Using a botanic garden collection to test a bioclimatic vegetation scheme

Master's thesis
Maria Hällfors
November 2010

Plant Biology, Department of Biosciences, Faculty of Biological and Environmental Sciences
University of Helsinki

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

Tiedekunta/Osasto Fakultet/Sektion – Faculty Faculty of Biological and Environmental Sciences	Laitos Institution – Department Department of Biosciences	
Tekijä Författare – Author Maria Hällfors		
Työn nimi Arbetets titel – Title Using a botanic garden collection to test a bioclimatic vegetation scheme		
Oppiaine Läroämne – Subject Plant Biology		
Työn laji Arbetets art – Level Master's thesis	Aika Datum – Month and year September 2010	Sivumäärä Sidoantal – Number of pages 82 (including 4 appendices)

Tiivistelmä Referat – Abstract

Vegetation maps and bioclimatic zone classifications communicate the vegetation of an area and are used to explain how the environment regulates the occurrence of plants on large scales. Many practises and methods for dividing the world's vegetation into smaller entities have been presented. Climatic parameters, floristic characteristics, or edaphic features have been relied upon as decisive factors, and plant species have been used as indicators for vegetation types or zones. Systems depicting vegetation patterns that mainly reflect climatic variation are termed 'bioclimatic' vegetation maps. Based on these it has been judged logical to deduce that plants moved between corresponding bioclimatic areas should thrive in the target location, whereas plants moved from a different zone should languish. This principle is routinely applied in forestry and horticulture but actual tests of the validity of bioclimatic maps in this sense seem scanty. In this study I tested the Finnish bioclimatic vegetation zone system (BZS). Relying on the plant collection of Helsinki University Botanic Garden's Kumpula collection, which according to the BZS is situated at the northern limit of the hemiboreal zone, I aimed to test how the plants' survival depends on their provenance. My expectation was that plants from the hemiboreal or southern boreal zones should do best in Kumpula, whereas plants from more southern and more northern zones should show progressively lower survival probabilities. I estimated probability of survival using collection database information of plant accessions of known wild origin grown in Kumpula since the mid 1990s, and logistic regression models. The total number of accessions I included in the analyses was 494. Because of problems with some accessions I chose to separately analyse a subset of the complete data, which included 379 accessions. I also analysed different growth forms separately in order to identify differences in probability of survival due to different life strategies. In most analyses accessions of temperate and hemiarctic origin showed lower survival probability than those originating from any of the boreal subzones, which among them exhibited rather evenly high probabilities. Exceptionally mild and wet winters during the study period may have killed off hemiarctic plants. Some winters may have been too harsh for temperate accessions. Trees behaved differently: they showed an almost steadily increasing survival probability from temperate to northern boreal origins. Various factors that could not be controlled for may have affected the results, some of which were difficult to interpret. This was the case in particular with herbs, for which the reliability of the analysis suffered because of difficulties in managing their curatorial data. In all, the results gave some support to the BZS, and especially its hierarchical zonation. However, I question the validity of the formulation of the hypothesis I tested since it may not be entirely justified by the BZS, which was designed for intercontinental comparison of vegetation zones, but not specifically for transcontinental provenance trials. I conclude that botanic gardens should pay due attention to information management and curational practices to ensure the widest possible applicability of their plant collections.

Avainsanat – Nyckelord – Keywords
boreal, curation, hardiness, logit models, odds ratio, phytogeography, provenance, vegetation zone, zonation

Säilytyspaikka – Förvaringställe – Where deposited
Department of Biosciences

Muita tietoja – Övriga uppgifter – Additional information

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

Tiedekunta/Osasto Fakultet/Sektion – Faculty Bio- och miljövetenskapliga fakulteten	Laitos Institution – Department Biovetenskapliga institutionen	
Tekijä Författare – Author Maria Hällfors		
Työn nimi Arbetets titel – Title Test av en bioklimatisk vegetationszonering på basis av en botanisk trädgårds samling		
Oppiaine Läroämne – Subject Växtbiologi		
Työn laji Arbetets art – Level Pro gradu	Aika Datum – Month and year September 2010	Sivumäärä Sidoantal – Number of pages 82 (inkl. 4 bilagor)

Tiivistelmä Referat – Abstract

Vegetationskartor och bioklimatiska zonklassificeringar beskriver ett områdes vegetation och används för att förklara hur omgivningen i stort reglerar växters utbredning. Många metoder för att indela världens vegetation i mindre enheter har presenterats. Klimatiska parametrar, floristiska särdrag eller edafiska faktorer har legat som grund för indelningen. Växtarter har också använts som indikatorer för olika vegetationstyper eller zoner. System som främst presenterar vegetationsmönster som en följd av klimatisk variation kallas ofta för ”bioklimatiska” vegetationskartor. På basis av dessa har det ansetts logiskt att anta att växter flyttade emellan motsvarande bioklimatiska områden frodas i målområdet, medan växter flyttade från ett annorlunda område lider. Denna princip brukas rutinmässigt inom skogsbruk och hortikultur även om egentliga test av dylika bioklimatiska kartors giltighet verkar vara få. I denna studie testade jag det finländska bioklimatiska vegetationszonsystemet (BZS). Jag använde Helsingfors universitets botaniska trädgårds växtsamling i Gumtäkt som enligt BZS ligger vid den nordliga gränsen av den hemiboreala zonen. Jag ville testa hur en växts överlevnad påverkas av dess proveniens. Jag förväntade mig att växter härstammande från den hemiboreala eller sydboreala zonen skulle klara sig bäst i Gumtäkt, medan växter från mer sydliga eller nordliga zoner skulle uppvisa progressivt lägre överlevnadssannolikhet. Jag beräknade överlevnadssannolikheten för växtbestånd av känt och vilt ursprung odlade i Gumtäkt sedan medlet av 1990-talet genom att använda mig av information i trädgårdens databas samt logistiska regressionsmodeller. Det totala antalet bestånd inkluderat i analyserna var 494. På grund av problem med vissa växtbestånd valde jag att analysera en del av datat separat, vilket resulterade i en analys på 379 växtbestånd. Jag analyserade också olika växtformer separat för att kunna urskilja skillnader i överlevnadssannolikheten hos växter med olika livsstrategier. I de flesta analyser visade växtbestånd av temperat och hemiarktiskt ursprung en lägre överlevnadssannolikhet än växtbestånd som härstammar från någon av de boreala underzonerna. Växtbestånd härstammande från de boreala underzonerna uppvisade tämligen jämnt hög överlevnadssannolikhet. Exceptionellt milda och våta vintrar under studieperioden kan ha påverkat dödligheten hos de hemiarktiska växterna. Vissa vintrar kan också ha varit alltför hårda för temperata bestånd. Träden betedde sig annorlunda. De uppvisade en nästintill stadigt ökande överlevnadssannolikhet från de temperata till de nordboreala ursprungen. Åtskilliga faktorer som inte kunde kontrolleras kan ha påverkat resultaten, av vilka en del är svåra att tolka. Detta gäller speciellt de örtartade växterna, för vilka analysens pålitlighet led på grund av svårigheter att förvalta deras växtsamlingsdata. Överlag stöder resultaten BZS till en del, speciellt dess hierarkiska zonindelning. Jag ifrågasätter ändå giltigheten av den testade hypotesens formulering eftersom den inte nödvändigtvis är berättigad av BZS, som är utformad för interkontinentala jämförelser av vegetationszoner men inte specifikt för transkontinentala provenienförsök. Jag drar slutsatsen att botaniska trädgårdar lämpligen borde uppmärksamma informationsförvaltandet och uppdateringspraktiker av dess databaser för att garantera växtsamlingarnas största möjliga tillämplighet för forskning.

Avainsanat – Nyckelord – Keywords
boreal, kuratering, härdighet, logit modeller, odds förhållanden, fytogeografi, proveniens, vegetationszon, zonering

Säilytyspaikka – Förvaringställe – Where deposited
Biovetenskapliga institutionen

Muita tietoja – Övriga uppgifter – Additional information

Table of contents

1. Introduction

Vegetation maps communicate the vegetation of an area (Kuchler 1988) by depicting areas in which chosen characteristics of the plant cover are relatively uniform. Such maps have important applications in many fields, e.g., for managing and describing biodiversity as well as for questions relating to global change and human interaction (Küchler 1988, Karlsen *et al.* 2006, CBVM 2008). Many practises and methods for dividing the world's vegetation into smaller entities have been presented. Climatic parameters, floristic characteristics, or edaphic features have been relied upon as decisive factors, and plant species have been used as indicators for vegetation types or zones. The different approaches have also been used in various combinations. Through the years numerous local monographs and smaller contributions on vegetation have been published (Ahti *et al.* 1968), and larger-scale attempts to delineate vegetation zones have also been made. However, the validity of the schemes has not often been tested. In this study I have tested a vegetation zone scheme with the help of botanic garden accessions of known provenance.

1.1. The development of vegetation maps

The structure and floristic composition of the world's vegetation varies greatly and the variation is not always continuous. Large tracts of similar vegetation frequently end relatively abruptly as, for instance, at the northern forest-line where the treeless tundra begins. In cases of more subtle and continuous change, however, it is a challenge to decide where exactly the line of discontinuity, i.e., the limit between two vegetation types should be drawn, and which criteria should be used to make the decision. On world maps, the boundaries of natural vegetation zones, soil types, and climatic regions roughly coincide (Trewartha 1968). This principle has guided research and development work of scientists. With the development of the fields of floristics, biogeography, and vegetation science in the 19th and 20th centuries, the understanding grew on the regularities of the occurrence of certain types of vegetation in different parts of the globe. Phytogeographers and vegetation

scientists in several countries began sketching vegetation maps and recorded observations on the ranges of certain vegetation types and how these coincided with floristic features or various abiotic variables, such as soil types and climate. Three main approaches could soon be separated: edaphic-topographic, floristic, and bioclimatic (Ahti *et al.* 1968). Essentially they are all attempts to locate the places of discontinuity in the variation of vegetation and to find suitable criteria for defining these places.

The first approach emphasizes edaphic and topographic features as governing factors in shaping vegetation, and has been applied for various areas by different authors (e.g., Linkola 1922, Naumann 1928, Kujala 1936, Regel 1940, Freitag 1962 *fide* Ahti *et al.* 1968). According to Ahti *et al.* (1968) edaphic-topographic and similar systems for vegetation zonation are primarily useful when doing internal comparisons within relatively small geographical areas but are not well suited for large-scale and intercontinental comparative studies, mainly because uniform criteria for delimitation of differing areas are not easily defined.

Phytogeographical divisions have also been done on the basis of the taxonomical character of an area, i.e., through a floristic approach (e.g. Sjörs 1956, Kujala 1964, Du Rietz 1925 *fide* Ahti *et al.* 1968). This approach, however, has similar disadvantages as the edaphic-topographic one and does not allow large scale comparisons since the taxonomic composition of floras varies greatly, and many times it is historical rather than present ecological conditions that determine the limits of many species (Ahti *et al.* 1968). However, floristic criteria are often valuable supplementary characters when defining vegetation divisions with the help of bioclimatic approaches. These approaches primarily make use of climatic variables, such as temperature sums, extreme temperatures, seasonality, and precipitation as the governing factors in shaping vegetation (Ahti *et al.* 1968). Additionally, these variables are often combined with studies on the actual distribution of vegetation, since pure climatic zones do not necessarily coincide with vegetation zones.

There have been many attempts to map the terrestrial world or parts of it bioclimatically with the aim of explaining the distribution of vegetation (e.g., Thornthwaite 1948, Küchler 1964, Krajina 1959, Hare & Richie 1972, Walter 1979, Box 1981, Rivas-

Martinez & Rivas-Saenz 1996-2009). The probably best known such constructs covering the whole world are Holdridge's life zone classification scheme (Holdridge 1947), Walter's classification of the geobiosphere (Walter 1979), and the Köppen-Geiger climate classification system (Köppen 1936).

The Holdridge life zone classification scheme (1947, 1967) is based on three climate parameters: mean annual biotemperature (i.e., the quantity of heat available to plants during the growing season defined as the mean of all temperatures above 0° C and all temperatures below freezing adjusted to 0° C), mean annual precipitation and the potential evapotranspiration ratio. It divides the land areas of the world into a three-dimensional scheme based on these parameters. Holridge's approach was originally developed for tropical regions, and although the life zone scheme was furthered to cover the whole world, it is less applicable to cold climates, such as the boreal zone, since in these areas the degrees of humidity become the determining factor as opposed to temperature (Hämet-Ahti *et al.* 1974). Walter's classification of the geobiosphere (Walter 1979) divides the world's vegetation into nine so-called zonobiomes, which are defined as large and climatically uniform environments within the geobiosphere with special reference to humidity. This classification system is quite coarse, and mainly depicts the large vegetation areas of the world. The Köppen-Geiger climate classification (Köppen 1936), as well as Trewartha's (1968) modification of it, divides the world's climates into classes according to their vegetation types. This scheme divides the world into five main classes according to mean temperature, and numerous subtypes according to precipitation and continentality features, among others.

In addition to these widely utilized climatic delineation methods, the hardiness zones for ornamental and other cultivated plants usually also follow climatic isoclines. The parameters applied include the mean temperature of the warmest and coldest month (Cathey 1990) as well as the length of the growing season, the effective temperature sum, and the standard frost for the winter, i.e., the mean of the three lowest temperatures measured (Solantie 1986).

When drawing up bioclimatic vegetation schemes, climatic parameters can be combined and partially substituted with edaphic, floristic, ecological and phytosociological

criteria (Ahti *et al.* 1968). One such construct is the Finnish school of bioclimatic vegetation mapping of the boreal region, which was initiated by the studies of Aarno Kalela (1908-1977) in the 1930s and is based on the work of several prominent Finnish biologists, botanists, and phytogeographers, starting with Petter Norrlin (1842-1917) and Ragnar Hult (1857-1899) in the 19th century and continuing with, e.g., Aimo Cajander (1879-1943), Viljo Kujala (1891-1977), Reino Kalliola (1909-1982), and Ilmari Hustich (1911-1982). During the mid and latter parts of the 20th century, it was gradually shaped into a circumpolar map of vegetation zones for the northern parts of the northern hemisphere (Kalela 1961, Ahti *et al.* 1968, Hämet-Ahti *et al.* 1974, Ahti 1980, Tuhkanen 1980, 1984, Hämet-Ahti 1981).

With the development of new techniques, e.g., Geographic Information Systems, satellite-based maps, and digital imagery, it has become exceedingly feasible to map vegetation and test suggested boundaries for vegetation zones (as foreseen already by Hare & Richie 1972). This has been attempted, e.g., by Brandt (2009) for revising the map of the North American boreal zone, as well as by Karlsen *et al.* (2005, 2006; see also Alexander and Millington (2000)). A relatively recent approach making use of the above mentioned technologies is the Model for Macroclimate and Plant Types (Box 1981), often called Climate Envelope Models (CEM). These are based on describing the climate or environment for the current distribution of a species, a plant type, or an ecosystem to infer their environmental requirements (Hijmans & Graham 2006). These models have mainly been used for predicting the distribution of species under various climate change scenarios by mapping a future location of a climate envelope corresponding to the present one. Other vegetation classification systems have also been applied for predicting the impacts of climate change (e.g., Emanuel *et al.* 1985, Cramer & Leemans 1992)

1.2. The Bioclimatic Zone System (BZS)

An essential aim of the vegetation mapping scheme developed by Finnish researchers was to find out which areas of the world are bioclimatically and ecologically corresponding (Hämet-Ahti *et al.* 1974). The bioclimatic vegetation maps or the so-called Bioclimatic Zone

System (BZS; Goward & Ahti 1992) was specifically designed for transcontinental and intercontinental comparisons (Hämet-Ahti *et al.* 1974).

The BZS divides the boreal zone into vegetation subzones while delineating the borders to its adjacent zones, i.e., the temperate zone in the south and the arctic zone in the north. However, corresponding work has also been done for Japan and adjacent East-Asia, which includes the zonation of the meridional and temperate zones (Hämet-Ahti *et al.* 1971), as well as for Tierra del Fuego in the southern hemisphere (Tuhkanen 1992).

The starting point for developing the BZS was the thermal zonation of the globe (e.g., Köppen 1936). Thermal zonation is a purposeful starting point when dealing with cool-temperate areas such as Northern Europe (Ahti *et al.* 1968), which was the first area to be investigated. The authors also relied on the forest vegetation zones delimited and thoroughly investigated by Kalela (1944, 1958, 1961, 1973) in Finland. The further development of the BZS is largely based on information extracted from the Nordic and international literature as well as observations and conceptual syntheses of these (Tuhkanen 1984). According to Hämet-Ahti *et al.* (1974) it was possible to delimit ecologically closely corresponding zones and subzones in different parts of the world on the basis of plant communities despite great floristic dissimilarities and different climatic regimes.

The method of developing the BZS pays less attention to floristic similarities and climatic isoclines, and relies more on the ecological indicator value of component species as well as on the abundance of these (Hämet-Ahti *et al.* 1974). It should however be pointed out that the component species used are not necessarily the same throughout the range of each species. Although some of the zone boundaries accurately coincide with the distribution limit of certain plant species, e.g., the northern boundary of the hemiboreal zone in Fennoscandia, which coincides with the northern distribution limit of *Quercus robur* (Ahti *et al.* 1968), these do not necessarily go hand-in-hand. The BZS is essentially based on plant communities and climatic characters and, according to the developers, it is generally not possible to establish a direct ecological correlation on the basis of the vascular plant floras of widely separated areas. There are few wide ranging species of zonal importance and the zonal amplitude of taxonomically corresponding vicariates can be quite different.

Examples of taxonomically corresponding species that are only partially ecologically substitutable include *Fagus sylvatica* in Europe and *F. crenata* in Japan as well as *Taxus baccata* in Europe and *T. cuspidata* in eastern Asia. The northern limits of these species pairs are not equivalent and thus not comparable when mapping vegetation zones (Hämet-Ahti *et al.* 1974; also see Hämet-Ahti (1979) on the problems of using the tree-line for delineating vegetation zones). Additionally, too few taxa have been mapped accurately enough for such a purpose. Instead, when delineating corresponding zones in different parts of the circumboreal area, widespread bryophytes and lichens were used as important guide plants (Hämet-Ahti *et al.* 1974). These are more wide-ranging and better comparative and they thus provide a tool for the study of vegetation zones as well as for direct comparisons in vegetation analyses (Hämet-Ahti *et al.* 1974). Ahti *et al.* (1968) also point out that one of the most essential features of their method is that the abundance and frequency of a species used to indicate a certain zone is a much more significant criterion than its mere presence, an approach already recognized by Petter Norrlin in the late 19th century (Enroth & Kukkonen 1999).

Even if much of the work relies on phytosociological features, the developers of the BZS by no means depreciate or belittle climatic data as a means for vegetation zone mapping. On the contrary, they did make use of some climatic variables in their work, as stated by Hämet-Ahti *et al.* (1974), and appreciated the accurate information and similar results such data would give. They also state that the basic principles in their method are similar to those of Holdridge (1964) described above. Through different methods, both principles delineate areas, or associations, within which climatic circumstances and biotic life are similar, although the BZS concentrates on a smaller entity, the boreal zone and its subzones, while Holdridge's scheme covers the whole globe. However, according to Hämet-Ahti *et al.* (1974), extensive information on climatic variables for large geographic areas is rarely available, especially when the aim is to go into detail and differentiate between subzones of a larger area (although this may have improved somewhat over the last three decades). Thus, the developers of the BZS chose to rely on observations, long-term field experience, and knowledge of the taxonomy and ecology of the species occurring in an area, when drawing up their scheme (Hämet-Ahti *et al.* 1974). It would seem that extensive

amounts of quantitative data was not used when developing the BZS. Instead, one apparently relied on the assumption that when a certain effect of climate can be observed in one area, e.g., through the characteristics of vegetation, another area showing the same features can be appointed as having a similar climate. This approach can thus be applied even if direct climate data are unavailable.

The zones recognised by the BZS are grouped into larger units indicating that some vegetation zone boundaries are more important than others (Ahti *et al.* 1968). This hierarchical system includes the larger zones arctic, boreal, and temperate. Within these zones subzones are recognised. As an example, the boreal zone consists of four subzones: the hemiboreal, southern boreal, middle boreal, and northern boreal subzones. Thus, the BZS divides the northern parts of the northern hemisphere into phytogeographically and climatically corresponding regions whose limits roughly follow the latitudes (Ahti *et al.* 1968; Figure 1). The latitudinal pattern is, however, interrupted by variation in edaphic and topographic features, and it is complemented by the variation in the humidity-aridity gradient as the zones traverse the continental land masses of Eurasia and North America. Therefore the zones are divided into sectors based on characters of the vegetation reflecting the oceanity versus the continentality of the climate (Hämet-Ahti *et al.* 1974).

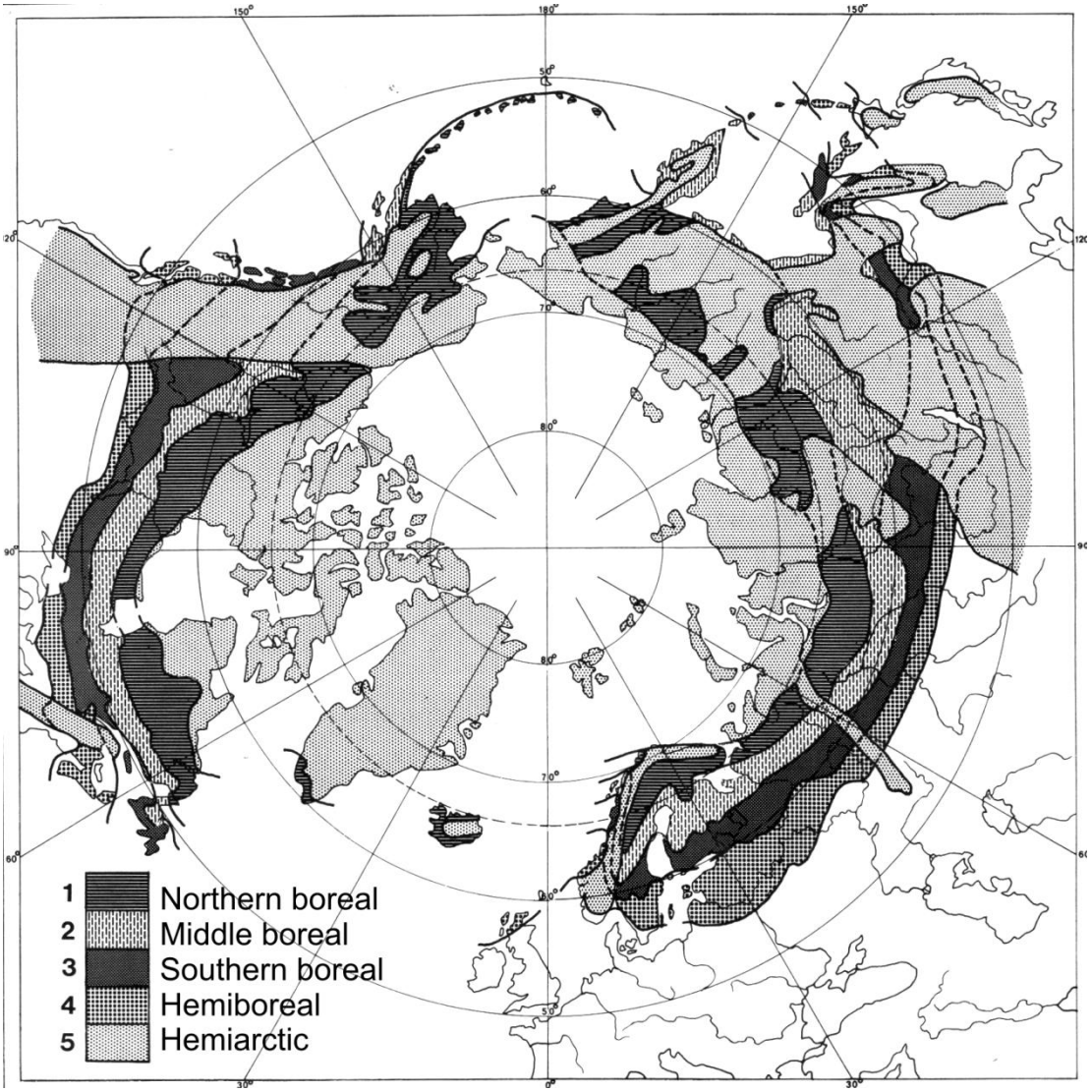

Fig. 1 The circumboreal zone and its transcontinental subzones according Hämet-Ahti (1981). Reproduced with kind permission from the Finnish Geographical Society.

For any given zone, bioclimatically similar regions can be found in mountain areas southward of the main distribution area of the zone (Ahti *et al.* 1968). In this case the bioclimatic zones are attributed the prefix *oro-* (from the Greek *oros* for mountain) to emphasize the elevated location of their occurrence. According to the BZS the *oro*-zones are bioclimatically more or less equivalent to the corresponding zone at sea level (Ahti *et al.* 1968; Table 1), a relationship that has also been formally established in the so-called bioclimatic law by Hopkins (1920).

The BZS and its nomenclature have been adapted in, e.g., The National Atlas of Norway (Moen 1999) and the Flora of Norway (Lid & Lid 2005). The scheme has also been employed for other purposes than strict description of vegetation zones and distribution of vascular plants (Koponen & Koponen 1995b). It has, for instance, been utilized in research for describing the study site or the distribution of various organisms including bryophytes, lichens, insects and birds (e.g., Ahti & Oksanen 1990, Haila *et al.* 1993, Kuusinen 1996).

1.3. Testing the validity of the BZS

Attempts have been made to define the decisive climatic parameters of the BZS. Tuhkanen (1984) was able to specify three prime elements that together control the main boundaries for the BZS: (1) the quantity of heat available to plants during the growing season, also called the biotemperature (after Holdridge 1964); (2) the humidity-aridity relationship; and (3) the degree of continentality versus oceanity. The term humidity represents the effective precipitation, i.e., the total precipitation received during the summer half-year (May-September). Tuhkanen (1984) defines the degree of continentality as the apportioning of heat over the year, with oceanic areas receiving heat more or less evenly over the year whereas continental sectors experience seasonality. Solantie (2005) approached the BZS through measuring the vegetative productivity of the subzones using three climatic variables: (1) the effective temperature sum; (2) the duration of the growth period; and (3) the maximum soil frost penetration. Solantie (2005) found that the boundaries between subzones correspond to a certain amount of forest productivity. There were especially steep gradients between the southern boreal and middle boreal subzones (also confirmed by Karlsson (1996) and Tomppo (2000)) and the change in productivity by the boundary between the hemiboreal and the temperate zones was found to be in accordance with the limit determined by vegetation. The central result of the study of Solantie (2005) was that the climatic and vegetational zones are equivalent. Accordingly, both Tuhkanen (1984) and Solantie (2005) were able to confirm the validity of the subzones according to the BZS. Tuhkanen was in a later study also able to find corresponding bioclimatic areas in South America (Tuhkanen 1992).

Another way of testing intercontinental vegetation maps would be by transplanting plants between different parts of the globe. Such provenance tests infer that plants transferred from similar bioclimatic regions would do better than plants originating from bioclimatically more differing regions. Since Finland, as well as Europe on a whole, has a rather impoverished flora mainly due to the effects of the last glacial period, provenance tests to find new tree species for silvicultural purposes have been carried out since the mid 18th century with systematic trials initiated in the 20th century (Silander *et al.* 2000). Although the aim of these experiments has been to introduce new tree species for forestry production, not to test existing vegetation maps, the importance of the origin of plants has nevertheless been perceived as essential when choosing possible provenances for silviculture (Sarvas 1964). However, because of the rather specific aims of these studies, these trials cannot directly be applied for large-scale testing of vegetation zone systems. Silvicultural trials aim to introduce economically viable trees for timber production, with the measure of success therefore including features such as productivity of wood mass and observed technical characteristics of the tree (Sarvas 1964, Silander *et al.* 2000), and not the actual fitness of the plant.

To my knowledge, no large-scale provenance trials with the specific aim of testing vegetation schemes have been carried out. Such an experiment would require plenty of funds, space, and time. However, since botanic gardens, among other things, deal with growing exotic plant species and hold documented collections on plants for the purpose of scientific research, they could be used for testing vegetation maps. Especially in harsh climates, selecting the right provenances of plants to be grown is crucial for their success in the garden collection. The selection can be guided by vegetation maps, since climate is among the decisive factors governing the occurrence of plants and, therefore, the vegetation they form. Botanic gardens also have a long history in 'plant hunting' and the discovery and breeding of new ornamental plants for horticulture (e.g., Musgrave *et al.* 1998). Already in 1747, Peter Kalm, the then Head of the Botanic Garden of the Royal Academy of Turku, which is now the Botanic Garden of the University of Helsinki (HUBG), left for a journey to North America to look for new plants suitable for ornamental and economic purposes in the Kingdom of Sweden (Enroth & Kukkonen 1999). He specifically

aimed for northern areas of North America for the obvious reason that the area's climate was similar to that of his fatherland. However, only three ornamental species (*Crataegus grayana*, *Rubus odoratus*, and *Parthenocissus inserta*) can be seen as lasting fruits of his efforts. The rest of the considerable number of plants he collected did not succeed (Enroth & Kukkonen 1999). The reason for this evidently was that he nevertheless collected the seeds in areas too dissimilar compared to southern Finland, where most of the collected plants were grown.

Peter Kalm's North American expedition in the mid 18th century was the first overseas collecting trip carried out by the Garden. My study is based on material collected on the second to fifth such expeditions, carried out in the 1990's. These expeditions also covered areas climatically similar to Helsinki, but instead of selecting the expedition areas by relying on general notions and ideas, the selection was now directed by existing bioclimatic vegetation maps, namely the BZS (Koponen & Koponen 1995b, Koponen 1996a). The expectation thus was that on these expeditions it would be possible to collect plant material that was pre-adapted to the climatic conditions prevailing in Helsinki.

The current study was set up to test whether plants collected from a bioclimatic vegetation zone corresponding to that of Helsinki have done better, when planted in the garden, than have plants collected from adjacent or more distant zones. I hence carried out a test on a hypothesis derived from the BZS established by the Finnish school of phytogeographers (Kalela 1961, Ahti *et al.* 1968, Hämet-Ahti *et al.* 1974, Ahti 1980,Tuhkanen 1980, 1984, Hämet-Ahti 1981). The material for the study consisted of the collection of Kumpula Botanic Garden and, therefore, this study also aims to evaluate the suitability of botanic garden collections for large-scale tests of bioclimatic provenance hypotheses.

2. Material and methods

2.1. Kumpula Botanic Garden

The Botanic Garden of the University of Helsinki (HUBG) was established in 1678 as a herbal garden of the Academy of Turku and was moved to Helsinki in 1829 together with the rest of the University (Schulman 2009). The new garden was established in Kaisaniemi and it consists of an outdoor garden and greenhouses. In the early 1980's the University decided to build a new campus in the Kumpula area, where also a botanic garden would be placed. The new garden was established in 1987 at the location of the old Kumpula manor with its previously cultivated 6-hectare surroundings. The garden was opened for the public in June 2009.

The botanic garden in Kumpula includes a garden of economic plants and a garden of ornamental plants as well as geographical garden, the latter constituting the main part of the garden (Figure 2). The geographical garden is divided into five sections; Japan, continental Far East, Western North America, Eastern North America, and Europe (e.g., Koponen & Koponen 1995a). Plant accessions are accordingly placed in the sections corresponding to their natural distribution. The newly established garden provided an excellent opportunity to introduce new plants to Finland.

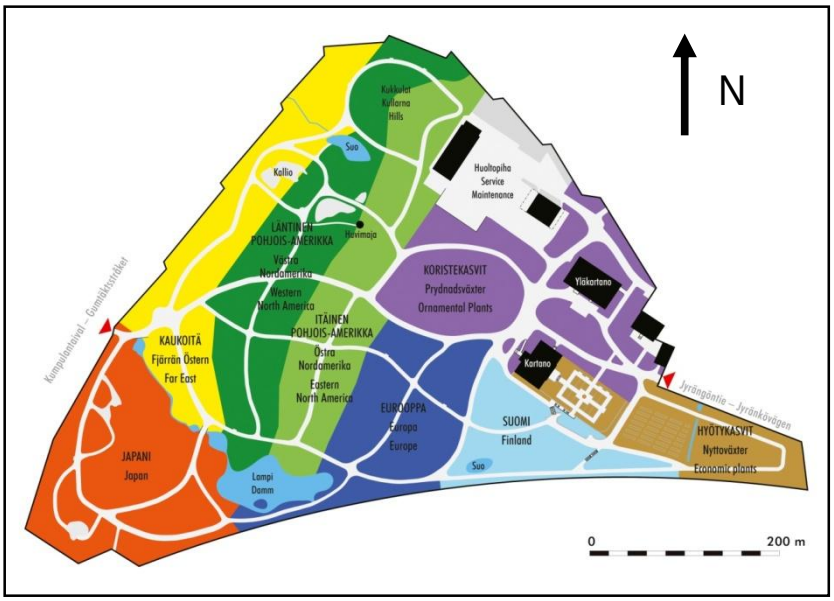

Fig. 2 Kumpula Botanic Garden. The colors on the map depict the sections of the garden.

According to the biogeographical subdivision of the boreal vegetation zone within the BZS, Kumpula Botanic Garden lies at the northern limit of the hemiboreal subzone, very close to the southern boreal subzone (Ahti *et al.* 1968; Figure 3). The climate is moderately oceanic; summers are cool and winters relatively mild, but very low temperatures, reaching below -30°C, may occur (Finnish Meteorological institute, www.fmi.fi/en).

Fig. 3 The vegetation zones and their sections in North western Europe according to Ahti *et al.* (1968). Reproduced with kind permission of the Finnish Zoological and Botanical Publishing Board. The position of Helsinki added.

2.2. The studied plant material

All plants in the geobotanical part of the garden originate from their natural habitats. They have been obtained partly through international seed exchange and partly through a series of collecting expeditions (Koponen 1996b; 2002, Schulman 2009). A total of c. 2,500 accessions have been planted, and c. 750 of these came from the garden's own expeditions. Of those still alive (c. 1,500 accessions in total), roughly 40% are from the expeditions (Schulman 2009, L. Schulman, pers. comm. August 2009).

The seed collecting expeditions were part of a project called 'The introduction of new ornamental and horticultural plants to southern Finland', which was initiated in 1993 at HUBG (Koponen 1996b). The aim of this project was to 1) collect living plant material from locations in Asia and North America that bioclimatically correspond to the Helsinki area, 2) propagate the material in Kumpula Botanic Garden, 3) test the different accessions' hardiness in Finnish climatic conditions and in different soil types, not only in Helsinki but also in other areas, 4) study the suitability of the new origins for different intentions (e.g. landscaping, cover plants, climbers), and 5) provide acclimatized and thriving accessions to garden centers and organizations within the horticultural industry for propagation and distribution to the public and other agents (Koponen 1996b).

On the basis of the BZS it was possible to outline areas in the world with bioclimatic conditions corresponding to those of Southern Finland, i.e., so-called homoclimatic areas (Figure 4). These can be found within the boreal region's hemiboreal and southern boreal zones, in areas that are climatically moderately oceanic to moderately continental (Tuhkanen 1984), as well as in boreal oro-zones found within the temperate zone. In Eurasia the areas that bioclimatically match southern Finland include: mountains in central Europe and the Balkans; northern Russia; northern parts of the former Soviet Far East such as the areas of Amur, Sakhalin and Kamchatka; the mountains of Hokkaido and Honshu in Japan; as well as mountainous areas of north-eastern China and Korea. In North America homoclimatic areas include: the coniferous forest areas of western North America and the northern Rocky Mountains; the mid-parts of British Columbia; central and northern

Ontario and Quebec; as well as maritime provinces of Canada (Koponen 1996a; 1996b, Koponen & Koponen 1995a).

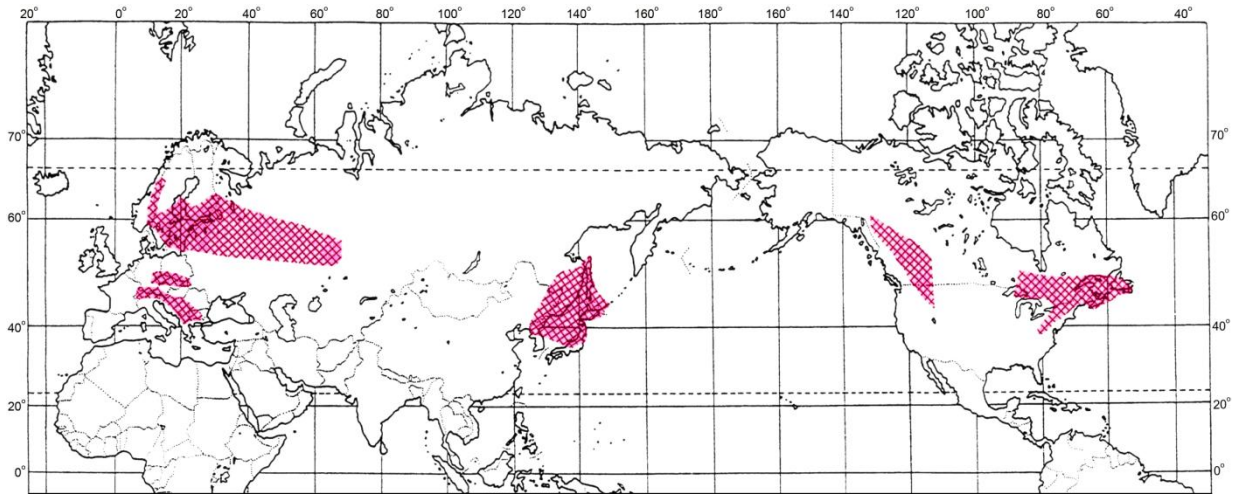

Fig. 4 Map of areas that correspond to Southern Finland climatically, i.e., homoclimatic areas as defined for the purpose of collecting plant material for Kumpula Botanic Garden (Koponen & Koponen 2002). The areas were outlined on the basis of personal experience, existing knowledge, and literature (T. Koponen pers. comm. Dec. 16, 2009).

Three major plant collecting expeditions were carried out to parts of the homoclimatic areas in cooperation with experts from local gardens: to Hokkaido, Japan, in 1993; to Northeast China in 1994; and to British Columbia and Alberta, Canada, in 1995. For more detailed descriptions on the expeditions and locations visited see Koponen (1994), Koponen (1995, 1998), and Koponen & Koponen (1994, 1995a, 1995b, 1996, 2008). A fourth trip, not part of the actual project, was carried out in 1999 to Honshu, Japan. When selecting areas to visit, previous studies in many of the areas were used as reference (e.g. Hämet-Ahti *et al.* 1974, Ahti & Goward 1992, Kujala 1945, Hämet-Ahti 1965; 1972)

The identification of the different bioclimatic zones in the field was based on firsthand observations and the personal evaluation of the botanists leading the expeditions (T. Koponen pers. comm. Dec. 16, 2009). This view, in turn, was built up as a result of long-term field experience and a thorough knowledge of the boreal flora. In other words, no explicit and quantifiable criteria were used for delimiting the zones during the expeditions. In some cases the bioclimatic zones were defined at the location using species of mosses whose occurrence largely coincides with the BZS zones (e.g., *Pleurozium schreberii* and

Hylocomnium splendens whose abundant presence was used to differantiate the boreal zone from the temperate zone) as well as other characteristics that the experienced participants were able to attribute to a certain bioclimatic zone. The latter characteristics include the abundance and size of different tree species, along with the occurrence of tree genera typical for a certain zone (e.g., *Fagus*, *Ilex*, and *Carpinus* for the temperate zone). All in all, 1043 accessions were collected during the expeditions, of which roughly 200 represent species of which there was no previous cultivation experience in Finland (Koponen 1996a).

The collectors used the following zone nominations in their records: temperate, temperate-orohemiboreal, orohemiboreal, hemiboreal, lower oroboreal, middle oroboreal, upper oroboreal, and orohemiarctic. It is unclear whether the nomination 'temperate-orohemiboreal' was used to describe the transition between these two zones or to express uncertainty about which zone the collection was from, or both. For simplicity, the zones will henceforth be referred to by the terms used at sea level or their abbreviations as defined in Table 1.

Table 1 The zones of the Finnish Bioclimatic Zone System (BZS; Ahti *et al.* 1968), their altitudinal equivalents and the abbreviations used for them in this study.

Zone	oro-zone	abbreviation
Temperate	Orotemperate	T
Temperate-Hemiboreal	Temperate-Orohemiboreal	T-HB
Hemiboreal	Orohemiboreal	HB
Southern boreal	Lower oroboreal	SB
Middle boreal	Middle oroboreal	MB
Northern boreal	Upper oroboreal	NB
Hemiarctic	Orohemiarctic	HA

Because of the manner in which the plants of the Kumpula geographical sections have been obtained, they genetically represent the wild populations from which they originate. They are, thus, adapted to the conditions prevailing in the source areas, instead of possibly being hybrids of parental plants growing in other *ex situ* collections, which often is the case in botanic gardens that obtain their plants from commercial nurseries or the collections of other botanic gardens.

In accordance with the third aim of the project, *to test the different accession's hardiness in Finnish climate conditions and in different soil types, not only in Helsinki but also in other areas*, the hardiness of the plants was to be investigated in collaboration with other institutions, namely the City Park Divisions of Helsinki, Kerava, Kotka, and Riihimäki; the horticultural schools of Harju, Lepaa, and Mäntsälä; the arboreta of Viikki and Mustila; the botanic gardens of Joensuu, Oulu, and Turku; as well as some private commercial nurseries (Koponen 1996b). Seeds were also distributed through the botanic gardens international seed exchange. Nevertheless, the follow-up on the plants distributed to other parts of the country has not been maintained and there is no information about these readily available. Hence, these accessions have not been considered in this study. While this study only covers the plants and accessions planted within the HUBG, it is, nevertheless, an initiative for realizing the third aim of the project.

2.3. The propagation and cultivation of the plants

The collected material mainly consisted of seeds, but also of seedlings of some woody plant species of which seeds were not available at the time of collection (Koponen 1996b). Some cuttings for vegetative propagation and micro propagation were also collected. The cuttings were sent by airmail from the collecting sites to HUBG and propagation was initiated directly as the cuttings reached the garden. The collected seeds were brought to Finland by the collectors, cold treated directly, and sown as soon as possible after that. Most of the seeds germinated soon after sowing, and with the ones that did not, enough time was provided to make sure that they would germinate if viable.

The seedlings were grown and pricked out in the propagation facilities in Kumpula Botanic Garden (Koponen 1996b). When of sufficient size, the plants were planted outside in the garden. The plantation area is situated on a gradual south-southwest-facing slope (Schulman 2009). It rises from a bed of clay, which used to be seafloor, and in the lowest parts the groundwater is near the surface. The mid-parts of the slope are of moraine. There are also a few rock outcrops, and the topmost parts of the garden grounds have restricted parts with a northern inclination. In parts of the planting sections the soil has

been improved by various means. Hence, there is some variation in the soil conditions of the plantings. The altitudinal range is roughly 5 to 15 m asl. The plant accessions were planted in different numbers and on varying sites according to availability, horticultural considerations and the design of the garden. The conditions were thus not controlled for or similar for all accessions, mainly since the quality of the soil and topography varied among plantings, the numbers of individuals planted per accessions varied, and since horticultural practises such as thinning, weeding, and irrigation have varied over the years. During the construction of the garden, large infrastructural modifications have also been carried out, which may have affected the plants to various degrees.

2.4. Weather conditions during the study period

The wintertime weather conditions were not exceptionally harsh during the study period (1994-2008; Table 2), as judged from data collected at the closest weather station, Helsinki-Kaisaniemi. The absolute minimum temperature in February, which statistically is the coldest month of the year in Helsinki, was never below that of the mean for the reference period (years 1971-2000). In the years 1994, 1996, 2006, and 2007, however, the mean temperature of February was at least three degrees lower than the mean in the reference period. The frost sum (i.e., the sum of daily mean temperatures that are below zero) of February was also high in these years, as well as in 2001; data on frost sums for the reference period are, however, not available.

A new weather station was established in Kumpula by the Finnish Meteorological Institute near the end of the study period. The available February measurements from the new station (Table 2) suggest that Kumpula is somewhat colder than Kaisaniemi, which is situated closer to the sea and more strongly affected by the warming effect of the urban centre.

I did not have data on summertime weather conditions available for this study.

Table 2 Minimum temperature (T_{min}), mean temperature (T_{mean}), and frost sum of February, and depth of snow on the 15th and 28th of February, in 1994-2008 in Helsinki-Kaisaniemi, and in 2007-2008 in Helsinki-Kumpula. The corresponding values for the reference period 1971-2000 for Helsinki-Kaisaniemi are also given. Data courtesy of the Finnish Meteorological Institute.

station	year	T_{min}	T_{mean}	$snow_{15}$	$snow_{28}$	frost sum
Reference period	1971-2000	-26.0	-4.9	23	24	
Kaisaniemi	1994	-23.6	-11.6	19	21	-311.4
	1995	-15.1	0.2	18	3	-21.4
	1996	-21.1	-9.1	24	30	-265.4
	1997	-18.4	-2.5	39	25	-86.7
	1998	-19.9	-3.6	15	1	-124.9
	1999	-25.1	-6.3	30	54	-177.6
	2000	-16.6	-1.6	7	6	-65.7
	2001	-22.7	-6.8	14	28	-201.5
	2002	-14.6	-0.4	15	18	-35.7
	2003	-20.9	-5.1	25	25	-143.7
	2004	-18.1	-4.0	30	44	-120.3
	2005	-15.7	-4.4	25	25	-126.1
	2006	-22.8	-7.9	24	22	-220.9
	2007	-21.7	-7.9	13	14	-224.7
	2008	-10.8	1.1	0	0	-15.3
Kumpula	2007	-23.0	-8.5	15	17	-238.3
	2008	-12.0	0.7	0	0	-18.4

2.5. Data collection

Although the geographical sections of the plant collection of Kumpula Botanic Garden contain only accessions of known wild origin, the analysis was limited to those accessions originating from the four expeditions mentioned above. Other accessions (mainly received through international seed-exchange) were not included since the information on their provenance does not correspond to the BZS.

The data on the accessions used were collated using HUBG's database 'T-puska' (Lipponen & Schulman 2005), where all the information the garden holds about the accessions was stored (HUBG has since changed to a different database system to which the information has been transferred). The garden's database is updated as a result of

inventories as well as when gardening practices demand amendment. Aside from information on the accessions' collection data and the date each accession was acquired by the garden, horticultural activities on the accessions are noted in the database. These include, e.g., numbers of plants planted, found dead, removed, and transferred. The garden's policy is to have the information updated regularly as a result of annual inventories as well as immediately after every event in the field. In practice, however, this is not always achieved, and uncontrolled lags and omissions occur (L. Schulman, pers. comm. August 2009).

The data used for the analyses in this study were gathered during the years 2007-2009 and, simultaneously, the usefulness and quality of each accession's data were evaluated. The aim was to obtain data that would allow the calculation of survival percentage per accession, and relate this to the source zones of the accessions. I therefore defined basic criteria for inclusion of accessions in the data to be analysed, i.e., I decided that each accession to be included had to have the following information available:

- the species;
- the accession number;
- the bioclimatic zone that it originated from;
- the original number of individuals planted in the plantation area; and
- the number of individuals that were still alive at the time when data for this study were gathered.

In addition to recording this base information, I checked the additional curational information on every accession, which contains written statements on, e.g., horticultural practises and observations made during inventories. This information allowed me to evaluate the correctness of the data on accessions as well as to calculate the actual number of planted versus survived individuals per accession. In case living individuals had been removed while still growing in the plantations (e.g., in order to thin the stands), I regarded them as having survived and added them to the total number of surviving individuals. If plants had been moved and replanted within the garden and shortly thereafter died, I

treated them as having survived since the most likely cause of death was the transplanting stress, not climatic factors. I also carried out field verification on the data of some accessions. For instance, in some cases the most recent up-date on numbers of individuals was so old that I found it best to re-count the accession in the field.

During the gathering of data I was forced to exclude quite a large number of accessions from my study, due to various reasons (Table 3; Appendix 2). Quite a few accessions (198) were lost in propagation and have directly been disregarded in the study. Within these accessions, the germination failed, all individuals of an accession died as seedlings, or the micro-propagation of plant tissue failed.

Table 3 Numbers of accessions collected during the expeditions on which material for Kumpula Botanic Garden was gathered. Numbers of accessions discarded from the analyses for various reasons, and numbers of accessions in the datasets analysed, are also given (lost in propagation = number of accessions whose seeds did not germinate or whose seedlings died before moving to the outdoors plantation area; n < 5 = number of accessions in which fewer than five individuals were planted outdoors; no data = number of accessions with no information after arrival to the collection; other reason = number of accessions for which data on origin was insufficient or unsuitable or inventories during the study period were insufficient, or which had been planted in HUBG's other collection area).

Excursion	Japan -93	China	Canada	Japan -99	Total
Total collected	402	336	250	55	1043
lost in propagation	-108	-40	-35	-15	198
n < 5	-46	-60	-26	-7	137
no data	-73	-18	0	-1	92
other reason	-22	-49	-29	-20	120
in complete dataset	153	169	160	12	494

Some of the accessions had to be excluded from the study for various other reasons:

- Parts of or whole accessions were planted in the other collection area of HUBG in the district of Kaisaniemi in the city centre. These have not been taken into account in this study since the local climate differs somewhat between Kumpula and Kaisaniemi and since gardening practices (e.g., planting densities) and curational quality have been dissimilar in the two parts of HUBG.

- For 92 accessions there were no follow-up data. These accessions were collected and entered into the database but since then information about them has never been updated. It remains unclear what the exact reason for this is.

- For enabling statistical analyses I had to discard all accessions with fewer than five planted individuals. This meant removing 138 accessions from the data.

- Accessions that at the time of data collection had been moved from the nursery to the plantations more recently than five years ago, were not included.

- 120 accessions had either unsuitable data on origin (e.g., lacked the information on source zone) or I determined their curational data to be too deficient to be included in the study. There were either obvious errors in the original or later counts or the up-dating had been too infrequent leading to plants having disappeared in between counts without an obvious reason. Some accessions, e.g. some herbs, were suspected to have reproduced in-between counts. For a few accessions the source zone was not mentioned and some accessions had not been collected in the wild but from, e.g., another garden during the expeditions. Regarding some accessions that I suspected contained obvious man-made errors, e.g. plant individuals having been manually removed but the information about the event never up-dated in the database, I investigated the case by interviewing staff members. The staff members interviewed (in August 2009) included Director Leif Schulman, Head Gardener Marko Pesu and Gardener Seppo Sinkkonen. In some cases this measure resulted in getting clarity or a sufficiently informed evaluation for the dubious information attached to an accession, allowing me to decide whether to include the accession in the study or not.

2.6. Defining subsets of the data

As a result of the above-described considerations and data evaluation, 494 accessions could be included in the analyses. These 494 accessions thus constitute the complete dataset of this study, i.e., all the accessions that fulfilled the basic criteria set for inclusion in the data to be analysed (Table 4; Appendix 1). However, there were cases within the complete dataset with ambiguous database information that I considered I could have misinterpreted. Since eventual misinterpretations may have introduced noise into the dataset, I decided to separately analyse a subset of the data from which the ambiguous accessions were removed. Finally, I decided to divide the species represented in this subset into life forms and analyse these separately.

The information in the database concerning the accessions was at times difficult to interpret. I decided to discard accessions of species of which the individuals are difficult to define, due to vegetative reproduction, and therefore also to count accurately. These include, e.g., species of *Rosa*, *Rubus*, *Sorbaria*, and *Spiraea.* I also decided to discard species which may be naturally short-lived and where one individual would therefore possibly not have survived this long a period of time regardless of external factors, such as some short-lived or hapaxanthic herbs, e.g., *Cirsium* and Apiaceae. Because I wanted to divide species into life forms I had to discard some large woody species that could not be readily accorded either to trees or shrubs.

Accordingly, in order to avoid extra noise due to possible misinterpretations stemming from the above-described aspects, I ended up selecting a subset of 379 accessions that is henceforth referred to as the core dataset (Table 4; Appendix 3).

2.7. Division of species into life forms

In order to minimize variation in the plants' responses to climate caused by differences in growth form and life history (in particular the longevity and resilience of individuals), I divided the core dataset into woody and herbaceous species. This resulted in a group of woody plants containing 307 accessions and another of herbaceous plants containing 72

accessions (Table 4). However, since the woody plants contained a heterogeneous array of species as regards how exposed to weather conditions the meristematic tissues of the plants are, I divided the woody plants into four life form groups following Raunkiær's categories of plant life forms (Raunkiaer 1937). Different life forms were also represented by different numbers of accessions, a fact that could introduce potential bias in the results, since a life form with many accessions would dominate the results, and there might be differences in the level of survival for different life forms.

According to Raunkiær (1937), phanerophytes are woody plants with resting buds more than 25 cm above soil level. Within the phanerophytes, I separated trees and shrubs on the basis of literature or, if the information on a species' life form was ambiguous, the separation was done by inspecting the individuals of the species growing in the collections. Plants that do not regularly produce new stems from below-ground parts were classified as trees, whereas species that do sprout were classified as shrubs. This was a meaningful delimitation, since re-sprouters can replace stems in case of damage. However, as mentioned earlier, some species were discarded since they could not readily be fitted into either the group of trees or that of shrubs.

According to Raunkiær (1937), dwarf shrubs or chamaephytes bear their buds no more than 25 cm above the soil surface, and are separated from other shrubs since they are thus better protected against low temperature by the snow cover. This was a meaningful rough limit between shrubs and dwarf shrubs also for my study, since the mean depth of the snow cover during the coldest month of the year (February) is 23 cm in Helsinki (Finnish Meteorological institute, www.fmi.fi/en). Lianas were separated into a group of their own because of their variable form of growth and mode of cultivation in the garden (ground cover vs. climber) and hence the difficulties of ascribing them to either trees, shrubs, or dwarf shrubs. The life form ascribed to each accession can be seen in Appendix 3.

Table 4 Numbers of accessions collected from different bioclimatic zones, and their distribution between life form groups. 'Woody' includes trees, shrubs, dwarf shrubs, and lianas; dwarfs. = dwarf shrubs. See text for description of complete dataset and core dataset, and for delimitation of growth forms. T= temperate zone; T-HB= the transition between the temperate and the hemiboreal zones; HB= hemiboreal zone; SB= southern boreal zone; MB= middle boreal zone; NB= northern boreal zone; HA= hemiarctic zone.

	Complete dataset	Core dataset	core woody	core herbs	core trees	core shrubs	core dwarfs.	core lianas
T	158	119	90	29	28	46	0	16
T-HB	42	33	26	7	12	9	3	4
HB	120	95	81	14	33	32	6	8
SB	91	66	52	14	14	27	10	1
MB	60	45	43	2	16	23	3	1
NB	15	13	11	2	1	7	3	0
HA	8	8	4	4	0	2	2	0
Total	494	379	307	72	104	146	27	30

2.8. Statistical analyses

The statistical analyses were done in collaboration with Dr. Hannu Rita. The success of each accession was measured as the proportion of survived individuals among those planted. In the analysis, these accession-wise proportions were pooled within each of the zones, resulting in a single survival probability characterizing the zone. To test the BZS hypothesis, the survival proportion of each of the zones was compared to that of the hemiboreal zone, the one where HUBG is situated. The called-for comparison of proportions can be done using logistic regression or logit models (Collett 2002). Due to the binary character of the response, i.e., that an individual is either dead or alive, this approach was seen as the most suitable since the model can be used to represent choice between two mutually exclusive options.

The results of the comparison of the survival proportions are represented as Odds Ratios (OR), which can be used to describe proportions and to compare probabilities

(Rita 2004). The Odds Ratio approach takes into account the special feature of proportions as quantities whose values are restricted to intervals. If one would simply compare quantitative units with their direct difference, one could easily end up drawing the wrong conclusion. This is because the differences between, e.g., 5% and 10% versus 50% and 55% are not equally large, although the difference in percentages is the same 5 units. Instead, one should compare them relatively, and quantitatively characterize how 'different' the two proportions are, i.e., establishing their Odds Ratio. When doing this one compares Odds derived from the proportions. The Odds is the ratio of the probability that an incident takes place to the probability that it does not. The Odds (o) for a proportion (p) is, hence, defined as:

$$o(p) = p \,/\, (1 - p) \qquad (1)$$

The Odds is another way of presenting the proportion, and the proportions under comparison are transformed into Odds through the equation presented above. The Odds Ratio can then be established, which implies ascertaining the relationship of two Odds or the distance between two Odds. For the proportion p_1 and p_2 the Odds Ratio is established through the following equation:

$$OR = o(p2) \,/\, o(p1) = [p2 \,/\, (1 - p2)] \,/\, [p1 \,/\, (1 - p1)] \qquad (2)$$

The difference derived through this equation can now be compared to the Odds Ratios of other proportion pairs. However, when one compares a larger proportion to a smaller one, one will obtain a figure that is bigger than one, and when comparing a smaller proportion to a larger one a figure smaller than one is obtained. These are not, however, directly comparable. For enabling direct comparison, figures smaller than one need to be inversed.

The direction of change, then, has to be marked in some way (Rita & Komonen 2008). This can be achieved by marking downward changes with the exponent $^{-1}$.

In this study all proportions were compared to the hemiboreal zone which was used as the reference zone in the analyses. The OR for the hemiboreal zone is always 1 because it is compared to itself. The closer to 1 the OR for a certain zone is, the more similar it is to the hemiboreal zone. As mentioned earlier, when a smaller proportion is compared to a larger one, the resulting OR is below 1 and vice versa. Hence, the BZS hypothesis leads to the expectation that each of the ORs characterizing a certain zone's relationship to the hemiboreal zone should have a value below one. Otherwise, the BZS hypothesis is not supported by the data. The values below 1 have been converted to positive figures marked with the exponent $^{-1}$, as suggested by Rita and Komonen (2008).

The analyses were performed using Statistix software, v. 9.0 (Analytical Software, Florida, USA). The Odds Ratios were compared using Wald's test (Collett 2002).

3. Results

3.1. Complete dataset

The analysis of the complete dataset showed no clear trend in the differences in the survival probability of plants originating from different zones (Figure 4). For the temperate zone, survival probability was somewhat lower (41.5%) than for the hemiboreal zone (45.4%) giving rise to an OR of 1.17^{-1} when comparing survival probabilities between the two. The survival probability of the hemiarctic zone (14.0%) was considerably lower (OR = 5.10^{-1}), but among the boreal subzones survival probability varied between slightly higher and slightly lower than that of the HB. The difference between survival probabilities for the hemiboreal and the temperate-hemiboreal as well as that between the hemiboreal and the southern boreal and middle boreal zones were statistically insignificant, which implies that the survival probabilities for all these three zones are very similar.

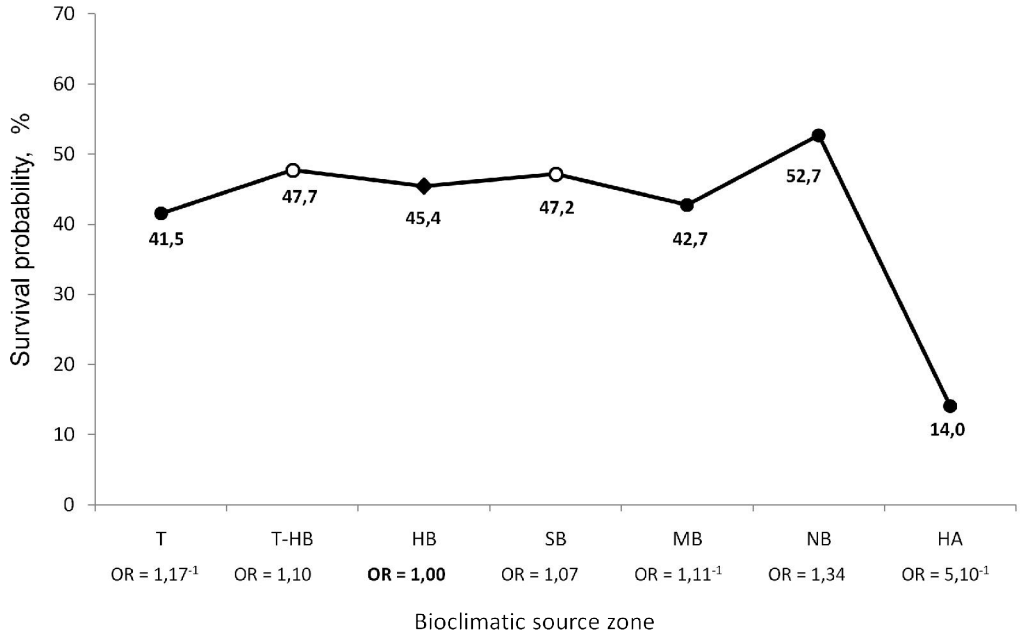

Fig. 4. Comparison of survival probabilities in the complete dataset (total n=494) of accessions collected from different source zones to that of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)}$ = 158; $n_{(T\text{-}HB)}$ = 42; $n_{(HB)}$ = 120; $n_{(SB)}$ = 91; $n_{(MB)}$ = 60; $n_{(NB)}$ = 15; $n_{(HA)}$ = 8. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively).

3.2. Core dataset

The analysis of the core dataset (Figure 5) provided a largely similar result to that derived from the complete dataset. However, survival probabilities now increased steadily from the temperate zone (41.9%; OR= 1.30^{-1}) towards the hemiboreal (48.4%), and the highest survival probability appeared for the middle boreal (58.6%; OR = 1.51) instead of the northern boreal subzone (51.2%; OR= 1.12), as in the complete dataset. For the hemiarctic zone, there is again a substantial drop in the survival probability.

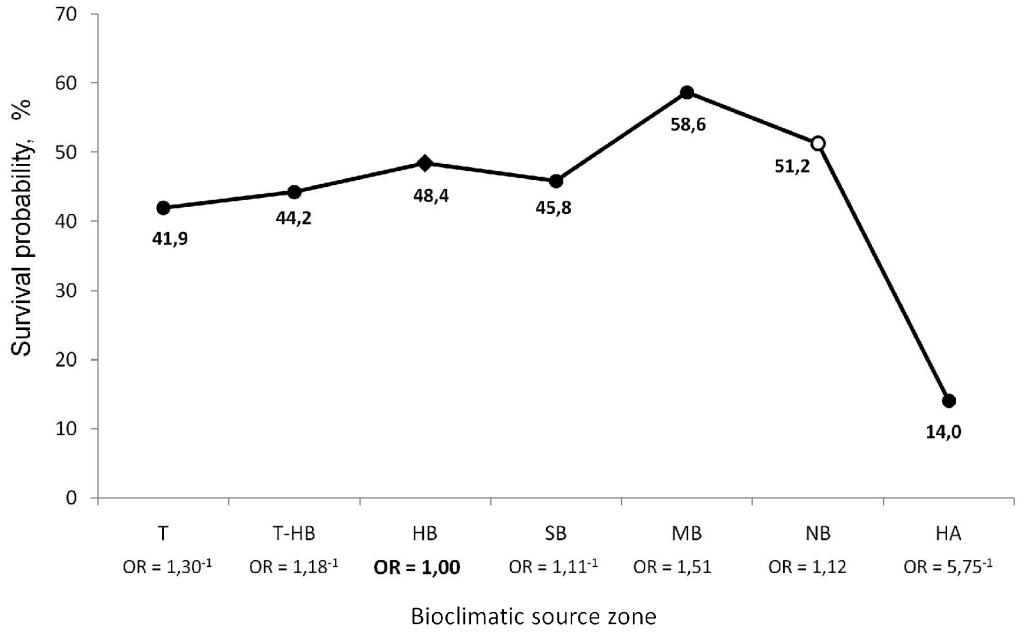

Fig. 5 Comparison of survival proportions in the core dataset (total n=379) of accessions collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)}$ = 119; $n_{(T\text{-}HB)}$ = 33; $n_{(HB)}$ = 95; $n_{(SB)}$ = 66; $n_{(MB)}$ = 45; $n_{(NB)}$ = 13; $n_{(HA)}$ = 8. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively).

3.3. Woody vs. herbaceous accessions in the core dataset

The accessions of woody species (Figure 6) in the core dataset showed a clear trend where accessions from all but the most northern subzone within the boreal zone had the highest, and among the subzones similar survival probabilities ($OR_{(T\text{-}HB)}$ = 1.02 ;$OR_{(HB)}$ = 1.0; $OR_{(SB)}$ = 1.01, $OR_{(MB)}$ = 1.02) as well as insignificant differences in probability of survival compared to that of the hemiboreal zone ($p_{(T\text{-}HB)}$= 0,68; $p_{(SB)}$= 0,81; $p_{(MB)}$= 0,78; Wald's test). The exception in the boreal macro zone was the northern boreal accessions whose survival probability (47.0%; OR = 1.33^{-1}) was closer to the survival probability of the temperate accessions (45.0%; OR = 1.44^{-1}) than to survival probabilities of accessions from the other boreal subzones. The very low survival probability in the hemiarctic zone (25.7%; OR = 3.41^{-1}) should be treated with caution because of small sample size (n=4). The survival probability

of accessions from the temperate zone was significantly lower (45.0%; OR= 1.44^{-1}; p<<0.01, Wald's test) than that of the hemiboreal accessions (54.1%).

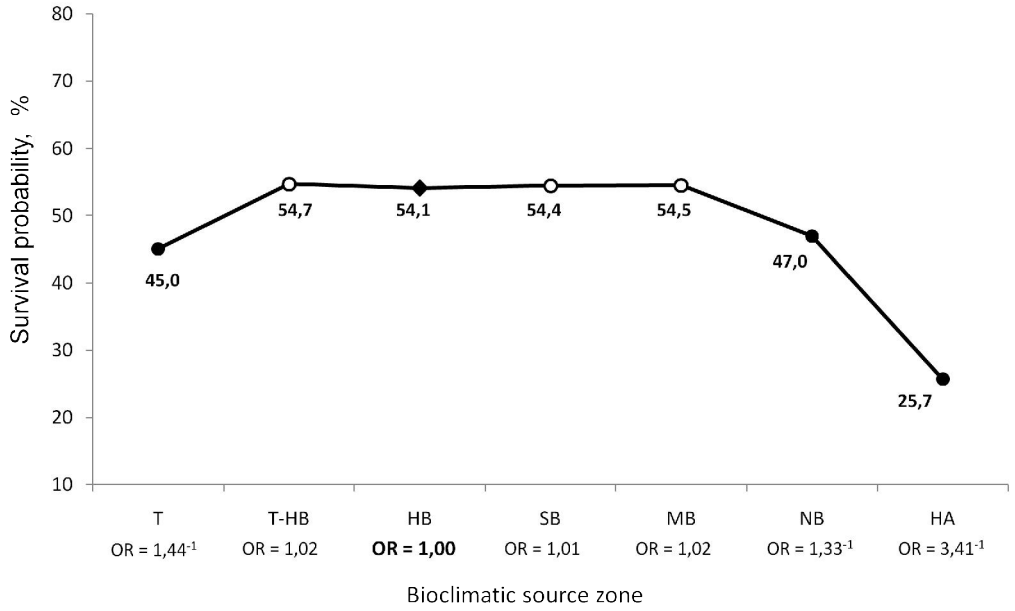

Fig. 6 Comparison of survival proportions in the dataset of woody accessions (total n=307) collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)} = 90$; $n_{(T\text{-}HB)} = 26$; $n_{(HB)} = 81$; $n_{(SB)} = 52$; $n_{(MB)} = 43$; $n_{(NB)} = 11$; $n_{(HA)} = 4$. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, p<0.05 and p>0.05 respectively).

Herbs of the core dataset (Figure 7) produced a clearly different picture than the core dataset as a whole. The temperate zone showed a higher survival probability (37.2%; OR= 1.22) than the three most southern boreal subzones, and the middle boreal subzone showed a very high survival probability (92.4%; OR= 24.8), with decreasing survival probabilities towards the northern zones. However, the three northernmost zones were represented by very few accessions ($n_{(MB)}=2$; $n_{(NB)}=2$; $n_{(HA)}=4$).

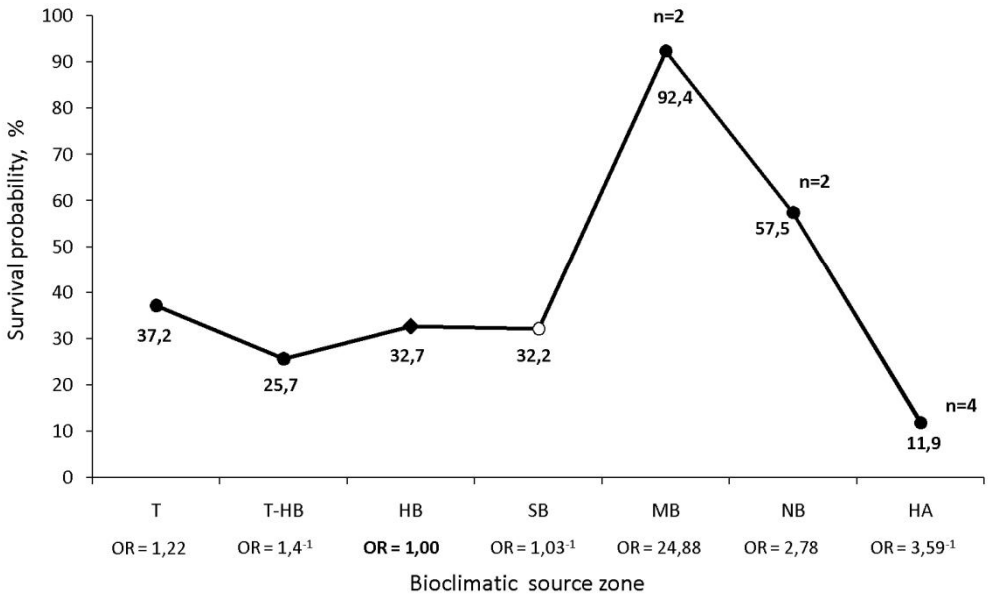

Fig. 7 Comparison of survival proportions in the dataset of herbaceous accessions (total n=72 collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)} = 29$; $n_{(T\text{-}HB)} = 7$; $n_{(HB)} = 14$; $n_{(SB)} = 14$; $n_{(MB)} = 2$; $n_{(NB)} = 2$; $n_{(HA)} = 4$. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively). Cases where n<5 marked.

3.4. Partition of woody plants in core dataset

Trees of the core dataset (Figure 8) showed an almost steady trend of survival probability increasing with the northerliness of the source zone. The northern boreal subzone, however, was represented by a single accession, and trees hardly occur in the hemiarctic, whereby this zone was not represented here. The transition between the temperate and the boreal zone (temperate-hemiboreal) and the southern boreal subzone have a similar survival probability with insignificant differences in probability of survival compared to the hemiboreal zone (T-HB= 61,7%, OR= $1,00^{-1}$, p= 0,98; HB= 61,8%; SB= 61,8%, OR= $1,06^{-1}$, p=0,67; Wald's test). The survival probability for trees from the temperate zone was significantly lower (49.1%; OR= 1.67^{-1}; $p<<0.01$; Wald's test) compared to the survival

probability for those from the hemiboreal zone. The survival probability for trees from the middle boreal zone was significantly higher (73.2%; OR= 1.69; p<<0.01; Wald's test) than the survival probability for the hemiboreal ones.

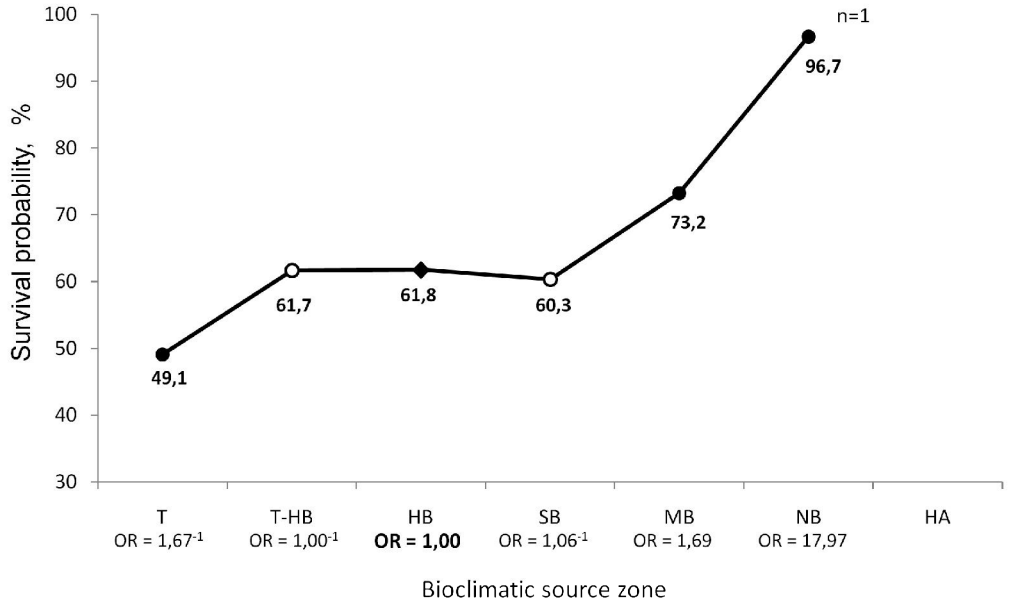

Fig. 8 Comparison of survival proportions in the dataset of trees (total n=104) of accessions collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)}$ = 28; $n_{(T\text{-}HB)}$ = 12; $n_{(HB)}$ = 33; $n_{(SB)}$ = 14; $n_{(MB)}$ = 16; $n_{(NB)}$ = 1; $n_{(HA)}$ = 0. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, p<0.05 and p>0.05 respectively). Cases where n<5 marked.

There was no clear trend in survival probability for shrubs collected from different zones (Figure 9). The overall picture, however, shows that accessions collected within the boreal zone have the highest survival probabilities (T-HB= 52,8%; HB= 51,1%; SB= 63,2%; MB= 49,5%; NB=59,5%). The temperate-hemiboreal zone and the middle boreal zone show an insignificant difference to the hemiboreal zone ($p_{(T\text{-}HB)}$= 0,46; $p_{(MB)}$= 0,45; Wald's test). The temperate zone and the hemiarctic zone exhibit the lowest survival probabilities of the sampled zones (T= 45,8%; HA= 30,4%). It should, however, be noted that the sample size for the hemiarctic zone was only two.

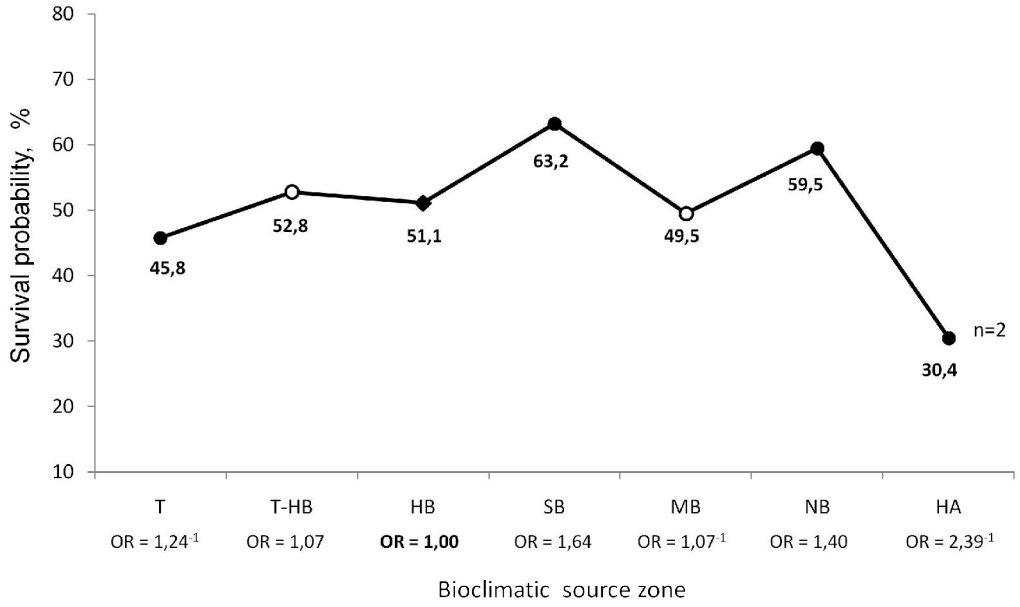

Fig. 9 Comparison of survival proportions in the dataset of shrubs (total n=149) of accessions collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)} = 46$; $n_{(T\text{-}HB)} = 9$; $n_{(HB)} = 32$; $n_{(SB)} = 27$; $n_{(MB)} = 23$; $n_{(NB)} = 7$; $n_{(HA)} = 2$. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively). Cases where n<5 marked.

No clear signal could be derived from the results of the analysis of the lianas (Figure 10). The total sample size of the lianas is low (n = 30) compared to the other life forms. The southern boreal and middle boreal zones are represented by only one accession each and the northern boreal and hemiarctic zones are not represented at all within this plant group. However, within the zones represented by a satisfactory number of accessions, i.e., the temperate, temperate-hemiboreal and hemiboreal zones, there is a sharp rise in probability of survival from the temperate to the hemiboreal zone (T= 38,3%, OR= $7{,}64^{-1}$; T-HB= 72,4%, OR= $1{,}8^{-1}$; HB= 82,5%).

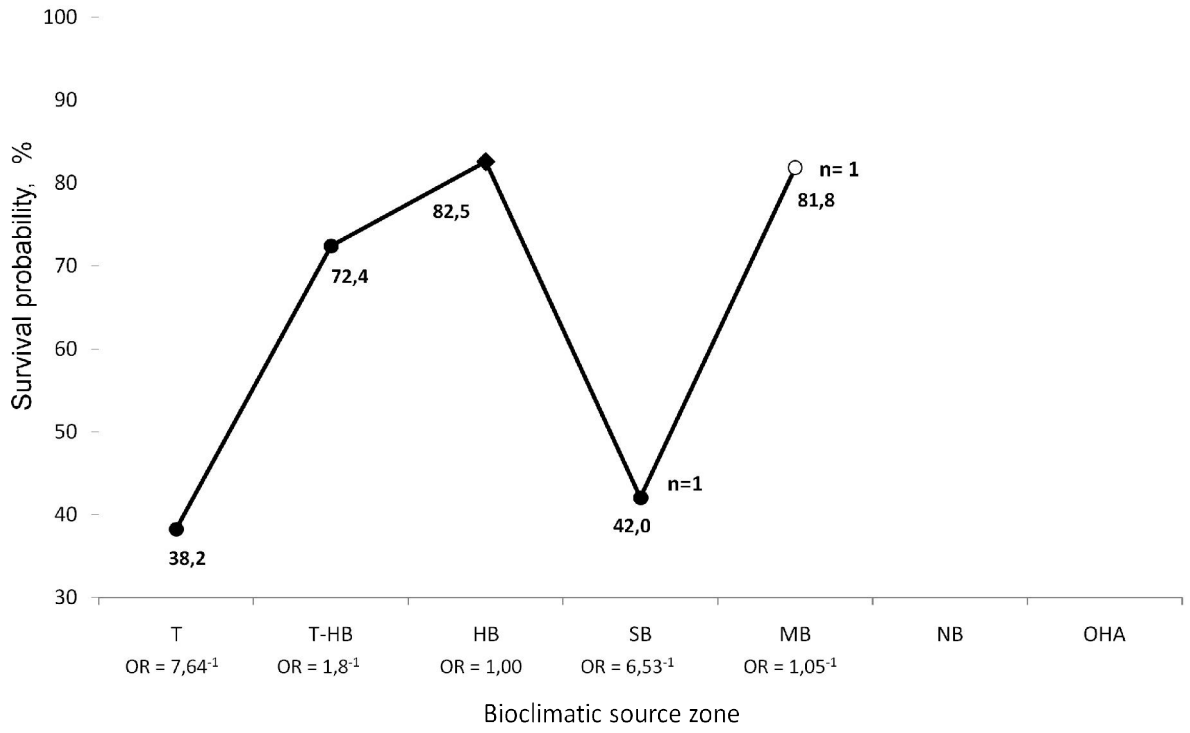

Fig. 10 Comparison of survival proportions in the dataset of lianas (total n=30) of accessions collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)}$ = 16; $n_{(T\text{-}HB)}$ = 4; $n_{(HB)}$ = 8; $n_{(SB)}$ = 1; $n_{(MB)}$ = 1; $n_{(NB)}$ = 0; $n_{(HA)}$ = 0. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively). Cases where n<5 marked.

For the dwarf shrubs there were no accessions representing the temperate zone (Figure 11). On the whole, the results for the dwarf shrubs are in agreement with the results of the woody by exhibiting the highest survival probabilities for the three most southern subzones of the boreal zone (HB= 36,4%; SB= 32,0%; MB= 42,9%). The difference between the hemiboreal and the southern boreal (OR= $1,22^{-1}$), as well as that between the hemiboreal and the middle boreal (OR= 1,31), is not significant ($p_{(SB)}$= 0,13; $p_{(MB)}$= 0,11; Wald's test). There is a significant difference between the reference zone and the temperate-hemiboreal (OR= $2,26^{-1}$, $p<<0.01$; Wald's test), the northern boreal (OR= $3,35^{-1}$, $p<<0.01$; Wald's test) and the hemiarctic (OR= $2,64^{-1}$, $p<<0.01$; Wald's test), all of which show a much lower probability of survival (T-HB= 20,2%; NB= 14,6%; HA= 17,9%) than the hemiboreal (36,4%). It should, however, be noted that the overall sample size for the dwarf shrubs is quite low

(N=27) and that most subzones are represented by few accessions only (see caption of Figure 10 for details).

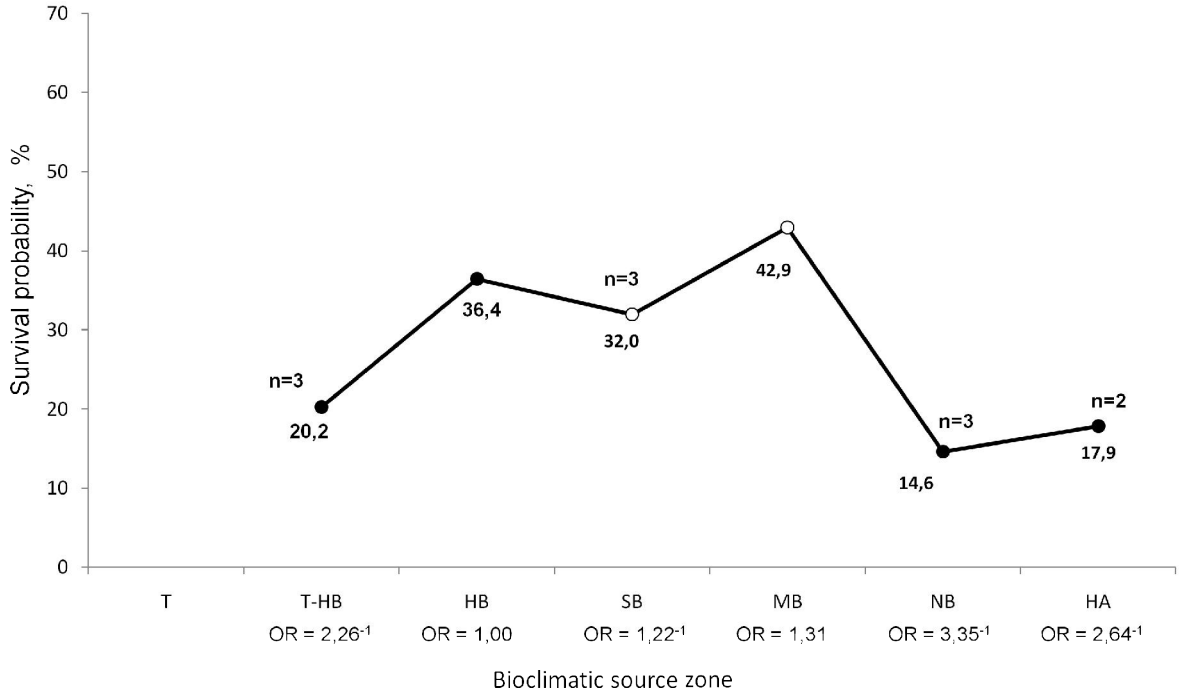

Fig. 11 Comparison of survival proportions in the dataset of dwarf shrubs (total n=27) of accessions collected from different source zones to those of the accessions collected from the hemiboreal zone. Odds ratios for each zone marked under the X axis. ORs below one (amount of decrease) and above one (increase) marked as suggested by Rita and Komonen (2008) to allow for comparison. $n_{(T)} = 0$; $n_{(T\text{-}HB)} = 3$; $n_{(HB)} = 6$; $n_{(SB)} = 10$; $n_{(MB)} = 3$; $n_{(NB)} = 3$; $n_{(HA)} = 2$. Abbreviations of zone names explained in Table 1. Rhomb = reference class, closed circle = significantly different from reference class, open circle = not significantly different from reference class (Wald's test, $p<0.05$ and $p>0.05$ respectively). Cases where n<5 marked.

4. Discussion

4.1. Test of the hypothesis

Although the possibility of intercontinental comparisons of vegetation was an aim in the development of the BZS (Kalela 1961, Ahti *et al.* 1968, Ahti 1980, Hämet-Ahti *et al.* 1974, Tuhkanen 1980; 1984, Hämet-Ahti 1981), the zone system was not specifically developed for seed transfers between the continents. Therefore, one could question the purposefulness of

relying upon this vegetation scheme in the acquisition of plant material to HUBG and, thus, the hypothesis of this study. The hypothesis I derived from the BZS states that plants originating from the same bioclimatic zone as that to which they were moved should do best in their new location. Survival probability should, hence, have peaked for the hemiboreal origin, or possibly southern boreal origin, and been progressively lower both towards the more northern and southern zones.

4.1.1. The dependence of survival on provenance

The results, in general, indicated a lower survival probability for accessions of temperate and hemiarctic origin than for those originating from any part of the boreal zone, which is in accordance with the hypothesis. The low survival probability of accessions of temperate origin could be interpreted as a lack of sufficient cold hardiness and, hence, increased mortality due to winter injury (cf. Solantie 1988). However, previous provenance trials indicate that it is possible to successfully extend the cultivation of a species to one subzone north of its natural area (Hämet-Ahti 1983). This would imply that many temperate species would thrive in hemiboreal Finland, but my results showed a clearly lower survival probability for plants originating in the temperate zone than for those from any of the boreal subzones. Nevertheless, Hämet-Ahti (1983) suggests that there are many exceptions to this rule, which are mainly caused by climatic factors, such as a varying degree of oceanity and continentality, and unsuitable provenances. The temperate zone, as any other zone, extends over large areas within which there is a certain degree of climatic variation and, hence, differing genetic adaptation of the plants. The BZS concentrates on the boreal zone, which it divides into subzones, while the temperate zone has not been considered as carefully. It would, nevertheless, be excpected to contain subzones of its own. Even if some material used in this study originated from the temperate zone as a whole, the continuous character of vegetation zones renders also the specific provenance within the zone important. Hence, too southern provenances may have affected the survival of the accessions, but the variability between oceanity and continentality likely has a stronger

effect, since the prevalence of continental and oceanic conditions in southern Finland varies between years and can thus make the conditions unsuitable for a variety of species.

The trend of temperate origins showing a low probability of survival was consistent for the core dataset and the life form partitions of it. The only exception to this rule was the herbs (Figure 7), which showed a highly irregular spectrum of survival probabilities. I do not, however, place much confidence in the analysis of herbs here, because the sample numbers for the middle boreal and northern boreal zones were low and because the herbs were exceedingly difficult to handle in this context. The inventory intervals of the garden plantations were not short enough to reliably capture true changes in herbaceous plant numbers as a result of survival; in many cases the herbs had probably reproduced both vegetatively and sexually, which resulted in erroneous counts of plant individuals during inventories. Moreover, in many stands the herbaceous individuals were difficult to tell apart and count, and some herb species probably are naturally too short-lived to allow an analysis of the kind I carried out.

For all the analysed datasets that included both temperate and hemiarctic accessions, i.e., the complete dataset, the core dataset, and the woody, herbaceous, and shrubby species analysed separately, the accessions of hemiarctic origin showed an even lower survival probability than the temperate ones. This could be because there were occasional anomalously mild and therefore wet winters during the study period, in particular the years 1995, 2000, 2002, and even 2008. Plants from hemiarctic conditions probably never experience such winters in their natural habitats and, hence, do not need to be adapted to them. Additionally, temperate accessions were not tested by a very harsh winter, since the study period did not include extremely low winter temperatures. On the other hand, the records of HUBG indicate that in certain years (e.g. 1998, 1999, 2000, 2003) exceptionally high numbers of accessions were lost in the garden as a whole, which may reflect unfavourable winter conditions despite the absence of very cold days in February, from which month I had reference data. It must also be noted that the number of hemiarctic accessions analysed was quite low, so whether the difference between the survival of the hemiarctic and the temperate accessions is relevant remains uncertain.

The survival proportions of the core dataset and the life form partitions of it behave in a similar way across the most southern boreal zones (temperate-hemiboreal, hemiboreal, southern boreal and middle boreal), by having a similar survival probability and by that the statistical analyses often show an insignificant difference between them. The exact pattern of variation in survival probabilities predicted by my hypothesis (peak at HB, progressively lower for more distant zones) could, hence, not be seen in the results; in most cases there were deviations from the expectation in one or more of the boreal subzones. This hierarchy in the zoning, i.e., that the studied area in the BZS is depicted as having three main zones of which the boreal zone is divided into subzones, was particularly well supported by the survival probabilities of woody plants of different provenances. The fact that the separate analysis of shrubs showed varied survival probabilities within the boreal zone could be because the included shrubs are quite a heterogeneous group. Some of the taxa, e.g., the genera *Spiraea* and *Rosa*, have a clearly stronger capability of rejuvenating their stands after winter damage than some other taxa analysed in the same group (e.g., *Lonicera*, *Syringa*, and *Weigela*). Some species of the latter group also resemble trees more than the former group, and the trees, when analysed separately, showed a different spectrum of survival probabilities (see following section).

4.1.2. The different signal derived from trees

Trees of the core dataset, when analysed alone, showed a clearly different pattern from any of the other life form groups. Trees exhibited an almost steady increase in survival probability from the temperate zone through to the northern boreal subzone, a tendency not predicted by my hypothesis. This would suggest that the more northern the origin of a tree, the better adapted it is to grow in the hemiboreal zone in Helsinki. That the survival probability for the trees does not decrease towards the north, as one could expect, is, to some extent, in accordance with earlier studies on the effect of provenance on *Pinus sylvestris* and *Picea abies*, which have shown that northern tree provenances, when moved southwards, survive and perform well, and are also more productive than at their natural location (Beuker 1994). Yet, other studies on the effect of climate change on forest trees

have shown that a warmer climate may increase the risk of frost damage by altering the timing of the annual development (Hänninen 1991, Leinonen *et al.* 1997). This was not seen in my results, which could be attributed to the lack of very harsh frost winters during the study period.

4.1.3. Photoperiodicity may affect transferred plants

As the BZS was not designed for the specific purpose of introducing exotic plant species to alien sites, photoperiodicity has not been a factor affecting the delineation of homoclimatic zones. Hence, the difference in photoperiodicity between the collection regions and the destination area has not been controlled for, although the latitudinal variation between the same BZS-subzone in different parts of the world is in some cases as high as 20 degrees as can be observed when comparing the latitudes of the homoclimatic areas (Figure 4). It is however, known that day length is often well adapted for in plants. Day length controls, e.g., leaf abscission and dormancy (e.g., Wareing 1948) and, hence, winter hardiness. Consequently, this adaptation may affect the way a plant reacts when transferred between zones where a different or similar light environment may prevail. This is, in fact, widely recognized within silvicultural research (Sarvas 1964, 1974). This would be an interesting aspect to study even though the dataset used here could not readily be used to analyse the effect on survival of the light conditions in the areas of origin. The accessions in Kumpula Botanic Garden represent quite a large array of species in addition to that every species is usually represented by only one or a few accessions. Also, although the Japanese and Chinese material came from roughly similar latitudes and, thus, light conditions, and the Canadian material is somewhat more northern, there is not an even more northern Finnish dataset available for comparison. It would thus not be purposeful to study photoperiodicity with this dataset, but it should be borne in mind as a possible reason why the results did not clearly corroborate nor refute my hypothesis.

4.1.4. Factors defining the success of plants

The concept of a species' *fundamental niche*, i.e., the conditions under which a species could potentially maintain a viable population, versus its *realized niche*, i.e., where the species actually does exist as a result of restrictions to its distribution (Hutchinson 1957), needs to be considered in the context of this study. The distribution of species is affected by a variety of factors including: their ability to disperse in time and space, for instance over geographical barriers; their behaviour and habitat selection; external biotic factors such as competition, predation, and parasites; as well as abiotic factors where the major constraints are temperature and water availability (Campbell & Reece 2002). Hence, species do not occur everywhere throughout their range, and the ones found in an area may have geographically different evolutionary and ecological histories and be controlled by diverse environmental factors (Crawford 2008), not only climate. Therefore, one could expect that some species could be able to succeed even outside their current range and thus show viability in a study like this.

In a garden or a similar managed area many of the agents acting upon a species' ability to survive are eliminated. Horticultural practices many times eliminate competition, predation, and parasite intervention, not to mention the geographical barriers being overcome through transplanting. Hence, an individual that thrives in garden conditions might not succeed in nature in the same bioclimatic area because of, e.g., failure in sexual reproduction, or insufficient growth when experiencing competition. Different species are constrained by different factors and will thus probably behave differently when moved from their natural range into managed conditions. In this study the BZS was tested by using samples of species collected in the wild within different vegetation zones. Because of this the validity of the hypothesis I set out to test may not be fully legitimate as a test of the BZS; even if some results (particularly the analysis of trees) refute the hypothesis it does not automatically warrant the conclusion that the BZS would not be valid. More generally, one needs to be cautious when drawing conclusions from managed provenance trials on different species' ability to, e.g., adapt to climatic change or of being potentially able to naturalize in a foreign location.

It is also important to note that in this study I analysed but one part of fitness, survival, whereas crucial variables such as growth rate, age at reproductive maturity, seed set, and seed germination rates were not included. Some individuals in the garden certainly do not thrive, even though they are alive, and would probably not be viable or productive in the wild, while other individuals of the same species are much more vigorous. This variability between the individual plants and also between the accessions has not been taken into account in this study. Instead also the individuals in bad condition have been recorded as living. A plant's overall fitness would, nevertheless, be the decisive measure of success in the wild, and perhaps also at least partly in silvicultural plantations. For this reason the result I obtained for the survival probabilities of the trees does not allow the conclusion that the overall success of trees would increase with increasing latitude or altitude of the seed source.

Solantie (1986) argues that as the BZS is based on the occurrence of native plants, controlled mainly by summer conditions, it is insufficient for introduced foreign taxa, whose performance often depends on their ability to harden and thus survive during winter. Within horticulture, hardiness zones are applied to indicate the potential cultivation area for exotic fruit trees and ornamental taxa. The Finnish division of hardiness zones (Solantie 1986) largely resembles the BZS, but is more detailed with, e.g., the southern boreal subzone enclosing as many as three hardiness zones (II-IV). While this approach might be more suited as a basis for plant transference tests, it fails on the point of not being internationally comparable, since different climatic parameters tend to be used for delineating hardiness zones and, hence, different hardiness zone schemes are applied in different areas of the world. Hence, using the location within hardiness zones of the original collecting sites of the analysed accessions as a basis for evaluating their relative success in Kumpula was not relevant in this study.

4.2 The validity of the BZS

4.2.1. The hierarchical zoning of the BZS

Considering the various aspects on the validity of the hypothesis elaborated on above, the results of this study cannot necessarily be generalized for drawing conclusions on the validity of the BZS. Even so, the fact that the boreal zone as a whole came apart from the adjacent zones is noteworthy. This pattern is particularly evident in the analysis of the woody accessions of the core dataset where survival probabilities were practically the same from the temperate-hemiboreal transition through to the middle boreal subzone. This was not predicted by the hypothesis, but it is quite interesting in the light of the BZS where the main zones are the temperate, boreal, and arctic ones, and the boreal zone has been divided into four subzones. The results thus lend support to the hierarchical main zone - subzone structure of the BZS.

According to the BZS, the hemiboreal zone is a subzone of the boreal main zone. The developers of the BZS specifically chose to include the hemiboreal zone into the larger boreal unit (Ahti *et al.* 1968), contrary to many other authors who argue that the hemiboreal zone is an independent macro zone or part of the temperate zone. (Regel 1952: part of the nemoral (temperate) zone; Zoller 1956: Nadellaubwaldregion; Hustich 1960: North European Mixed Forest Region; Sjörs 1963: Boreo-nemoral zone; according to Ahti *et al.* 1968). There are many recent attempts of vegetation zoning also claiming the hemiboreal subzone to be part of the temperate zone (Brandt 2000; the Köppen-Geiger climate zone classification (1936); Bohn *et al.* 2000; Rivas-Martinez & Rivas-Saenz 1996-2009; CVBM-project according to T. Ahti, *in litt*., April 2010). Ahti *et al.* (1968) believe the hemiboreal subzone is more closely associated with the boreal zone than with the temperate, referring to the prevalent forest type (coniferous) as well as the type of soil prevailing in the hemiboreal area. In the light of the results of this study, it seems as the hemiboreal subzone is more closely related to the boreal zone than to the temperate zone, considering the overall trend of the accessions from the southern boreal subzones (including the temperate-hemiboreal and hemiboreal) reacting similarly. This would be in

accordance with the BZS and refute the claim that the transition zone (i.e. the hemiboreal subzone according to the BZS) is part of the temperate region, as claimed by many researchers especially in North America (Brandt 2000).

In all, my results lend some support to the BZS even though they only partly supported my hypothesis. From this I draw the conclusion that the hypothetical expectation regarding peaking survival probability at hemiboreal or southern boreal origins could actually be seen as a misconception. The BZS itself does not predict this. Rather, the hypothesis should perhaps have been that the boreal zone stands out as one unit with the temperate and hemiarctic origins doing worse, as well as the hemiboreal subzone being part of the boreal zone. This would be in accordance with the hierarchical system of zoning applied in the BZS.

4.2.2. Possible effects of climate change

The currently on-going climate change is also interesting to consider in this context. As the BZS was developed about 50 years ago, the distribution of the zones might have shifted since. In fact, Solantie (2010) maintains that, climatically, the zones have already moved northwards with the extent of about half a zone. Nevertheless, vegetation does not respond as quickly and may to some extent also adapt to a new climatic environment. Thus, the predicted vegetation characteristics per zone may still prevail. In any case, the material for this study was collected only about 15 years ago and the provenance zones were recognized *in situ* while collecting the material. Hence, I do not see climate change and the concurrent altering of zone distributions as a main problem in this study.

Yet, in the future, plant associations and, consequently, the distribution of bioclimatic zones, may be altered even further. The change brought about by climate change may not necessarily happen in unison across the continents, but may vary as a response to different degrees of climatic changes, edaphic factors, and the ability of the plants occupying the area to adapt or migrate. The extent and pace of these changes could be monitored by mapping vegetation at regular intervals (Solantie 2010).

4.3. The value of botanic garden collections in provenance studies

The scientific plant collections of botanic gardens are useful as material for a multitude of different research questions dealing with the effect of climate on plants, such as observations on phenological changes or morphological adaptations of individual plants (Primack & Miller-Rushing 2009, and references therein). Certainly they have also served as primary testing grounds of the hardiness of various plant species in ambient climates. However, since the present study represents a broader analysis of the relevance of bioclimatic vegetation maps on the basis of a relatively large botanic garden collection, it is worthwhile evaluating the suitability of botanic garden collections for this kind of studies.

4.3.1. Curational problems

The prerequisites for this study were good considering the availability of a large collection of plant accessions of known wild origin. In the current study I was forced to discard a notable number of accessions. There were accessions that obviously were not qualified for use in the analyses, e.g., the ones that were never sown or never germinated. However, there were also many accessions which would otherwise have fulfilled the qualitative and quantitative criteria used, but because the follow-up on the changes in numbers of individuals was of insufficient quality, entries in the database contained errors, or the number of individuals planted was too low, they had to be discarded from the analyses. This left me with only c. ⅓ of the original number of accessions in the database for the actual analyses. Herbaceous plants were particularly problematic. Insufficient recording routines rendered them practically useless for this study. The difference in the clarity of the results between woody and herbaceous accessions may be attributed to the fact that woody species are easier to count and handle. Many woody species do not spread vegetatively and their sexual reproduction does not go unnoticed. The data on woody accessions are therefore more reliable.

By separating species with different life forms and curational needs I was able to decipher sources of error and to find possible explanations for the results. But even though I reduced uncertainty factors that could introduce noise into the results I was still

constrained by the use of a botanic garden collection as opposed to a common garden experiment specifically designed for this purpose.

4.3.2. Planting conditions and cultivation practices

The non-standardized planting conditions and cultivation practices in the botanic garden is one factor that could not be controlled for retrospectively. The plants had been grown in different parts of the landscaped six-hectare botanic garden, which by no means can be considered a homogeneous testing ground. Hence, growing conditions other than the general climate were not standardised. Edaphic site factors including topography varied among the plantings and, hence, different sites were more or less favourable. In fact, regarding the hardiness zone approach, site factors, such as soil quality, microclimatic conditions, and topography, are considered of importance for the success of exotic species, and depending on a plantation site's characteristics, the hardiness zone may change to a more northern or southern one (Solantie 1986). I did not, however, analyse eventual effects of this variation because of lack of relevant edaphic-topographical data with sufficiently detailed spatial resolution.

Horticultural practices have varied in different parts of the garden and for different accessions (L. Schulman, pers. comm. August 2009). For instance, thinning of stands has progressed at different pace in different plantings, and means of soil improvement have also varied. The number of individuals planted per accession also varied greatly, ranging between a hand-full to over a hundred planted individuals per accession. The accessions represented by small numbers of individuals have been more susceptible to stochastic events and biased survival numbers. The accessions represented by large numbers of individuals, on the other hand, were often planted densely, whereby competition for resources could affect the number of surviving individuals. Different accessions had also been cultured for different lengths of time and thus exposed to the climate in the target area for periods of different length.

4.3.3. The length of the study period

As mentioned, the reliability of the analysis of herbaceous species was affected by the relatively long study period, among other things. However, for other species groups, mainly trees and other large woody species, the results may be affected by the study period being too short to allow climatic conditions to affect the survival of plants and whole accessions. The study period did not involve particularly severe winters as judged from mid-winter minimum temperatures (Table 2). A few years may, though, have been critical in this respect. In particular 1996, with a lower than average mean temperature and considerable frost sum in February, could have damaged young plants in the beginning of their life in the outdoors plantations. Tender plants may have suffered also in 2007, when the temperatures in February were low and the snow cover more than 40% thinner than the mean of the reference period. Nevertheless, the data were not detailed enough to distinguish the consequences of individual years on the survival of the studied accessions.

4.3.4. Taxonomic variability

The wide array of species that I analysed was very heterogeneous taxonomically and, hence, represented a diverse selection of morphological structures and life history traits. Because the test includes such a wide array of species with different ecological characteristics, even a so-called common-garden method may not have been the best approach (Sarvas 1964), since different plant species require different growing conditions. Instead, a better way to overcome these restrictions could be to divide the data even further than by the life-form approach executed in this study. I would suggest studying ecologically or taxonomically similar species. Plant types (*fide* Box 1981) could also be an apt approach. As an example, one could compare trees or woody species more specifically by, for instance, dividing the accessions into broadleaf species and conifers, or study species that are represented by accessions originating from several vegetation zones. Another way of finding species that behave similarly, and thus readily could be compared, could be by comparing their different features in an ordination analysis (Ranta *et al.* 2005). Through an ordination analysis one

could find species or accessions that behave in a similar way, which then could generate new hypotheses for subsequent testing (Begon *et al.* 2006). However, this approach may not be feasible since the sample size, at least among these data, could grow too small considering the manifold variables that testing the BZS requires. Even in the study presented here, when dividing the data into five life form groups, the sample sizes per zone were in many cases very low. Also, the outcome of an ordination analysis would depend on the researcher's ability to sample an appropriate variety of variables, a task that is not necessarily straightforward.

4.3.5. Data on origin

Botanic Gardens hold documented collections on plants, which includes data on origin. Within the botanic gardens of the world, however, the quality of the information varies greatly (e.g., Badley *et al.* 2004). From the very beginning, the policy for the collection of Kumpula Botanic Garden has been to be most conscientious at this point, by for instance only approving accessions of known and wild origin and even making the effort of collecting the accessions on specific organized expeditions. Nevertheless, a noteworthy possible source of error for the current study are the data on origin recorded in the field. The identification of the different bioclimatic zones, while collecting, cannot have been a straightforward task. The data may, thus, contain inaccuracies. In addition, the zones are broad belts and, hence, the source zone is a rather coarse class denomination instead of a high-resolution nominal variable, let alone a continuous variable.

4.3.6. Recommendations for botanic gardens

The plentiful data connected to botanic garden collections makes them potentially extremely valuable for testing bioclimatic hypotheses and for other research efforts. The collection in Kumpula Botanic Garden had good prerequisites for providing data for scientific research considering, e.g., the wild-collected plants with exact information on provenance zone and a good testing ground in the newly established botanic garden.

However, the quality of the data had been allowed to deteriorate. While it is probably unavoidable that part of the potential data is lost with seeds failing to germinate and with human mistakes involved in collection management, it would be of utmost importance to be meticulous with curation and up-dates to prevent unnecessary loss of accessions and deterioration of the quality of the collection. The deterioration of the data in the case of Kumpula Botanic Garden was an unfortunate waste of the effort put into the gathering of the plant collection. The obvious explanation for the imperfect collection curation is variation in management resources over the years. The collection simply was too large for the available staff to be perfectly curated constantly (L. Schulman, pers. comm. August 2009), or the converse: the funding was inadequate to secure the retention of the valuable collection. For the Botanic Garden community I hence recommend to only keep as many accessions as one is able to properly manage, and funders should remember the necessity to keep up a constant resourcing for facilities of this kind. It is crucial that inventories and updates on changes in numbers of individuals in the accessions as well as other events in the field are regularly and meticulously reported to the databases and other information systems the gardens hold on their scientific plant collections. Furthermore, within accessions it would be important to have several individuals instead of building 'stamp collections' with plenty of taxa represented by single accessions consisting of only one or two individuals. This is important not only for the value of the collections in conservation, but also for studies demanding a large volume of raw data.

4.4. Conclusions

Although I was able to find significant effects of provenance on survival, I could not unequivocally interpret all parts of the results as either supporting or refuting the hypothesis I set out to test. I believe this stems from the problematic study setup, which contained many uncontrollable variables. Additionally, the hypothesis may not have been adequate for testing the BZS.

Considering the various problems encountered during the study it was not surprising that some of the results were quite difficult to interpret, but despite the problems I was able to achieve some significant results that made sense biologically and shed light on

the effect of provenance on the survival of the plants in the botanic garden. I was even able to find some support for the validity of the BZS, by there being a general trend for the accessions of the southern boreal subzones to react in a similar way and by that accessions of temperate and hemiarctic origin had a lower probability of survival when grown within the hemiboreal zone.

Since many species have the potential for a much broader ecological range than they actually exhibit in their natural distribution, the study set-up used here may not be the most appropriate for testing the validity of a vegetation zone system. The factors acting upon the ability of plants to thrive in a location are manifold and may not easily be detected by transfer tests. Additionally, one must keep in mind that although dividing vegetation into zones may be justifiable, they are still artificial in the sense of being man-made constructs for classifying a variable biosphere. However, botanic garden collections, when properly analysed, could provide much useful information on the conditions under which plant species could exist, and thus enhance studies on, e.g., plants under a changing climate. The prerequisite is, though, that botanic gardens themselves pay due attention to the origin of the plants they grow and carefully curate their accessions.

Of the hundreds of species Peter Kalm imported from North America in 1751 only three persisted in Finnish gardens, whereas more than 50% of the accessions brought back from the Kumpula expeditions are still alive (Schulman 2009). Careful selection of source areas thus seems to be leading to far greater success than earlier, and systematic recording of data on origin enables the use of the plant material for meaningful ecological analyses.

5. Acknowledgements

I am very grateful to my supervisor Dr. Leif Schulman for his expert guidance, advice and constructive critique, as well as for the support and time he offered me during the course of the study. I am grateful to my supervisor Dr. Leena Lindén who offered valuable insights into horticultural aspects and literature, and provided relevant comments on the manuscript. I thank Dr. Hannu Rita for help with statistical analyses and prof. Heikki Hänninen for commenting the manuscript. HUBG staff members Marko Pesu and Seppo Sinkkonen contributed with valuable insights on the plant accessions. I am also grateful to prof. emer. Teuvo Ahti for his advice on literature, as well as to Leo Junikka and the HUBG library for providing me with a large part of the literature used. Finally, I wish to express my thanks to prof. emer. Timo Koponen, the staff of the HUBG, and collaborators who collected the plant material analysed in this study, and the staff members who have cared for the plant accessions and regularly recorded information on them over the years. The climate data were provided by the Finnish Meteorological Institute.

6. References

Ahti T., Hämet-Ahti L. & Jalas J. 1968: Vegetation zones and their sections in northwestern europe. — *Annales Botanici Fennici* 5: 169–211.

Ahti T. 1980: Definition and subdivision of the subarctic. A circumpolar view. — *Canadian Botanical Association Bulletin* 13:2(supplement):3–10.

Ahti T. & Oksanen J. 1990: Epigeic lichen communities of taiga and tundra regions. — *Vegetatio* 86: 39–70.

Alexander R. & Millington A.C. (eds.) 2000: *Vegetation Mapping: from patch to planet.* — John Wiley & Sons Ltd, West Sussex. 336pp.

Badley C., Hill D. & Wray N. 2004: Inadequate accession data compromises the conservation value of plant collections. — *Sibbaldia* 2: 5–19.

Begon M., Townsend C.R. & Harper J.L. 2006: *Ecology. From individuals to ecosystems.* — Blackwell publishing, Victoria. 4th ed. 738pp.

Beuker E. 1996: *Implications of climate adaptability in provenance trials with Scots pine and Norway spruce in Finland for the possible effects of climate warming.* — University of Joensuu, Faculty of Forestry Research notes 42. Joensuun yliopiston monistuskeskus. 33pp.

Bohn, U., Gollub G. & Hettwer C. (eds.) 2000: *Karte der natürlichen Vegetation Europas. Map of the natural vegetation of Europe.* — Bundesamt für Naturschutz, Bonn. 153pp.

Box E.O. 1981: *Macroclimate and plant forms: An introduction to predictive modelling in phytogeography.* — Dr W. Junk Publishers, The Hague. 258pp.

Brandt J. P. 2009: The extent of the North American Boreal Zone. — *Environmental Review* 17: 101–161.

Cambell N.A. & Reece J.B. 2002: *Biology.* — Benjamin Cummins, San Francisco. 6th ed. 1247pp.

Cathey H.M. 1990: Plant hardiness zone map. — *U.S. Department of Agriculture, Agricultural Research Service Miscellaneous Publications 1475*. National Arboretum, Washington, D. C.

Collett D. 2002: *Modelling binary data.* — Chapman & Hall/CRC Press, London. 2nd ed. 387pp.

CVBM; CircumBoreal Vegetation Mapping 2008: *Resolutions and work plan. Helsinki workshop November 3-6, 2008.* — Available at http://caff.arcticportal.org

Cramer W.P. & Leemans R. 1992: Assessing impacts of climate change on vegetation using climate classification systems. — In: Solomon A.M. & Shugart H.H. (eds.), *Vegetation Dynamics & Global Change.* Chapman and Hall, New York. 338pp.

Crawford 2008: *Plants at the margin. Ecological limits and climate change.* — Cambridge University Press, Cambridge. 494pp.

Goward T. & Ahti T. 1992: Macrolichens and their zonal distribution in Wells Gray provincial park and its vicinity, British Columbia, Canada. — *Acta Botanica Fennica* 147: 1–60.

Du Rietz G.E. 1925: Die regionale Gliederung der skandinavischen Vegetation. — *Svenska Växtsociologiska Sällskapets Handlingar* 4: 1–80.

Emanuel W.R., Shugart H.H. & Stevenson M.P. 1985: Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. — *Climatic Change* 7: 29–43.

Enroth J. & Kukkonen I. 1999: Kasvitiede Suomessa. — In: Morton A. G. 1999: *Kasvitieteen historia : Kuvaus kasvitieteen vaiheista muinaisajoista nykypäivään.* Gaudeamus, Helsinki. 479 pp.

Freitag H. 1962: *Einführung in die Biographie von Mitteleuropa unter besonderer Berücksichtung von Deutschland.* — Stuttgart. 214 pp.

Hare F.K. & Ritchie J.C. 1972: The boreal bioclimates. — *Geographical Review* 62: 333–365.

Haila Y., Hanski I.K., Raivio S. 1993: Turnover of breeding birds in small forest fragments: the "sampling" colonization hypothesis corroborated. — *Ecology* 74: 714–725.

Hämet-Ahti L. 1965: Notes on the vegetation zones of western Canada, with special reference to the forests of Wells Gray Park, British Columbia. — *Annales Botanici Fennici* 2: 274–300.

Hämet-Ahti L. 1972: Pohjois-Japanin (Hokkaidon) metsävyöhykkeistä. — *Dendrologian Seuran Tiedotuksia* 4(3): 4–11 [In Finnish with English summary].

Hämet-Ahti L. 1979: The dangers of using the timberline as the 'zero line' in comparative studies on altitudinal vegetation zones. — *Phytocoenologia* 6: 49–54.

Hämet-Ahti L. 1981: The boreal zone and its biotic subdivision. — *Fennia* 159(1): 69–75.

Hämet-Ahti L. 1983: Actual and potential exotic trees of landscaping and forestry in Finland. — *ANUBiH Radori Knjiga 72, Knjiga* 21: 27–35.

Hämet-Ahti L., Ahti T. & Koponen T. 1974: A scheme of vegetation zones for Japan and adjacent regions. — *Annales Botanici Fennici* 11: 59–88.

Hänninen H. 1991: Does climatic warming increase the risk of frost damage in northern trees? — *Plant, Cell and Environment* 14(5): 449–454.

Hijmans R.J. & Graham C.H. 2006: the ability of climate envelope models to predict the effect of climate change on species distributions. — *Global Change Biology* 12: 2272–2282.

Holdridge L. R. 1947: Determination of world plant formations from simple climatic data. — *Science* 105(2727): 367–368.

Holdridge L.R. 1967: *Life zone ecology.* — Tropical center, San Jose. 206pp.

Hopkins A.D. 1920: The bioclimatic law. — *Monthly weather review* 48: p. 355.

Hustich I. 1960: Plant geographical regions. pp. 54–62. — In: Sömme A. (ed.), *A geography of Norden.* Oslo. 359pp.

Hutchinson G.E. 1957: Concluding remarks. — *Cold Spring Harbour symposium on quantitative biology.* 22: 415–427.

Kalela A. 1944: Kangasmetsäformation aluellisesen vaihtelun vastaavaisuudesta Euraasiassa ja Pohjois-Amerikassa. — *Metsätaloudellinen Aikakauslehti* 2–3.

Kalela A. 1958: Über die Waldvegetationszonen Finnlands. — *Botaniska Notiser* 11: 353–368.

Kalela A. 1961: Waldvegetationszonen Finnlands und ihre klimatischen Paralelltypen. — *Archivum Societatis Zoologicae-Botanicae Fennicae 'Vanamo'* 16(supplement): 65–83.

Kalela A. 1973: Suomen yleisimpien metsätyyppien floristinen rakenne. pp. 260–267. — In: Kalliola, R. (ed.), *Suomen kasvimaantiede*. WSOY, Helsinki. 308pp.

Karlsen S.T., Elvebakk A., & Johansen B. 2005: A vegetation-based method to map climatic variation in the arctic-boreal transition area of Finnmark, north-easternmost Norway. — *Journal of Biogeography* 32: 1161–1186.

Karlsen S.T., Elvebakk A., Høgda K.A. & Johansen B. 2006: Satellite-based mapping of the growing season and bioclimatic zones in Fennoscandia. — *Global Ecology and Biogeography* 15: 416–430.

Karlsson K. 1996: Kasvupaikkojen puuntuottokyvyn ja puuston kasvun alueellinen vaihtelu Pohjanmaan rannikolta sisämaahan. — *Folia forestalia — Metsätieteen aikakauskirja* 1996(2): 113–131.

Koponen T. & Koponen A. 1994: *Delectus seminum. List of seeds available in 1994. Supplement. Seeds from natural habitats in Hokkaido, Japan.* — Botanical Garden, University of Helsinki. 15pp.

Koponen T. and Koponen A. 1995a: *Delectus seminum. List of seeds available in 1994. Supplement 2. Seeds from natural habitats in Northeast China.* — Botanical Garden, University of Helsinki. 15pp.

Koponen T. and Koponen A. 1995b: Botanical Garden goes Far East – test of theory. — *Universitas Helsingiensis* 2: 4–8.

Koponen T. and Koponen A. 1996: *Delectus seminum. List of seeds available in 1996. Supplement 3. Seeds from natural habitats in Canada.* — Botanical Garden, University of Helsinki. 23pp.

Koponen, T. 1996a: Uusi kasvitieteellinen puutarha perusteilla; mistä puutarha- ja koristekavimme tulevat? pp. 65–68. — *Yliopiston almanakka vuodeksi 1997 jälkeen Vapahtajamme Kristuksen syntymän.*

Koponen, T. 1996 b: *Ulkomaisten koriste- ja puutarhakasvien kotiuttaminen Etelä-Suomen oloihin 1993-1995. Selvitys määrärahojen turvin tehdyn työn toteutumisesta ja tuloksista.* Unpublished project report (in Finnish).

Koponen T. and Koponen A. 2002: *Introduction to the new Botanical Garden at the University of Helsinki. 2nd edition with updated taxon list.* — Botanical Garden, University of Helsinki. Yliopistopaino, Helsinki. 74pp.

Köppen W. 1936: Das geographische System der Klimate. — In: Köppen W. & Geiger G. (eds.), *Handbuch der Klimatologie*. Gebrüder Bornträger, Berlin. Vol 1 part C. 44pp.

Krajina V.J. 1959: Bioclimatic zones in British Columbia. — *University of British Columbia, Bot. Series.* 1: 1–48.

Küchler, A.W. 1964: Potential natural vegetation of the conterminous United States. — *Special Publication No. 36, American Geographical Society.* New York. 38pp.

Küchler, A.W. & Zonneveld I.S. 1988: *Vegetation mapping (Handbook of vegetation science; vol 10)*. — Kluwer Academic Press, Dordrecht. 635pp.

Kujala V. 1936: Kasvillisuus. — In: *Suomen maantieteen käsikirja,* pp. 331–337. Helsinki. 715pp.

Kujala V. 1945: Waldvegetationsuntersuchungen in Kanada, mit besonderer Berücksichtigung der kanadischer Holzarten auf natürlichen Waldböden in Finnland. — *Annales Academiæ Scientiarum Fennicæ* 7: 1–434.

Kujala V. 1964: Metsä ja suokasvilajien levinneisyys- ja yleisyyssuhteista Suomessa. — *Communicationes Instituti Forestalis Fenniae* 59(1): 1–137.

Kuusinen M. 1996: Cyanobacterial macrolichens on Populus tremula as indicators of forest continuity in Finland. — *Biological Conservation* 75(1): 43–49.

Leinonen I., Repo T. & Hänninen H. 1997: Changing environmental effects on frost hardiness of Scots pine during dehardening. — *Annals of Botany* 79: 133–138.

Lid J. & Lid D.T. 2005: *Norsk flora*. — Norske Samlaget, Oslo. 1014pp.

Linkola K. 1922: Zur kenntnis der Verteilung der landwirtshaftlichen Siedlungen auf der Böden verschiedener Waldtypen in Finnland. — *Acta Forestalia Fennica* 22(3): 1–67.

Lipponen V. & Schulman L. 2005: *T-Puska, tieteellisille puutarhoille suunniteltu kasvitietokanta* [A plant database designed for scientific gardens; in Finnish]. — Helsinki University Botanic Garden: MS-Access based relational database.

Musgrave T., Gardener C., Musgrave W. 1998: *The plant hunters.* — Ward Lock, London. 224pp.

Moen A. 1999: Vegetation. — In: Lillethun A. (Ed.): *National atlas of Norway.* Norwegian Mapping Authority, Hønefoss. 200pp.

Naumann E. 1928: Die regionale Gliederung von Süd- und Mittelschweden in pflanzengeographischer bezv. limnoloischer Hintsicht. Eine vergleichende Übersicht. — *Botaniska Notiser* 1928: 31–48.

Primack R. B. & Miller-Rushing A. J. 2009: The role of botanical gardens in climate change research. — *New Phytologist* (182): 303–313.

Ranta E., Rita H., Kouki J. 2005: *Biometria. Tilastotiedettä ekologeille.* — Yliopistopaino, Helsinki. 569pp.

Raunkiær C. 1904: Om biologiske typer, med hensyn til planternes tilpasninger til at overleve ugunstige aarstider. — *Botanisk Tidsskrift* 26:14.

Regel K. 1940: Über die Begrenzungen von pflanzengeographischer gebieten. — *Memoranda Societatis pro Fauna et Flora Fennica* 15: 197–200.

Regel K. 1952: Botanische betrachtungen auf einer reise in Schweden. — *Ibid* 1951: 35-55.

Rita H. 2004: Vetosuhde (*odds ratio*) ei ole todennäköisyyksien suhde. — *Metsätieteen aikakauskirja* 2/2004: 207-212.

Rita H. & Komonen A. 2008: Odds ratio: An ecologically sound tool to compare proportions. — *Annales Zoologici Fennici* 45(1): 66–72.

Rivas-Martinez, S. & Rivas-Saenz,S. 1996-2009. Worldwide Bioclimatic Classification System. Phytosociological Research Center, Spain. — http://www.globalbioclimatics.org. Cited on July 20, 2010.

Sarvas R. 1964: *Havupuut.* — WSOY, Porvoo. 518pp.

Sarvas R. 1974: Investigations on the annual cycle of development of forest trees. II. Autumn dormancy and winter dormancy. — *Communicationes Instituti Forrestralis Fenniae* 84(1): 1–101.

Schulman L. 2009: *From cloudberry to amur cherry : Kumpula botanic garden.* — University of Helsinki. Esa Print, Helsinki. 25pp.

Silander V., Lehtonen J., & Nikkanen T. 2000: *Performance of exotic conifers in southern Finland.* — Metla, Vantaan tutkimuskeskus. [In Finnish with English summary]. 127pp.

Sjörs H. 1956: *Nordisk växtgeografi.* — Victor Petterson Bokindustri, Stockholm. 240pp.

Sjörs H. 1963: Amphi-Atlantic zonation, Nemoral to Arctic. — In: Löve A. & Löve D. (Eds.) 1963: *North Atlantic biota and their history.* pp. 109–125. Oxford etc. 430pp.

Solantie R. 1986: The growing zones for fruit trees and woody ornamental plants in Finland – revision of earlier divisions. — *Sorbifolia* 17(4): 201–209. [In Finnish with English summary].

Solantie R. 1988: Modification of the climatic zones for fruit trees and woody ornamental plants in Finland. — *Sorbifolia* 19(3): 124–126. [In Finnish with English summary].

Solantie R. 2005: Productivity of boreal forests in relation to climate and vegetation zones. — *Boreal Environment Research* 10: 275–297.

Solantie R. 2010: Climatic comparison between boreal zones in Canada and Finland. — Sorbifolia 14(1): 29–36. [In Finnish with English summary].

Thornthwaite C. W. 1948: An approach toward a rational classification of climate. — *Geographical Review* 38: 55–94.

Tomppo E. 2000. Kasvupaikat ja puusto. — In: Reinikainen A., Mäkipää R., Vanha-Majamaa I. & Hotanen J.-P. (eds.), *Kasvit muuttuvassa metsäluonnossa* [*Changes in the frequency and abundance of forest and mire plants in Finland since 1950*], Jyväskylä, pp. 60–83. [In Finnish with English summary].

Trewartha G.T. 1968: *An introduction to climate.* — McGraw-Hill, New York. 416pp.

Tuhkanen S. 1980: Climatic parameters and indices in plant geography. — *Acta Phytogeographica Suecica* 67. 100 pp.

Tuhkanen S. 1984: A circumboreal system of climatic-phytogeographical regions. — *Acta Botanica Fennica* 127:1–50.

Tuhkanen S. 1992: The climate of Tierra del Fuego from a vegetation geographical point of view and its ecoclimatic counterparts elsewhere. — *Acta Botanica Fennica* 145: 1–64.

Walter H. 1979: *Vegetation of the earth and ecological systems of the geo-biosphere.* — Springer-Verlag, New York. 527pp.

Wareing P.F. 1948: Photoperiodism in woody species. — *Forestry* 22: 211–222.

Zoller H. 1956: Die natürliche Grossgliederung der fennoskandischen Vegetation und Flora. *Berichte des Geobotanische Instituts der ETH Stiftung Rübel Zürich* 1955: 74–98.

Appendix I. Accessions in complete dataset. Accession number, species name, and zone of origin as given in HUBG's database (Lipponen & Schulman 2005). Orig = original number of individuals planted in collection area. Sur = number of individuals not died before time of data collection. % = proportion of survived individuals.

Japan 1993 accession	species	zone	orig	sur	%
1993-0476	Sorbus commixta	OHB	92	88	95,7
1993-0478	Menziesia pentandra	OHB	41	0	0,0
1993-0480	Alnus hirsuta	OHB	5	0	0,0
1993-0483	Betula ermanii	OHB	35	24	68,6
1993-0486	Picea glehnii	OHB	31	29	93,5
1993-0488	Filipendula kamtschatica	T	73	60	82,2
1993-0493	Cornus canadensis	OHB	12	0	0,0
1993-0497	Vaccinium smallii	OHB	74	11	14,9
1993-0501	Vaccinium praestans	OHB	126	126	100,0
1993-0505	Vaccinium hirtum var. pubescens	OHB	59	3	5,1
1993-0506	Hemerocallis dumortieri	OHB	23	20	87,0
1993-0508	Betula maximowicziana	T	44	13	29,5
1993-0511	Toxicodendron trichocarpum	T	79	1	1,3
1993-0517	Cirsium kamtschaticum	T	33	0	0,0
1993-0521	Aralia cordata	T-OHB	82	82	100,0
1993-0523	Picea jezoensis	T-OHB	12	12	100,0
1993-0524	Abies sachalinensis	T-OHB	9	9	100,0
1993-0526	Actinidia kolomikta	T-OHB	55	43	78,2
1993-0530	Phellodendron amurense	T-OHB	10	8	80,0
1993-0534	Clintonia udensis	LOB	8	0	0,0
1993-0536	Cornus canadensis	LOB	20	0	0,0
1993-0537	Sorbus commixta	LOB	40	13	32,5
1993-0545	Aruncus dioicus	OHB	74	74	100,0
1993-0548	Betula ermanii	OHB	41	18	43,9
1993-0552	Cirsium kamtschaticum	OHB	24	0	0,0
1993-0557	Skimmia japonica	OHB	8	0	0,0
1993-0559	Rhododendron diversipilosum	OHB	39	1	2,6
1993-0564	Abies sachalinensis	OHB	23	22	95,7
1993-0566	Betula maximowicziana	OHB	51	0	0,0
1993-0569	Gentiana trinervis	T-OHB	42	0	0,0
1993-0570	Viburnum furcatum	T-OHB	43	5	11,6
1993-0572	Spiraea betulifolia var. betulifolia	T-OHB	50	50	100,0
1993-0573	Aruncus dioicus	T-OHB	206	54	26,2
1993-0574	Berberis amurensis	T-OHB	24	24	100,0
1993-0576	Alnus maximowiczii	T-OHB	60	12	20,0
1993-0580	Sorbus sambucifolia	T-OHB	71	18	25,4
1993-0582	Fallopia sachalinensis	T	7	7	100,0
1993-0587	Angelica dahurica	T	55	0	0,0
1993-0588	Aconitum sachalinense	T	31	0	0,0
1993-0591	Weigela middendorffiana	MOB	47	42	89,4
1993-0595	Spirea betulifolia var. betulifolia	MOB	9	8	88,9
1993-0598	Betula ermanii	MOB	13	13	100,0
1993-0600	Vaccinium ovalifolium	MOB	85	19	22,4
1993-0608	Vaccinium vitis-idaea	UOB	13	13	100,0
1993-0611	Sorbus matsumurana	UOB	29	14	48,3
1993-0612	Gaultheria miqueliana	UOB	95	4	4,2

accession	species	zone	orig	sur	%
1993-0613	Lonicera chamissoi	UOB	53	44	83,0
1993-0616	Prunus nipponica	UOB	27	17	63,0
1993-0618	Actinidia kolomikta	LOB	50	21	42,0
1993-0619	Cacalia hastata var. orientalis	OHB	18	0	0,0
1993-0620	Picea jezoensis	OHB	17	12	70,6
1993-0621	Sorbus alnifolia	OHB	5	4	80,0
1993-0623	Euonymus macropterus	OHB	6	3	50,0
1993-0624	Sambucus sieboldiana var. miquelii	OHB	76	11	14,5
1993-0632	Actaea erythrocarpa	OHB	31	2	6,5
1993-0638	Rubus mesogaeus	T	15	0	0,0
1993-0639	Rubus phoenicolasius	T	105	20	19,0
1993-0645	Pachysandra terminalis	T-OHB	5	5	100,0
1993-0648	Aralia cordata	T-OHB	12	12	100,0
1993-0649	Euonymus macropterus	T-OHB	5	5	100,0
1993-0650	Actinidia kolomikta	T-OHB	55	18	32,7
1993-0651	Rubus phoenicolasius	T-OHB	38	5	13,2
1993-0652	Actinidia arguta	T-HB	50	33	66,0
1993-0656	Cercidiphyllum japonicum	T-OHB	20	9	45,0
1993-0657	Celastrus orbiculatus	T	62	53	85,5
1993-0658	Sorbaria sorbifolia var. stellipila	OHB	51	13	25,5
1993-0664	Morus alba	OHB	99	75	75,8
1993-0666	Alnus hirsuta	OHB	5	1	20,0
1993-0668	Menziesia pentandra	OHB	79	2	2,5
1993-0672	Euonymus macropterus	OHB	5	4	80,0
1993-0678	Sorbus commixta	OHB	71	39	54,9
1993-0683	Toxicodendron radicans subsp. orientale	OHB	8	5	62,5
1993-0684	Hydrangea anomala subsp. petiolaris	OHB	17	1	5,9
1993-0685	Viburnum furcatum	OHB	16	1	6,3
1993-0686	Populus maximowiczii	OHB	30	9	30,0
1993-0690	Rubus parvifolius	T	34	34	100,0
1993-0691	Salix urbaniana	T	86	62	72,1
1993-0692	Salix arbutifolia	T	16	0	0,0
1993-0693	Salix sachalinensis	T	81	27	33,3
1993-0694	Salix arbutifolia	T	52	0	0,0
1993-0698	Lonicera alpigena var. glehnii	OHB	44	35	79,5
1993-0700	Rhododendron brachycarpum	OHB	99	27	27,3
1993-0701	Clematis ochotensis	OHB	11	8	72,7
1993-0704	Taxus cuspidata	T-OHB	21	21	100,0
1993-0708	Spiraea salicifolia	T-OHB	6	6	100,0
1993-0709	Malus baccata var. mandshurica	T-OHB	5	5	100,0
1993-0711	Betula pendula	T-OHB	35	30	85,7
1993-0714	Filipendula kamtschatica	T	118	110	93,2
1993-0716	Rubus crataegifolius	T	7	7	100,0
1993-0718	Rubus phoenicolasius	T	92	1	1,1
1993-0719	Rosa amblyotis	T	101	89	88,1
1993-0721	Rosa amblyotis	T	133	133	100,0
1993-0723	Ribes latifolium	OHB	151	48	31,8
1993-0727	Actaea erythrocarpa	OHB	248	17	6,9
1993-0728	Hypericum ascyron	OHB	258	17	6,6
1993-0730	Acer ukurunduense	OHB	63	18	28,6
1993-0732	Lonicera alpigena var. glehnii	OHB	69	29	42,0
1993-0734	Rosa amblyotis	OHB	103	103	100,0

accession	species	zone	orig	sur	%
1993-0735	Spiraea salicifolia	OHB	50	8	16,0
1993-0741	Cimicifuga simplex	OHB	5	3	60,0
1993-0746	Primula japonica	T-OHB	86	0	0,0
1993-0748	Aconitum yezoense	T-OHB	143	2	1,4
1993-0750	Picea jezoensis	OHB	22	20	90,9
1993-0752	Ligularia hodgsonii	LOB	162	162	100,0
1993-0754	Aconitum yezoense	LOB	118	0	0,0
1993-0756	Betula ermanii	LOB	60	27	45,0
1993-0758	Rhododendron brachycarpum	OHB	97	12	12,4
1993-0759	Rosa rugosa	T	73	73	100,0
1993-0761	Rubus parvifolius	T	40	32	80,0
1993-0765	Spiraea miyabei	T	50	50	100,0
1993-0768	Rubus parvifolius	T	45	45	100,0
1993-0769	Rubus mesogaeus	T	75	0	0,0
1993-0770	Ribes japonicum	T	96	4	4,2
1993-0774	Cardiocrinum cordatum var. glehnii	T	152	6	3,9
1993-0780	Callicarpa dichotoma	T	158	64	40,5
1993-0781	Syringa reticulata var. reticulata	T	47	45	95,7
1993-0782	Alnus japonica	T	26	16	61,5
1993-0785	Veronica kiusiana var. japonica	T	133	0	0,0
1993-0791	Staphylea bumalda	T	22	18	81,8
1993-0796	Schisandra chinensis	T	14	6	42,9
1993-0797	Sanguisorba japonensis	T	67	67	100,0
1993-0800	Schisandra chinensis	T	96	74	77,1
1993-0801	Hydrangea paniculata	T	93	24	25,8
1993-0804	Arisaema serratum	T	30	12	40,0
1993-0813	Carex siderosticta	T	15	9	60,0
1993-0816	Rubus parvifolius	T	35	35	100,0
1993-0820	Alnus maximowiczii	LOB	41	40	97,6
1993-0821	Leucothoe grayana	LOB	11	0	0,0
1993-0822	Weigela middendorffiana	LOB	51	40	78,4
1993-0823	Tripetaleia bracteata	LOB	131	4	3,1
1993-0824	Spirea betulifolia var. betulifolia	LOB	53	53	100,0
1993-0825	Gaultheria miqueliana	LOB	64	9	14,1
1993-0826	Hydrangea anomala subsp. petiolaris	OHB	20	20	100,0
1993-0829	Viburnum furcatum	OHB	7	3	42,9
1993-0831	Agastache rugosa	T	200	0	0,0
1993-0834	Polygonatum odoratum var. maximowiczii	T	221	221	100,0
1993-0837	Alnus pendula	T	104	8	7,7
1993-0840	Angelica indet	T	9	0	0,0
1993-0841	Fraxinus mandshurica var. japonica	T	33	11	33,3
1993-0843	Veronicastrum sibiricum	T	130	130	100,0
1993-0844	Nepeta subsessilis	T	173	3	1,7
1993-0848	Maianthemum japonicum	T	43	43	100,0
1993-0849	Thalictrum aquilegiifolium var. intermedium	T	207	0	0,0
1993-0857	Sorbus commixta	LOB	83	33	39,8
1993-0858	Sasa kurilensis	LOB	5	5	100,0
1993-0859	Oplopanax horridus	LOB	7	0	0,0
1993-0860	Kalopanax septemlobus	LOB	6	4	66,7
1993-0863	Salix integra	LOB	28	12	42,9
1993-0864	Fragaria iinumae	LOB	15	0	0,0
1993-0865	Rubus pseudojaponicus	LOB	10	10	100,0

1993-0869	Tilia japonica	OHB	6	6	100,0
1993-0871	Sasa senanensis	OHB	5	5	100,0
1993-0872	Acer pictum	OHB	17	6	35,3
1993-0875	Vitis coignetiae	OHB	7	7	100,0
subtotal		154			

Appendix II. Accessions excluded from complete dataset for the reasons given in the column 'comments'. No data = HUBG's database (Lipponen & Schulman 2005) contained no other data on the accession than those entered on acquisition of the accession; n<5 = original number planted smaller than 5.

Japan 1993 accession	species	comments
1993-0475	Weigela indet.	no data
1993-0477	Magnolia hypoleuca	no data
1993-0479	Ilex sugerokii brevipedunculata	died in nursery
1993-0481	Eupatorium chinense	propagation failed
1993-0482	Euonymus macropterus	propagation failed
1993-0484	Viburnum furcatum	propagation failed
1993-0485	Hydrangea paniculata	no data
1993-0487	Hydrangea paniculata	n<5
1993-0489	Ilex sugerokii brevipedunculata	n<5
1993-0490	Pinus pumila	propagation failed
1993-0491	Alnus japonica	removed before planting
1993-0492	Skimmia japonica	propagation failed
1993-0494	Leucothoe grayana	died in nursery
1993-0495	Miscanthus sinensis	propagation failed
1993-0496	Senecio cannabifolius	propagation failed
1993-0498	Euonymus macropterus	no data
1993-0499	Toxicodendron trichocarpum	propagation failed
1993-0500	Hydrangea anomala subsp. petiolaris	wrong species, removed
1993-0502	Hosta indet.	no data
1993-0503	Carex michauxiana var. asiatica	date of removal unknown
1993-0504	Rhododendron diversipilosum	data deficient
1993-0507	Magnolia hypoleuca	no data
1993-0509	Viburnum furcatum	propagation failed
1993-0510	Ilex sugerokii brevipedunculata	propagation failed
1993-0512	Tilia japonica	no data
1993-0513	Skimmia japonica	no data
1993-0514	Vitis coignetiae	propagation failed
1993-0515	Aster glehnii	propagation failed
1993-0516	Senecio cannabifolius	propagation failed
1993-0518	Cornus controversa	propagation failed
1993-0519	Schizopepon bryoniaefolius	no data
1993-0520	Toxicodendron radicans subsp. orientale	propagation failed
1993-0522	Actaea asiatica	n<5
1993-0525	Magnolia hypoleuca	no data
1993-0527	Clintonia udensis	died in nursery
1993-0528	Polygonatum odoratum var. maximowiczii	n<5
1993-0529	Prunus nipponica var. kurilensis	n<5
1993-0531	Cercidiphyllum japonicum	n<5
1993-0532	Vincetoxicum caudatum	removed before planting
1993-0533	Alnus maximowiczii	n<5
1993-0535	Pinus pumila	propagation failed
1993-0538	Toxicodendron radicans subsp. orientale	propagation failed
1993-0539	Hydrangea anomala subsp. petiolaris	no data
1993-0540	Euonymus macropterus	propagation failed
1993-0541	Toxicodendron trichocarpum	no data
1993-0542	Cardiocrinum cordatum var. glehnii	no data

accession	species	comments
1993-0543	Schizopepon bryoniaefolius	no data
1993-0544	Laportea bulbifera	propagation failed
1993-0546	Cornus controversa	propagation failed
1993-0547	Salix miyabeana	n<5
1993-0549	Magnolia hypoleuca	mix-up of seeds during trip
1993-0550	Salix bakko Kimura	no data
1993-0551	Prunus nipponica	no data
1993-0553	Euonymus macropterus	propagation failed
1993-0554	Toxicodendron trichocarpum	propagation failed
1993-0555	Sasa kurilensis	propagation failed
1993-0556	Hemerocallis indet.	disappeared
1993-0558	Menziesia pentandra	disappeared
1993-0560	Juncus effusus subsp. decipiens	treatment not standardized
1993-0561	Rosa indet.	propagation failed
1993-0562	Taxus cuspidata	disappeared
1993-0563	Toxicodendron trichocarpum	no data
1993-0565	Magnolia hypoleuca	no data
1993-0567	Viburnum furcatum	propagation failed
1993-0568	Sanguisorba tenuifolia	propagation failed
1993-0571	Quercus mongolica	no data
1993-0575	Prunus maximowiczii	n<5
1993-0577	Cimicifuga simplex	propagation failed
1993-0578	Leucothoe grayana	propagation failed
1993-0579	Euonymus macropterus	propagation failed
1993-0581	Fallopia sachalinensis	no data
1993-0583	Spiraea betulifolia	no mentioning of zone
1993-0584	Sorbaria sorbifolia var. stellipila	no data
1993-0585	Phellodendron amurense	no mentioning of zone
1993-0586	Prunus sargentii	micropropagation unsuccessful
1993-0589	Sorbaria sorbifolia var. stellipila	propagation failed
1993-0590	Acer ukurunduense	propagation failed
1993-0592	Acer tschonoskii subsp. tschonoskii	propagation failed
1993-0593	Clintonia udensis	died in nursery
1993-0594	Gaultheria miqueliana	died in nursery
1993-0596	Sorbus matsumurana	n<5
1993-0597	Pinus pumila	n<5
1993-0599	Prunus nipponica	n<5
1993-0601	Acer ukurunduense	propagation failed
1993-0602	Acer tschonoskii subsp. tschonoskii	propagation failed
1993-0603	Prunus nipponica	no data
1993-0604	Picea glehnii	propagation failed
1993-0605	Pinus pumila	died in nursery
1993-0606	Vaccinium praestans	no data
1993-0607	Sasa kurilensis	no data
1993-0609	Tripetaleia bracteata	propagation failed
1993-0610	Rosa acicularis	no data
1993-0614	Ilex rugosa	no data
1993-0615	Leucothoe grayana	propagation failed
1993-0617	Tilingia ajanensis	wrong species, removed
1993-0622	Fraxinus mandshurica var. japonica	propagation failed
1993-0625	Cardiocrinum cordatum var. glehnii	removed before planting
1993-0626	Cimicifuga simplex	propagation failed

accession	species	comments
1993-0627	Acer pictum	propagation failed
1993-0628	Vitis coignetiae	propagation failed
1993-0629	Celastrus orbiculatus	n<5
1993-0630	Acer japonicum	propagation failed
1993-0631	Prunus maximowiczii	no data
1993-0633	Ixeris stolonifera	data deficient
1993-0634	Euonymus oxyphyllus	propagation failed
1993-0635	Syringa reticulata var. reticulata	propagation failed
1993-0636	Schisandra chinensis	n<5
1993-0637	Ostrya japonica	no data
1993-0640	Styrax obassia	propagation failed
1993-0641	Carpinus cordata	no data
1993-0642	Acer palmatum	propagation failed
1993-0643	Tilia maximowicziana	propagation failed
1993-0644	Acer palmatum	propagation failed
1993-0646	Acer pictum	propagation failed
1993-0647	Cephalotaxus harringtonia	propagation failed
1993-0653	Magnolia kobus	no data
1993-0654	Prunus ssiori	n<5
1993-0655	Rubus crataegifolius	propagation failed
1993-0659	Ulmus davidiana var. japonica	no data
1993-0660	Euonymus hamiltonianus	propagation failed
1993-0661	Ulmus davidiana var. japonica	no data
1993-0662	Acer ukurunduense	n<5
1993-0663	Euonymus planipes	propagation failed
1993-0665	Ulmus laciniata	n<5
1993-0667	Tilia japonica	no data
1993-0669	Actinidia arguta	removed before planting
1993-0670	Vitis coignetiae	propagation failed
1993-0671	Acer pictum	propagation failed
1993-0673	Acer pictum	propagation failed
1993-0674	Acer japonicum	propagation failed
1993-0675	Ribes sachalinense Nakai	no data
1993-0676	Kalopanax septemlobus	propagation failed
1993-0677	Acer japonicum	propagation failed
1993-0679	Magnolia hypoleuca	no data
1993-0680	Prunus ssiori	no data
1993-0681	Euonymus planipes	n<5
1993-0682	Prunus ssiori	propagation failed
1993-0687	Taxus cuspidata	garden origin
1993-0688	Salix arbutifolia	no data
1993-0689	Salix integra	n<5
1993-0695	Juglans ailanthifolia	no data
1993-0696	Spiraea salicifolia	n<5
1993-0697	Euonymus macropterus	propagation failed
1993-0699	Prunus ssiori	propagation failed
1993-0702	Euonymus planipes	propagation failed
1993-0703	Crataegus chlorosarca	no data
1993-0705	Toxicodendron trichocarpum	no data
1993-0706	Viburnum wrightii	no data
1993-0707	Prunus maximowiczii	n<5
1993-0710	Prunus nipponica var. kurilensis	no data

accession	species	comments
1993-0712	Syringa reticulata var. reticulata	propagation failed
1993-0713	Clematis ochotensis	n<5
1993-0715	Juglans ailanthifolia	propagation failed
1993-0717	Rubus phoenicolasius	Death caused by invasive neighbor
1993-0720	Prunus sargentii	no data
1993-0722	Cimicifuga simplex	propagation failed
1993-0724	Arisaema serratum	propagation failed
1993-0725	Prunus ssiori	propagation failed
1993-0726	Eleutherococcus senticosus	propagation failed
1993-0729	Fraxinus mandshurica var. japonica	propagation failed
1993-0731	Juglans ailanthifolia	propagation failed
1993-0733	Euonymus macropterus	n<5
1993-0736	Acer japonicum	propagation failed
1993-0737	Actinidia kolomikta	no data
1993-0738	Alnus hirsuta	removed before planting
1993-0739	Euonymus macropterus	propagation failed
1993-0740	Magnolia hypoleuca	no data
1993-0742	Sorbaria sorbifolia var. stellipila	no data
1993-0743	Acer ukurunduense	propagation failed
1993-0744	Acer japonicum	propagation failed
1993-0745	Prunus nipponica var. kurilensis	no data
1993-0747	Senecio cannabifolius	data deficient
1993-0749	Fraxinus lanuginosa	no data
1993-0751	Abies sachalinensis	propagation failed
1993-0753	Spiraea salicifolia	n<5
1993-0755	Sasa nipponica	propagation failed
1993-0757	Sasa palmata	propagation failed
1993-0760	Iris ensata	data deficient
1993-0762	Pourthiaea villosa	no data
1993-0763	Alnus japonica	wrong plant, removed
1993-0764	Zanthoxylum piperitum	propagation failed
1993-0766	Viburnum wrightii	propagation failed
1993-0767	Staphylea bumalda	no data
1993-0771	Hosta indet.	no data
1993-0772	Ampelopsis brevipedunculata	no data
1993-0773	Cercidiphyllum japonicum	propagation failed
1993-0775	Clerodendrum trichotomum	no data
1993-0776	Styrax obassia	propagation failed
1993-0777	Stephanandra incisa	n<5
1993-0778	Maackia amurensis var. buergeri	n<5
1993-0779	Rhododendron kaempferi	n<5
1993-0783	Staphylea bumalda	no data
1993-0784	Pachysandra terminalis	no data
1993-0786	Cornus controversa	n<5
1993-0787	Carpinus laxiflora	no data
1993-0788	Humulus lupulus cordifolius	no data
1993-0789	Actinidia polygama	n<5
1993-0790	Cardiocrinum cordatum var. glehnii	propagation failed
1993-0792	Acer cissifolium	n<5
1993-0793	Pinus parviflora	n<5
1993-0794	Vaccinium oldhamii	no data
1993-0795	Amorpha fruticosa	propagation failed

accession	species	comments
1993-0798	Castanea crenata	no data
1993-0799	Prunus sargentii	no data
1993-0802	Ligustrum tschonoskii	no data
1993-0803	Ilex macropoda	no data
1993-0805	Daphne kamtschatica var. jezoensis	n<5
1993-0806	Maianthemum japonicum	no data
1993-0807	Euonymus alatus	no data
1993-0808	Picrasma quassioides	no data
1993-0809	Rhamnus japonicus	no data
1993-0810	Fraxinus lanuginosa	n<5
1993-0811	Magnolia kobus	no data
1993-0812	Euonymus fortunei	no data
1993-0814	Berchemia racemosa	micropropagation unsuccessful
1993-0815	Viburnum dilatatum	no data
1993-0817	Ilex crenata	no data
1993-0818	Malus toringo var. sargentii	n<5
1993-0819	Polygonatum indet.	deficient data
1993-0827	Patrinia gibbosa	no data
1993-0828	Toxicodendron trichocarpum	propagation failed
1993-0830	Quercus mongolica	no data
1993-0832	Sasa kurilensis	n<5
1993-0833	Euonymus alatus	propagation failed
1993-0835	Corylus heterophylla var. thunbergii	no data
1993-0836	Symplocos chinensis var. leucocarpa	propagation failed
1993-0838	Rhododendron cf. albrechtii	n<5
1993-0839	Sorbus alnifolia	n<5
1993-0845	Sorbus alnifolia	wrong species, removed
1993-0843	Euonymus oxyphyllus	propagation failed
1993-0846	Tilia japonica	n<5
1993-0847	Juglans ailanthifolia	propagation failed
1993-0850	Ribes japonicum	removed before planting
1993-0851	Sasa kurilensis	n<5
1993-0852	Vitis coignetiae	propagation failed
1993-0853	Weigela hortensis	propagation failed
1993-0854	Hydrangea anomala subsp. petiolaris	died in nursery
1993-0855	Toxicodendron radicans subsp. orientale	propagation failed
1993-0856	Hydrangea anomala subsp. petiolaris	n<5
1993-0861	Eleutherococcus sciadophylloides	n<5
1993-0862	Quercus mongolica	no data
1993-0866	Botrychium virginianum	n<5
1993-0867	Scirpus wichurae	removed before planting
1993-0868	Miscanthus sinensis	propagation failed
1993-0870	Quercus mongolica	no data
1993-0873	Corylus indet.	n<5
1993-0874	Acer japonicum	n<5
1993-0877	Cardiocrinum cordatum var. glehnii	insufficient mentioning of zone
subtotal	248	
China 1994 accession	species	comments
1994-0821	Caulophyllum robustum	n<5
1994-0824	Rhamnus davurica	propagation failed
1994-0825	Tilia amurensis	n<5

accession	species	comments
1994-0827	Acer barbinerve	n<5
1994-0828	Lonicera chrysantha	data deficient
1994-0829	Dioscorea nipponica	probable cause of death treatment error
1994-0830	Eleutherococcus senticosus	no data
1994-0831	Acer triflorum	n<5
1994-0832	Abies nephrolepsis	propagation failed
1994-0835	Carpinus cordata	n<5
1994-0836	Lonicera chrysantha	data deficient
1994-0837	Deutzia glabrata	data deficient
1994-0844	Rhamnus davurica	n<5
1994-0845	Acer pseudosieboldianum	n<5
1994-0846	Acer tegmentosum	n<5
1994-0853	Rhododendron confertissimum	wrong species
1994-0854	Rhododendron redowskianum	n<5
1994-0858	Rosa acicularis	n<5
1994-0862	Picea jezoensis var. Komarovii	propagation failed
1994-0863	Picea jezoensis var. Komarovii	n<5
1994-0865	Lonicera maximowiczii	n<5
1994-0866	Ribes distans	n<5
1994-0867	Alnus mandschurica	n<5
1994-0869	Abies nephrolepsis	propagation failed
1994-0870	Viburnum opulus	n<5
1994-0872	Eleutherococcus senticosus	propagation failed
1994-0873	Tripterygium regelii	n<5
1994-0876	Corylus sieboldiana var. mandschurica	no data
1994-0877	Lycopodium obscurum	no data
1994-0882	Tilia mandshurica	n<5
1994-0883	Astragalus membranaceus	n<5
1994-0884	Tripterygium regelii	n<5
1994-0885	Philadelphus schrenkii	data deficient
1994-0887	Glycine max	WG origin
1994-0888	Betula fruticosa	propagation failed
1994-0895	Rhamnus davurica	probable cause of death treatment error
1994-0896	Viburnum sargetii	propagation failed
1994-0897	Lespedeza bicolor	n<5
1994-0898	Betula fruticosa	propagation failed
1994-0899	Betula fruticosa	propagation failed
1994-0901	Sanguisorba parviflora	data deficient
1994-0907	Crataegus maximowiczii	n<5
1994-0909	Sanguisorba officinalis	data deficient
1994-0911	Ledum palustre var. angustum	n<5
1994-0914	Ledum hypoleucum	probable cause of death treatment error
1994-0917	Ligularia fischeri	deficient data
1994-0921	Philadelphus tenuifolius	data deficient
1994-0922	Acer pseudosieboldianum	propagation failed
1994-0923	Eleutherococcus senticosus	n<5
1994-0924	Tilia amurensis	disappeared
1994-0925	Corylus sieboldiana var. mandschurica	disappeared
1994-0926	Lychnis cognata	Removed from data since was suffocated by weeds
1994-0928	Acer truncatum	n<5
1994-0929	Quercus mongolica	n<5

accession	species	comments
1994-0937	Juglans mandshurica	n<5
1994-0940	Viburnum burejaeticum	n<5
1994-0941	Euonymus alatus	propagation failed
1994-0943	Eleutherococcus senticosus	n<5
1994-0947	Lonicera maackii	suffocated by weeds
1994-0948	Ribes mandshuricum	n<5
1994-0949	Clematis serratifolia	no data
1994-0950	Calystegia sepium var. communis	no data
1994-0952	Deutzia amurensis	data deficient
1994-0953	Philadelphus schrenkii	data deficient
1994-0954	Lilium distichum	probable cause of death treatment error
1994-0957	Tilia mandshurica	n<5
1994-0959	Deutzia amurensis	data deficient
1994-0960	Paeonia obovata	n<5
1994-0961	Juglans mandshurica	propagation failed
1994-0962	Lilium distichum	no data
1994-0964	Euonymus alatus	propagation failed
1994-0966	Rubus crataegifolius	n<5
1994-0969	Juglans mandshurica	propagation failed
1994-0970	Prunus indet.	Garden origin
1994-0971	Prunus indet.	propagation failed
1994-0972	indet.	no data
1994-0974	Crataegus pinnatifida	n<5
1994-0975	Rhamnus schneideri	propagation failed
1994-0977	Fraxinus chinensis var. rhynchophylla	data deficient
1994-0978	Juglans mandshurica	n<5
1994-0979	Cimifuga dahurica	no data
1994-0984	Tilia amurensis	removed before planting
1994-0985	Lonicera maackii	n<5
1994-0986	Lilium dauricum	data deficient
1994-0987	Astilbe chinensis	data deficient
1994-0988	Veratrum maackii	no data
1994-0992	Malus domestica	Garden origin
1994-0993	Pyrus ussuriensis	Garden origin
1994-0994	Tilia amurensis	n<5
1994-0995	Tripterygium regelii	n<5
1994-0996	Acer tegmentosum	propagation failed
1994-1006	Cornus alba	propagation failed
1994-1011	Crataegus pinnatifida	propagation failed
1994-1013	Philadelphus tenuifolius	data deficient
1994-1015	Abies holophylla	n<5
1994-1016	Rhamnus davurica	data deficient
1994-1018	Tripterygium regelii	original amount unknown
1994-1020	Rubus crataegifolius	data deficient
1994-1022	Polygonum lapathifolium	seeds never set
1994-1027	Indigofera kirilowii	removed before planting
1994-1028	Lespedeza hedysaroides subsericea	deficient data
1994-1029	Amorpha fruticosa	n<5
1994-1030	Robinia pseudoacacia	propagation failed
1994-1031	Lespedeza davurica	n<5
1994-1033	Crataegus pinnatifida	no data
1994-1035	Syringa dilatata	Garden origin

accession	species	comments
1994-1037	Robinia pseudoacacia	n<5
1994-1039	Ulmus pumila	no data
1994-1040	Salix babylonica	no data
1994-1041	Populus pseudosimonii	removed before planting
1994-1042	Salix babylonica	Garden origin
1994-1043	Pyrus ussuriensis	Garden origin
1994-1044	Betula schmidtii	data deficient
1994-1046	Lysimachia clethroides	no data
1994-1047	Magnolia sieboldii	no data
1994-1051	Acer barbinerve	propagation failed
1994-1055	Lespedeza cyrtobotrya	removed before planting
1994-1056	Betula chinensis	n<5
1994-1058	Euonymus macropterus	n<5
1994-1059	Magnolia sieboldii	no data
1994-1060	Acer ukurunduense	n<5
1994-1067	Acer pseudosieboldianum	propagation failed
1994-1073	Symplocos paniculata	propagation failed
1994-1075	Rhamnus schneideri	n<5
1994-1076	Euonymus alatus	n<5
1994-1078	Fraxinus chinensis var. rhynchophylla	data deficient
1994-1087	Paeonia obovata	n<5
1994-1089	Crataegus pinnatifida	propagation failed
1994-1094	Styphnolobium japonicum	Garden origin
1994-1095	Lonicera maackii	n<5
1994-1096	Amorpha fruticosa	n<5
1994-1099	Alangium platanifolium	no data
1994-1100	Rhus chinensis	n<5
1994-1101	Rhamnus ussuriensis	n<5
1994-1103	Juglans mandshurica	n<5
1994-1104	Carpinus cordata	no data
1994-1106	Staphylea bumalda	no data
1994-1108	Prunus verecunda	disappeared
1994-1109	Prunus tomentosa	propagation failed
1994-1110	Acer tataricum	propagation failed
1994-1113	Prunus maackii	probable treatment error
1994-1114	Staphylea bumalda	removed before planting
1994-1116	Symplocos paniculata	propagation failed
1994-1119	Morus alba	probable treatment error
1994-1120	Sorbus alnifolia	disappeared in nursery
1994-1122	Weigela florida	data deficient
1994-1123	Sorbus alnifolia	propagation failed
1994-1124	Actinidia polygama	data deficient
1994-1125	Rhus chinensis	n<5
1994-1127	Quercus mongolica	n<5
1994-1129	Prunus verecunda	propagation failed
1994-1131	Maackia amurensis	propagation failed
1994-1133	Dioscorea nipponica	no data
1994-1134	Ulmus japonica var. suberosa	propagation failed
1994-1136	Euonymus planipes	n<5
1994-1139	Clematis koreana	probable treatment error
1994-1140	Ligustrum suave	propagation failed
1994-1141	Juniperus chinensis	propagation failed

accession	species	comments
1994-1142	Juniperus rigida	n<5
1994-1143	Juniperus sabina var. davurica	propagation failed
1994-1144	Juniperus sabina var. davurica	n<5
1994-1147	Populus koreana	n<5
1994-1148	Populus koreana	propagation failed
1994-1150	Prunus glandulosa	propagation failed
1994-1151	Buddleja alternifolia	Garden origin
1994-1152	Phyllostachys propinqua	n<5
1994-1187	Lonicera chrysantha	data deficient
1994-1190	Alnus hirsuta	never collected
subtotal	168	
Canada 1995		
accession	species	comments
1995-0500	Solanum melanocerasum	n<5
1995-0502	Chimaphila umbellata subsp. occidentalis	removed before planting
1995-0516	Maianthemum racemosum	cause of death: treatment error
1995-0520	Abies lasiocarpa	propagation failed
1995-0521	Lysichiton americanus	propagation failed
1995-0526	Alnus viridis subsp. sinuata	curational data deficient
1995-0528	Spiraea douglasii subsp. menziesii	data deficient
1995-0530	Disporum hookeri	propagation failed
1995-0531	Corylus cornuta	propagation failed
1995-0533	Populus trichocarpa	propagation failed
1995-0541	Geocaulon lividum	propagation failed
1995-0542	Amelanchier alnifolia	n<5
1995-0544	Ceanothus sanguineus	propagation failed
1995-0548	Pinus monticola	killed by the fungus Cronartium ribicola
1995-0551	Picea engelmannii	no seeds collected
1995-0552	Veratrum viride	propagation failed
1995-0553	Sorbus sitchensis	n<5
1995-0556	Spiraea douglasii subsp. menziesii	data deficient
1995-0562	Salix lucida subsp. lasiandra	propagation failed
1995-0567	Taxus brevifolia	n<5
1995-0576	Taxus brevifolia	n<5
1995-0578	Salix bebbiana	propagation failed
1995-0581	Pedicularis bracteosa	removed as seedlings
1995-0582	Erytronium grandiflorum	propagation failed
1995-0583	Picea engelmannii	died beore planting outside
1995-0584	Salix barclayi	propagation failed
1995-0585	Pulsatilla occidentalis	probable treatment error
1995-0586	Lupinus arcticus	n<5
1995-0588	Prunus virginiana var. melanocarpa	probable treatment error
1995-0591	Prunus pensylvanica	n<5
1995-0594	Picea glauca var. albertiana	n<5
1995-0595	Luetkea pectinata	n<5
1995-0597	Salix barclayi	propagation failed
1995-0598	Salix barclayi x barrattiana	propagation failed
1995-0600	Rhododendron albiflorum	n<5
1995-0601	Sorbus sitchensis	n<5
1995-0605	Spiraea betulifolia	probable treatment error
1995-0608	Pseudotsuga menziesii subsp. glaucescens	n<5
1995-0611	Streptopus amplexifolius	propagation failed

accession	species	comments
1995-0612	Tsuga heterophylla	no seeds
1995-0620	Cornus indet	n<5
1995-0623	Viburnum edule	n<5
1995-0625	Juniperus communis subsp. depressa	n<5
1995-0630	Pinus albicaulis	died before planting outside
1995-0632	Picea mariana	treatment error
1995-0634	Prunus pensylvanica	n<5
1995-0638	Chamaecyparis nootkatensis	data deficient
1995-0639	Blechnum spicant	propagation failed
1995-0640	Vaccinium parvifolium	n<5
1995-0652	Prunus virginiana var. melanocarpa	n<5
1995-0653	Prunus virginiana var. melanocarpa	n<5
1995-0657	Populus trichocarpa	probable treatment error
1995-0660	Heracleum sphondylium subsp. montanum	not in data since hapaxanthic
1995-0672	Salix planifolia	propagation failed
1995-0676	Picea mariana	no seeds found in cones
1995-0678	Picea mariana	propagation failed
1995-0682	Juniperus horizontalis	n<5
1995-0683	Dryas drummondii	probable cause of death treatment error
1995-0684	Juniperus horizontalis	no mentinoing of zone
1995-0685	Lilium philadelphicum	no mentinoing of zone
1995-0686	Betula occidentalis	curational data defiecient
1995-0687	Pinus flexilis	killed by the fungus Cronartium ribicola
1995-0689	Gaillardia aristata	curational data deficient
1995-0692	Betula occidentalis	curational data deficient
1995-0693	Salix arbusculoides	propagation failed
1995-0696	Salix scouleriana	unsuccessful upbringing
1995-0697	Lonicera dioica	n<5
1995-0698	Salix bebbiana	propagation failed
1995-0699	Salix barclayi	propagation failed
1995-0700	Populus tremuloides	unsuccessful upbringing
1995-0701	Populus balsamifera	unsuccessful upbringing
1995-0702	Salix bebbiana	propagation failed
1995-0703	Salix bebbiana	propagation failed
1995-0704	Salix myrtillifolia	n<5
1995-0712	B. occidentalis	curational data defiecient
1995-0717	Picea pungens	not of wild origin
1995-0719	Salix barrattiana	propagation failed
1995-0721	Picea engelmannii	n<5
1995-0722	Salix glauca	propagation failed
1995-0725	Salix glauca	propagation failed
1995-0729	Prunus virginiana var. melanocarpa	n<5
1995-0731	Salix exigua	propagation failed
1995-0735	Viburnum edule	probable treatment error
1995-0737	Ribes hirtellum	n<5
1995-0740	Artemisia ludoviciana var. gnaphalodes	propagation failed
1995-0744	Shepherdia argentea	Garden origin
1995-0745	Prunus fruticosa	Garden origin
1995-0746	Prunus japonica	n<5
1995-0747	Prinsepia sinensis	Garden origin
1995-0748	Salix pentandra	propagation failed
subtotal	90	

Japan 1999 accession	species	comments
1999-0440	Larix kaempferi	propagation failed
1999-0441	Abies veitchii	n<5
1999-0442	Taxus cuspidata	died in nursery
1999-0444	Sciadopitys verticillata	died in nursery
1999-0445	Tsuga sieboldii	n<5
1999-0446	Taxus cuspidata	unsuccessful propagation
1999-0448	Carex pumila	n<5
1999-0449	Calystegia soldanella	no mentioning of zone
1999-0450	Leymus mollis	no mentioning of zone
1999-0451	Carex bohemica	no mentioning of zone
1999-0452	Lobelia sessilifolia	no mentioning of zone
1999-0453	Hosta rectifolia	no data
1999-0454	Carex kobomugi	n<5
1999-0455	(Salicaceae) indet.	propagation failed
1999-0456	Fallopia japonica	unsufficient mentioning of zone; oroboreal
1999-0457	Clematis indet.	unsufficient mentioning of zone; oroboreal
1999-0458	Rhododendron brachycarpum	disappeared
1999-0459	Spiraea indet.	deficient data
1999-0460	Deutzia indet.	propagation failed
1999-0462	Camellia japonica	n<5
1999-0463	Pieris japonica	no mentioning of zone
1999-0464	Neolitsea sericea	propagation failed
1999-0465	Eurya japonica	t<5a
1999-0466	Trachelospermum asiaticum	propagation failed
1999-0467	Smilax china	died in nursery
1999-0470	Ampelopsis brevipedunculata	propagation failed
1999-0471	Clematis apiifolia	removed before planting
1999-0472	Stewartia pseudocamellia	no mentioning of zone
1999-0473	Mitchella undulata	died in nursery
1999-0474	Aesculus turbinata	propagation failed
1999-0475	Daphniphyllum humile	propagation failed
1999-0480	Styrax obassia	wrong plant, removed
1999-0485	Taxus cuspidata	no mentioning of zone
1999-0486	Alnus maximowiczii	no mentioning of zone
1999-0487	Deutzia crenata	propagation failed
1999-0488	Menziesia ciliicalyx	died in nursery
1999-0489	Symplocos coreana	no mentioning of zone
1999-0490	Acer micranthum	no mentioning of zone
1999-0491	Weigela hortensis	no mentioning of zone
1999-0492	Spiraea japonica	deficient data
1999-0493	Cornus controversa	n<5
1999-0494	Rhododendron lagopus	died in nursery
1999-0543	Abies veitchii	n<5
subtotal	43	
Total	549	

Appendix III. Accessions in core dataset. Accession number, species name, and zone of origin as given in HUBG's database (Lipponen & Schulman 2005). Orig = original number of individuals planted in collection area. Sur = number of individuals not died before time of data collection. % = proportion of survived individuals. S = shrub; T = tree; H = herb; D = dwarf shrub; L = liana.

Japan 1993 accession	species	zone	orig	sur	%	life form
1993-0478	Menziesia pentandra	OHB	41	0	0,0	S
1993-0483	Betula ermanii	OHB	35	24	68,6	T
1993-0486	Picea glehnii	OHB	31	29	93,5	T
1993-0488	Filipendula kamtschatica	T	73	60	82,2	H
1993-0493	Cornus canadensis	OHB	12	0	0,0	H
1993-0497	Vaccinium smallii	OHB	74	11	14,9	D
1993-0501	Vaccinium praestans	OHB	126	126	100,0	D
1993-0505	Vaccinium hirtum var. pubescens	OHB	59	3	5,1	D
1993-0506	Hemerocallis dumortieri	OHB	23	20	87,0	H
1993-0508	Betula maximowicziana	T	44	13	29,5	T
1993-0521	Aralia cordata	T-OHB	82	82	100,0	H
1993-0523	Picea jezoensis	T-OHB	12	12	100,0	T
1993-0524	Abies sachalinensis	T-OHB	9	9	100,0	T
1993-0526	Actinidia kolomikta	T-OHB	55	43	78,2	L
1993-0530	Phellodendron amurense	T-OHB	10	8	80,0	T
1993-0534	Clintonia udensis	LOB	8	0	0,0	H
1993-0536	Cornus canadensis	LOB	20	0	0,0	H
1993-0545	Aruncus dioicus	OHB	74	74	100,0	H
1993-0548	Betula ermanii	OHB	41	18	43,9	T
1993-0557	Skimmia japonica	OHB	8	0	0,0	S
1993-0559	Rhododendron diversipilosum	OHB	39	1	2,6	D
1993-0564	Abies sachalinensis	OHB	23	22	95,7	T
1993-0566	Betula maximowicziana	OHB	51	0	0,0	T
1993-0569	Gentiana trinervis	T-OHB	42	0	0,0	H
1993-0570	Viburnum furcatum	T-OHB	43	5	11,6	S
1993-0572	Spiraea betulifolia var. betulifolia	T-OHB	50	50	100,0	S
1993-0573	Aruncus dioicus	T-OHB	206	54	26,2	H
1993-0574	Berberis amurensis	T-OHB	24	24	100,0	S
1993-0580	Sorbus sambucifolia	T-OHB	71	18	25,4	S
1993-0582	Fallopia sachalinensis	T	7	7	100,0	H
1993-0588	Aconitum sachalinense	T	31	0	0,0	H
1993-0591	Weigela middendorffiana	MOB	47	42	89,4	S
1993-0595	Spirea betulifolia var. betulifolia	MOB	9	8	88,9	S
1993-0598	Betula ermanii	MOB	13	13	100,0	T
1993-0600	Vaccinium ovalifolium	MOB	85	19	22,4	D
1993-0608	Vaccinium vitis-idaea	UOB	13	13	100,0	D
1993-0611	Sorbus matsumurana	UOB	29	14	48,3	S
1993-0612	Gaultheria miqueliana	UOB	95	4	4,2	D
1993-0613	Lonicera chamissoi	UOB	53	44	83,0	S
1993-0618	Actinidia kolomikta	LOB	50	21	42,0	L
1993-0619	Cacalia hastata var. orientalis	OHB	18	0	0,0	H
1993-0620	Picea jezoensis	OHB	17	12	70,6	T
1993-0621	Sorbus alnifolia	OHB	5	4	80,0	T
1993-0624	Sambucus sieboldiana var. miquelii	OHB	76	11	14,5	T
1993-0632	Actaea erythrocarpa	OHB	31	2	6,5	H
1993-0645	Pachysandra terminalis	T-OHB	5	5	100,0	D

accession	species	zone	orig	sur	%	life form
1993-0648	Aralia cordata	T-OHB	12	12	100,0	H
1993-0650	Actinidia kolomikta	T-OHB	55	18	32,7	T
1993-0652	Actinidia arguta	T-HB	50	33	66,0	L
1993-0656	Cercidiphyllum japonicum	T-OHB	20	9	45,0	L
1993-0657	Celastrus orbiculatus	T	62	53	85,5	L
1993-0658	Sorbaria sorbifolia var. stellipila	OHB	51	13	25,5	S
1993-0664	Morus alba	OHB	99	75	75,8	T
1993-0668	Menziesia pentandra	OHB	79	2	2,5	S
1993-0683	Toxicodendron radicans subsp. orientale	OHB	8	5	62,5	L
1993-0684	Hydrangea anomala subsp. petiolaris	OHB	17	1	5,9	L
1993-0685	Viburnum furcatum	OHB	16	1	6,3	S
1993-0686	Populus maximowiczii	OHB	30	9	30,0	T
1993-0691	Salix urbaniana	T	86	62	72,1	T
1993-0692	Salix arbutifolia	T	16	0	0,0	T
1993-0694	Salix arbutifolia	T	52	0	0,0	T
1993-0698	Lonicera alpigena var. glehnii	OHB	44	35	79,5	S
1993-0700	Rhododendron brachycarpum	OHB	99	27	27,3	D
1993-0701	Clematis ochotensis	OHB	11	8	72,7	T
1993-0704	Taxus cuspidata	T-OHB	21	21	100,0	T
1993-0708	Spiraea salicifolia	T-OHB	6	6	100,0	S
1993-0709	Malus baccata var. mandshurica	T-OHB	5	5	100,0	T
1993-0711	Betula pendula	T-OHB	35	30	85,7	T
1993-0714	Filipendula kamtschatica	T	118	110	93,2	H
1993-0719	Rosa amblyotis	T	101	89	88,1	S
1993-0721	Rosa amblyotis	T	133	133	100,0	S
1993-0723	Ribes latifolium	OHB	151	48	31,8	S
1993-0727	Actaea erythrocarpa	OHB	248	17	6,9	H
1993-0728	Hypericum ascyron	OHB	258	17	6,6	H
1993-0730	Acer ukurunduense	OHB	63	18	28,6	L
1993-0732	Lonicera alpigena var. glehnii	OHB	69	29	42,0	S
1993-0734	Rosa amblyotis	OHB	103	103	100,0	S
1993-0735	Spiraea salicifolia	OHB	50	8	16,0	S
1993-0741	Cimicifuga simplex	OHB	5	3	60,0	H
1993-0746	Primula japonica	T-OHB	86	0	0,0	H
1993-0748	Aconitum yezoense	T-OHB	143	2	1,4	H
1993-0750	Picea jezoensis	OHB	22	20	90,9	T
1993-0752	Ligularia hodgsonii	LOB	162	162	100,0	H
1993-0754	Aconitum yezoense	LOB	118	0	0,0	H
1993-0756	Betula ermanii	LOB	60	27	45,0	T
1993-0758	Rhododendron brachycarpum	OHB	97	12	12,4	D
1993-0759	Rosa rugosa	T	73	73	100,0	S
1993-0765	Spiraea miyabei	T	50	50	100,0	S
1993-0770	Ribes japonicum	T	96	4	4,2	S
1993-0780	Callicarpa dichotoma	T	158	64	40,5	S
1993-0782	Alnus japonica	T	26	16	61,5	T
1993-0785	Veronica kiusiana var. japonica	T	133	0	0,0	H
1993-0791	Staphylea bumalda	T	22	18	81,8	S
1993-0796	Schisandra chinensis	T	14	6	42,9	H
1993-0797	Sanguisorba japonensis	T	67	67	100,0	H
1993-0800	Schisandra chinensis	T	96	74	77,1	H
1993-0801	Hydrangea paniculata	T	93	24	25,8	S
1993-0804	Arisaema serratum	T	30	12	40,0	H

accession	species	zone	orig	sur	%	life form
1993-0813	Carex siderosticta	T	15	9	60,0	H
1993-0821	Leucothoe grayana	LOB	11	0	0,0	H
1993-0822	Weigela middendorffiana	LOB	51	40	78,4	S
1993-0823	Tripetaleia bracteata	LOB	131	4	3,1	D
1993-0824	Spirea betulifolia var. betulifolia	LOB	53	53	100,0	S
1993-0825	Gaultheria miqueliana	LOB	64	9	14,1	D
1993-0826	Hydrangea anomala subsp. petiolaris	OHB	20	20	100,0	L
1993-0829	Viburnum furcatum	OHB	7	3	42,9	S
1993-0831	Agastache rugosa	T	200	0	0,0	H
1993-0841	Fraxinus mandshurica var. japonica	T	33	11	33,3	T
1993-0843	Veronicastrum sibiricum	T	130	130	100,0	H
1993-0844	Nepeta subsessilis	T	173	3	1,7	H
1993-0849	Thalictrum aquilegiifolium var. intermedium	T	207	0	0,0	H
1993-0860	Kalopanax septemlobus	LOB	6	4	66,7	T
1993-0864	Fragaria iinumae	LOB	15	0	0,0	H
1993-0869	Tilia japonica	OHB	6	6	100,0	T
1993-0872	Acer pictum	OHB	17	6	35,3	T
1993-0875	Vitis coignetiae	OHB	7	7	100,0	L
subtotal		116				
China 1994 accession	species	zone	orig	sur	%	life form
1994-0820	Eleutherococcus senticosus	T	27	15	55,6	S
1994-0822	Acer pseudosieboldianum	T	8	8	100,0	T
1994-0826	Aralia elata	T	35	14	40,0	S
1994-0833	Acer ukurunduense	T	9	0	0,0	T
1994-0834	Hypericum ascyron	T	218	50	22,9	H
1994-0838	Acer tschonoskii subsp. koreanum	OHB	14	10	71,4	T
1994-0839	Actinidia kolomikta	T-OHB	79	79	100,0	L
1994-0840	Tilia amurensis	T-OHB	21	14	66,7	T
1994-0842	Aconitum fischeri	OHB	8	4	50,0	H
1994-0843	Fraxinus chinensis var. rhynchophylla	T-OHB	12	9	75,0	T
1994-0847	Acer ukurunduense	OHB	13	7	53,8	T
1994-0848	Abies nephrolepsis	OHB	20	20	100,0	T
1994-0849	Acer mandshuricum	OHB	10	7	70,0	T
1994-0850	Pinus koraiensis	T-OHB	51	25	49,0	T
1994-0851	Rhododendron aureum	OHA	10	0	0,0	D
1994-0852	Vaccinium uliginosum	OHA	46	10	21,7	D
1994-0855	Sanguisorba canadensis	OHA	211	66	31,3	H
1994-0856	Aconitum artemisiifolium	UON	25	0	0,0	H
1994-0857	Cimicifuga simplex	UOB	236	150	63,6	H
1994-0859	Betula ermanii	UOB	30	29	96,7	T
1994-0860	Rosa acicularis	UOB	17	15	88,2	S
1994-0864	Betula ermanii	MOB	10	9	90,0	T
1994-0868	Rosa acicularis	MOB	87	2	2,3	S
1994-0874	Lonicera chrysantha	T	66	15	22,7	S
1994-0875	Deutzia amurensis	T	91	31	34,1	S
1994-0878	Lonicera chrysantha	T	10	4	40,0	S
1994-0879	Quercus mongolica	T	15	12	80,0	T
1994-0880	Actinidia arguta	T	20	2	10,0	L
1994-0881	Aristolochia manshuriensis	T	25	10	40,0	L
1994-0886	Spiraea chamaedryfolia	T	67	1	1,5	S
1994-0889	Spiraea salicifolia	T	94	74	78,7	S

accession	species	zone	orig	sur	%	life form
1994-0891	Acer tataricum	T	35	35	100,0	T
1994-0892	Viburnum burejaeticum	T	30	0	0,0	S
1994-0894	Berberis amurensis	T	5	5	100,0	S
1994-0900	Iris sanguinea	LOB	168	63	37,5	H
1994-0902	Vaccinium uliginosum	LOB	23	23	100,0	D
1994-0904	Dasiphora fruticosa	LOB	85	50	58,8	S
1994-0905	Hylotelephium pallescens	LOB	70	1	1,4	H
1994-0906	Gentiana uchiyamai	LOB	70	0	0,0	H
1994-0908	Spiraea salicifolia	LOB	57	22	38,6	S
1994-0910	Rhododendron lapponicum	LOB	50	0	0,0	D
1994-0913	Rosa davurica	LOB	56	56	100,0	S
1994-0915	Spiraea chamaedryfolia	LOB	45	0	0,0	S
1994-0916	Ribes triste	LOB	5	0	0,0	S
1994-0918	Acer barbinerve	OHB	15	1	6,7	T
1994-0919	Actinidia kolomikta	OHB	40	40	100,0	L
1994-0920	Rosa davurica	OHB	66	56	84,8	S
1994-0927	Vitis amurensis	OHB	75	75	100,0	L
1994-0930	Viburnum sargentii	OHB	29	24	82,8	S
1994-0931	Rosa cf. davurica x amblyotis	OHB	71	71	100,0	S
1994-0932	Schisandra chinensis	OHB	11	0	0,0	L
1994-0933	Prunus padus	OHB	19	19	100,0	T
1994-0934	Rosa acicularis	OHB	34	22	64,7	S
1994-0936	Veronicastrum sibirica	OHB	85	27	31,8	H
1994-0938	Dioscorea nipponica	OHB	64	64	100,0	H
1994-0939	Betula pendula	T-OHB	10	9	90,0	T
1994-0942	Prinsepia sinensis	T	34	16	47,1	S
1994-0944	Asparagus schoberioides	T	45	15	33,3	H
1994-0946	Vincetoxicum acuminatum	T	25	0	0,0	H
1994-0955	Lonicera chrysantha	T-OHB	50	33	66,0	S
1994-0956	Ribes mandshuricum	T-OHB	76	51	67,1	S
1994-0958	Deutzia amurensis	T-OHB	79	79	100,0	S
1994-0963	Berberis amurensis	T-OHB	34	30	88,2	S
1994-0965	Schisandra chinensis	T	5	0	0,0	L
1994-0967	Lespedeza bicolor	T	9	0	0,0	S
1994-0968	Lonicera chrysantha	T	49	38	77,6	S
1994-0976	Betula davurica	T	10	10	100,0	T
1994-0981	Rhododendron mucronulatum	T	67	67	100,0	S
1994-0982	Ribes komarovii	T	92	26	28,3	S
1994-0983	Paeonia japonica	T	7	2	28,6	H
1994-0989	Actinidia arguta	T	16	3	18,8	L
1994-0991	Paeonia obovata	T	149	149	100,0	H
1994-1000	Betula pendula	OHB	12	12	100,0	T
1994-1001	Betula costata	OHB	26	23	88,5	T
1994-1003	Berberis amurensis	OHB	75	7	9,3	S
1994-1005	Sorbaria sorbifolia	OHB	71	71	100,0	S
1994-1009	Picea jezoensis var. komarovii	OHB	94	86	91,5	T
1994-1010	Picea jezoensis var. komarovii	OHB	61	56	91,8	T
1994-1012	Lonicera chrysantha	T	105	54	51,4	S
1994-1014	Ribes komarovii	T	15	2	13,3	S
1994-1017	Abies nephrolepis	T	7	7	100,0	T
1994-1021	Aralia continentalis	T-OHB	59	6	10,2	H
1994-1023	Phellodendron amurense	T-OHB	12	2	16,7	T

accession	species	zone	orig	sur	%	life form
1994-1024	Acer tegmentosum	OHB	13	7	53,8	T
1994-1025	Larix gmelinii var. olgensis	T	21	2	9,5	T
1994-1026	Securinega suffruticosa	T	23	0	0,0	S
1994-1032	Celastrus orbiculatus	T	18	18	100,0	L
1994-1036	Lonicera maackii	T	38	28	73,7	S
1994-1045	Weigela praecox	T	87	34	39,1	S
1994-1048	Berberis amurensis	T	77	72	93,5	S
1994-1050	Vitis amurensis	T	145	15	10,3	L
1994-1053	Rhododendron schlippenbachii	T	68	28	41,2	S
1994-1054	Rhododendron mucronulatum	T	68	11	16,2	S
1994-1057	Weigela praecox	T	38	3	7,9	S
1994-1061	Duchesnea indica	T	178	0	0,0	H
1994-1062	Astilbe chinensis	T	190	98	51,6	H
1994-1063	Aruncus dioicus	T	44	44	100,0	H
1994-1064	Actaea asiatica	T	56	7	12,5	H
1994-1065	Eleutherococcus senticosus	T	58	27	46,6	S
1994-1066	Deutzia amurensis	T	76	9	11,8	S
1994-1068	Spiraea media	T	95	22	23,2	S
1994-1069	Spiraea trichocarpa	T	97	4	4,1	S
1994-1071	Celastrus orbiculatus	T	46	30	65,2	L
1994-1072	Rosa davurica	T	68	68	100,0	S
1994-1074	Viburnum sargentii	T	32	23	71,9	S
1994-1079	Arisaema serratum var. peninsulae	T	6	6	100,0	H
1994-1080	Pinus koraiensis	T	9	4	44,4	T
1994-1081	Betula costata	T	10	8	80,0	T
1994-1082	Rhododendron schlippenbachii	T	55	38	69,1	S
1994-1083	Caulophyllum robustum	T	16	0	0,0	H
1994-1085	Aruncus dioicus	T	179	54	30,2	H
1994-1086	Betula ermanii	T	7	6	85,7	T
1994-1090	Pyrus ussuriensis	T	5	5	100,0	T
1994-1091	Gleditsia japonica	T	6	6	100,0	T
1994-1092	Schisandra chinensis	T	76	4	5,3	L
1994-1093	Actinidia arguta	T	40	40	100,0	L
1994-1097	Deutzia glabrata	T	41	6	14,6	S
1994-1098	Rhododendron mucronulatum	T	70	25	35,7	S
1994-1102	Arisaema serratum var. peninsulae	T	40	24	60,0	H
1994-1105	Spiraea chamaedryfolia	T	90	0	0,0	S
1994-1107	Rosa cf. beggeriana	T	68	58	85,3	S
1994-1111	Salix koreensis	T	21	21	100,0	T
1994-1115	Pyrus ussuriensis	T	21	13	61,9	T
1994-1118	Salix maximowiczii	T	12	0	0,0	T
1994-1121	Schisandra chinensis	T	10	0	0,0	L
1994-1126	Staphylea bumalda	T	13	3	23,1	S
1994-1128	Weigela florida	T	93	3	3,2	S
1994-1130	Miscanthus sinensis	T	79	25	31,6	H
1994-1132	Ulmus laciniata	T	20	9	45,0	T
1994-1135	Prunus maackii	T	67	23	34,3	T
1994-1137	Populus cathayana	T	6	6	100,0	T
1994-1138	Arisaema serratum var. peninsulae	T	35	23	65,7	H
1994-1146	Stephanandra incisa	T	87	42	48,3	S
1994-1149	Aristolochia contorta	T	36	23	63,9	H
1994-1188	Astilbe grandis	T	206	84	40,8	H

subtotal		135				
Canada 1995 accession	species	zone	orig	sur	%	life form
1995-0504	Clintonia uniflora	LOB	40	0	0,0	H
1995-0505	Acer glabrum	LOB	23	15	65,2	T
1995-0507	Menziesia ferruginea	LOB	94	6	6,4	S
1995-0508	Sorbus scopulina	LOB	21	21	100,0	T
1995-0510	Betula papyrifera	LOB	17	15	88,2	T
1995-0511	Picea engelmannii	LOB	13	9	69,2	T
1995-0512	Thuja plicata	LOB	18	15	83,3	T
1995-0513	Cornus alba subsp. stolonifera	LOB	12	4	33,3	S
1995-0514	Rosa nutkana	LOB	39	39	100,0	S
1995-0515	Pinus contorta var. latifolia	MOB	20	16	80,0	T
1995-0518	Viburnum edule	MOB	9	0	0,0	S
1995-0519	Menziesia ferruginea	MOB	100	36	36,0	S
1995-0522	Mahonia aquifolium	LOB	120	120	100,0	S
1995-0523	Shepherdia canadensis	LOB	9	4	44,4	S
1995-0524	Vaccinium membranaceum	LOB	70	33	47,1	D
1995-0525	Rosa gymnocarpa	LOB	19	10	52,6	S
1995-0529	Actaea rubra	LOB	42	30	71,4	H
1995-0535	Thuja plicata	LOB	23	22	95,7	T
1995-0536	Vaccinium ovalifolium	LOB	48	27	56,3	D
1995-0537	Ribes lacustre	LOB	23	0	0,0	S
1995-0538	Betula pumila	LOB	9	5	55,6	S
1995-0539	Ledum groenlandicum	LOB	39	15	38,5	D
1995-0540	Kalmia polifolia	LOB	21	9	42,9	D
1995-0543	Symphoricarpos albus var. laevigatus	LOB	39	39	100,0	S
1995-0545	Spiraea betulifolia	LOB	120	120	100,0	S
1995-0546	Pseudotsuga menziesii subsp. glaucescens	LOB	10	7	70,0	T
1995-0547	Tsuga heterophylla	LOB	35	14	40,0	T
1995-0549	Sorbus sitchensis	LOB	12	5	41,7	
1995-0550	Sorbus scopulina	LOB	5	2	40,0	T
1995-0554	Abies lasiocarpa	MOB	23	16	69,6	T
1995-0555	Viburnum opulus subsp. trilobum	OHB	41	23	56,1	S
1995-0557	Rosa blanda	OHB	42	11	26,2	S
1995-0558	Prunus virginiana var. melanocarpa	OHB	64	10	15,6	T
1995-0559	Spiraea pyramidata	OHB	56	10	17,9	S
1995-0561	Ribes lacustre	OHB	20	3	15,0	S
1995-0563	Betula papyrifera	OHB	47	33	70,2	T
1995-0564	Acer glabrum	OHB	25	22	88,0	T
1995-0565	Picea engelmannii	MOB	20	15	75,0	T
1995-0566	Lonicera involucrata	MOB	30	30	100,0	S
1995-0568	Vaccinium ovalifolium	OHB	64	25	39,1	D
1995-0570	Mahonia aquifolium	OHB	20	12	60,0	S
1995-0571	Rosa gymnocarpa	OHB	39	5	12,8	S
1995-0572	Mahonia aquifolium	OHB	15	13	86,7	S
1995-0573	Vaccinium membranaceum	OHB	94	3	3,2	D
1995-0577	Rhododendron albiflorum	MOB	53	14	26,4	D
1995-0579	Menziesia ferruginea	MOB	62	40	64,5	S
1995-0580	Ribes lacustre	MOB	68	11	16,2	S
1995-0589	Viburnum edule	OHB	30	15	50,0	S
1995-0596	Mimulus lewisii	HOA	190	0	0,0	S
1995-0599	Aster modestus	HOA	210	32	15,2	H

accession	species	zone	orig	sur	%	life form
1995-0602	Carex mertensii subsp. mertensii	HOA	210	0	0,0	H
1995-0603	Ribes lacustre	MOB	63	6	9,5	S
1995-0604	Menziesia ferruginea	MOB	100	75	75,0	S
1995-0607	Acer glabrum	MOB	48	0	0,0	T
1995-0609	Ribes laxiflorum	UOB	26	11	42,3	S
1995-0610	Rhododendron albiflorum	UOB	22	2	9,1	D
1995-0613	Aruncus dioicus	MOB	227	227	100,0	H
1995-0614	Thuja plicata	MOB	19	12	63,2	T
1995-0615	Spiraea douglasii subsp. menziesii	LOB	105	10	9,5	S
1995-0616	Spiraea pyramidata	LOB	25	12	48,0	S
1995-0617	Ribes lacustre	MOB	165	165	100,0	S
1995-0618	Tsuga heterophylla	MOB	26	18	69,2	T
1995-0619	Thuja plicata	MOB	27	2	7,4	T
1995-0622	Solidago canadensis	LOB	215	40	18,6	H
1995-0624	Ribes lacustre	LOB	39	15	38,5	S
1995-0626	Betula glandulosa x pumila	LOB	11	5	45,5	S
1995-0627	Picea mariana	LOB	11	11	100,0	T
1995-0628	Vaccinium myrtilloides	LOB	23	14	60,9	D
1995-0631	Larix laricina	LOB	27	12	44,4	T
1995-0636	Prunus virginiana var. melanocarpa	HB	7	6	85,7	T
1995-0637	Symphoricarpos albus	HB	42	5	11,9	S
1995-0641	Rosa nutkana	HB	39	39	100,0	S
1995-0644	Alnus rubra	HB	29	12	41,4	T
1995-0646	Tsuga mertensiana	MOB	133	120	90,2	T
1995-0648	Menziesia ferruginea	MOB	97	7	7,2	S
1995-0656	Viburnum edule	LOB	14	4	28,6	S
1995-0658	Ribes oxyacanthoides	LOB	64	64	100,0	S
1995-0659	Aster conspicuus	LOB	218	111	50,9	H
1995-0661	Symphoricarpos albus var. laevigatus	LOB	39	39	100,0	S
1995-0662	Juniperus scopulorum	LOB	11	5	45,5	T
1995-0663	Pinus contorta var. latifolia	LOB	29	17	58,6	T
1995-0664	Delphinium glaucum	LOB	109	0	0,0	H
1995-0665	Juniperus scopulorum	LOB	12	5	41,7	T
1995-0667	Arctostaphylos uva-ursi	LOB	38	28	73,7	D
1995-0668	Picea glauca var. albertiana	MOB	6	6	100,0	T
1995-0669	Betula glandulosa	MOB	60	27	45,0	S
1995-0670	Delphinium glaucum	MOB	22	3	13,6	H
1995-0671	Dasiphora fruticosa	MOB	8	8	100,0	S
1995-0673	Shepherdia canadensis	MOB	18	10	55,6	S
1995-0674	Shepherdia canadensis	MOB	42	10	23,8	S
1995-0675	Ledum groenlandicum	MOB	60	52	86,7	D
1995-0677	Larix laricina	MOB	15	15	100,0	T
1995-0681	Dasiphora fruticosa	MOB	98	71	72,4	S
1995-0690	Rosa woodsii	MOB	42	42	100,0	S
1995-0691	Elaeagnus commutata	MOB	61	6	9,8	S
1995-0694	Picea glauca	MOB	60	59	98,3	T
1995-0695	Shepherdia canadensis	MOB	18	5	27,8	S
1995-0705	Lonicera dioica	MOB	22	18	81,8	T
1995-0706	Elaeagnus commutata	MOB	63	5	7,9	S
1995-0708	Picea glauca	MOB	11	11	100,0	T
1995-0711	Salix brachycarpa subsp. brachycarpa	MOB	36	5	13,9	T
1995-0713	Pseudotsuga menziesii subsp. glaucescens	MOB	10	8	80,0	T

accession	species	zone	orig	sur	%	life form
1995-0714	Spiraea betulifolia	MOB	63	55	87,3	S
1995-0718	Salix glauca	OHA	57	10	17,5	S
1995-0720	Betula glandulosa	OHA	35	18	51,4	S
1995-0723	Shepherdia canadensis	UOB	30	30	100,0	S
1995-0724	Betula pumila	UOB	55	8	14,5	S
1995-0726	Ribes oxyacanthoides	UOB	7	7	100,0	S
1995-0728	Symphoricarpos occidentalis	HB	39	39	100,0	S
1995-0730	Cornus alba subsp. stolonifera	HB	85	10	11,8	S
1995-0732	Prunus pensylvanica	HB	25	20	80,0	T
1995-0734	Betula neoalaskana	HB	66	41	62,1	T
1995-0736	Spiraea alba	HB	59	12	20,3	S
1995-0738	Rosa nutkana	HB	39	39	100,0	S
1995-0739	Potentilla arguta	HB	232	75	32,3	H
1995-0741	Solidago canadensis	HB	230	50	21,7	H
1995-0742	Symphoricarpos occidentalis	HB	38	15	39,5	S
1995-0743	Pinus banksiana	HB	12	7	58,3	T
subtotal	118					
Japan 1999 accession	species	zone	orig	sur	%	life form
1999-0443	Tsuga diversifolia	MOB	11	11	100	T
1999-0461	Rodgersia podophylla	OHB	63	63	100	H
1999-0468	Schisandra repanda	T	11	0	0	L
1999-0469	Stephania japonica	T	38	0	0	L
1999-0476	Pterostyrax hispida	T	31	4	12,9	S
1999-0477	Schizophragma hydrangeoides	T	45	0	0	L
1999-0481	Magnolia salicifolia	T	16	9	56,3	T
1999-0482	Acer micranthum	T	12	3	25,0	T
1999-0483	Magnolia salicifolia	T	10	5	50	T
1999-0484	Acer rufinerve	T	19	2	10,5	T
subtotal	10					
total	379					

Appendix IV. Accessions excluded from core dataset for the reasons given in the comments. LF = life form.

Japan 1993		
accession	species	comments
1993-0476	Sorbus commixta	data deficient
1993-0480	Alnus hirsuta	LF classification difficult
1993-0511	Toxicodendron trichocarpum	LF classification difficult
1993-0517	Cirsium kamtschaticum	hapaxantic
1993-0537	Sorbus commixta	data deficient
1993-0552	Cirsium kamtschaticum	hapaxanthic
1993-0576	Alnus maximowiczii	data deficient
1993-0587	Angelica dahurica	hapaxanthic
1993-0616	Prunus nipponica	data deficient
1993-0623	Euonymus macropterus	LF classification difficult
1993-0638	Rubus mesogaeus	LF classification difficult
1993-0639	Rubus phoenicolasius	LF classification difficult
1993-0649	Euonymus macropterus	LF classification difficult
1993-0651	Rubus phoenicolasius	LF classification difficult
1993-0666	Alnus hirsuta	LF classification difficult
1993-0672	Euonymus macropterus	LF classification difficult
1993-0678	Sorbus commixta	data deficient
1993-0690	Rubus parvifolius	data deficient
1993-0693	Salix sachalinensis	data deficient
1993-0716	Rubus crataegifolius	data deficient
1993-0718	Rubus phoenicolasius	LF classification difficult
1993-0761	Rubus parvifolius	probable treatment error
1993-0768	Rubus parvifolius	data deficient
1993-0769	Rubus mesogaeus	data deficient
1993-0774	Cardiocrinum cordatum var. glehnii	data deficient
1993-0781	Syringa reticulata var. reticulata	data deficient
1993-0816	Rubus parvifolius	data deficient
1993-0820	Alnus maximowiczii	LF classification difficult
1993-0834	Polygonatum odoratum var. maximowiczii	data deficient
1993-0837	Alnus pendula	LF classification difficult
1993-0840	Angelica indet	hapaxanthic
1993-0848	Maianthemum japonicum	data deficient
1993-0857	Sorbus commixta	data deficient
1993-0858	Sasa kurilensis	data deficient
1993-0859	Oplopanax horridus	LF classification difficult
1993-0863	Salix integra	data deficient
1993-0865	Rubus pseudojaponicus	data deficient
1993-0871	Sasa senanensis	data deficient
subtotal	38	
China 1994		
accession	species	comments
1994-0823	Lilium distichum	geophyte; LF classification difficult
1994-0841	Syringa reticulata var. amurensis	LF classification difficult
1994-0861	Alnus mandschurica	LF classification difficult
1994-0871	Crataegus maximowiczii	LF classification difficult
1994-0890	Syringa reticulata var. amurensis	LF classification difficult
1994-0893	Crataegus maximowiczii	LF classification difficult
1994-0903	Lilium distichum	data deficient

accession	species	comments
1994-0912	Syringa indet.	data deficient
1994-0935	Rubus crataegifolius	difficult to count individuals
1994-0945	Clematis fusca var. violacea	data deficient
1994-0951	Saussurea amara	possibly hapaxanthic
1994-0973	Clematis fusca	data deficient
1994-0980	Caragana arborescens	data deficient
1994-0990	Alnus hirsuta	LF classification difficult
1994-0997	Syringa patula	data deficient
1994-0998	Syringa wolfii	data deficient
1994-0999	Alnus hirsuta	data deficient
1994-1002	Syringa wolfii	LF classification difficult
1994-1004	Syringa reticulata var. amurensis	LF classification difficult
1994-1007	Syringa wolfii	LF classification difficult
1994-1008	Syringa wolfii	data deficient
1994-1019	Sorbus pohuashanensis	LF classification difficult
1994-1034	Euonymus hamiltonianus subsp. maackii	LF classification difficult
1994-1038	Clematis mandshurica	data deficient
1994-1049	Sorbus pohuashanensis	data deficient
1994-1052	Rhamnus schneideri	data deficient
1994-1070	Crataegus pinnatifida	data deficient
1994-1077	Rhus chinensis	LF classification difficult
1994-1084	Sorbus pohuashanensis	LF classification difficult
1994-1088	Syringa reticulata var. amurensis	data deficient
1994-1112	Rhamnus ussuriensis	data deficient
1994-1117	Rhamnus schneideri	LF classification difficult
1994-1145	Rhamnus ussuriensis	data deficient
subtotal	34	
Canada 1995 accession	species	comments
1995-0501	Rubus parviflorus	data deficient
1995-0503	Alnus viridis subsp. sinuata	LF classification difficult
1995-0506	Oplopanax horridus	data deficient
1995-0509	Clematis columbiana	data deficient
1995-0517	Alnus viridis subsp. sinuata	data deficient
1995-0527	Alnus incana subsp. tenuifolia	LF classification difficult
1995-0532	Streptopus amplexifolius	vegetatively spreading, difficult to count
1995-0534	Oplopanax horridus	LF classification difficult
1995-0560	Sorbus indet.	LF classification difficult
1995-0569	Lilium columbianum	geophyte, vegetatively spreading, difficult to count
1995-0574	Lilium columbianum	geophyte, vegetatively spreading, difficult to count
1995-0575	Amelanchier alnifolia	data deficient
1995-0587	Juniperus communis subsp. depressa	LF classification difficult
1995-0590	Crataegus douglasii	LF classification difficult
1995-0592	Alnus viridis subsp. sinuata	LF classification difficult
1995-0593	Alnus incana subsp. tenuifolia	data deficient
1995-0606	Lilium columbianum	geophyte, vegetatively spreading, difficult to count
1995-0621	Maianthemum stellatum	data deficient
1995-0629	Lilium columbianum	geophyte, vegetatively spreading, difficult to count
1995-0633	Crataegus douglasii	data deficient
1995-0635	Malus fusca	LF classification difficult
1995-0642	Malus fusca	data deficient
1995-0643	Sorbus scopulina	data deficient

accession	species	comments
1995-0645	Rubus spectabilis	data deficient
1995-0647	Alnus viridis subsp. sinuata	LF classification difficult.
1995-0649	Oplopanax horridus	data deficient
1995-0650	Amelanchier alnifolia	LF classification difficult.
1995-0651	Crataegus douglasii	data deficient
1995-0654	Malus fusca	data deficient
1995-0655	Rubus parviflorus	data deficient
1995-0666	Clematis columbiana	data deficient
1995-0679	Zigadenus elegans	data deficient
1995-0680	Juniperus communis subsp. depressa	LF classification difficult.
1995-0688	Juniperus horizontalis	data deficient
1995-0707	Alnus incana subsp. tenuifolia	LF classification difficult.
1995-0709	Artemisia campestris subsp. caudata	are biennials or short-lived perennials
1995-0710	Lilium philadelphicum	geophyte, vegetatively spreading, difficult to count
1995-0715	Lilium philadelphicum	geophyte, vegetatively spreading, difficult to count
1995-0716	Clematis occidentalis	LF classification difficult.
1995-0727	Crataegus chrysocarpa	LF classification difficult.
1995-0733	Salix serissima	LF classification difficult.
1995-0814	Rubus indet.	data deficient
subtotal	42	
Japan 1999 accession	species	comments
1999-0478	Ilex geniculata	LF classification difficult
1999-0479	Corylus sieboldiana	LF classification difficult
subtotal	2	
Total	116	