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Impact of quarantine procedures on weed biodiversity and abundance: Implications for the management of the golden potato cyst nematode, *Globodera rostochiensis*

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ABSTRACT

In 2006, the golden nematode, *Globodera rostochiensis*, a regulated pest causing heavy losses in potato fields was discovered in Quebec, Canada. The rapid application of quarantine measures by the Canadian Food Inspection Agency significantly changed the use and management of infested fields. The objectives of this study were to assess the evolution of weed populations following these measures and assess their impact on the management of *G. rostochiensis*. A comparison of weed inventories conducted in 2008 and 2011 on the edges of the affected fields has shown that the composition of the flora had changed considerably. Alarmingly, the presence of Solanaceae that could potentially serve as host plants for the potato cyst nematode increased significantly. The biodiversity index was also significantly affected by this change and decreased by more than 50% between the two years. Interestingly, the lowest biodiversity was observed in one of the few fields where potatoes were grown in 2011 and where an explosion of *Solanum sarrachoides* was observed. Meanwhile, eight species of nightshade were evaluated for their ability to support the growth of *G. rostochiensis*. *Solanum villosum* allowed the greatest rates of reproduction while only a few cysts were produced on *Solanum nigrum* and *Solanum dulcamara*. This study has shown that the modifications in weed control regimes associated with the implementation of quarantine procedures could hamper its success by favouring the multiplication of potential pest refuges.

1. Introduction

Potato cyst nematodes (PCN), *Globodera pallida* Stone and *Globodera rostochiensis* (Wollenweber) Skarbilovich, are serious quarantine pests of potato that cause severe damage. Once established in a new area, they are very difficult to eradicate because of their ability to survive for extended periods without a suitable host (Turner, 1996). Both species have co-evolved with their host in the Andean regions of Peru and Bolivia, in South America (Grenier et al., 2010). *G. rostochiensis* is now found in 75 countries around the world (Yu et al., 2010). In Canada, it has been present since 1962 in Newfoundland (Olsenand and Mulvey, 1962) and since 1965 in British Columbia (Orchard, 1965). More recently, *G. rostochiensis* was detected in several fields in Quebec (Sun and Miller, 2007). These areas have been subject to strict quarantine regulations and a recent survey on Vancouver Island, British Columbia showed that fields with no known quarantine infractions were found to be free of viable cysts (Rott et al., 2010). Quarantine measures have also proven to be effective in New York State where United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) announced on December 2010 that two counties had been removed from the quarantine area after being tested free of PCN (USDA APHIS PPQ, 2011). This was the first deregulation since the establishment of *G. rostochiensis* quarantine area in 1944.

Since it is imperative to react promptly following the discovery of a regulated pest, changes in field usage and management practices can be abrupt. Producers often turn to alternative crops that they are less familiar with and work is frequently contracted out. The combination of rapid change, new crops and cultivation

Abbreviations: PCN, Potato cyst nematode.

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practices that may not be optimized could impact the weed composition at the field margins. It is of interest to understand how these changes may affect the dynamics of disease and efficacy of quarantine procedures. We chose to focus on the impact of *G. rostochiensis* quarantine procedures on weed biodiversity in quarantined fields as weeds are generally good hosts for plant-parasitic nematodes (Bélair and Benoit, 1996).

In soybean, it is well known that various weeds may enable soybean cyst nematode reproduction in infested fields during the early or late growing season, even when soybean plants are absent (Venkatesh et al., 2000). There are also reports in the literature that PCN can reproduce on weeds belonging to the same family as potato (Solanaceae) (Bates, 1945; Boydston et al., 2010; Rott et al., 2011; Sullivan et al., 2007). In this case, even if a good rotation system with non-host crops is implemented, the nematode could still survive and multiply if such weeds were present in and around the fields. Nightshades are *Solanum* species that have a widespread distribution. They are already known to substantially reduce yield in several major crops and to interfere with harvest, causing reduction in crop quality (Crotser and Witt, 2000; Majek, 1981). Sullivan et al. (2007) listed over 30 nightshade species as potential hosts for PCN. In the province of Quebec, four species of nightshade have been recorded in the past: *Solanum nigrum* L., *Solanum dulcamara* L., *Solanum sarrachoides* Sendtner (Doyon et al., 1987) and *Solanum pseudocapsicum* L. (Lemieux, 1988). *S. sarrachoides* has previously been reported in 11% of the surveyed potato fields of the region of Lanaudière (Doyon et al., 1987). A recent study on *G. pallida* host range has indicated that *S. sarrachoides* and *Solanum physalifolium* Rusby were good host plants, while the other species tested (*S. dulcamara*, *Solanum triflorum* Nutt. and *S. nigrum*) were unable to support *G. pallida* reproduction (Boydston et al., 2010). For *G. rostochiensis*, Doncaster (1953) showed that *S. nigrum* is resistant but conflicting results are found in the literature and the same species is often rated both resistant and susceptible by different authors (Prummel, 1958; Sullivan et al., 2007).

Recently, Rott et al. (2011) showed that most of the nightshades were resistant to *G. rostochiensis* populations from Newfoundland and British Columbia, Canada. No reproduction was observed on *Solanum americanum* Mill., *S. physalifolium*, *Solanum carolinense* L., *Solanum ptycanthum* Dunal, *Solanum rostratum* Dunal., *Solanum sisymbriifolium* Lam., *S. sarrachoides* and *S. triflorum* Nutt. Most of the *S. nigrum* tested were also fully resistant to *G. rostochiensis*. Conversely two accessions (probably hybrids between *Solanum villosum* Mill. and *S. nigrum*) were found to be susceptible to *G. rostochiensis* from Newfoundland but resistant to the British Columbia isolate. The most problematic weeds were *S. dulcamara* and *S. villosum* for which susceptible plants to *G. rostochiensis* have been found.

In 2006, a unique opportunity arose in Canada with the detection of *G. rostochiensis* in several fields in Quebec (Mahran et al., 2010; Sun and Miller, 2007; Yu et al., 2010) and the subsequent implementation of quarantine measures in these fields. This situation allowed for the assessment of weed populations over time following PCN quarantine measures. More specifically, the occurrence, cover and distribution of *Solanum* spp. were considered in these fields and the host status of *Solanum* spp. to the Quebec population of *G. rostochiensis* was determined in controlled experiments.

2. Material and methods

2.1. Weed survey

2.1.1. Inventories

All the fields tested were sandy soils either in commercial production ($n = 21$), in meadow ($n = 2$) or an experimental site for Agriculture and Agri-Food Canada (AAFC) ($n = 1$) located in the quarantine area of the locality of St-Amable, QC. In each field, the percent cover of weeds was evaluated in 0.5 m by 1 m (0.5 m^2) quadrats. One quadrat was placed every 50 m along all sides of the field or closer in smaller fields (less than 150 m/side) in order to obtain a minimum of three observations per side. The composition of the immediate environment (river, forest, grass, road, etc.) and the adjacent crop (corn, potato, etc.) were also noted for each quadrat. In addition, the edges of the fields were walked and every weed belonging to the Solanaceae family was identified to the species level and its geographical position determined using a GPS device. The inventories were repeated in the same fields during the summer of 2008 and 2011.

2.1.2. Biodiversity

All statistical analyses were performed using the R software environment (R Development Core Team, Vienna, Austria). Average weed richness and diversity (functions *specnumber* and *diversity* in the vegan package, Oksanen et al., 2008) were estimated for the whole dataset ($n = 1470$ points, 22 fields) and compared between years using the *t*-test (*t.test* function in stats package in R). To characterize the weed composition, a truncated and pre-transformed matrix of weed-species cover was used: species which occurred in less than 10% of the points were eliminated and the percentage cover of the weed species was subjected to a Hellinger's transformation (function *decostand*, vegan package in R), which is well suited for community analyses of such data. The Hellinger's transformation gives less weight to abundant species and avoids problems arising from Euclidean distance where the distance between two sites sharing no species can be smaller than that between two sites sharing species (Legendre and Gallagher, 2001). The influence of year, cultivation type and adjacent environment on weed composition in the field margins was evaluated using a redundancy analysis (RDA).

2.1.3. Changes in occurrence and cover of Solanaceae spp. in field margins

To estimate the spread of *Solanaceae* spp. in the field margins, we compared the frequency, cover, distribution and aggregation of *S. sarrachoides* and *Solalum tuberosum* in 2008 and 2011. For each field, the frequencies of occurrence were estimated as the ratio of the number of quadrats in which either species was present over the total number of quadrats visited, and the average percentage cover when the species were present. The values between the two years were compared using a paired *t*-test.

2.1.4. Changes in patch size and aggregation

The distribution and aggregation of *Solanaceae* spp. were estimated by calculating patch number and average patch size and changes between years for each field and for the entire dataset. Patch sizes were calculated using the GPS coordinates of points with Solanaceae as the number of consecutive points where the presence of either *S. sarrachoides* or *S. tuberosum* had been registered within a maximum of 15 m of each other (to account for GPS error). A relative size was used based on the number of points, where a single point would have a value of one. Re-occurrence of single points and patches between years was also estimated to determine if the patches were likely to persist over time once established.

2.2. Host range study

2.2.1. Solanum weeds accessions

Seeds of *Solanum* weeds were obtained from the United States Department of Agriculture (USDA) Germplasm Resources