loosestrife infestations, thus reducing redistribution efforts from resource managers.

Keywords: *Galerucella* spp., purple loosestrife, biological control, geostatistics

INTRODUCTION

In 1992, leaf beetles *Galerucella calmariensis* and *G. pusilla* were introduced from Europe as biological control agents against purple loosestrife, *Lythrum salicaria* L. These two species cannot be reliably identified in the field and dissection of male genetalia is necessary for species determination. Here we report field observations and thus are reporting distribution of *Galerucella* spp. These beetles inhabit similar niches and have similar phenologies (Blossey 1995). The ability of *Galerucella* spp. to control or reduce purple loosestrife infestations has been well documented. However, there is a limited knowledge regarding the ability of this insect to disperse (Grevstad and Herzig 1997). Grevstad and Herzig (1997) showed that beetles could disperse up to 1 km within a short time period along a contiguous stand of loosestrife in roadside ditches. However, long-range dispersal over areas that do not contain purple loosestrife and spatial distributions within larger infested wetlands is not known. Successful biological control programs over a region are dependent upon the biocontrol agent to disperse to noncontiguous host plant patches. Documentation of the movement of biocontrol agents on a landscape scale has not been done with *Galerucella* spp. Here we describe movement of insects observed throughout a wetland and among wetlands that exist as isolated patches of host plants.

A statistical technique used to study spatial distribution of various organisms is geostatistics. The use of geostatistics to answer entomological questions regarding dispersal of insects has increased within the past ten years, and as a result, geostatistical techniques have been used to describe within-field spatial structures of many insect systems (Williams et al. 1992, Midgarden et al. 1993, Darnell et al. 1999, Schotzko and Quisenberry 1999, Barrigossi et al. 2001, Blom et al. 2002, Dávalos and Blossey 2004). In general, "the degree of association (correlation) between samples is based on the direction and distance between them" (Schotzko and Quisenberry 1999). Thus, geostatistics provide a new approach to describe variability between spatially separated samples (Rossi et al. 1992). The closer the points are geographically, the greater the chance of spatial relatedness (Liebold et al. 1993). In geostatistics, a semivariogram is used to plot distances "between sample pairs against a semivariance statistic (variation between two points) for all possible sample pairs at each distance" (Ellsbury et al. 1998). Kriging is an interpolative technique that describes these spatial relationships across the landscape (Liebold et al. 1993).

The objectives of this study were to 1) characterize the spatial distribution of *Galerucella* spp. within a wetland and 2) evaluate the ability of *Galerucella* spp. to disperse to noncontiguous loosestrife infested wetlands on a landscape-scale.

MATERIALS AND METHODS

Within-wetland beetle movement. The spatial distribution of *Galerucella* spp. was characterized in four wetlands heavily infested with purple loosestrife, which were ideal for our long-term, small-scale dispersal study. The first two sites in the study, referred to as Frontenac Lake (UTM X:552768, Y:4928465) and Wacouta Pond (UTM X:546798, Y:4930447), were located in Goodhue County, MN. A third site, referred to as Sherburne Pool (UTM X:446755, Y:5034811), was located in the Sherburne National Wildlife Refuge in Sherburne County, MN. The final site used in the study was located in Hennepin County, MN and is referred to as Stonebridge Road (UTM X:463979, Y:4977743).

Spring sampling. Varying densities of *Galerucella* spp. beetles (4000 to 37,000) were released into Frontenac Lake in 1998, Wacouta Pond in 1999, Sherburne Pool in 1999, and Stonebridge Road in 2001. The initial release points for each wetland are noted in Fig. 1.

Within each wetland, waypoints were staked with polyvinyl chloride (PVC) pipe in a grid pattern (i.e., ≈ 25-m spacing between points in all cardinal directions). Global Positioning System (GPS) coordinates were recorded for each waypoint using a Garmin® 12 GPS Map. In the spring of 2001, 2002, and 2003 the number of purple loosestrife crowns in a 2-m radius and the number of these crowns showing beetle damage were recorded. The tallest stem from each of the closest 10 crowns at each waypoint was collected and the total number of egg masses/stem was recorded.

Fall sampling. In the fall of 2002 and 2003, plant biometrics (i.e., measurable plant characteristics) were assessed to describe purple loosestrife damage within each wetland. Biometrics included: height and number of inflorescences/stem for the five tallest stems/m^2, total number of stems/m^2, total number of inflorescences/m^2, and percent cover.

Geostatistics. Point maps were created in the GIS ArcMap 8.2 (Environmental Systems Research Institute 1999) to predict distribution of all variable measured in 2001, 2002, and 2003. Spatial autocorrelation was determined using the variogram analysis in GS+ (Gamma Delta Software, Plainwell MI). Distributions of all datasets were tested for normality using the Royston (1992) modification to the Shapiro–Wilk W-test (Shapiro and Wilk 1965) (PROC UNIVARIATE, SAS Institute 2001). Prediction maps for beetle egg mass density and plant biometrics were interpolated using ordinary kriging in ArcMap 8.2. Maps were visually compared to investigate the impact of *Galerucella* spp. on purple loosestrife infested wetlands.

Landscape-scale beetle movement. In 2001 and 2002, four geographic regions in Minnesota that contained numerous, loosestrife infested wetlands with at least one release site where purple loosestrife was being reduced by beetle feeding. The areas used in our study were located in the following county clusters: Swift/Pope Counties, Wright/Carver/Hennepin Counties, Anoka/Ramsey/Chisago/ Washington Counties, and Goodhue/Wabasha Counties (Fig. 2). A database containing all known purple loosestrife infestations maintained by the Minnesota Department of Natural Resources was used to locate regions of the state that met the above criteria. We used the same database to locate wetlands that had beetles released. We visted these infested sites, to determine the level of plant damage caused by all life stages of the *Galerucella* spp. beetles. At each site visited, randomly selected purple loosestrife plants (100 maximum per site) were assessed for insect presence (i.e. defoliation, eggs, larvae, adults). The *Galerucella* spp. life stages present and the type of damage observed (i.e., shot-hole and tip feeding, reduced flowering) were recorded and GPS coordinates were recorded at each site (Fig. 3). Purple loosestrife density and plant numbers were estimated and recorded for each site. Once overall damage was assessed, a letter grade ranging from A-F (A = highest percent damage with an abundance of insects and extensive plant damage. Insects from a site with a grade of A can be repeatedly collected and redistributed, B = insects were commonly found and insects could be collected and redistributed, plant damage is observable, but not a dramatic reduction in plant stand, C = insects can be found, but plant damage is modest and beetle density too low to collect and redistribute, D = occasional insects can be observed, but virtually no or only limited plant damaged can be found, and F = no plant damage and absence of beetles) was given to each site. The letter grades are used as a guide to when insect density and damage is sufficient to begin removing insects from the site for redistribution. The overall visual appearance of the plants in the spring and again in the summer after flowering is a key indicator of the success of biocontrol agents used by practitioners who manage.

Sites that received a grade of C or higher (on an A-F scale) in 2001 were not surveyed in 2002. However, sites receiving a grade of D or F in 2001 were re-sampled in 2002. Each year new purple loosestrife infestations not previously graded were also added as they were discovered. Using GIS, when an apparent early colonization (beetles present but damage low) was discovered on a non-release site, the distance to the closest release site was determined. By evaluating the insect population from the closest source we estimated the number of years it took for beetles to colonize these non-release sites and used ArcMap 8.2 to spatially analyze these data. For each region, we calculated mean dispersal distance (km), maximum dispersal distance (km), mean number of years to detect beetle presence, and the proportion of all non-release sites visited with beetles present.

RESULTS

Within-wetland beetle movement. Significant spatial correlations were present in nearly all the datasets and semivariograms for all data are presented in Table 1. However, when data are not spatially correlated, interpreting kriged surfaces is not possible. Instead, the mean value between all waypoints can be used to describe unknown locations within a site. At Wacouta Pond in the spring of 2001, high egg mass densities were localized around the initial release point (Fig. 4A). However, low to moderate damage (i.e., percent crown damage) was evident in over 80% of the wetland (Fig. 4D). By the spring of 2002, egg mass densities were observed across the entire wetland; the greatest concentration of egg mass densities (i.e., 20-30 egg masses/stem) were found near or at the release point (Fig. 4B). Percent crown damage increased across the entire wetland compared to the previous year with 50-75% of the purple loosestrife crowns in a 2 m radius of the waypoint showing damage (Fig. 4E). When comparing egg mass densities to plant biometrics that were measured in the fall at Wacouta Pond, areas of heavy oviposition were correlated to a reduction in percent purple loosestrife coverage (Fig. 5A), average stem height (Fig. 5C), mean number of inflorescences (Fig. 5E), and total number of infloresences/m^2 (Fig. 5I). There were no inflorescences found in over half of Wacouta Pond in 2002.

In 2003, we started to see a shift in the location of high egg mass densities within Wacouta Pond (Fig. 4C). The largest amount of *Galerucella* spp. egg masses was found ≈ 150 m south of the initial release point. Insect presence (i.e., shot-hole and tip feeding) was observed across the entire wetland with 75-100% of the crowns showing beetle damage (Fig. 4F). Egg mass densities reported in the spring of 2003 were visually similar to changes in plant biometrics measured in the fall. Since egg mass densities observed in the spring were lower than previously observed near the initial release points we expected to see less plant damage. Indeed we observed a rebound in the number of flowering stems near the initial release point (Fig. 5F,H) compared to the previous year, confirming that egg mass density in the spring appears to be a good predictor of overall plant damage seen late in the summer and into the fall. However, it should be noted that the overall height and the number of inflorescences was reduced across the entire wetland compared to those biometrics measured in 2002 (Fig. 5C-D).

At Sherburne Pool we observed similar trends. In 2001, there were low egg mass densities across the wetland plus we were unable to find *Galerucella* spp. eggs in the northeast half of the wetland and the southeast half of the wetland ranged from 1-5 egg masses/stem (Fig. 6A). Though no egg masses were found in the northeast half, evidence of feeding was observed across the entire wetland with 1-25% of the purple loosestrife crowns having damage (Fig. 6D). In 2002, egg mass densities slowly continue to spread across the wetland with two areas identified in the grid sampling as having substantially more egg masses (10-15 egg masses/stem) which were close to the initial release point (Fig. 6B). Adult activity was also greater and there was an overall increase in percent crown damage (Fig. 6D). However, despite the increase of egg masses in isolated areas, we do not see the same trend in plant biometrics as we did at Wacouta Pond in 2002. In contrast, percent cover, stem height, and number of inflorescences were apparently unaffected by the increase in egg mass densities (Fig. 7A,C,E,G,I).

By 2003, egg mass densities at the Sherburne Pool generally increased across the entire wetland averaging 5-10 egg masses/stem compared to densities that were 50% lower in 2002. In general, crown damage remained unchanged and the most damage was observed near the west edge of the wetland (Fig. 6F). When we relate this to the fall plant biometrics, we see similar trends that were observed at Wacouta Pond in 2003. High egg mass densities corresponded to a reduction in plant height (Fig. 7D) and a large reduction in the number of flowering plants (Fig. 7F,G). The total number of inflorescences was greatly reduced in 2003 compared to 2002; average number of inflorescences/m^2 in 2002 was > 25/m^2 and in 2003 there was only a small patch of purple loosestrife that had an average of 1-10 inflorescences/m^2 (Fig. 7G, H).

At the Stonebridge Road site, eggs were found throughout the wetland both years (Fig. 8A-B). In general, larger egg mass densities were located in the middle of the wetland and densities increased from 1-5 masses/stem in 2002 (Fig. 8A) to 20-25 masses/stem (Fig. 8B) in 2003. A similar trend was observed when comparing percent crown damage (Fig. 8C-D). As seen in the previous two sites, egg mass densities correlate with fall plant biometrics where higher egg mass densities correspond to reduction in percent cover, stem height, number of inflorescences, and number of stems both years (Fig. 9). We also observed this trend between years within a given biometric (i.e., greater egg mass densities resulted in a greater reduction in percent cover, plant height, and number of inflorescences).

At Frontenac Lake in 2001, egg mass densities and percent crown damage were highest near the release point and lowest at the opposite end of the wetland, some 300 meters distant (Fig. 10A,D). However, in 2002 an area of increased egg mass density was observed away from the release point (Fig. 10B). In the north half of the site percent crown damage increased from 0-25% damage in 2001 to 75-100% damage in 2002. By 2003, egg mass densities decline dramatically (i.e., no egg masses found in over 50% of the site) and beetle feeding appeared to decrease (Fig. 10C,F). Percent cover of purple loosestrife at Frontenac Lake was uniform (Fig. 11A). However, total inflorescences were greatly reduced across the south half of the wetland (Fig. 11I). The decrease in egg mass densities from 2002 to 2003 resulted in a rebound in plant height (Fig. 11C-D), total number of inflorescences (Fig. 11E-F), and number of stems (Fig. 11I-J).

Landscape-scale beetle movement. The number of sites visited in each region ranged from 19 sites in Goodhue and Wabasha Counties to 62 sites in the Minnetonka area during the two year study (Table 2). Beetle damage was evident in 85% of the 167 non-release sites visited. Purple loosestrife infestations located in the Minnetonka area had the most damage. Recall, this area also had a greater number of established release sites per km^2 (Table 2). Conversely, the region with the least amount of non-release sites with *Galerucella* spp. beetles present had the fewest established release sites per km^2 (i.e., Goodhue and Wabasha Counties). On average, beetles dispersed 5 km from established release sites to non-release sites within 3 years (Table 2). This trend is consistent between all regions used in the study. The slightly faster colonization of sites within the Minnetonka area ($\approx$ 2 yr) could be attributed to the greater proportion of established release sites compared to non-release sites. *Galerucella* spp. was able to colonize infestations a considerable distance away from established release sites, and the average maximum dispersal distance from all four locations was approximately 19 km.

DISCUSSION

Galerucella spp. disperse and colonize a wetland habitat within 1-2 years after the initial release. In our sites, apparent reductions in purple loosestrife infestations as measured with a variety of plant biometrics in the fall were correlated with high egg mass densities of *Galerucella* spp. observed in the spring. This trend was present in all four wetlands studied. These beetles appear to be well adapted to changing environments and are capable of dispersing and colonizing within large purple loosestrife infestations. This information is important for resource managers in minimizing distribution efforts for controlling purple loosestrife. Although it may take a few years for beetles to distribute themselves across a large wetland, clearly the insects can accomplish this feat without further assistance from resource managers. A recommendation arising from this study would be to select a single location within a wetland to make a release rather than making several smaller releases throughout the wetland, thus minimizing redistribution efforts. As *Galerucella* spp. increase in population, there is a corresponding decrease in purple loosestrife. As a result when loosestrife density declines appreciably the following spring, fewer beetles are produced which in turn releases the plant from herbivory. Plant populations may temporarily rebound as insect pressure declines, but as plant quantity increases there is a concomitant increase in beetle density resulting eventually in an equilibrium where purple loosestrife declines in abundance (Landis et al. 2004). Here we could document small scale (within-wetland) changes in beetle density and plant biometrics.

The ability of *Galerucella* spp. to disperse is not limited to within-wetland movement. *Galerucella* spp. will disperse and locate purple loosestrife infestations over large geographic regions. In particular, beetles were able to find purple loosestrife infestations that were some distance from a known release site and more importantly where there was not a contiguous patch of loosestrife connecting two distant wetlands. These data collected here will enable us to maximize redistribution efforts and we advise resource managers to select wetlands that are greater than 5 km from known release sites for *Galerucella* spp. redistribution. Our analysis demonstrates that, on average, beetles dispersed 5 km from established release sites to non-release sites within 3 years. Because of the constraints of the landscape-scale study, beetles could be moving at a much faster rate than reported, therefore our estimate is likely a conservative prediction of *Galerucella* spp. movement among wetlands. Regardless, *Galerucella* spp. is capable of locating and colonizing new purple loosestrife infestations, thus reducing redistribution efforts from resource managers. This study provides a basic model for assessing the impacts of other potential biological control agents on other invasive species like buckthorn (*Rhamnus cathartica* L.) and garlic mustard (*Alliaria petiolata* [Bieb]).

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Table 1. Semivariograms models, parameters, and r^2 values for all variables used to assess impacts of *Galerucella* spp. movement within wetlands.

Variable	Field site	Year	Model	Nugget[a]	Sill[b]	Range[c]	r^2
Spring Sampling							
Egg masses/stem							
	Frontenac						
		2001	spherical	0.001	0.489	50	0.925
		2002	linear	0.716	1.518	86	0.987
		2003	spherical	0.005	0.454	40	0.922
	Sherburne						
		2001	linear	0.352	0.738	86	0.985
		2002	spherical	0.010	15.750	53	0.985
		2003	linear	1.236	1.236	86	0.894
	Stonebridge						
		2002	spherical	0.178	0.356	79	0.987
		2003	exponential	0.000	0.287	28	0.796
	Wacouta						
		2001	spherical	0.000	0.219	35	0.421
		2002	spherical	0.133	0.345	75	0.946
		2003	exponential	0.170	0.546	72	0.973
% Crown damage							
	Frontenac						
		2001	spherical	0.001	1.875	47	0.729
		2002	linear	2.434	4.584	86	0.991
		2003	spherical	1.34	5.02	69	0.985
	Sherburne						
		2001	linear	0.915	2.096	86	0.958
		2002	spherical	115	1788	31	0.755
		2003	linear	2159.9	215.9	83	0.937
	Stonebridge						
		2002	linear	0.7765	0.7765	87	0.0392
		2003	linear	0.3364	0.3364	87	0.0278
	Wacouta						
		2001	exponential	0.001	1.158	8	0.072
		2002	spherical	0.001	0.958	20	0.000
		2003	spherical	0.065	1.248	20	0.000
Fall Sampling							
% PLS cover							
	Frontenac						
		2002	exponential	0.72	4.39	21	0.964
		2003	spherical	0.01	5.382	48	0.941
	Sherburne						
		2002	exponential	0.357	2.371	32	0.989
		2003	spherical	0.001	1.184	22	0.000
	Stonebridge						
		2002	exponential	0.056	0.6	31	0.997
		2003	spherical	0.053	0.94	49	0.962
	Wacouta						
		2002	exponential	43	997	27	0.999
	Wacouta	2003	spherical	0.001	1.549	47	0.974

Stem height (cm)							
	Frontenac						
		2002	spherical	0.160	10.880	30	0.756
		2003	spherical	6.020	15.340	103	0.999
	Sherburne						
		2002	spherical	1	2464	56	0.967
		2003	linear	2.101	3.613	86	0.852
	Stonebridge						
		2002	exponential	0.000	0.064	37	0.993
		2003	linear	0.417	0.417	87	0.581
	Wacouta						
		2002	spherical	230	1835	164	0.979
	Wacouta	2003	spherical	447	1438	51	0.996
Average inflorescences/m^2							
	Frontenac						
		2002	linear	0.1238	0.1238	86	0
		2003	exponential	0.698	1.815	108	0.967
	Sherburne						
		2002	spherical	0.001	0.94	51	0.935
		2003	spherical	0.0097	0.0664	49	0.967
	Stonebridge						
		2002	spherical	0.258	1.137	59	0.999
		2003	exponential	0.001	1.124	37	0.949
	Wacouta						
		2002	spherical	0.452	0.976	71	0.917
		2003	exponential	0.018	0.724	12	0.572
Total Infloresences/m^2							
	Frontenac						
		2002	linear	1.024	1.024	86	0.537
		2003	exponential	2.800	35.600	39	0.940
	Sherburne						
		2002	spherical	0.001	2.640	56	0.990
		2003	spherical	0.600	3.913	38	0.727
	Stonebridge						
		2002	spherical	0.263	2.970	54	0.996
		2003	exponential	0.250	4.393	38	0.960
	Wacouta						
		2002	spherical	0.819	2.663	64	0.979
		2003	spherical	0.851	2.322	55	0.992
# Stems/m^2							
	Frontenac						
		2002	exponential	0.856	2.614	20	0.768
		2003	spherical	0.010	6.383	80	0.980
	Sherburne						
		2002	exponential	0.094	1.086	17	0.691
		2003	linear	0.736	1.111	86	0.749
	Stonebridge						
		2002	linear	0.386	0.635	87	0.988
		2003	exponential	0.060	0.689	33	0.895
	Wacouta						

	2002	spherical	0.312	0.877	98	0.921
	2003	spherical	0.001	0.970	42	0.956

a--experimental error.
b--sample variance (i.e., measures the degree of similarity between samples).
c--average distance where samples remain correlated spatially.

Table 2. Summarized data from the 2001 and 2002 landscape-scale study.

Location	Area (km^2):	Number of Established Release Sites:	Number of Non-Release Sites Visited:	Mean Dispersal Distance (km) from Release Site ± SE:	Max Dispersal Distance (km) from Release Site:	Number of years to *Galerucella* presence ± SE:	% of Sites Visited with *Galerucella* spp. Present:
Pope and Swift Counties	1,772	11	39	5.5 ± 1.0	20.9	3.2 ± 0.2	72
Minnetonka area[a]	2,129	28	62	2.4 ± 0.4	17.9	2.4 ± 0.1	95
Northeast area[b]	1,154	6	47	7.0 ± 0.7	20.4	2.8 ± 0.2	89
Goodhue and Wabasha Counties	825	3	19	4.1 ± 1.1	17.8	3.8 ± 0.2	69
Total	5,880	48	167	4.7 ± 0.4	19.3 ± 8.2	2.8 ± 0.1	85

[a] includes Wright, Hennepin, and Carver Counties.
[b] includes Anoka, Chisago, Ramsey, and Washington Counties.

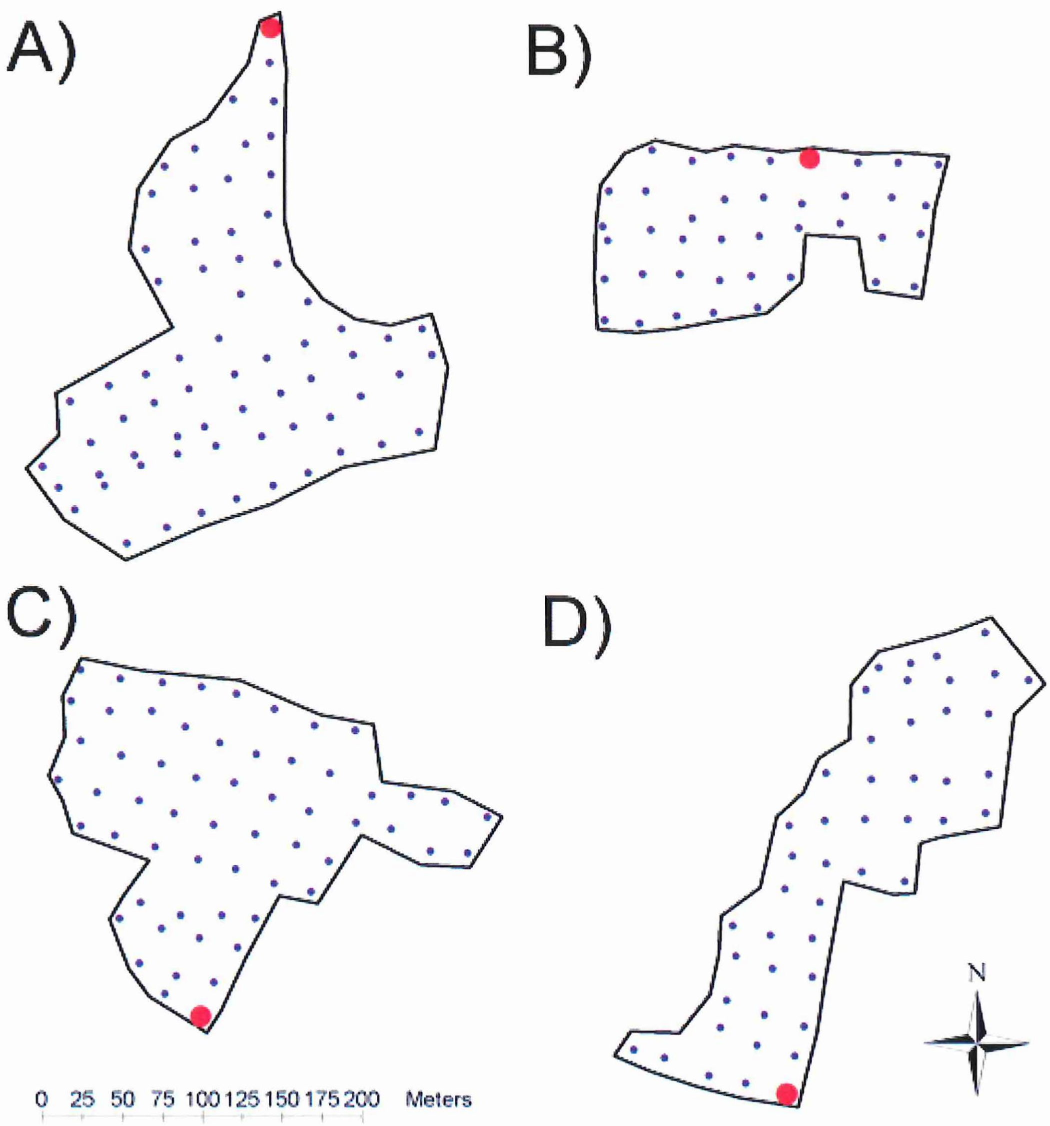

Figure 1. Map of waypoints and release points (●) for all four wetlands used in the within-wetland study of *Galerucella* spp. beetle movement. A) Wacouta Pond, B) Sherburne Pool, C) Stonebridge Road, and D) Frontenac Lake.

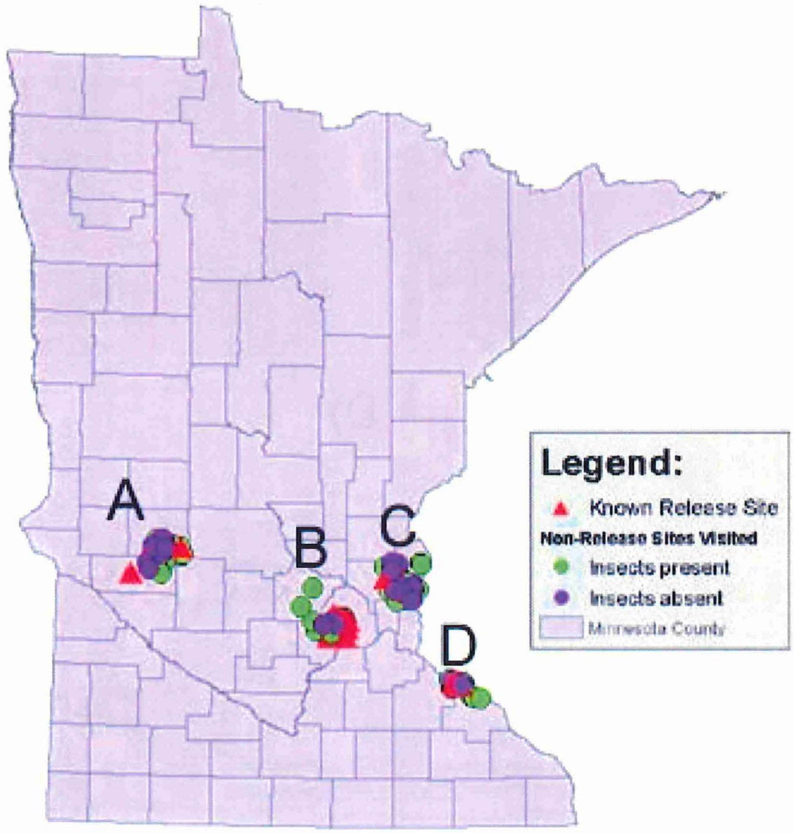

Figure 2. Map of four geographic regions used in the landscape-scale movement study. Areas included: A) Pope and Swift Counties, B) Wright, Hennepin, and Carver Counties referred to as Minnetonka area, C) Anoka, Chisago, Ramsey, and Washington Counties referred to as Northeast area, and D) Goodhue and Wabasha Counties.

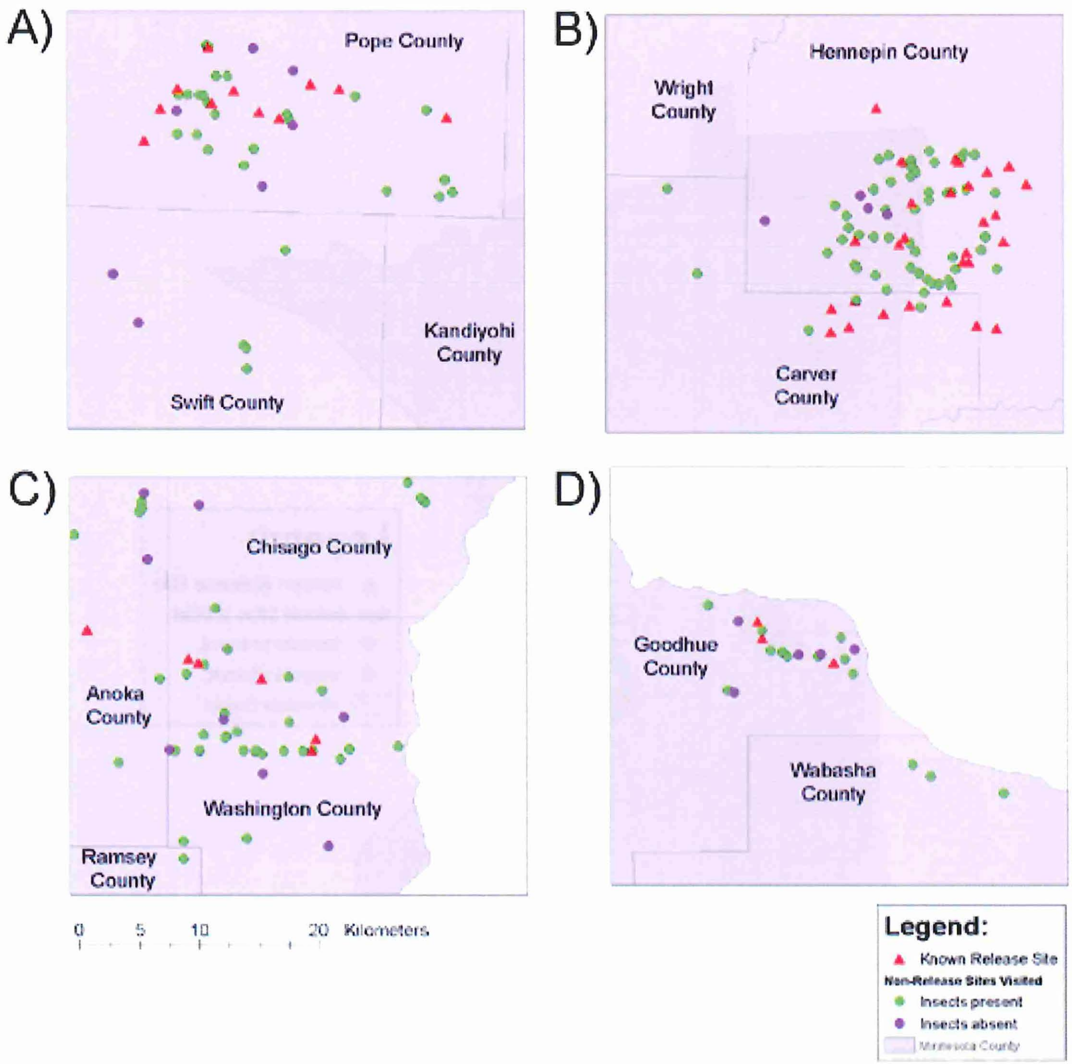

Figure 3. Distribution of purple loosestrife infested wetlands visited in 2001 and 2002. *Galerucella* spp. presence/absence was noted in all areas visited. Areas included: A) Pope and Swift Counties, B) Wright, Hennepin, and Carver Counties referred to as Minnetonka area, C) Anoka, Chisago, Ramsey, and Washington Counties referred to as Northeast area, and D) Goodhue and Wabasha Counties.

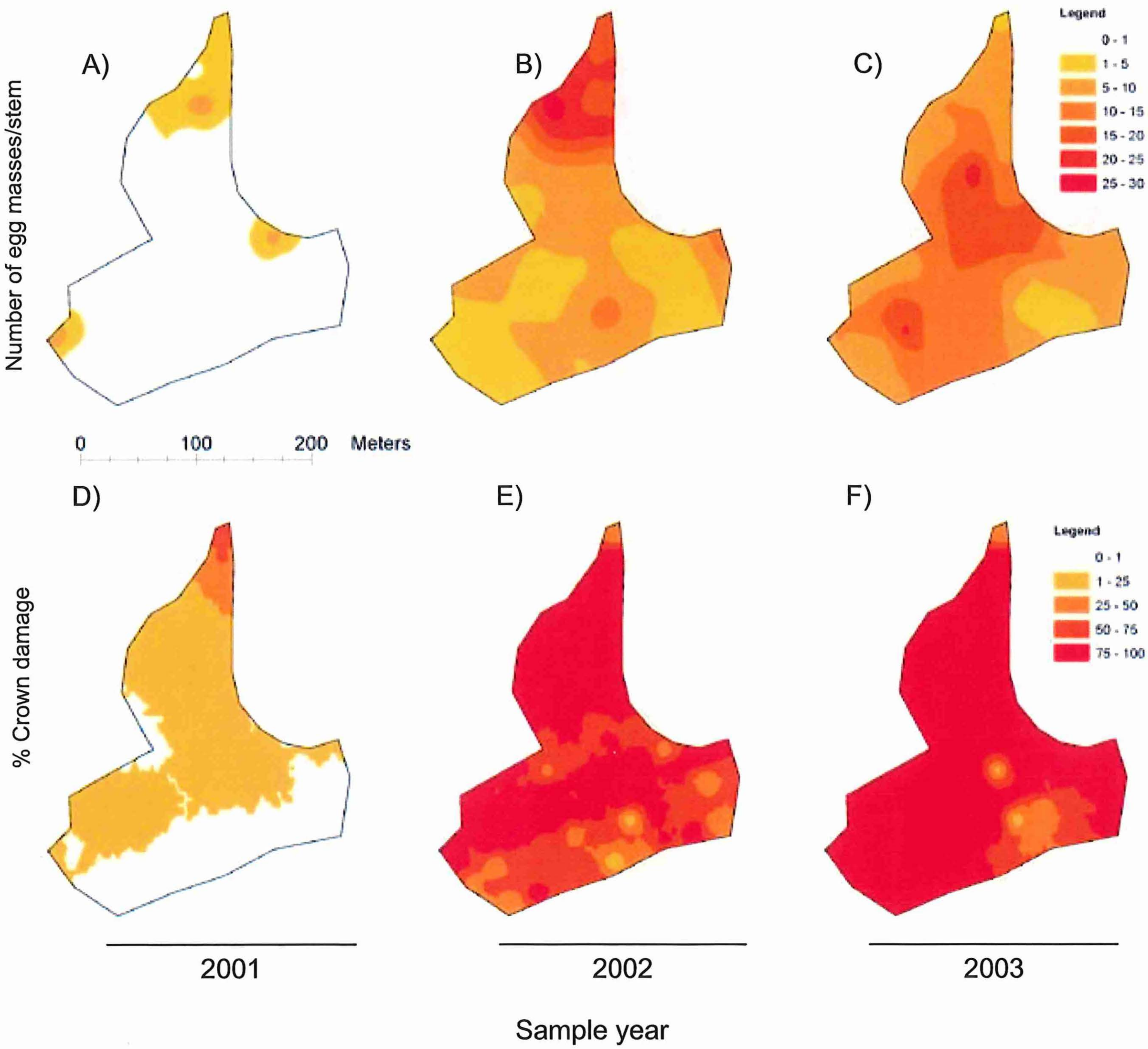

Figure 4. Contour maps showing interpolated surfaces of egg mass densities measured in A) 2001, B) 2002, and C) 2003 and percent purple loosestrife crown damage observed in D) 2001, E) 2002, and F) 2003 at Wacouta Pond.

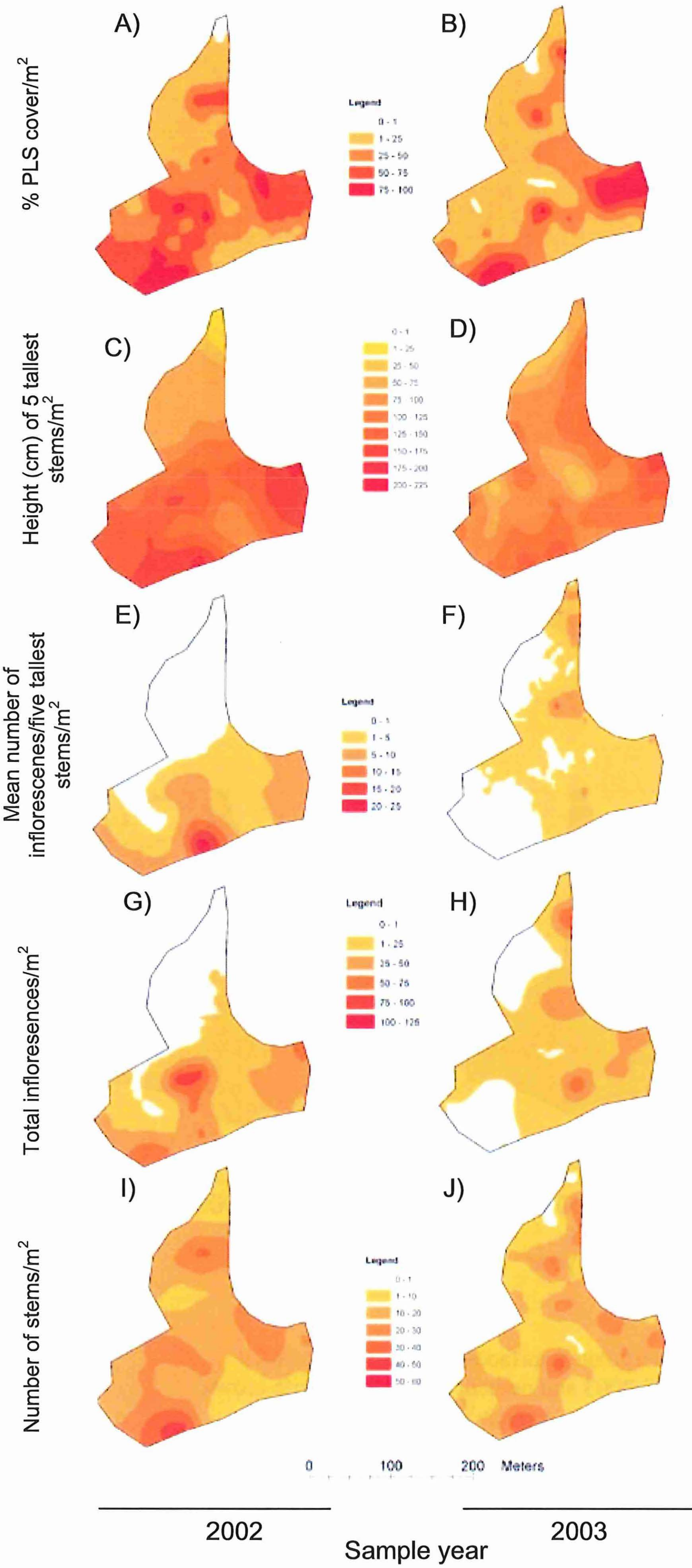

Figure 5. Contour maps showing interpolated surfaces for percent purple loosestrife (PLS) cover per m^2 (A, B), height (cm) of the five tallest stems per m^2 (C, D), mean number of inflorescences of per five tallest stems per m^2 (E, F), total inflorescences per m^2 (G, H), and number of stems per m^2 (I, J) at Wacouta Pond in 2002 and 2003, respectively.

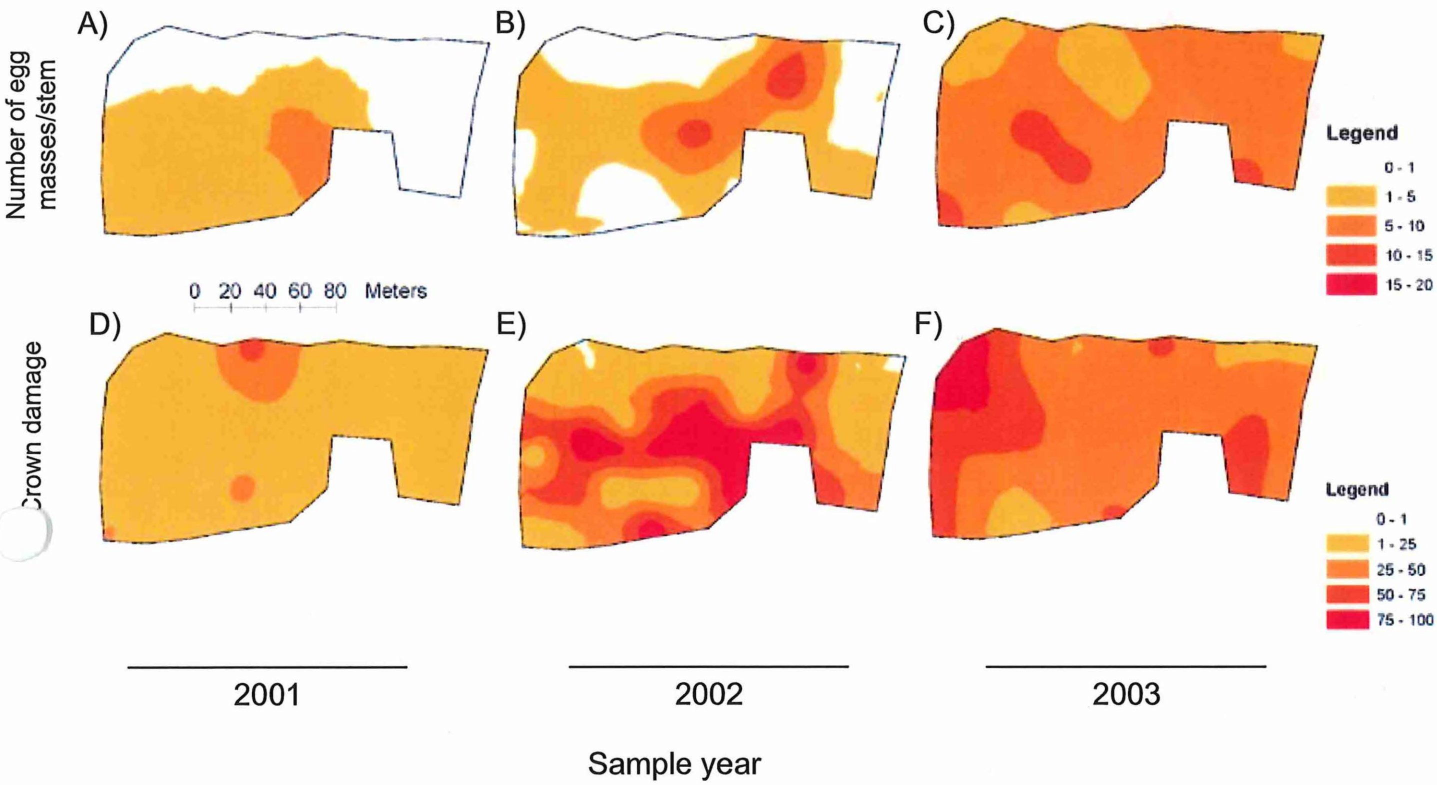

Figure 6. Contour maps showing interpolated surfaces of egg mass densities measured in A) 2001, B) 2002, and C) 2003 and percent purple loosestrife crown damage observed in D) 2001, E) 2002, and F) 2003 at Sherburne Pool.

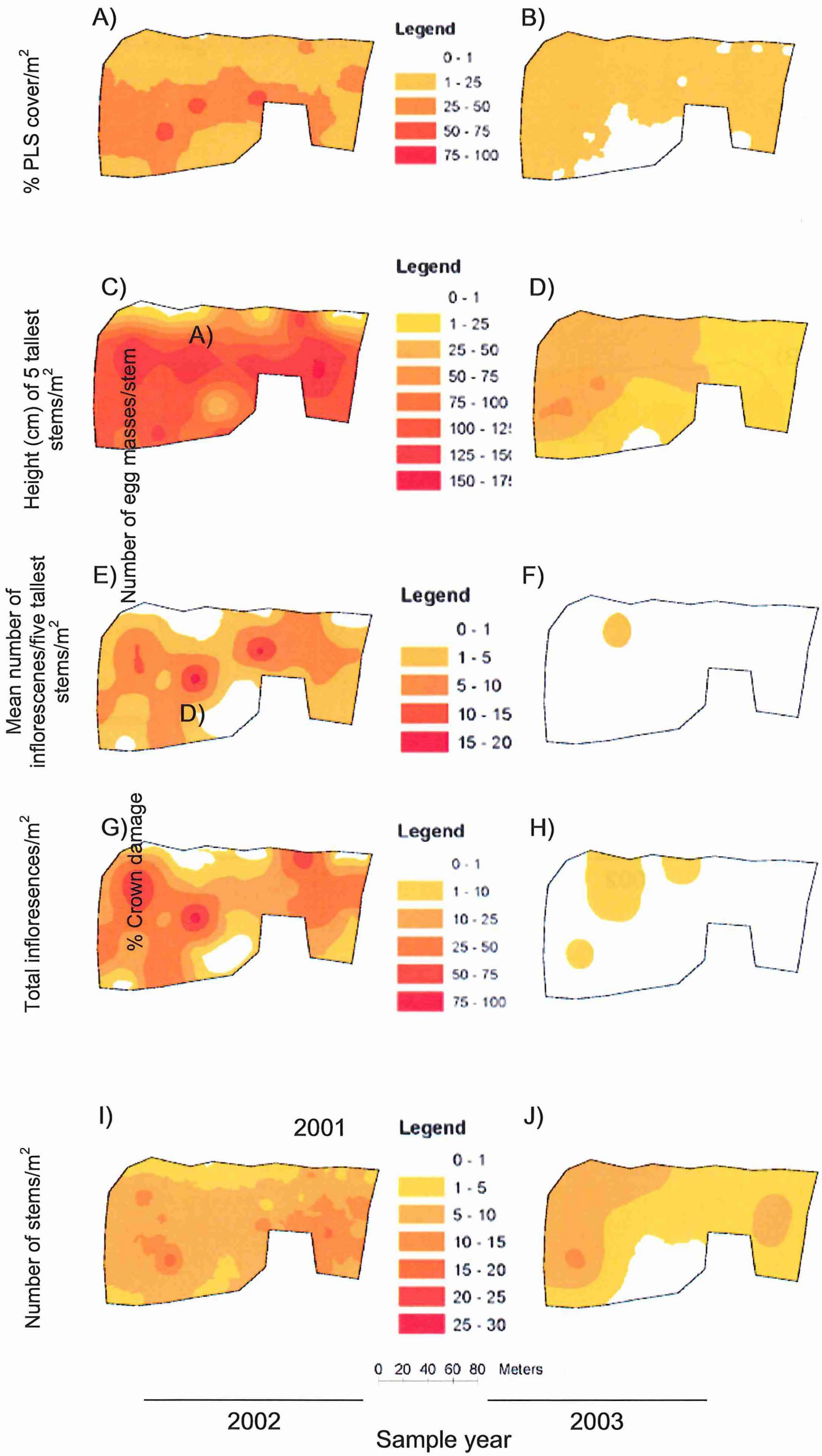

Figure 7. Contour maps showing interpolated surfaces for percent purple loosestrife (PLS) cover per m^2 (A, B), height (cm) of the five tallest stems per m^2 (C, D), mean number of inflorescences of per five tallest stems per m^2 (E, F), total inflorescences per m^2 (G, H), and number of stems per m^2 (I, J) at Sherburne Pool in 2002 and 2003, respectively.

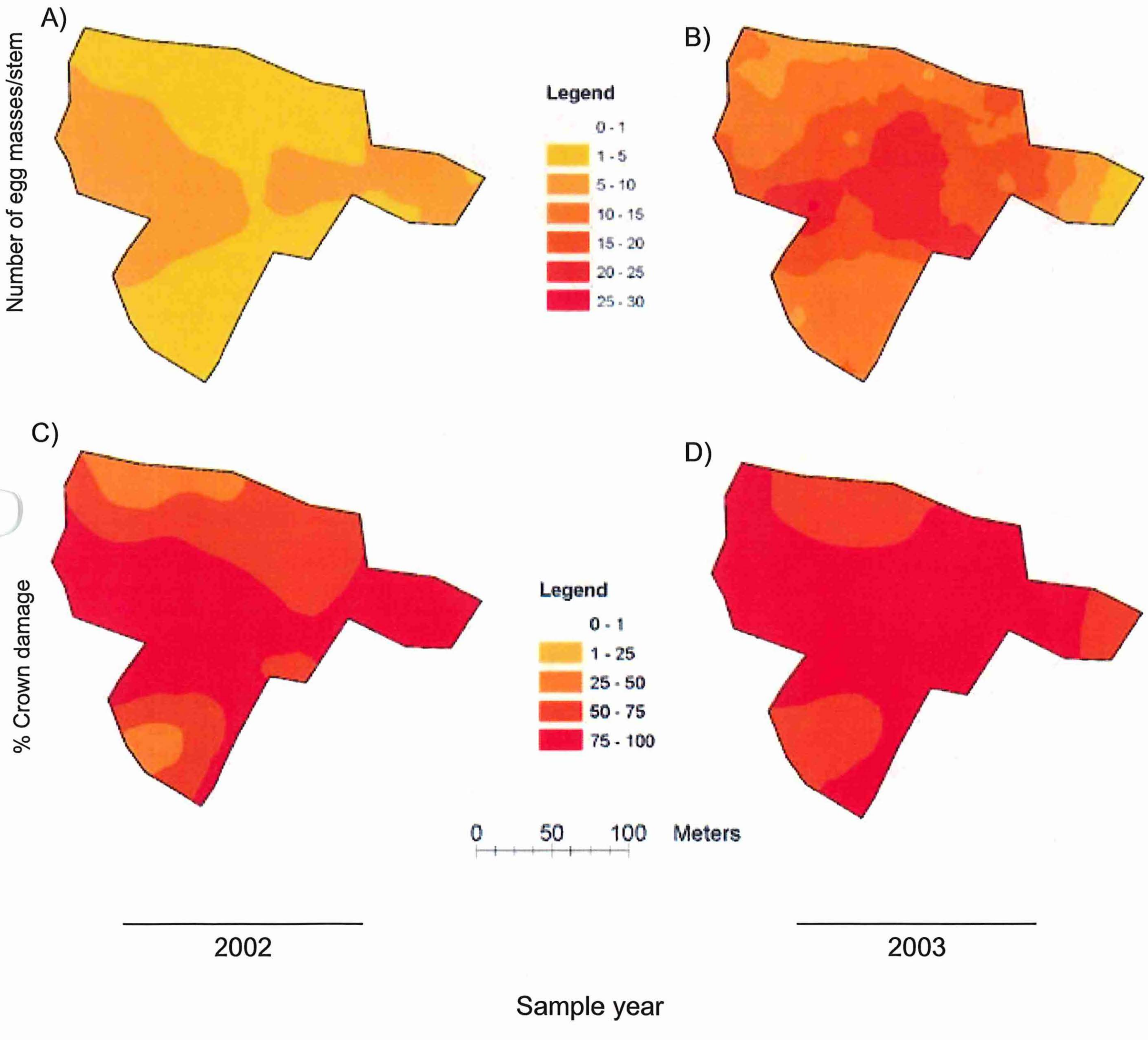

Figure 8. Contour maps showing interpolated surfaces of egg mass densities measured in A) 2002 and B) 2003, and percent purple loosestrife crown damage observed in C) 2002 and D) 2003 at Stonebridge Road.

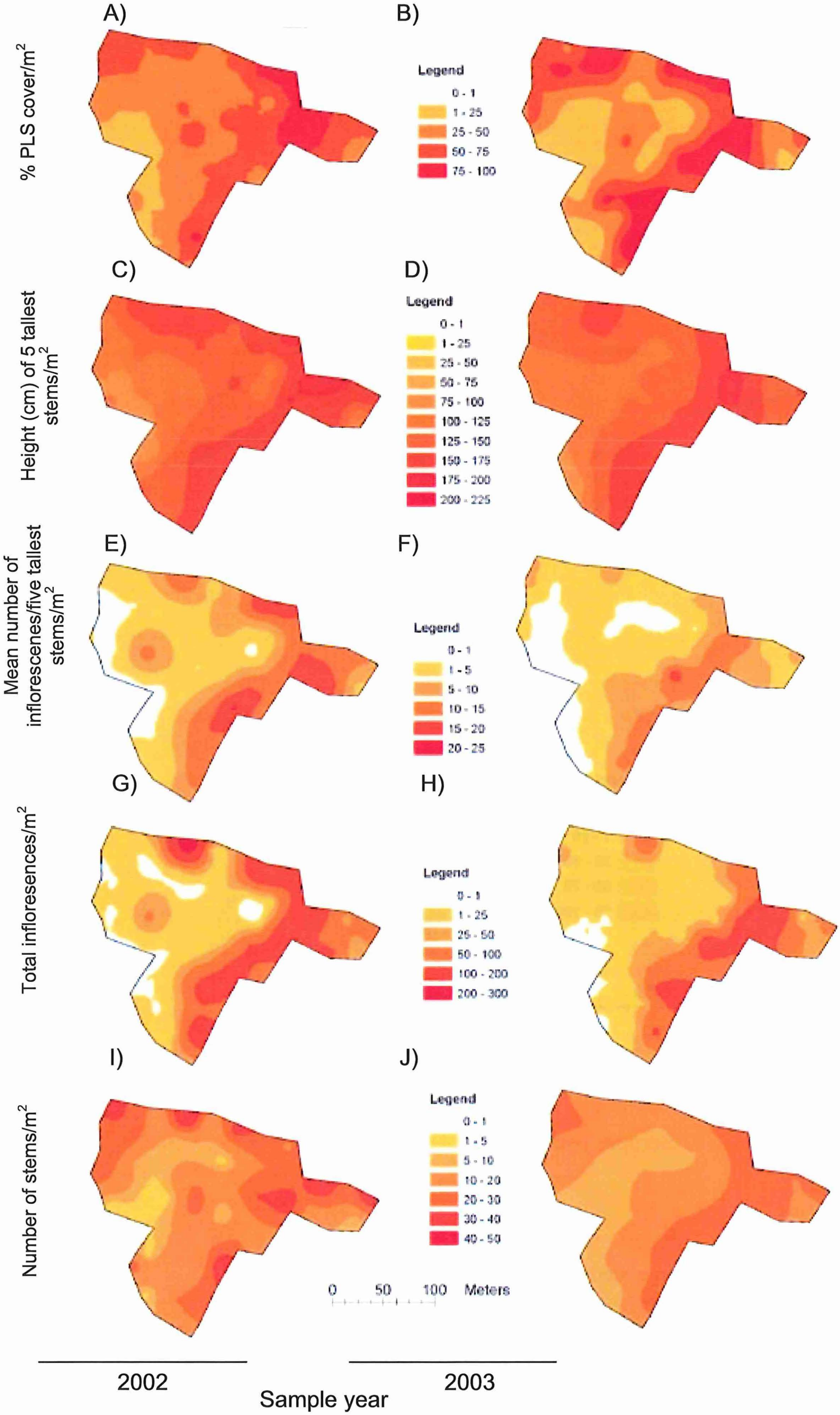

Figure 9. Contour maps showing interpolated surfaces for percent purple loosestrife (PLS) cover per m^2 (A, B), height (cm) of the five tallest stems per m^2 (C, D), mean number of inflorescences of per five tallest stems per m^2 (E, F), total inflorescences per m^2 (G, H), and number of stems per m^2 (I, J) at Stonebridge Road in 2002 and 2003, respectively.

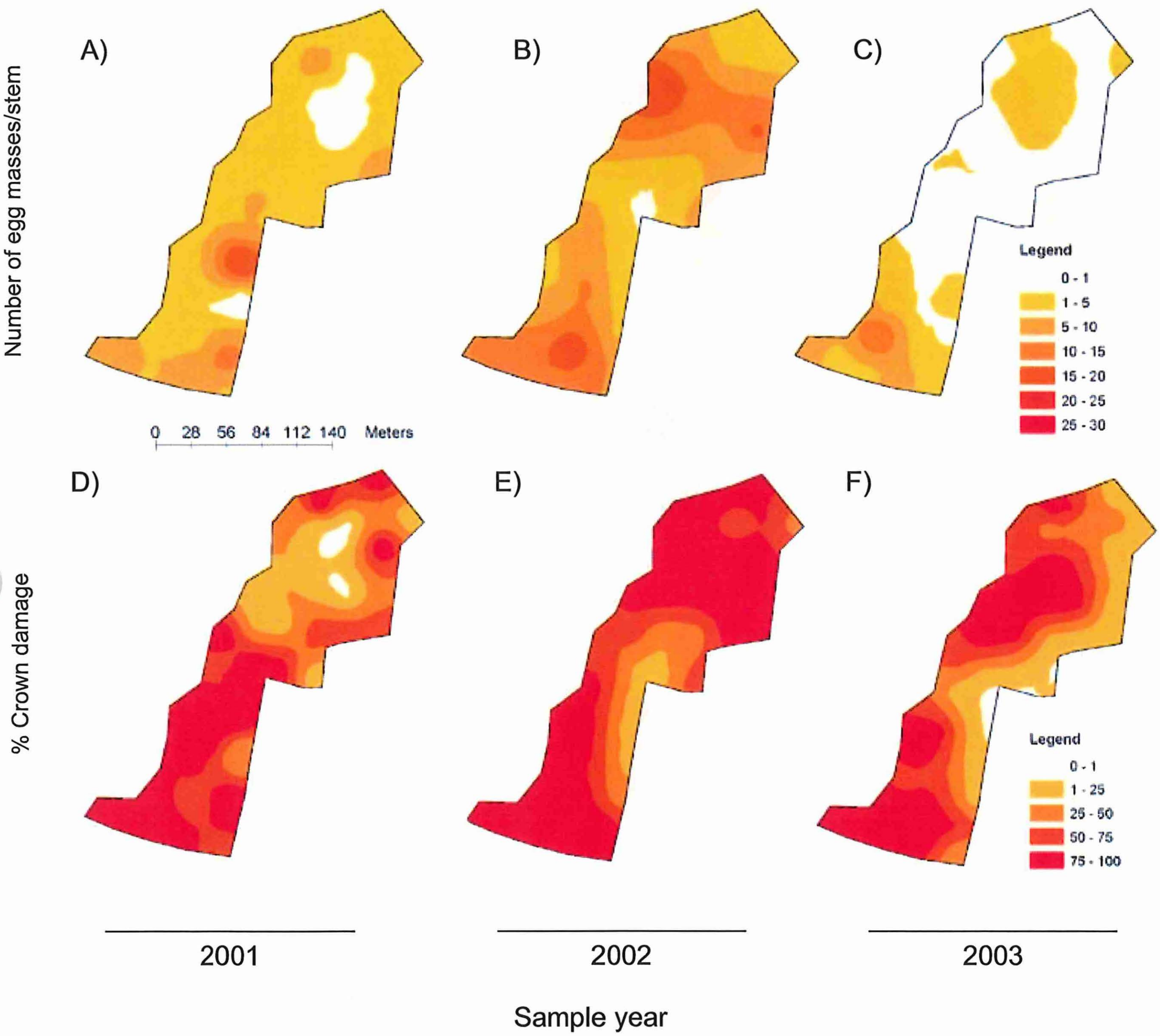

Figure 10. Contour maps showing interpolated surfaces of egg mass densities measured in A) 2001, B) 2002, and C) 2003 and percent purple loosestrife crown damage observed in D) 2001, E) 2002, and F) 2003 at Frontenac Lake.

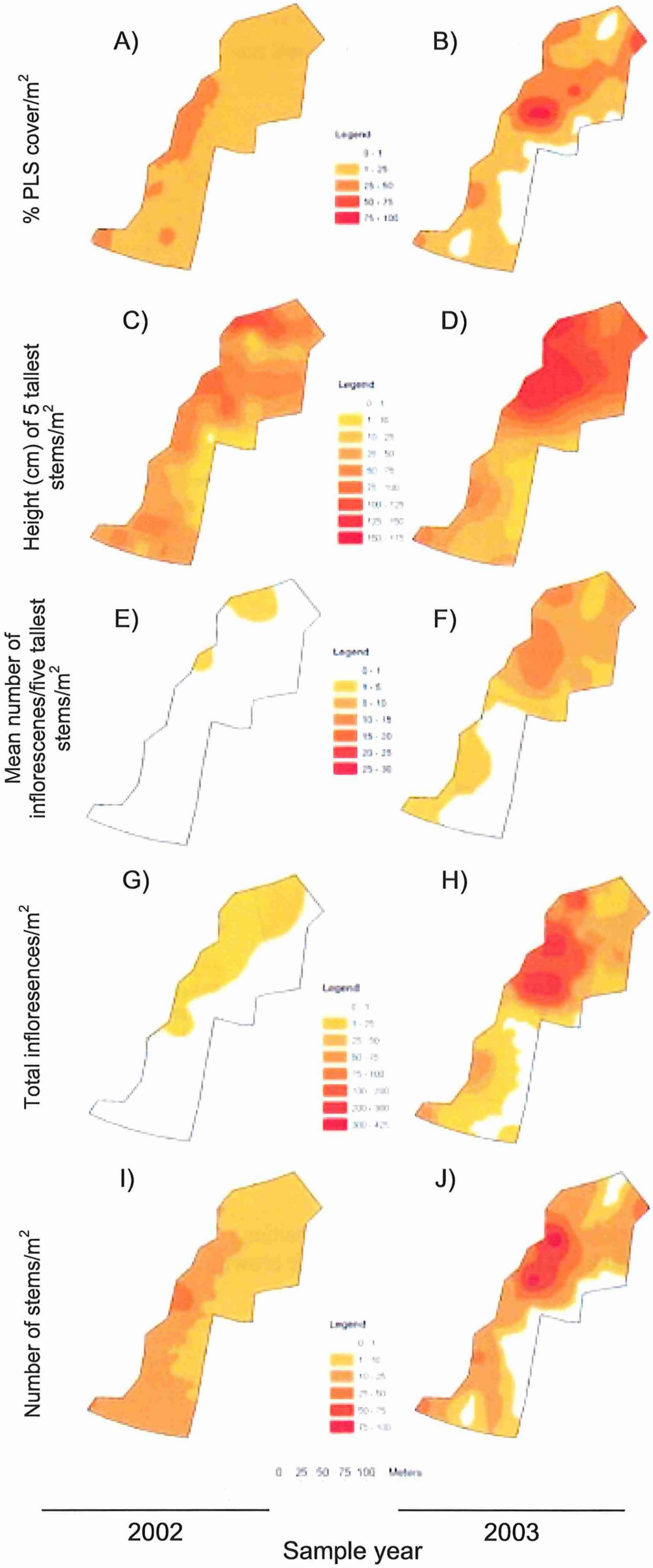

Figure 11. Contour maps showing interpolated surfaces for percent purple loosestrife (PLS) cover per m^2 (A, B), height (cm) of the five tallest stems per m^2 (C, D), mean number of inflorescences of per five tallest stems per m^2 (E, F), total inflorescences per m^2 (G, H), and number of stems per m^2 (I, J) at Frontenac Lake in 2002 and 2003, respectively.