Recent Expansion of *Spiranthes cernua* (Orchidaceae) into Northern Ontario due to Climate Change?

PAUL M. CATLING[1] and MICHAEL J. OLDHAM[2]

[1]Agriculture and Agri-Food Canada, Environmental Health, Biodiversity, Saunders Building, Central Experimental Farm, Ottawa, Ontario K1A 0C6 Canada; e-mail: catlingp@agr.gc.ca

[2]Ontario Natural Heritage Information Centre (NHIC), Ontario Ministry of Natural Resources, 300 Water Street, 2nd Floor, North Tower, P.O. Box 7000, Peterborough, Ontario K9J 8M5 Canada; e-mail: michael.oldham@ontario.ca

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The expansion northward since 1980 of the native orchid Nodding Ladies'-tresses (*Spiranthes cernua*) in Ontario is described and assessed with respect to the possibility of the expansion being a recent response to climate change. Based on evidence of the extent of the orchid's distribution from prior botanical surveys, it is considered to be a recent arrival in a previously unoccupied area of northern Ontario. Second-order polynomial regression revealed a significant increase in mean yearly temperature of 1 Celsius degree in parts of northern Ontario since 1980. Based on close association with limits of yearly temperature, this is considered sufficient to explain the expansion, and the individual extensions of range fit well into the anticipated newly available territory. Based on a consideration of the location of extensions with respect to plant hardiness zones, the landscape that has become available since 1980 is 160 000 km^2, in a band approximately 200 km wide across the southern part of northern Ontario. Assuming further temperature increases, this band is expected to expand to a width of approximately 300 km by 2040, providing 360 000 km^2 of newly available landscape over six decades. *Spiranthes cernua* produces thousands of seeds per flower by adventitious embryony, allowing single individuals to establish populations through long-distance wind dispersal with no reliance on pollination. *Spiranthes cernua* is therefore well adapted to quickly colonize new territory that becomes available through climate warming.

Key Words: *Spiranthes cernua,* Nodding Ladies'-tresses, orchid, range extensions, climate change, Ontario, Canada.

As a result of both field reconnaissance and a survey of major collections (Canadian Museum of Nature (CAN), Agriculture and Agri-Food Canada (DAO), Royal Ontario Museum (TRT), and Erindale College, University of Toronto (TRTE)) (acronyms follow Holmgren 2005*), we noticed that a conspicuous native orchid species, Nodding Ladies'-tresses (*Spiranthes cernua* (L.) Rich.), had extended its range northward into cooler regions of Ontario beyond the range limit indicated in a synthesis of geographic distributions up to 1980 (Whiting and Catling 1986). The objective of the present work is to assess the evidence for recent northward expansion since 1980, to determine the likelihood of this being due to climate change, and to project current and future potential distributions.

Methods

Assessment of range extensions

We obtained additional information on recent expansion of *Spiranthes cernua* from label data from recently collected herbarium specimens at the herbarium of Algoma University College, CAN, DAO, Royal Botanical Gardens (HAM), Ontario Ministry of Natural Resources (NHIC), Queen's University (QK), TRT, TRTE, University of Western Ontario (UWO), and University of Waterloo (WAT). We also gathered information from databases and field botanists, and we conducted field surveys in the region of interest. The number of specimens collected/observed was insufficient to allow any statistical tests of significance to be applied or to indicate periods of spread using proportion curves (e.g., Delisle et al. 2003). The interpretation of these range extensions is subject to the bias related to variation in sampling effort that applies to all collections, but interpretation taking this bias into account is possible, as described below.

To obtain a general view of distribution using a dot distribution map (Figure 1), we consulted the following sources: Whiting and Catling (1986) for Ontario distribution up to 1980; Smith (1993) and Homoya (1993) for the states of Minnesota and Indiana (respectively); Case (1987) for the rest of the western Great Lakes region; Barker et al. (1977) for the area west of the Great Lakes; Angelo and Boufford (2010*) for New England; Welby and Werier (2010*) for New York; and Rhoads and Klein (1993) for Pennsylvania. For the Quebec distribution, the map in Catling (1980) was employed. The distribution was obtained by positioning of the grey dots on a base map using map overlays from photographs of maps in the preceding texts using Arcmap 9.3.

After the distributions and range extensions had been established and mapped, we considered the possibility that the plant had been overlooked in its newly discovered areas of occurrence. Since *Spiranthes cernua* is conspicuous as a result of white inflorescences 3 cm wide and up to 10 cm long and it grows in open habitats such as roadsides and shorelines, we believe that it is unlikely that it was overlooked in botanical surveys that were done in the region of new occurrence. *Spiranthes cernua* blooms in late summer and fall, but botanical surveys are frequently carried out during this period so as to include many late-blooming species. Thus the late blooming time is not considered a factor that would lead to the species being overlooked.

Assessment of climate change

The northward extensions are assessed with respect to the possibility that they represent a recent response to climate change. The basic question has two components: (1) has the climate changed and (2) has it changed enough over three decades to enable a change in distributional limit?

(1) The extent to which climate has changed in the region of concern in northern Ontario was considered with regard to historical data on mean yearly temperature, which is closely associated with plant distribution limits in the province. The mean yearly temperature may be only a surrogate for an actually influential array of climatic phenomena, including frost-free period, snow cover, winter temperature, and growing degree days. It is, however, not a concern with regard to the present application, because a change in mean yearly temperature can still reliably suggest a trend.

Data on mean yearly temperature were obtained from Environment Canada (2010*). Three stations in the general region of the extensions—North Bay, Timmins, and Kenora—were used to determine trend, since these had a continuous record spanning many decades. Data for Timmins and Kenora were available for the period 1940–2010, and data for North Bay were available for the period 1960–2010. A second-order polynomial regression was used to obtain a reasonable line fit to the data. This method was used because the value of the highest order term was significant or nearly significant at the 95% level and the R-squared values indicating amount of variation explained by the fit were higher than for lower order models.

A significant relationship between year and temperature was obtained with an analysis of variance (ANOVA). The two dashed lines closest to the regression line on the plots indicate the 95% confidence limits for mean response at a given value of X, and the furthest pair of dashed lines indicates the range within which 95% of observations would occur for predictions. All of the statistical procedures and plots utilized Statgraphics Centurion 15 software (Statpoint 2005*).

(2) Has the climate changed enough over three decades to enable a change in distributional limit? A number of authors have noted that the distributional limits of plants in Ontario are correlated with climatic conditions (e.g., Cody 1982; Reid 1985). The mean yearly temperature isotherm of 7.8°C (Brown et al. 1980), for example, corresponds well with the irregular northern limit of the Carolinian zone in southern Ontario, as established by W. S. Fox and J. H. Soper, based on the northern limits of 54 plant species (e.g., Soper 1962). Yearly temperature isotherms for northern Ontario (Chapman and Thomas 1968) also correspond approximately to plant distribution limits (personal observation, PMC). The correspondence is nearly exact with regard to a particular irregular isotherm over hundreds of kilometres where the difference between the isotherms is 1–2 Celsius degrees. Since landscape conditions are similar on each side of many of these limiting lines, it is strongly implied that it is climate rather than substrate which is the salient factor. Thus a change of 1–2 Celsius degrees appears to be sufficient for distribution to assume a new isotherm limit.

Since the position of isotherms on the landscape is controlled by major landscape features, the value of the lines may change with time but the lines may remain in more or less the same position on the landscape. If an isotherm assumes a new and higher value, the associated distributional limit of an organism should be able to move to the new isotherm limit so that potential new range can be delineated by expansion to the next limiting line. The area between the old limiting isotherm and the new limiting isotherm is the "new territory," and this can be inferred on maps of isotherms when the amount of warming is known. Although substrate features may play a role in distributions, in the present case the entire region under consideration is the Canadian Shield with essentially similar landscape throughout. For climate change to be an explanation for northward expansion, we consider a minimum requirement to be a significant relationship between temperature and year with an increase in 1 Celsius degree since 1980. If the extensions fit nicely into the anticipated new territory associated with such an increase, then the possibility of climate warming playing a role is further supported.

Determination of current potential distribution and future distribution

To indicate current potential distribution, we anticipated full occupation of hardiness zones (Agriculture and Agri-Food Canada 2010*) presently occupied by northward range extensions since 1980. Hardiness zones, which are based on an assessment of plant response to climate and an assessment of climate data, were updated in 2000 to reflect recent changes in Canadian climate and to develop a more objective approach to climate mapping (McKenney et al. 2001). This version of the hardiness zones was used throughout. Mean maximum temperature of the coldest month and frost-free days are the most important correlates of hardiness, but mean yearly temperature, length of growing season, and many other factors are also highly correlated.

A future potential distribution area was determined based on a projected temperature increase of 1 or 2 Celsius degrees between 2011 and 2040 (using a higher greenhouse gas scenario) (Colombo et al. 2007*) and the correspondence between hardiness zones (Agriculture and Agri-Food Canada 2010*) and mean yearly temperature.

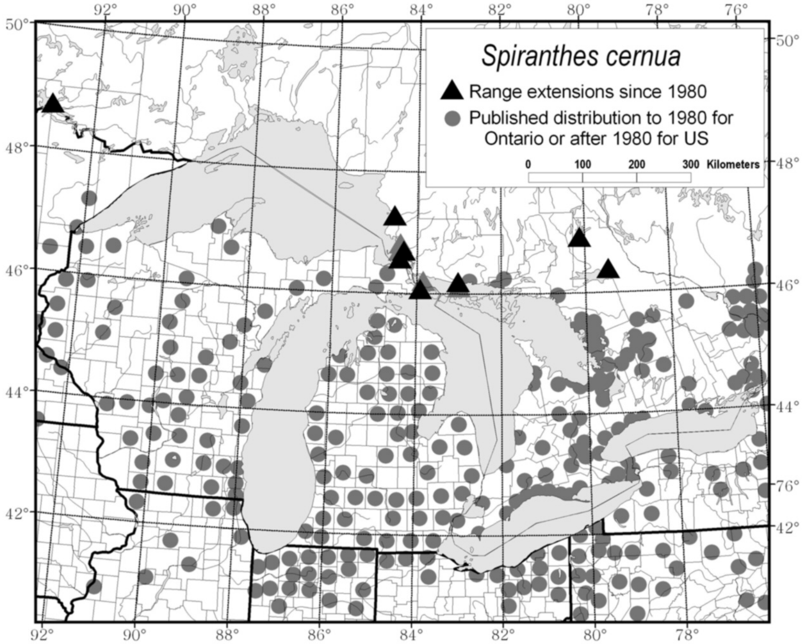

FIGURE 1. Distribution of *Spiranthes cernua* (Nodding Ladies'-tresses) in the north-central part of its range, showing northward range extensions in Ontario since 1980 (triangles). Black triangles indicate collections and grey triangles indicate sight records. Either kind of triangles are centered over one or more location and/or sight records of the plant. The positioning of the grey dots was achieved with map overlays from texts listed in Methods.

Results and Discussion

Documentaion of extensions

The first record of *Spiranthes cernua* for the Lake Superior drainage in Ontario was made by Larry Johnson on 10 September 1994 in Algoma District, Lake Superior Provincial Park, at the south end of Kenny Lake, 47.28°N, −84.56°W (photo, DAO). It was also found here subsequently on 10 September 2005 by M. J. Oldham and W. D. Bakowsky (*32205*, DAO). Other range extensions for Algoma District include extensive peatland on the east side of Highway 17, south of Goulais River, 46.71°N, −84.34°W, 12 August 2001, *M. J. Oldham and W. D. Bakowsky 26664* (DAO, MICH); the north side of Highway 17, ca. 1 km east of Pancake River bridge, 46.96°N, −84.64°W, 10 September 2003, *W. D. Bakowsky and M. J. Oldham 2003-134* (DAO); Sault Ste. Marie, gravel pit on the west side of Maki Road, northwest outskirts of town, 46.57°N, −84.42°W, 10 September 2005, *M. J. Oldham and W. D. Bakowsky 32214* (DAO); Fort St. Joseph National Historic Site, between Rains Point and La Pointe, south shore of St. Joseph Island, North Channel of Lake Huron, southeast of Sault Ste. Marie, 46.07° N, −83.93° W, 11 September 2005, *M. J. Oldham and W. D. Bakowsky 32249* (DAO). In addition, there are several sight records by M. J. Oldham and W. D. Bakowsky for western Algoma District (Lake Superior beach, ca. 3 km south of the mouth of Goulais River, near the mouth of Cranberry Creek, north of Sault Ste. Marie, 46.70°N, −84.43°W, 2 September 2005; St. Joseph Island, 46.21°N, −83.86°W, 11 September 2005; South Point of Mississagi Island, North Channel, on the east shore, 7 km south of the mouth of the Mississagi River, 46.11° N, −83.01° W, 29 August 2006; Haviland Bay, Lake Superior, north of Sault Ste. Marie, 46.82° N, −84.41° W, 28 August 2010). *Spiranthes cernua* has now been found in at least nine sites at the southeast corner of Lake Superior in Algoma District (Figure 1) west and north of the range mapped in Whiting and Catling (1986).

Two records in 2010 from north of North Bay in Nipissing District are also range extensions: the west side of Lake Temagami on Gull Lake portage trail, 46.92°N, −80.13°W, August 2010, *D. Adams* (photo, DAO); north of North Bay on Highway 11, 46.40°N, −79.47°W, *P. M. Catling and B. Kostiuk s.n.* (DAO).

One of the most interesting range extensions is in northwestern Ontario (Figure 1), where *Spiranthes cernua* was found on the east arm of Rainy Lake by A. Harris and R. Foster (Harris et al. 2002*). The species is apparently not present near the Canadian border in northern Minnesota (Smith 1993) or in adjacent Manitoba (Ames et al. 2005). The Rainy Lake location approximately 200 km northwest of the nearest location in Minnesota shown by Smith (1993) is the first for northwestern Ontario.

Previous botanical survey work

The area of the east shore of Lake Superior has been extensively studied by Claude Garton, with specimens deposited at Lakehead University (LKHD), but this shoreline has attracted the attention of many botanists, including in particular those based at the Canadian Museum of Nature (CAN) (Hosie 1938; Given and Soper 1981; Soper et al. 1989). Two large parks occur on the eastern shore of the Lake Superior region, Pukaskwa National Park of Canada and Lake Superior Provincial Park, both of which have had botanical surveys conducted in them which did not reveal *Spiranthes cernua* (e.g., Garton 1978*; Ontario Ministry of Natural Resources 1985*; White 1988*; Brunton 1991*). Despite at least three earlier botanical surveys and lists (Ontario Ministry of Natural Resources 1985*; White 1988*; Brunton 1991*), *Spiranthes cernua* was not found in the Lake Superior drainage in Ontario until 1994, when it was found in Lake Superior Provincial Park. The level of botanical work here makes it seem very unlikely that the species was overlooked previously. Most likely it was simply not present.

With respect to northwestern Ontario, Rainy River District has received much less attention than eastern Lake Superior, but there have been inventories of Quetico Provincial Park (Walshe 1980; Ahlgren and Ahlgren 1989*; Scott 2009), and botanists such as Claude Garton (LKHD) have collected in the area. Recent botanical inventory work (since 1990) has also been undertaken in Rainy River District by several botanists (W. D. Bakowsky, S. R. Brinker, R. Foster, A. Harris, M. J. Oldham, P. Scott), resulting in surveys of over 100 sites and the collection of >1000 vascular plant specimens and >5000 sight records. Consequently, it again seems unlikely that *Spiranthes cernua* was overlooked.

With regard to the Temagami area, W. R. Watson conducted an extensive botanical survey of the Temagami Forest Reserve in the early 1920s (specimens at TRT), and this was a region that botanists examined en route to other areas in the north, such as the Clay Belt, that were under study (Baldwin 1958, 1962). Thus the Temagami area is considered to be relatively well known botanically, making the absence of collections of *Spiranthes cernua* there (until recently) also likely due to absence of the plant

There is one final way of obtaining an indication of the extent of prior botanical survey work in the area of these extensions and that is to check a map showing collections of plants in the region of the extensions that occur in the same habitat as the putatively spreading species. Hooded Ladies'-tresses (*Spiranthes romanzoffiana* Cham.) often occurs in the same habitats as *Spiranthes cernua. Spiranthes romanzoffiana* was found prior to 1980 throughout the region of the *Spiranthes cernua* extensions (Whiting and Catling 1986), indicating that botanists had visited habitats in the region

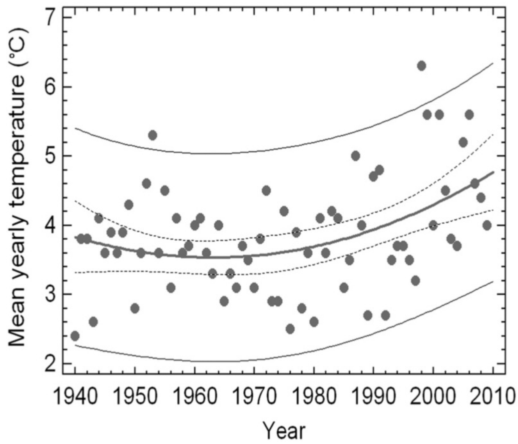

FIGURE 2. Mean annual temperature from 1960 to 2010 at North Bay, Ontario, with fitted second-order polynomial regression.

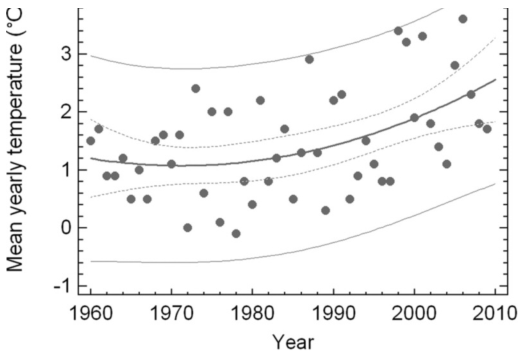

FIGURE 3. Mean annual temperature from 1940 to 2010 at Timmins, Ontario, with fitted second-order polynomial regression.

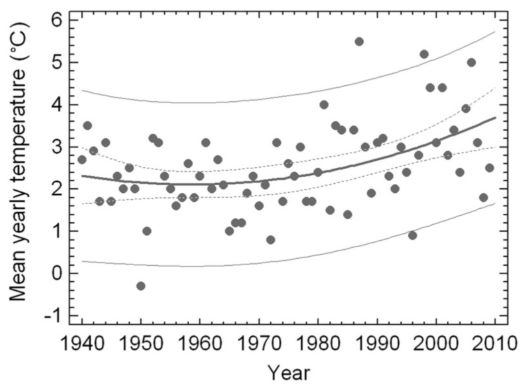

FIGURE 4. Mean annual temperature from 1940 to 2010 at Kenora, Ontario, with fitted second-order polynomial regression.

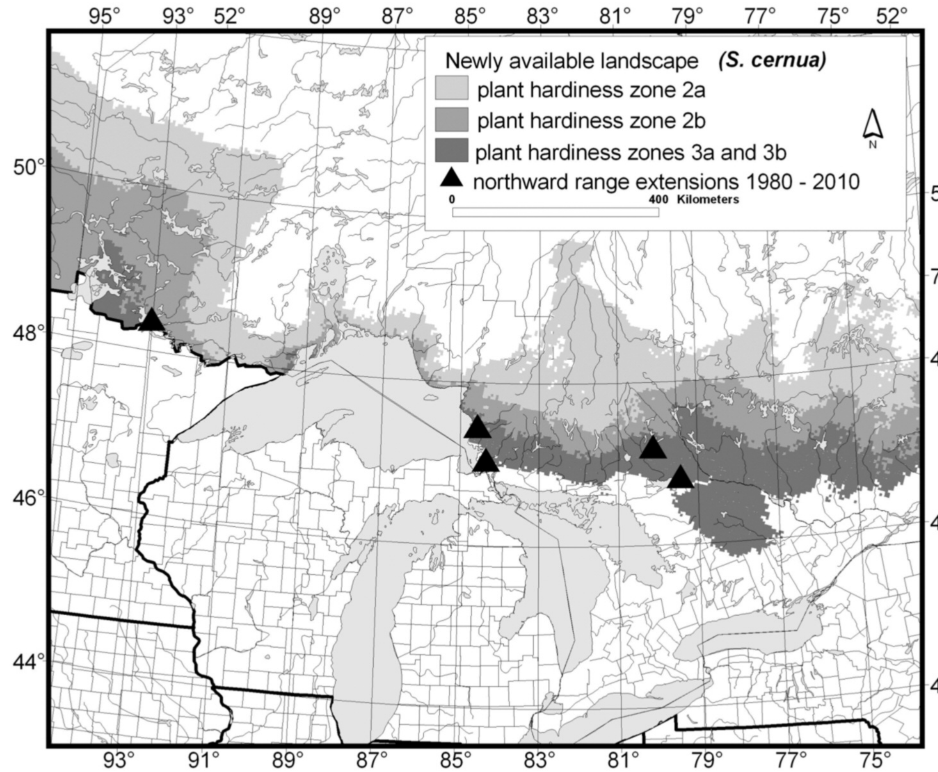

FIGURE 5. Plant hardiness zones (2000 version) 2a (above, – light shading), 2b (middle, – medium shading), and 3a and 3b (combined below, – dark shading) and northward range extensions of *Spiranthes cernua* since 1980 (triangles). Based on the locations of the extensions and the general similarity of the landscape throughout these regions, the current potential distribution of *Spiranthes cernua* extends to the limit of the current zone 3 (a and b). These hardiness zones indicate the landscape that has become available to the species between 1980 and 2010, apparently as a result of climate warming of 1 Celsius degree over that period. By 2040, current zone 2a is expected to be at least partially occupied.

and had found a very similar plant but did not find *Spiranthes cernua*. The same can be found by examining maps of Loesel's Twayblade (*Liparis loeselii* (L.) Rich.) and Tall Northern Green Orchid (*Platanthera aquilonis* Sheviak; = *P. hyperborea* (L.) Lindl.). The evidence thus is strongly in favour of regarding these new occurrences as genuine indications of range extension since 1980.

Has the climate changed enough to explain the extensions?

The polynomial regressions for mean yearly temperature at North Bay, Timmins, and Kenora show a similar trend toward increase by approximately 1 Celsius degree since 1980 (Figures 2, 3, and 4). For North Bay, the P value for the analysis of variance (ANOVA) is 0.0019, indicating a significant relationship between year and temperature, and the R-squared value indicates that the fitted model explains 17.11% of the variability in mean annual temperature. Similarly, for Timmins and Kenora, the P values for ANOVA were 0.0029 and 0.0011, respectively, and the R-squared values were 22.04% and 18.47%, respectively. In all cases, the Durbin-Watson statistic was not significant, indicating absence of serial autocorrelation. Thus climate has changed enough for climate warming to be a factor.

Since older climate data for parts of southern Ontario show lower temperatures throughout the 20th century, the second-order fits are adequate for the present purpose, even though they suggest higher temperatures around 1940; however, the second-order fits cannot be used to extrapolate either forward or backward.

Do the extensions fit well into an anticipated newly available territory?

Prior to 1980, *Spiranthes cernua* generally reached its northern limit in a region indicated as 4.4–5.6°C mean annual temperature (Chapman and Thomas 1968; Brown et al. 1980) or 4–5°C (Watson and MacIver 1995*). Now *Spiranthes cernua* exists within a region that was indicated on these older maps as 2–3°C. The newly available territory extends north to Kenora in the west and north to Timiskaming in the east and includes the general region of Temagami. The extensions fit well into an anticipated new territory that has become available due to an increase of 1 Celsius degree in mean yearly temperature since 1980.

Current distribution and potential future distribution

The landscape (zones 3a, 3b, and 2b), newly available since 1980, is 160 000 km^2, in a band approximately 200 km wide across the southern part of northern Ontario that became available over three decades (Figure 5). Based on further temperature increases of 1–2 Celsius degrees, using a higher greenhouse gas scenario (Colombo et al. 2007*), this band is expected to expand to a width of approximately 300 km by the year 2040, including zone 2a, and provide 360 000 km^2 of newly available landscape over six decades.

Conclusions

The distribution of *Spiranthes cernua* appears to have expanded northward since 1980, based on 15 records within previously unoccupied regions of northern Ontario where the flora has been well documented. The change in climate reflected by the increase of 1 Celsius degree in mean yearly temperature over the past three decades is widespread in northern Ontario within the regions of the extensions and is considered sufficient to explain them. *Spiranthes cernua* produces thousands of very light, wind-dispersed seeds from a single blossom by adventitious embryony so that single individuals are capable of high seed production in situations lacking pollinators; *Spiranthes cernua* can therefore rapidly produce large populations in new areas (Catling 1980, 1982, 1983). However, the use of this species as a bioindicator must take into account the potential for fluctuation in the fraction of plants that flower from year to year. Response to climate change may be occurring more rapidly than anticipated, and the response to it by some organisms may be well underway. Large areas appear to have already become available to species occurring on the southern edge of the boreal shield ecozone, and by 2040 the northern limits of quick response species in this region may have expanded 300 km north of their 1980 position.

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