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Do Woody Plants Prevent the Establishment of Common Reed along Highways? Insights from Southern Quebec

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The common reed (*Phragmites australis*) is one of the most invasive vascular plants in northeastern North America. A competitive genotype from Eurasia has recently invaded road and agricultural ditches, which facilitate the dispersal of the plant over long distances. However, large tracts of roadsides—apparently propitious for the establishment of the plant—are not invaded by the grass. We hypothesized that the absence of the invader is associated with physical and biological characteristics of roadsides. To test this hypothesis, we collected field data and developed two statistical models to explain the presence or absence of the common reed along a highway of southern Quebec highly invaded by the plant but with contrasting patterns of common reed distribution. The models explained 23 to 30% of the total variance and correctly predicted the presence or absence of common reed 71% of the time. The models suggest that a dense woody plant cover over a drainage ditch limits the establishment and/or expansion of the common reed, probably by competition for light and space. Also, shaded ditches are not subjected to a frequent maintenance, and are therefore less disturbed, probably further reducing common reed invasion because the germination of their seeds is less likely without soil disturbance. This study yields insights on the potential of woody plants for controlling the expansion of invasive grasses, and could help to justify the preservation of dense shrubs and tree hedges along right-of-ways.

Nomenclature: Common reed, *Phragmites australis* (Cav.) Trin. ex Steud.

Key words: *Phragmites australis*, plant competition, plant invasion, right-of-way management, road ecology.

Roadsides and their associated drainage ditches form open habitats for plants well adapted to disturbance (roadside mowing, ditch cleaning) and pollution (deicing salts, fertilizers from nearby agricultural fields, heavy metals). Although they can be colonized by a large variety of native plants (Karim and Mallik 2008; Rentch et al. 2005), their characteristics (open and disturbed) are particularly suitable for the establishment of opportunistic exotic species (Gelbard and Belnap 2003; Hansen and Clevenger 2005; Hulme et al. 2008). Moreover, roadsides function as corridors for invasive plants (Floerl and Inglis 2005; Hulme 2009; Joly et al. 2011), although their importance has usually been overlooked in statistical models predicting the spread of plant invaders (Christen and Matlack 2009; Hulme 2003; Hulme et al. 2008).

The common reed, *Phragmites australis* (Cav.) Trin. ex Steud. (Poaceae), is one of the most invasive vascular plants in northeastern North America (Bertness et al. 2002; Catling and Mitrow 2011; Lelong et al. 2007; Mal and Narine 2004; Saltonstall 2002). A particularly competitive genotype from Eurasia (subspecies *australis*, or haplotype M) has invaded coastal wetlands of the United States (Lathrop et al. 2003; Philipp and Field 2005; Rice et al. 2000) and, more recently, freshwater wetlands and road and agricultural ditches of eastern Canada (Hudon et al. 2005; Jodoin et al. 2008; Kirk et al. 2011; Lelong et al. 2009; Maheu-Giroux and de Blois 2007; Tulbure et al. 2007; Tulbure and Johnston 2010; Wilcox 2012; Wilcox et al. 2003). The common reed is especially abundant along roads, with linear populations covering thousands of kilometers in southern Quebec (Jodoin et al. 2008; Lelong et al. 2009). This grass proliferates along roadsides because: (1) it finds the resources (light, nutrients, water) essential

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Management Implications

The common reed (*Phragmites australis*) is one of the most invasive vascular plants in northeastern North America. A competitive genotype from Eurasia has recently invaded road and agricultural ditches, which facilitate the dispersal of the plant over long distances. However, large tracts of roadsides—apparently propitious for the establishment of the plant—are not invaded by the grass. We suggest here that a dense woody plant cover over a drainage ditch is likely to prevent the establishment or the subsequent expansion of the common reed. In jurisdictions where the use of herbicides is prohibited for controlling the common reed, preserving well-established shrub or tree hedges over roadside ditches could be an efficient low-cost alternative to prevent common reed invasions. Planting shrub hedges in drainage ditches could also be a measure to prevent the establishment or survival of common reed seedlings along newly created highways, especially where the roads cross wetlands highly susceptible to be invaded.

for its growth; (2) there is usually no competition with shrubs and trees for light and space; and (3) the species is tolerant to deicing salt and frequent mowing (Brisson et al. 2010; Haslam 1972; Mal and Narine 2004; Vasquez et al. 2006).

Even though roadsides, and especially those of paved roads which are larger and sunnier (see Lelong et al. 2009 for details), are prone to common reed invasions, we recently noted that large tracts of roadsides—apparently propitious for the establishment of the plant—are exempt of the grass. This phenomenon is particularly intriguing in the St. Lawrence River lowlands of southern Quebec where a very large proportion of roadsides have been colonized by the plant (Lelong et al. 2009). Recent genetic studies from eastern Canada (Belzile et al. 2010; Kirk et al. 2011) have clearly shown that the establishment of new common reed populations essentially results from seed dispersal, which is usually a very efficient mechanism for rapidly invading new sites, especially far from the parent plants (Barrett 2011). It is unclear whether it is only a matter of time before these roadsides are colonized, or if they present characteristic which are safeguarding them from invasion. We hypothesized that the absence of the invader along these roadsides is associated with physical (soil types) and biological (trees and shrubs in ditches) characteristics. Precisely identifying these characteristics will help road system managers to identify sectors vulnerable to invasion, and eventually to justify the promotion of planting protective vegetation. To test this hypothesis, we developed statistical models, based on biotic and abiotic characteristics, to explain the presence or absence of the common reed along a highway located in a region of southern Quebec highly invaded by the species. This highway (H30) was selected because of contrasting patterns of common reed distribution; the southern part is densely colonized by the species and the northern part has only a few common reed populations.

Materials and Methods

Study Area. The spatial distribution of the common reed along highways in southern Quebec was studied in 2003 by Jodoin et al. (2008). The common reed was found to be widely distributed, especially in the region surrounding the city of Montreal (the Montérégie administrative region). However, field observations highlighted the fact that along H30, particularly in the section located between H20 and the town of Sorel, the common reed was more sparsely distributed, especially near Sorel (Figure 1). This is in stark contrast with the other sections of H30, where the common reed forms continuous hedges in the drainage ditches bordering the highway (Jodoin et al. 2008; Figure 2a).

The H30 was sampled in July and August 2010 between H20 (km 130) and Sorel (km 180), which corresponds to 100 km (62 mi) of drainage ditches, 50 km on each side of the highway. The central drainage ditch separating opposing lanes was not sampled for safety reasons. This highway section has two distinct parts. The land around the northern part (23 km long) is covered by sandy surface deposits (Soil Landscapes of Canada Working Group 2010) and is more forested (Figure 1). The southern part (27 km long) is covered by clay soils, and the surrounding landscape is largely dominated by agricultural lands used for the cultivation of corn and soybean.

Data Sampling. The H30 is subdivided into 1-km-long segments separated by official kilometer markers positioned along the highway. A total of 93 sampling sites, located in front of each kilometer marker on both sides of the highway, were surveyed. It was not possible to sample seven additional sites because of the presence of an exit road very close to the kilometer marker. Six environmental characteristics that could potentially explain the presence (or absence) of the common reed along H30 were sampled at each site. Four characteristics were easily sampled in the field: (1) the roadside width, i.e., the distance from the border of the paved road to the bottom of the drainage ditch (prediction: a larger width favors the presence of the common reed by offering more habitat space); (2) the roadside slope (a slighter slope favors the common reed through less effective drainage); (3) the presence of water in the drainage ditch (all sites were sampled the same day in August) (the presence of water in the drier part of the summer favors the common reed); and (4) the presence of an agricultural field bordering the highway (the presence of a field favors the common reed by supplying a nutrient resource such as fertilizers or by being a source of additional disturbance, e.g., herbicides, soil erosion, etc.).

The other two characteristics required more sophisticated sampling or laboratory procedures. (5) The percentage

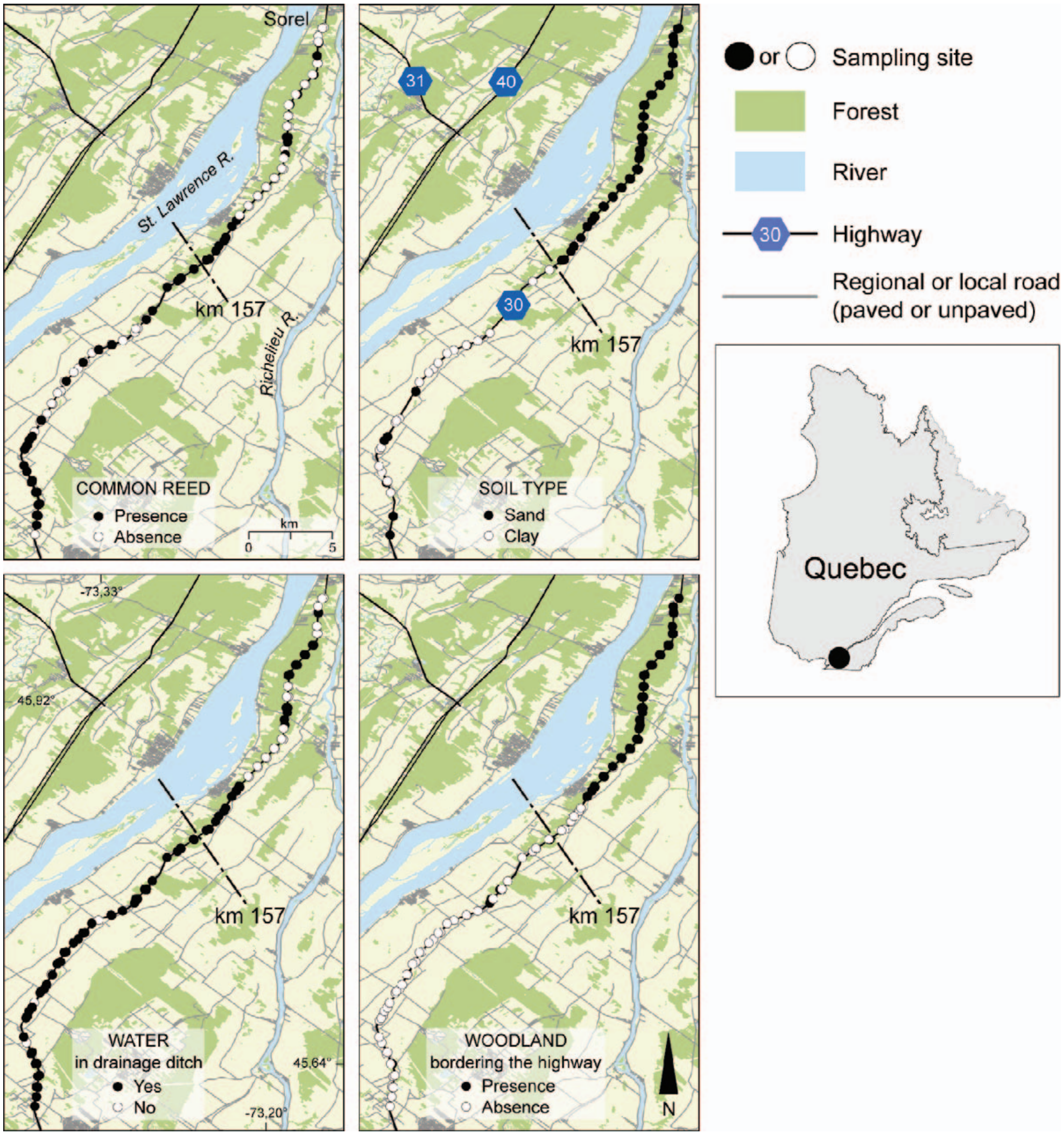

Figure 1. Presence or absence of the common reed in front of the kilometer markers located on both sides of the Highway 30 (Quebec, Canada) in summer 2010. Other characteristics of the sampling sites (sandy or clay soil types, presence of water in the drainage ditch, woodland directly adjacent to the highway) are also mapped. The border between north and south sections of the highway (km 157) is indicated. (Color for this figure is available in the online version of this paper.)

of clay in the top 15 cm of soil was determined from five samples collected in the bottom of the ditch at 3-m (9 ft) intervals. In the laboratory, the particle size was determined following Boyoucos (1962); the size distribution provided an accurate estimation of the clay, sand, and silt content. We predicted that the higher the clay content, the higher the probability of common reed presence, because clay soils are usually poorly drained compared to sandy soils. (6) The cover by woody plants (shrub or tree species) over the drainage ditch was assessed using nine digital photographs taken in the bottom of the ditch, at 1-m elevation from the ground and at 2-m intervals along the ditch. The camera, on a tripod, was oriented toward the sky, and the photograph was taken after a clearing of the field of vision from grass and forb species. A grid with 100 squares was then digitally superimposed on each photograph and the vegetation cover (presence of a woody plant) was assessed for each square, permitting us to calculate the average percentage of squares with a woody plant over the nine photographs of each site. We predicted that the higher the

Figure 2. (a) Dense common reed population occupying the drainage ditch separating each roadway of Highway 30 (Quebec, Canada); (b) drainage ditch along the northern section of Highway 30 densely shaded by trees and shrubs from the forest located at the edge of the roadside; (c) destruction of shrub and tree hedges in 2011 along the Highway 40 (Quebec), such actions are likely to facilitate the establishment of new common reed populations in the disturbed roadside ditch because of the removal of woody plant competitors; (d) willows (*Salix miyabeana* Seemen) along a section of Highway 50 (Quebec), newly opened in 2011, that were planted to prevent the establishment or survival of common reed seedlings in the drainage ditches through competition for light and space. Photographs: (a) J. Brisson; (b) A. Albert; (c) C. Lavoie; (d) P. Boivin). (Color for this figure is available in the online version of this paper.)

woody plant cover, the lower the probability of common reed presence because this species is particularly shade intolerant (Havens et al. 2003; Jodoin et al. 2008; Lelong et al. 2009).

Statistical Analyses. Two binary logistic regression models (Hosmer and Lemeshow 2000) correcting for potential problems of variance heteroskedasticity (White 1980) were constructed with the data. The presence (1) or absence (0) of a common reed population at a sampling site was the binary dependent variable explained by the models. The six other variables (environmental characteristics) were integrated into the first model as independent variables. Four variables were continuous (roadside width, roadside slope, clay content, woody plant cover) and two were binary (presence of water in the ditch, presence of an agricultural field). Two additional binary variables were created for the second model, one identifying observations located in the northern (N) part of H30, and one identifying observations located in the southern (S) part. The limit separating the two parts (km 157) was based on the soil type (Figure 1): in the northern part, the mean clay content in the soil was about 10 $\pm$ 10% (standard deviation), whereas it was much higher in the southern part (47 $\pm$ 15%). These two new variables (N and S components), associated to each of the six environmental characteristics, were used in the

Table 1. Results of the two binary logistic regression models, i.e., without or with a north/south component (+N/S), that were used to establish a link between the presence (or absence) of common reed populations and environmental characteristics along the drainage ditches of Highway 30 (Quebec, Canada): a classification table comparing fitted probabilities and dichotomous outcomes. Three sampling sites were not used by the +N/S model, because for one of the environmental characteristic (woody plant cover, S), the observations were not useful for explaining the variance; the variable and the sampling sites were thus rejected.

Prediction (model)	Observation (in the field)		
	Presence	Absence	Total
Model 1			
Presence	34	18	52
Absence	9	32	41
Total	43	50	93
Model 2 (+N/S)			
Presence	29	12	41
Absence	14	35	49
Total	43	47	90

second model, for a total of 12 variables. This approach was equivalent to producing a specific model for each part of the highway, although it specifically tested the effects of northern and southern locations of sampling sites directly through the variables.

Three approaches were used to evaluate the goodness-of-fit and the performance of the models. The first relied on the pseudo R^2 measure (McFadden 1974), the second on the comparison of predicted probabilities with sample frequencies (Hosmer and Lemeshow 2000), and the third on the comparison of predicted outcomes with actual outcomes using a classification table (Cameron and Triverdi 2009). The Stata and GeoDa software applications (Anselin 2006; StataCorp LP 2009) were used for calculations and to test for possible influence of spatial autocorrelation on the models (Moran 1950).

Results and Discussion

Of the 93 sites sampled, 43 were invaded by the common reed (Figure 1). Common reed populations were found in 25 sites in the southern part of H30 ($n = 47$) and 18 sites in the northern part ($n = 46$). Water was found in the drainage ditch of almost all (93%) sampling sites colonized by the plant. In the northern part of H30, only 29% of sites without common reed had water. The ditches were totally free from shrubs and trees in most (81%) of the invaded sites.

The statistical models, without and with (+N/S) the north/south component, explained 23 and 30% of the total variance (presence/absence of the common reed), respectively. The Hosmer–Lemeshow statistic, which was not significant at more than 31% and 61% (+N/S), indicated

Table 2. Results of the two binary logistic regression models, i.e., without or with a north/south component (+N/S), that were used to establish a link between the presence (or absence) of common reed populations and environmental characteristics along the drainage ditches of Highway 30 (Quebec, Canada).

Variable	Variable type	β (slope)	Odds ratio	Wald's statistic	P
Model 1					
Woody plant cover	Continuous (%)	−0.03	0.97	10.69	< 0.001
Presence of water	Binary (0/1)	1.81	6.09	4.04	0.044
Roadside slope	Continuous (°)	0.16	1.17	1.82	0.177
Presence of an agricultural field	Binary (0/1)	−0.69	0.50	1.23	0.268
Roadside width	Continuous (m)	0.11	1.12	0.55	0.459
Clay content	Continuous (%)	−0.01	0.99	0.30	0.580
Model 2 (+N/S)					
Presence of water, N	Binary (0/1)	2.80	16.41	6.40	0.011
Woody plant cover, N	Continuous (%)	−0.04	0.96	6.10	0.013
Roadside slope, N	Continuous (°)	0.29	1.33	3.10	0.078
Presence of an agricultural field, S	Binary (0/1)	−1.18	0.31	2.22	0.136
Clay content, N	Continuous (%)	0.04	1.04	1.23	0.268
Roadside width, S	Continuous (m)	0.26	1.29	1.17	0.280
Presence of an agricultural field, N	Binary (0/1)	1.09	2.98	1.00	0.320
Roadside slope, S	Continuous (°)	0.07	1.07	0.14	0.715
Presence of water, S	Binary (0/1)	0.38	1.46	0.08	0.776
Clay content, S	Continuous (%)	0.01	1.01	0.06	0.805
Roadside width, N	Continuous (m)	−0.03	0.97	0.02	0.883

Table 3. Results of the two binary logistic regression models, i.e., without or with a north/south component (+N/S), that were used to determine the relationship between the presence (or absence) of common reed populations and some environmental characteristics along the drainage ditches of Highway 30 (Quebec, Canada): spatial autocorrelation analyses among residuals, with a comparison between one, two, three, four, or five neighbors, for a cut-off criterion probability of 0.05.

Form of the W matrix	Statistics[a]			
Nearest neighbors	Moran's *I*	E (*I*)	Var (*I*)	t-stat
Model 1				
1	0.0044	−0.0109	0.1367	0.11
2	0.0987	−0.0109	0.0948	1.16
3	0.1892	−0.0109	0.0788	2.54
4	0.1491	−0.0109	0.0724	2.21
5	0.1599	0.0109	0.0639	2.33
Model 2 (+N/S)				
1	−0.0524	−0.0109	0.1416	0.29
2	0.0588	−0.0109	0.0951	0.73
3	0.1687	−0.0109	0.0780	2.30
4	0.1329	−0.0109	0.0687	2.09
5	0.1390	−0.0109	0.0625	2.40

[a] E (*I*) indicates the expected value of Moran's *I* under the null hypothesis; Var (*I*) indicates the variance of Moran's *I*; *t*-stat indicates the value of the *t* test.

that there was no significant difference between field observations and model predictions for presence/absence of the plant. Moreover, the models correctly predicted 71% of the presence or absence of common reed along H30 (Table 1). The first model produced a better prediction of presence (79%) than of absence (64%), whereas the reverse (67% and 74%) was obtained for the +N/S model. No correlations between independent variables were significant in both models. Other recent regression models explaining the presence of plant invaders along southern Quebec roads had a somewhat better performance for correct presence/absence predictions (78 to 89%; Joly et al. 2011; Meunier and Lavoie 2012), but the H30 models explained a larger fraction of the total variance than other very similar models built for the common reed (18 to 21%; Jodoin et al. 2008; Lelong et al. 2009).

In the first model, two (water and woody plant cover) of the six independent variables that were used in the logistic regression analysis were significant ($P < 0.05$; Table 2). The woody plant cover was weighted more heavily in the model (Wald's statistic). The model indicated that there were significantly lower chances of finding a common reed population in a shaded drainage ditch than in a ditch without trees and shrubs. Moreover, the probability of finding a common reed population along the highway was higher in wet sites than in dry sites. The second model (+N/S) suggested that water and woody plant cover only had a significant impact in the northern section of H30 (Table 2); in the southern section where the landscape is much less forested, no environmental factors explained the presence/absence of common reed, probably because too few sites had a woody plant cover (Figure 1). In summary, the drier and shadier a ditch, the less likely the presence of common reed.

There was a significant ($P < 0.05$) spatial autocorrelation among residuals, as indicated by the Moran's *I* statistic (Table 3). A weak spatial autocorrelation was present when considering the first two, three, or four nearest neighbors (model without N/S), or for the three or four nearest neighbors (model with N/S). The introduction of the N/S component reduced the values of Moran's *I* statistic; these values were low and not likely to play a fundamental role in the outcomes.

Land managers from the Department of Transportation of Quebec, in charge of the maintenance of highways, have suggested that the well-drained sandy soils of the northern part of H30 were intrinsically resistant to the establishment of common reed (G. Bédard, personal communication). This is possible, but the absence of common reed is more likely associated with the drier nature of sandy soils than with other physical or chemical soil properties (our H30 models and Lelong et al. 2009). Moreover, sandy soils are not very suitable for the cultivation of corn or soybean, whereas properly drained rich clay soils are more appropriate for large-scale crops, at least in this part of southern Quebec (Domon and Bouchard 2007). Woodlands on sandy soils are thus less likely to be cleared for cultivation (Bouchard and Domon 1997; Domon and Bouchard 2007; Pan et al. 1999), and consequently more likely to border a road located in their vicinity (Figure 2b). The H30 models suggest that a dense woody plant cover over a drainage ditch prevents the establishment or the subsequent expansion of the common reed, a result also suggested by other studies (Havens et al. 2003; Jodoin et al. 2008; Lelong et al. 2009). Finally, shaded ditches are apparently less frequently maintained and are therefore less disturbed. The germination of common reed seeds is less likely without soil disturbance (Brisson et al. 2008; A. Albert, unpublished data). This probably explains why some sites along the southern part of H30, which have apparently not been recently excavated for maintenance, have not yet been invaded. Unfortunately, we have no data on the maintenance history of H30 to test this assertion.

In jurisdictions such as Quebec where the use of herbicides is prohibited for controlling the common reed, preserving well-established shrub or tree hedges along roadside ditches would probably be an effective low-cost alternative to prevent common reed invasions. Unfortunately such hedges are sometimes destroyed for "aesthetic" reasons (Figure 2c), while paradoxically, experimental shrub hedges have been implanted elsewhere along newly created highways to protect against common reed invasion (Figure 2d; Boivin et al. 2011). This study adds to the growing body of evidence suggesting that woody plants can help control the spread of invasive grasses (Foster and Wetzel 2005; Kim et al. 2006) in addition to providing other services such as landscape beautification and noise reduction.

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