European Cooperative Programme for Plant Genetic Resources
ECP/GR

Climatic change and genetic resources in northern Europe

Report of a Workshop
18-19 September 2006, Rovaniemi, Finland
M. Veteläinen, Á. Helgadóttir and J. Weibull, *compilers*

Bioversity International

IPGRI and INIBAP operate under the name Bioversity International

Supported by the CGIAR

European Cooperative Programme for Plant Genetic Resources

ECP/GR

Climatic change and genetic resources in northern Europe

Report of a Workshop on "Genetic resources in the northern parts of Europe: current status and the future in relation to major environmental changes"

18-19 September 2006, Rovaniemi, Finland

M. Veteläinen, Á. Helgadóttir and J. Weibull, *compilers*

Bioversity International is an independent international scientific organization that seeks to improve the well-being of present and future generations of people by enhancing conservation and the deployment of agricultural biodiversity on farms and in forests. It is one of 15 centres supported by the Consultative Group on International Agricultural Research (CGIAR), an association of public and private members who support efforts to mobilize cutting-edge science to reduce hunger and poverty, improve human nutrition and health, and protect the environment. Bioversity has its headquarters in Maccarese, near Rome, Italy, with offices in more than 20 other countries worldwide. The Institute operates through four programmes: Diversity for Livelihoods, Understanding and Managing Biodiversity, Global Partnerships, and Commodities for Livelihoods.

The international status of Bioversity is conferred under an Establishment Agreement which, by January 2007, had been signed by the Governments of Algeria, Australia, Belgium, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Chile, China, Congo, Costa Rica, Côte d'Ivoire, Cyprus, Czech Republic, Denmark, Ecuador, Egypt, Greece, Guinea, Hungary, India, Indonesia, Iran, Israel, Italy, Jordan, Kenya, Malaysia, Mali, Mauritania, Morocco, Norway, Pakistan, Panama, Peru, Poland, Portugal, Romania, Russia, Senegal, Slovakia, Sudan, Switzerland, Syria, Tunisia, Turkey, Uganda and Ukraine.

Financial support for Bioversity's research is provided by more than 150 donors, including governments, private foundations and international organizations. For details of donors and research activities please see Bioversity's Annual Reports, which are available in printed form on request from bioversity-publications@cgiar.org or from Bioversity's Web site (www.bioversityinternational.org).

The European Cooperative Programme for Plant Genetic Resources (ECPGR) is a collaborative programme among most European countries aimed at facilitating the long-term conservation and the increased utilization of plant genetic resources in Europe. The Programme, which is entirely financed by the member countries, is overseen by a Steering Committee composed of National Coordinators nominated by the participating countries and a number of relevant international bodies. Bioversity International provides the Coordinating Secretariat. The Programme operates through nine networks in which activities are carried out through a number of permanent working groups or through *ad hoc* actions. The ECPGR networks deal with either groups of crops (cereals; forages; fruit; oil and protein crops; sugar, starch and fibre crops; vegetables, medicinal and aromatic plants) or general themes related to plant genetic resources (documentation and information; *in situ* and on-farm conservation; inter-regional cooperation). Members of the working groups and other scientists from participating countries carry out an agreed workplan with their own resources as inputs in kind to the Programme.

Citation:
Veteläinen, M., Á. Helgadóttir and J. Weibull, compilers. 2007. Climatic change and genetic resources in northern Europe. Report of a Workshop, 18–19 September 2006, Rovaniemi, Finland. Bioversity International, Rome, Italy.

Cover illustration: Winter habit of *Achillea millefolium* L. (yarrow, a medicinal plant) in Ruukki, Finland. Courtesy of © M. Veteläinen, MTT Finland.

Acknowledgements to Dr L. Currah for English language editing and to E. Lipman and L. Maggioni for their contribution to the compilation.

ISBN: 978-92-9043-745-1

Bioversity International
Via dei Tre Denari 472/a
00057 Maccarese
Rome, Italy

CONTENTS

SUMMARY OF THE MEETING

Background

The most northerly part of Europe, situated approximately above latitude 64ºN, covers areas from Greenland (Denmark) and Iceland to Norway, Sweden, Finland and Russia. Parts of these areas are where the world's most northerly agriculture and horticulture are practised. Wild berries and natural pastures are commonly used as livestock feed, especially for reindeer. Since the environmental conditions are very special, with an extremely short, cool growing season with long days, the cultivars used in the area have to be adapted to these conditions. For example, earliness and winter-hardiness are required characteristics. Consequently, plant breeding for this area relies on genetic resources that include genes for adaptation to northern marginal conditions. The wild genetic resources of plants and lichens depend on specific edaphic and climatic conditions for their survival.

The genetic resources of this area are preserved mainly in genebanks (Nordic Gene Bank, NGB and Vavilov Institute, VIR) and in national collections as clonal archives in the field. *In situ* conservation rarely occurs, except in areas receiving environmental support from the European Community. The number of *ex situ* genebank samples originating from the area is difficult to estimate, since for many samples the information on origin is inadequate. The number of accessions with location data above 64ºN (including all accessions from Greenland and Iceland) is approximately 1175, which is 6% of the total NGB collection. In addition, the relevant accessions conserved at VIR and other genebanks would increase this number and should be included in the total.

This area is facing a major environmental change through the anticipated global warming, which will most probably have a significant effect on the diversity of wild relatives of crops and wild species. One scenario hypothesizes that more southerly species and populations will replace the vulnerable northern populations due to the increase in average temperature, which is predicted to be 4–6°C by year 2080, based on estimates of future climatic change in Finland. We believe that changes in biodiversity and its utilization will be significant and extensive. For example, mosses and twigs may replace lichens grazed by the reindeer. Wild berry production may be threatened by flowering earlier when there is still a risk of frost.[1]

For plant breeding in the north, the anticipated climate change means new challenges in the use of genetic diversity. For example, even with warmer climates the use of varieties bred in the more southerly latitudes will not be an option. The unsuitability of more southern varieties to the northern conditions can be explained by the need for adaptation to the extreme summer long-day conditions and special growth rhythms, as well as the different edaphic conditions of the north. Today, there are only a few breeding companies developing varieties for this area. For example, in Sweden, breeding for the north receives state funding since it is considered to be cost-ineffective without this support.[2]

Consequently, we may face a situation where the development of early and frost-hardy varieties is interrupted, if breeding companies are deprived of economic support. In such a case, the farmers of the north may have to be content with varieties that are not fully adapted for the area. This will probably increase their already inferior economic situation compared to farmers of the south. Thus, the availability of genetic resources for future plant

---

1 Finland's national strategy for adaptation to climate change: http://www.mmm.fi/sopeutumisstrategia/

2 Swedish Farmers' Foundation for Agricultural Research: http://www.lantbruksforskning.se/about_slf/

breeding is essential for the preservation of the existence of agriculture in northern marginal conditions.

Strengthening the conservation of genetic resources of northernmost Europe

Today, the genetic resources of the north do not receive any special attention from the genetic resources community. Established genebanks possess germplasm from the area, but due to their relatively southerly locations they may not always be aware of the vulnerable nature of the genetic resources of the north.

With these aspects as background, a workshop was organized as one of the European Cooperative Programme for Plant Genetic Resources (ECPGR) cross-cutting activities. Eleven participants representing eight countries with territories above 64ºN were brought together to discuss the consequences of global climate change on plant genetic resources.

Welcome on behalf of MTT AgriFood Research Finland, Lapland's Research Station

Dr Oiva Nissinen, Head of Lapland's Research Station, welcomed the participants and wished everybody a pleasant stay in Rovaniemi and a successful meeting. He informed the participants of the tasks and organizational structure of MTT AgriFood Research Finland and the developmental activities conducted by MTT Rovaniemi. The research at the station focuses on the following areas:

1. **Field crops:** Grassland plants (winter hardiness, species and varieties, fodder quality, biodiversity, production technique)
2. **Horticulture:** Production techniques (wild species, special production methods, landscape plants)
3. **Landscaping:** Landscape management and methods for construction
4. **Rural developmental projects:** New enterprises
5. **Conservation of plant genetic resources:** Plant collections, maintenance growing.

Regional developmental projects are a core activity of the station. Four major projects are carried out: 1) Tourist destinations as landscape laboratories; 2) From nature to industry; 3) Barents Agro Forum; and 4) Multifunctional countryside.

Ms Marja Uusitalo, Research Scientist from Lapland's Research Station, presented research on genetic resources for ornamental woody plants at MTT Rovaniemi. The challenges of landscaping in northern Finland include the demanding growing conditions, the availability of few winter-hardy cultivars, and confusion in the authenticity and nomenclature of cultivars. Three projects (KALOTTI, KESKAS, POHKAS) concerning testing of a wide diversity of plant material for Lapland have been carried out. They have resulted in the identification of 109 different accessions of plant material suited for cultivation in northern Finland. Furthermore an arboretum for clonal collections has been established in cooperation with the city of Rovaniemi.

Introduction

Dr Merja Veteläinen, Coordinator of the Finnish national programme for plant genetic resources, welcomed the participants on behalf of the national programme. She thanked both the local organizers for their excellent help with the arrangements, as well as for making possible this cross-cutting activity within the framework of the ECPGR Programme. She declared her satisfaction with the broad expertise and geographical coverage amongst the participants of the meeting.

She introduced the workshop issue to the participants through a short overview of climate change in the northern hemisphere. Using as examples species of plants which are distributed naturally in the northern marginal environments, she highlighted the fact that many plant populations may be considerably threatened as a consequence of climate change. Finally, she reminded the participants of the goals and expected outcomes of the workshop, which were:

Goal	**Outcome**
Assessment of the impact of global warming on the wild relatives of cultivated crops in the area	Identification of collection needs for *ex situ* conservation and usefulness of *in situ* conservation in the changing environment
Identification of the samples originating from the area	Proper conservation through regeneration/multiplication at the "right" site, increased utilization
Regional inventory of species having present and future potential as genetic resources	Improved conservation
To find ways to enhance the use of the most northern genetic resources for the benefit of agriculture in the area	Continued agricultural production in the northern marginal environment
To initiate regional cooperation for the benefit of the most northerly genetic resources (through identification of actors in the area)	Awareness of the genetic resources in the area and improved conservation and use

Lorenzo Maggioni, ECPGR Coordinator, welcomed the participants on behalf of the International Plant Genetic Resources Institute (IPGRI[3]) and thanked the organizers of the meeting. He gave an overview of the history and achievements of ECPGR, stressing activities during the ongoing phase (2004–2008) and the cross-cutting issues of the Programme. He especially mentioned that the expected outcomes from this workshop should offer a model for similar actions in other parts of Europe and that they will give indications on the opportunity and relevance for ECPGR to invest funds in this area of work in the future.

After the introductions the workshop continued with presentations in two sessions: "The change" and "The present state of the northern material in *ex situ* collections". The summaries of the presentations are included in this report, as well as the summary of the final discussion with recommendations for further actions.

[3] With effect from 1 December 2006, IPGRI and INIBAP operate under the name "Bioversity International", Bioversity for short. This new name echoes their new strategy, which focuses on improving people's lives through biodiversity research.

Session 1. The change

Plants and climate

Frans Emil Wielgolaski
Department of Biology, University of Oslo, Norway

Climate change influences plant growth and development and species composition in boreal regions mainly by variation in temperature, but also in precipitation and wind, directly or via the influence on soil conditions as moisture, decomposition and nutrient availability.

There have always been "natural" climate changes, even BEFORE the last Ice Age which ended >10 000 years ago. In the warm post-glacial period, 5000–6000 years before the present, the temperature was 1–3°C higher than today. Then, heat-demanding deciduous trees like elm, hazel, linden and oak entered the lowlands of e.g. Fennoscandia, and the tree line was considerably higher than it is today. During the "Little Ice Age" between about 1450 and 1800 the temperature was low and the winter precipitation high, and the tree line became lower again.

It has been calculated that flowering phenology for various plant species was earlier along the coast both in southern and northern Fennoscandia based on higher temperatures over the past 150–200 years.

However, flowering time has been more stable or even delayed in some inland and mountain districts, maybe because of more and later melting snow, in spite of somewhat higher temperatures.

Detailed phenological studies of several plant species at various lowland sites in southern Norway have been showing roughly 11-year cycles in the timing of phenophases by smoothing phenological curves since 1930 (all species seem to follow a similar cycle). The phases were as early in the mid-1930s as in the early 1970s due to high temperatures but since the early 1980s increasing temperatures have generally caused even earlier phenophases. Tree saplings becoming established up to 300 m above the common tree line in Fennoscandian mountains have been observed after the high temperatures of the 1930s and recently.

Above the tree line, vascular plant species diversity, particularly in the lower Norwegian southern mountains, was found generally to increase during the last 70 years, although species number was found to decrease at about 20% of the sites (and especially in the west). More than half of the species were found at a higher elevation in the recent observation compared to 70 years ago.[4]

Climatological scenarios for the next about 100 years in Fennoscandia predict 3.5°C higher annual temperatures in the northeastern parts of the region and 4°C higher values in southernmost Finland. Generally, smaller increases are expected in the summer. Precipitation may increase up to 25% in the same period, e.g. in some coastal districts of Norway, mostly in autumn and partly in winter, while slightly decreasing in summer in some districts.

If these scenarios are fulfilled, it will mean that we should expect an even higher temperature increase than 5000–6000 years ago. This, of course, may lead to important changes in the vegetation with earlier springs, although maybe also earlier autumn tree

[4] Klanderud, K. and H.J.B. Birks. 2003. Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. The Holocene 13(1):1-6.

colours, particularly in the north, because of darker days in the autumn caused by more cloudy weather.

Higher temperatures normally increase the speed of litter decomposition and thereby, at least temporarily, also an increase in soil fertility. This will partly change and most often reduce the plant species diversity of natural vegetation, although in some cases it may increase production, as seen in e.g. Fennoscandian mountain birch trees. Higher temperatures are also important for cultivated plants, e.g. in making it possible to grow many species further north. Total heat accumulation for plant development is also very often lower in the longer summer days in the north.

Increased winter precipitation combined with higher temperatures may, in cold regions, cause ice to crust after mild periods. Crusting has been found to kill arbuscular lichens important as reindeer fodder, probably caused by "drowning" of the lichens. It is also been observed that "oceanic" plant species have recently invaded more inland continental districts.

We always have to remember that mankind, by its use of the land, e.g. through grazing management, strongly influences the vegetation. Many mountain plant species are found to have a HIGH adaptability to changes in climate, even to more severe changes than those predicted in most scenarios for the near future.

Climate change and genetic structure changes in marginal plant populations of the north

Outi Savolainen

Department of Biology, Oulu University, Finland

In northern Scandinavian areas, temperature is likely to increase by about 4°C in the next hundred years. This change is believed to be very rapid relative to previous changes experienced by natural populations in this area. Plant populations can respond in various ways to environmental change. During evolutionary history, most species have become extinct, often due to environmental changes. Some species are so plastic that they can withstand environmental changes. Environmental changes are often accompanied by range changes, as the species migrate to suitable conditions in order to maintain their "climate envelope".

Many species of plants and animals show evidence of having genetically adapted to the local conditions. Local adaptation means that, for instance, a northern population has higher fitness in its original location than other populations. Note that a northern population may well have higher absolute fitness in a more southern location, but essentially, in relation to the southern local population, it will fare worse. Reciprocal transplant experiments can provide evidence for local adaptation. Further, clinal variation of potentially adaptive traits along environmental gradients can also provide evidence for local adaptation, if other causes can be excluded. There is a large body of literature showing local adaptation in forest trees, but also in many other plant populations, such as *Arabidopsis lyrata*, and also in many animals, e.g. in many insect populations. However, many human commensals may show less local adaptation, as they may have adapted to a weedier life history. Earlier studies have shown that many northern species may at least initially benefit from warmer climates, whereas in the southerly range limit, the temperatures may become too high or precipitation too low to favour the existing species.

Thus it seems possible that evolutionary change can take place within populations so that they adapt to the new conditions. In principle, the potential to adapt depends on the availability of genetic variation, measured as heritability (V_A/V_P) or even better, evolvability ($\sqrt{V_A}$/mean). Response to selection cannot be large if V_A is small, even if heritability is high. Further, there must be opportunities for natural selection, i.e. there must be an opportunity for differential survival and/or differential reproductive success. If there is much genetic variation and strong selection, response can be rapid. However, the current evolutionary and ecological situation is more complex. If we consider the Scots pine, efficient pollen flow will have an influence on adaptation, sometimes furthering evolutionary response, sometimes delaying it. Further, the landscape is already occupied by trees which are surviving well in the warming climate. Thus, there is less opportunity for the new, better adapted seedlings to become established. Simulations taking into account this complexity show that in the next 100 years Scots pine will not be able to adapt to the temperature conditions expected in 2100. The phenotypic response is much less than required. Interspecific interactions with birch and other species will complicate the picture further. It should also be considered that environmental change places different demands on populations in different parts of the range. Further, plant species with fragmented small populations with little migration, will not be very likely to be able to evolve sufficiently rapidly to adapt to the environmental change. The environmental change is so rapid that small marginal populations may not have enough genetic variation. *Arabidopsis lyrata* in some regions may represent such a species, if populations are quite small.

The genetic responses to climate change in complex ecological situations need much more research effort.

Climate change scenarios in Canada and plant genetic resources

Ken W. Richards

Canadian Genetic Resources Program, Agriculture and Agri-Food Canada (AAFC), Saskatoon Research Centre, Saskatoon, Saskatchewan, Canada

(See also longer version in Appendix I, pp. 24–35)

Early European settlers to Canada brought with them various landrace crop germplasms that they were accustomed to producing, and on which they hoped to sustain themselves. Many of these first attempts at introducing genetic resources failed, due either to natural disasters or lack of closeness to suitable markets. Early Canadian plant breeders recognized very few agriculturally important plant species evolved in North America. Considerable introduction of plant germplasm for a diversity of crop species from a number of sources has occurred over the centuries/decades and continues today. Plant breeding research has focused on cultivar development with high yield, strong adaptation, resistance to biotic and abiotic stresses and economically sustainable value. Phenotypic traits receiving attention involved those associated with early maturity (germination, seedling growth, flower initiation) and good winter hardiness with rapid spring growth. Over the past 140 years of active plant introduction and breeding in Canada, a considerable number of new crops (examples include soybean, lentil, chick peas and canola) have been introduced, and genetic improvements were made to existing ones such as wheat, barley and oats. Yield increases of 0.5 to 1% per year for several crops are well documented. Canada's reliance on genetic resources from across the world is likely to continue, irrespective of the pressures of environmental change through global warming.

Canada experiences and will experience a number of environmental pressures and limitations for sustainable crop production. Many different soil types exist across Canada, ranging from fertile black chernozemic to saline regosol across the Prairie Provinces, to ferro-humic podzols common in the Maritime Provinces, to the poorer quality grey-wooded and relatively highly acidic soils further north. The poorer quality soil in northern Canada is a limitation to anticipated expansion of agriculture into more northern latitudes. Another major impediment to agricultural expansion in the north is the Canadian Shield, a rocky outcropping of igneous and metamorphic rock overlaid by a very thin soil. Seven major climatic regions are recognized across Canada and for most of these regions the growing season is generally described as short with cool nights, long summer days and cold winters. Predicting the future climatic conditions across Canada requires considerable effort. Various scenarios exist for the various physiographic regions. In general, it is predicted that mountainous areas will experience increased winter precipitation, a disappearance in permafrost, glaciers will retreat and spring flooding will probably increase. In the main agricultural area, the Prairie Provinces, there is an expectation of increased air temperatures and decreased soil moisture with an expected increase in the frequency and length of droughts. Average crop yields could fall by 10–30%. Alternatively, higher temperatures could lengthen the growing season, providing opportunities for the development of different crop species. Central Canada may experience warmer temperatures, less snow and a longer growing season with a reduction of water levels in the Great Lakes and along the St. Lawrence River. Atlantic Canada may continue to experience a slight cooling trend together with rising sea levels.

Climate change will bring with it many research challenges regarding the quality or nutritional aspects of germplasm or crops grown, occurrence and impact of new or adapted plant pathogens or insect pests, and the overall risk to native Canadian plant species. Proactive research must take place now so that Canada and other countries may better manage the consequences of climate change. Some suggested directions include: continued acquisition of relevant/adapted germplasm, increased plant physiology research and evaluation for abiotic stresses, evaluation of plant growth and productivity in poorer quality soils, and the conservation of existing native plant species which may be lost or displaced by other more aggressive species.

Genetic variation in plants from Greenland and Svalbard

Marianne Philipp
Institute of Biology, University of Copenhagen, Denmark

A characteristic of plants both in Greenland and Svalbard is that they are found on islands which have been almost totally glaciated. Consequently, almost all organisms have migrated to these islands since deglaciation; also probably as a consequence of the glaciations, a very high proportion of the plant species are polyploids. Central to our understanding of the genetic variation is the knowledge of the reproductive system. In arctic environments nearly all kinds of reproductive systems are found. The majority of species possess, however, clonal propagation combined with a mixed mating system, where the amount of selfing versus outcrossing may depend on local environmental conditions. We have most often combined studies of reproductive systems and genetic variation. The species we have chosen are all fairly common at least in parts of Greenland and some are also quite common in Svalbard. They represent different kinds of reproductive systems: mainly outcrossing species (*Silene acaulis, Honckenya peploides*), mixed mating species (*Dryas integrifolia-octopetala*, *Saxifraga tricuspidata*), mainly selfing species (*Campanula uniflora*) and highly clonal species (*Salix herbaceae*, *Polygonum viviparum*).

Our main conclusions are:

- Genetic variation is not as limited as we expected.
- Genetic variation strongly depends upon the reproductive system.
- Genetic variation in common species is as high as in other climate zones for species with similar traits.
- Genetic variation in seed banks can differ from what is found in the actual vegetation.
- Genetic distance across Greenland can be larger than that across the Atlantic Ocean.

Session 2. The present state of the northern material in *ex situ* collections

Nordic Gene Bank – accessions from the north, their documentation, regeneration and gaps in the collection

Fredrik Ottoson, Lene K. Christensen and Bent Skovmand

Nordic Gene Bank, Alnarp, Sweden

The Nordic countries have joined forces to conserve the biological cultural heritage of the region. In 1979 the Nordic Gene Bank (NGB) was established as an institution under the Nordic Council of Ministers and forms the core of Nordic cooperation on plant genetic resources. The Nordic Gene Bank conserves and documents the genetic variation of Nordic plant species useful for agriculture and horticulture. The material stored in the bank is available for plant breeding, research and any other *bona fide* use.

The main seed store of NGB is located in Alnarp, Sweden. There are about 27 000 accessions of cultivars, breeding lines, old landraces and material collected from wild populations. The storage methods are developed for long-term preservation of seeds at NGB. The seeds are dried to a water content between 3 and 6% before storage in air-tight aluminium bags at a constant temperature about -20°C in deep freezers. In order to minimize the risk of losing material, NGB also has a safety base collection at Svalbard in a coal mine belonging to the "Norske Spitsbergen Kulkompani A/S". The seed samples are stored there under permafrost conditions and can be preserved for the future without additional inputs of energy being required. The temperature in the mine is constant, varying between -3°C and -4°C.

The Nordic Gene Bank is in possession of accessions collected from locations covering most areas of the Nordic countries, from the southern parts of Denmark to areas north of the Arctic Circle. Material collected in the far northern locations (i.e. collected at a latitude of 64ºN or higher) consists currently of 737 accessions accepted for long-term storage (Fig. 1). Of these, 146 accessions are from Finland, 225 from Iceland, 117 from Norway and 249 from Sweden. The majority of this material (98%) consists of different kinds of forage crop accessions. The rest are vegetable and cereal accessions.

A recent collection expedition has just been conducted in the most northern Nordic region. This collection expedition took place in Greenland in August and September 2006. The collected material from this trip will result in the addition of 390 accessions of Greenlandic origin to the NGB collections. Within the collected accessions, 237 were grasses and 153 were medicinal plants.

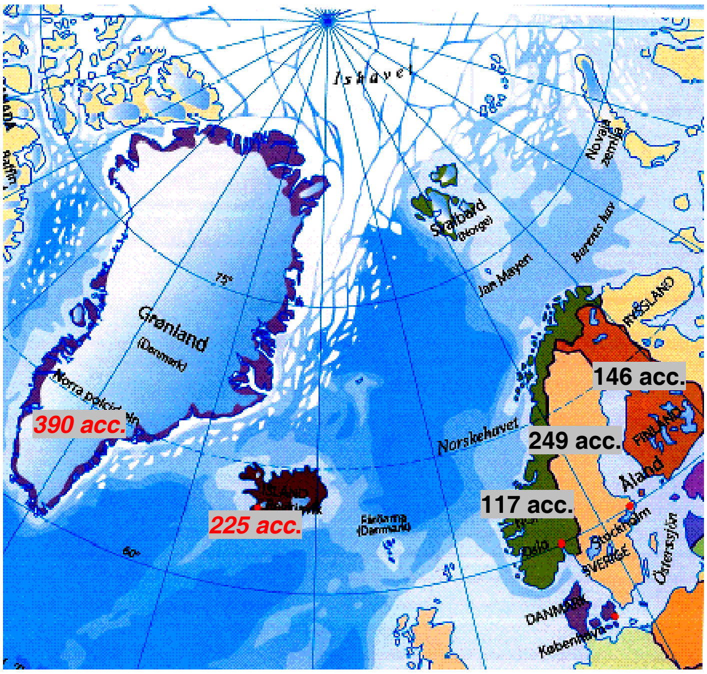

Fig.1. Number of accessions collected north of the Arctic Circle (except for accessions illustrated for Greenland and Iceland, in red font and italic) and stored at the Nordic Gene Bank.

N.I. Vavilov Institute (VIR): plant genetic resources accessions from the north

Sergey Alexanian

N.I. Vavilov Research Institute of Plant Industry (VIR), St. Petersburg, Russian Federation

The founder of VIR, Academician N.I. Vavilov, a famous “plant hunter” and collector of genetic resources, was thoroughly convinced that plant diversity needs to be conserved not as “a museum exhibit”, but for enhancing agricultural production and providing mankind with more food and nutrition.

His approach is especially topical for the modern world because of the following circumstances:

- World population is expected to be around 8 billion in 2025, with 80% concentrated in the developing world.
- At the beginning of the 21st century there were 790 million people classified as starving. Despite the progress in food consumption, since the mid-1970s their number has grown by 17%.
- There will be a requirement for higher-grade foodstuffs.
- Arable lands will probably remain at the level of 1.4 billion hectares.
- Areas potentially suitable for agriculture will continue to be reduced by urban development, erosion, pollution and salinization.
- Rapid process of migration of the agricultural population from rural areas is expected.
- Agricultural production will have to double and consumption increase from 5.1 x 10^{12} to 10.6 x 10^{12} kilocalories per year.
- Climate changes, leading to the expansion of agriculture northwards.

Being the key component of biodiversity, plant genetic resources (PGR) are vital for food security, food production and development of national economies, and a major tool for human and environment sustainability.

The VIR collections date back to the 19th century when efforts of Russian scientists resulted in laying the bases for the present globally important collections of the diversity of agricultural plants and their wild relatives. By means of systematic exploration of most countries of the world, VIR's researchers collected plant diversity in natural environments and preserved it. It represents the world's diversity of plants, encompassing over 320 000 germplasm accessions of 155 botanical families, 2532 species of 425 genera.

The fundamental objectives of the Institute's scientific activities are:

- to collect PGR both within and outside the country in order to accumulate specific and varietal diversity of cultivated plants and their wild relatives in the Institute's genebank;
- to preserve accessions of the world collection in viable conditions and to provide for their long-term storage;
- to study worldwide plant genetic diversity with the goal of identifying promising materials for breeding, to supply the breeding centres and all users with initial genetic material for practical breeding or scientific use.

The VIR's collections include the following PGR:

- wild species – relatives of cultivated plants, including weedy plants (the most important ones from the centres of origin of cultivated plants);
- landraces (varieties developed by farmers), especially from the countries covering the initial centres of origin of cultivated plants, and from regions with extreme environmental conditions;
- bred varieties and breeding lines combining a complex of commercially valuable characters and biological properties;
- rare botanical forms, mutants, new species of agricultural crops, vanishing taxa;
- new forms, sources and donors developed in the course of genetic experiments by means of cell and gene engineering (lines, varieties, stable remote hybrids[5], mutants with identified genes or gene combinations controlling morphological, biochemical, physiological and cytological characters).

In terms of the number of major food crops conserved *ex situ*, the global collection of VIR is among the top five in the world and one of the largest in Europe. Its crop collections of wheat, oat, tomato, alfalfa, clover and cucurbits are the most significant on the European continent.

An important part of N.I. Vavilov's activities on plant production was dedicated to the development of the extreme northern regions of USSR. This does not seem surprising, since about 15% of Russia's territory is situated in the Transpolar zone or climatically close areas. He clearly realized that to develop agriculture in the northern territories of Russia one should utilize the experience of such countries as Canada, Norway, Sweden, Finland, Denmark and Iceland. Having analyzed their experience, he concluded that development of the above territories would require wide application of fertilizers and special equipment in agricultural production as well as significant power inputs. But above all, this aim cannot be achieved without plant diversity as a source material for breeding. Taking advantage of his scientific contacts and friendly links with foreign colleagues, Vavilov received from these countries plant material to be used in research and breeding work. He established

[5] Remote hybrids = resulting from the hybridization of distantly related species.

cooperation and germplasm exchange with renowned companies such as Svalöf and Weibull. Among these important contributions were those from collecting missions and explorations undertaken by Vavilov himself.

The material acquired needed to be studied and to undergo ecogeographic trial analysis. Thus, in 1923 he decided to establish the northernmost experiment station in the USSR – the Polar Station. Today at the Polar Station 3631 crop accessions belonging to 38 species are maintained in a viable condition, including potato (2758 accessions), berries (419), vegetables (262) and fodder crops (174).

Almost all the plant material of Nordic origin accumulated since 1921 and stored in VIR's collections is now being studied, supplied with passport and evaluation databases, utilized in breeding practice and placed in long-term storage. It is freely accessible, and various users, including those from foreign countries, utilize the germplasm from VIR's genebank. For example, in the past decade over 2000 accessions of different crops have been shipped to foreign users (1285 to Canada, 517 to Sweden, 183 to Finland, 168 to Denmark and 10 to Norway). We also continue to receive germplasm samples from our colleagues. During the same period 910 accessions have been received from the above-mentioned countries.

Notwithstanding its notable achievements, the potential of such cooperation, in our opinion, is far from being exhausted. It is recommended to enhance mutually advantageous collaboration between the countries of the Nordic region both within the ECPGR framework and on bilateral bases for the benefit of the world community.

Such collaboration may have the following priorities:

- Study, screening and evaluation for commercial qualities of the existing genetic diversity of various crops suitable for northern regions.
- Collecting in northern and Siberian meadows, pastures and forests it is possible to find valuable plant genetic resources (forage grasses, fruit and berry plants) deserving exceptional attention in terms of their conservation (*in situ*/on-farm/*ex situ*) and utilization in breeding practice.
- Monitoring of genetic erosion in the crop plants of the northern region.
- Regeneration of the available accessions of crop diversity collections in the areas of their origin.
- Identification of duplicates in different national collections by means of modern techniques (DNA markers).

Alaskan efforts in collecting, cataloguing and the regeneration of high latitude accessions

Stoney Wright

Alaska Plant Materials Center, Palmer, Alaska, USA

The Alaska Plant Materials Center (AkPMC) was established by the State of Alaska in 1972. AkPMC functions in cooperation with the United States Department of Agriculture (USDA) and among its missions are the mandates to:

1. assemble, evaluate, select and increase plant materials needed in soil and water conservation, agriculture and industry, and maintain genetic purity of these materials;
2. increase promising plant materials for field scale testing.

Collection of wild, native species for commercialization has been a primary activity of the AkPMC from inception. However, significant resources were not spent on exploration and acquisition until 1990 when an infusion of funding from the US Department of Defense arrived. This continued through 1996 with most of the collection activity on the Aleutian Islands. In 1994 the Alaska Department of Transportation became the primary funding agency for seed acquisition projects. The entire AkPMC germplasm programme significantly expanded in 1998 with funding from the USDA, Agricultural Research Service and Natural Resource Conservation Service. This funding allowed and facilitated exploration efforts in the Falkland Islands, South Georgia Island, Iceland, Faeroe Islands, Spitzbergen (Svalbard), Greenland and the Canadian High Arctic. The primary target species (at least by this author) have been grasses. Species identical to or closely related to Alaskan species are the primary goal. However, other species of interest may include those requested by the host country or those that have a special habit or niche, such as the Tussock grass (*Poa flabellata*) from the South Atlantic. In the northern hemisphere the targeted genera have been *Deschampsia, Poa, Festuca, Leymus, Elymus* and *Alopecurus*. To date the AkPMC has assembled 3688 accessions of high latitude plant germplasm with complete passport data, plus an additional 1285 accessions of this material with partial passport data, amounting to a total of 184 species. All material collected from 1998 to date has been fully shared with the USDA. The material recently collected in Canada has been divided between the US and Canadian germplasm systems. The AkPMC only retains 50–100 seeds from an accession and conducts all germination tests, field evaluations and regeneration from this small sample of the main collection. The AkPMC remains fully committed to the prospect of making available well-equipped seed testing and cleaning laboratories as well as clean ground for regeneration, storage and acquisition of high latitude plant germplasm. We take pride in our abilities and commitment to serve the cause of plant genetic resources preservation.

Swedish PGR activities above 64°N

Jens Weibull

Swedish Biodiversity Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden

More than one-third of the Swedish landmass lies above the 64°N line of latitude. Most of this land comprises forests, mountains, bogs and mires, and other difficult terrain. While natural grasslands cover a fairly large area (16%), agricultural land represents only a small fraction (1%). Nevertheless, agriculture is still important in areas along the Bothnian coast and up the great river valleys, not least from the point of view of regional politics.

The area in question includes three vegetation zones: boreal, sub-alpine and alpine. North Sweden represents the most westerly extension of the taiga that stretches around half of the northern Palaearctic. This means that many species live here at the very margin of their normal distribution.

Sweden can be considered as part of the centre of origin for a few plant groups, notably many forage grass and legume species, as well as berries. The inventory and collecting of mainly agricultural plant genetic resources has been carried out since the late 1970s within the framework of the Nordic Gene Bank. In recent years these activities have partly been taken over by the National Programme for diversity of cultivated plants, POM (http://www.pom.info/english/index.htm). The current mandate also includes plant groups of horticultural importance.

On the basis of climate models, predictions have been made primarily regarding possible changes in temperature. In contrast, predictions about the effects of the proposed global warming on precipitation have been more speculative. So far, the possible consequences of climate change have mostly been considered in terms of the wild flora.

As indicated above, agriculture in North Sweden will probably continue to play an important role. This will require a continuing supply of adapted plant varieties. However, Swedish commercial plant breeding is currently undergoing considerable deconstruction. Furthermore, it is unclear for how long the State is prepared to lend further economic support to such activities. Therefore, a future solution to plant cultivar development in this region may lie in the hands of regional collaboration. Conservation should also be the focus of closer cooperation.

Norwegian collections of plant genetic resources in the different climatic zones

Even Bratberg

Department Horticulture and Crop Sciences, Norwegian University of Life Sciences (UMB), Ås, Norway

In natural ecosystems, there is a never-ending, if slow process whereby genetic material changes and adapts to the environment through the processes of natural selection. Human influences on livestock and plants stretches back many thousands of years and has produced a diverse range of species, landraces and cultivars adapted to different climate and forms of management.

Both wild and domesticated species are vital elements of our natural and cultural heritage and represent important resources for breeding programmes in the future. It is difficult to say which biological material will be important in the long term, because biological knowledge and natural and productive environments are constantly changing. The conservation of biological diversity, and genetic variation in particular, is therefore essential if we are to successfully deal with whatever the future has in store in an industrial, political and climatically changing world.

Norway is a country that stretches over more than 12 degrees of latitude, from 57°58′N (Lindesnes) to 71º08′N (Kinnarodden). It is a long country that covers many climatic zones and vegetation zones from south to north. In addition we have the altitude factor, from sea level up to 2468 m, and the day-length factor, from midnight sun to winter darkness.

But the Norwegian climate is milder than the geographical location may lead one to expect, due to the long coastline and the warm Gulf Stream. Our wild species have adjusted to the different climatic and vegetation zones: low temperatures, long summer days and a relatively short growing season. Our domesticated plants for agriculture and horticulture follow the location of human settlements. In Norway only 3% of the surface is cultivated land.

Most plants used in agriculture and horticulture originally came from areas with climate and growing conditions different from those of the Nordic countries. Over several hundred years plants have adapted or proven hardy enough to withstand our harsher climate. Even vegetatively propagated plants given time will adjust to the more northerly environments.

In our efforts to conserve genetic resources of agricultural and horticultural plants the task is bipartite. Plants propagated from seed can be conserved by long-term seed storage at low temperature (-20ºC). For these collections we in the Nordic countries have a close cooperation with the Nordic Gene Bank (NGB), with a safety collection stored in the coal mine (in permafrost) in Spitzbergen/Svalbard. Other plants reproduce vegetatively and require preservation as living plants. These are taken care of nationally, through our National Programme for PGR, in clonal archives and plant collections.

In this task we work successfully with museums, botanical gardens, arboreta and other local collections from south to north all over the country. We have chosen to use a decentralized system where the plants remain in their natural habitat. The reason for this is primarily climatic, but this model is also cheaper and gives us a better network. Through it, we can reach out to the public with information in a better way.

Icelandic plant genetic resources confronting climate change

Áslaug Helgadóttir
Agricultural University of Iceland, Keldnaholti, Reykjavik, Iceland

Plants grown in Iceland can be classified into three groups depending on origin. In the first group we have wild plants that either survived the last Ice Age or have arrived in the country by various means since. The second group consists of old cultivated plants imported by man after the settlement of the country 1100 years ago. These are now considered as indigenous and valid members of the Icelandic flora. Finally, we have commercial cultivated plants of foreign origin which have been imported with the advancement of cultivation from the early years of the 20th century.

For the first 1000 years of settlement in the country agriculture was based on the utilization of indigenous plants. The cultivation of agricultural land began in earnest in the second decade of the last century and from the early days fodder production has relied to a large extent on the importation of commercial cultivars. Grazing on unfertilized rangelands, on the other hand, is entirely based on indigenous species. Wild plants have been utilized for the development of speciality products such as medicines, herbal remedies, cosmetics and drinks.

Local breeding efforts have resulted in two commercial timothy cultivars, and similarly two barley cultivars are now commercially available, with more promising lines under way. Three local landraces of potatoes are currently conserved in the Nordic Gene Bank and three local populations of rutabaga (swede) are of conservation value, of which one is in commercial cultivation.

The increase in greenhouse gases in the atmosphere is expected to lead to substantial changes in the future climate in Iceland. By 2050 the mean temperature is expected to rise by 1.5°C during summer and 3.0°C during winter, and precipitation by 7.5% during summer and 15% during winter. The proposed changes in temperature will mean that there will be more days during the summer when the mean temperature will exceed 10°C, but more importantly, cold spells during winter and spring (number of days with $T<0°C$) will virtually disappear. These changes will have both positive and negative effects on our plant genetic resources and their utilization in agriculture. Less winter stress, a longer growing season and greater mineralization of organic matter will lead to increased yields of our common crop plants. Cultivation of marginal species, such as fodder legumes, will become more secure and increased numbers of day-degrees during summer will give more secure yields of barley and expand its area of cultivation. More importantly, new crop species will be introduced, such as perennial ryegrass, root crops, annual legumes, oats, wheat, rye and various horticultural crops. Warm winter thaws, however, may lead to de-hardening, thus making perennial plants vulnerable to subsequent stress. Similarly, the depletion of reserves due to higher respiration rates and low light intensities would be further enhanced by increased cloud cover in winter. More favourable climatic conditions will both cause increased threat and lead to increased damage from existing pests and diseases, and new pests and diseases will certainly arrive on the scene.

Increased temperature and precipitation during the growing season will generally benefit wild plants by increasing mineralization and allowing more prolific growth in soils with poor water retention. Higher winter temperatures will lead to less snow cover at higher altitudes. This could increase frost and ice cover stress of alpine plants and influence their natural distribution. New plant species will certainly arrive in the country and, hence, increase biological diversity.

Finnish national programme for plant genetic resources and anticipated climate change

Merja Veteläinen

MTT Agrifood Research Finland/ Finnish national programme for plant genetic resources

Finnish plant genetic resources have been conserved in the Nordic Gene Bank (NGB) since 1979. In 2003 a national programme for plant genetic resources was established in order to facilitate the conservation of agricultural and horticultural crops, as well as forest genetic resources. Due to Finland's northerly location in the northern hemisphere great attention has always been paid to germplasm that is adapted to this area with long days during the short growing season and cold winters. In light of anticipated global warming it is essential to review the state of the most northern plant genetic resources, since their wild relatives may be threatened in their northern locations due to their insufficient capacity for adaptation.

At present there are only 253 Finnish accessions of agricultural and horticultural crops collected north of latitude 64ºN and conserved at the NGB. These accessions represent 14 different genera and are mostly gene resources for forage crops and cereals. The number of accessions collected per species is low and barely covers the existing genetic diversity of northern Finland. Some gaps in the range of species are also probable in the collection. Guidelines to complement the collections at the species level are provided in the "Nordic mandate lists" for various crop groups (http://www.ngb.se/Organization/wgroups.php – see species lists under respective working group). Collecting missions ensure that the variation of important plant genetic resources will be conserved for future uses in plant breeding, research and utilization.

Increasing temperatures will have great effects on Finnish plant husbandry, allowing cultivation of later maturing cultivars in the north. Even new species and cultivation come into question, e.g. use of autumn sown cereals. The use of more southern genotypes and varieties is not an option in the north since adaptation to the long-day conditions is required. Wider variation for overwintering traits in breeding material may also be needed due to expected fluctuations in weather conditions during wintertime. Furthermore, the importance of resistance breeding for cultivars to be used in the northern latitudes will increase since pests and pathogens will benefit from a warmer climate and longer growing season. As a consequence of the changing breeding goals for northern Finland, the importance of germplasm enhancement is increasing in the future.

At present, the Finnish national programme for plant genetic resources is focused on inventory, conservation and research of the national collections of mainly horticultural crops. Enhancement of *on-farm* conservation of cereal landraces is a part of the programme activities. Research on cryopreservation and DNA fingerprinting of fruit trees are carried out in order to secure and rationalize the conservation of the field collections. Utilization of plant genetic resources is part of the implementation of the programme. For this task, wide genetic variation is needed for breeding varieties suitable to northern Finland and thus, supplementing both Nordic and national collections with additional material from the north is required.

Round table discussion and summing up

What do we know – knowledge gaps – where to go

On the second day of the meeting, the participants discussed well-defined questions. Under the main topics some specific questions are also reviewed:

- Genetic and climatic aspects.
  - What do we know about genetic variation of northern marginal populations (wild relatives of PGR)?
  - What do we know about adaptation capacity (intraspecific variation) of marginal populations?
  - What is the state of available knowledge on species/populations above 64ºN in threat of extinction?
  - Do we need to collect threatened populations?
  - *In situ* conservation and monitoring needs to be enhanced and will involve cooperation of government agencies.

- Conservation of PGR
  - What is the current coverage of genetic diversity of the most northern PGR in *ex situ* collections?
  - What is the coverage of species in the existing collections?
  - Can we improve the regeneration/rejuvenation of *ex situ* collections in the right environment (at present only a limited number of facilities is available) so that genetic drift is minimized?

- Status of the most northern PGR
  - There are few actors in the area and little attention is being paid to the issue.
  - Are inventories on PGR and actors needed? This may also lead to gaps being identified.
  - Is there a need for a global PGR network for the most northern circumpolar areas?

- Plant breeding aspects: genetic enhancement
  - Concerns about the importance of future plant breeding for the northern latitudes. Who specifically will address this issue? Governments or industry?
  - Germplasm enhancement is required for the benefit of northern agriculture.

- Actions after meeting.

The key conclusions from the discussions were in summary:

- Many of the ecological effects of global warming are closely related, working "cooperatively". These effects include for example, changes in plant phenology, physiology, survival, geographical distribution and species composition. Evidence for these changes can already be seen, for example, as earlier flowering of many plant species or poor competitive ability of lichens compared to grasses.

- The potential to adapt depends on the availability of genetic variation. There must be an opportunity for natural selection, i.e. there must be an opportunity for differential survival and/or differential reproductive success. If there is much genetic variation and strong selection, response can be rapid. However, the current evolutionary and ecological situation is more complex. It should also be considered that environmental change imposes different demands on populations in different parts of the range. Plant species with small fragmented populations that are unable to migrate are unlikely to be able to evolve sufficiently rapidly and scientists may be unable to track the environmental and genetic changes. At present there are, however, very few studies on existing genetic variation on PGR from northern margins, which makes it difficult to assess species-specific threats as climate change is progressing. Thus, genetic responses to climate change in the complex ecological situation needs further research.

- The most vulnerable areas to climate change are high-elevation and coastal sites. They are not often habitats for crop wild relatives (CWRs). The CWRs from both of these areas should be targeted for collection as a priority as they may face extinction sooner than in other ecosystems.

- Genetic variation of plants from Greenland and Svalbard is not as limited as expected and moreover genetic variation highly reflects the reproductive system of the species. In addition, genetic variation in seed banks can differ from that found in the actual vegetation. Considerable more research is required in both areas.

- Climate change will bring many challenges regarding the quality or nutritional aspects of germplasm or crops grown, the occurrence and impact of new or adapted plant pathogens or insect pests, and an overall risk to native plant species. Proactive research must take place now so that northern areas may better manage climate change and be in a position to benefit from the opportunities which may arise.

- The current collections lack material from the most northern areas and attempts should be made to fill in the geographic and genetic gaps in order to serve plant breeding with adapted material for the northern conditions, as well as to secure conservation of threatened plant populations in germplasm collections.

Based on the discussions, workshop participants agreed on a list of activities to be carried out after the meeting as related to the conservation of genetic resource in northern areas. These activities and recommendations can be adapted to any other geographical area as well:

1. Compile national lists of germplasm originating from above 64°N including germplasm in genebanks and botanic gardens.
2. Make an inventory of organizations (genebanks, institutes, industry, botanic gardens) maintaining and conserving material from above 64°N.
3. Establish which species are relevant/important including target sites (vulnerable areas; transition zones). Mandate lists of Nordic Gene Bank can be utilized as a model (see http://www.ngb.se/Organization/wgroups.php and further mandate lists of each working group). **This action is urgent in order to conserve material under threat.**
4. Identify gaps in collections.
5. Fill the gaps by collecting (or acquiring) material and geo-referenced information.

6. Document existing and new material (passport data minimum) that is being collected.
7. Make the germplasm available for others to use and if possible, generate some relevant characterization and evaluation data.

At a later stage other activities may follow:

8. Conservation/regeneration – development of new protocols, especially as related to reproductive strategies.
9. Identification and selection of sites for regeneration.
10. Analysis of genetic and phenotypic variation.
11. Physiological studies in the field and lab will need to be initiated (e.g. abiotic stresses).

The actions for other parts of Europe can include activities 3 to 6, as well as later stage activities defined for the northern hemisphere.

It was decided that each participating country will send the germplasm lists (activity 1) and inventories (activity 2) to the coordinator of the Finnish national programme ***by the end of 2006.*** The lists and inventories will be the basis for gap identification (activity 4), which could be done by the informal network composed by the workshop participants. In order to carry out the suggested follow-on activities, a more formalized network or working group should be established, preferably within the frame of ECPGR. Connections with groups (or groups to be established) from other geographical areas that focus on PGR and climate change could form a basis for an ECPGR-wide network on the topic.

Furthermore it was recommended to conduct more interdisciplinary studies (population genetics, plant ecology, plant physiology and genetic resources) on adaptation capacity of northern altitudinal or marginal plant populations (wild relatives of PGR) and develop through research new evaluation methods for abiotic stresses. Studies on adaptation capacity are valuable in identifying sites/populations that are most sensitive to climate change (activity 3).

Finally, it was agreed to prepare a review paper on the workshop topic to be published in a peer-reviewed publication.

APPENDICES

Appendix I. Climate change scenarios in Canada and the role of plant genetic resources

Ken W. Richards

Plant Gene Resources of Canada, Agriculture and Agri-Food Canada (AAFC), Saskatoon Research Centre, Saskatoon, Saskatchewan, Canada

Introduction

Canada is a large country in the northern hemisphere with most of its land mass above latitude 49°N. Agriculture production exists to a great extent in western Canada as far north as latitude 58°N. Considerable variation in environmental conditions exists across Canada with the growing season generally described as short with cool nights, long days and cold winters. Cultivars have been adapted to these conditions with crop traits such as early maturity and winter hardiness a necessary requirement. Over the decades Canadian plant breeders have relied on genetic resources from across the world that include genes for adaptation for northern agriculture.

Canada, like all countries, is experiencing a major environmental change through global warming, which will probably greatly affect the agricultural landscape along with the diversity of wild plants related to crops existing within its borders. It is anticipated that climates will be drier and warmer and therefore crops will need to be more drought-tolerant. It is also anticipated that crop production areas will change and may move further north, although limitations of soil quality and the Canadian Shield will limit how far north crops may move. Also, new crops may be grown.

Canadian plant breeders anticipate new challenges related to climate change. Breeders have improved crop productivity over the past century by introducing genetic resources from across the world. A potential problem may be that not all southern adapted germplasm may be adapted or useful in northern climates as day-length sensitivity and other growth rhythms may prevent rapid adaptation.

The following is a brief historical view of Canadian crop development with some emphasis on longer trends in crop improvement. Following this are reflections on some of the environmental pressures facing Canadian crop improvement, including the diversity of soil profiles existing across Canada, historical and current climatic conditions and the anticipated climate conditions for various regions across Canada. Suspected or potential influences of climate change on Canadian crop production are briefly outlined and future research directions are suggested.

Canadian crop development and utilization

Canada is a comparatively young country. European settlement of eastern Canada began in the 16th century and in the western part during the 1800s. Wheat and other crop production in eastern Canada started at Port Royal, Nova Scotia in about 1605 (Campbell and Shebeski 1986). In eastern Canada the subsequent spread of wheat and other crop production coincided with the movement of settlers westward or upriver along the St. Lawrence. Wheat was the major crop in English Canada from 1800 to about 1860 because it was easily grown and had a ready market in Britain. Because of changing markets, the lack of suitable, adapted cultivars in eastern Canada and the production of high-quality hard red spring wheats in western Canada, the acreage and production gradually declined after 1880. Eastern wheat production experienced numerous problems such as major epidemics of rust, smut, attacks by Hessian fly, wheat midge and chinch bugs. Successions of landraces, mainly introduced from Europe, were grown in search of ones that would overcome some of the impediments for successful wheat production.

The history of western Canada is closely tied to the production of wheat with the first records from about 1750 (Ellis 1970) when the first sustained attempt to grow wheat is credited to the Selkirk settlers of Manitoba (Buller 1919; Hind 1931). First attempts failed due to either natural disasters or to rivalries among fur-trading companies. Wheat seed needed to be reintroduced from Wisconsin and Minnesota, and it is believed that 'Red Fife' arrived about 1869. Mennonite immigrants also introduced and grew the cultivar 'White Russian', a strain which appears to be a winter wheat with 41 names. One 'White Russian' type (CAN 1567, CN 12174) was actually a spring wheat selected out of 'Red Fife' and distributed in western Canada in 1891 (Dickinson 1976).

'Red Fife' was broadly grown across the prairies as it was well adapted and had high quality. 'Red Fife' was acknowledged as the "finest wheat in the world for milling bread wheat" (Irvine 1983). As part of an incentive programme, free seed of 'Red Fife' was given to new settlers. Growing wheat and other crops was a risky business. Frosts frequently damaged crops before they reached maturity. Extremely cold winters often killed winter wheat, various diseases damaged up to 40% of crops in some years (Johnson 1961) and insect pests, primarily grasshoppers, caused significant crop losses for 38 out of 138 years (Crawford 1939).

The first cultivars of wheat and other crops grown in Canada were representatives of the varieties grown in the area from which the new immigrants came. The vast majority of these introductions were unadapted to Canadian conditions; a few survived the rigours of the Canadian climate. Some early wheat introductions originated from the London Corn Exchange (Saunders 1888) and one strain came from near Lake Ladoga, Russia, latitude 60°N, and matured about 10 days earlier than 'Red Fife'. Introductions from early settlers showed plant-to-plant variation, and selections were made and propagated.

W. Saunders (1899), first director of the Dominion Experimental Farms, considered three major factors to be fundamental in the development of a stable wheat economy. First, the majority of the agricultural areas of Canada were characterized by a very short growing season, so early-maturing cultivars were essential. Second, wheat of the quality of "Manitoba"-grown 'Red Fife' could only be produced in limited areas of the world, and Canada should exploit this advantage. Third, the development of western Canada could lead to the production of immense quantities of wheat, and this would have to be of very high quality to offset the high transportation costs to world markets. To achieve these objectives all early wheat introductions were evaluated for early maturity, adaptation and quality.

Very early, plant breeders recognized that very few agriculturally important plant species evolved in North America. Notable exceptions included corn, beans and several horticultural species such as strawberry, raspberry, saskatoon, currant and gooseberry. Thus over the decades, plant breeders introduced considerable plant germplasm for a diversity of crop species from a number of sources. The "New Crops Development Program" introduced and evaluated for general adaptation a wide diversity of crops and some of these such as safflower, fenugreek and several pulse crop species became economically important.

One of the more important crops to be developed was rapeseed. Early introductions from Argentina were evaluated for uniformity, lodging resistance, high oil content in the seed and low iodine value in the oil. During the last 40 years, rapeseed or canola has developed from a minor to a major crop across Canada with annual production in excess of 3.5 million metric tonnes (Stefansson and Downey 1995). This development has changed Canada from a major importer to a net exporter of edible vegetable oil and oilseeds. Plant breeding has devolved from the public sector led by Agriculture and Agri-Food Canada (AAFC) to the private sector. Over the years the number of cultivars released has increased significantly with currently about 40 new lines being proposed for registration in Western Canada each year.

Another *Brassica, B. juncea*, mustard, is known to be well adapted to the drier parts of the southern Prairie Provinces and also has relatively good resistance to sclerotinia white mould. Recently, a plant breeding team led by Gerhard Rakow (AAFC, Saskatoon) has released cultivars with an oil profile (low-erucic, low-glucosinolate yellow mustard) almost identical to canola, thereby increasing the potential area for growing canola-like crops. This is an excellent example of adapting existing crops to drier and warmer climates, and may be an example for future plant breeding efforts as climates across Canada change.

Other crops significantly expanding in production over the past 20 years are the pulse crops, mainly pea, lentil and dry bean. Canada has had some dry pea production for more than a century (Slinkard and Blain 1988), however dry pea production has rapidly increased in western Canada, especially since 1985 with the opening of the European feed pea market. The major reason for this increase is that the net return from dry pea is much greater than from hard red spring wheat, especially in the black soil zone of Saskatchewan and Alberta where peas are best adapted. Other factors contributing to increased pea production are increased emphasis on crop diversification, crop rotation, value-added processing, new industries in the rural areas and pressure to improve the sustainability of agriculture in western Canada. There has been a tremendous increase in the number of registered cultivars. This was further stimulated by the advent of Plant Breeders' Rights legislation in 1990. Many of the new cultivars were developed in Europe and are well adapted to the cooler, moister pea production areas, particularly in Alberta, as summarized by Ali-Khan and Slinkard (1995).

Lentil production has continually increased over the past 35 years. Early plant introductions from the USDA Plant Introduction, Pullman, Washington encouraged the development of two leading cultivars, 'Laird' from PI 343028 and 'Eston' from PI 179307 (Slinkard and Bhatty 1979; Slinkard 1981). 'Laird' became the most widely grown cultivar in the world, and these two cultivars comprised the major lentil production in western Canada until the present. Various other lentil cultivars for specific markets and with specific attributes have been developed, as summarized by Slinkard and Vandenberg (1995). Aschochyta blight and anthracnose are serious diseases of lentil. Some germplasm resistant to ascochyta has recently been found and is being incorporated into newer cultivars.

Garden bean and dry bean breeding and production began in Canada about 1880 in eastern and western Canada with introductions from the United States, Britain, France and Germany. Early eastern garden bean breeding programmes emphasized increased yield, earliness, disease resistance and shorter pod-producing period (less than 60 days) along with suitable appearance, size and quality of seed. Twenty-six garden cultivars were registered between 1925 and 1936. Dry bean breeding and evaluation has taken place across Canada at a number of locations. Breeding objectives varied depending on the region, but earliness and seed yields were important at all sites. Anthracnose, a pod spot disease, became widespread and resistance breeding tended to dominate the programmes. A significant number of cultivars were registered in Canada as summarized by Park and Buzzell (1995). G. Kemp at Lethbridge searched genetic sources and evaluated for characteristics related to favourable response to low temperature, such as germination, seedling growth, flower initiation stage, and leaf growth and angle. He initiated a programme to improve plant type for direct combining so as to reduce the severity of sclerotinia white mould. He sought a high-profile plant type that had the number of branches reduced to three or four, a narrow canopy, tall stature and about four pods on a long flower stem in crosses such as 'Kentwood'/'Redcloud'.

The above examples of successful crop improvement for various crop species indicate that Canadian plant breeders have introduced and continue to introduce germplasm from various parts of the world.

Canadian plant breeding: historical emphasis and trends

From the earliest days the research focus for crop improvement was on cultivars with high yield, strong adaptation, resistance to biotic and abiotic stresses and economically sustainable value. Quality was not an early priority although because of their milling and baking properties, some wheats commanded a premium in international markets.

Genetic improvement programmes commonly emphasized a number of phenotypic traits associated with adaptation to climatic conditions, especially to the lower temperatures encountered across Canada. For annual species these traits included general adaptation, earliness in various forms (germination, seedling growth and flower initiation stage), increased yield, and resistance to various insect pests (grasshoppers, sawfly, Hessian fly) or plant diseases (rusts, aschochyta blight, sclerotinia, fusarium head blight). For the perennial species the desirable traits included increased tolerance to cold winters, rapid regrowth during the spring or summer, and resistance to various winter plant diseases (e.g. snow mould).

In western Canada, assessment for agricultural merit resulted in the evolution of the cooperative testing system whereby western Canada was divided into natural soil-climate zones (Harrington 1936). This system still exists today. A modified system also exists across eastern Canada.

Examples of agronomic change in genetic improvement over time can be found for some Canadian cultivars. For example, studies on short-season soybean (Voldeng *et al.* 1997; Morrison *et al.* 1999, 2000) have shown yields increasing about 0.5% per year since the early 1930s. The increase in seed yields with years of release was associated with a significant increase in the number of seeds per plant, yet there was no relationship between seed yield and seed weight. Newer cultivars tended to be more phenotypically stable for plant height than older cultivars and tended to be more efficient at establishing, supporting and filling seeds on a per-plant basis than older cultivars.

Long-term average wheat yields in Saskatchewan from 1908–1996 indicated a significant yield increase over time. This is not surprising given the advancements in improved germplasm, production practices, use of improved fertilizers, introduction of herbicides and utilization of mechanized equipment. However, upon more recent examination, wheat yields have tended to stagnate since 1970 in spite of increased investments in wheat breeding, improved herbicides, and increased use of inorganic fertilizers (Furtan and Edwards 1997). And in an earlier spring wheat study, Hucl and Baker (1987) determined that yield-related traits were altered over time. Plant height and the length of the vegetative growth stage were shortened during the pre-'Thatcher' wheat cultivar era. Spikelet number has fallen but kernel weights increased during the period of cultivar development. Tiller production changed little since the turn of the century while spike number reduced slightly. A significant cultivar x environment interaction resulted from adverse environment having a greater negative impact on grain yield of older cultivars 'Red Fife' and 'Marquis' relative to their descendants.

Canola as a crop only recently came into existence, and significant yield increases are not yet present. Average yields in Canada of about 24 bushels/acre (bu/A[6]) are slightly less than those in the USA (26 bu/A), however yields up to 96 bu/A have been recorded on a fairly consistent basis (http://www.ppi-far.org/ppiweb). Higher yields are associated with significant inputs of nitrogen fertilizer, optimizing of cropping sequences and tillage systems and to the absence of brown girdling root rot and sclerotinia (Soon *et al.* 2005).

Concern has often been expressed that modern plant breeding techniques reduce crop genetic diversity (Velle 1993; Clunier-Ross 1995; Tripp 1996). Such reduction may have consequences both for the vulnerability of crops to their pests and diseases and for their ability to respond to changes in climate or agricultural practice (FAO 1998). Canadian

[6] 1bu/acre = 67.26 kg/ha

research, lead by Yong-Bi Fu, has been investigating this issue using various molecular techniques and for various crop species (Fu *et al.* 2002, 2003a, 2003b, 2004, 2005, 2006). Analysis of his data suggests allelic increases and decreases in genetic diversity at various loci are occurring in the crop species he studied.

Native plant ecosystems and vegetation

The large tracts of land where only native plants grow are perhaps more susceptible to climatic change than the agricultural cropping areas. Past climate variations may provide a basis for predicting how ecosystems may respond to future changes in global climates. The geological record for the Northern Great Plains shows conclusively that (a) climate has changed quickly before and can be expected to do so again, and (b) relatively small perturbations in the climate system resulted in large environmental changes. We should therefore heed warnings that seemingly minor changes, some of which humans are introducing, could induce major consequences in native ecosystems (Fox and Seielstad, http://www.umac.org/climate/Papers/pg12-21.html). This point is emphasized in the research of Knapp *et al.* (2002) in a detailed examination of rainfall variability, carbon cycling, and plant diversity in a mesic grassland environment.

Results from various research projects indicate the key vulnerabilities of native ecosystems. Vegetation dynamics as associated with hydrological balance have proven pivotal in prairie pothole[7] communities, while specific animal-plant interactions and variations in time windows of suitability played significant roles in other communities, such as forests. Some of these land changes can act directly or synergistically on the same variable as climate change. For example, in the prairie pothole system, cultivation of nearby land exacerbated the dry summer conditions associated with a warmer, drier climate (Eddy and Fuad 1996).

It may be difficult to document the anticipated changes for native ecosystems because of their complexity. Efforts to conserve, collect and evaluate the existing native genetic resources are useful. *Ex situ* efforts to conserve these resources may be combined with *in situ* conservation efforts for these same resources so that genetic changes may be evaluated and documented.

From GRIN-CA descriptors

Canada has adopted the USDA Germplasm Resources Information Network system (GRIN-CA) and has included many of the crop-specific descriptors from the USDA system. The descriptor list used in Canada has benefited from consultations with relevant crop breeders to reflect the needs of Canadian agriculture. Over the years, individual descriptors have evolved in their use. For example, oat or wheat maturity or days to anthesis, which were originally categorized as early, medium or late, are now recorded in exact days. Winter hardiness descriptors frequently read as a percent of plants surviving the winter based on fall stands relative to check(s). Or as in alfalfa, an indicator, winter hardiness can be obtained by measuring height of plants (breeding lines or cultivars) after first cut. A negative linear relationship exists between winter hardiness and height of plant after first cut. The Canadian plant germplasm database can be found on the Internet at http://www/agr.gc.ca/pgrc-rpc.

---

[7] A prairie pothole is a wetland area found in the glaciated northern Great Plains of the United States and Canada. These shallow or bowl-like depressions have variable wetness. They are often used for breeding by birds. Prairie potholes are not wet year-round.

Environmental pressures on modern crop development – Ecological framework for Canada

Reviews of the history and the application of ecological regionalization in Canada are given by Bailey *et al.* (1985) and summarized by the Ecological Stratification working group in the National Ecological Framework for Canada (1995). This group delineated individual areas on the Canadian surface into ecozones, ecoregions and ecodistricts using a combination of landscape characteristics. Principal characteristics include geomorphology, soils, vegetation and climate.

Soils

Considerable efforts have been made on classifying the various soil types across Canada. These can be located at: http://sis2.agr.gc.ca/cansis/. Many different types of soils exist across Canada, ranging from fertile black chernozemic to saline regosol across the Prairie Provinces, to ferro-humic podzols common in the Maritime Provinces, to grey luvisols in southern Ontario and Quebec. Unfortunately, as one moves further north the quality of the soil for productive and sustainable agriculture tends to decrease and soils become more grey-wooded and relatively highly acidic (eutric burnisol). Productivity in these more northern soils tends to be low, and few crop species can adapt to them except for certain forage species, particularly grasses and some forage legumes.

Canadian Shield

To the north, the Canadian Shield, also called the Precambrian Shield or the Laurentian Plateau, is a vast horseshoe-shaped area around Hudson Bay covering eastern and central Canada, and a small part of the northern United States. Some 1.9 M square miles, very nearly half of Canada's total area, are occupied by the Canadian Shield. It was formed in Precambrian times 500 million years ago and is composed of igneous and metamorphic rock. The Shield has very thin soil with rocky outcroppings frequently showing. It is mainly undulating land with small hills and with numerous lakes. It is unsuitable for farming, but large parts in the south have forests, and mining is also fairly common. The Shield covers a vast amount of Canada including (in summary): Labrador, but not the island of Newfoundland; most of Quebec, except for the small part of the Province which lies south of the St. Lawrence River, amounting to about 90% of Quebec's land area; southeastern, central and northwestern Manitoba; northern half of Saskatchewan; extreme northeastern corner of Alberta; that part of Northwest Territories and Nunavut which lies north of Manitoba and Saskatchewan; and part of Baffin Island.

Canadian climate

Past and current

Canada is a country of vast coastlines and diverse weather with seven major climatic regions recognized (modified Koppen classification):

1. mountain – cold year-round;
2. tundra – short, cold summers, continuous permafrost;
3. subarctic – long, cold winters;
4. continental – cool summers;
5. marine east coast – cool winters, cool summers;

6. marine west coast – mild winters, cool summers; and
7. steppe – dry year round, cold to warm.

The country is bordered by the Pacific Ocean to the west, the Arctic Ocean to the north, and the Atlantic Ocean to the east. Additionally, the eastern half of Canada is divided by Hudson's Bay. Frozen more than half of the year, Hudson's Bay greatly influences eastern Canada's climate, facilitating the southward movement of cold Arctic air.

The Gulf Stream brings warmer air to the southeast of Canada, but its effects are limited. The icy Labrador Current sends temperatures in the northeast of the country plummeting. The summer months warm the Prairie Provinces in the west.

Eastern Canada

Eastern Canada is where the bulk of the Canadian population lives. The Maritime Provinces are damp, cold, and cloudy. Occasionally, hurricanes that have travelled up the coast of the United States bring heavy rains and winds to the maritime regions.

The Prairie Provinces

Canada's Prairie Provinces include Manitoba, Saskatchewan, and Alberta. This region is characterized by fertile lands that experience long, warm (>40°C) summer days ideal for growing grain and oilseed crops. Summers also are characterized by thunderstorms and enough rainfall to support agriculture. Winter in the Prairie Provinces brings blizzards (frequently with wind chills to -50°C), cold winds from the Arctic in the form of northerlies and somewhat warmer westerly winds (Chinooks) from the Rocky Mountains.

British Columbia

British Columbia's climate is similar to that of Oregon and Washington. This province has two distinct climate zones, the wet (some locations with more than 250 mm rainfall per year) milder coastal region and the drier inland region (about 40 mm rainfall/yr). The effects of El Niño and La Niña are felt in British Columbia and can produce abnormal dryness or exceptionally heavy precipitation. The extreme climates of the mountains range from alpine to near desert.

Northern Canada

Northern regions of Canada experience inhospitably cold weather during the winter months with average temperatures in the range of -25°C to -35°C. In the summer, the days are long and daily highs are often above 16°C. Summertime fog and clouds are a common feature in the coastal areas along the Arctic Ocean.

Future predictions

Considerable effort is being placed into predicting the future climatic conditions across Canada. Federal government departments, specific action networks and research institutes for modelling and assessing climate change have come into existence in recent years. The Canadian government in 2004 generated a Country Study (http://adaptation.nrcan.gc.ca/perspective_e.asp) as the first-ever assessment of the social, biological and economic impacts of climate change on the different regions of Canada. Climate experts from government, industry, academia and non-governmental organizations were brought together to review existing knowledge on climate change impacts and adaptation, identify gaps in research, and suggest priority areas where new knowledge is urgently needed.

Highlights of regional reports are included here for British Columbia/Yukon, the Prairies, the Arctic, Ontario, Quebec and the Atlantic. It is important to bear in mind that uncertainty regarding the character, magnitude and rates of future climate change remain. These uncertainties impose limitations on the ability of scientists to project impacts of climate change, particularly at the regional level as well as on smaller scales.

British Columbia/Yukon

Climate change will have significant impacts in British Columbia and the Yukon including increased flood dangers in some areas, drought in others, and widespread disruption to forests, fisheries and wildlife. Sea levels are expected to rise up as much as 30 cm on the north coast of British Columbia and up to 50 cm on the north Yukon coast by 2050, mainly due to warmer ocean temperatures. This could cause increased sedimentation, coastal flooding and permanent inundation of some natural ecosystems. It could place low-lying homes, docks and port facilities at risk. Other changes that may result from climate change include:

- In winter, increased winter precipitation, permafrost degradation and glacier retreat due to warmer temperatures may lead to landslides in unstable mountainous regions, and put fish and wildlife habitat, roads and other man-made structures at risk. Increased precipitation will put greater stress on water and sewage systems, while glacier reduction could affect the flow of rivers and streams that depend on glacier water. These would cause potential negative impacts on tourism, hydroelectric generation, fish habitat and human lifestyles.
- Spring flood damage could be more severe both on the coast and throughout the interior of British Columbia and the Yukon; existing flood protection works may no longer be adequate.
- Summer droughts along the south coast and southern interior will mean decreased stream flow in those areas, putting fish survival at risk, and reducing water supplies in the dry summer season when irrigation and domestic water use is greatest.

Prairies

Current models suggest climate change could result in increased air temperatures and decreased soil moisture. There is less confidence about whether precipitation will increase or decrease or about how climate change may affect severe weather events. Most scenarios suggest the semi-arid regions of the Prairies can expect an increase in the frequency and length of droughts. Some of the potential impacts of these changes include:

- Average potential crop yields could fall by 10–30% due to higher temperatures and lower soil moisture. However, higher temperatures could lengthen the growing season, and may increase crop production in northern regions where suitable soils exist.
- Increased demand for water pumping and summer cooling, due to drought, and decreased winter demand due to higher temperatures, could push electrical utilities into a summer peak load position at the same time as hydro-power production is reduced by decreased water flow. This could result in increased thermal power production with an increase in fossil fuel consumption and greenhouse gas emission.
- Semi-permanent and seasonal wetlands could dry up, leading to reduced populations of waterfowl and other wildlife species.

Arctic

In the past 100 years, the Mackenzie District has warmed by 1.5°C and the Arctic tundra area by 0.5°C, while the Arctic mountains and fjords of the eastern Arctic have cooled slightly. Future winter temperature increases of 5–7°C over the mainland and much of the Arctic Islands, and modest cooling in the extreme eastern Arctic are projected. Summer temperatures are expected to increase up to 5°C on the mainland, and 1–2°C over marine areas. Annual precipitation is expected to increase up to 25%. These changes in temperature and precipitation would have dramatic effects on tundra and taiga/tundra ecosystems, reducing their areas by as much as two thirds. More than one half of the discontinuous permafrost area could disappear, with marked surface instability in the short term. Streams may shift northward 150 km for each degree increase in air temperature. Wildlife would also be affected, with many species of fish and High Arctic Peary caribou, muskoxen and polar bears running the risk of extinction. Climate change would extend the shipping season in the Arctic, while rising sea levels in the Beaufort Sea areas would endanger coastal infrastructures.

Ontario

Ontario could experience anywhere from 3–8°C average annual warming by the latter part of the 21st century, leading to fewer weeks of snow, a longer growing season, less moisture in the soil, and an increase in the frequency and severity of droughts. Other impacts of climate change could include:

- more days when heat stress and air pollution adversely affect people's health
- likely increases in the frequency and severity of forest fires
- changes to aquatic ecosystems and alterations to wetlands.

Water levels in the Great Lakes could decline to record lows by the latter part of the 21st century, thus reducing shipping capacity.

Quebec

If carbon dioxide levels were to double, Quebec would experience average temperature increases of 1–4°C in the south and 2–6°C in the north. Precipitation would probably remain the same or decrease slightly in the south, while increasing 10–20% in the north. Likely consequences include:

- lower water levels in the St. Lawrence River, which will affect shipping, navigation, and the marine environment of the river
- positive effects on agriculture, including a longer growing season and the extension of agriculture further north.

Atlantic

Climate change in the Atlantic region has not followed the national warming trend of the past century, and in fact, a slight cooling trend has been experienced over the past 50 years. This trend is consistent with projections made by climate models. Atlantic Canada is particularly vulnerable, however, to rising sea levels, the impacts of which could include greater risk of floods, coastal erosion, coastal sedimentation and reductions in sea and river ice. Other potential impacts include:

- loss of fish habitat
- changes in ice-free days, which could affect marine transportation and the offshore oil and gas industry
- changes in range, distribution and breeding success rates of seabirds.

Unknown or/and potential influences of climate change

1. Will any of the various climate change scenarios influence the quality or nutritional aspects of the germplasm currently being conserved? Will the specific protein or oil profiles that we are currently evaluating change, and need to be repeated?
2. There are strong suggestions that various new plant pathogens or races of existing pathogens will appear or will change and current germplasm may need to be re-evaluated.
3. Entomologists are suggesting that new insect pests may appear in Canada as climates warm, and those that currently exist may adapt and generate multi-generations per year, causing an increased negative impact on crop productivity.
4. Will there be any influence on diversity of endemic native Canadian horticultural crops such as saskatoon, raspberry, strawberry, cranberry, goose berry?

Suggested directions related to climate change scenarios

5. Canada will continue to acquire germplasm for its major and minor crop species and for new crop development from elsewhere in the world. Acquisitions through collection, exchange and donation will continue. In the future these new acquisitions may need to be targeted to meet changing climatic conditions.
6. There is a need to increase plant physiology research and evaluation of germplasm for abiotic stresses. Emphasis may need to be placed on linked traits such as drought tolerance and salt/salinity tolerance. This will also require the development of new techniques which are accurate and rapid to assess germplasm for these traits.
7. There is a need to increase in plant physiology research into crops adapted to poorer quality soils (grey-wooded and relatively highly acidic (eutric burnisol)) such as those existing in the more northern areas of Canada.
8. There is a need to increase the genetic diversity within existing crops so that they are better adapted to dryer hotter climates.
9. Increased emphasis is required to conserve (ex situ) the existing genetic diversity of native Canadian plant species as this diversity is expected to change over time and may be lost.
10. Canada should work toward further cooperative efforts to share or evaluate germplasm adapted to northern regions.

References

Ali-Khan, S.T. and A.E. Slinkard. 1995. Field pea. Pp. 181–190 *in* Harvest of Gold. The history of field crop breeding in Canada (A.E. Slinkard and D.R. Knott). University Extension Press, University of Saskatchewan.

Bailey, R.G., S.C. Zoltai and E.B. Wiken. 1985. Ecological regionalization in Canada and the United States. Geoform 116:265–275.

Buller, A.H.R. 1919. Essays on wheat. The Macmillan Company, New York.

Campbell, A.B. and L.H. Shebeski. 1986. Wheat in Canada – past and present. Pp. 1–14 *in* Wheat production in Canada – a review (A.E. Slinkard and D.B. Fowler, eds). University of Saskatchewan, Saskatoon, SK.

Clunier-Ross, T. 1995. Mangolds, manure and mixtures: The importance of crop diversity on British farms. Ecologist 25:181–187.

Crawford, H.G. 1939. Insects as a factor in wheat production to Canada. Canadian Geographical Journal 18:217–224.

Dickinson, F.L. 1976. Prairie wheat. Canada Grains Council. Winnipeg, Man.

Ellis, J.H. 1970. The Ministry of Agriculture in Manitoba, 1870–1970. Manitoba Department of Agriculture, Winnipeg, Man.

Ecological Stratification Working Group. 1995. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Environment Canada, Ottawa/Hull. 125pp.

Eddy, J.O.F. and T.D. Fuad. 1996. Global Climate Change Impacts on Habitats: Assessing Ecological Implications of Changes in Climate. Bulletin of the Ecological Society of America 77:109–112.

Fu, Y.B., A. Diederichsen, K.W. Richards and G. Peterson. 2002. Genetic diversity within a range of cultivars and landraces of flax (*Linus usitatissimum* L.) as revealed by RAPDs. Genetic Resources and Crop Evolution 49:167–174.

Fu, Y.B., G.W. Peterson, G. Scoles, B. Bossnagel, D.J. Schoen and K.W. Richards. 2003a. Allelic diversity changes in 96 Canadian oat cultivars released from 1886 to 2001. Crop Science 43:1989–1995.

Fu, Y.B., G.G. Rowland, S.D. Duguid and K.W. Richards. 2003b. RAPD analysis of 54 North American flax cultivars. Crop Science 43:1510–1515.

Fu, YB, S Kibite, KW Richards 2004. AFLP analysis of 96 Canadian oat cultivars released between 1996 and 2001. Canadian Journal of Plant Science 84:23–30.

Fu, Y.B., G.W. Peterson, J.M. Clarke, K.W. Richards and D.J. Somers. 2005. Allelic reduction and genetic shift in the Canadian red hard spring wheat germplasm released from 1886 to 2004. Theoretical and Applied Genetics 110:1505–1516.

Fu, Y.B., G.W. Peterson, J.K. Yu, L. Gao, J. Jai and K.W. Richards. 2006. Impact of plant breeding on genetic diversity of the Canadian hard red spring wheat germplasm as revealed by EST-derived SSR markers. Theoretical and Applied Genetics 112(7):1239–47.

Furtan, H.W. and C.K. Edwards. 1997. Wheat yields and nitrogen margins: questioning the sustainability of wheat production on the prairies (http://www.csale.usask.ca/PDFDocuments/sustainWheatProdPrairie.pdf).

Harrington, J.B. 1936. Report of the variety zone Co-ordinating committee of the Western Canadian Society of Agronomy. Scientia Agricola 17:260–263.

Hind, E.C. 1931. A story of wheat. Canadian Geographical Journal 11:89–114.

Hucl, P. and R.J. Baker 1987. A study of ancestral and modern Canadian spring wheats. Canadian Journal of Plant Science 67:87–97.

Irvine, G.N. 1983. The history and evolution of the western Canadian wheat grading system. Canadian Grain Commission, Winnipeg, MB.

Johnson, T. 1961. Rust research in Canada and related plant-disease investigations. Research Branch, Agriculture Canada. Publication 1098.

Knapp, A.K., P.A. Fay, J.M. Blair, S.L. Collins, M.D. Smith, J.D. Carlisle, C.W. Harper, B.T. Banner, M.S. Lett and J.K. McCarron. 2002. Rainfall variability, carbon cycling, and plant species diversity in a mesic grassland. Science 298:2202–2205.

Morrison, M.J., H.S. Vodeng and E.R. Cober. 1999. Physiological changes from 58 years of genetic improvement of short-season soybean cultivars in Canada. Agronomy Journal 91:685–689.

Morrison, M.J., H.S. Vodeng and E.R. Cober. 2000. Agronomic changes from 58 years of genetic improvement of short-season soybean cultivars in Canada. Agronomy Journal 92:780–784.

Park, S.J. and R.I. Buzzell. 1995. Common bean. Pp. 197–212 *in* Harvest of Gold. The history of field crop breeding in Canada (A.E. Slinkard and D.R. Knott). University Extension Press, University of Saskatchewan.

Saunders, W. 1888. Pp. 2–7 *in* Bull. C. Central Experimental Farm. Canada Department of Agriculture.

Saunders, W. 1889. Ladoga wheat. Central Experimental Farm Bulletin 4:I-. Canada Department of Agriculture.

Slinkard, A.E. 1981. Eston lentil. Canadian Journal of Plant Science 61:733–734.

Slinkard, A.E. and R.S. Bhatty. 1979. Laird lentil. Canadian Journal of Plant Science 59:503–504.

Slinkard, A.E. and A. Vandenberg. 1995. Lentil. Pp. 191–196 *in* Harvest of Gold. The history of field crop breeding in Canada (A.E. Slinkard and D.R. Knott). University Extension Press, University of Saskatchewan.

Soon, Y.K., H.W. Klein-Gebbinck and M.A. Arshad. 2005. Residue management and crop sequence effects on the yield and brown girdling root rot of canola. Canadian Journal of Plant Science 85:67–72.

Stefansson, B.R. and R.K. Downey. 1995. Rapeseed. Pp. 140–152 *in* Harvest of Gold. The history of field crop breeding in Canada (A.E. Slinkard and D.R. Knott). University Extension Press, University of Saskatchewan.

Slinkard, A.E. and H.L. Blain. 1988. Production of pea, lentil, faba bean and chickpea in North America. Pp. 1059–1063 *in* World Crops: Cool season food legumes (R.J. Summerfield, ed.). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Tripp, R. 1996. Biodiversity and modern crop varieties: sharpening the debate. Agriculture and Human Values 13:48–63.

Velle, R. 1993. The decline of diversity in European agriculture. Ecologist 23:64–69.

Voldeng, H.D., E.R. Cober, D.J. Hume, C. Gillard and M.J. Morrison. 1997. Fifty-eight years of genetic improvement of short-season soybean cultivars in Canada. Crop Science 37:428–431.

Some relevant Environment Canada and Natural Resources Canada Web sites

Environment Canada - climate change (general)	www.ec.gc.ca/climate
Science assessment	www.msc.ec.gc.ca/saib
Adaptation	http://adaptation.nrcan.gc.ca
Climate modelling	http://www.cccma.bc.ec.gc.ca
Climate trends and variation	http://www.msc-smc.ec.gc.ca/ccrm/bulletin/

Appendix II. Acronyms and abbreviations

AAFC	Agriculture and Agri-Food Canada
AkPMC	The Alaska Plant Materials Center, Palmer, Alaska
CWR	Crop wild relative
ECPGR	European Cooperative Programme for Plant Genetic Resources
GRIN	Germplasm Resources Information Network (USDA)
IPGRI	International Plant Genetic Resources Institute *(now Bioversity International)*
NGB	Nordic Gene Bank, Alnarp, Sweden
PGR	Plant genetic resources
USDA	United States Department of Agriculture
USSR	Union of Soviet Socialist Republics
VIR	N.I. Vavilov Institute, St. Petersburg, Russian Federation

Appendix III. Agenda

Genetic resources in the northern part of Europe:
Current status and the future in relation to major environmental changes
18–19 September 2006, Rovaniemi, Finland

Monday 18 September		
9.00	Welcome	MTT AgriFood Research Finland, Lapland's Research Station, Oiva Nissinen and Marja Uusitalo
9.15	Introduction	Lorenzo Maggioni, Bioversity, and Merja Veteläinen, MTT AgriFood Research Finland
	The change	
9.30	Plants and climate	Frans Emil Wielgolaski, University of Oslo, Norway
10.15	Climatic change and genetic structure changes in marginal plant populations of the north	Outi Savolainen, Oulu University, Finland
11.30	Climate change scenarios in Canada and plant genetic resources	Ken Richards, Canadian Genetic Resources Program
12.15	Genetic variation in plants from Greenland and Svalbard	Marianne Philipp, University of Copenhagen, Denmark
	The present state of the northern material in *ex situ* collections	
14.00	Nordic Gene Bank – accessions from the north, their documentation, regeneration and gaps in the collection	Lene K. Christensen, Nordic Gene Bank
14.30	Vavilov Institute - accessions from the north, their documentation, regeneration and gaps in the collection	Sergey Alexanian, VIR, Russia
15.00	Alaskan efforts in collecting, cataloguing and the regeneration of high latitude accessions.	Stoney Wright, Alaska Plant Material Centre, USA
16.00	Swedish PGR activities above 64°N	Jens Weibull, Swedish Biodiversity Centre
16.30	Norwegian collections of plant genetic resources in the different climatic zones	Even Bratberg, Norwegian University of Life Sciences
17.00	Icelandic PGR confronting climate change	Áslaug Helgadóttir, Agricultural University of Iceland
17.30	Finnish PGR and Introduction to the round table discussion	Merja Veteläinen, Finnish National Programme for Plant Genetic Resources

Tuesday 19 September		
9.30	Round table discussion and summing up	What do we know – knowledge gaps – where to go
13.00	Visit to Arktikum - Introduction Dr John Moore: Inferring mechanisms behind climate from paleoclimatic records using non-linear time series analysis	http://www.arktikum.fi/
16.00	Closure	

Appendix IV. List of participants

Genetic resources in the northern part of Europe: Current status and the future in relation to major environmental changes 18–19 September 2006, Rovaniemi, Finland

Sergey M. Alexanian
N.I. Vavilov Research Institute of Plant Industry (VIR)
Bolshaya Morskaya Street 42-44
190000 St. Petersburg
Russian Federation
Tel: (7-812) 3119901/3144848 (direct)
Fax: (7-812) 5718762
Email: s.alexanian@vir.nw.ru

Even Bratberg
Department Horticulture & Crop Sciences
Norwegian University of Life Sciences (UMB)
PO Box 5003
1432 Ås
Norway
Tel: (47-64) 965654
Fax: (47-64) 947802
Email: even.bratberg@umb.no

Lene Krøl Christensen
Nordic Genebank
PO Box 41
23053 Alnarp
Sweden
Tel: (46-40) 536646
Fax: (46-40) 536650
Email1: lene@ngb.se
Email2: lene.k.christensen@ngb.se

Aslaug Helgadottir
Agricultural University of Iceland
Keldnaholti
112 Reykjavik
Iceland
Tel: (354) 843 5325
Fax: (354) 433 5201
Email: aslaug@lbhi.is

Lorenzo Maggioni
European Cooperative Programme for Plant Genetic Resources
Regional Office for Europe
Bioversity International
Via dei Tre Denari 472/a
00057 Maccarese (Fiumicino)
Rome
Italy
Tel: (39) 066118231
Fax: (39) 0661979661
Email: l.maggioni @cgiar.org

Marianne Philipp
Institute of Biology
University of Copenhagen
Universitetsparken 15
2100 Copenhagen Ø
Denmark
Tel: (45) 35320064
Email: marianp@bi.ku.dk

Ken Richards
Canadian Genetic Resources Program
Agriculture and Agri-Food Canada (AAFC)
Saskatoon Research Centre
107 Science Place
S7N 0X2 Saskatoon, Saskatchewan
Canada
Tel: (1-306) 9567641
Fax: (1-306) 9567246
Email: richardsk@agr.gc.ca

Outi Savolainen
Department of Biology
University of Oulu
90014 Oulu
Finland
Tel: (358-8) 5531782
Fax: (358-8) 5531061
Email: outi.savolainen@oulu.fi

Merja Veteläinen
MTT Agrifood Research Finland
Biotechnology and Food Research/Genetic Diversity
Tutkimusasemantie 15
92400 Ruukki
Finland
Tel: (358-8) 2708 4527
Fax: (358-8) 2708 4599
Email: merja.vetelainen@mtt.fi

Jens Weibull
Swedish Biodiversity Centre
Swedish Uni. of Agricultural Sciences
PO Box 54
230 53 Alnarp, Sweden
Tel: (46-40) 415531
Fax: (46-40) 415519
Email: jens.weibull@cbm.slu.se

Frans Emil Wielgolaski
Department of Biology, University of Oslo
PO Box 1045 or 1066
Blindern
0316 Oslo
Norway
Tel: (47) 22854627
Email: f.e.wielgolaski@bio.uio.no

Stoney J. Wright
Alaska Plant Materials Center
5310 S. Bodenburg Loop Spur
Palmer, Alaska 99645
USA
Tel: (1) 907 7454469
Fax: (1) 907 7461568
Email: stoney.wright@dnr.state.ak.us

Local organizers

Oiva Nissinen
MTT AgriFood Research Finland
Plant Production Research, Plant Production
Tutkijantie 28
96900 Saarenkylä
Tel: (358-16) 331 1622
Fax: (358-16) 331 1633
Email:oiva.nissinen@mtt.fi

Marja Uusitalo
MTT AgriFood Research Finland
Plant Production Research, Plant Production
Tutkijantie 28
96900 Saarenkylä
Tel: (358-16) 331 1644,
Fax: (358-16) 331 1633
Email: marja.uusitalo@mtt.fi

INDEX OF AUTHORS

ISBN: 978-92-9043-745-1