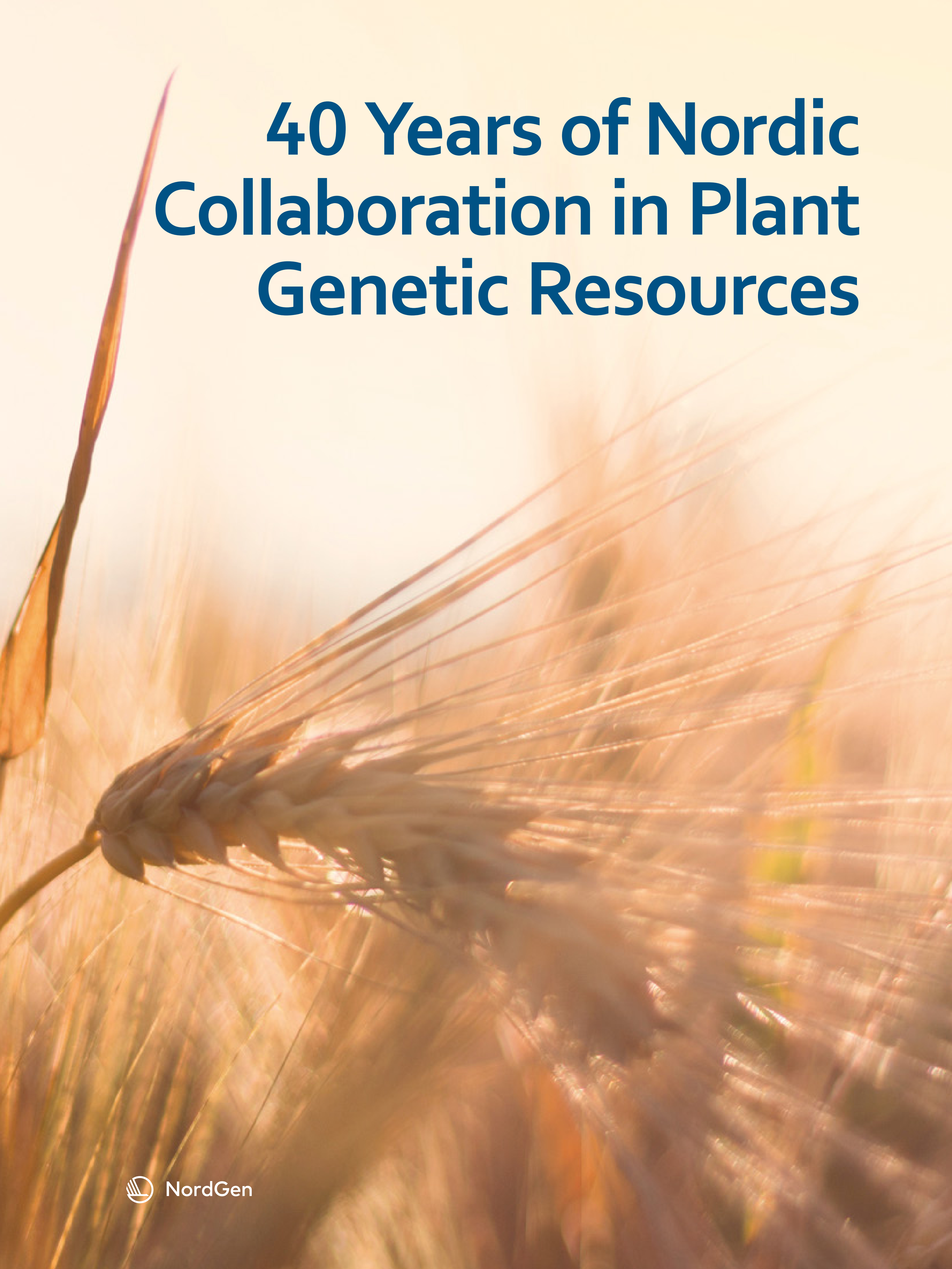
40 Years of Nordic Collaboration in Plant Genetic Resources



NordGen

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NordGen

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40 Years of Nordic Collaboration in Plant Genetic Resources

Flemming Yndgaard and Svein Øivind Solberg (eds)

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Prologue

Lise Lykke Steffensen, Executive Manager, NordGen

It is said that a picture can say more than a thousand words. The old image above, with colored glass bottles and delicate sealed test tubes sure does. Inside these containers, genetic diversity is stored in the shape of landrace wheat, wrinkly peas and patterned beans. Each seed has its own history, its own traits – its own superpowers. It is beautiful. But then again, genetic diversity has always been special and fascinating. Once you have worked within genetic resources, you most likely become a lifelong ambassador of this field. Like the authors contributing to this book.

Genetic diversity in the crops we cultivate for food and feed is essential for our livelihood. It is the basic of new developments and innovation in horticulture and agriculture and today also important for life science and biotechnology. But modern agriculture, urbanization, climate change and altered land use are some of the factors leading to the urgent decline in genetic diversity. In the best of worlds, we could reverse this trend by preserving plant varieties in the wild, *in situ*. But the reality is another and without *ex situ* conservation of plant varieties in genebanks we know that even more diversity would be lost. The genebanks of the world carry a heavy responsibility. Fortunately, the Nordic countries have taken this responsibility seriously.

In 1978, when the decision to form the Nordic Genebank was taken by the Nordic Agricultural Ministers, it was taken in a time, where the threats of declining biodiversity and climate change were not as obvious as they are today. But the need to conserve and document the genetic heritage were present and the importance of having national genebanks high on the agenda. In this setting and with the support of five countries and numerous

"Inside these containers, genetic diversity is stored in the shape of landrace wheat, wrinkly peas and patterned beans. Each seed has its own history, its own traits – its own superpowers."

hardworking state officials, the Nordic Genebank was born in 1979. Seeds were collected and donated, personnel employed, and routines were set. The Nordic Genebank has since then been the national and Nordic genebank for Denmark, Sweden, Norway, Finland and Iceland. A collaboration model that create Nordic added value, works well for the Nordic countries and is truly unique in its set up.

Today, much of the routines have changed as we have gained more knowledge on conservation and new techniques has been introduced to get more information on the germplasm. The focus on obtaining donations and collecting genetic diversity has diverted to long-term conservation and utilization. The seeds that were once stored in green glass bottles are today stored in sealed and moist proof trifoil packages. Today, we can genotype, use spectroscopy and video microscopes. But the seeds still contain the same essence, an important part of biodiversity that enables us to develop crops that give higher yields that can feed a growing population, plant varieties with more relevant traits and plants that can withstand drought and extreme weather events that comes with climate change. The diversity that each seed in the Nordic seed collection is part of, can lead to advantages for the Nordic agriculture today and in the future.

Not too long ago, the partnership between private and public actors within pre-breeding (the PPP-project) found that one of the landraces stored in NordGen carried rust resistance in its genes. A great finding as rust is among the diseases that we can expect more of as the climate changes. Another example of how the Nordic seed collection is used today is when large companies use old carrot varieties to produce natural colorants. Further, a recent research project showed that a changed diet with old varieties of cabbage could lead to Danish taxpayers saving millions on lower health costs. Many more solutions are found and in use, while others are still hidden in the 33 000 seed samples that constitutes the Nordic seed collection. Who knows what the future holds and what needs we'll have in another four decades? In other words, these seeds are invaluable.

Today, the Nordic Genebank is part of NordGen (Nordic Genetic Resource Center) that was formed in 2008. Today, we are both a genebank and a knowledge center for genetic resources for plants, farm animals and forests. Today, we continue the journey that the Nordic Genebank embarked on more than 40 years ago. These 40 years have led to change. Thanks to the people working here, the politicians taking brave decisions and government officials and the continuous support from the Nordic Council of Ministers, we have together built a foundation for the future. A future where we can hope to tackle the challenges threatening us with the help of the resources given to us by farmers, collectors, research and breeders and not least from nature.

Colored glass bottles and delicate sealed test tubes filled with the colors and shapes of genetic diversity. The picture above is a historic testimony. So is this book. It is not the complete narration of the first 40 years of the Nordic Genebank. But it gives glimpses of different time periods and relevant events. It gives you insights in the 40 years of Nordic collaboration within plant genetic resources.

I hope you enjoy reading it.

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Contents

Keeping track of the accessions is important. Here it is done by marking the NGB accession number into the surface of the glass bottle for base storage.

Editors' Introduction

Flemming Yndgaard and Svein Øivind Solberg

Already 40 years ago, there were forecasts that predicted climate change. A few people were concerned if climate change would influence plant breeding and saw that genetic resources from Central Europe and the Mediterranean could be interesting for the Nordic countries, besides the resources we had from before. However, the predictions at that time were rather uncertain and no direct actions were taken on genebank evaluations. However, the Intergovernmental Panel on Climate Change (IPCC) was established in 1988 and there was some international cooperation between genebanks, amongst others in establishing international collections of the major food crops such as rice, wheat and maize.

Now in retrospect, we see that climate change is an issue but also that international genebank collaboration has developed and is working. Still, let us take some steps back and look at what happened and how things became as they are.

Certainly, the Nordic genebank was established and the work was organized.

Below, we refer to a text written by Ebbe Kjellqvist, the first director of NGB who together with Flemming Yndgaard, the first IT manager of NGB (and co-editor of the current book), wrote about the establishment and mission of the Nordic genebank. The text is from the Symposium on Nordic Co-operation in the Field of Plant Breeding held in 1981 (Yndgaard and Kjellqvist 1983):

> *Nordic Gene Bank (NGB) was founded on January 1, 1979, as a Nordic institution established and operated by the Nordic Council of Ministers. The purpose of the NGB*

is to conserve and document the genetic variation of agricultural and horticultural materials, basic as well as cultivated ones, relevant to the climatic zones of the Nordic countries. The NGB is a service institution for plant breeders and other plant scientists in the Nordic countries, with close collaboration with these groups.

The Nordic relevance of NGB was clear from the beginning, as was the mission to serve breeding and research. This was made clear in working groups with representation from national institutions and a recognition of the value of the local genetic material.

The genetic variation of the cultivated plants in the Nordic countries is a result of hundreds of years of selection and adaptation. Modern high-yielding varieties are a result of breeding programmes, which lead to genetically rather uniformly based genotypes. Their genetic constellation is very specific and adapted to the technological and environmental situation at present.

Furthermore:

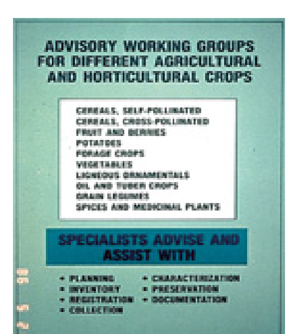
Modern varieties are genetically rather uniformly based, consequently the breeders need other resources for genetic variation. It is the purpose of NGB to serve the breeders with all genetic variation present in the Nordic countries. Through its co-operation with other gene banks it is able to supply Nordic breeders with material and information from countries outside the Nordic area.

An idea was present that NGB also should serve breeders through its collaboration with genebanks outside the Nordic area. Regarding the role of NGB in Europe (and the rest of the world), one can read,

Being a regional gene bank, NGB plays an important role in Europe. NGB has been asked by the European Cooperative Programme (ECP) to be responsible for Pisum, assisted by the gene banks in Bari, Italy and in Gatersleben, DDR. In the same programme it has been asked to assist Gatersleben, DDR with Hordeum and Radzików, Poland with Secale. NGB is expected to be made responsible by the International Board for Plant Genetic Resources (IBPGR) for the European collection of Hordeum and to hold duplicates of the world collection of Avena. IBPGR also wants NGB to be responsible for Pisum. Accepting the suggested responsibilities for Pisum, Hordeum, Secale and Avena, NGB will be able to provide an excellent service to Nordic breeders of those crops. Another consequence will be that other gene banks may in a similar way take responsibility for one or a few crops. Through the cooperation between NGB and the other gene banks, Nordic breeders can be served satisfactorily even though NGB itself does not hold wanted genetic material.

A system of collaboration and responsibility among European genebanks was already on the agenda in the early 1980s, and NGB was expected to take European responsibility for barley (*Hordeum*) and pea (*Pisum*). Today these two crops are making up a significant proportion of the Nordic collection, but the European collaboration has developed differently. The international dimension of NGB was clear from the beginning, as was the importance of a genebank information system.

In the European Cooperative Programme (ECP) established by UNDP and operated by FAO, NGB plays an important role, being a regional gene bank. This applies to the global scale as well in its co-operation with the International Board for Plant Genetic Resources (IBPGR). A flexible data-processing system based on genetic and biological principles allows all Nordic plant breeders and plant scientists to have access to all relevant gene bank information and material, including that of other gene banks.



Outline of the working groups at the Nordic Genebank in the early 1980s.

What is interesting is the idea that breeders, through a genebank data system, should have access to germplasm data, and this should also be from other genebanks. We could trace lines to what later was developed into the NGB's data system, but also European and global systems EURISCO and Genesys. One can also read that NGB, as a regional gene bank, should have a data processing system that could serve plant breeding in the whole region. The Weibullsholm *Pisum* collection served as a model for how a germplasm data system should be built. Technically, the first genebank data management system for NGB was outlined in this text from 1981.

The current book is a celebration of 40 years of Nordic collaboration on plant genetic resources. International perspectives are highlighted and the first chapter is written with input from Axel Diederichsen from Plant Gene Resources of Canada and Igor G. Loskutov from the N.I. Vavilov Institute of Plant Genetic Resources (VIR), and the chapter traces lines back to the pioneers and with a specific focus on Vavilov and how he had influenced scientists in the Nordic countries. Roland von Bothmer and Peter Tigerstedt give an over-view of the Nordic plant breeding and genetic resources. Jens Weibull discusses the role of NGB (and NordGen) in the European genebank collaboration. A special section is given to a historical recap of how NGB worked with the Gatersleben gene bank in the early 1980s, at a time when computers were large and collaboration with GDR was not straight forward for western countries, and this section is written with inputs from Jan Engels (former Bio-versity International) and Helmut Knüpffer (former IPK Gatersleben). The data manage-ment systems at NGB and NordGen are discussed by inputs from Dag Endresen (former IT leader at NGB, now at University of Oslo). We also have chapters on the collaboration with VIR and the Baltic States, the 100-years experiment on seed longevity in permafrost, and the Svalbard Global Seed Vault. Regarding the collections, Roland von Bothmer gives the story of the international Hordeum and Triticeae project and Udda Lundqvist of the Swedish Barley Mutant Collection. The celebration book is finished by chapters on the NordGen's Plant Genetic Resource Collection of today with perspectives on conservation and use, amongst others the ongoing Public-Private Partnership project, written by the current staff at the genebank and Anders Nilsson at the Swedish University of Agricultural Sciences, Alnarp. A special thanks to Helmut Knüpffer, Kit Lundborg, Roland von Bothmer and Sara Landqvist for their comments and proof-readings of this book.

Over the 40 years, NGB/NordGen has physically moved from Stora Råby in Lund to its present location at Alnarp, a distance of only approx. 10 km, but the institution has built a unique germplasm collection and has inspired thousands of people across borders and institutions. We are thankful to all who have contributed along this path, both as staff, as working group members or as board members.

Lund/Alnarp, July 2019

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Part I
Crop Conservation

Household freezers were part of the conservation concept at NGB. Such freezers were easily available, they were flexible, but the seeds needed to be dried and sealed properly before such storage.

1 Why Conserve the Diversity of Cultivated Plants: the Impact from Vavilov

Svein Ø. Solberg
Axel Diederichsen
Igor G. Loskutov

Genebanks are facilities for *ex situ* conservation of genetic diversity of cultivated plants including their wild relatives (Walters 2004). The most important mission of genebanks is, however, to enhance utilization of the diversity in plant breeding and research. Therefore, intensive collaboration with research and providing access to diverse germplasm is a major activity of genebanks. In 1979, when the Nordic Genebank was established, there were already many genebanks around the world. A few were large and well established, such as the N.I. Vavilov Institute of Plant Genetic Resources (VIR) in Russia, the Gatersleben gene bank in (former) East Germany[1]; the USDA genebanks. The majority of the genebanks were, however, small and were kept at local research stations or universities, and mostly for internal use. Such collections existed also in the Nordic countries. Breeders and researchers kept germplasm, more or less properly and more or less well documented. In 1979, such collections, as far as seed germplasm was concerned, were merged into what became the common Nordic Genebank (NGB) for the five countries Denmark, Finland, Iceland, Norway and Sweden. In this chapter, we like to highlight influential ideas and scientists along this path. We structure our chapter around Nikolai Ivanovich Vavilov (1887–1943). He was the pioneer for genebank establishments and made many fundamental contributions to crop evolution research. Over a twenty-year period, from 1920 to 1940, he headed the VIR genebank (Loskutov 1999). Vavilov himself and his many associates conducted numerous collection missions, from which they brought plant material to the VIR genebank collections and conducted extensive research as a basis for

1. At that time named ZIGuK, presently IPK (cf. Yndgaard et al. 2019)

developing new cultivars for agriculture and horticulture in the Soviet Union (USSR). In the following sections, we seek to trace historical connections from Vavilov back to scientists such as Linnaeus and Darwin, but we also discuss concepts of conservation and highlight the impact of Vavilov on scientists in the Nordic countries.

Vavilov's visits in the region

Vavilov made two visits to the Nordic region. The first visit was in connection with a long trip to Europe and the Unites States in 1921. He visited Svalöf (the Swedish Seed Association) and commended the breeding efforts made at this world centre for plant breeding research. He stated that Sweden and the Netherlands were the only countries with a viable, normally functioning scientific sector after World War I (Vavilov 1922a). Svalöf had already been visited in 1909 by E.R. Regel, Vavilov's predecessor as Head of the Bureau of Applied Botany in St. Petersburg (Loskutov 1999). In September 1931, Vavilov was invited by the scientific community in Denmark and Sweden to lecture and to get acquainted with the works of biological, plant breeding and agricultural research institutes. During this second trip to the region, Vavilov visited Copenhagen, Stockholm, Lund, Svalöv and Landskrona. Professor Åke Gustafsson recalled his meetings with Vavilov with great warmth. After this trip, Vavilov described his impressions in several letters to his colleagues working at the stations:

> *I've been in Denmark and enjoyed their work in the struggle to put new lands into cultivation* (cf. Loskutov 1999);

> *...This year I have twice had a chance to go abroad lecturing in Denmark and Sweden. It was a great hindrance, although it was interesting because I met all the European plant breeders* (cf. Loskutov 1999).

What became clear was that Vavilov very much looked at genetic resources as a global issue and did not restrict himself to Russia or the USSR. In 1925, he explained the particular situation for plant breeding:

> *Looking at plant breeding for the European and Asian Russia, we have no choice but being geographers.* Vavilov (1925)

This contrasted with what was common at that time in most of Europe with small, privately owned plant breeding stations or enterprises having already made selections for regional use in locally adapted gene pools. Vavilov clearly envisioned a systematic approach for the USSR by employing genetic diversity of crop plants from around the globe.

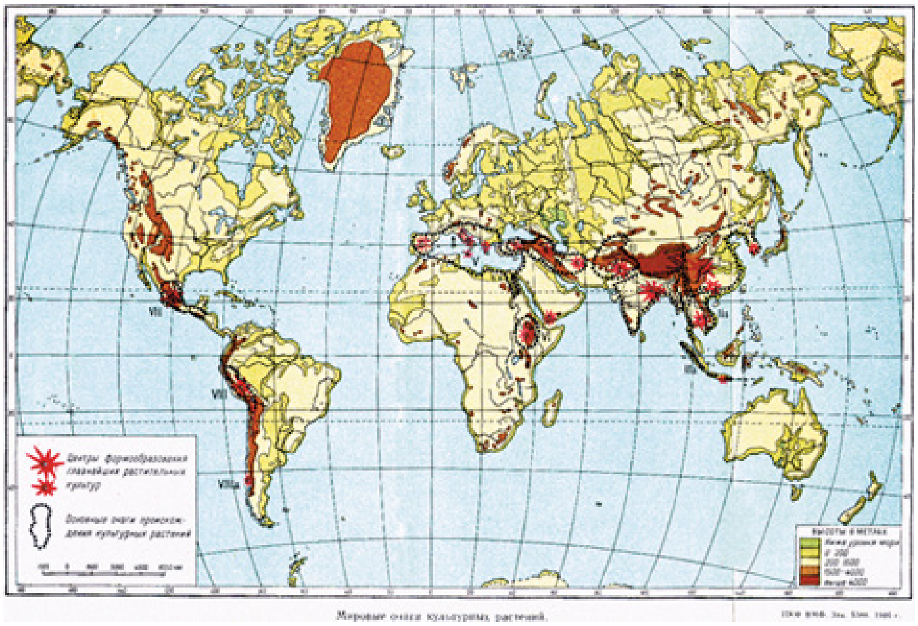
A shift from mass selection to crossing came during the first decades of the twentieth century, a shift that was not without challenges in the Nordic region. At the Swedish Seed Association (Svalöf), Hjalmar Nilsson (1856–1925) was working at this time. He was a botanist and plant breeder, and he became the director from 1894 to 1924. The ordinary cultivated varieties at that time (the landraces) were not pure, but were populations of different types, thus with a great potential for line selection. Nilsson became known for a selection method based on individual progenies, a method introduced by Vilmorin in France and utilized by others, but not at the same extent as by Nilsson. The method was based on a single initial selection with subsequent rapid multiplication, also termed "The Svalöf method" (De Vries 1907). Nilsson worked with what he termed elementary forms (Nilsson 1899). These were definite botanical characters that were associated with certain industrial qualities. Nilsson was a botanist and he applied the distinction of phenotypic/morphological lines that could be selected out of genetically variable landraces also in self-pollinating cereals. It can be assumed that this botanical approach helped to establish the pedigree method, by keeping track of the origin of the purified lines in stock books (Tedin 1921). At Svalöf, Herman Nilsson-Ehle (1873–1949) later demonstrated that economically important traits followed Mendel's laws also in quantitative traits and established the theory of polygenic inheritance and crossing methods (see Nilsson-Ehle 1909). Certainly, also Nilsson-Ehle and Vavilov met, at least in 1921 and 1931 (Reznik 2017; Loskutov 1999). The earlier static, taxonomic approach fell out of fashion, although it remains an important principle in genebank management to this day. The rediscovery of Mendel's laws of inheritance around 1900 changed plant breeding very much. It became clear that the botanist Nilsson and the geneticist Nilsson-Ehle represented differing attitudes to this new breeding technique (Åkerberg 1986). Nilsson-Ehle stressed the value of making crossings to combine good characteristics and saw that single crosses produced a wealth of different forms. He took over as the director of the Swedish Seed Association in 1925 and stayed until 1939. Later, he turned to induced mutation breeding. One of his experiments from the 1930s was to carry seeds up into the stratosphere to expose them to radiation, and for this, he used hot air balloons! The radiation methods were improved, and mutation research became the focus of Swedish plant breeding for decades. Some of the very large collections at the current Nordic Genetic Resource Centre are a result of this Swedish mutant research. Although mutation research certainly created new genetic material, one could raise the question if this focus was so strong that classical Swedish collections were neglected. For some in Sweden and in other places it became a paradigm that all necessary variation for plant breeding could be obtained from induced mutation. In this context it is remarkable that many of the Swedish wheat landraces presently available in the Nordic Genebank were not preserved in Sweden but came from the KVL in Copenhagen, Denmark.

One could argue that the modern Swedish School clashed with the Vavilovian School in the second half of the 20th century. Mac Kay criticized the application of the morphological species concept and hierarchical taxonomic classifications in crop plants such as wheat for two reasons: (1) they do in most cases not reflect evolutionary relationships and (2) they are of no or limited relevance for plant breeding, because most modern wheat cultivars would all fall into the same botanical variety: *Triticum aestivum* L. var. *lutescens* (Alef.) Mansf. Gustafsson et al (1970) documented the discussions of this subject among Swedish and Soviet scientists. On the other hand, Lehmann and Blixt (1984) showed how the genetic and taxonomic approaches could fertilize each other, by listing alleles described in peas in their associations with formal intraspecific botanical varieties described in the species *Pisum sativum* L.

Concepts in crop evolution

Vavilov's pivotal role in researching crop evolution is built on several directions of related research carried out around the globe. As the current publication is to honour the 40 years of the Nordic Genebank collaboration, the Swedish physician and biologist Carolus Linnaeus (1707–1787) needs to be mentioned. He established the binary nomenclature in his "*Species plantarum*" published in 1753 and onwards. The Linnaean systematic principle influenced Vavilov fundamentally as a botanist. However, being a creationist, Linnaeus had quite a critical view of cultivated plants and in a way declined to assign crops the status of being true species. From his *Critica botanica* (1737, cf. Stearn 1986) we can read; "Cultivated plants are not created, therefore they are not species." He continues; "All monstrous flowers and plants derive their origin from normal forms.", and; "Such monstrosities, variegated, abnormal, multiplied, double, cruciferous, gigantic, wax fat and charm the eye of the beholder with protean variety so long as gardeners perform daily sacrifice to their idol." In the publication "*The Linnaean species as a system*" (1931), Vavilov stated;

> *A Linnaean species is an isolated complex dynamic morpho-physiological system bound in its origin to a certain environment and area.*

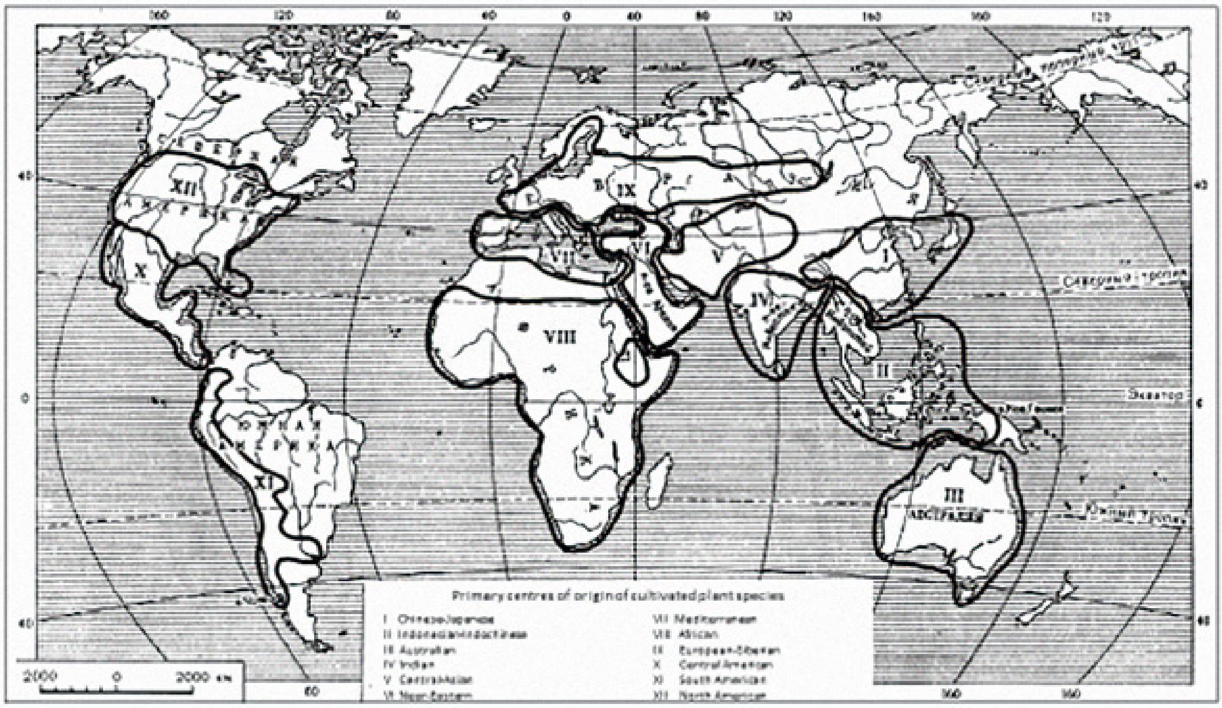


The Centres (hearths) of origin of cultivated plants as described by Vavilov (1935). Vavilov reduced the number of centres from eight to seven in 1940.

Despite Linnaeus' advice, the Vavilov School elaborated the principles of botanical nomenclature and taxonomy to capture the diversity of cultivated plants and their wild relatives. The enormous range of genetic variation of all important species of cultivated plants of the temperate regions were documented in the many volumes of the Cultivated Flora of the USSR published by the All-Union Institute for Plant Industry (today: VIR) since the 1930s.

Vavilov developed the idea of parallels in variation based on ideas from W. Bateson (1894) and C. Darwin, pointing at the gigantism of certain organs and phenotypic variation in such domesticates. Vavilov formulated the "*Law of homologous series in variation*" (Vavilov 1922b), which is presently referred to as synteny (Hammer and Schubert 1994). Traits could be predicted, e.g. the absence of alkaloids in Lupine, low erucic acid and low glycosinolates in various species of Brassicaceae.

A very important person for Vavilov was Alphonse de Candolle (1806–1893). He was a French-Swiss botanist who used a multidisciplinary approach to study the evolution of crop plants. He included botany, archaeology, history, and linguistics and was the first to distinguish old world and new world crops. The most known publication is "*Origine des plantes cultivées*" (De Candolle 1883). Vavilov dedicated his great publication "*Studies on the origin of cultivated plants*" (Vavilov 1926) to de Candolle. He, however, criticized de Candolle and others for considering mostly the genetic species (biological species) – and not particular and distinct entities within a species. Vavilov worked with terms such as "centres of origin of cultivated plants" or "centres of formation of cultivated plants". These are geographical areas of concentration of morphologically distinct forms and maximal concentration of diversity. Vavilov then suggested main centres of origin and listed the crops occurring in these centres. This was certainly a concept in flux, from "tsentr proiskhozhdeniya – centre of origin" in 1926 to "ochag (tsentr) proiskhozhdeniya – hearth of origin" in 1935. Vavilov also emphasized mountainous regions or foothills as important origins for crops and he furthermore distinguished between primary and secondary centres of origin. Vavilov acknowledged the contributions of a large team of scientists, e.g., E.I. Barulina, K.A. Flaksberger, P.M. Zhukovsky, E.A. Stoletova, A.P. Popova, N.R. Ivanov, E.N. Sinskaya, N.V. Zinger, and E.V. Wulff.



The concept of Vavilov's Centres of Diversity inspired many scholars. Here the proposal by P.M. Zhukovsky with very large mega-centres (Zeven and Zhukovsky 1975.

We should also mention Friedrich Alefeld (1820–1872). He was a German physician and botanist, known for producing the first ever inventory of cultivated plants (Alefeld 1866). He included 202 species in his main work and described intraspecific variation in these species. By formal taxonomic names, he described 1793 botanical varieties and established the intraspecific category "Varietätengruppe", which was translated to the Latin "*convarietas*" (convar.), which is still used in agricultural botany. His most known publication was "*Agricultural flora*" (Alefeld 1866). In addition, Henry de Vilmorin (1843–1899) inspired Vavilov, at least when it comes to collecting germplasm. He was a French botanist and plant breeder who established living collections of wheat and sugar beet during the second half of the nineteenth century.

From Vavilov onwards

Vavilov succeeded in building what was the world's largest collection of cultivated plants, which to this day is influential and among the top four global collections. Over a twenty-year period, 140 national expeditions and 40 expeditions to 64 foreign countries were organized and the collections increased to more than 200 000 accessions (Brezhnev 1969). However, Vavilov was arrested in 1940 and he died in prison in 1943. His ideas were widely recognised and developed, both by his associates in USSR and in the West.

At the All-Union Institute for Plant Industry, Evgeniya Nikolaevna Sinskaya (1889–1965) elaborated the eco-geographical classification of crops, amongst others of the genera *Brassica*, *Medicago*, *Triticum*, and *Linum*, and she published her results in "*Historical geography of the cultivated flora at the dawn of agriculture*" (Sinskaya 1968). She refined the method developed by Vavilov for researching crop evolution, by integrating evolutionary and ecological aspects, and with an emphasis on archaeology. She added an African region of origin of cultivated plants and used the term "regions" (oblast') instead of "centre" (tsentr). Peter M. Zhukovsky (1888–1975) developed what he termed mega-gene-centres and endemic micro-gene-centres (see e.g. Zeven and Zhukovsky 1975). Zhukovsky was the director of VIR from 1951 to 1961. In Germany, Elisabeth Schiemann (1881–1972) discussed Vavilov's gene-centres and pointed at the importance of diversity from secondary centres. She also placed particular emphasis on the crop wild relatives (Schiemann 1939; cf. also Kilian et al. 2014).

Perhaps more than anywhere else, Vavilov's ideas were put into work in the United States of America. Here, Vavilov had met Harry Harlan (1882–1944) and his son Jack Harlan (1917–1998), who continued to elaborate the concept of geographic origin of crop plants. Zeven and Zhukovsky (1975) and Zeven and de Wet (1982) framed this into agricultural crop centres and non-centres. The true centres were a few regions of special importance for domestication of plants, like the Fertile Crescent, while non-centres were most of the rest of the world. Harlan and de Wet (1971) introduced the gene pool concept, where wild progenitors were classified into primary, secondary, and tertiary gene pools according to their potential utilization in breeding.

"Wild progenitors were classified into primary, secondary, and tertiary gene pools according to their potential utilization in breeding."

Regarding the conservation of crop diversity, Sir Otto Herzberg Frankel (1900–1998) was certainly inspired by Vavilov. Frankel was very much concerned about the loss of genetic variability caused by the green revolution. In 1968, he coined the term "plant genetic resources" and called upon preservation of these resources (see Evans 1999). Together with Erna Bennett, a Scottish breeder who at that time worked for the UN Food and Agriculture Organization (FAO) they certainly influenced the awareness of genetic erosion (Pistorius 1997; Hanelt et al. 2012). In 1970, Frankel and Bennett (1970) wrote a publication that greatly influenced the outcome of the 1972 United Nations Stockholm Conference on the Human Environment that called for a global programme on the conservation of genetic resources. In 1971 the Consultative Group on International Agricultural Research (CGIAR) had been given the mandate to follow up the success of the green revolution to all major food crops and all regions of the developing countries. Soon after, in 1974, a genetic resources programme was set up; The International Board for Plant Genetic Resources (IBPGR). This is also the period of time in which many national genebanks came about, for example in Canada in 1970.

Indeed, genetic resources have been collected and conserved, and today there are more than 1750 *ex situ* collections around the world, and these collections are housing more than seven million accessions (FAO 2010). The global conservation system of plant genetic resources includes important components. International crop specific collections have been established under CGIAR and other international organisations like the World Vegetable Centre. In addition, there are regional genebanks, national genebanks, and collections in national or local research institutions and in private enterprises, all more or less publicly accessible. The international collections are legally "in trust" and they are in the public domain, but with obligations of benefit sharing as outlined in the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO 2009) that came into force in 2004.

Impact on the Nordic genebank (NGB)

Certainly, Vavilov has influenced breeders and scientists in the Nordic countries like in other parts of the world. The first director of the Nordic Genebank was Ebbe Kjellqvist and prior to this, he worked for FAO with establishing a regional plan for conservation and evaluation of genetic resources at the Izmir genebank in Turkey. In collaboration with national institutes in Syria, Iraq, Iran, Afghanistan and Pakistan, he worked for joint and systematic collection missions in this centre of origin of selected crop species, and with a combined national and regional conservation and evaluation system (Kjellqvist 1975). He attended the 1972 United Nation's Stockholm Conference where a joint Nordic genebank was discussed (Tómasson 2012). Another important event was the EUCARPIA conference in 1966, where the European plant breeding institutes recommended regional collaborations on genebank conservation. The Nordic region was one, and Ebbe Kjellqvist and

Stig Blixt became the primary instigators for such an establishment (Scarascia-Mugnozza and Perrino 2001). Stig Blixt worked at that time at the Weibullsholm plant breeding station in Sweden and was maintaining one of the world's largest collections of peas with accessions from all over the world including landraces, improved lines, mutation lines and wild relatives. Birger Kajanus (at Weibullsholm) had initiated the collection as early as 1915 and the collection included 3 427 accessions in 1990, with a description of roughly 200 individual genes and data on about 45 characters expressed quantitatively. The Weibullsholm collection became a model for documentation of genetic resources (Blixt and Williams 1982) but when breeding of peas declined in the early 1990s, the tasks of maintenance and documentation were handed over to the Nordic Gene Bank and the John Innes Centre (England).

Nordic breeders and scientist have been proactive in finding solutions to the funding challenge of breeding and conservation. As an example, the idea of a royalty system was proposed in Sweden as early as 1948 (Fajersson 1997). At that time Gunnar Weibull was the president of the International Association for Plant Breeders for the Protection of Plant Varieties, and this organisation suggested an international convention for plant breeders' rights, a convention that became a reality in Paris in 1961 and formed the basis for the International Union for the Protection of New Varieties of Plants (UPOV). Former board members of the Nordic Genebank from Denmark and Norway were active in the process of establishing the UPOV convention for Plant Breeders' Rights (Tómasson 2012). Official variety tests and controls were important components of the new seed system. Plant Breeders' Rights were implemented when the countries ratified the UPOV convention in 1969. The Nordic Genebank (NGB) was placed under the intergovernmental Nordic Council of Ministers and was secured long-term commitments from the ministries of agriculture in the five Nordic countries.

Nordic countries and crop evolution

Vavilov did not indicate that Northern Europe or the Nordic region was a centre of origin but rather that crops domesticated in the Mediterranean and Near Asian centres were brought here. However, the area could be part of a secondary gene centre for certain species, such as for *Brassica napus* where the crop rutabaga, also termed swedes [*B. napus* L. var. *napobrassica* (L.) Rchb.], is found. Agriculture reached Northwest Europe at about 4000 BC, and several crops have been cultivated and diversity has developed here, including rye and oats, although the area is not referred to as a secondary centre for these species. Darlington (1956) was the first to refer to Europe as a region of origin and Zeven and Zhukovsky (1975) suggested a European-Siberian Centre, as one of twelve centres of origin of the world's cultivated plants. Species included in this centre are given in Table 1 and they cover various pasture and forage crops and some vegetables and herbs used for preservation and fresh greens.

In one of his last works published in 1940, he divided the Old World (excluding Africa south of N. Africa and tropical Asia) into 19 areas each characterized by plants with similar general 'ecological passport'. This was based on parallelisms in evolution, which could be seen for plants belonging to the same general group and have followed the same geographic route in their evolution. Vavilov was able to establish 'ecological passports' for annual cereals, grain legumes, oil and fibre flax.

Relevant for the Nordic area are the Northern Agricultural Territory (Number 19) and the West-European Agricultural territory (Number 17). The Northern Agricultural Territory included Northern European USSR, Siberia, and Northern parts of Scandinavia and Finland. General characteristics were plants with low heat requirements and cold resistant, medium sized plants. Examples included were very early types of barley and rye.

Table 1

Some crop plants from the European-Siberian region of diversity as given by Zeven and Zhukovsky (1975).

Species	Common name	Comment
Forage grasses		
Festuca pratensis Huds.	Meadow fescue	Widely cultivated, pasture and hay plant
Festuca rubra L.	Red fescue	Widely cultivated, pasture and hay plant
Phleum pratense L.	Timothy	Widely cultivated, pasture and hay plant
Dactylis glomerata L.	Orchard grass	Widely cultivated, pasture and hay plant
Poa pratensis L.	Meadow grass	Widely cultivated, pasture and hay plant
Poa palustris L.	Marsh meadow grass	Arctic Europe, varieties developed
Forage legumes		
Trifolium hybridum L.	Alsike clover	Possibly first cultivated in Sweden
Trifolium repens L.	White clover	Cultivation started in N Italy and Holland
Trifolium pratense L.	Red clover	Cultivation started in UK and Holland
Vegetables and herbs		
Humulus lupulus L.	Hops	Widely cultivated, spice plant
Carum carvi L.	Caraway	Widely cultivated, spice plant
Allium scorodoprasum L.	Sand leek	Formerly cultivated in the USSR
Rumex acetosa L.	Garden sorrel	Formerly cultivated in N Europe
Beta vulgaris L.	Beet root	Wild coastal distributed along the coast
Brassica rapa L.	Turnip	Root types and leafy types, Finland
Brassica napus (L.) Rchb.	Swede	Europe is a secondary gene centre
Fruit and berries		
Ribes nigrum L.	Black currant	Very winter-hardy types in Scandinavia
Fragaria spp.	Strawberries	Also includes wild strawberry (*F. vesca* L.)

The West-European Agricultural Territory covered Western parts of Europe and included southern Scandinavia and the south of Finland. General characteristics were tall and hydrophytic plants. The stems were generally thick and stiff. The leaves were large and broad and for cereals, the spikes were generally large and dense with medium-sized or large grains. Local varieties could have lax spikes, were tall and relatively early-maturing.

Conclusions

N.I. Vavilov was extraordinarily productive in various areas of cultivated plant research. He pioneered works in the area of crop plant pathology, geography, evolution, genetics and breeding. He integrated historical and botanical research. It is not easy to point out where his research efforts have had the most impact. He always pioneered new paths in various research areas. At the same time, he was managing probably the largest agricultural plant research centre that existed in the world at his time. Even today, his works inspire many scientists in genebanks and beyond.

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2 Plant Breeding and Genetic Resources in the Nordic Region – in the Past and in the Future

Roland von Bothmer
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Every historical period has its challenges as well as its visions for the future. The measures are based on the current knowledge and on technology available at the time. In a perspective it is important to look in the rear view mirror to experience how scientists, plant breeders and politicians at a certain time thought about the future. To compare the situation 40–50 years ago with the situation today is rewarding and it offers better possibilities for a prognosis about the future.

Genetic resources and genebanks

The importance of plant genetic resources was first recognized by the pioneering work in the 1920s by the Russian geneticist N. I. Vavilov founding the great Russian gene bank in St. Petersburg now carrying his name (Vavilov 1997). Somewhat later (in the 1930s), the American plant breeder Harry Harlan promoted the use of exotic landraces in cereals in breeding, barley in particular (Harlan 1957). Both collected crop landraces in remote areas of the world. They explored crop genetic resources at a large scale after the era of botanical missions in earlier centuries. They claimed the importance of collection and conservation of plant genetic resources for the future, which ultimately should be used in breeding for environmental challenges and for new demands from growers and from the market. In the 1960s the importance of plant genetic resources became a global concern and the establishment of gene banks became an urgent issue over the world.

The real breakthrough for genetic resources at a global scale came in the late 1950s when Norman Borlaug at CIMMYT, Mexico, started so-called "shuttle breeding" in wheat which led to a broad adaptation, better disease resistance and drastically increased yields. Eventually, Borlaug's efforts became known in the 1960s as The Green Revolution, which has saved a poor population from famines in many countries in Asia, Africa and South America. New and high yielding varieties of wheat and rice could be cultivated in many areas of the world to meet a wide array of environmental and climatic challenges including resistance to pest and diseases, drought and other stress factors. But the green revolution varieties were also more demanding and needed a much improved environment to produce more.

Activities in the Nordic area

In the late 1960s a very dynamic period started in the Nordic plant breeding community leading to establishment of new institutions and other important changes. Which where the problems and which where the organizational, economic and political solutions?

Like in many other parts of the world discussions about the value of plant genetic resources started in the Nordic countries in the end of the 1960s. It now became obvious that, if not all so at least a major part of the old landraces, which were well adapted to different regions in the Nordic area were gone. These landraces were basis for the successful plant breeding in the Nordic countries starting in the late 19th century. The concern about the lost material started among plant breeders who claimed the need for collecting remaining landraces and their wild relatives over the Nordic area with high priority. Collecting missions both in the Nordic region and in other countries were implemented by breeding companies and university researchers (Olsson and Ellerström 1957) and a great deal of material was assembled.

In a Swedish state investigation in the early 1970s the global and national challenges and needs concerning the conservation and use of plant genetic resources were outlined (cited by Yndgaard and Kjellqvist 1982). This became the starting point for further discussions and actions concerning the whole Nordic area. The priority at that time was to set up individual, national gene banks for each of the five Nordic countries. Further discussions among plant breeders and at the political level, mainly at The Nordic Council of Ministers (NMR) showed that it would be more effective and rational to handle similar issues of different countries together. This process eventually led to the foundation of a joint, regional institution, The Nordic Genebank (NGB), which was inaugurated in 1979.

The objective for NGB was quite clear: the new organization should work with the conservation of plant genetic resources (PGR) in various ways: collection, seed conservation and distribution of germplasm – at that time they should not work directly with the utilization or improvement of the material.

The utilization of plant genetic resources – Nordic Plant Breeding (SNP) takes shape

The Nordic countries have much in common: they are small, have scattered markets, have severe and varying edaphic and climatic conditions with both South-North and West-East gradients, making the breeding for new varieties a complex task. The specific Nordic situation was described by Tigerstedt (1999) at the 20th anniversary of NGB: "There are virtually no other regions in the world with equivalent regional adaptation to the long summer days but relatively short growing season. Nowhere else in the world is wheat grown north of the 60th latitude." Breeding for northerly latitudes (especially above the polar circle) would be of a common interest particularly for Iceland, Norway, Finland, and Sweden where there is no basis for commercial breeding activities.

In earlier times there were often close contacts between private and public plant breeders in the Nordic countries. Exchange of material, results and ideas was regularly taking place, mostly on a bilateral basis. In the middle of the 1970s it became evident that a deeper contact and increased collaboration was needed also for utilization of genetic resources at a non-competitive level.

This situation was described in a Swedish governmental survey (SOU1978:23) made by the well known geneticist Åke Gustafsson, a pioneer of mutation breeding. This investigation ultimately led to great changes in Swedish plant breeding organization and related research, but it also stressed the need for a broader, collateral collaboration particularly in the Nordic region. This message was taken up by the Swedish Ministry of Agriculture and referred to The Nordic Council of Ministers (NMR), which assigned a group of Nordic specialists to make a detailed proposal for joint Nordic activities. A report was presented in July 1980 with the suggestion for an extended Nordic collaboration in plant breeding and related research. The political level in each of the five countries realized the long term benefits for agriculture and after negotiations in The Nordic Council of Ministers (NMR) a new organization was decided on: Joint Nordic Plant Breeding (Samnordisk Planteförädling, SNP). SNP started in 1981 and was a network organization with minimal administration with a budget to support different projects. The actual work should be performed at the participating plant breeding institutions or companies and university departments and SNP should collaborate with other Nordic organizations, especially NGB.

The objectives for SNP were to act for coordination of national contributions in plant breeding included targeted research, practical breeding and variety testing. The joint efforts were mainly, but not exclusively, directed to crops grown in specific areas, especially in Northern Scandinavia or minor crops where breeding was non-profitable and where joint efforts for the production of new and better adapted varieties would be of great value for agriculture in the area.

The activities of Nordic Plant Breeding (SNP)

This was the time before the term *pre-breeding* was coined but in many respects SNP was a tool for these kinds of activities. Even if the problems with climatic change were not as evident in the early 1980s as they are today, it is obvious from the project proposals and reports that environmental, geographic, edaphic and climatic conditions were a concern during this period.

Over the more than ten years SNP was operative, a number of smaller or more substantial projects were supported. One type of projects were short-termed, usually one or two years, for investigating or reviewing possibilities for future practical plant breeding efforts in the Nordic region for various plant groups, especially minor crops. Several studies were made in vegetables, fruits and berries and some agricultural crops not widely grown in the area, but having a potential for future cultivation. Such projects were made in potatoes (several studies), maize (for forage and for consumption), white cabbage, triticale, raspberry, plums, apples and woody ornamentals.

Some of the SNP projects were more general concerning methodology, specific cultivation conditions or for solving environmental problems, such as: haploidy in vegetables, gene technology (already in 1984!), quality problems, winter hardiness, Nordic climatic zones, breeding for low-input agriculture, breeding for reduced nitrogen leakage, and breeding for insect resistance as an alternative to chemical treatments.

Many of the problems tackled in the older SNP studies are still valid and target for research and pre-breeding activities, others have become more obsolete. For example, there is no

The SNP-project "Variation and stability in Nordic barley material" included 220 varieties and breeding lines from all Nordic countries in a study of genetic diversity. They were multiplied and distributed for trials in different climatic zones in the whole region. The trial was prepared at Department of Plant Breeding, Swedish University of Agricultural Sciences during 1987. The great diversity in the material was evident during the flowering time, early in July (top). Harvesting was made in September 1987 (bottom).

longer commercial breeding in vegetables for the Nordic countries, and the breeding for fruit and berries has diminished considerably.

A few of the SNP projects were more substantial, lasting over several years and included real research and development projects on major crops. Some of these are:

The project **"Variation and stability in Nordic barley material",** which lasted for three years, studied genetic diversity and broad adaptation in a number of quantitative and adapted traits as a basis for further breeding. It included all barley breeders and many barley scientists in the region. 220 varieties and breeding lines from all Nordic countries were selected to represent as large genetic diversity as possible. They were multiplied and distributed for trials in different climatic zones in the whole region. The trial was repeated over three years and yielded interesting results which were presented in several articles and a PhD thesis (Nurminiemi 1995; Ortiz et al. 2002).

Forages are an important plant group for all the Nordic countries based mainly on indigenous grass and legume species, and breeding of these crops is of common concern in the area. The SNP project **"Breeding of grazing and pasture species for the northernmost**

areas in the Nordic region" involved all Nordic countries. The aim was to breed new varieties for Greenland, Faeroe Islands and Iceland as well as for the northernmost parts of Finland, Norway and Sweden. The project lasted for almost 15 years (thus longer than SNP) and was the most expensive of all SNP projects. It had great ambitions and included several grass species, such as timothy, red and meadow fescue and bluegrass as well as some legumes (red and white clover). The main attention was given to grasses and the project was later called "Nordgrass" (Nordgräs). Many comparative field trials were performed but the programme was perhaps too ambitious with too many species included. The best outcome was probably that the Nordic breeders had an arena for networking. Eventually, one new timothy variety, 'Snorri' came out from the project (Helgadóttir and Sveinsson 2006).

During the 1980s, barley was the major crop of concern in breeding mainly for increasing its nutritional value as feed. At that time malting quality was of less concern. Research departments in the area were actively involved. Beside the quality aspects, disease resistance was an important issue. A long term project (1981–1987), coordinated by the Agricultural Department at Risø National Laboratory in Denmark, was **"Resistance against plant diseases/non-specific mildew resistance in barley"**, which was followed by **"The strategy for attack by barley mildew (ml-o)"**.

"The Nordic Biometry Programme" started in 1985 as a survey and workshop project to study the need of data treatment in plant breeding. In 1987 it developed as a collaboration between SNP, NGB, and SNS (Samnordisk Skogsforskning – Nordic Forest Research) with SNP as coordinator with the purpose of supplying Nordic plant and forest tree breeders with relevant computer programmes. This led to the development of NOBIS (Nordic Biometry System) as a supplement to the NGB documentation system which was created and maintained as a PC computer system (Yndgaard 1990). It was described in the following way: "The system is constructed so that users with minimal knowledge for applied statistics are able to use advanced computers and statistical programmes".

SNP sponsored **a number of joint Nordic symposia**, workshops and other meetings. The first symposium, held in Helsinki in 1981 was: "Nordic cooperation in the field of plant breeding" (Manner and Sigurbjörnsson 1983). It was a start-up meeting for the whole SNP programme. Other meetings were more specific, such as "Nordic Cell and Tissue Culture Symposium" (arranged twice, 1984 and 1988) and "Molecular Analysis of Plant Genes" (1986). These symposia were attended by many scientists and breeders and improved further collaboration.

A specific annual meeting where SNP was involved as organizer in the 1980s was arrangement of the joint Nordic PhD courses in plant breeding. That is a special arena for breeders, scientists and graduate students to meet, present their own results and discuss major problems in breeding and agriculture. These appreciated courses were started already in the mid-1970s and are continued to this day.

The relation between NGB and SNP

Even if NGB and SNP were separate institutions there was a tight contact between the two – not least due to the fact that to a large part the same persons were engaged in boards, working groups and as project partners in both organizations. During the 1980s the two organizations gradually came closer to each other. In NGB many considerations where made about a more efficient utilization of gene bank material and in SNP the importance of genetic resources for future plant breeding became even more obvious. One of these ideas developed at NGB was to create a "Dynamic gene pool", which comprised a composite cross system for promoting base broadening and introduction of new genes from exotic sources to be used in breeding programmes (Yndgaard and Kjellqvist 1982). A dynamic gene pool could also make gene banks work more effective. The idea was taken up by a Finnish-Swedish collaboration with the aim of base broadening and introduction of new resistance genes from exotic sources in barley. The study resulted in a PhD thesis where these thoughts were implemented (Veteläinen 1997). The whole project yielded one Finnish and one Swedish gene pool, both comprising 40 parents, 20 of which were exotic germplasm and 20 were national varieties, different for the two countries. Both dynamic gene pools are now available at NordGen.

The end of SNP

The ten years activity of SNP was evaluated in 1990. The report stated that SNP had a stimulating effect on Nordic collaboration especially for public breeders and research, but less so with the private breeding companies. SNP had contributed with significant results in crop resistance and quality and not least with research on environmental issues, like breeding for reduced nitrogen leakage. The SNP projects had in some cases had difficulties regarding ownership issues of new crop varieties developed in joint programmes. In these cases the problems should have been anticipated and settled before the start of the projects. There had been too much focus on minor crops and the evaluation noted that more resources should have been invested in major crops.

"SNP had contributed with significant results in crop resistance and quality and not least with research on environmental issues."

The evaluation noted that woody landscape plants were gradually used in an increasing scale in all Nordic countries. It is important with a climatically adapted, hardy material instead of cheap, mass produced, imported plants. This kind of tested and improved material was predicted to get an increased use in the Nordic countries.

It was further stated that NGB and SNP had developed a very close contact over the years and the delimitation between the two organizations had become rather unclear. The two organizations had joint activities in working groups for e.g. ornamentals, landscape plants and herbs and medicinal plants (which was later to be taken up by the National Programmes and was no longer part of NGB's activity). It was stressed that a close relation between gene bank and plant breeding industry is necessary and that not least Nordic plant breeding should be further strengthened (Sigurbjörnsson 1999). However, NGB should be more involved in breeding issues, such as evaluation and other pre-breeding activities.

The final recommendation from the evaluation group was to merge NGB and SNP into one unit: Nordic Institute for Plant Genetic Resources (NIPR). In this new organization the activities in forestry at SNS (Samnordisk Skogsforskning) should be included (but domestic animals were not mentioned here). This was almost 20 years before the establishment of NordGen.

However, a new institute was not implemented – the time was obviously not ripe for this drastic change. Instead it was decided to close down Nordic Plant Breeding (SNP) and transfer the resources to NGB's ordinary budget with the commission to include more of pre-breeding and evaluation activities. Some of the new funding was handled by the respective working group who decided about applied, mainly external projects. Successively, however, the resources diminished and NGB's budget was then mainly used for core activities.

Major changes over the last 30 years and need for further collaboration

In the early 1990s, about the same time as NGB and SNP were merged, a period of escalating changes started, which radically has changed the pre-requisites for gene banks and the plant breeding industry.

The major international issue over the last 30 years has been the growing concern for upcoming climate change and all the problems it will cause for nature, environment, agriculture and food security. It will influence the future way of living and even survival.

Many international agreements have been adopted in the same period, which will have a great impact for the future; some of these are:

- Convention of Biodiversity (CBD) in 1992, stating the state sovereignty over genetic resources;
- The International Treaty in 2004, regulating the access to genetic resources of crops and their wild relatives;
- The Nagoya Protocol in 2010 for access and benefit sharing of genetic resources.

In the Nordic region some of the more evident changes have been:

- The map of plant breeding has seen many changes, including merge of companies, changed ownerships and new actors (similar as on the international arena);
- National Programmes for Plant Genetic Resources were initiated complementing the work at NGB and having responsibility for vegetatively dispersed plants, such as ornamentals, medicinal and landscape plants;
- The Nordic Genebank (NGB) became The Nordic Genetic Resource Centre (NordGen) in 2008 merging the work on plants, domesticated animals and forestry.

How will all these changes and initiatives influence our future? Will conscious use of genetic resources and effective plant breeding contribute to a future sustainable agriculture? The need for a substantial input through increased pre-breeding activities is urgent.

To produce a new plant variety in a major crop takes around ten years if the breeding procedure includes already advanced and adapted parental material. If exotic material should be included for increasing the gene pool or for introduction of desirable genes the breeding programme will be prolonged, in some cases up to 20 years or more. The exotic germplasm may contain many interesting and valuable genes but also many unwanted traits such as inferior adaptation, shattering, lodging and low seed fertility – so-called linkage drag, which considerably will prolong the breeding procedure. A single company or public breeder cannot cope with this alone – it is too costly and risky and a broader collaboration and share of costs are necessary.

"The major international issue over the last 30 years has been the growing concern for upcoming climate change."

Collaboration in pre-breeding programmes between competing companies has been practiced in Germany and Britain for many years. The idea came up for a similar arrangement in the Nordic region, thus the concept of SNP from 1980s could perhaps be rejuvenated. A survey initiated by NMR was presented in 2010 (Nilsson and Bothmer 2010). After many discussions with all breeding companies and public breeding entities as well as with the Ministries of Agriculture (or equivalents) of all five countries an agreement was reached to launch a Public-Private-Partnership, PPP, for pre-breeding. Even if the companies are bitter rivals on the market they have found no (or minor) problems to work together at the pre-breeding, non-competitive level. The programme is financed by input jointly from the companies and from the five countries. It has now been operative for eight years and a further issue is important – NordGen is the coordinator of the whole programme (Hägnefelt and Nilsson 2019). Thus genebanking and breeding are again closely connected.

What are the major problems in the future and how can they be handled?

In retrospect – 40 years ago the main concern for the future in SNP treated close problems of adaptation such as increased winter hardiness, better pest and disease resistance and possibilities for cultivation of a number of minor crops. The breeding goals contained a number of environmental issues to promote a sustainable agriculture, for example, reduction of nitrogen leakage and reduced use of chemicals in agriculture. An increased competitiveness for Nordic companies was regarded as an important issue but food security was not mentioned and neither was climate change. The serious questions for tomorrow and for the next century are of another dignity and problems are far more serious than earlier. New species and races of pests and diseases will appear as well as a completely new situation for abiotic stresses with drastically changed patterns of precipitation and temperatures. Many of those changes will be local and fluctuate between years and it will be extremely difficult to predict local conditions. For the future, genetic resources, research, pre-breeding and practical plant breeding will be even more urgent to further develop and secure a decent life.

The influence of global climate change is here exemplified by estimated changes in the yearly average temperatures and precipitation for the years 2020, 2050 and 2100 in the southern boreal zone which includes Finland and central parts of Sweden north of Stockholm:

	2020	2050	2100
Temperature increase (°C)	+1.2	+2.4	+4.4
Increased rain/snowfall (%)	+3.0	+6.0	+11.0

The climate will be more maritime and the snow cover will probably be thinner and there will be an increase of snow free periods which may cause frost injuries. Climatic changes may influence forest yield in 2050 in the following way:

- Growth increases with 20–30% in southern Finland and other areas in the southern boreal zone.
- The limit for noble hardwood forests will advance 100–200 km to the north.
- For environmental causes deciduous forests should be more widely cultivated.
- The risks for damages caused by fires or storms increase with injuries by fungi, parasites, and insects.
- To reduce the risks the genetic diversity needs to be improved: mixed forests by deciduous trees and conifers should be promoted.

Equivalent changes will affect both agriculture and horticulture. In order to increase the yield and improve sustainability NordGen and the pre-breeding initiative in PPP should be more active in promoting the use of Nordic plant genetic resources. Here the Geographic Information System (GIS) is crucial. GIS together with Global Positioning System (GPS) and High Resolution Satellite Imagery (HRSI) can produce very detailed maps with capacity to predict the yield in agriculture and forestry and not least can predict the risks for pests and diseases.

"This material must be preserved in living conditions in clone archives."

In 1977 The Nordic Council of Ministers implemented a report with a map of the phytogeographical conditions in the Nordic area. This map is valid as a starting point for common Nordic contributions concerning conservation and development of Nordic plant genetic resources in agriculture, horticulture and forestry. The map from 1977 needs an update with new information especially concerning long-term changes of the climate and with these new data it will be extremely useful.

In all sectors – forestry, agriculture and horticulture – the Nordic collaboration must be further strengthened in characterization and evaluation of genetic resources, pre-breeding and breeding for specific areas or for minor crops where there are weak economic incentives for a commercial breeding. All five Nordic countries must realize the economic benefits with joint projects reducing the national costs. That is why earlier NGB, SNP, SNS, NordGen, PPP and other Nordic institutions were established. These joint initiatives may comprise collectively developed populations in agriculture, joint progeny testing in forestry and common collections of fruits and berries in horticulture. An updated map of the phytogeographical subdivision of the Nordic area will be of uttermost importance.

Climate changes will demand a relocation of Nordic forest trees in the future. Local material of today will probably not be optimally adapted to the new conditions. A transfer of genotypes from south to north will be urgent from year 2050.

More attention should be invested in other plant groups presently not part of NordGen's mandate. In coming decades, landscape plants and ornamentals will attract an increasing importance as was stated already in the evaluation report of SNP in 1990. Together with many fruits and berries this material must be preserved in living conditions in clone archives and other types of collections in different climatic zones which have been established in different parts of the Nordic area covering most climatic conditions.

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Part II
International Work

NGB co-operated very much with the gene bank in Gatersleben in the former GDR in the 1980s, supporting the important UNDP/ECPGR work. On the photo we see Helmut Knüpffer (left) and Frank Mortensen, IT manager at Milog Software Company, on a mission in 1985.

3 NGB/NordGen and the European Cooperative Programme for Plant Genetic Resources, ECPGR

Jens Weibull

The European network to conserve and exchange plant genetic resources (PGR) was established by the United Nations Development Programme, UNDP, back in 1979, as a means to bridge on-going activities in the Eastern and Western economic zones. This means that ECPGR and the Nordic Gene Bank (NGB) were born the same year. The formal inception of ECPGR took place on 1 October 1980. At the time, ECPGR was named a project and it was suggested to coordinate its activities with those of the EUCARPIA Gene Bank Committee and to consider becoming a part of the IBPGR programme (International Board for Plant Genetic Resources), the predecessor of IPGRI (International Plant Genetic Resources Institute) and, later, Bioversity International of today (UNDP/IBPGR 1984).

At this time, two persons instrumental to the establishment of ECPGR were also closely associated with the NGB, namely Ebbe Kjellqvist and Stig Blixt. Kjellqvist, having spent ten years in Turkey establishing the Turkish National Gene Bank, became NGB's first director to be followed by Blixt as a result of Kjellqvist's untimely death in the mid 1980s. For many years Blixt served as a specialist on documentation and information management, due to the knowledge and experiences he had built up working on the *Pisum* mutant collection at the Weibullsholm Plant Breeding Institute.

The objectives of the Programme have been basically the same since its onset, i.e.

- to facilitate: contact between genetic resources workers, unhindered exchange of plant material, and exchange between gene banks of documentation and information;
- to provide up-to-date information about *ex situ* collections held by gene banks, researchers and breeders;
- to pursue crop-specific activities, including collecting missions and characterisation and evaluation of germplasm.

For this purpose, six Crop Working Groups, considered the backbone of the cooperation, were established with the following over-arching aims:

1. to document existing collections, and establish a computerised database of germplasm conserved in Europe;
2. to develop standard crop descriptor lists;
3. to promote an effective data exchange network;
4. to rationalise collections, i.e. remove unnecessary duplications;
5. to identify collection gaps and promote selective collecting where necessary;
6. to systematically assemble characterisation data, and work jointly to evaluate quantitative traits; and
7. to support training of gene bank personnel;

The initial Working Groups of barley, forages and *Prunus*, were later complemented with those of oat, *Allium* and sunflower. The ongoing work in the genera *Pisum* and *Secale* (rye) were thought to be strong enough not to need specific funding during the early period of the cooperation (1983–1986), when the programme was moved under the auspices of IBPGR.

In 1979 it was concluded that both a Steering Committee and an Executive Committee were needed. While the Steering Committee (until 1998 named the Technical Consultative Committee, TCC) has met at regular intervals since 1983, and for the 15th time in Thessaloniki in May 2018, the historical documents show no existence of an Executive Committee. It was, however, re-established at the 12th meeting in Bratislava 2010 following the recommendations made by an independent external evaluation during 2010.

Today, ECPGR activities focus around the Programme's 18 Working Groups and three cross-cutting networks (wild species conservation, on-farm conservation, and documentation and information). Funding of WG activities is based upon a grant scheme principle. Important achievements, among others, include: AEGIS – a virtual European gene bank system with harmonized quality assurance mechanisms; EURISCO – the centralised European search catalogue for plant genetic resources; and adopted ECPGR Concept Notes for on-farm conservation and management and *in situ* conservation of crop wild relatives, respectively.

Participation and influence of NGB/NordGen

Directors of the former Nordic Gene Bank were actively involved in establishing ECPGR in the first place. The unique setup of NGB as a regional gene bank was long seen as an asset within the European gene bank context. However, the fact that ECPGR evolved as a network, and supported by member countries, led to the situation that NGB itself was never recognized as a formal member but maintained observer status, a situation prevailing still today. To safeguard Nordic representation in the working groups, the TCC meeting in Nitra, Slovakia, in 1995 confirmed that NGB would be able to nominate two attending members to each working group meeting.

> "The unique setup of NGB as a regional gene bank was long seen as an asset within the European gene bank context."

"A central theme of the European cooperation has always been to assemble, maintain and provide up to date and computerised information about genetic resource collections."

At the Nitra meeting it was also decided to reform the operational structure of the working groups, and much along the setup that had been applied by NGB during many years. This meant clustering the existing working groups into crop categories (cereals, vegetables, etc.), in addition to forming the three cross-cutting networks that are still in operation. Thanks to the long-standing character of the NGB/NordGen working groups, over the years a significant number of Nordic crop specialists have taken part in the collaborative work of ECPGR. This includes the development of descriptor lists for proper characterisation and evaluation, characterising and evaluating crop collections for a range of traits that are important for plant breeding, taking part in collecting missions, sharing responsibilities for regeneration and multiplication, participating in grant scheme applications from the EU Genetic Resources Programmes, and much more. Some of the crop working groups have also been chaired by NGB/NordGen staff, which is currently the case for the Barley and the Forages Working Groups.

As already mentioned, a central theme of the European cooperation has always been to assemble, maintain and provide up to date and computerised information about genetic resource collections. This objective was already formulated for Phase III of the programme (1986–1989), with the main aim to use it as a tool to identify redundancies in crop collections and allowing for them to be rationalised. To that end, NGB has been entrusted to maintain so-called Central Crop Databases of the genera *Phleum* and *Prunus*. The responsibility of maintaining the *Prunus* database has later been transferred to France, while NGB/NordGen has accepted to uphold a database on minor grasses. As of today, the *Phleum* database holds altogether 5 741 records whereas that of the minor grasses (*Agropyron*, *Agrostis*, *Arrhenatherum*, *Brachypodium*, *Bromus*, *Elymus*, *Elytrigia*, *Phalaris* and *Trisetum*) holds 4 705 records (most recent updates February 2012 and March 2013, respectively).

NordGen and AEGIS

AEGIS – A European Genebank Integrated System – was first conceived by decision at the 9th Steering Committee meeting in Turkey in 2003. The rationale behind AEGIS is, in fact, simple and serves "[...] to improve coordination and share responsibilities with respect to the conservation and management of and access to PGRFA in Europe [...]"[2]. While membership in AEGIS is restricted to countries, article 9(a) of the AEGIS Memorandum of Understanding (MoU) from 2009 establishes that "[...] appropriate eligible public, private and civil society institutions [can] become Associate Members of AEGIS, in accordance with their national policy and legal frameworks." This is where NordGen comes in.

Being the common Nordic platform for *ex situ* conservation of orthodox seed, NordGen is a natural partner within AEGIS and an obvious Associate Member. NordGen's responsibility as regards the conservation, and documentation, of genetic variation in species that are of Nordic benefit and relevance is explicitly formulated in the statutes and governing documents of the gene bank. As Associate Member, NordGen accepts, among other things, to:

- identify Nordic accessions to be proposed as AEGIS accessions;
- manage the collection in accordance with the objectives of AEGIS and the General Principles applicable to European accessions under AEGIS;

2. http://www.ecpgr.cgiar.org/aegis/about-aegis/

- ensure safety-duplication of the collection;
- facilitate access to, and availability of, these accessions; and, finally,
- make public domain accession-level information regarding passport data available through the National Inventory System and EURISCO.

With NordGen actively engaged as a reliable partner within the European integrated gene bank system – AEGIS – and implementing the adopted quality management system AQUAS, the Nordic countries will contribute, as they have done since the early 1980s, to the benefit of ECPGR and the proper conservation and sustainable use of European plant genetic resources also in the decades to come.

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4 The Collaboration of NGB with IPK Gatersleben in the Frame of ECPGR in the Early 1980s

Johannes M.M. Engels
Flemming Yndgaard
Helmut Knüpffer

From its inception, the Nordic Gene Bank cooperated with other gene banks, and this collaboration was coordinated within the European Cooperative Programme for the Conservation and Exchange of Crop Genetic Resources (ECP/GR, later ECPGR). At that time, during the early 1980s, the period of Cold War, a special challenge was to facilitate the cooperation between countries of east and west Europe. The predecessor institute of IPK Gatersleben[3] was located in the former German Democratic Republic (GDR, in the plant genetic resources context often also referred to as DDR, its former FAO country code) and was (and still is) one of the ten largest gene banks in the world. In the early 1980s, working with institutions in Eastern Europe was not without challenges for western countries. Here we give some insights into a fruitful collaboration.

The main purpose of any gene bank is to collect, register, document, and preserve valuable plant material for future use in agricultural and horticultural plant breeding and research. The European Cooperative Programme (ECP), established by UNDP and FAO, was very important for establishing functional solutions for gene banks. At this time and in this connection, NGB played an important role, being a regional gene bank (Yndgaard and Kjellqvist 1983).

The European collaboration

The origin of the European Cooperative Programme on Genetic Resources dates back to the mid-1970s (Maggioni 2002). The original concept of the "European Cooperative

3. At that time called Zentralinstitut für Genetik und Kulturpflanzenforschung (Central Institute of Genetics and Cultivated Plant Research) – ZIGuK

Programme for the Conservation and Exchange of Crop Genetic Resources" (ECP/GR) was developed by the European Office of the United Nations Development Programme (UNDP) as one of the areas to facilitate the cooperation between countries of east and west Europe in the field of plant genetic resources.

"During the early 1980s a special challenge was to facilitate the cooperation between countries of east and west Europe."

The preparation phase (1975–1979) of this project was initiated because of the evidence that, on the one hand, the fast disappearance of especially landraces could have limited the ability of plant breeders to respond to the needs of a changing world and, on the other hand, the potential of plant material held in collections was far from being fully exploited.

The importance of the European region for plant genetic resources, also as the collective holder of almost two-third of the germplasm accessions maintained world-wide, was an important reason to establish collaboration between the European countries and its many gene banks. This, in turn, would be an effective way to contribute to an intended global coordinated PGR conservation effort. The role of ECP/GR was foreseen to strengthen inter-governmental and sub-regional links and to coordinate activities, thus eventually becoming the European component of a global PGR network.

At the time of establishing ECP/GR, four sub-regional initiatives for plant genetic resources were active in Europe. These were (Maggioni 2002):

- the European Commission Programme on Better Use of Gene Banks and Resistance Breeding (nine countries);
- the Genetic Resources Network of the Council for Mutual Economic Assistance (CMEA) (seven countries in Eastern Europe cooperating in the frame of the "Scientific-Technical Council on Plant Genetic Resources");
- the Nordic Gene Bank (five Nordic countries); and
- the Mediterranean Germplasm Programme of the International Board for Plant Genetic Resources (IBPGR) involving 13 countries of which eight were from Europe.

The task to formulate the ECP/GR project proposal was assigned to the Food and Agriculture Organization (FAO) as the executing agency and Ms Erna Bennett acted as the first coordinator of the programme in this preparatory phase. An intense series of consultative missions and discussions took place between 1975 and 1979, involving the UNDP European office, the EUCARPIA Gene Bank Committee, FAO and IBPGR. A project document, finalized by a UNDP/FAO Coordination mission (FAO 1980), was eventually unanimously endorsed in 1979 by the representatives from twenty-two countries.

The development objective of the ECP/GR was set as "to contribute to the development of agriculture in the member countries by the more effective use of plant genetic resources, which are well conserved and accessible, and to further the activities of national and sub-regional institutions for plant genetic resources in Europe, by strengthening cooperation between such institutions" (FAO 1980). Immediate objectives were also defined as:

1. to create the means for full and free exchange of available plant genetic resources (PGR) and related data, in order to make this material available to all European plant breeders;
2. to coordinate collecting and conservation of European PGR not yet existing in collections;
3. to make the above-mentioned PGR material and related data available to the plant breeders in developing countries and facilitate participation of Europe in the global network of PGR; and

4 to coordinate the evaluation of PGR, to be carried out by national and sub-regional centres for PGR in Europe and allow reduction of duplication of efforts regarding rejuvenation of PGR.

A strategy was defined whereby each country would contribute, besides financial contributions, in kind to the project, by inserting its national activities in the field of PGR conservation for plant breeding into the coordinated regional programme.

In the following, only the first two phases of the UNDP-supported project implementation are briefly described as during this period the foundation for the European Cooperative Programme for PGR was laid.

Phase I (1980 –1982)

ECP/GR became operational on 1 October 1980, after the first eight countries had signed the project document. These initial two years, i.e. Phase I, were funded by UNDP, with FAO as the executing agency. The Executive Secretary (Mr G. De Bakker) was based at the UNDP headquarters in Geneva, Switzerland. A Governing Body was composed of members (21 member country representatives; UNDP; FAO; Executive Secretary, Chairman of Scientific Advisory Committee) and observers (i.e. sub-regional European organizations; IBPGR; other European countries; ECP/GR Scientific Advisory Committee, UPOV; consultants to the Executive Secretary). The accomplishments of Phase I consisted in meetings of the established eight crop working groups, the appointment of National Coordinators, the stimulation to fund activities and the organization of genetic resources activities by a number of countries, as well as training of scientists from various countries.

Phase II (1983–1986)

At the request of the member countries and starting from 1 January 1983, the project was operated under the *aegis* of IBPGR, with FAO as the executing agency. Mr J.H.W. Holden from Aberystwyth, UK, facilitated this transfer from the side of IBPGR. An Executive Secretary (Mr P. Perret) was appointed and based at the IBPGR headquarters in Rome. As initially planned, during Phase II, the member countries matched the UNDP funding with 50% of the programme's budget. A project evaluation mission, commissioned by UNDP/FAO during Phase I, clearly recommended not imputing to ECP/GR capabilities that it could not fulfil, such as "creating the means for full and free exchange of available plant material..." Consequently, a modified set of objectives, that would remain unaltered for the following ten years, was defined.

ECP/GR objectives (from Phase II onwards)

The objectives from Phase II onwards were (Maggioni 2002):

1 to create a system to facilitate direct contact between workers engaged in genetic resources activities i.e. unhindered exchange of PGR and establishment of information systems and data exchange between gene banks;
2 to place at disposal of all interested plant scientists up-to-date information on collections of both seeds and living plants held by public institutions and private breeders in Europe;
3 to establish for specific crops joint activities including expeditions to collect genetic variants not held in existing collections and characterization and evaluation of germplasm; and
4 to establish a self-sustaining cooperative network of genetic resources activities between the participating countries, which would be effective for Phase III and in the future without UNDP help.

The IBPGR Board of Trustees, photo from the 1982 Annual Report (IBPGR 1983). Prof. Kåhre is sitting in the front row, fourth from the left.

The International Board for Plant Genetic Resources (IBPGR)

The International Board for Plant Genetic Resources (IBPGR) was established in 1973 by the CGIAR and was composed of 14 members from 13 countries, including Prof. L. Kåhre from the Swedish State Seed Testing Institute. Its Secretariat was provided by FAO. Its basic function, as defined by the Consultative Group of the CGIAR, was "to promote an international network of genetic resources centres to further the collection, conservation, documentation, evaluation and use of plant germplasm and thereby contribute to raising the standard of living and welfare of people throughout the world" (IBPGR 1977). A regional programme to coordinate activities across Europe, in particular between East and West/ South Europe, had been initiated by EUCARPIA for funding by UNDP.

The establishment of the Nordic Genebank

Below we provide the most relevant information on the relationship between IBPGR and the Nordic countries, as given in IBPGR's Annual Reports up to 1985 (cf. IBPGR 1977–1986). In the 1977 Annual Report, it is noted that "Another one [genebank] is expected to be established shortly in Sweden for the Nordic countries" at the suggestion of the EUCARPIA Gene Bank Committee, after genebanks in Braunschweig-Völkenrode (Federal Republic of Germany) and in Bari (Italy) had been established a few years before. The 1978 Report states that through the stimulation by the EUCARPIA Gene Bank Committee established in 1968, "... another genebank has just been established at Lund (Sweden)" and that each European genebank serves a distinct major agroecological zone. In the 1979 Report, IBPGR refers to the arrangements UNDP had made for the preparation of an inventory of all European institutions, personnel and programmes involved in genetic resources conservation as well as of a Government Consultation to finalize plans for the establishment of a European collaborative programme (see above). For the first time, reference is made to the Nordic Genebank at Lund to have accepted responsibilities to serve as "world repository" for the pea base collection. During 1979 Prof. Kåhre was one of the members of the Executive Committee of the Board.

In 1982 Prof. Kåhre was Chairman of the Board. At the end of 1982, NGB had assumed global responsibilities for the base collections of cultivated and wild barley, for cultivated and wild oats, for Mediterranean and South European pea material as well as for beet (IBPGR 1983). In May 1983, a *Prunus Working Group* meeting was held at NGB in Lund and, among others, a recommendation was made that IBPGR should accept NGB's offer to form a central data base for *Prunus*. In the 1983 Report it is stated that NGB is responsible for European barley germplasm, for (global) oats, for (global) rye and pea as well as for beet as part of the network of base collections for seed crops (IBPGR 1984, 1986). The following elements of the agreement to hold base collections as part of the network have been reported (Engels 2000):

1 that the collection will continue to receive adequate operating funds and personnel;
2 that if the material stored is not available from an active collection, it will be made freely available in reasonable quantities from the base collection to any professionally qualified institution or individual seriously interested in using it;
3 that the material will be accepted for storage on a global or regional basis;
4 that appropriate arrangements will be made for regeneration of the material; and
5 that arrangements will be made to duplicate the material for safety.

The above described UNDP-supported project and the foundation of the early ECP/GR had gradually evolved into the present ECPGR. The changes to the Programme over the years had not been drastic, the priorities have changed from one Phase to the next and the membership included (almost all) European countries. NordGen had been an active member of ECPGR since its establishment and played an important coordinating role among the Nordic countries, currently the only formally established and operating sub-regional network for PGR in Europe.

The Gatersleben genebank

At the beginning of the 1980s, the genebank of the Zentralinstitut für Pflanzengenetik und Kulturpflanzenforschung (ZIGuK) in Gatersleben, German Democratic Republic, was already one of the largest genebanks worldwide, covering crops that can be grown in the temperate zones from all over the world. The Institute was founded in 1943 in Vienna and transferred to its present location in 1945 (Stubbe 1982; Müntz and Wobus 2013). From the beginning, the research to be conducted in the institute was projected to focus on the plant genetic resources collection that was brought together from earlier (mostly German and Austrian) collecting expeditions and from various breeders' and research collections (Hammer et al. 1994). The institute was one of the numerous research institutions of the (East German) Academy of Sciences, focussing on applied and basic research.

First approaches to computerized documentation of the Gatersleben genebank started in the second half of the 1970s, however, the available hardware and software was hardly suitable for flexibly handling large amounts of diverse data on plant genetic resources (Knüpffer 1983).

With the establishment of ECP/GR, there was a great interest of ZIGuK's genebank to join this European collaboration. Since the early 1960s, the Gatersleben genebank had participated in the cooperation on plant genetic resources within the Council of Mutual Economic Aid (CMEA, also often referred to as COMECON in the West). A "Scientific-Technical Council"[4] (STC) was established in 1962 (Loskutov 1999:133ff.). Its aimed at coordinating PGR activities in the East European countries (for some period also involving Mongolia), conducting joint scientific research and collecting expeditions, exchanging of material and information, developing standardized descriptor lists ("classificators", cf. Knüpffer 1983), and harmonizing PGR documentation. Besides regular meetings of the Board, the work was organised in the frame of expert groups on particular crops or groups of crops, but also on crop-overarching matters such as documentation. During the second half of the 1980s, the plan to develop a common PGR database of the CMEA countries emerged, and a crop-independent passport descriptor list was proposed (Rogalewicz et al. 1988).

4. Full title: Scientific-Technical Council for Collections of Cultivated Plants and their Wild Relatives of the CMEA countries

In GDR, barley was one of the most important crops. The breeders' communities that existed for many crops also involved representatives of the genebank. When ECP/GR developed the concept of crop working groups, the East German genebank was highly interested in taking responsibility for barley as a European lead institute for this crop[5], and to develop the European Barley Database (EBDB). This was approved by the Council of Ministers. In 1982, ZIGuK offered ECP/GR to take over the role as lead institute for barley, and to develop the EBDB.

The efforts devoted by ZIGuK staff for the work within the Working Group on Barley (Barley WG), especially for developing the EBDB, were seen as a welcome opportunity to provide "input in kind" to ECP/GR, since it was impossible to pay GDR's country contribution to ECP/GR in convertible currency. At the other hand, the existing hardware and software was far from being suitable for setting-up a European Barley Database. From early meetings with ECP/GR representatives it became clear that ECP/GR was willing to support the delivery of suitable hardware and software to ZIGuK for the task of developing the EBDB, with the beneficial side effect of speeding-up the registration of passport data of the Gatersleben genebank. However, in the beginning, ZIGuK tried to find technical solutions for the EBDB within the country. Among these attempts were: (1) using ZIGuK's own hardware, a minicomputer KRS 4201 with magnetic tapes, punch tape for data input and output; (2) renting hard disk space (2 MB) on a mainframe computer of the Academy of Sciences of GDR in Berlin, preferably with a data connection via the (rather unreliable) phone line[6], and using MIMER, a relational database management system available there; (3) using a mainframe computer at the VVB Saat- und Pflanzgut in Quedlinburg, the state-owned company for plant breeding and seed production, with the necessity to develop own software solutions for the EBDB. None of these variants were really successful, due to various additional constraints.

After a visit of Dr Holden from IBPGR to ZIGuK in November 1982, the PGR documentation activities focussed on the first steps to develop the EBDB, and to prepare a "preliminary barley catalogue" for the ECP/GR Barley WG meeting in Gatersleben[7] in May 1983.

NGB and ZIGuK Gatersleben

In NGB, a flexible data-processing system was built and was based on genetic and biological principles that allowed breeders and scientists to access all relevant gene bank information and material, including that from other gene banks. The first system was called NGB IRS-83, a designation that applied both to the hardware (microcomputers from the Danish company Milog Data A/S; IRS="Intelligent Registration Station") and the software (a file management system tailored to PGR data handling; IRS="Information Retrieval System"). Often researchers from other gene banks visited NGB to study the system. The system and different aspects of it are discussed in another chapter of this book (Yndgaard and Endresen 2019). Here we focus on how it was transferred to IPK and what it was used for[8].

In May 1983, Stig Blixt, at that time Weibullsholm Plant Breeding Institute, Landskrona, Sweden, participated in the Barley Working Group Meeting in Gatersleben as IBPGR consultant for PGR documentation. We reproduce a letter of August 8, 1983, by Stig Blixt to Trevor Williams, director of IBPGR:

> *Dear Dr Williams,*
>
> *At the Barley Working Group meeting May 16–19 in Gatersleben it was agreed that a Central Database for barley was to be collected and that it was to be recorded and*

5. GDR's expression of interest to become a regional base collection for barley was already documented in the Report of an IBPGR ad hoc working group on barley (IBPGR 1981).

6. At that time, ZIGuK could use only four outgoing phone connections simultaneously, and one of them would be blocked for hours during data transfer.

7. Due to the travel restrictions that applied for a large part of scientific staff of East German research institutions, all Barley WG meetings during the 1980s as well as two international barley workshops were held in Gatersleben.

8. Most of the information provided on the following pages was taken from unpublished notes and internal documents of ZIGuK, as well as from correspondence with IBPGR and NGB.

stored by the Institute for Genetics and Crop Plant Research in Gatersleben. I was present as Consultant on Information at that meeting.

The Gatersleben Institute has access to some computer power. Barley is, however, one of the biggest and most complicated of the European crops from an information point of view. The computer power available to the institute is therefore totally inadequate. If the Central Barley Database is to be recorded on these facilities it might well be a matter of decades as well as problems with compatibility.

I therefore recommend that the Department for Genetic Resources at the Institute for Genetics and Crop Plant Research in Gatersleben is provided with the NGB computer and software. The reasons for recommending this particular combination are:

1. Software is already available from NGB.
2. The problems of maintenance, etc. will probably be at a minimum, for various known reasons.
3. The equipment is quite adequate for the recording.

I have discussed the matter with the Nordic Genebank and they are ready to assist. The costs involved would be about $US 6 300 for the machinery and $US 500 for freight and insurance. I enclose some more detailed information on the computer.

Sincerely yours
Stig Blixt

Appended to this letter was a detailed description of NGB's hardware and software used for PGR documentation at that time, which can be summarised as follows:

- NGB IRS-83 with 64 kB RAM, CP/M operating system, 12" display with 24x80 characters, keyboard, matrix printer (up to 136 characters/line), two diskette drives (5¼", double-sided, 800 kB)
- NGB Information Retrieval System with user manual and other documentation, allowing for basic functions of structuring data files, data entry and validation; a word-processing software, and various system programmes.

In response, Dr. Williams wrote to Dr. Kjellqvist on September 23, 1983:

Dear Dr. Kjellqvist,

Letter of Agreement between IBPGR and the Nordic Gene Bank, Lund

I am pleased to inform you that, following the meeting of the Working Group on Barley in May 1983, and on the advice of Dr. S. Blixt who attended the meeting as IBPGR Consultant on Information, the IBPGR has approved an allocation of $US 6 800 to support the provision of computer facilities (hardware and software) to the Department for Genetic Resources, Institute for Genetics and Crop Plant Research, Gatersleben, DDR.

I request you to confirm that you agree to assist in the above and in particular assist specialists at Gatersleben to initiate the setting up of a central database for barley as soon as possible.

You shall be required to submit a financial statement to the IBPGR Secretariat and to certify that the funds have been spent for the purpose outlined above.

Payment of the approved allocation shall be made as follows: 90 percent on signature of the Letter of Agreement; the balance on submission of the financial statement and of a report on the activities undertaken. Payment shall be made by cheque in the name of the Nordic Gene Bank, unless otherwise notified.

"Physical and logical data structures were far from being standardised, both for diskettes and magnetic tapes."

Guest researcher working with NGB-IRS.

If you are in agreement with the foregoing, please so indicate by signing two copies of the Letter of Agreement and return them to the IBPGR Secretariat (the two additional copies enclosed are for your files).

Thank you for your cooperation with the IBPGR programme.

Yours sincerely,
J.T. Williams, Executive Secretary

NGB accepted the request from IBPGR on October 25, 1983.

The requested equipment was sent to ZIGuK, and Flemming Yndgaard visited Gatersleben in January 1984 to assist Helmut Knüpffer, documentation expert of the genebank, with the installation of the computer and getting started with its use. Due to a delay at the customs in Copenhagen, the equipment had not arrived at the time of F. Yndgaard's visit, but the procedures were explained based on the user manuals of hardware and software (some of which were available only in Danish). Data structures for the EBDB were designed. At that time, NGB had an electronic connection with the computing centre of the University of Copenhagen, which was used for data transfer between magnetic tapes (Copenhagen) and diskettes (NGB). After the arrival of the equipment, H. Knüpffer made himself familiar with it and configured the system for recording barley passport data of ZIGuK and other contributing institutions that had sent data on typewriter or computer printouts. Since only one NGB microcomputer was available, the technicians continued to register data also on punch tapes for the KRS. It was still planned to establish the EBDB on an external mainframe computer. At that time, physical and logical data structures were far from being standardised, both for diskettes and magnetic tapes.

In the beginning of the 1980s, various European institutions had started to set up what was later termed "Central Crop Databases" (CCDBs). Each of these institutions struggled with similar technical problems of compatibility of magnetic storage media. Therefore, ECP/GR organised a "Workshop on Exchange of Information" in Radzików, Poland, in October 1984 (ECP/GR 1984) that brought together the managers of 11 such emerging CCDBs together with other PGR documentation experts. The participants presented their documentation systems (e.g. Knüpffer 1984), from which it was obvious that there was a large diversity of systems and data formats in use. Two categories of systems were identified: (1) mainframe or mini computers with access to magnetic tapes as storage medium; (2) microcomputers of different makes with floppy disks. The workshop recommended to establish ECP/GR file transfer centres (FTC)[9], and to nominate IHAR Radzików as FTC for communication between Apple II microcomputers and computers with magnetic tapes, and NGB for institutions equipped with NGB IRS-83 technology. It also proposed a standard format for recording genetic resources data for exchange, and formulated, for the first time, crop-overarching definitions of passport descriptors[10].

About a year later, ZIGuK received another NGB computer, which was equipped with a hard drive.

We quote a letter of April 25, 1985, to Dr. Williams, IBPGR:

> *Dear Trevor,*
>
> *Enclosed please find the information Jan [Konopka] wanted for the assistance to Gatersleben.*
> *Referring to the two letters of 11 February from Professor D. Mettin to IBPGR we have the pleasure to give you the following information.*
> *Flemming is prepared to visit Gatersleben for two days together with the Head of Computer Systems Frank Mortensen from our cooperating software house Milog Data A/S in week 24 this year.*
> *During their visit they will install the NGB IRS-83W, instruct about its use and its communication with the NGB IRS-83 installed in Gatersleben in January 1984.*
> *They will also establish communication between the NGB IRS-83 micro computers and the KRS 4201 computer in Gatersleben. However, they may need access to the KRS 4201 for establishing this communication and ask you to get this permission.*
> *The total costs for IBPGR will be 111 062 SEK, which is approximately 12 500 US$. This [will] cover the hardware and software indicated in the enclosure delivered in Gatersleben as well as the payment to the consultant from Milog Data A/S. It includes also the travel expenses for the consultant and Flemming.*
> *We are looking forward to hearing from you.*
> *Best wishes.*
>
> *Yours sincerely*
> *Flemming Yndgaard   Ebbe Kjellqvist*

The requested equipment was delivered in May 1985 when F. Yndgaard visited Gatersleben together with Frank Mortensen, a consultant from Milog Data A/S. The new equipment consisted of an NGB IRS-83W (with 32 MB "Winchester" hard disk), financed by ECP/GR and delivered by NGB, together with the standard file management package dBASE II (including a separate fast sorting programme for dBASE files, dSORT). Besides the installation of the NGB IRS-83W, there were discussions held with scientists and technicians during the visit.

The new system made the continuation of attempts to use external mainframes redundant, and H. Knüpffer and his team focused on using the NGB microcomputers for work on both the EBDB and passport data registration for the Gatersleben genebank. Although planned and prepared in advance, an attempt to connect the NGB IRS-83 with ZIGuK's KRS 4201 that hosted part of the data recorded earlier, failed, due to technical problems that could not be overcome despite of joint efforts of F. Mortensen and ZIGuK computer experts.

9. File Transfer Centre was defined as "a centre which will copy the data files from one communication medium to another, e.g. from disks to magnetic tapes".

10. At that time, passport descriptors might have different structures and definitions for different crops, as can be seen by comparing early IBPGR crop descriptor lists.

For the import and export of diskettes and magnetic tapes from/to East and West European countries, ZIGuK had obtained from the Academy of Sciences a "General Permission No. 50", which was quite unique for GDR institutions.

In the beginning of the compilation of the EBDB, Stig Blixt had a contract with ECP/GR to assist in transferring data received from the various contributing institutions on different media to NGB-IRS-formatted diskettes. He also started to standardize (harmonize) the information received and sent the transformed data on diskettes to ZIGuK. When the NGB IRS-83W with hard disk became available, all data were transferred to dBASE II, and further work on the EBDB was carried out in this system.

The history of NGB's ECP/GR-assisted technical aid to ZIGuK is also briefly reflected in the "History of the Gatersleben Institute" (Müntz and Wobus 2013:385).

Progress with the development of the EBDB, including the approaches to designate possible duplicates between the contributing genebanks, was reported by H. Knüpffer at the meetings of the Barley WG held in Gatersleben (ECP/GR 1983; IBPGR 1986, 1989a, b; Anon. 1986a; Knüpffer 1989a), as well as at two international barley workshops (UNDP/IBPGR 1986; Anon. 1986b, c; IBPGR 1989b). Various papers in journals and newsletters were published (e.g. Knüpffer 1988). Using the NGB IRS-83 and the matrix printer, several versions of a "European Barley List" (EBL) were produced in a few copies, mainly for presentation to the participants of the Barley WG and the barley workshops. In 1987, IBPGR produced 300 copies of the EBL that documented ca. 55 000 accessions from European genebanks and included material from the Ethiopian genebanks, on almost 1 000 pages (Knüpffer 1987).

At the end of the 1980s, when NGB turned to using IBM-PC compatible 16-bit computers, Sigfús Bjarnason, at that time documentation officer of NGB, donated to ZIGuK several NGB-compatible microcomputers which was a valuable gift, since it allowed to simultaneously use more workstations for data entry. The technical ECPGR support to ZIGuK was concluded with the provision of a Compaq 386/20e with unbelievable 120 MB hard disk capacity, directly imported from the United States, after positively solving the question whether this would not be in contradiction with the US embargo on electronic technology for "communist countries".

Outlook

The fruitful collaboration between the Gatersleben genebank and NGB, later NordGen, continued to this day. Since 1989, Roland von Bothmer (Swedish Agricultural University, partly also at NGB) and H. Knüpffer (IPK) collaborated in the development of the International Barley Core Collection (cf. Bothmer 2019). After the unification of Germany, H. Knüpffer could for the first time visit NGB. Besides work on PGR documentation aspects, NGB provided assistance in layouting and formatting a publication on Italian Plant Genetic Resources (Hammer et al. 1992). Present cooperation between IPK and NordGen includes joint membership in various ECPGR working groups and ECPGR-funded projects of the working groups on barley, forages, and information and documentation.

"An attempt to connect the NGB IRS-83 with ZIGuK's KRS 4201 that hosted part of the data recorded earlier failed."

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5 NGB and Collaboration with the Baltic States and Russia (VIR)

Igor Loskutov
Jens Weibull

The fact that the Nordic countries (Swedish "Norden") share ecogeographic conditions with the Baltic states and Russia has obviously contributed strongly to early and, over many years, continuously developed cooperation. During the Soviet period in the 1970s–1980s, researchers from the N.I. Vavilov Research Institute of Plant Industry (VIR) had close and productive scientific relations with Nordic countries, such as Sweden, Finland and Denmark. VIR was responsible in the country for the introduction, breeding, conservation, use and documentation of all cultivated crops, and through its network of research stations covered most of the vast landmass of the Soviet Union. Collaborating parties actively exchanged genetic resources and scientific teams. Colleagues from Norden familiarized themselves with the work of VIR and its experiment stations, while Russian experts visited leading plant breeding and academic institutions of the Nordic countries many times. When NGB was founded in 1979, and the Nordic countries transferred their collections of genetic resources to its jurisdiction, VIR began to cooperate more closely with this cognate institution. By the beginning of the 21st century, NGB became fully recognized as the regional centre for plant genetic resources, for both Scandinavian and Baltic countries.

A period of change and development

Following the dissolution of the Soviet Union in December 1991, rapid changes began to take place. Estonia, Latvia and Lithuania had already regained their independence in September the same year. In June 1992, all three countries as well as the newly emerged

Members of the Nordic-Baltic collaborative project meet with Emile Frison, former Director of ECPGR, in late 1995. From left to right: Isaak Rashal, Vahur Kukk, Stig Blixt, Emile Frison, Kalju Kask, Jens Weibull, Alma Būdvytytė and Sigfús Bjarnason.

Russian Federation, had signed the Convention on Biological Diversity. However, a period of economic weakening followed that had severe consequences for the long-established academic collaboration. A number of Baltic researchers and plant breeders soon realised that the status for conservation and use of important cultivated crops was getting more and more difficult. The historically fruitful and important linkages to VIR were also suffering. Beginning in 1994, therefore, the Nordic Council of Ministers (NMR) approved a two-year project that aimed at setting up a joint Nordic-Baltic collaborative programme for conservation and sustainable use of plant genetic resources for food and agriculture (PGRFA). The series of project cycles continued until 2002 when it ceased as the Baltic States were in the final negotiations about entering the European Union.

The joint Nordic-Baltic project focused on five major areas of collaboration: gene bank facilities and management, training and education, research and breeding projects, crop working groups, and international cooperation.

The first, and immediate, activity involved setting up facilities, including simple and robust equipment, to handle, dry and store orthodox seeds. Staff was being trained at NGB in Alnarp not only in gene bank management, but also in documentation and database management. Crop working groups were set up following the Nordic model, as a means of bringing gene bank staff, researchers and plant breeders closer together in their joint undertaking of safeguarding domestic PGRFA. This included establishing crop descriptor lists and documentation standards with the aim of describing material, identifying redundant accessions and rationalising collections. At the end of 1997, a total of 38 Baltic breeders and researchers were active in six different crop working groups. In addition, so-called black-box agreements were entered with the NGB as a means of safety-duplicating plant material of particular interest.

The political context

A major mission of the Nordic-Baltic collaboration was to pave the ground for and, later, assist in establishing national PGR programmes in line with FAO's First Global Plan of Action of PGRFA. All three Baltic States and Russia had become Parties to the Convention on Biological Diversity before the end of 1996. Baltic PGR Networks were quickly formed encompassing many relevant stakeholders of society, including the botanic gardens, but domestic funding was mainly project based and therefore temporary and insecure. The gene bank in Estonia was, however, set up thanks to the funding through the Nordic-Baltic joint project. Efforts were made, notably in Lithuania, to have a National PGR Conservation Law approved as a contextual framework wherein the national PGR programme would operate. In 2001, the Lithuanian Parliament adopted the Law on national plant genetic resources, which was to be followed by 13 other associated legal acts during 2002–2003. In 2004 the Plant Gene Bank was established through a government resolution, and the following year Lithuania acceded to the International Treaty of Plant Genetic Resources ('the Treaty').

In similar ways, Estonia and Latvia established, upon the entry as Parties to the Treaty in 2004, national systems – or programmes – for the collection, conservation and sustainable use of domestic PGRFA. In fulfilling their obligations towards the Treaty, Latvia established its Genetic Resources Centre in 2006, and Estonia has since embarked on two subsequent national PGR programmes (2007–2013 and 2014–2020).

Collaboration with VIR

VIR has been active in the work with PGR at the regional level. A Memorandum of Understanding between VIR and the Nordic Gene Bank (NGB, from 2002 till 2008) provided VIR's experts with an opportunity to take active part in the programmes of Nordic countries and obtain new plant material. For instance, in 2002, a coordinating meeting was held in Estonia, attended by the leaders of the national PGR programmes from the Baltic republics (Latvia, Lithuania and Estonia), Russia, and the Nordic Gene Bank. As a result, a memorandum on joint activities to collect and conserve the agricultural biodiversity of the Baltic region was signed. In the framework of the signed memorandum, two workshops were conducted in Sweden for the experts of the participating countries in forage and fruit crop plants. Researchers from VIR carried out the identification of the oat collections held by VIR and NGB to sort out duplicate accessions and adjust the computerized databases. The framework of this project envisaged a detailed field study of the duplicate accessions stored in both collections: oat and barley, and since 2009 also rye (Loskutov 2009). The results of studying oat and barley duplicates from both gene banks were later published (Perchuk et al. 2016; Yndgaard et al. 2016).

The Nordic Gene Bank provided financial support for scientists from VIR in order to enable them to attend the World Congress on Fruit and Ornamental Plants in Canada. Meetings of the members of the regional fruit working group were held in 2003 in St. Petersburg and in 2004 in Finland. Members of the working group developed a working plan of actions whose first phase envisaged establishment and exchange of fruit crop plant databases aimed at ordering missing accessions to replenish the national collections. In the same year, a meeting of the regional working group on potato was organized in Estonia to outline research priorities in conservation and utilization of potato genetic resources from the national collections of the collaborating countries. In the period of 2002–2004, germplasm material of Baltic origin was sent by VIR to the Baltic states (about 250 accessions), while VIR received around 100 accessions from the region's countries to add them to VIR's genetic diversity collection (Loskutov 2009). Besides, a joint meeting of the working group on cereals was held in 2004 in Finland with the purpose of coordinating the work on PGR.

Above: Prof. Vytautas Rančelis, Vilnius University, demonstrates barley mutants in the field. From left to right: Laimutė Balčiūnienė, Nikolai Dzyubenko, VIR, two unknown researchers, Alma Būdvytytė, Jens Weibull and Juozas Labokas (possibly 1995).

Above: A heartily meeting in St. Petersburg (possibly 1998). From left to right: A. Dyakov, Isaak Rashal and Viktor Dragavtsev.

Right: The art of documentation is on the table. A Nordic-Baltic project meeting in Lithuania (year unknown).

In 2005, a meeting was organized in the Nordic Gene Bank in order to work out a plan of actions for the nearest five years. An intention was development of scientific research on cryopreservation and the establishment of a regional cryobank based on the facilities of VIR's Long-Term Storage Laboratory. In addition, the regional working group on potato could have an opportunity to, by combined efforts, introduce the methods of improving the health of potato genetic resources, so that later they may be preserved by *in vitro* techniques (Loskutov 2009).

In 2009, VIR and NGB signed an agreement to study seed accessions of Nordic origin from the collection of VIR (*On evaluation, characterization and exchange of crop-genetic resources of Nordic origin*). Such studies were conducted in the fields of VIR's experiment stations in 2009–2010, and included crops such as barley, oat, rye, rapeseed, turnip, and timothy grass. All information on the accessions studied, as well as the reproduced seeds themselves, was transferred in 2011 to the NordGen collections in accordance with the agreement on PGR repatriation.

In 2011, a working meeting on cooperation between VIR and NordGen was held in Malmö, Sweden. The meeting summarized the work over the past two years and adopted a work plan for the future. It was supposed to continue the work on the exchange of information on stored accessions, finding duplicates, carrying out ecological-geographical evaluation of accessions of Nordic origin and the completion of genebanks with missing accessions. In 2014, this work was completed by the repatriation of about 300 accessions of main agricultural crops of the VIR global collection of Scandinavian origin to the Nordic Gene Bank (Loskutov 2014).

Prospects for future collaboration

Gene bank management can prove to be a heavy responsibility. Collections must be maintained under suitable and cost-effective conditions, safety-duplicated to mitigate risks of losses, carefully regenerated and/or multiplied when necessary and safe-guarded not to lose valuable genetic variability. Furthermore, all plant material must – among other things – be properly archived and documented, characterised and evaluated for the purpose of increased use for e.g. plant breeding, and expeditiously distributed according to international agreements to users that request them.

The 2nd FAO State of the world report (2010) reported a nearly 25% increase of accessions held *ex situ* worldwide, but also concluded that 70–75% of all accessions are likely to be duplicates. This global redundancy of plant collections represents a major challenge for gene banks as it draws resources for regeneration and maintenance that could, and should, be used for other purposes. It is for this specific reason that the European gene bank community has been collaborating under the auspices of AEGIS (Weibull 2019), aiming at improving coordination and sharing responsibilities with respect to the conservation of, management of and access to PGRFA in Europe. Similarly, the Nordic-Baltic and Russian collaboration has always aimed at making the best use of available resources for the benefit of research and plant breeding and should continue to do so.

Our northern ecogeographic region is expected to meet new challenges following in the footsteps of climate change and need for sustained food security. The scenarios put forward by the Intergovernmental Panel on Climate Change (IPCC) suggest that changes in biodiversity and its utilization will be significant and extensive. From a plant breeding point of view, new genetic variation will be required to satisfy the needs of future crop production. Photoperiodic response must be combined with high-yielding capacity, market quality requirements, adaptability to altered overwintering conditions, and emergence of new pests and diseases. It is our firm belief that by continuing the historically fruitful collaboration between our countries, we will be much better prepared to meet the challenges.

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Part III
Two Special Collections at NGB/NordGen

Barley is an important crop at NGB/
NordGen, also in the special collections.

6 The International *Hordeum* and Triticeae Project – 40 Years of Collaboration with Plant Genetic Resources in Focus

Roland von Bothmer

In the 1970s the interest in crop wild relatives was low in comparison to now – 40 years later. Breeders mainly saw the difficulties in gene transfer from wild species to crops with reduced fertility and linkage drag instead of possibilities for introduction of new valuable genes. Researchers in botany and related areas showed a higher interest for the wild flora than for domesticated species and their relatives.

However, the Danish brewery giant, Carlsberg, had an interest in strengthening research in general and increasing the knowledge of cultivated plants, as well as to find unconventional solutions in applied research not least in improving malting and brewing quality. The Research Director at Carlsberg, Diter von Wettstein, suggested that the barley genus, *Hordeum*, should be explored and investigated with basic studies in botany and genetics. A grant application was submitted to the Danish Research Council by Arne Strid, Professor of Systematic Botany at Copenhagen University – and the application was approved. At the time, I was working at the Ludwig Maximilian University in Munich but could not resist the interesting challenge when being offered the possibility to lead the project. I started in Copenhagen on March 1, 1976.

Björn Salomon studies an *Elymus* plant during a collecting mission to the Altai area in southern Russia in 1990

The *Hordeum* project takes shape

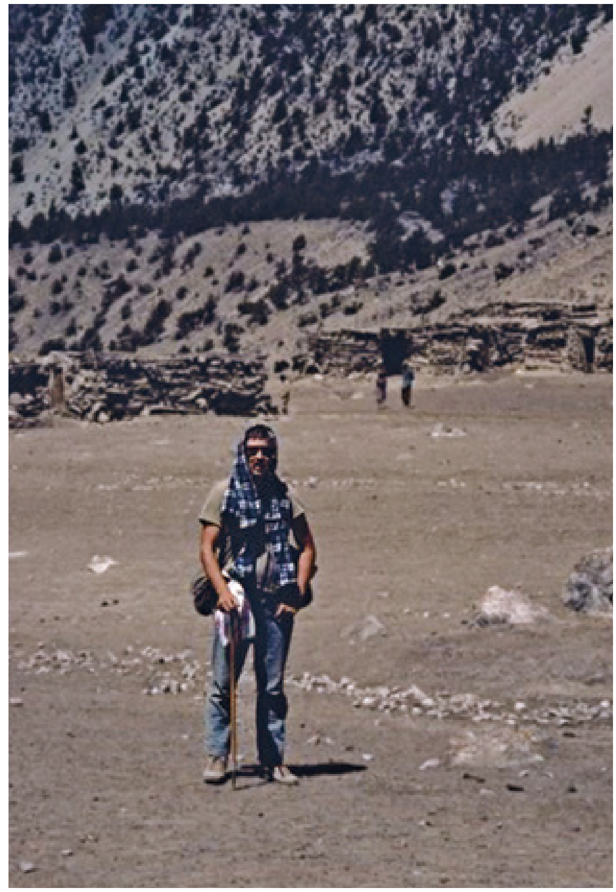
From the first literature screening it was obvious that knowledge about the genus *Hordeum* was scarce in many fields and these areas should be prioritized in the project:

- The taxonomic knowledge in *Hordeum* was generally poor at the time and raised many fundamental and relevant questions: Which and how many species comprise the genus? What are their distributions? What are their variation patterns and relationships?
- The access to correctly determined and viable material was scarce – the available gene bank material was very limited and often in bad condition (non-viable seeds, passport data lacking, or incorrectly determined accessions). It was thus important to put emphasis on our own collecting expeditions in order to get access to good material.
- Relationships and evolutionary patterns between wild species of many genera (such as *Hordeum*) and between crops and their wild relatives were imperfectly known.
- There was scanty knowledge about crossing barriers and sterility patterns between cultivated barley and its wild relatives as well as gene content and genetic diversity in the wild taxa.

It became obvious that it would be a huge task to approach all the four priority areas. Good national and international cooperation with gene bank plant breeders, botanists and other researchers would be required in order to succeed. The task needed long term funding and several collaborating specialists and institutions in Denmark and abroad. We were lucky in many respects and could develop the project over more than 35 years and to collaborate with specialists and institutions in more than 20 countries.

The *Hordeum* and Triticeae collections

Collecting in remote, often extreme areas became essential. The genus *Hordeum* is distributed in many temperate areas of the world with diversity centres in Central Asia and in southern South America. When the project was expanded to comprise the whole



Left: *Elymus sibiricus* in a gorge at Mt. Sentjo, Japan, 1997.

Right: Roland on a just harvested wheat field on 4000 m a s l close to the Bathura glacier in the Hunza valley, Gilgit province in northern Pakistan at the Chinese border during the collecting mission in 1983.

tribe Triticeae with an even larger distribution it became more urgent that access to new material was needed.

The collecting missions were started before the Convention of Biodiversity (CBD; i.e. before 1992), and missions were then comparatively easy to perform – even in remote areas. It was important to establish contact with researchers and institutions in the target areas. Mostly the expeditions were arranged in collaboration with research institutes or state authorities in different countries. Sharing collected material as seeds, living plants and herbarium specimens was obvious as well as joint publication. After the entrance into force of the CBD, we have made collections according to the regulations of the International Treaty. In the beginning mainly wild species of *Hordeum* were the target for collecting but successively other wild species of the Triticeae were included as well as cereal landraces. Support for the collecting expeditions was received from many organisations and individual scientists in several countries. Some examples of collaboration are:

In 1978/79 the *Hordeum* project was invited to take part in the large Danish-Argentinian expedition to southern South America. The whole expedition lasted almost six months and included ca 30 scientists in zoology, ecology, systematic botany and geography. The journey was very rewarding for all participants.

In 1982 we planned a collecting tour in western USA. From the International Board for Plant Genetic Resources, IBPGR (now Bioversity International) we got a request that during our expedition we would also investigate the current status of the endemic, annual species *Hordeum intercedens*, endemic to SW California. It occupies vernal pools – a very sensitive biotope here. We found that several of the earlier known growing sites were

Table 1

Major collecting missions and approximate number of collected accessions made by the Danish–Swedish Research teams.

Year	Target area	Collected material	No.	Collector(s)
1977	Turkey, Iran	*Hordeum*	110	R. von Bothmer
1977	Spain, Greece	*Hordeum*	130	N. Jacobsen
1978/79	Argentina, Chile	Triticeae	650	R. von Bothmer & N. Jacobsen
1980	USA, Mexico	*Hordeum, Elymus*	210	R. von Bothmer & N. Jacobsen
1982	USA, Canada	*Hordeum, Elymus*	65	R. von Bothmer & N. Jacobsen
1983	Argentina, Chile	*Hordeum*	145	P. Frederiksen
1983	Pakistan	Triticeae	140	R. von Bothmer
1985	USA	*Hordeum, Elymus, Leymus*	20	R. von Bothmer
1986	China	Triticeae	500	CS* R. von Bothmer
1986	Argentina	*Hordeum, Elymus*	75	O. Seberg
1987	Argentina	*Hordeum, Elymus, Leymus*	310	O. Seberg
1987	China	Triticeae	215	CS* C. Baden & B. Salomon
1988	China	Triticeae	410	CS* R. von Bothmer & B. Salomon
1988	Greece	Triticeae	15	R. von Bothmer
1989	Argentina, Chile	Triticeae	70	O. Seberg
1989	China	Triticeae	275	CS* C. Baden & B.-R. Lu
1990	USA, Canada	*Hordeum, Elymus, Leymus*	45	R. von Bothmer
1990	China	Triticeae	190	CS* N. Jacobsen
1990	Russia	*Elymus, Leymus*	150	R. von Bothmer & B. Salomon
1990	Turkey	Triticeae	80	G. Petersen & M. Ørgaard
1991	Turkey	Triticeae	50	G. Petersen & M. Ørgaard
1991	Tajikistan	Triticeae	105	B. Salomon & B.-R. Lu
1993	Chile	Triticeae	15	M. Ørgaard
1993	Sweden, Norway, Finland	*Elymus*	60	R. von Bothmer & M. Gustafsson
1994	Iceland	*Elymus*	10	R. von Bothmer & M. Ørgaard
1995	Russia	*Elymus, Leymus*	50	B. Salomon
1996	Russia	*Elymus, Leymus*	40	B. Salomon & A. Agafonov
1996	Canada	*Elymus, Leymus*	40	R. von Bothmer
1996	Denmark	*Elymus, Hordelymus*	45	N. Jacobsen & M. Ørgaard
1997	Norway, Sweden	*Elymus*	15	O. Diaz
1997	Greenland	*Elymus*	20	M. Ørgaard
1997	Japan	*Elymus, Leymus*	45	R. von Bothmer
1998	Chile, Argentina	*Elymus, Hordeum*	10	O. Diaz
1999	Canada	*Elymus, Leymus*	10	B. Salomon
1999	Bhutan	*Elymus*	20	R. von Bothmer
1999	Greece, Chios	*Dasypyrum, Hordeum*	10	O. Seberg
2003	Bulgaria, Burgas	Triticeae	15	B. Salomon

*CS=Chinese–Swedish joint collecting expeditions 1986–1990.

ruined and the distribution was drastically diminished. There was an urgent need for *in situ* protection of the species.

IBPGR also initiated a closer collaboration with China for exploring the Triticeae in this country which is a diversity centre for the whole tribe. During five successive years (1986–1990) we got the unique possibility to have collecting expeditions in western China together with scientists from Sichuan Agricultural University. This contact led to a very close scientific collaboration, many joint publications and an intense research exchange.

During the many field expeditions, a very rich, representative and variable material was gathered as the basis for further studies. It was cultivated at the Botanical Garden in Copenhagen for taxonomic studies, in Taastrup Field station outside Copenhagen for maintenance and multiplication and at the Agricultural Department, Risø National Research Centre outside Roskilde in other research areas (see below) and after 1980 also at the Swedish University of Agricultural Sciences (SLU) in Svalöv, Sweden, for research and multiplication. Selected accessions were cultivated at plant breeding companies and screened for agricultural traits, mainly for resistance to pests and diseases. In collaboration with research institutions in other countries screening for abiotic stress characters, mainly resistance to drought and salinity, could be performed.

The interest for crop wild relatives increases

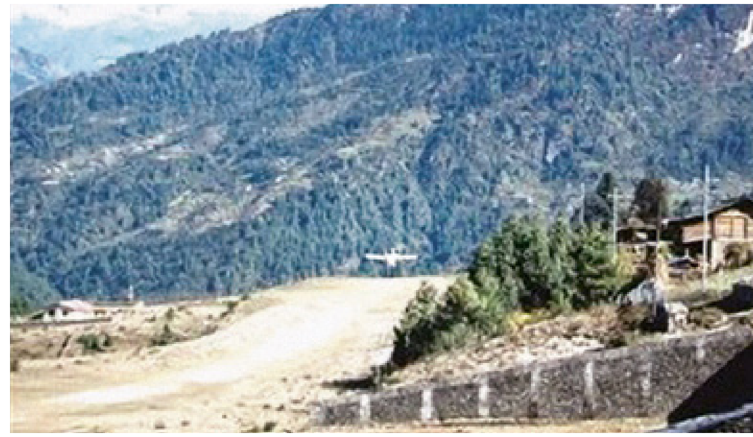
Wild species show a great variation in biological traits such as life form (annuals or perennials), reproductive patterns (self- or cross-fertilizers), genetic variation, dispersal and germination (dormancy). These were conditions we had to handle. It became clear with the large amount of research material that we had to learn how to grow, multiply and store seed material of many different species – with quite different demands for external conditions during cultivation and handling. We had early contact with the Nordic Gene Bank (NGB) and several other gene banks (e.g. IPK in Germany, ICARDA in Syria, and CGN in The Netherlands) resulting in support and exchange of experiences.

During the 1980s there was an internationally increasing interest for wild *Hordeum* and Triticeae species for breeding and research purposes and not least to get access to new genetic material from these plant groups. It became widely known that we had assembled a large germplasm collection and we started to act as a "university gene bank" sharing material with other breeders and scientists around the world. It was discussed and agreed that parts of the collection should be included in NGB (later NordGen) for long term conservation – since most of our material is not preserved elsewhere.

Progress of the project and broad collaborations

A single person cannot achieve much – the *Hordeum*-project with high scientific intentions required involvement from several co-workers, both academics and technical staff – and this was actually accomplished over several years. The first two co-workers joining the projects (then as PhD students) were Niels Jacobsen, later Professor in Botany at The Royal Veterinary and Agricultural University (now included in Copenhagen University) and Rikke Bagger Jørgensen, later Senior Research Scientist at Risø National Laboratory, and many were to follow.

The Agricultural Department of Risø National Laboratory was at the time (late 1970s) one of the world leading institutions for barley research. The cytogenetic techniques for chromosomal studies were particularly well developed (Dr. Ib Linde-Laursen), as well as crossing and embryo rescue techniques (Dr. John Jensen) and electrophoresis, mainly of isoenzymes which were then the leading technique for studying genetic diversity (Dr. Hans



Doll). We were welcome in the Risø labs with our material to utilize their excellent facilities and great experiences. In this way we got a "flying start" of the wild *Hordeum* project and we used the facilities at Risø for many years which is an important reason for the positive progress of the project. A great number of joint papers with Risø scientists have been published over the years.

Left: Grant Bailey and Niels Jacobsen collect seed of *Hordeum brachyantherum* in California, USA during the collecting expedition in 1980.

Top right: Collecting in remote areas can be adventurous. The airstrip in Phaplu, northeastern Nepal, at the track to base camp. It is only accessible when the weather is optimal. The expedition was jointly made with Japanese colleagues in 1999.

Bottom right: Collection of wheat landraces in Tibet at the village of Nedong during the joint Chinese–Swedish collecting mission in 1988.

In 1980 I got a position at the Swedish University of Agricultural Sciences (SLU) at the new Department of Plant Breeding as Research leader (later Professor in Plant Genetics and Breeding). The department was placed in the village of Svalöv in southern Sweden close to the internationally well-known Swedish plant breeding companies Svalöf AB (earlier the Swedish Seed Association), W. Weibull AB and Hilleshög AB. This vicinity to the practical plant breeding and skilled breeders added a new dimension to the *Hordeum* project, and by necessity turned the project into a more applied direction. The move to Sweden also meant that we got access to Swedish funding, new facilities and interested students. At the same time a high activity could be maintained in Denmark with new funding and new collaborators. The *Hordeum* project became a joint Danish and Swedish undertaking.

During the early 1980s the importance of the entire tribe Triticeae in the grass family became evident. The tribe comprises not only the cereals wheat, barley and rye (and triticale) and their close wild relatives but many important forage grasses, such as Russian wildrye (*Psathyrostachys juncea*) as well as around 500 wild species distributed in most temperate areas in the world. This is a gigantic gene pool but to a large extent imperfectly known and unexplored. Thus, we decided to expand the project to include the whole tribe and we had the opportunity to make collections of many of these wild species at a great extent besides of the *Hordeum* material at our expeditions.

Barley harvest in Bhutan.

The International Barley Core Collection

In connection with the *Hordeum* project we became enrolled in many activities related to gene bank issues. One of these was the development of the International Barley Core Collection (BCC).

During the 1980s, the concept of core collections was a hot issue (Knüpffer and Hintum 2003). The definition states that "a core collection consists of a limited set of accessions derived from an existing germplasm collection, chosen to represent the genetic spectrum in the whole collection. The core should include as much as possible of its genetic diversity". Many types of core collections were developed in different crops mainly based on existing holdings in one or more gene banks. The main purpose in establishing a core collection was to rationalize gene bank collections, to get an easier overview of the genetic diversity in a certain crop, to make gene bank material more accessible, and thus facilitate use in breeding and research. The argument against core collections was that the concept could be misused as a reason to reduce funding for gene bank activities. It was supposed to be more efficient to use the core collection instead of making use of the entire gene bank, since the diversity of a crop should to a large extent be represented in the core.

For barley, the core collection concept became an interesting example of how to study and visualize genetic variation in a crop and its wild relatives and how gene banks could collaborate. At the European Cooperative Programme for Genetic Resources (ECPGR), a meeting with the Barley Working Group in 1989 organized at the gene bank in Gatersleben (then GDR), the idea was proposed and supported of creating a core collection of barley which should be based on the entire European holdings of barley, as documented in the newly erected European Barley Database (EBDB) (ECP/GR 1989). A working group was set up to further explore the idea and suggest a practical set up of a core collection. Four persons were elected into the group: me as a chairperson (representing NGB), Helmut Knüpffer (gene bank in Gatersleben), Theo van Hintum (The Dutch gene bank, CGN) and Gerhard Fischbeck (University of Weihenstephan, Germany). At our first meeting we realized that if a Barley Core Collection (BCC) should represent the entire diversity of the crop and its wild relatives we needed to mirror the domestication, migration and breeding history of barley and different pedigrees at a global scale – not only in a European context. It should mirror the relationships between the crop and its wild relatives (i.e. various gene pools), the diversity of genetic stocks, and wild species representing their entire distribution area. Setting up a BCC must be an international undertaking in order to be meaningful and widely accepted. Thus, we invited barley specialists from outside Europe for discussions. At the meeting in Helsingborg in 1991 it was decided to set up an international BCC including barley and its wild relatives in *Hordeum* (IBPGR 1992). Later, meetings of the international BCC group were arranged in conjunction with the International Barley Genetics Symposia (IBGS), arranged every four years. This gave continuity to the development and progress of the BCC and made it possible to inform the whole "barley world" of breeders and researchers.

The BCC accessions should be selected from all internationally available accessions, rather than from a single gene bank collection and should be set up as a separate, physical collection. This approach was called a "synthetic core collection".

The reason for developing the BCC was to:

- increase the knowledge about the barley gene pool;
- increase the efficiency of evaluation and thus of utilization of existing collections;
- provide a manageable, representative and highly diverse selection of barley germplasm;
- Provide adequate standards for studies of genetic diversity.

We designated specialists being responsible for developing a subset of the core for their respective area. Their respective gene banks should be responsible for multiplying and making the accessions available for distribution. The total number of accessions should not exceed 2000.

The following groups were designated subsets and a particular gene bank was assigned to set up each subset. For each group the responsible specialist is indicated and in parenthesis the suggested maximum numbers of accessions:

- Landraces and cultivars (300 landraces + 15 cultivars) from West Asia and North Africa – ICARDA; *Jan Valkoun*;
- Landraces and cultivars (300 + 80) from South and East Asia – Barley Germplasm Centre, Japan; *Takeo Konish*i later replaced by *Kazuhiro Sato*;
- Landraces and cultivars (100+5) from Ethiopia and Eritrea – Plant Genetic Resources Centre of Ethiopia; no specialist selected;
- Landraces and cultivars (80 + 200) from Europe – The German gene bank, IPK; *Gerhard Fischbeck* and *Helmut Knüpffer*;
- Landraces and cultivars (30 + 150) from the Americas – USDA Small Grain Collection; *Harold Bockelman*;
- Cultivars (35) from Oceania and other parts of the world – The Australian gene bank; *Michael Mackay*;
- *Hordeum vulgare* subsp. *spontaneum* (150), the progenitor of barley – ICARDA; *Jan Valkoun*;

- Wild *Hordeum* species (two accessions per taxon, ca 100 in total) – The Nordic Gene Bank, NGB; *Roland von Bothmer*;
- Genetic stocks (ca 200) – No single gene bank was assigned; *Udda Lundqvist*, Sweden and *Jerry Franckowiak*, USA.

During the work with the BCC, a number of interesting issues were raised and discussed which deepened our knowledge of barley. Establishing the BCC took several years and several problems were faced along the way. For example, the subset from Ethiopia and Eritrea was not accomplished for political reasons and the subset of subsp. *spontaneum* took a long time to set up due to problems in multiplication. Breeders and researchers were encouraged to use the core and to give feedback to the BCC group concerning the results of a study or a breeding programme. Many individual accessions as well as subsets of the core were distributed but so far, we have no overview over what has been achieved based on the BCC. All established subsets are now transferred to IPK in Germany being responsible for keeping the entire BCC and distribution of accessions.

The concept and ideas with core collections are now more or less outdated. When new molecular techniques have become available and huge sets of accessions can be screened there is no longer a need to set up separate cores. However, even if the outcome of the work with the BCC was not as fruitful as expected, being *the* entrance to existing gene bank collections the process and considerations of setting up the core have nevertheless contributed to improve gene bank work and the knowledge of barley. The compilation of data, putting specialists and gene bank managers closer together and learning more about genetic diversity was highly significant – the process was more important than the result. The work with the BCC was a cradle for further research with barley as a model crop.

Is it possible to describe the full genetic diversity in a crop?

During the work with the *Hordeum* project and the establishment of the Barley Core Collection we had gained a deep knowledge in gene bank issues related to genetic variation and utilization of germplasm in breeding and research. Not least through the engagement in The Barley Genetics Symposium we had got a large network of breeders and researchers in barley over the world. Several scientific questions were raised over the years, but one particular issue predominated – the nature and magnitude of genetic diversity in a crop. Together in a small international group, we found it a challenge to elucidate the issue of genetic diversity in barley. We introduced the idea to a number of barley experts, and they were mostly positive and promised to contribute. After some years the result became a book with 14 chapters (Bothmer et al. 2003) where various aspects of creation, development and maintenance of genetic diversity are dealt with. Not unexpectedly the major conclusion was that the picture of diversity in barley is highly complex. Was it at all feasible to draw any general conclusions concerning diversity? The full answer was *no*! There were still many empty spaces and too complex patterns to allow easy visualisation. However, it was possible to show several major tendencies of development and distribution of diversity, and not least – it was possible to identify gaps in our knowledge and to indicate ways of tackling the problems.

Main achievements of the Hordeum and Triticeae project

Due to the good possibilities for funding and for broad collaborations, the *Hordeum* and Triticeae projects could survive in various shapes for almost 40 years (my last *Hordeum* publication was in 2014) and proliferate into related issues in breeding and gene banking. From the start the focus was on solving taxonomic problems in *Hordeum* and to illuminate evolutionary patterns and relationships. When the project developed to include the whole tribe, more attention was directed to genetic diversity, gene content, gene transfer from wild relatives to the crops and not least crop improvement. At the core for the whole project was the access to large and representative material assembled mainly through our own collecting missions. This created the need for the practical handling of accessions and insight into conservation and utilization of plant genetic resources. In later years, much focus has been invested to study gene bank issues, such as problems with redundancies and gaps in existing collections, how to capture a maximum of genetic diversity in a collection and how to improve the efficiency of gene transfer from wild species to crops. During the whole project we worked in close collaboration with many gene banks of the world and were often consulted as specialists.

"We had gained a deep knowledge in gene bank issues related to genetic variation and utilization of germplasm in breeding and research."

During the course of the *Hordeum* and Triticeae project, ca 4 500 accessions of wild species and landraces were collected and studied. Altogether, more than 300 scientific and more popular articles and two books have been published. Around 30 PhD and licentiate degrees have been implemented within the project. Some of the major achievements of the project are:

- One of the largest and best documented seed collections in the world of wild *Hordeum* and Triticeae material was assembled – and a selected number of accessions are transferred to NordGen and other gene banks for long term conservation.
- Many taxonomic problems have been brought up and solved. A monograph of *Hordeum*, based on a number of taxonomic papers was published (Bothmer *et al*. 1995). Taxonomic treatments have been published also in several other genera in Triticeae. A number of new taxa have been described in several genera.
- By various cytogenetic, molecular and biosystematics techniques the understanding of relationships and evolutionary patterns has increased.
- Large scale crossing experiments have revealed the gene pool pattern in *Hordeum* and Triticeae and thus the potentials for gene transfer.
- Genetic diversity patterns have been elucidated in the cereal crops and in many genera of wild species.
- Gene content in several wild species has been studied.
- The need for gene bank preservation and tackling gene bank problems has been elucidated.

Doctorate and licentiate theses performed in the *Hordeum* and Triticeae project or where plant material or ideas from the project have been used

Taxonomic and evolutionary studies

Niels Jacobsen, Copenhagen University, 1979: En biosystematisk undersøgelse af *Hordeum* sect. *Trichostachys* (A biosystematic study of *Hordeum* sect. *Trichostachys*)

Rikke Bagger Jørgensen, Copenhagen University, 1984: Evolutionary relationships in the *Hordeum* (barley) genus. An electrophoretic examination of proteins

Gitte Petersen, Royal Veterinary and Agricultural University, Copenhagen, 1990: Intergeneric hybridization between *Hordeum* and *Secale*

Björn Salomon, Copenhagen University, 1991: Biosystematic studies of the *Elymus semicostatus* group (Poaceae)

Marian Ørgaard, Royal Veterinary and Agricultural University, Copenhagen, 1992: *Leymus* Hochst. (Poaceae, Triticeae), studies of relationships

Susanne Pelger, Lund University, 1993. The evolution and organization of multigene families exemplified by the hordein genes in barley

Zandra Andersson, SLU, 1993: Biosystematic studies in the genus *Hordeum*

Baorong Lu, SLU, 1993: Biosystematic investigations of Asiatic wheatgrasses – *Elymus* L. (Poaceae, Triticeae)

Sergei Svitashev, SLU, 1997: Analysis of Triticeae genomes using DNA markers.

Claus Baden, SLU, 1998: Taxonomy and phylogeny in some perennial genera of the Triticeae

Tommy Knutsson, SLU, 1998: Taxonomy and relationships in the genus *Hordeum*

Pernilla Ellneskog-Staam, SLU, 2002: Relationships in the Triticeae: Genomes and wide hybridization

Studies in genetic diversity, applied issues and gene bank problems

Jens Weibull, SLU, 1987: Resistance in the genera *Avena* and *Hordeum*, to the aphid *Rhopalosiphum padi* (L.): genetic resources and nutritional aspects

Zemede Asfaw, Uppsala University, 1989: The barley of Ethiopia: A focus on the infraspecific taxa

Eva Thörn, SLU, 1992: Selective chromosome elimination in barley: The '*bulbosum*' system – Possibilities and limitations in plant breeding

Theo van Hintum, SLU, 1994: Drowning in the genepool – Managing genetic diversity in genebank collections

Lotta Claesson, SLU, 1996: Wide hybridization in wheat

Merja Veteläinen, SLU, 1997: Dynamic genepool of barley – Utilization of exotic germplasm in Nordic plant breeding

Oscar Diaz, SLU, 1999: Genetic diversity in *Elymus* species (Triticeae) with special emphasis on the Nordic region

Karin Persson, SLU, 2000: Genetic diversity in landraces of rye (*Secale cereale* L.) and turnip (*Brassica rapa* L. ssp. *rapa*) from the Nordic area

Birgitte Lund, KVL, 2002: Repatriation of Nordic barley germplasm

Alaina Jane Garthwaite, The University of Western Australia, Perth, 2005: Physiological traits associated with tolerance to salinity and waterlogging in the genus *Hordeum*

Agnese Kolodinska Brantestam, SLU, 2005: A century of breeding – is genetic erosion a reality? Temporal diversity changes in Nordic and Baltic Barley

Michael Mackay, SLU, 2011: Surfing the genepool

Birjan Usubaliev, SLU, 2013: Barley genetic resources for Kyrgyz plant breeding

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7 The Swedish Barley Mutant Collection

Udda Lundqvist

Swedish research on induced mutations in barley started in 1928 in a small scale at Svalöf on initiation by the eminent Swedish geneticists Herman Nilsson-Ehle and Åke Gustafsson although L.J. Stadler had published negative results on induced mutations in barley (Stadler 1928). But Herman Nilsson-Ehle and Åke Gustafsson did not share this pessimism and started the first treatments with X-rays and ultraviolet radiation also with different pre-treatments as it was known that the mutation frequency increased when seeds were soaked in water before irradiation. The first chromosome aberrations were observed followed by the first phenotypic changes in the seedlings, the chlorophyll mutations. The first viable mutants were isolated in the mid-1930s, and it was already possible to distinguish two subgroups: Morphological and Physiological mutants. The most common group at that time was the compact dense spikes with more stiff straw, the *Erectoides* mutants. In the following years, several very valuable characters were considered: high yielding, straw-stiffness and -length, early maturity, tillering capacity, changes in spike and culm architecture, changed pigmentation and surface wax composition (Gustafsson 1941, 1947).

The results of all these experiments were considered so promising, both for plant breeding and theoretical research, that the Swedish milling industry sponsored this new research, and experiments got extended. In 1948, the Wallenberg Foundation incorporated the mutation activities in their research programme, and in 1953, at the instigation of the Swedish Government the 'Group for Theoretical and Applied Mutation Research' was established. The Agricultural Research Council provided funding, and it was possible for Gustafsson to gather around him a group of specialists to carry out research for improving methods for plant breeding (Gustafsson 1954).

Left: Herman Nilsson-Ehle (1873–1949).
Right Åke Gustafsson (1908–1988).

X-irradiation on dry barley seeds was the standard method but it was soon followed by other types of irradiation, in the mid-1940s chemical mutagenesis entered the scene and concluded with the inorganic chemical mutagen 'sodium azide' in the mid-1970s. They became included in experiments together with different irradiation types. Also, different soaking times of the seeds were an important trait as it was known that the water content of the seeds is important in relation to radiation sensitivity and different environmental conditions. This mutation research was non-commercial even if some important mutants have been used in plant breeding – directly or after recombination breeding. The aim was to study basic research problems in order to influence and improve methods for breeding of cultivated plants (Gustafsson 1954; Ehrenberg et al. 1956, 1961; Lundqvist 1992). Other aims were to study evident genetic differences between the action of ionizing radiations and chemical mutagens, differences in the mutation spectrum and the idea was to direct mutagenesis.

The Swedish Collection of barley mutants

Genetic diversity in barley has been of great importance and has long been studied in great detail. It is an important feature for investigations and localization studies of the barley genome but also for plant breeding. There is and will be always a large demand for a broad diversity, including genetically characterized mutants that will serve as basic material for all kinds of barley research (Lundqvist 1986). Over all the years, a very large collection of morphological and physiological mutations, about 12 000 different mutant alleles, have been brought together with a very broad diversity. The collection has been intensively genetically studied, forms a major input for gene mapping, and is immensely valuable for molecular-genetic analyses of cloned mutant genes. It consists of five main categories, two of them are divided into at least twelve sub collections with its broad variation (Table 1, 2) (Lundqvist 2005).

Table 1

Survey of the five main categories

Group	Category name
A	Barley: Morphological and physiological characters
B	Barley: Near Isogenic Lines in Bowman
C	Barley: Near Isogenic Lines in Bonus
D	Barley: Duplication Lines
E	Barley: Translocation Lines

This collection is unique since all the alleles of different investigated genes have been taken care of, which is important as a major source for to-days gene mapping, important for cloning mutant genes, it is valuable for investigations within radiobiology, genecology, gene physiology, ultra-structural research, genetic fine mapping, gene localizations, plant biochemistry and molecular marker research.

Table 2

Survey of the twelve morphological and physiological barley sub-collections.

Sub-group	Character
1.	Changes in spikes and spikelets
2.	Changes in awn length and formation
3.	Changes in days to maturity
4.	Changes in epicuticular wax composition
5.	Changes in leaf blades
6.	Changes in culm length and composition
7.	Changes in kernel development and formation
8.	Changes in growth habit
9.	Changed pigmentation
10.	Changes in chlorophyll pigmentation
11.	Intermedium double mutants
12.	Resistance to powdery mildew

Grouping and naming of the barley morphological and physiological characters were chosen systematically based on the life cycle of the barley plant. The first barley genes were already described in the 1920s but when more genes were reported it was necessary to follow the methods for naming and grouping barley genes and assigning gene symbols (Smith 1951; Nilan 1964; Gustafsson 1969). The first genes were assigned as symbols single-letter codes, later two-letter codes, and even later phenotypically similar mutants were grouped together, assigned the same basic symbol and the three-letter codes were recommended.

The use of barley mutants

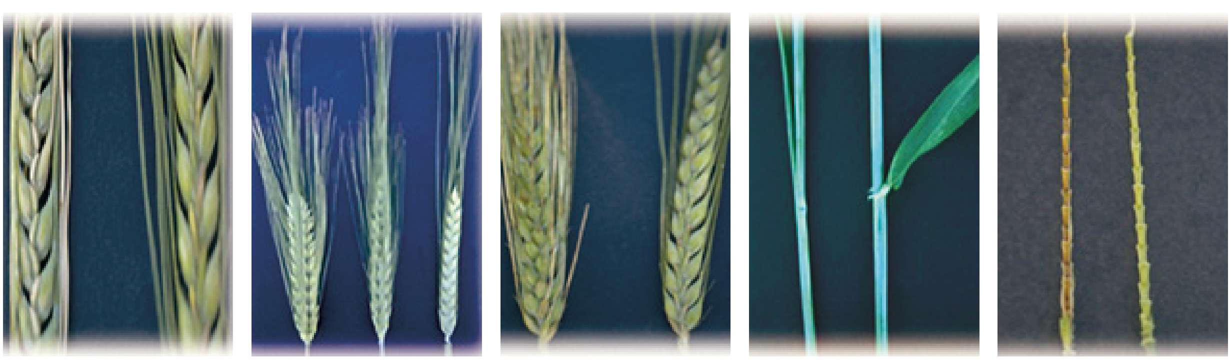
The barley mutant collection is conserved at the Nordic Genetic Resource Centre in Alnarp, Sweden, and is available for all types of research and plant breeding. It is a major source for gene mapping and also serves as an important gene pool. During the peak years of mutation research, more than half of these mutants were analysed genetically more or less in detail, but they form only a minor part of the range of the mutant characters. In Table 3, the mutant groups that are studied in more detail genetically are presented, also with regard to mutagen specificity. These studies have increased the knowledge of the mutation process and the architecture of different characters, especially the following groups: *Erectoides* (dense spike), *Hexastichon* (six-rowed spike), *Intermedium* spike, *Praematurum* (early maturity) and *Eceriferum* (glossy) (Lundqvist 1992, 2005, 2008, 2014).

All the Swedish mutants were induced in different cultivars. By Jerome D. Franckowiak's, Minneapolis, USA, tremendous efforts and skilful crossing work, it was possible to transfer most of the genes into a common background, namely the two-rowed high malting barley cultivar of the Midwest, USA, 'Bowman'. He established about 1000 "Barley Near Isogenic

Different characters of the barley mutation collection

From left to right: Erectoides-r.52 (BGS 332b); Erectoides-d.7 (BGS 29f); Erectoides-k.32 compared with Bonus (BGS 562a); Erectoides-ii.76 to the right compared with Bonus (BGS 135c); Laxatum-a.8 (BGS 474e).

From left to right: Breviaristatum-d.15 (BGS 10a); Calcroides-e.23 (BGS 622a); Naked caryopsis-1.a (BGS 7a); Elongated outer glume-1.a (BGS 57c); Deficiens spike 2 (BGS 67a).



From left to right: Globosum-a (BGS 168b); Hexastichon-v.3 and Intermedium-d.12 (BGS 6d); Intermedium-c.5 (BGS178c); Liguleless1.b1 (BGS 60.a); Orange lemma1.a" rachis internodes" (BGS254d).

From left to right: Albino lemma1.a (BGS 108e); Anthocyanin-less 2.15 (BGS 80a); Segregating albino4.d (BGS 94a); Eceriferum-a.1 (BGS 356b); Chlorina seedling12.b (BGS 2c).

Lines in Bowman" (NIL), 60% of them include Swedish mutant genes. These NIL lines are very useful and are much easier to use for linkage studies, assessment of specific marker genes, determination of linkage drag, and marker assisted gene transfer for all barley researchers world-wide. Due to this very important backcross-derived Bowman collection, kept at the Nordic Genetic Resource Centre, Alnarp, it was possible to define the genetic location to chromosomal segments, to show how the gene content in these segments can be predicted through conservation of synteny with model cereal genomes, providing a route gene identification, and several of the mutant genes have been cloned through the last decades (Druka et al. 2011)

Table 3

Survey of the genetically investigated Scandinavian mutant groups.

Mutant group	Number of Alleles	Number of loci
Praematurum (Early maturity)	195	9
Erectoides (Dense spikes)	222	31
Breviaristatum (Short awns)	196	25
Eceriferum (Waxless, Glossy)	1 580	79
Hexastichon (Six rowed spike)	65	1
Intermedium spike mutants	81	10
Elongated outer glume (*Macrolepis*)	54	1
Third outer glume (*Bracteatum*)	12	4
Calcaroides	22	5
Anthocyanin mutants	766	31
Liguleless (Auricleless and Eligulum)	25	3
Albino lemma (*Eburatum*)	5	1
Orange lemma (*Robiginosum*)	7	1
Powdery mildew resistant mutants	77	several
Chlorophyll synthesis and chloroplast development	455	106

In the 1950s it was already evident that mutation programmes should be regularly included in breeding programmes of crop plants. In Sweden it was shown that the work through the joint work with barley workers and scientists can be used as an example of how mutation breeding can be employed in a crop improvement programme (Gustafsson 1963). The main interest was focused on macro-mutations that were approved to be more successful than recurrent mutagenic treatments. The most important characters are earliness, straw-stiffness, higher yields, semi-dwarfs, protein content and disease resistance. Not only new direct mutants but also the indirect use of mutations was applied. A rather large number of mutant cultivars of two-row barley were registered as originals and commercially released, 15 in total. Two of these cultivars, 'Pallas', a straw-stiff, lodging resistant, high-yielding *Erectoides* mutant, and 'Mari', an extremely early, photo- and thermo-intensive mutant, were produced directly by X-irradiation. All other cultivars derive from crosses and backcrosses with the X-ray induced mutants 'Pallas', 'Mari' and 'Sv44/3' (Gustafsson et al. 1971). The series of cultivars obtained after crossing were found to be agriculturally suitable for different parts of Scandinavia and other parts of the world. The aim of this work was to demonstrate that original mutant materials can be used successfully in recombined breeding programmes and in the hands of skilful breeders. Different methods ought to be used together, to-day also with many modern technologies, adding to the results of ordinary crossing and selection. Useful mutations in barley include a wide diversity of economically important characters that influence morphological as well as physiological and biochemical properties that will be important tools for plant breeding, even more when the chemistry of the gene has been studied more intensively (Gustafsson 1969, 1986).

Establishment of the 'International Barley Database'

The request and necessity of an "International Database for Barley Genes and Barley Genetic Stocks" was already discussed in 1989 at a FAO working group on Plant Genetic Resources in Lund, Sweden. The author, at that time the International Overall Chairman for the barley linkage groups, was asked to help establishing such a database including induced mutants. During 1991, the author together with Sigfús Bjarnason, the head of the Nordic Gene Bank at that time, investigated if the yearly barley reports in Barley Genetics Newsletter were based on own research, literature studies or other information.

At the IBPGR, later IPGRI, to-day Bioversity International, workshop in Helsingborg, Sweden, in 1991, Sigfús Bjarnason demonstrated a proposal of his constructed database for Barley Genes and Barley Genetic Stocks. There he stressed the importance of gene, allele, synonym, stock and reference tables. The participants urgently called upon the Scandinavian barley geneticists together with NGB to proceed in developing this detailed database (Bjarnason 1991). At the 15th North American Barley Researchers Workshop in Guelph, Canada, 1993, Dave Matthews and co-workers introduced the Triticeae Genome Database "GrainGenes", developed under the Plant Genome Research Programme, USDA, USA. It already included the AceDB database server system for wheat, therefore it was completely natural to use it for barley and was finally demonstrated at the EUCARPIA meeting in Italy, 2002 (Lundqvist and Huldén 2004). After several years of use the system became unfashionable and had to become reconstructed. It was demonstrated at the 12th International Barley Genetics Symposium in Minneapolis, USA, 2016 (Lundqvist et al. 2016).

International Database for Barley Genes and Barley Genetic Stocks

The database includes all information on genetics, cytogenetics, information on phenotypes, pedigree of cultivars, genetic stocks and other germplasm. The main part shows an overall structure of the descriptions with special paragraphs dedicated to cover previous nomenclature, inheritance, locus location, descriptions of morphological and physiological characters, the first detected mutant, mutant events, mutants used for description, parent germplasm, and references. It includes for the locus name the use of the three-letter symbols, the chromosome numbers and arms designations are based on the Triticeae system. Both systems were approved at the business meeting of the Seventh International Barley Genetics Symposium on August 5, 1996, in Saskatoon, Canada. Each mutant is

The banner of the database

associated with a stock number, this barley genetic stock (BGS) number corresponds to an accession (GSHO or NGB) number kept in the Barley Genetic Stock Collection, Aberdeen, Idaho, USA, or at NordGen, Alnarp, Sweden. Only one allele of each description is kept at the Main Stock Centre in Aberdeen, but all alleles are stored at NordGen (Lundqvist et al. 2016) which is very important for molecular basic research. The Barley Genetic Stock database comprises now about 750 descriptions with more than 4 500 alleles and about 2 300 references. Many of the genes are illustrated with images, both overviews and close-up character photographs. The second part of the database comprises basic information of about all 11 000 Swedish barley mutants to find their original stock accession for degeneration, mutagens used for induction, year of isolation, cultivar used for isolation, inheritance, allele designation, descriptions of phenotypes, and their relation to BGS descriptions.
The database is easy to use, by names, symbols and other objects you are looking for. It is available at: www.nordgen.org/bgs.

Concluding remarks

The barley plant is a very complex organism but is one of the best investigated crop plants, and our knowledge has increased considerably by using many modern techniques of biotechnologies, especially by induction of mutants and establishing a large mutant collection with a broad diversity. Many different marker genes provide us with a detailed understanding of the genetic composition of the barley genome, especially when combined with increased chromosome and genetic analyses of linkage and biochemical studies of the DNA constitution and the amino acid composition. This collection of barley mutants with their defined source of mutant genes will always form a major input for gene mapping and is immensely valuable for molecular genetically analyses of cloned mutant genes.

Many genetic studies have been performed to determine the number of gene loci involved in the different morphological and physiological groups. Due to the low chromosome number, 2n=2x=14, and the annual life cycle of barley, chromosome maps for the marker genes could be established very soon. Interchange break-points have been used to establish the independence of seven genetic linkage groups, associate them with the individual barley chromosomes, 1H–7H, and many different Swedish barley mutants have been involved. Many morphological, physiological markers, pest resistance genes, isozymes and molecular markers have been mapped. The number of mapped loci has increased very rapidly, and linkage maps could be established (Franckowiak 1997). There will always be a large demand for a broad diversity and genetically characterized mutants and the Swedish barley mutant collection is a gold mine for molecular genetics and barley breeding. It is now and will in the future be serving as the basic material for all kind of barley research.

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Part IV
At Svalbard

The first safety backup of the NGB collection was stored in Mine 3 at Svalbard.

8 The Story Behind the First Safety Backup of Seeds in Permafrost at Svalbard

Flemming Yndgaard

Longevity of seeds depends very much on seed moisture content and storage temperature. For maximum storage life, these two conditions must be kept low and carefully controlled. Low seed moisture content can be achieved by proper drying and packing and low temperature by freezers. However, freezers all depend on energy supply, which means electricity. A consequence of power failure can be that the temperature is raised to above 0°C and the seed storage is thawing, which in the long-term will reduce the longevity. In the areas around the poles, the soil temperature is permanently below freezing point, which means that it is permafrost. From the very beginning, a permafrost location for the safety backup of the Nordic collection was investigated. The NGB board decided at their meeting on July 6, 1982, to establish a three-person *permafrost working group*. The group consisted of Arne Wold, director of the Norwegian State Seed Testing Station (as president), Professor Lennart Kåhre, director of the Swedish Seed Testing and Certification Institute, and a representative of NGB which became Flemming Yndgaard. The mandate of the Working Group was to:

- perform preparatory technical inquiries at NGB;
- involve the Norwegian Polar Institute in the project, especially when relevant measures were available;
- investigate any conditions for the projected storage at environment authorities;

- develop a survey of storage needs and accompanying costs for NGB and possibly also for other gene banks;
- explore international interests to participate in the project.

"Some mines were already emptied of coal, leaving an empty gallery into the area."

Selection of an appropriate location

The Norwegian Polar Institute had knowledge about potential permafrost areas and was helpful with the investigations. One location was found in the mountain area Jotunheimen in Norway, more than 2 000 meters above sea level. At a depth of ten meters into the rock, the temperature was minus 2.3°C. This was on 9 September 1982. Closer to the surface, the temperature was higher (+1°C). Fluctuation in temperature between summer and winter was not expected to exceed 0.5°C at a depth of ten meters or more. Construction of a storage facility in the rock in Jotunheimen would however be rather difficult and expensive. Furthermore, it was foreseen that it could take time to get permission to build the facility. Another small permafrost area was found in Torneträsk between Kiruna in Sweden and Narvik in Norway. Measurements had been made during reconstruction of a highway in the area. However, the temperature was only about minus 1°C and the construction problems were foreseen to be the same as in Jotunheimen.

It was known that the mountains around Longyearbyen at Svalbard contained coal and had permafrost. For more than fifty years, Store Norske Spitsbergen Kulkompani (SNSK) had been mining in the district. It was known that some mines were already emptied of coal, leaving an empty gallery into the area. Therefore, such a gallery could possibly be used for a permafrost storage for seed. This could keep the construction costs rather low. Furthermore, SNSK could inform that radon and gamma radiation was negligible in the mines, meaning that there was no risk for mutations in the seed (caused by ionizing radiation). This could be a problem in the alternative rocks in the Jotunheimen.

Arne Wold and Flemming Yndgaard made an expedition to Svalbard during 4–7 July 1983 to investigate the possibilities for a security storage. SNSK had prepared the excursion and arranged the accommodation. The local manager at SNSK, Gunnar Christiansen, and his colleagues had already investigated the possibilities. The excursion could therefore start immediately at mine 7, located 15 km to the south-east of Longyearbyen. The entrance was about 400 m above sea level and could be reached by car. Equipped correctly with miner's helmets, lights, boots etc., the expedition walked about 800 m into the mountain. Here, we found several transverse passages that could be used, and the overlay rock was about 12 m. The expedition then went to mine 3 and this was located three km to the west of Longyearbyen. The entrance was situated 200 m above sea level and could also be reached by car. The airport of Longyearbyen is one km from mine 3.

The expedition found that one of the transverse passages, AT2, in mine 3 would be the most suitable place for the construction of a seed security storage. This transverse passage was located 285 m from the entrance, and 200 m of which is a gallery. AT2 was about 19 m in length and was separated from the main passage with a wooden wall to avoid draught to a mining area, which was emptied from coal about ten years earlier. The width was about 4 m and so was the height. The overlay of rock was about 70 m. The manager of mine 3, Terse Johansen, expected the temperature to be constant at around minus 3°C.

The permafrost working group was expected to establish a security storage which would be stable in all respects, including temperature. A concrete construction with a height of 2 m, a width of 2 m and a length of 2, 4, 6 or 8 m was discussed. Before returning, SNSK and the permafrost working group agreed to cooperate on establishing a security seed storage at Svalbard in AT2, in mine 3 in Longyearbyen. Using the temperature sensor 2812 from Aanderaa Instruments, the temperature was measured over a period of one year at two positions, one in the air in the middle of AT2 and one at the bottom of a 1 m deep hole with a diameter of 2 cm in the rock. The temperature was constantly minus 3.7°C in the air and minus 3.8°C in the rock, except from the middle of July to the end of August, when the temperatures in air and rock were minus 3.6°C and minus 3.7°C, respectively. It was concluded that a temperature variation of 1/10°C was negligible and absolute satisfactory for a permafrost storage of seeds.

Selection of construction material

Concrete had been considered as the construction material for the security storage. It would be slow in deteriorating and it could protect the material against possible falling rocks and fluctuations in temperature. However, as mentioned, the temperature was found to be extremely stable and SNSK informed that a protection against falling rock could be made independently from the storage. A metal container, which was specially treated against corrosion, was found to be the best solution. Standard produced steel containers in several measures are available in the market. Here, knowledge from offshore industry could be used for corrosion protection of the steel. A container that measured 400 x 160 x 200 cm, made of double pickled steel 42, and protected against corrosion was chosen. Before corrosion treatment, the container was sandblasted. Within three hours after sandblasting, 60–80 µm zinc silicate, Galvanosil 1570, was applied. Then came four times spraying of 125 µm of tar epoxy, Hempadur Tar 1517. The total thickness of the corrosion protection layers was 560 µm.

SNSK agreed with NGB to arrange the transport of the container from the Airport to AT2 in mine 3. SNSK also made the necessary base for the container as well as the constructions to secure against falling rocks. Furthermore, SNSK built a wooden wall as a separator to the emptied coal mine area to protect against draught of air and gas during ventilation. The agreement between SNSK and NGB (1984) included future assistance in maintenance and access to the seed security storage.

Arne Wold and Flemming Yndgaard visited Svalbard a second time, 13–16 November 1984. The aim of this trip was to inspect and approve the constructions and the storage facility. Small damages of the corrosion protection resulting from the transport were detected and repaired but everything else was in order and the storage could be approved.

Opening in 1984

The first dispatch of glass ampoules with seeds from the Nordic Gene Bank arrived at Svalbard in November 1984. The opening ceremony was held on 14 November 1984, where the first wooden box with seed ampoules was placed in the steel container in AT2. The ceremony was documented by Svalbardposten (Nr. 12, 1984/1985). SNSK named AT2 "Frøyhall" in honour of Frøy, the Nordic goddess of fertility. A local artist had made a plate with the name and this was placed at the entrance gate. The start of the Nordic Permafrost Security Seed Storage was also marked by SNSK holding a reception in the evening the same day in 1984. A picture and quote from Svalbardposten are given on the next page.

100 Year Investigation of Seed Longevity

The amount of time that seeds can survive is limited. Seeds are living material and how long they will survive depends on the conditions under which they are stored. Low moisture and low temperature will slow down the deterioration processes, but the storage time will still not be endless. Cromarty et al. (1982) thoroughly discussed the theories of this


PIONERARBEID I GRUVE 3

Kassen med frø har nådd fram til permafrostlageret i gruve 3. Fra venstre Arne Wold fra Statens Frøkontroll, Terje Johansen, Gunnar Hansen, Flemming Yndgaard fra Nordiska Genbanken, Karl Johan Eide og Gunnar Thuv Johansen. Det er disse som har hatt arbeidet med å bygge opp "Frøyhall" for de to frøekspertene.

Translation of caption: "Wednesday 14 November 1984 comes to be a particularly historic day for Store Norske and the Nordic Gene Bank. This was namely the opening day for the world's first permafrost storage of seeds from cultivated plants. A box containing 20–30 vials with gene material or plant seed from many different species was placed in a specially prepared container in a gallery in the Store Norske's mine 3."

phenomenon and gave many valuable references that were appreciated by the permafrost working group as to the scientific communities even today. The Security Seed Storage in permafrost at Svalbard gave an exceptional possibility to test the theories of seed deterioration. Its independence of any energy supply ensured the same physical conditions during a long period of time. This was the initiation of the 100-years trial at Svalbard.
The Board of NGB decided at their meeting on August 7, 1985, to accept the experiment plan of the 100-year trial prepared by the permafrost working group. The aim of this trial was to produce reliable data for the lifespan of seeds from common agricultural and horticultural crops (Yndgaard 1985). More details about the trial are discussed in the next chapter (Asdal et al. 2019).

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9 The Ongoing 100-Years Trial in Permafrost

Åsmund Asdal
Guro Brodal
Svein Ø. Solberg
Flemming Yndgaard
Roland von Bothmer
Eivind Meenv

When the Nordic Gene Bank was established in 1979, the knowledge about longevity of seeds was quite limited. It was known that low temperatures and low moisture contents in the seeds increased the longevity of seeds, but not how much. Knowledge about the differences between species and crops, and even between cultivars of the same crop was also in demand.

The establishment of the security storage of the Nordic seed collection in the coal mine at Svalbard in 1984 gives a good possibility also to test the theories of longevity of seeds. Stable permafrost at between –3.5°C and –4.0°C, maintained without energy supplies will ensure the same physical conditions during a long testing period.

To gain knowledge about the longevity of seeds conserved in permafrost in the coal mine a *Permafrost Working Group* prepared plans for the '100-year experiment' which were approved by the NGB Board in 1985. The aim of the experiment was to study the seed longevity and the health conditions during storage in permafrost over a period of 100 years. Forty-one seed samples of 16 agricultural and horticultural crops commonly grown in the Nordic countries were prepared, packed and placed in the container in the same way as in the security storage (Brodal et al 1992). The experiment was started when the prepared seeds material was were transferred to Svalbard in the autumn 1986. Seeds for the experiment were transferred to Svalbard in the beginning of 1987.

The aim of the experiment is to produce reliable data for the lifespan of seeds from agricultural and horticultural crops that are commonly cultivated in the Nordic countries and

that are represented in the Nordic seed collection. Forty-one varieties/cultivars of 16 crops were included in the project (see tables).

The experiment is divided in two parts; Series A focuses on changes in seed germination in 15 crops and includes two cultivars of each crop. Series B focuses on survival of seed borne pathogens in seeds of host plants. Seed samples of ten different crops infected with pathogens are tested both for germination and for survival of the pathogens. In addition, one sample consisting of sclerotia of *Sclerotinia sclerotiorum* from *Brassica*, is included.

The experimental design implies that test samples of seeds should be taken out for analysis every two and a half year during the first 20 years and every five years thereafter. Seeds for the experiment were prepared at NGB. In compliance with the seed material storage procedures in the gene bank, the seed samples for the experiment were dried to 3–5% moisture content (Johansson 1983). The dry seeds were packed in sealed glass ampoules.

Each seed lot was divided into 25 sub-samples consisting of 1000 seeds, one for each testing date during the 100 years. Each sub-sample was encapsulated in glass ampoules. To facilitate the withdrawal of seeds for testing, all samples to be tested at one testing date were placed into one separate wooden box that could be taken out and transported to the test laboratory. The first series of samples were analysed in December 1986, and the last box will be analysed in December 2086.

During the first 30 years of the experiment, eleven boxes have been retrieved and the seeds analysed. The seed samples were analysed at Kimen Seed Laboratory (previously the State Seed Testing Station) in Ås, Norway according to ISTA standards (ISTA 1986). It was decided that all germination and disease analyses should be carried out in Norway in order to avoid possible problems with cross-border transfers of seed samples.

Table 1

Crop species and cultivars included in seed longevity investigations in the 100-years storage experiment (Series A).

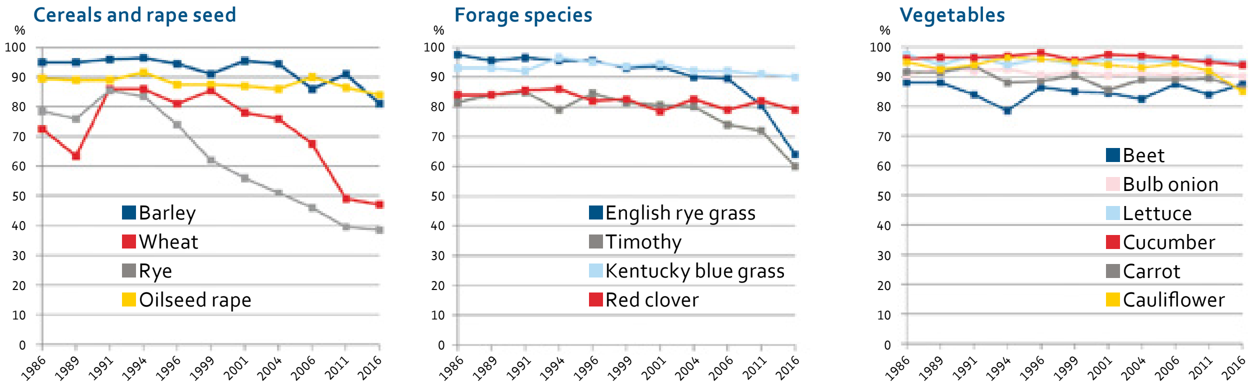
Crop	Species	Cultivars
Barley	*Hordeum vulgare*	Inga Abed, Tunga
Wheat	*Triticum aestivum*	Vakka, Solid
Rye	*Secale cereale*	Petkus II, Voima
English ryegrass	*Lolium perenne*	Pippin, Riikka
Timothy	*Phleum pratense*	Tammisto, Bodin
Kentucky bluegrass	*Poa pratensis*	Hankkijan Kyösti, Annika
Red clover	*Trifolium pratense*	Jokioinen, Molstad
Pea	*Pisum sativum*	Weitor, Hankkijan Hemmo, Weitor pt. 10468
Beet	*Beta vulgaris*	311 N typ, 70500
Oilseed rape	*Brassica napus*	Jupiter, Linrama
Bulb onion	*Allium cepa*	Hamund, Owa
Lettuce	*Lactuca sativa*	Attraktion Sana, Hilro
Cucumber	*Cucumis sativus*	Langelands gigant, Rhensk Druv
Carrot	*Daucus carota*	Nantes Fancy, Regulus
Cauliflower	*Brassica oleracea* var. *botrytis*	Svavit, Pari

Table 2.

Plant pathogens tested for survival in the 100-years storage experiment.
The table shows crop species and cultivars used in the experiment (Series B).

Pathogen	Crop	Species	Cultivar
Septoria nodorum, *Fusarium* spp.	Wheat	*Triticum aestivum*	Runar
Ustilago nuda f.sp. *tritici*	Wheat	*Triticum aestivum*	Line 79 CBW "A" No 72
Sclerotinia sclerotiorum	Cabbage*	*Sclerotia* from *Brassica*	
Drechslera spp. *Fusarium* spp.	Barley	*Hordeum vulgare*	Bamse
Drechslera dictyoides	Meadow fescue	*Festuca pratensis*	Salten
Drechslera phlei	Timothy	*Phleum pratense*	Forus
Lettuce mosaic virus	Lettuce	*Lactuca sativa*	Attractie
Botrytis allii *Fusarium* spp.	Bulb onion	*Allium cepa*	Laskala
Alternaria radicina *Alternaria dauci*	Carrot	*Daucus carota*	Forto Nantes
Phoma betae	Beet	*Beta vulgaris*	Hilma
Alternaria brassicicola	Cabbage	*Brassica oleracea* ssp. *capitata* f. *alba*	Trønder Lunde

*) Cabbage (*Brassica oleracea*) was the host plant for collection of the *sclerotia*, which were conserved separately without any plant material attached in the ampoules.



Left: The germination percentages for three cereal crops and oilseed rape (*Brassica napus*), shown as the average of two cultivars of each crop; barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), rye (*Secale cereale*) and oilseed rape conserved in permafrost through 30 years.

Middle: The results for four forage species, shown as the average of two cultivars of each crop; timothy (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), English ryegrass (*Lolium perenne*) and red clover (*Trifolium pratense*).

Right: The results for vegetable species including beets (*Beta vulgaris*), shown as the average of two cultivars of each crop; cauliflower (*Brassica oleracea var. botrytis*), bulb onion (*Allium cepa*), lettuce (*Lactuca sativa*), carrots (*Daucus carota*) and cucumber (*Cucumis sativus*).

The germination results during the first 30 years of the 100-year experiment are shown in the graphs above. Results are presented as average of the two cultivars of each crop and 14 crops are grouped in three groups; three cereal species and oilseed rape, forage species, three grasses and red clover and vegetables including beets (see figures). Results from three cultivars of peas are not presented in these graphs partly as results differ a lot between the cultivars and because the results do not show reasonable changes between years.

Conclusions of the experiment

During its first 30 years, the 100-year experiment has given interesting results about longevity of seeds of agricultural and horticultural crops commonly cultivated in the Nordic countries. Seeds of all tested species have survived over 30 years in permafrost, when dried to 3–5% moisture content and packed in waterproof containers. Significant differences in seed longevity between species have been observed in the project.

To some extent there are also differences between varieties/cultivars within the same species, however, the predominant trend is that the two tested cultivars of the same crop show the same degree of change in germination over the years. Therefore, the results for the two cultivars of each crop are here presented as averages, except for peas.

The most long living seeds in this project, displayed as minimal loss of germination percentage over 30 years, have been the vegetable seeds from cucumber, lettuce, onion, beet, cauliflower and carrots. The picture is more varying within cereal, grass and legume species.

Among cereals, barley seeds have maintained a high level of seed germination over 30 years, while wheat and rye have declined significantly during the last half of the period. The forages show a scattered picture as red clover and Kentucky bluegrass have maintained germination on a more or less unchanged level, while timothy and English ryegrass have declined. The drop in viability has speeded up considerably during the last five to ten years.

The initial level of the seed borne pathogens varied considerably among the crop species included in the experiment. However, after 30 years of storage in permafrost the infection levels were in general only slightly changed in most of the species.

The experiment will still have 70 years to go, and it will produce further results and interesting observations for a long period. The results can be used to make plans for a new long term project for investigating seed longevity that includes a broader range of crops that are important in other regions and climates and involve storage in permafrost in the Svalbard Global Seed Vault as well as in the permafrost coal mine.

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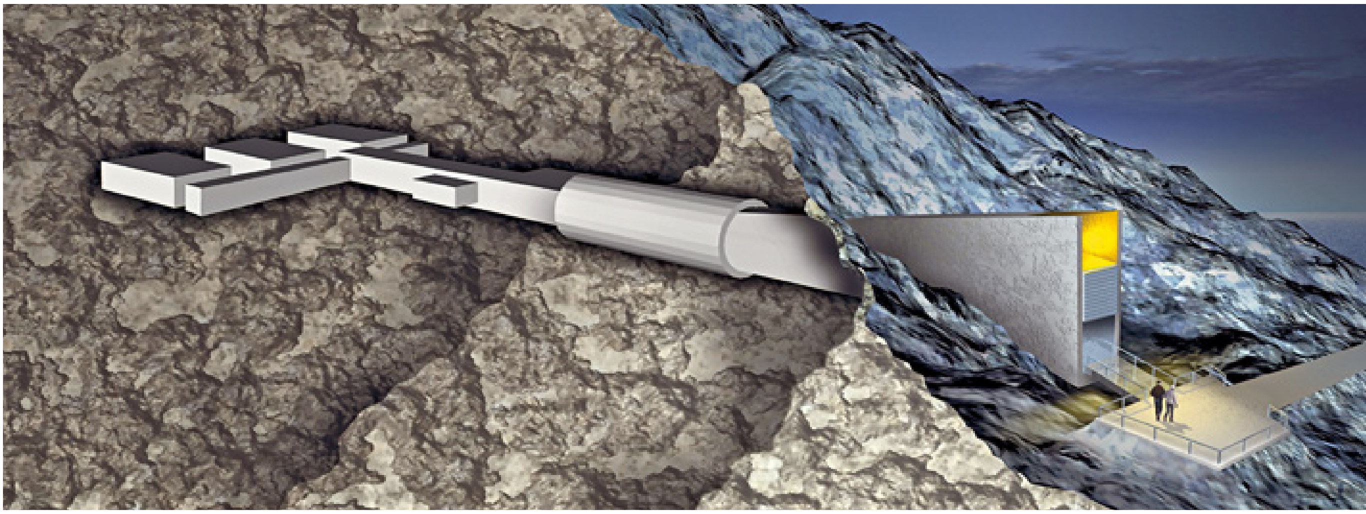
10 The Svalbard Global Seed Vault – Operated by NordGen

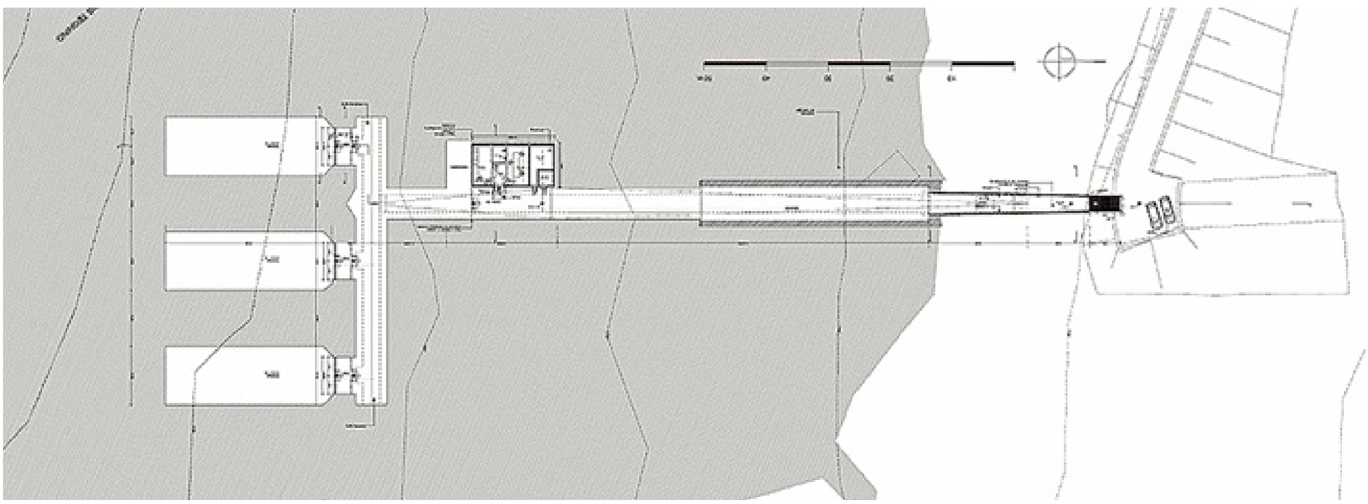
Åsmund Asdal
Roland von Bothmer

The history about the Svalbard Global Seed Vault was initiated already in 1984 when the Nordic Gene Bank started to use an abandoned coal mine gallery in Svalbard as a safe place for backup of the Nordic seed collection. At that time the permafrost condition with a yearly constant temperature of between –3.5°C and –4.0°C was used as the only source of low temperature, thus being independent of external energy supply.

Inspired by the Nordic safety seed storage in the Arctic area, discussions about a possible global facility has been going on for a long time. In parallel with the negotiations on the International Treaty on Plant Genetic Resources for Food and Agriculture, a facility study on establishing a global seed store in Svalbard commissioned by the Norwegian Ministry of Agriculture and Food was conducted. The offer of building the Svalbard Global Seed Vault was launched by the Norwegian delegation to the FAO Commission on Genetic Resources for Food and Agriculture meeting in 2004. The offer gained significant support among nations and organisations, and several gene bank representatives expressed their will to take advantage of a Seed Vault in Svalbard.

The Seed Vault was built and funded by the Norwegian government during 2007 and opened on 26 February 2008. NordGen was involved in the planning process and has been responsible for management and operation since the start. Thanks to significant joint efforts and financial support from the Global Crop Diversity Trust, many gene banks, in parallel with the construction works, prepared seed samples for depositing at the Seed





Storage halls embedded in solid rock, 120 m inside rock, 130 m above sea on a geologically stable location. Temperature maintained at –18°C, permafrost provides natural freeze guarantee at –4°C in the event of equipment failure.

Vault. Thanks to these efforts, 320 549 seed accessions from 22 gene banks were deposited in the Seed Vault already during the first year 2008.

The Svalbard Global Seed Vault has served as safety storage for conservation of duplicate seed samples of crops and their wild relatives deposited by gene banks all over the world. The establishment of the Seed Vault has turned out to be a great success. At the ten year anniversary in February 2018, the number of accessions deposited in the Vault passed one million, more than anyone could expect when it was opened. So far 76 institutes have deposited seeds in the Seed Vault.

Why a Seed Vault on Svalbard?

Svalbard was chosen for a global seed conservation facility for several reasons. The permafrost in the soils securing frozen seeds without additional cooling systems is one of these. Additional cooling systems bring the temperature in the Seed Vault down to -18°C, which is the recommended temperature for long term storage of seeds, as used by most gene banks. In addition, Svalbard is a remote and calm site with good infrastructure, such as regular flight connections and public services e.g. electricity supplies, cargo handling capacities and roads, and municipal and governmental departments and staff. Svalbard is Norwegian territory but with a special international status regulated in the Svalbard Treaty from 1920 assuring the access to the island to all nationalities who have signed the treaty. The area is also a demilitarized zone, which is important for an increased security at the international level.

Further, having a Seed Vault on Norwegian territory and funded by Norway is clearly in accordance with Norwegian commitment and contributions to international efforts on conservation of biological and genetic diversity. The international community involved in genetic resources trusts that Norway, together with Nordic partners, will take good care of the seeds and comply with agreed terms for the storage.

Unlike the Nordic security storage in the abandoned coal mine, the Seed Vault is constructed in virgin solid rock without any coal layers. The facility consists of a tunnel of about 100 m, a fore hall and three seed storage chambers, each with the capacity to store around 1.5 million seed samples. The Seed Vault is located 130 m above sea level, which is above worst case climate change scenario for sea level rise.

Operation and Management of the Seed Vault

The Seed Vault is owned by the Norwegian government and the management is the responsibility of NordGen. Funding is secured through a three party agreement between the Ministry and the Crop Trust with a limited contribution by NordGen. Daily monitoring of the facility is taken care of by the local Statsbygg office (The Norwegian Directorate of Public Construction and Property) in Longyearbyen, the regional capital town of Svalbard.

The operation of the Seed Vault is overseen by an International Advisory Panel reporting to the Ministry. The Svalbard Global Seed Vault is considered to be a vital part of the global system for conservation and use of plant genetic resources (FAO and ITPGRFA 2017).

Conditions and principles for depositing seeds in the Seed Vault are settled in a Depositor agreement that is signed by the depositing gene bank and by NordGen on behalf of the Ministry. All major public and private holders of Plant Genetic Resources for Food and Agriculture (PGRFA) are invited to deposit seed samples in the Seed Vault. They have to agree with the terms and conditions given in a Standard Deposit Agreement. Invitations are regularly submitted to gene banks and national plant genetic resource programmes. An open invitation is published on Seed Vault webpages.

Gene banks are invited to ship seeds to Svalbard on three or four regular opening occasions every year. Every year since 2008 between 12 and 29 institutes have deposited seeds. Many of these have deposited seed several times, as part of a comprehensive programme for securing major parts of their collections. NordGen maintains a web portal database where transparent data about all deposited seed samples, depositor institutes, countries of origin etc. is displayed (The Seed Portal).

The main conditions for depositing seeds in the Seed Vault imply that the depositing gene bank shall conserve the original and primary seed sample in its own long-term gene bank. Only orthodox seeds of crops and their wild relatives can be accepted for storage in The Vault. The genetic material should be available for breeding and research in accordance with applicable international law, e.g. according to the Material Transfer Agreement under the Plant Treaty. Storing seed samples in the Vault is free of charge, and the seeds remain the property of the depositor. The seeds are returned to the depositor on request if the accessions are lost or inaccessible from their own or from cooperating gene banks' repositories. Only the depositing institution can obtain access to the seeds it has deposited in the Vault.

Experiences of Safety Backup of seeds on Svalbard after ten years

After eleven years of operation, the number of deposited seed samples has reached 1 077 552. The major part, about two thirds, has been deposited by International Agricultural Research Centres (CGIAR institutions). Four of these have deposited more than

100 000 samples each: CIMMYT (International Maize and Wheat Improvement Centre) in Mexico, IRRI (International Rice Research Institute) in The Philippines, ICRISAT (International Crop Research Institute for the Semi-Arid Tropics) in India and ICARDA (International Institute for Agricultural Research in Dry Areas), which until recently had its genebank in Syria.

The largest depositors among national genebanks are the USA, Germany, Canada, Australia, The Netherlands, South Korea, and Switzerland. NordGen, the regional genebank of the Nordic countries, has secured a significant part of its seed collection in the Vault. Genebanks in several developing countries have deposited seeds as well: Mali, Nigeria, Sudan, Uganda, Zambia, Burundi, North Korea, Myanmar and Pakistan, among others.

The Seed Vault now holds samples of about 5 000 different species. Rice and wheat are represented by more than 150 000 seed samples each. Further, 15 major cereal, vegetable and forage crops are represented by more than ten thousand seed samples. A review five years ago estimated that about a third, in some cases ½ of globally distinct samples of 156 crop genera with orthodox seeds are safety duplicated in the Vault (Westengen et al. 2013).

So far, only one institute has requested seeds to be returned. This took place in the autumn 2015, when ICARDA, which until then had its headquarter in Aleppo, lost access to its gene bank due to the ongoing war in Syria, and needed seeds from Svalbard to establish new functional genebanks at ICARDA units in Lebanon and Morocco. Seeds from the Seed Vault have been shipped back on two occasions, and have been sown and multiplied at these sites. Since the spring of 2017, it has already re-deposited new seeds in the Vault on three occasions. Withdrawals and redeposits of seeds by ICARDA imply that the current number of seed samples in the Vault in mid-2019 is 985 122. Currently only the middle chamber (no. 2) is used for seed storage.

During snow melting seasons and at heavy rainfalls, the Seed Vault has experienced water intrusion in the entrance tunnel. In order to establish a complete watertight Seed Vault complex, prepared for a warmer climate in Svalbard, comprehensive construction improvements started up in 2018. A significant grant for funding the construction work was announced by the Norwegian Minister for Agriculture and Food just at the celebration of the 10-year anniversary in February 2018.

The work started just after the celebration and was completed during the first half of 2019. It included building of a completely watertight entrance tunnel and a new service building just outside the entrance. This will increase the security of the seeds even more in a long term perspective.

The Seed Vault upgrade has been highly appreciated by depositing gene banks, and the confidence in the safety of the seeds has been further strengthened.

The celebration events in February 2018 became an important manifestation of the importance of the Seed Vault as a security backup for seeds and may be even more important, as an iconic symbol of the importance of taking care of plant genetic resources. Significant attention from depositing gene banks and from media, politicians and other stakeholders underlines that the Seed Vault and the cooperation between all involved partners has been a great success.

Ever since the Seed Vault opened it has been a great attraction. It has drawn attention to the issues on conservation and sustainable utilization of plant genetic resources.

"The Svalbard Global Seed Vault is considered to be a vital part of the global system for conservation and use of plant genetic resources."

Influential politicians and policy makers have regularly paid visits to Svalbard and the Seed Vault and there has been a continuous great interest from many of the world's leading media to tell the story about the global undertaking of conservation and utilization of crops and their wild relatives. The Seed Vault is now Norway's internationally most well-known building and not least there is a great interest from the general public for the activities in the Seed Vault. Svalbard visitors of all kinds are attracted to visit the entrance of the Vault and learn more about its operation.

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Part V
Data Management and Information

Keeping track of information is a key issue of any genebank.

11 The First NGB Data Management System, the Current System and the Future Perspectives

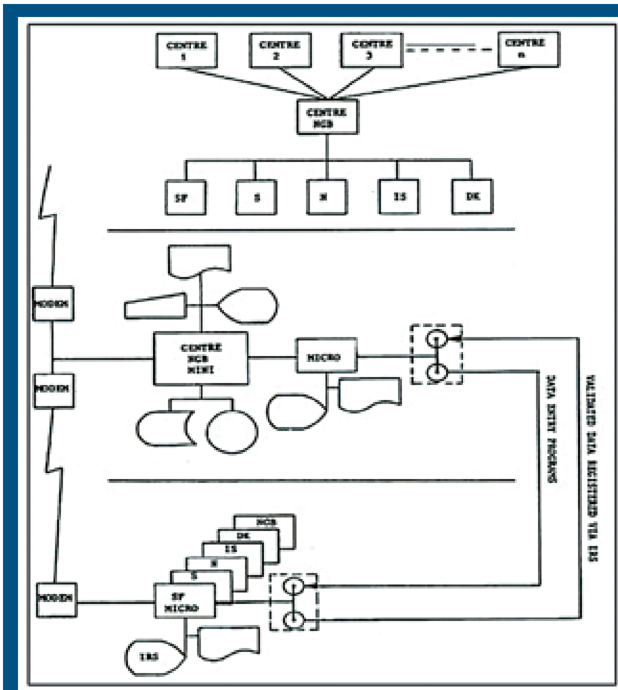
Flemming Yndgaard
Dag T.F. Endresen

The Nordic Gene Bank (NGB) was founded on January 1, 1979, as a Nordic institution, established and operated by the Nordic Council of Ministers. The purpose of NGB was and is to collect, register, document, preserve and make inventories of all Nordic genetically valuable plant material for future use in agriculture and horticulture. Later, forest and animal genetic resources have been added.

The work was carried out by NGB in close co-operation with plant breeders and other scientists. While serving gene bank purposes, a substantial part of the projects formed part of university research and teaching programmes as well.

In the European Cooperative Programme for Plant Genetic Resources (ECPGR) operated by IBPGR, which is discussed further in another chapter (Engels et al. 2019), NGB played an important role, being a regional gene bank.

NGB was one of the very first gene banks to develop a flexible data-processing system based on genetic and biological principles that allowed all Nordic plant breeders and plant scientists to have access to all relevant gene bank information and material, including that of other gene banks.



The network structure of NGB's data management system

The upper part represents the connection between the national gene bank activities and the gene bank centre NGB.

Centres 1 to n at the top of the diagram represent other gene bank centres, university computer centres, etc. in which gene bank information, powerful computing facilities etc. are available.

The micro at the bottom of the diagram represents an Intelligent Registration Station, IRS, i.e. a microcomputer, which performs registration on its own diskette or on the NGB disk via a modem.

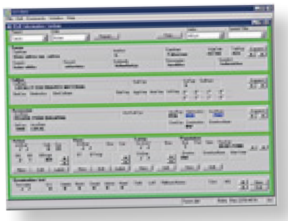
The registration is facilitated by special "data entry" programmes developed on NGB's microcomputer. Using a "formatted screen", the operator is guided through the data entering by the IRS.

Just as a railway without a timetable is of limited value, a gene bank without an information system has restricted potential. The aim of the NGB information system was to meet the following expectations:

- ease of data input (registration) onto a storage medium;
- data validation during the input phase;
- flexible data storage and retrieval;
- availability of multiple analyses of the data;
- exchange of computerized information with other gene banks;
- the system and its terminology must be based upon genetic and biological principles;
- being a regional gene bank, the data processing system of the Nordic Gene Bank served plant breeding in the whole region.

The concept of the system was created in 1980 and presented at the Symposium on Nordic Co-operation in the Field of Plant Breeding, 30 November to 4 December 1981 (Yndgaard and Kjellqvist 1983). Until the late 1970s, most of data management was carried out on mainframe computers, where large disks and magnetic tapes were used for data storage. Mini computers were used as standalone as well as terminals connecting via a modem to mainframe computers at computer centres. About that time, microcomputers were developed and became popular because of their much lower price. At the same time the "floppy disk" was developed for data storage.

A very efficient system for management of large amounts of data is a relational database management system (RDBMS). A relational database is a digital database based on the relational model of data. This model organizes data into one or more tables (or "relations") of columns and rows, with a unique key identifying each row. Generally, for a gene bank each table/relation represents one "entity type" (such as passport or lab analyses). The rows represent instances of that type of entity (such as "accession") and the columns represent values attributed to that instance (such as origin or species). Each row in a table has its own unique key. Rows in a table can be linked to rows in other tables by adding a column for the unique key of the linked row (such columns are known as foreign keys).



The SESTO database was developed as a desktop Visual dBase system between 1995 and 2001.

Unfortunately, a commercial RDBMS was only available for mainframe computers at the time NGB was established. NGB therefore developed its own, together with a small software house, which would fulfil the expectations mentioned above. The unique key was chosen to be the NGB accession number. Between 1983 and 1988 the NGB Biological Information Retrieval System (BIRS) was in use on the IBM minicomputer platform, and later recompiled for use on IBM PCs (Rydström 1989).

There were several good reasons for choosing exactly the same equipment as "IRS" (intelligent registration station) in the five Nordic countries:

- NGB had only to develop one set of data entry programmes, which were sent in compiled form as "load modules" on diskettes. Therefore, no local programme development was necessary.
- Purchase of compilers was necessary at NGB only.
- The very common problem of incompatibility between different equipment was avoided.
- NGB maintained and developed the programme library at the time. At intervals, the latest version was sent to the breeders' IRS on diskette.

The data entry programmes were developed in close cooperation with the plant breeders. In this way, very efficient subroutines for validating the data immediately on entry by using "formatted screen" in special "data entry" programmes could be incorporated. In most cases, data were registered on diskette and a diskette copy was mailed by letter post to NGB for incorporation into the common database on NGB's disk.

The registered data was stored in the NGB database. As soon as data was incorporated into the NGB database from the diskettes it was available to all NGB users in the Nordic countries. Therefore, it was very important that the data was validated at the moment of registration.

Using identical procedures, the breeder could retrieve his or her own data locally stored on diskettes as well as those of the database at NGB. The request to NGB's database was made on the IRS via modem and telecommunication or via a mailed diskette.

An adequate analysis of the enormous amount of data in the database sometimes required more powerful computer installations and more specialized software than was available at NGB. This demand was met by working at a computer centre, e.g. at the Computer centre in Lund or at The Technical University of Copenhagen. The data to be analysed was transferred on magnetic tapes.

An easy way of exchanging computerized information with other gene banks was by means of magnetic tape. The exchange of data between gene banks was easy using the internal files of systems such as BMDP, SPSS, SAS and GENSTAT.

During 1985 and 1986 Internordic Plant Breeding, SNP, in cooperation with the Nordic Gene Bank made an investigation into breeders' need for computer programmes as a tool in their work. Most breeders wanted better programmes for statistical analysis of single trials as well as series of trials, testing groups of material in several locations and in several years.

The Nordic Council of Ministers then on August 1, 1987, established the Nordic Biometry Project with the purpose of supplying Nordic plant and forest tree breeders with relevant computer programmes. The executive committee of Nordic Biometry Project, NBP, represented the Nordic Council of Ministers institutes: The Internordic Plant Breeding, SNP, The Nordic Forest Research Co-operation Committee, SNS, and the Nordic Gene Bank, NGB. The secretary of the Nordic Senior Executives' Committee for Agricultural and Forestry Affairs, NEJS, participated in the committee meetings.

As a supplement to the NGB documentation system Nordic Biometry Project created and maintained a PC computer system "Nordic Biometry System", NOBIS (Yndgaard 1990). Like the NGB documentation system it was menu-driven and contained three computer programme modules for:

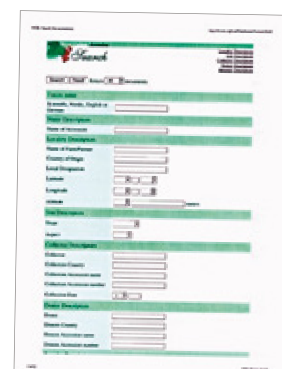
- Experiment Planning and Layout
- Experiment Analysis
- Database Management.

NOBIS was designed for the Nordic breeders and researchers.

Following the rapid developments of computers and commercial database management software systems, the information system for the Nordic Gene Bank, now NordGen, became modernized over time.

During the 1990s the NGB databases were migrated to the Borland dBase system. Starting from 1995 a major improvement in user interface was enabled by the move to Visual dBase 5. Between 1995 and 2001 the Visual dBase version of the SESTO (SEedSTOre) database was developed at NGB including an online search interface implemented on a Linux server with the Apache web server (Huldén 1999).

Starting from 2002, the NGB SESTO database started a new and major migration from the desktop Visual dBase system to a true online database with online data entry and edit forms and a personal login authentication for NGB staff and remote online users (Endresen and Knüpffer 2012). This online version of SESTO was implemented on a Linux server as a two-tier system, using a PostgreSQL database server as back-end and PHP (hypertext preprocessor) server-side scripting language for the front-end. SESTO was rather quickly adopted for use by gene banks in other countries including Russia (Vavilov Institute), Estonia, Latvia, Lithuania, Bhutan, Albania, North Korea, Uganda, Sudan, Kyrgyzstan, Tajikistan, and more. A modified version of the SESTO database was later used to build the data portal for the Svalbard Global Seed Vault before its opening in 2008 (Endresen 2011).

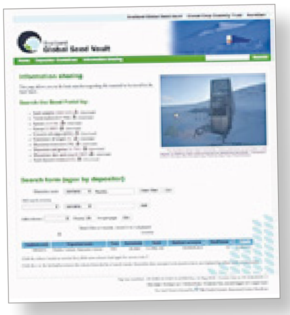


An online search interface for the NGB database was published online between 1994 and 2001.

Future perspectives

The Nordic Gene Bank was one of the first gene banks, together with IHAR in Poland and IPK Gatersleben in Germany, to join the Global Biodiversity Information Facility (GBIF) when the NGB membership in GBIF as associate international organization was approved in 2004 (Endresen and Knüpffer 2012). Active participation from gene banks in the larger biodiversity informatics community opens up new possibilities that are not possible to achieve within the network of agricultural diversity and genetic resources alone. Adopting international standards and contributing to their development and harmonization with the specific needs of the gene banks ensures data compatibility across a wider set of information sources (Endresen 2017). From the perspective of plant genetic resources, the crop wild relative information sources provide a particularly relevant example. Gene banks have primarily focused on conservation efforts and expert knowledge on cultivated materials. However, with the emergence of new and powerful genetic tools to transfer and utilize genetic diversity from outside of the primary gene pools, gene banks experience an increasing demand for crop wild relative genetic diversity from plant breeders and researchers. Shared biodiversity information standards provide easier linking between

Starting in 2002, SESTO was migrated as a completely online gene bank database.



The Svalbard Global Seed Vault data portal was based on the software source code for the NordGen information system SESTO and released in 2008.

gene bank information resources and relevant information sources outside the agricultural information network.

An important element to enable larger interoperable networks of distributed linked information resources is the implementation of shared globally unique and permanent object identifiers (Endresen 2017). The Global Information System (GLIS) under development by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) provides a service for assigning digital object identifiers (DOI) to gene bank accessions and other germplasm samples. DOIs are the recommended solution for signatory parties of the ITPGRFA to comply with article 17 of the Treaty (FAO 2009, 2018).

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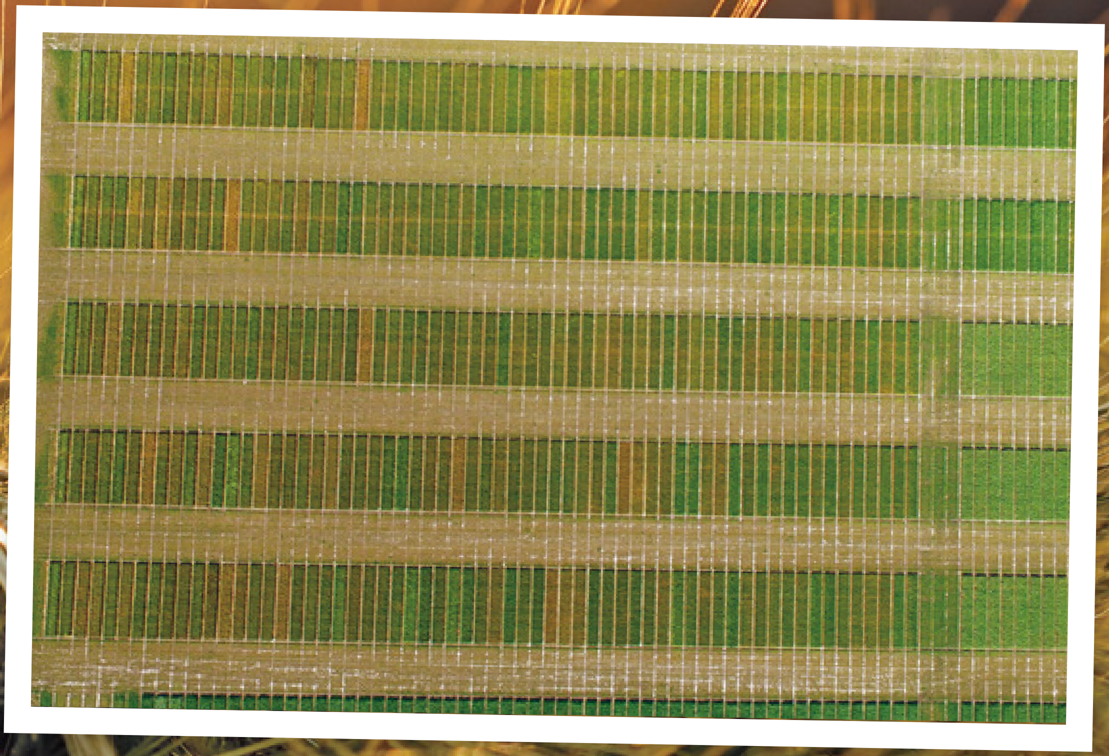
Part VI
Today and Tomorrow



Drone photo of gene bank accessions showing differences in crown rust infection.

12 NordGen's Plant Genetic Resources Collection 2018 – Conservation and Use

Anna Palmé
Annette Hägnefelt
Mohammad El-Khalifeh
Ulrika Carlson-Nilsson
Jan Svensson

The purpose behind NordGen's collection is the conservation of plant genetic resources of relevance to the Nordic countries and sustainable use of these resources. The main focus lies on resources of relevance for future food security, for example material that can be used in breeding and research on agricultural productivity, climate change adaptation and sustainable agriculture. In addition, the genetic resources stored at NordGen are used in basic research, for educational purposes and directly in production. Older material, such as old cultivars and landraces, are valuable for understanding and connecting to our cultural history.

The collection today

The collection in numbers

The collection at NordGen started to be accumulated after 1979, when the Nordic Gene Bank was founded. Today the collection includes about 35 500 accessions (see Table 1), which is an increase of about 10 000 accessions compared to twenty years ago (NGB 1999). Most of the accessions in the current collection are accepted for long-term conservation (ACC) but some are accepted for short-term conservation (TEM) and for others the conservation mandate has not been decided yet (see Table 1). In addition to these accessions, NordGen also stores safety duplicate samples for other gene banks, historic seeds and a large number of accessions that have been donated to NordGen, but for which decision on inclusion in the collection has not yet been made. A recent inventory suggests that the latter group comprises about 32 000 accessions.

Table 1

Conservation mandates of the accessions in NordGen's collection (May 2018). ACC – accepted for long-term conservation; TEM – accepted for short-term conservation; PEN – decision on conservation mandate pending.

Conservation mandate	Number of accessions (ACC+TEM+PEN)
ACC	26 286
TEM	7 313
PEN	1 903
In total	**≈ 35 500**

NordGen's mandate is to conserve accessions of Nordic origin and Nordic relevance. The former is generally rather easy to define but the latter has been discussed extensively, both within NordGen and NordGen's working groups. Since we cannot see into the future, it will always be a subjective decision to determine what accessions might be of future use for Nordic plant breeders and researchers. Today over 70% of the accessions in the collection are of Nordic origin. The rest of the accessions come from a wide range of countries with most accessions originating in the USA, Eritrea and Israel.

Table 2

The number of accessions of each crop type in the collection in May 2018. Accessions accepted for long-term (ACC) and short-term (TEM) conservation included.

Crop group	Number of accessions (ACC+TEM)
Cereals	21 182
Forages	4 739
Fruits and berries	17
Potato	88
Oil, fibre and root crops	1 512
Vegetables	5 464
Ornamentals	232
Medicinal plants and spices	343
In total:	**≈ 33 600**

The collection is divided into different crop groups as shown in Table 2. Cereals constitute by far the largest group in terms of the number of accessions, with over 60% of the accessions, followed by vegetables (≈16%), forages (≈14%) and oil, fibre and root crops (≈5%). A large part of the cereal collection consists of special collections of breeding and research material, which also dominates the whole collection. In addition, there are wild and semi-wild accessions (20%), cultivars (13%) and landraces (12%).

Status of the collection

During the lifetime of NGB, and later NordGen, the tasks and focus have changed. In the beginning there was naturally a strong focus on the collection and registration of material, while today maintenance of the collection is a central task. This is a natural transition, as

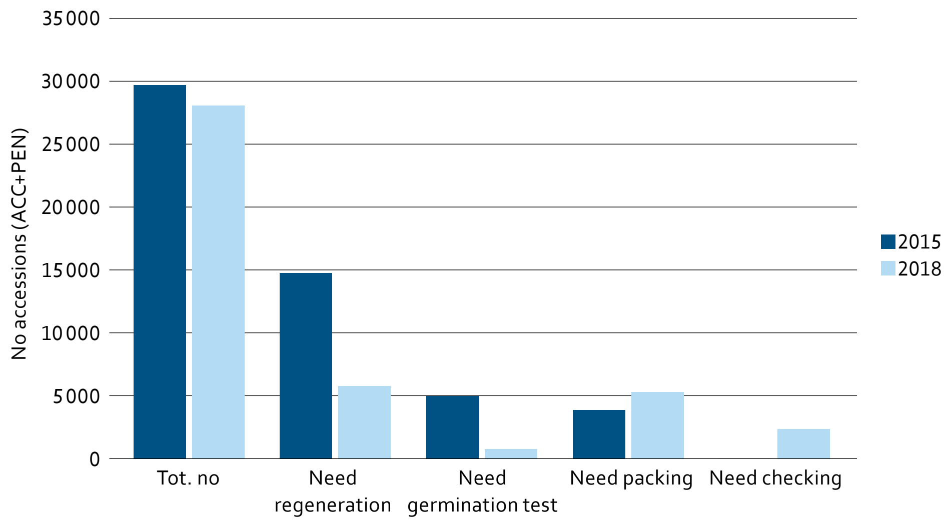
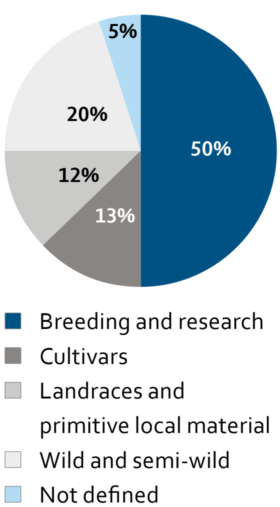


Fig. 1

The current status of the collection (January 2018) compared with the status in 2015 (January). Both accessions accepted for long-term conservation (ACC) and accessions that are still pending decision on conservation mandate (PEN) are included in this figure.

Fig. 2

The cultivar types (breeding and research, cultivars or landraces and primitive local material) among the accessions accepted for long-term (ACC) and short-term (TEM) conservation, May 2018.



over time the collection has aged and increased in size. However, the responsibilities and tasks to be performed by NordGen have increased over time, while the budget and staff has not been increased to the same extent. This has led to backlogs on a wide range of tasks, including tasks associated with the maintenance of the collection, which in turn endanger the long-term survival of the accessions stored.

During the period 2015–2018 the status of NordGen's collection has been improved. The estimated number of accessions that need regeneration has decreased from 50% to 21% and the number of accessions that need germination tests has decreased from 17% to 3%. This has been achieved since extra funding has been used for germination testing in NordGen's seed laboratory, the regeneration has been increased both at NordGen and in external locations, a new algorithm has been used to estimate the need for germination testing and regeneration and efforts have been made to take decisions on conservation mandate. This decision to focus on reducing the backlog on tasks associated with collection maintenance has been successful, but most progress has been made on the species and accessions which are relatively easy to germinate and regenerate. The remaining accessions are more time consuming and much remains to be done. In addition, by focusing on certain tasks, others have not been prioritized and therefore not performed to an adequate extent, for example documentation, incoming material, international cooperation and evaluation of the material.

Cereals

The cereal collection at NordGen comprises over 21 000 accessions (Table 2) from 15 different genera constituting a total of 93 different species. The most common genera in descending order are *Hordeum*, *Triticum*, *Avena*, and *Secale*. The cereal collection can broadly be divided into three groups, namely, cultivated cereals, wild relatives to the cultivated species, and breeding and research material.

The Nordic Gene Bank, together with Nordic breeding companies, made inventories of cereals cultivated in the region, and material was sent to NGB for long-term conservation. Today, the Nordic cereal collection contains 1 244 cultivars and 467 landraces. Many Nordic barley landraces are conserved, for example the two-rowed Danish barley landrace "Gammel dansk" that was grown all over Denmark in the later part of the 19^{th} century, and one accession of Finnish midsummer rye. Several Swedish wheat landraces are conserved from different cultivation areas – Dalarna, Halland, Uppsala and Värmland – and all these are now registered as conservation varieties and once again grown on fields in Sweden.

Part of NordGen's outdoor seed propagation facilities in June 2018. In the tunnels to the left, clover accessions, in the middle forage beets and to the right beans. All crops transplanted in a field with six years crop rotation cycle. In the background the new net-isolation-cages can be seen.

The collection of wild relatives to cultivated cereals mainly includes species from the genus *Hordeum* and it covers all species in the genus. It was collected from all major distribution areas of wild *Hordeum*. This collection is probably the largest collection of wild *Hordeum* species in the world and it is very important for studies of taxonomy, speciation/evolution and the relationship between cultivated barley and wild *Hordeum* species (Bothmer 2019).

The collection of barley mutants is an example of breeding and research material. Mutation research started as early as 1928 in Sweden and in 1953 the Swedish government funded a research group for mutation research. A large collection of morphological and physiological mutants was identified, and about nine thousand were incorporated into the Nordic Gene Bank. The value of this collection has increased by the development of high throughput and low-cost genomics assays, and since the material is well characterized it can be used to identify genes for specific morphological or physiological traits (Lundqvist 2019).

Vegetables

The vegetable collection is a diverse and species rich group with 55 different genera. The five largest are *Pisum*, *Brassica*, *Allium*, *Daucus*, and *Lactuca*. These genera all contain crops that had active Nordic breeding programmes for many years but are now closed, except for breeding programmes in peas and beans. The lack of vegetable breeding activities in the Nordic countries decreases the amount of incoming material to a minimum. Focus is instead on regeneration of landraces and old open-pollinated cultivars already in the collection. Open-pollinated material can be maintained over time if it is cultivated with an adequate population size. Modern F1-hybrids that dominate the vegetable market today, for example in carrot, onion, leek, *Brassica*-vegetables, tomato, pepper etc., can only be multiplied by the breeding entities which have the parental lines. However, gene banks may conserve and multiply the parents to the hybrids, but these lines usually often of

Collection of forage species in 1980 in Norway, Petter Marum.

Examples of accessions stored at NordGen:

Top left: the Chinese aster cultivar 'Salome rosa', originating from Hammenhögs.

Bottom left: the pea landrace "Solleröärt" from Dalarna in Sweden.

Right: the Danish cabbage cultivar 'Amager høj Kalida'.

lower interest to the users due to inbreeding depression and the specific knowledge needed to multiply them. NordGen also handles wild material from the Nordic countries of crop wild relatives such as *Allium*, *Apium*, *Brassica*, *Daucus*, *Lactuca*, and *Pastinaca*.

For our focused regeneration, growing facilities and approaches have been developed during recent years. Many of the vegetables are cross-pollinating species with a high risk of inbreeding depression. Therefore, we give special attention to the number of plants per accession used during regeneration, to maintain vitality and diversity within each accession.

Forages

Forages are an important crop group in the Nordic countries, especially in the northern part of the region. There is active breeding of forages in all the Nordic countries and forage breeders have been involved in the creation of the collection at NordGen since the start of the gene bank. Many of the forage species have large natural distributions in the Nordic region and there has been an interest in collecting a representative sample of this diversity to make sure that it is conserved for the future. A large number of sampling missions took place in the early 1980s with the aim to sample old meadows before the forages were replaced by modern cultivars.

"There has been an interest in collecting a representative sample of this diversity to make sure that it is conserved for the future."

Today the forage collection consists of over 4 700 accessions (see Table 2), mainly grasses and clovers but also a few other legume species. In total there are 89 taxa from 24 different genera. The largest number of accessions comes from species used as forage crops, such as timothy (795) and red clover (521), but there are also species used for lawns and others that are close relatives to the cultivated species. Most of the collection (about 70%) is classified as wild or semi-wild and the rest mainly consists of landraces and cultivars and some breeding and research material. Most of the accessions are of Nordic origin (97%), and the non-Nordic accessions are mainly from previously Finnish areas in Karelia.

Oil, fibre, root crops, etc.

This crop group, which is sometimes called "industrial crops", includes the agricultural crops that do not fit into the cereal, vegetable, or forage groups. Today the collection consists of over 1 500 accessions (Table 2) but the majority of these are under short-term conservation (over 1 100). The latter includes both collections deemed not to be of long-term importance for Nordic breeding, such as the Danish collections of winter cress and field poppies, and accessions that cannot be propagated in the gene bank, such as modern hybrid cultivars of sugar beets. Brassica oil crops and fodder beets are the largest groups among the accessions accepted for long-term conservation.

Ornamentals, medicinal plants and herbs

During the twentieth-century Nordic plant breeding of ornamental species, mainly annuals, was conducted at Swedish and Danish companies such as Hammenhögs, Weibulls, Ohlsens Enke, and Daehnfeldt. At the end of the century the breeding programmes were closed down and when NordGen in 2005 got the responsibility to conserve ornamental species, an active search for cultivars originating from the old breeding programmes was initiated. For instance, a seed call for annual and biennial ornamentals arranged by the NordGen working group for fruit, berries and ornamentals resulted in 46 accessions. *Dianthus barbatus* (Sweet William) and *Aquilegia vulgaris* (Columbine) were the most common. Several accessions have also been received through the Swedish Seed Call (Fröuppropet). Unfortunately, many of the cultivars originating from the breeding programmes were already lost at the time of the seed calls and today there are only minor chances to find additional ones.

The ornamental collection is dominated by material from Sweden and Denmark. Together with *Dianthus barbatus* and *Aquilegia vulgaris*, the five most well-represented species include *Verbascum nigrum* (black mullein), *Saponaria officinalis* (soapwort), and *Callistephus chinensis* (Chinese aster).

In total, the ornamental collection includes 59 taxa from 41 different genera. Around 20% of the ornamental collection consists of cultivars or landraces/local primitive accessions, whereas the majority consists of wild or semi-wild material collected during different collection missions. A number of the accessions are cultural relict plants collected by NordGen from historical sites in Denmark inventoried by Bernt Løjtnant (Solberg 2014).

In addition to ornamentals, the collecting missions for cultural relict plants resulted in several accessions of medicinal plants and herbs. Around 90% of the collection of medicinal plants and herbs at NordGen are wild or semi-wild material. Besides the relict plants, *Thymus*, *Rhodiola* and *Angelica* collected on the Faroe Islands and material from the Finnish collection of Medicinal and Aromatic plants are examples of material included in this rather diverse group including 67 different species from 54 genera. The three most well represented species are *Malva sylvestris*, *Ballota nigra* and *Chelidonium majus*. Several of the species in this group are difficult to conserve, as knowledge regarding germination protocols, cultivation practice and reproduction biology is scant or non-existing in many species.

Potatoes

Potatoes are the only vegetatively propagated crop maintained at NordGen, whereas the responsibility for the other clonal crops was transferred from NordGen to the national Nordic authorities in 2000. The *in vitro* collection consists of 76 clones including cultivars, landraces and a minor number of breeding lines from Swedish and Norwegian breeding programmes. Material from all Nordic countries is included in the collection (Denmark 16%, Finland 18%, Iceland 4%, Norway 20% and Sweden 42%). In addition, there is a dynamic field collection where incoming clones are kept for evaluation for potential acceptance into the *in vitro* collection. All incoming material not certified as virus free has to undergo virus cleaning before acceptance and future distribution. This is an expensive procedure performed as a purchased service. Molecular as well as morphological studies have been performed to aid identification of duplicates within the two collections.

Utilization of plant genetic resources

NordGen sends out thousands of seed bags to seed requesters throughout the world each year. There is substantial variation among those requesting plant genetic resources (PGR) material from NordGen, although the most important group are plant researchers and breeders. Another group is represented by museums and botanical gardens interested in cultural history, which use the PGR for exhibitions. A third group is the public – private hobby gardeners, who frequently wish to grow material and thus help with the conservation of rare and endangered local landraces and old cultivars.

During 2010–2017, 38% of the PGR material delivered was used for research and breeding, 11% was intended for "other professional use", and 51% of the seed samples delivered were dispatched to private, non-commercial users.

NordGen always aims to further increase the use of PGR for research and breeding purposes, as well as to draw attention to the value of PGR among the public, both from a biological and a cultural-historical point of view. As part of this process, many efforts have been made to achieve this goal, for example by simplifying the ordering process:

1. the FAO Standard Material Transfer Agreement (SMTA) was introduced in 2007;
2. NordGen improved its ordering system by introducing a "shopping cart" in 2010:

3 a system for electronic confirmation of Material Transfer Agreements was introduced in 2012;
4 a web shop specifically aimed at hobby users was created at NordGen website in 2017.

The international media attention that NordGen received in connection with its role as the administrator of the Svalbard Global Seed Vault also increased the interest in PGR.

As expected, the above efforts have contributed to increase the number of seed orders and seed samples year by year. The number of seed requests gradually increased from two requests in 1979 to 1 065 requests in 2016; and the number of seed samples sent increased from 2 835 seed samples in 2005 to 9 855 in 2015. The PGR material requested from NordGen is delivered worldwide. During 2010–2017, 86% of the requests came from the Nordic countries, 10% from other parts of Europe, and 4% from the rest of the world (Fig. 4).

Challenges for gene bank management

To be able to assure long-term conservation in a seed collection such as the one at NordGen, many different tasks need to be performed and correctly adapted to each specific crop. Seeds from each accession need to be harvested, threshed and cleaned and then tested for germination, all with a protocol adapted to the correct crop/species. The accessions stored at NordGen have so-called orthodox seeds, which means that they can all be dried and stored in the freezer under similar conditions. However, when the germination monitoring indicates that the seed quality is going down, the seeds will have to be cultivated and new fresh seeds produced (regeneration) and the cultivation approach will also have to be adapted to the crop/species. In a collection such as NordGen's, with over 550 taxa, this means that the streamlining of processes is difficult and that a complex system needs to be maintained. In addition, for species that are seldom conserved at gene banks or cultivated for seed production, knowledge of appropriate approaches for germination testing and regeneration is often missing. Below, we address some of the challenges associated with regenerating gene bank accessions.

Isolation in self- and cross-pollinators

Long-term conservation of self-pollinating species is easier than of cross-pollinating species. Crops like wheat, barley, oat, lettuce, tomato, peas and beans are mainly considered as self-pollinated. They are genetically nearly homozygous, which means that no segregation of traits occurs between generations and hence, diversity will remain stable for long-term conservation, even if very few plants are grown when regenerated. Many cultivars can grow side-by-side without a risk of cross-pollination and loss of the accession's typical characteristics.

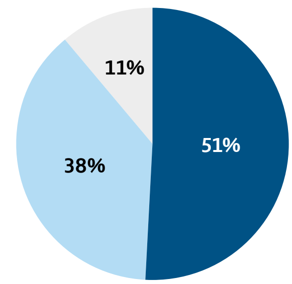
The cross-pollinating species are trickier, and we have two kinds of cross-pollinators: wind- and insect-pollinated. In these species, accessions need to be isolated from each other to avoid pollen contamination between accessions. Isolation can be achieved by geographical distance between regeneration plots or by using isolation cages/cabins. For insect pollinated species NordGen generally uses simple and flexible isolation-cages with insect nets that can be moved to new fields to assure crop rotation. The wind-pollinated crops like rye, forage grasses, sugar beets, spinach and asparagus are generally separated using geographical distance and by cultivating a limited number of accessions of each species each year. Since the cross-pollinated species thus need either large cultivation areas or isolation cages, the number of accessions that can be regenerated each year is limited.

Life cycle

Another challenge is that the collection at NordGen includes many biennials and perennials, meaning that regeneration will take at least two years. These species generally need a period of vernalization and for some accessions the length of this period is unknown in

Fig. 3

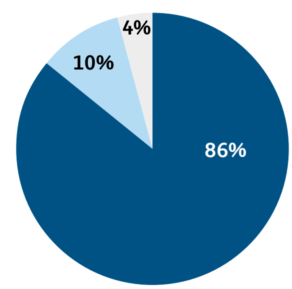
Intended use of material distributed NordGen during 2010–2017.



- Private
- Breeding and research
- Other professional use

Fig. 4

Countries from which seed orders came, 2010–2017.



- Nordic countries
- Rest of Europe
- Rest of the World

"The resulting plants are smaller and less space demanding, compared to a dug-up whole plant."

advance, and this has an impact on the planning of the cultivation cycle. As an example, different cauliflower cultivars can have as different curd initiation periods as from 8–18 true leaves, which in practice is several weeks of difference depending on temperature. Some crops are very labour intensive to cultivate, for example cabbage. They are sown outdoor in spring and grown as a "normal crop" until the heads are mature. The plants are de-capitated and after some weeks, small cuttings evolve on the remaining plant stem. These cuttings are harvested, transplanted and rooted in pots and then vernalized in glasshouses over the winter. In spring they are transplanted and isolated in net cages. The method using cuttings is preferable since the resulting plants are smaller and less space demanding, compared to a dug-up whole plant transplanted into a glasshouse for vernalization.

Number of plants needed

The number of plants used for an accession when propagated is crucial for out-crossing species. Cross-pollinators just "hate to be self-pollinated" and there will be a high risk of inbreeding depression in just a few generations. Another problem is that the smaller the number of plants is during regeneration, the larger the loss of diversity will be during each regeneration cycle. In addition, the regenerated accession will differentiate from the original sample. At NordGen we have set up rules for our different species, based on international and European guidelines, on the minimum number of plants needed to secure the diversity and vitality of the accessions for long-term conservation. We predominantly use 100 plants as an optimum number for cross-pollinators, but for different reasons we often need to decrease this number to 60 plants and the absolute minimum is 30 plants per accession.

Monoecious or dioecious

One last challenge to mention for cross-pollinated species is if the species is monoecious or dioecious. Cucumber is such a crop. Old cultivars are mainly monoecious, but there can still be problems getting male or female flowers and this can depend on e.g. the temperature. With different chemical methods such as silver nitrate treatment of the shoot tips, male flowers can be stimulated. Another example is asparagus which is mainly a dioecious species. In this case one can just hope for a good segregation between male and female plants to secure a good pollination.

Conclusion

Today, the plant genetic resource collection at NordGen contains a wide range of crop types and species, with cultivars, landraces, crop wild relatives and breeding and research material from over 220 genera and over 550 taxa. In this way a wide range of diversity of Nordic relevance is conserved and made available to users but the wide range of diversity also offers challenges concerning seed management and regeneration.

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13 Communicating Genetic Resources

Sara Landqvist

Working as a communications manager at NordGen is a very rewarding job. Not only do I have a greenhouse, gardens and fields right outside my window – I work on behalf of our children and grandchildren, contributing to assure that the genetic diversity of our past is preserved for the generations to come.

But let's be frank: NordGen is unfortunately not a well-known institution within the Nordic countries. Our mission at large, preserving genetic diversity, however important, is not an issue high on the agenda of the politicians or the general citizen today. The fact that our mission is unknown is unfortunate for many different reasons. Firstly, the important task executed by us is a matter everyone ought to be aware of due to the fact that it concerns everyone. If we don't maintain the genetic diversity among our Nordic plants, forests and farm animals connected to food and agriculture, no one else does it. And that will affect our future food security. Secondly, we are funded by the Nordic tax payers, and therefore have a responsibility to spread information about our work. In other words, what do we do with their money? Thirdly, if the knowledge of NordGen and our mission isn't known by the stakeholders interested in using our seeds and taking our advice, our "raison d'être" is compromised. Because honestly, if the genetic diversity isn't being used or has the potential of being used, why do we work to preserve it? With that said, we have an enormous potential to reach a wider audience. The work of NordGen includes lush plants, tranquil forests and adorable farm animals. In a high-tempo media landscape, these are ingredients that have great potential of reaching its audience. Additionally, the importance of our work is regulated both on a national and an international level – in other words, what we do is important. Our challenge ahead is to improve the communication in a resource effective way, letting the Nordic and global population understand more about our important mission.

Everything is communication

So, what do we mean when we talk about communication? Well, this book is communication, you talking to your friends is communication, and the words on the advertiser's billboard is communication. In short, communication is many different things. NordGen today works with communication in various ways. In our working groups, councils and the board we discuss different issues concerning genetic diversity. We have staff meetings, post news on our website and sometimes attend fairs and larger network meetings. All this and more is communication. Therefore, it's vital that communication is integrated in all our operations and at an early stage. If we receive grants in a project, how do we communicate what we have done? All the important work we do mustn't stay within these walls. Be it a scientific article, be it a post in social media, a report, a well-functioning database, a video or pictures documenting the beautiful growth of our crops in the fields. In many ways, today we are – even more than in 1979 – living in the age of communication. I dare say that never before in human history have we communicated so vividly with each other – at least not on platforms that can be shared with millions of other people. We are connected globally in a way that we've never been before.

The world has changed, and the views upon genetic resources with it

In a summary of the first ten years of the Nordic Gene Bank, it is stated that there have been profound changes in the global view upon genetic resources during 1979–1989.

> *What in the beginning was an acute situation concerning mainly cultivated plants, is now a global matter concerning all living organisms. Conserving biological diversity has become some kind of a slogan.* (Freely translated, NGB 1991)

Today, thirty years later, we can still agree with the statement above. Biological diversity, and the importance of maintaining it, is most definitely something most people are willing to accept and make a stand for. Still, while biological diversity was a buzzword in the late 1980s and early 1990s, with the Brundtland-report in 1987 and the UN meeting in Rio de Janeiro in 1992, climate change is a word that probably creates even more buzz today. NordGen plays an important part in tackling future climate change scenarios, but we must communicate our potential for anyone to understand it. And to do that we must know who our target group is. Is it the politicians making stands for biological diversity? Or the breeding companies who in the future might need to rely on the traits of older seeds stored at NordGen? Or do we put our faith in the general public, hoping that they will raise the issues for us? The answers to these questions determine how well we communicate.

Communication – for whom?

When it comes to the external communication, NordGen, as opposed to companies selling printers or high fashion shoes, have quite a wide target audience. Botanical gardens are interested in what we do, but so are politicians, gardeners, breeders, officials and many other groups. This means that we need to communicate in many different ways. Does the elderly man with an interest for medical plants have the same interests as a young woman working with politics? Perhaps, but the messages most probably need to be tailored for them respectively to gain the most possible understanding and commitment. Both of them perhaps need a clarification of what the word 'accession' means, whereas this of course would be redundant for the gene bank manager in India. We need to speak in different ways depending on who we talk to, and this is something we need to keep in mind

"Paper and print are getting more and more obsolete, and we spend almost every working hour in front of a computer."

every time we communicate our work. And not only do we need to tailor our package of information, we also need to choose our channel – an area where much has happened the last 40 years.

Technical development

While writing this book, we as authors find our facts in machine typed papers becoming yellow of age, printed sheets and books from libraries. A visit in a time capsule, one might argue, of how everyday life looked 40 years ago, when the Nordic Gene Bank was founded. Although the Nordic Gene Bank adapted computers for data base handling early on, the printed catalogues, common in the 1980s are no longer in use. Our work with information and communication has changed radically during these years. Since 1979 we have seen the introduction of computers, electronic mail, Internet, cell phones, as well as advanced software and complicated databases. Today, paper and print are getting more and more obsolete, and we spend almost every working hour in front of a computer. We answer e-mails instead of phone calls and hand-written letters. And should there be any technical errors with the Internet connection, many of us would find ourselves helpless in performing many of our work tasks.

Many may argue today that the technical development has laid a pressure on us to perform more in a higher, and sometimes less healthy, tempo. But no one can deny that the technicalities also have made our work more efficient in many areas. We can easily cooperate over the national borders, for example by coordinating our genetic resources on a European level through the project AEGIS or discussing deposits to Svalbard Global Seed Vault by inviting gene bank managers in Canada or Thailand to video conferences.

The technical development has offered enormous possibilities when it comes to communication. Not only in how we communicate internally every day, but also in our external communication. We live in an age where most people have a social media account. Many have these accounts as their main provider of news. In one way, it has become a more equal reality, where everyone has the possibility of making their voice heard. But on the other hand, that voice must be strong, because with everyone eager to have their say – the challenges in order to get through the buzz are increasing. We also live in an age where the message we send out is controlled by mathematical algorithms. Facebook, for example, changed their algorithms in 2017. For the private user of social media this led to more relevant posts being displayed, but for us as an organization it means that we now need to pay for our posts being visible to the larger audience.

NordGen today holds accounts in Flickr, Facebook, Instagram, Twitter and LinkedIn. Posts are published with regular intervals, primarily spreading information about our work and the importance of a genetic diversity. Here, we communicate with stakeholders from all over the world. Our followers are people interested in gardening, seed collectors, politicians, representatives from private corporations and so on. I believe that social media has granted us more direct channels of communicating with our stakeholders, but at the same time they demand easily accessible information. We cannot count on any additional efforts from them, their time is too precious and just a scroll below there might be a cute kitten more interesting than us. The navigation in this jungle is quite the challenge, but if we master it the reward is worth it.

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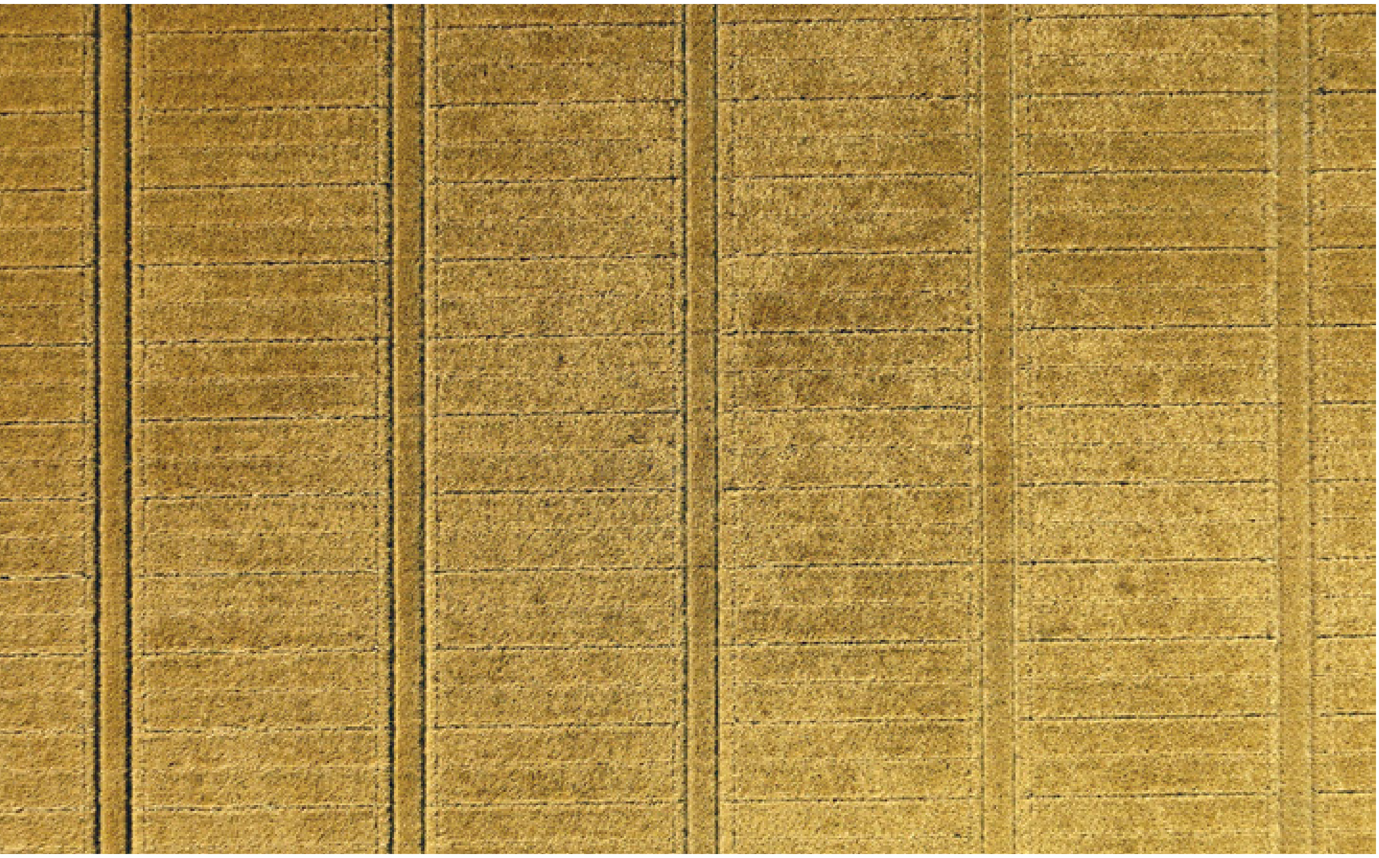
14 Public-Private Partnership – the Market, the Idea and the Set-up

Annette Hägnefelt
and Anders Nilsson

Before starting to read, pick up a globe and look up the Nordic countries. Then estimate how large the possible total area of cultivation is in Denmark, Finland, Iceland, Norway and Sweden. Compare with the potential cultivation acreage of other European countries. Then think about how the climate and growing conditions differ at the different latitudes. In the southernmost area there is a long growing season and mild winters with small risk of winter damage. In the north where we live, the growing season is shorter, and autumn sown crops are sometimes spoiled. The further up north we come in Sweden, Norway and Finland, the more specific adaptations to the environment become crucial. Above all, it is the increasing day-length during the summer that can radically affect the induction of the generative phase that influences the seed assortment you need. Also, winter damage is more prevalent here. With an expected climate change, major fluctuations and more significant drought and rainy periods are expected.

So, now we have done a rough market analysis and the new question is: who is the seed supplier for the Nordic area in the future?

Exactly these facts described above were clear to Roland von Bothmer and Anders Nilsson when they were commissioned by the Nordic Council of Ministers (NCM) in 2008 to look into how Nordic plant breeding could be strengthened. The background was that major European plant breeders focused their breeding programmes on a belt between the 37th and 55th latitudes. If the varieties worked well in the Nordic market, it was a bonus for



Drone picture of a barley field at Lantmännens trial site in Svalöv, Sweden.

them, but there was certainly not an interest in starting or extending a breeding programme for Nordic needs. Also, in Sweden and Denmark, major restructurings in the plant breeding and seed business sector had been made in a short period of time, resulting in considerable down-sizing in Sweden. It was clear that with a continued negative trend in this important area, domestic food supply would be at risk of being jeopardized.

With great conviction and enthusiasm, Nilsson and von Bothmer visited Nordic ministries, universities and plant breeding entities. The interest arose and eventually the concept of establishing a Public-Private Partnership (PPP) was anchored in the NCM and with the Nordic countries through the respective ministry responsible for issues on plant breeding. After continued discussions with the Nordic breeding entities to overcome prevailing distrust and competition in the market all except one joined the PPP for pre-breeding. The aim was that the Nordic plant breeding entities would jointly initiate pre-breeding projects in collaboration with universities and institutes to secure the continued development of Nordic plant breeding.

How? – Administration and funding

As always, money is required if major projects are to be launched. The commonly used rule that two stakeholders each pay half were also applicable in this context. Thus, the Nordic countries together fund 50% of the total budget for PPP-projects and the breeding entities contribute the other half, project-by-project. Each Project Leader must pick up at least half of the breeders in a specific crop and convince them of the excellence of his or her project idea.

Then a decision-making and an administering body were needed. As a decision-making body, a Steering Committee (SC) was formed with representatives from the five countries and four from the breeding entities. A tenth representative was chosen from the academic world.

NordGen was chosen by NCM as the administering body. Among many tasks the PPP Secretariat handles the funds from the ministries as well as the payments to the project leaders. They announce the Calls, four so far, and administer the registration and evaluation of the project proposals before the SC decision. The secretariat also evaluates the annual project reports, both economically and scientifically, but all approvals are made by the Steering Committee.

The result – Ongoing projects

In connection with the establishment of the PPP certain prerequisites were set up. The pre-breeding projects should aim for one of three items:

1. base-broadening of Nordic crops;
2. introduction of specific traits in adapted germplasm;
3. development of efficient tools and methods.

It was also stated that the projects should be non-competitive and strategic. The first projects should also either involve as many countries and breeding companies as possible or deal with a non-commercial crop, where the breeding was publicly funded.

Apples

Items 2 and 3 are fulfilled in the project "Pre-breeding for Future Challenges in Nordic Apples". In this project, focus is on improvement of disease resistance in apples. Main goals are (Nilsson et al. 2016):

- improvement of cooperation among Nordic fruit breeders;
- analysis of resistance towards apple canker and storage rot in apple cultivars;
- identification of candidate genes and development of DNA markers;
- DNA-based analyses of disease resistance in apple;
- information distribution to stakeholders.

Apples have been grown in the Nordic countries for centuries and are an important crop, rich in many nutrients and vitamins. However, the degree of self-sufficiency of apples is very low in all Nordic countries. The climate conditions are highly variable and at the edge of where it is possible to grow most of the fruit and berry species. This has led to difficulties for Nordic fruit production to compete with imports from fruit exporting countries, even if the quality of Nordic fruit has specific values. Concerning fruit breeding, most of the activities in the world are made at public institutions, because it is not profitable to breed, market and sell apple cultivars for many reasons. Apple is a vegetatively propagated crop, so you don't sell seed but grafted trees. Orchards stand for decades and replanting is seldom done due to the high cost. The license level, which is set internationally, is quite low. Furthermore, apple is an out-crossing species which means that after a cross you will get a huge variation in the offspring. When a beautiful exterior as well as a good interior is required, there will be many discarded plants with the wrong combination of traits before you find what you seek. From a cross to when the first apple can be harvested takes a few years, however finding something special and getting it into the market can take decades. And then the growers need to be convinced of the merits of the new variety. This means that the market for a new cultivar might not develop until the period of protection is almost over.

In this project, focus is on different diseases attacking apples, both in the field and during storage. For this work, a specific multipurpose cultivar panel is assembled that represents the genetic variation needed. This panel will serve as a first step towards transition to the genome-informed breeding.

In the Nordic countries we have a long tradition of fruit breeding. It is significant that we

Pollination
of apple.

let this profession continue since imported apple cultivars are less adapted to our growing conditions.

"What started with some hesitation in 2011 has become a big success."

Barley

"Combining Knowledge from Field and from Laboratory for Pre-breeding in Barley" is the title of another project that fulfils the three prerequisites set up. Main goals are (Nilsson et al. 2016):

- to find a larger variability of genes for abiotic and biotic stresses;
- to find a larger variability of genes in relevant breeding material by using multi-parent advanced generation inter-cross (MAGIC) populations;
- to develop 'easy-to-use' DNA markers to be used in the breeding of new cultivars;
- to educate the next generation of breeders by assigning PhD Students and PostDocs to the project.

The genetic background is narrow in many crops, and it has become more difficult to exceed yield and improve other characters demanded in the crop, such as different disease resistances within the current gene pool. With the expected changing climate, breeders are therefore focused on broadening the genetic base with the aim to introduce genes for abiotic as well as for biotic stress from material like landraces, cultivars and breeding lines. To achieve maximum diversity several MAGIC population designs were set up in the project start with multiple parents with earlier mentioned background. In a MAGIC setup, all parents are crossed with all in a well-planned manner. For some diseases, evaluation of the resistance in the parents and offspring is partly performed through newly developed DNA markers, and the work continues now with phenotyping of the different MAGIC populations. The selected diseases are Fusarium, Net blotch, Net Type and Spot Type, Rust and Ramularia and the selected agronomical traits are heading, lodging, plant height, early vigour and tillering. The focus within the third phase will be on the utilization of the MAGIC populations and the setup of genomics assisted pre-breeding using genome-wide association (GWAS) studies and genomic selection (GS). Further, in some lines, previously unknown mutations were found causing up to three weeks' earlier flowering and maturing. Traits that may enable spring barley to be grown even further north compared with today.

In this project focus is also on the education of the next generation of breeders. Two Post-Docs, one PhD student and one Master's student have been involved in the project. They will be trained in both traditional methods of practical breeding and disease scorings well as in quantitative genetics, including new techniques such as GWAS and GS.

Perennial ryegrass

In the project with the title "PPP for Pre-breeding in Perennial Ryegrass (*Lolium perenne* L.)" all three items are fulfilled. The main goals are (Nilsson et al. 2016):

- Develop improved germplasm with a suitable adaptation to future climates in the Nordic region; and
- Create an arena for collaboration, capacity building and synergy among plant breeding companies and academic institutions in the Nordic and Baltic regions.

Ryegrass is a crop for forage production in northern Europe, and high protein yield is an important breeding goal, along with winter hardiness and resistance. In this ongoing project, eleven entities from all five Nordic countries and three Baltic countries participate. They started with 383 accessions from gene banks worldwide and with a selection of well adapted ryegrass varieties. Different field trials were established in all the participating countries. With the help of all involved breeders and researchers the use of new breeding techniques has developed. The

Variation in winter survival of gene bank accessions of perennial ryegrass due to pink snow mould (Microdochium nivale) infection and spring frost.

plant material is phenotyped in traditional ways as well as genotyped by GBS and the scores and data are put together for associating the molecular markers with important traits for developing genomic selection schemes. In a normal commercial breeding programme, it takes 10–20 years until a new variety can be released, so in that context seven years is just the beginning. In this case with crosses made between both well adapted material and more wild material the breeding process will take longer time. That is also an important reason for conducting pre-breeding jointly. It is resource-intensive and the pay-back will not come for many years.

6P

The fourth project, recently continued in its second phase, is approved within the area of the third item "development of efficient tools and methods". The title is Nordic Public-Private Partnership Plant Phenotyping Project and is often shortened as 6P. These projects divide into two different scopes.

In part A, The Nordic Plant Phenotyping Network (NPPN), the main goal is (Nilsson et al. 2016): "To become the hub of Nordic plant phenotyping activities by facilitating stronger precompetitive collaboration through information exchange and networking between research institutes, technology providers and plant breeding companies".

In part B, Research and Innovation of High-throughput Phenotyping in Field Trials (6P R&I), the main goals are (Nilsson et al. 2016):

- develop non-destructive high-throughput field phenotyping methods;
- make it possible for breeders to use drones to regularly and objectively follow the breeding plots;
- score characteristics with different wave lengths not visible to the human eye.

While high-throughput genotyping is possible today, large scale phenotyping remains a bottle-neck. In this project, focus is on achieving easy-to-use techniques to fasten up the breeders' scoring work in the field, often taking many days per crop cycle to complete.

The overall goal is to develop fast, non-destructive methods for field phenotype in trial fields, using Unmanned Aerial Systems (UAS), cameras, sensors and advanced computing. The 6P project has built up a Nordic network of public and private actors in plant breeding. This means that 12 Nordic organizations participate together in the network, as well as participants from Estonia and Lithuania. The project has been user-driven, which means that research and communication have been performed with the clear goal of quickly getting research results into practical application.

"What started with some hesitation in 2011 has become a big success."

Properties such as crop establishment, earliness/regrowth, biomass, straw strength and maturity have been studied in the project and UAS images have been correlated with phenotype data collected by partners. Different indexes have been used for calculations and demonstrated that collected image data can be successfully used as indirect measurements in plant breeding programmes. Data has been collected and processed in winter wheat and perennial ryegrass, spring barley, and potatoes. A unique problem has been to merge a lot of images into a clear field map, but now a suitable data tool, "Plot Cutter", has been developed in the project and distributed to the participating companies.

A significant network has evolved

The cooperation was established seven years ago, and four projects are currently underway. What started with some hesitation in 2011 has become a big success. Initially doubts as to whether competing companies would actually work jointly. They would share plant material and breeding progress together, but perhaps worst of all, they would also publish their results and successes. Not a very common thing to do among competitors in the business world. However, today all partners and participating institutions from academia certifies that without this cooperation they wouldn't have the successes they've had. The joint funding and efforts from engaged and devoted co-workers make a difference.

An important success factor was that the entire process from project idea to the grant in your hand rested on the firmly established Nordic Public-Private Partnership for pre-breeding. The answer to the question in the beginning "who is the seed supplier for the Nordic area in the future?" is now answered – The Nordic countries will, in important crops, be self-sufficient in seed or plant supply thanks to locally adapted plant breeding.

Current PPP-partners

The current PPP partners are: Danespo, DLF Trifolium, NordicSeed and Sejet from Denmark. Boreal Plant Breeding and Luke from Finland, LBHI from Iceland, Graminor from Norway; Lantmännen, Findus and SLU from Sweden. Associated partners are the Estonian Crop Research Institute, the Latvian Institute of Agricultural Resources and Economics and the Lithuanian Research Centre for Agriculture and Forestry.

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1 Map sourced from https://www.vir.nw.ru/blog/publications/botaniko-geograficheskie-osnovy-selektsii-uchenie-ob-ishodnom-materiale-v-selektsii/, accessed 22 August 2019.

2 Map sourced from http://plantlife.ru/books/item/f00/s00/z0000032/st018.shtml, accessed 22 August 2019.

Nordic Gene Bank (NGB) was founded on January 1, 1979, as a Nordic institution, established and operated by the Nordic Council of Ministers. The purpose of the NGB was to conserve and document the genetic variation of agricultural and horticultural materials, basic as well as cultivated ones, relevant to the climatic zones of the Nordic countries.