Natural England Research Report NERR037

# Crop Wild Relatives: Plant conservation for food security

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# Crop Wild Relatives: Plant conservation for food security

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# Project details

This report is a review of the scientific literature relating to Crop Wild Relatives and related aspects of crop genetic diversity conservation, carried out by the authors.

A summary of the findings covered by this report, as well as Natural England's views on this research, can be found within Natural England Research Information Note RIN037 – Crop Wild Relatives: Plant conservation for food security.

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The views expressed in this report are solely those of the authors.

# Summary

Crop Wild Relatives are the wild ancestors of crop plants and other species closely related to crops, many of which still grow in the English countryside. Crop Wild Relatives are likely to play a significant role in securing 21st century food security. This is due to their potential use in plant breeding to produce crops which withstand adverse impacts of climate change, increasing scarcity of nutrients, water and other inputs, and new pests and diseases.

A high proportion of global food production is from a small number of scientifically-bred crop varieties, with narrow genetic variation. This has resulted in loss of approximately 75% of global crop genetic diversity as these new varieties replaced a much greater range of more genetically diverse traditional crop varieties (FAO 1998a).

In cultivation wild plants have been transformed to make them more useful to humans. Many crops look different from their wild ancestors although they can freely interbreed.

The gene pool for a crop is composed of:

- commercial varieties;
- landraces (i.e. varieties developed by farmers saving their own seed rather than through formal plant breeding); and
- Crop Wild Relatives.

Crop Wild Relative conservation has received least attention of the three components of crop diversity.

Identifying which plants are Crop Wild Relatives is not straightforward. Most emphasis has been on conservation of wild populations of the same species as the crop. A much wider range of species need conservation as in crops such as wheat and potato genes from several wild species have already been used in plant breeding.

The global value of crop varieties bred from Crop Wild Relatives was estimated in 1997 to be US$115 billion per year. It is likely to have increased since then through the breeding of new varieties.

In the UK 303 taxa (i.e. species, subspecies and varieties) belonging to 15 families are wild relatives of significant agricultural and horticultural crops. Whilst some such as Plymouth pear *Pyrus cordata* and least lettuce *Lactuca saligna* are extremely rare, others are relatively common. More than 50% occur in more than one hundred 10 km squares of the national grid.

**It is the conservation of the genetic diversity of Crop Wild Relatives that is critical**. Genetic analysis of populations to identify those that contain large, or very distinctive genetic diversity should ideally inform conservation strategy.

The main options for conservation of Crop Wild Relatives are *ex situ* conservation in gene banks and *in situ* conservation in the natural or farmed environment.

Crop Wild Relatives are particularly suited to *in situ* conservation as they are able to maintain themselves in the wild under conservation management. Conservation of selected Crop Wild Relative genetic diversity in gene banks is also desirable as insurance against loss and to make material available to breeders.

A range of existing mechanisms conserve Crop Wild Relatives. Thirteen Crop Wild Relatives are on the UK Red List, of which five are protected by listing in Annex 8 of the Wildlife and Countryside Act

1982 and creeping marshwort *Apium repens* (a relative of celery) is protected under Annexes II and IVb of the EU Habitats Directive.

Statutorily protected areas and agri environment schemes in England cover almost the full range of habitat diversity and some protected areas are selected for the conservation of rare plants. The exact situation is not known but these mechanisms almost certainly conserve a large number of rare, local and common Crop Wild Relatives.

Although of fundamental importance to future food security, no country in the world is self-sufficient in genetic resources of the crops it grows. International collaboration is therefore required.

Forging a better relationship between specialists working on the conservation and utilisation of crop genetic resources and those working on biodiversity conservation is needed to optimise Crop Wild Relative conservation.

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# 1 Introduction

1.1 There are many ways in which we benefit from a healthy, biodiverse natural environment (MEA 2005; Harlow and others 2010).

1.2 At first sight it might seem counter intuitive to suggest that one of the important benefits of biodiversity is the usefulness of wild plants in the future security of our food supply. However all crops were originally wild plants. In cultivation we have changed them into the crops we now grow. In the past century we very successfully applied scientific methods to this process. We have developed new high-yielding genetically uniform varieties of crops which have consistent yield and quality and these now dominate global food production. But this means many older more genetically diverse crop landraces and varieties are no longer grown and have become extinct. An inadvertent consequence of this success in raising yield is therefore that the greater part of the genetic diversity of our domesticated plants, which we might want to use to breed new crop varieties in the future, has been lost.

1.3 As a result Crop Wild Relatives (i.e. the wild ancestors of crop plants and other species closely related to crops) are increasingly being turned to as sources of genetic diversity to breed new crop varieties. This is important as we now need crops adapted to changing climates, requiring less fertiliser and fewer energy inputs and resistant to new pests and diseases (Maxted, Ford-Lloyd & Hawkes 1997).

1.4 In this report we explore the way in which wild plant conservation may underpin future food security, the nature of crop genetic diversity, the range and diversity of Crop Wild Relatives which occur in England, and ways in which these vital genetic resources can be secured for future use.

# 2 Food security, plant breeding and crop genetic resources

## 21st century food security challenges

2.1 We have become accustomed in the past 50 years to a relatively abundant and cheap supply of food in England, the great majority produced by farming. Only recently have we again become concerned about how secure our food supply is, a concern which in a country such as England, dependent on imports for a significant part of its food, cannot be separated from concern about global food security and the need for an international response (Godfray and others 2010).

2.2 Our future food security is dependent upon a wide range of factors including:

- being less wasteful of the food we produce;
- maintenance of natural soil fertility;
- making better use of increasingly scarce natural resources such as energy, mineral phosphorus (Gilbert 2009) and water (Environment Agency 2009); and
- maintaining a highly skilled farming population.

2.3 However an additional critical factor underpinning food security is conserving and making available genetic diversity for use in the breeding of new crop varieties. This includes not just the genetic resource of the crops themselves, but also the genetic resource of Crop Wild Relatives, the wild plants from which our crop plants are descended, or to which they are related (Godfray and others 2010; Tester & Langridge 2010).

**Leading experts' views of the importance of Crop Wild Relatives:**

- "*Domestication inevitably means that only a subset of the genes available in the wild-species progenitor gene pool is represented among crop varieties and livestock breeds. Unexploited genetic material from landraces, rare breeds, and wild relatives will be important in allowing breeders to respond to new challenges.*" Godfray and others 2010.
- "*Most crop geneticists agree that enrichment of the cultivated gene pool will be necessary to meet the challenges that lie ahead.*" Tester and Langridge 2010.

2.4 During the 20$^{th}$ century we saw large increases in productivity of most of the world's major crops. Although part of this yield increase was due to the use of fertilisers, herbicides, pesticides, and mechanisation, the breeding of novel higher-yielding crop varieties has played a key role. It has been estimated that 20%-40% of increased crop yields between 1945 and 1990 was due to plant breeding (Pimentel and others 1997).

2.5 Advances in plant breeding are likely to be needed even more in the 21$^{st}$ century to secure the food supply of an increasing world population. This will require new varieties which not only increase already high levels of yield and food quality but which (Defra 2009; Tester & Langridge 2010):

- make less demand upon the environment in terms of nutrient, water and energy use;
- are adapted to changing climates; and
- are resistant to new pests and diseases.

2.6 Plant breeding is currently the only proven technology able to rise to all these challenges.

## Global loss of crop genetic diversity

2.7 In the 20th century as crop productivity increased, there was a major loss of crop genetic diversity, the raw material on which plant breeders rely. The UN Food and Agriculture Organisation (FAO) has estimated that 75% of crop genetic diversity was lost in the last century (FAO 1998a). A survey of 75 US crop species showed that 97% of historic varieties catalogued by the US Department of Agriculture are now extinct (Fowler and Mooney 1990). The European situation is no less severe. In Germany approximately 90% of crop genetic diversity has been lost and in Italy 75% has disappeared (Hammer and others 2002). Although no comparable figures are available for England it seems highly probable that similar if not greater loss of genetic diversity has occurred[1].

2.8 The reason for this loss of genetic diversity is ironically the very success of plant breeding. A relatively small number of highly productive but genetically uniform crop varieties now dominate global production of the major food crops (Jain 1988). For example more than half of all the world's wheat lands were already planted with such improved varieties by 1990 (FAO 1998a), a figure which is likely to be far higher today. Virtually all production of the major arable crops in England now uses such varieties[2] - one exception being wheat varieties grown specifically for niche markets such as thatching straw or corn dollies (Scholten and others 2003), although undiscovered examples may occur in other crops (see Appendix 1).

2.9 These genetic losses have not been confined to the developed economies. In the developing world, stimulated by the "green revolution" of the 1960s, high yielding crop varieties were introduced (along with the fertilisers, irrigation, herbicides and pesticides needed to grow them) displacing a much greater genetic diversity of crops. For example in the Philippines just two rice varieties accounted for 90 per cent of rice production in the dry season of 1984 (Stolten and others 2006).

2.10 This erosion of crop genetic diversity on a global scale coupled with a need for novel crop varieties to meet emerging environmental and other challenges, has resulted in much greater interest in the role of Crop Wild Relatives in future plant breeding. This requires a more strategic approach to their conservation (see Stolten and others 2006; Maxted & Kell 2009).

2.11 However this is not a new and untried idea. Crop Wild Relatives played a role in scientific plant breeding programmes throughout the 20th century particularly when dealing with sudden, major outbreaks of pests and diseases where no existing crop varieties or races held genes for resistance (Hijmans and others 2000). Historic use of Crop Wild Relatives has primarily been focused on the major crops such as wheat and maize, but offers significant potential for improvement of a far wider range of crops.

2.12 The diversity of Crop Wild Relatives is also under pressure as major declines in distribution and abundance have occurred. Although not scientifically researched, it is highly likely that for many species this decline is associated with a loss of genetic diversity. In the approximately 40 years before 2000, 28% of native plants declined in Britain (Thomas and others 2004). However this may under estimate the declines shown by Crop Wild Relatives. Many important Crop Wild Relatives found in England are ancient introductions by man (Maxted and others 2007), and are classified as *archaeophytes*, that is plants introduced to Britain from other parts of the world by humans, before 1500 (Preston and others 2002, 2004). Some of these are now scarce agricultural weeds (Maxted and others 2007). The largest decline in the British flora over the last

[1] In addition globally there has been use of a smaller number of crop plants. By 1998 95% of the world's dietary energy and protein was supplied by just 30 crop plants, with wheat, rice and maize contributing half of the global plant derived energy intake (FAO 1998b).

[2] Many such varieties include genetic material from Crop Wild Relatives, for example, use of wild emmer wheat *Triticum dicoccoides* is currently being explored by wheat breeders in the UK (M.Ambrose pers. comm.).

approximately 40 years has been amongst the 141 archeophytes, which despite their small number (approximately1% of the British flora) account for 39 of the 100 British plant species showing the largest decline of range (Preston et al. 2002). Such rates of loss are not confined to Britain. For example Maxted and others (1997) concluded that 25-35% of global plant genetic diversity may have been lost in the period 1988 to 2000.

2.13 Because no country in the world is today self-sufficient in the crop genetic resources it needs, the problem of genetic erosion is one of global importance and an international coordinated response is required. For example wheat is the most extensively grown crop in England, yet our farmers cultivate only highly bred strains and no wild relatives of wheat occur in North West Europe. Breeding new wheat varieties to meet 21$^{st}$ century challenges of food security depends upon genes from material stored in gene banks, landraces (i.e. crop varieties not developed through breeding programmes) maintained by traditional farming systems and the wild relatives of wheat. With the exception of material in gene banks, such as at the John Innes Centre, Norwich, such plant breeding will rely upon conservation activities in the Middle East where the greatest diversity of wheat genetic resources occur, not least in wheat's wild ancestors (Maxted and others 2008).

2.14 Although modest by comparison with the eight major global centres of crop genetic diversity which include Mediterranean parts of Europe (see Stolten and others 2006; Maxted & Kell 2009), nonetheless approximately 8% of European Crop Wild Relatives occur in the UK ( Kell and others 2008) and England can play a significant part in the conservation of Crop Wild Relatives. For some economically important crop species such as sugar beet *Beta vulgaris* and the many types of brassica *Brassica oleracea* (for example, cabbage, cauliflower, Brussels sprouts, kale, kohlrabi) populations of sea beet *B. vulgaris* ssp *maritima* and wild cabbage *B. oleracaea* ssp *oleracea* on the English coast (Preston and others 2002) may play a critical role in the development of new varieties. Oil seed rape *Brassica napus*, although not a native plant in England, arose as a species by natural hybridisation of wild cabbage *B. oleracea* and wild turnip *B. rapa .* Both these wild species occur in England and have played a role in its recent development as a globally important oil crop (Murphy 2007).

# 3 The origins of crop genetic resources

## Crop domestication

3.1 All of the crop plants we grow for food, energy and other purposes have their origin as wild plants. Harvests from most of these are known, or thought, to have been taken in the wild, long before the plants were taken into cultivation. Subsequently in domestication crop plants have undergone complex genetic changes. Over time the wild plants became modified in cultivation by selecting varieties which were more productive, disease-resistant or otherwise suited to farming. Today such crop improvement is carried out using a range of scientific techniques but throughout most of history the selection and improvement of crop plants has been carried out by those who grew them.

3.2 Establishing where and when individual species were first domesticated is by no means simple, although we can be reasonably confident it was within the geographical range of the crop's wild ancestors. Cultivation of some species goes back to the very start of agriculture which developed independently in several parts of the world. There is for example archaeological evidence in the form of preserved seed that wheat, one of the very earliest crops for which we have evidence, was first grown as a crop in the Near East approximately 10,000 years ago (Zohary and Hopf 2000; Murphy 2007).

3.3 In contrast crops in which leaves and roots are eaten, such as cabbage, carrot and parsnip have left little archaeological evidence as only these soft tissues are stored and consumed. For these three species the first known evidence of domestication is from Greek and Roman writings, although they are likely to have been domesticated earlier (Zohary and Hopf 2000).

3.4 Not all plant domestication has occurred in the distant past and even today wild species are being taken into cultivation for the first time as we continue to find new uses for wild plants. The largest number of these new domesticates are likely to be garden plants grown for ornamental purposes. However quite recently in England elder *Sambucus nigra,* a familiar hedgerow shrub, has been taken from the wild and grown commercially on farms for the first time; in order to provide a more reliable and easily harvested supply of flowers for making cordials (Prendergast & Sanderson 2004), while at the same time preventing over-collection from the wild. The unusual case of Thale cress *Arabadopsis thaliana* illustrates the much wider range of uses we find for plants (see 3.10 – 3.13), as does the non-British giant silver-grass *Miscanthus* x*. giganteus* which has been recently bred by crossing two wild grasses (*M. sinensis* and *M. sacchariflorus*) and is now being grown in England as a source of biofuel (Karp and others 2009). Elsewhere in the world jojoba *Simmondsia chinensis,* first harvested in the wild, is now grown as a planted crop for use in cosmetic and skin care products (Altieira & Merrick 1987).

3.5 Our new understanding of the very precise genetic changes which have allowed a rather limited range of plant species to be domesticated for food in the past, may mean that in the future new species of food crop can be bred from wild plants (Murphy 2007).

3.6 When a plant was first domesticated inevitably there was an arbitrary element to the selection of individual plants from a much larger wild population. This results in the crop having a narrower genetic base than its wild ancestor, a so called "domestication bottleneck" (Gepts 2004)[3]. The first farmers then made changes to the genetics of the crop through selective seed saving, potentially further reducing its original genetic diversity. Some of this selection is unconscious.

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[3] The fact that chance was involved in the initial domestication has recently led breeders and researchers to re-synthesise or re-domesticate some crops to capture a greater range of natural wild diversity.

Most notably individual plants which have lost some of their natural ability to shed their seeds when ripe are more likely to be collected and re-sown. This "non-shattering" character will become fixed in the population and one of the most striking features of crop plants grown for seed or fruit is that, unlike their wild relatives, they retain their seeds for harvesting, and come to depend entirely upon humans to gather and sow their seed. This is one reason why crop plants do not often become pernicious invasive weeds, indeed many would rapidly die out if there were no humans to sow or plant them. This has been shown in the UK for wild populations of black oats *Avena strigosa* which have escaped from cultivation. The decline of records in the wild of black oat is directly linked to its reduced cultivation (Scholten and others 2009). Other characters which often evolve due to unconscious selection by famers are:

- synchronous flowering and fruiting;
- switching from out-crossing (i.e. requiring fertilisation by pollen from another plant) to self-fertilising; and
- loss of seed dormancy (Murphy 2007).

3.7 Further genetic change in crop plants has been due to farmers consciously saving and sowing seeds selected from plants with favoured characters, such as:

- larger seeds, fruits, leaves or tubers;
- lower levels of unpleasant tasting or toxic chemicals; and
- ornamental features such as seed and flower colour (Gepts 2004).

3.8 Over time many crops have also been taken by humans beyond the limits of their wild ancestors' geographic ranges, often to new continents. For example potatoes, tomatoes and maize are familiar plants in England but originate in the Americas and form part of a major "Columbian exchange" of crop plants between the Old and New World, which occurred after the discovery of the Americas (Hawkes 1993). In these new environments crops have been subjected to further selection pressures upon their already reduced gene pool from, for example, new pests and diseases, more frequent droughts, or a colder climate.

3.9 In combination these processes have changed the character of crop plants, making them different from their wild ancestors in terms of genetics and appearance such that very often the crop and wild ancestor have been given different scientific names[4]. One of the species where this is most visually strikingly is wild cabbage *Brassica oleracea*, which is a large-leaved, woody-stemmed herbaceous plant found at scattered localities on cliffs in England, but has been bred into forms as varied as the many types of cabbage, cauliflower, Brussels sprouts, kale and kohlrabi. No fewer that eighteen different forms of *B. oleracea* are recognised in the UK National List of Varieties of Agricultural and Vegetable Crops (Kell and others 2009).

## Thale cress Arabidopsis thaliana – an unlikely new "crop" plant

3.10 A striking example of the hidden potential for practical usefulness of wild plants is provided by Thale cress *Arabidopsis thaliana*. Growing just a few inches high, with tiny white flowers and simple leaves, this superficially uninteresting annual plant appears briefly in spring in disturbed places in England and other temperate parts of the world. Today millions of plants of this "crop" are grown every year, not on farms, but in laboratories.

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[4] The scientific naming of crops and crop wild relatives is a topic of great confusion and complexity. This is partly because i) the wild plant and crop may not look at all similar even if they freely interbreed and have only a few gene differences, as is true for maize; ii) the complex variation in shapes, colours and forms of some crop plants, such as the many types of beet and cabbage; and iii) genetic exchange between crop and wild relatives.

3.11 Little known to the scientific community before the 1980s, today the great majority of investigations of plant genetics, biochemistry, cell biology and development are conducted using Thale cress. Thale cress was the first plant to have its entire genome sequenced in 2000.

3.12 The reason for this research interest in Thale cress is because it is an ideal laboratory organism and has become the plant equivalent of the fruit fly and guinea pig. Due to its small size and life span of only a few weeks, experiments take up little room and can yield quick results. The small number of genes Thale cress possesses (approximately 25,000) and the ease with which its genome can be manipulated means that the link between plant genome and plant structure and function are relatively easily explored. There are also very many known genetic variants of Thale cress available for researchers to use to probe its biology.

3.13 It is by no means an exaggeration to say that studies of Thale cress have revolutionised our understanding of plants and will underpin many advances in agriculture and plant exploitation we will see this century (Meyerowitz 2001, Somerville & Koornneef 2002).



**Plate 1** Thale cress *Arabidopsis thaliana* growing in the experimental glasshouses at the John Innes Centre, Norwich

## Crop-weed complexes – natural genetic exchange

3.14 The farming conditions which are suitable for crop plants are often similar to those to which their wild ancestors and other relatives are adapted. Crop wild ancestors are not always found in pristine semi-natural vegetation but often occur in highly anthropogenic, disturbed habitats (Jain1975). Many Crop Wild Relatives are found as weeds of agriculture. As a consequence, especially in the areas where the crop was first domesticated, a weed may be of the same species as the crop with which it grows. In such close proximity crop plant and “weed” may interbreed. The crop and its weedy wild relative are therefore not genetically isolated and form a “crop-weed complex” with an extended gene pool and a shared evolutionary history (Hawkes 1993). This transfer of genes within the crop-weed complex to some degree reduces the genetic bottleneck of domestication and is likely to have played an important role in restoring useful genetic diversity to the crop (Hawkes 1993).

3.15 Crop-weed complexes are becoming increasingly rare and persist mainly in traditional or economically marginal farming systems. In such systems crop-weed complexes may nonetheless be recognised by farmers as valued sources of useful adaptive variation. This is the case with maize farmers in parts of Mexico where the contribution of wild maize “teosinte” to the genetic resilience of maize crops is recognised (Wilkes 1967; Altieri & Merrick 1987). A particularly striking example of exploitation of the genetic exchange between crop and wild relative is in Benin, West Africa, where traditional farmers collect superior quality hybrids between domesticated and wild yams in the bush and bring these into cultivation (Scarcelli and others 2008).

3.16 Even in modern industrialised farming systems such genetic exchanges are not impossible, although their impact upon crop improvement is likely to be minimal. They have been researched recently mainly due to concerns about escape into the wild of genes from Genetically Modified (GM) crops. Widespread genetic exchange has been observed between oil-seed rape *Brassica napus* and wild turnip *B. rapa* in the UK (Wilkinson and others 2003). However possibly the most significant crop-weed complex found in developed farming contexts is in sugar beet *B. vulgaris ssp. vulgaris* where genetic studies in France have shown that in addition to wild sea beet *B. vulgaris* ssp. *maritima* and domesticated crop varieties, ruderal forms derived from hybridisation between wild and domesticated beets occur as “weeds” of agricultural fields and other disturbed habitats such a river banks (Fénart and others 2008; Viard and others 2002; Arnaud and others 2009).

## Native or non-native – does it matter?

3.17 Whilst nature conservationists have been particularly interested in whether or not a species is native to the area in which it occurs, for the conservation of crop genetic diversity this distinction is much less important.

3.18 The aim of crop diversity conservation is **to protect as much of the genetic diversity of crops and their wild relatives as possible**. This is in the expectation that some of this genetic diversity will be of value in future breeding programmes.

3.19 Non-native taxa may therefore host important genetic diversity from an agridiversity perspective. This is likely to be most notable in archaeophytes (i.e. species which were introduced into Britain before 1500) which over such timescales are likely to have adapted to local conditions, and so have unique genetic features of potential economic value. There is also an argument for prioritising the conservation of genetic diversity of archaeophyte taxa as their rate of decline is much greater than for native British species.

3.20 Some archaeophytes are of cultural interest as arable weeds seemingly introduced in prehistory with crops themselves. Remains of four archaeophytes have been found in Neolithic archaeological sites in Britain, approximately 4,500-6,000 years ago, in the period when agriculture first spread to England (Preston and others 2004).

# 4 Types of crop genetic diversity

4.1 The total genetic diversity of a crop consists of three gene pools with very different characteristics:

- Commercial varieties.
- Landraces and old varieties.
- Crop Wild Relatives.

## Commercial varieties

4.2 Often referred to by plant breeders as “elite germplasm” due to their proven value to modern agriculture, commercial varieties have been developed through scientific breeding programmes. Sale to growers is often strictly regulated to protect the rights of those who bred the variety. In the UK, varieties offered for sale must be registered on the UK National List of Varieties of Agricultural and Vegetable Crops and such registration requires that varieties pass the test of Distinctiveness, Uniformity and Stability (DUS) of appearance. This, together with the fact that farmers require cultivation and yield stability, inevitably means nearly all such modern cultivars have a very narrow range of genetic variation (FAO 1998a)[5].

## Landraces and old varieties

4.3 Throughout most of history farmers have routinely kept back part of the seed from their crop for sowing in a subsequent year. Often the seed was selected by the farmer consciously or unconsciously on the basis of presence of desirable traits. A consequence of this process was the development of distinctive local crop varieties, so-called “landraces”, similar to ecotypes for wild plant species. As well as having local cultural significance individual landraces have some or all of the following characteristics (Camacho Villa and others 2005):

- High genetic diversity.
- Local genetic adaptation.
- Recognisable identity.
- Lack of formal genetic improvement.
- Associated with traditional farming systems.
- Historical association with specific localities.

4.4 It can be difficult to separate landraces from old commercial varieties no longer offered for sale but which have been maintained by seed-saving (Negri and others 2009). Consequently two types of landrace can be defined:

- **Primary landrace:** a crop variety that has developed its unique characteristics through *in situ* selection by growers, without being subject to formal plant breeding.
- **Secondary landrace:** a crop variety that has been historically developed in the formal plant breeding sector but which is now maintained through *in situ* grower selection and seed-saving.

[5] A related class of genetic resources are “breeders materials”. During the plant breeding process increased genetic diversity is sometimes artificially induced (Brown & Caligari 2008) or found spontaneously. Many genetic lines are bred but not developed for commercial release. Some of these genetic resources are maintained in public and private collections and subsequently used in breeding programmes.

4.5 However often there is insufficient information in more developed countries such as England for a crop to be assigned confidently to one or other of the types.

4.6 Due primarily to the spread of commercial varieties, landraces are one of, if not the, most vulnerable components of global biodiversity (Maxted 2006). Although not the subject of this review the status of landraces and old varieties in England is briefly summarised in Appendix 1 based upon recent surveys (Scholten and others 2003; Kell and others 2009).

4.7 Recently, new European legislation has been introduced on "conservation and amateur varieties of vegetables" (Commission Directive 2009/145/EC). The overall aim of the Directive is to promote the sustainable use of plant genetic resources, specifically those traditionally grown varieties and landraces that are of 'no intrinsic value for crop production but developed for growing under particular conditions'.

## Crop Wild Relatives

4.8 For most domesticated species it is likely that Crop Wild Relative populations contain far more genetic diversity than the crops themselves. This is because they have not been selected from a larger population to be domesticated, and may occur in a wide range of environments with contrasting soils, climate and other factors. In addition wild species must continue to adapt to the environments they are found in, as climate and other environmental factors change. Whilst we can protect crop plants from pests and diseases with pesticides and from drought by irrigation, wild populations must have the genetic composition to naturally withstand all such stresses.

4.9 Simplistically it might be said that a Crop Wild Relative is a plant which is genetically related to a crop. However this broad definition creates difficulty, because all flowering plants are thought to have a common ancestor (Soltis and others 2005); so all might be considered to be Crop Wild Relatives. It is therefore important to establish some estimate of the degree of relatedness between crop and wild relative in order to prioritise wild genetic resources for conservation.

4.10 The most rigorous approach to delimiting the relationship between crop plants and their wild relatives is to use the Gene Pool Concept proposed by Harlan and de Wet (1971) which uses a hierarchy of three gene pools:

- **Gene Pool 1** within which Gene Pool 1A is the crop itself and Gene Pool 1B the wild forms of the crop including those which grow as agricultural weeds.
- **Gene Pool 2** which includes less closely related species from which gene transfer to the crop is possible but more difficult using conventional breeding techniques.
- **Gene Pool 3** which includes the species from which gene transfer to the crop is impossible, or if possible only using sophisticated techniques such as genetic engineering.

4.11 The Gene Pool Concept normally maps onto the taxonomic hierarchy but this may not always be the case. Populations of the same morphological species may not always be freely interfertile. For example partial hybridisation barriers exist between the three varietal groups (Japonica, Javanica and Indica) of Asian cultivated rice *Oryza sativa* (Engle and others 1966 cited in Murphy 2007), while as discussed below bread wheat *Triticum aestivum* is a product of spontaneous hybridisation of grasses from two different genera.

4.12 It is only for a small number of crops which have been the subject of the most intensive breeding programmes, such a wheat, that experimental crosses have been carried out to identify with any certainty which species fall into the 3 gene pools. In the absence of knowledge of crossing relationships Maxted and others (2006) have proposed the following classification of crop plant relatedness based upon existing taxonomic classifications:

- **Taxon[6] Group 1a** – the crop.
- **Taxon Group 1b** – the same species as the crop but not domesticated[7].
- **Taxon Group 2** – members of a group of closely related species forming a series or section of the genus in which the crop occurs.
- **Taxon Group 3** – other members of the same subgenus as the crop.
- **Taxon Group 4** – other members of the same genus as the crop.
- **Taxon group 5** – same tribe but different genus to the crop.

4.13 In both the Gene Pool and Taxon Group systems an attempt is being made to arrange taxa in a descending series reflecting the increasing difficulty of cross breeding with crops. Often species outside of Gene Pool 1 and Taxon Group 1 have been used in plant breeding. Indeed such wide crosses have been fundamental to the early development of several crops. Specifically, one of the world's most economically important crops, bread wheat *Triticum aestivum*, is a hexaploid with three species contributing genomes, *Triticum urartu* (A genome), *Aegilops speltoides* (B genome) and *A. tauschii* (D genome). The two latter species are not even in the same genus as wheat and few would guess upon seeing them that they are wheat's wild ancestors. What is more remarkable is that this hybridisation occurred naturally in prehistoric times, not using modern scientific methods (Zohary and Hopf 2000).

4.14 A review of hybridisation between species of *Brassica* and allied genera by FitzJohn and others (2007) illustrates the breadth of gene pools which may be available to breeders in some taxonomic groups, even without recourse to methods of genetic engineering. These authors found reports in the scientific literature of cabbage *Brassica oleracea* having been hybridised experimentally at least once with 15 wild species in the genus *Brassica* and seven wild species in six other genera ( *Eruca vesicaria*; *Raphanus sativus*; *Erucastrum abbyssinicum; Sinapis alba; S. arvensis; Hirschfeldia incana; Moricandia arvensis*). Wilkinson and Ford (2008) report 16 crucifer species found in the wild in England (including some rare casuals such as pale cabbage *Brassica tournefortii)* which are capable of hybridising with oil seed rape. A recent review of the use of Crop Wild Relatives in plant breeding (Maxted & Kell 2009) reported that for 29 major crop species, 183 wild taxa had been used in breeding, and others have argued that in the future plant breeding will require such broadening of the genetic base if we are to meet the challenges of 21st century production (Feldman & Sears 1981; Gepts 2004).

4.15 A case for conservation strategies which aim to conserve genetic resources beyond Gene Pool 1 and Taxon Group 1 is therefore clear, as increasingly the wide range of available crosses between species are being used in breeding programmes[8].

[6] The term taxon (pl. taxa) has been coined to refer to any formal unit of taxonomic classification, whatever its hierarchical rank, so families, genera, species and varieties are all taxa.

[7] Rather confusingly it is quite common for the crop and wild forms of the same species to be given different scientific names even though they interbreed freely.

[8] The exchange of genetic material between species by "hybridisation" is increasingly being recognised as an important process in the natural evolution of wild plants, animals and micro-organisms in the absence of human intervention (see Arnold 2006).

## Forage and fodder crops

4.16 The rearing of livestock, notably cattle and sheep, is a major part of English agriculture and this farming sector relies upon an exceptionally broad range of wild and domesticated plant genetic resources.

4.17 In 2007 36% of England was covered by various types of permanent grassland managed mainly for livestock production, a larger area than that of arable and horticultural crops (30%) (Countryside Survey 2009). Areas of moorland, heath and other habitats are also commercially grazed. In many of these grazing lands a great diversity of wild grasses and herbs are eaten by livestock.

4.18 Much of the English grassland area is improved grassland, in which particularly as a result of fertiliser application, a narrow range of high productivity species occur, notably perennial ryegrass *Lolium perenne* and white clover *Trifolium repens* (Countryside Survey 2009).

4.19 In two contexts commercially bred strains or landraces of forage and fodder crops are sown:

- Varieties bred to be sown to produce short term ley grasslands or permanent pastures, mainly grasses and clovers. Particularly important species in this context are perennial rye-grass *L. perenne*, Italian rye-grass *L. multiflorum* and white clover *T. repens*. Less extensively sown but still commercially produced species include red clover *T. pratense* (increasingly gown in organic systems), cock's-foot grass *Dactylis glomerata* and timothy *Phleum pratense*.
- Fodder crops sown as field crops. In some cases. particularly with cereals, this consists of varieties which might have entered the human food chain, but are instead fed to livestock. For some crop species familiar as human food, including turnip *Brassica rapa*, maize *Zea mays*, and beet *Beta vulgaris*, there are fodder varieties bred specifically for feeding to livestock.

4.20 In addition there are field-crop species only fed to animals. In England this is uncommon but includes a small production of sainfoin *Onobrychis vicifolia* and in many other parts of the world lucerne (alfalfa) *Medicago sativa* is grown extensively for feeding to animals, although it is not currently often grown in the UK.

# 5 Use of wild genetic resources in plant breeding programmes

5.1 Breeding programmes which involve Crop Wild Relatives have already played a role in tackling some of the world's most important crop pest and disease problems and more recently have been used to address more complex crop characteristics such as product quality and husbandry traits. The most widespread use of Crop Wild Relatives has been and remains in the development of disease and pest resistance, with 39% of use associated with improving disease resistance, 17% with pest resistance, 13% with abiotic stress, 10% with yield increase, 11% with quality improvement, 6% with husbandry improvement and 4% with cytoplasmic male sterility and fertility restoration[9] (Maxted & Kell 2009).

5.2 An early example of such breeding is the crossing in the 1900s of domesticated potatoes with the wild Mexican potato species *Solanum demissum* to produce varieties resistant to potato blight, which in the mid19$^{th}$ century caused famine in Ireland and parts of Scotland (Hawkes, 1990). More recently in the 1970s corn blight *Helminthosporium maydis* in the southern United States destroyed more than US$ 1,000 million worth of maize, reducing the crop by as much as 50% (Stolten and others 2006). The problem was solved by introducing blight resistance genes into the crop from wild Mexican maize plants (Shand 1993).

5.3 The potential of European genotypes in breeding for disease resistance has been shown in the case of sugar beet *Beta vulgaris* ssp. *vulgaris*. Rhizomania, a virus transmitted by the fungus *Polymyxa betae,* was first recorded in Italy in 1952 and has now spread to more or less all areas where sugar beet is grown. It is a persistent soil borne disease which results in malformed roots and up to 80% loss of crops (Asher 1999). Sources of resistance to rhizomania were found in wild sea beet *Beta vulgaris ssp. maritima* gathered in England, Denmark and France and were used to breed rhizomania-resistant varieties of sugar beet in the 1980s. Even though only a small amount of wild material was analysed in this research it also revealed significant genetic resistance to three other pests and diseases of sugar beet- Erwinia root rot, sugar beet root maggot and moderate leaf spot- illustrating the wide potential value of wild genetic resources in sugar beet improvement (Doney & Whitney 1990).

5.4 Beyond disease resistance some of the great diversity of opportunity which exist for use of Crop Wild Relatives in crop improvement is shown by the tomato *Lycopersicon esculentum* which has been crossed with two wild tomatoes *L. hirsutum* and *L. peruvianum* for fungus resistance, with *L. peruvianum* for nematode worm resistance and with *L. cheesmaninae* for improved adaptation to drier conditions. Crossing with *L. chmielewskii* resulted in a 2.4% increase in solid content of the fruit, worth an estimated US$250 million in California alone (Esquinas–Elcázar 1981). *Aegilops speltoides* a wild ancestor of bread wheat *T. aestivum* has provided wheat with tolerance to drought, heat, salinity, and water-logging. Varieties of durum wheat *T. durum* with improved protein content have been bred by crossing with its wild relative *T. dicoccoides* (see review by Maxted & Kell 2009).

5.5 Suffice to say, a significant proportion of modern crop varieties contain some beneficial genetic material from a Crop Wild Relative. It was estimated in 1997 that the economic value of crops incorporating genes from Crop Wild Relatives was already US$115 billion per year (Pimentel and others 1997) whilst ten Kate & Laird (1999) estimate the value of products derived from the

[9] Cytoplasmic male sterility and fertility restorers are genes which play a technical role in plant breeding and the production of F1 commercial hybrid varieties. They allow plant breeders and those producing F1 hybrids for sale to control hybridisation without labour-intensive physical sterilisation of plants.

exploitation of plant genetic resources at US$500-800 billion per year. Maxted and Kell (2009) analysed the numbers of reported uses of Crop Wild Relatives in plant breeding in the last five decades and found only five reported uses in the 1960s rising to over 100 cited uses since 2000. It is therefore likely that due to further use of Crop Wild Relatives in breeding programmes for new crop varieties the value of wild genetic resources will have increased significantly since the 1990s.

## Crop Wild Relatives, plant breeding technology and GM crops

5.6 To date less use has been made by plant breeders of Crop Wild Relatives than crop varieties and landraces. In part this is due to the fact that breeders do not have good access to these genetic resources because they are poorly represented in gene banks and breeders' collections, and until recently there have been few databases available to tell breeders where Crop Wild Relatives occur in the wild (Heywood and Dulloo 2006).

5.7 A more critical reason for the hitherto limited use of Crop Wild Relatives by plant breeders, is that with traditional scientific methods, use of Crop Wild Relatives introduces extra delay and cost into a breeding programme. This is because after crossing wild and domesticated plants the first generation plant, whilst it may have the desirable characteristics of the wild form, such as disease or drought resistance, will have many features which are undesirable in a food plant. For example a wild x domesticated carrot hybrid may lack a swollen storage root and orange colour. This is referred to as **linkage drag**, where a desirable trait "X" lies close on the chromosome to an undesirable gene affecting trait "Y", so in most crosses both bad and good genes are transferred together. Traditionally breeders have been able to overcome these effects by repeatedly back crossing the hybrid to a crop variety, in this case to restore the familiar appearance of domesticated carrot, and at each stage testing to ensure the desirable wild type genes have been retained (Brown and Caligari 2008). However with improved techniques for genome analysis (for example, Marker Assisted Selection, Next Generation Sequencing and Transcriptomics), breeders are now able to short-cut this process and "break" the linkage drag.

5.8 The suite of techniques often referred to as genetic modification (GM)[10] is also being used to identify and transfer single or small groups of genes of economic value into commercial varieties. With such specificity of gene transfer the multiple back-crosses of traditional plant breeding would not be needed. This could further open up the prospect for much greater use of Crop Wild Relative genetic material. There has been considerable controversy and concern of genetic escape and potential ecological disruption associated with GM technology. This has been due to the use of **trans-genesis**, which involves exchanges of genes which could not occur in nature, as between a bacterium and a plant. However, the majority of Crop Wild Relatives would probably be used to enhance food crops through the GM process known as **cis-genesis**.

5.9 Cis-genesis is the use of GM technology to transfer genes which could occur naturally or could be transferred to the crop using slower conventional breeding methods. The use of cis-genesis to transfer genes from Crop Wild Relatives into crops is likely to have far lower risks as the transferred genes already occur in the wild, so ecological disruption would appear much less likely. However proof of concept research has yet to be done in this area.

[10] The term genetic modification is used here to refer to use of i) a bacterium or ii) a "gene gun" to transfer DNA between organisms and produce new organisms containing recombinant DNA. (see Stewart 2004; Brown & Calgiari 2008).

# 6 Wild crop genetic resources in the UK

6.1 The objective of conserving crop genetic resources is not to conserve species for their own sake but to conserve the maximum range of their genetic diversity, in the expectation this will include genetic resources of future economic value. In concept **the unit of conservation is not the species *per se* but the genetic diversity within the species**. This results in a somewhat different emphasis to that of mainstream biodiversity conservation, where species number, distribution and abundance alone have been used in the analysis of resources. However rare alleles[11] of genes of potential economic importance may occur in a very limited number of populations of common species. Conversely rare species populations may be genetically impoverished especially if they are found in small number or have passed through such a genetic bottleneck in the past (Lawrence & Marshall 1997; Leimu & Fischer 2008). For example recent genetic research on white clover *Trifolium repens*, an important forage herb found very commonly throughout Britain, has shown that populations on the largest islands in the archipelago of St Kilda, 40 miles off the coast of the Outer Hebrides, Scotland hold a wider genetic diversity than found in all white clover populations sampled in the rest of Britain (Hargreaves and others 2010) and may include genes of potential economic importance not found elsewhere. It is possible that such hot-spots of genetic diversity occur for other Crop Wild Relatives in more remote or ecologically atypical localities, especially where they have been isolated from the genetic swamping of bred varieties, which is a likely interpretation of the St Kilda white clover example.

6.2 Ideally we would have knowledge of the genetic structure of species populations to inform our decisions about Crop Wild Relative conservation, because for common and widespread species it is clearly neither practical nor likely to be necessary to protect them all (see 6.3 – 6.7). Recent advances in genomics technology means that the gathering of this sort of information is becoming more widely and cheaply available although as yet there are very few Crop Wild Relatives in England that have been assessed.

## Genetic variation in wild *Brassica* species of England and Wales

6.3 The most efficient conservation of genetic resources is to encompass as wide a range as possible in the smallest number of “samples”, whether that be populations maintained in the wild or accessions in gene banks. Research by Watson-Jones and others (2005) demonstrates the important role of genetic analysis in optimising conservation strategies for individual Crop Wild Relative species.

6.4 The genus *Brassica* includes the cabbage, turnip, swede, mustard, oilseed rape and several other crops. It is one of the most economically important plant genera and one for which a wide range of wild genetic resources occur in England. Eight main species occur either in the wild or in cultivation in England, with several species having both wild and domesticated forms.

6.5 Studies of the genetic composition of the wild populations of three *Brassica* species were carried out:

[11] Alleles are different forms of the same gene. They control variations in plant characteristics. For example a simple hypothetical case is where a single gene controls disease resistance there may be two alleles, one giving disease resistance and the other disease susceptibility. However many variations in plant characters are controlled not by alleles of a single gene but. by alleles at several gene loci. In some cases crop improvement depends upon new combinations of alleles of several genes, possibly including common and widespread alleles in some cases.

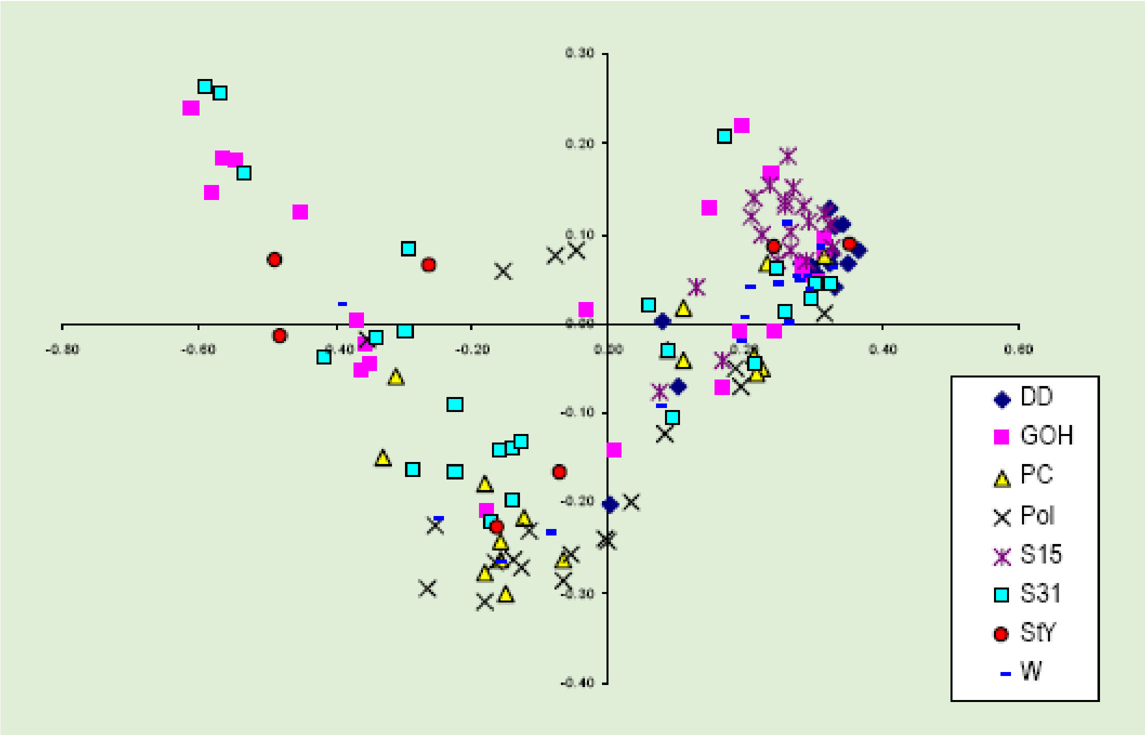
- **Cabbage** (*B. oleracea*) which occurs both as a wild plant (ssp. *oleracea*) on sea cliffs and coastal shingle and inland in many cultivated forms (for example, Brussels sprout, kale, cauliflowers, broccoli).
- **Black mustard** (*B. nigra*), a widespread wild plant of coasts, stream and river banks and disturbed places, but also grown until about the 1950s as a source of mustard seed.
- **Turnip** (*B. rapa*) which is widespread as a wild plant (ssp. *campestris*), often beside streams and rivers, and occurs both as a root and foliage crop.

6.6 Relatively minor differences were found between populations of wild cabbage (Figure 1), although populations on the more acid soils were the most genetically diverse. In contrast black mustard and wild turnip (Figure 2) populations were shown to exhibit significant genetic differences between populations.



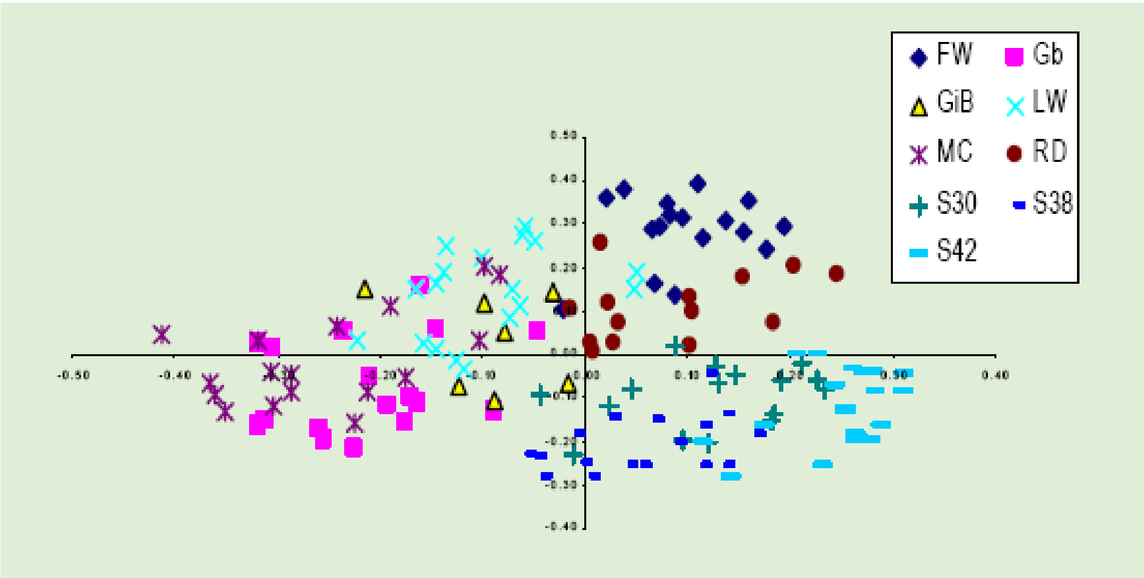
**Plate 2** Wild cabbage *Brassica oleracea* growing on chalk sea cliffs above Durdle Door, Dorset

6.7 In terms of *in situ* conservation management this means that a large part of the genetic variation of cabbage might be conserved at a relatively small number of sites but for black mustard and turnip a larger number of sites carefully chosen to cover the range of genetic variation is required.




Samples from each population are widely scattered across the graph indicating wide overall genetic variation but little genetic differentiation between populations.

**Figure 1** Principal coordinate analysis of genetic diversity for 8 wild cabbage *B. oleracea* populations (DD,GOH,PC, Pol, S15, S31,StY,W) (Watson-Jones and others 2005)




Samples from individual populations are clustered together in the graph indicating there is limited genetic variation in individual populations but significant differentiation between populations.

**Figure 2** Principal coordinate analysis of genetic diversity for 9 wild turnip *B. rapa* populations (FW,GiB,MC,S30,S42,Gb,LW,RD,S38) (Watson-Jones and others 2005)

## Taxonomically based conservation assessment

6.8 In the absence of genetic information we are fortunate in England to have the best recorded flora anywhere in the world, which gives us an unparalleled understanding of the distribution and abundance of our Crop Wild Relative taxa (i.e. species, subspecies and scientifically named varieties) with which to guide conservation decisions.

6.9 The *New Atlas of The British and Irish Flora* (Preston and others 2002) provides a comprehensive account of the current status of the British flora and patterns of distribution change shown by wild plants in the second half of the 20th century. Using these findings Maxted and others (2007) have compiled an inventory of Crop Wild Relatives and other economically and socially important wild plants in the UK. This includes plants relevant to crop improvement, plants harvested from the wild, fodder, feed and forage crops fed to animals, ornamentals, forestry, medicinal and aromatic plants, including plants used for these purposes in the past; 78% of approximately 1,400 taxa listed as native by Preston and others (2002) are included in the inventory as are 98% of 141archaeophytes. This illustrates the high proportion of species in the UK that have some realised or potential usefulness to humans.

6.10 Three hundred and three taxa in the UK inventory are identified as wild relatives of agricultural crops (including fodder crops), because they are of the same species or genus as a significant crop. Notable amongst this group are two taxa with very restricted ranges for which English populations are internationally significant:

- Perennial flax *Linum perenne* ssp. *anglicum,* as this subspecies only occurs in Britain (all but one of its populations in Eastern England) and is a relative of the important oil seed and fibre crop flax (linseed) *Linum usitatissimum.*
- Wild asparagus *Asparagus prostratus,* a rare, low-growing coastal species[12] which is confined to the western seaboard of Europe and has its largest British populations in Cornwall.

6.11 Some Crop Wild Relatives are exceptionally rare, such as Plymouth pear *Pyrus cordata* which has only two small populations in hedgerows near Plymouth, Devon and Truro, Cornwall, and least lettuce *Lactuca saligna* which has been recorded from only three 10 km squares in England since 1987, all on the South East coast, although it was previously more widespread and occurred inland in East Anglia (Preston and others 2002). Not all Crop Wild Relatives have such restricted distributions and some such as wild parsnip *Pastinaca sativa* ssp. *sylvestris* and wall barley *Hordeum murinum* are common in the UK. Indeed more than 50% of the 303 Crop Wild Relative taxa identified by Maxted and others (2007) occur in more than 100 10 km squares (see Figure 3). However the diversity of Crop Wild Relatives is highest in the lowlands of southern England with many becoming scarcer in northern England and Scotland.

[12] Wild asparagus is recognised as a distinct species *Asparagus prostratus* by most recent authorities for example, Kay and others 2001 but previously has been recognised as *Asparagus officinalis* ssp. *prostratus*.

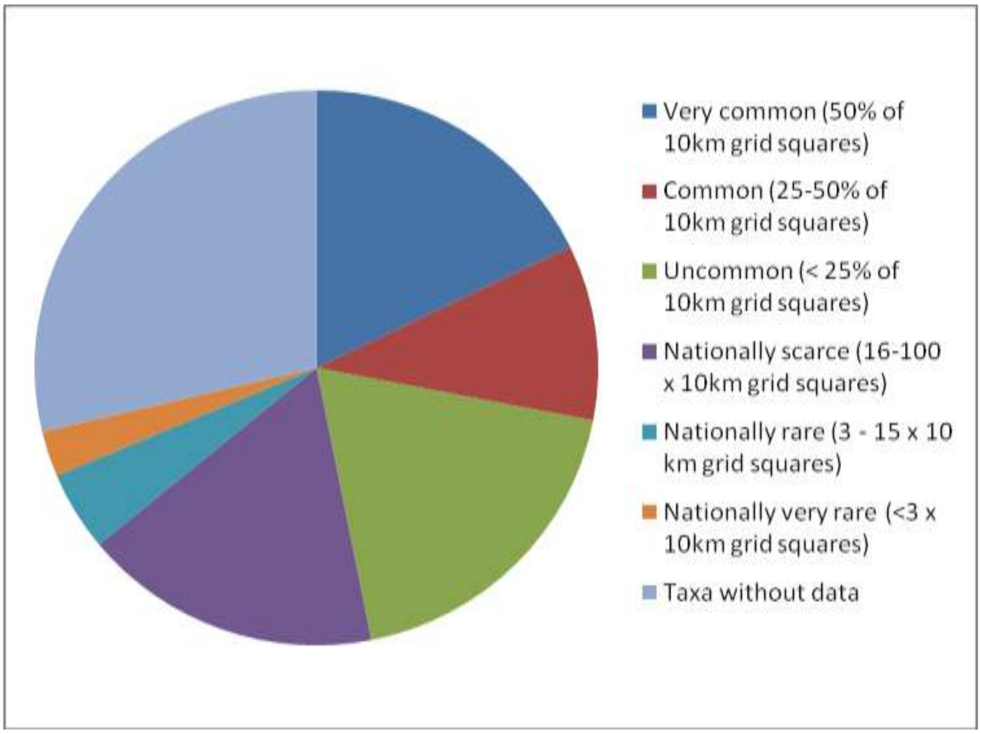



**Figure 3** Taxon distribution categories for 303 UK Crop Wild Relatives (adapted from Maxted and others 2007)

6.12 In the UK 15 families of flowering plant contain Crop Wild Relatives, encompassing 50 genera. Amongst the largest families in terms of Crop Wild Relative taxa in the UK (see Table 1) are:

- **Grass family** (Poaceae) which in the UK are mainly of value as wild relatives of forage crops, but in the case of the barley genus *Hordeum* its wild species may contain genes of value in cereal crop improvement.
- **Legume family** (Fabaceae) including vegetable wild relatives in the genus *Vicia*, and a wider range of fodder crop relatives, most notably wild clovers in the genus *Trifolium*. An important feature of this family is that its members have the ability to fix nitrogen from the atmosphere reducing the need for artificial fertilisers.
- **Rose family** (Rosaceae) the family to which most temperate fruits belong and contains wild relatives of strawberry, apple, plum, pear, blackberry and raspberry.
- **Cabbage family** (Brassicaceae) including wild relatives of a wide range of vegetable crops including cabbage, turnip, mustard, water-cress and radish.
- **Carrot family** (Apiaceae) which contains wild relatives of carrot, celery, fennel, parsnip and several herbs.

6.13 In order to illustrate the diversity of Crop Wild Relatives found in England selected examples of Crop Wild Relatives of familiar food plants are listed in Table 2, along with the names of crops they are related too, brief details of their status and habitats and the number of 10km$^2$ squares in Britain in which they were recorded between 1987 and 1999 (Preston and others 2002). The list is by no means exhaustive but illustrates the particularly high importance of coastal, grassland, hedgerow, woodland and disturbed habitats in the conservation of Crop Wild Relatives in England.

**Table 1** Major UK agricultural Crop Wild Relative families and genera (adapted from Maxted and others 2007)

| Family[13] | Genera | Taxa | Genera with number of species |
|---|---|---|---|
| Grass (Poaceae) | 15 | 113 | *Agrostis* (6), *Alopecurus* (6), *Arrhenathrum* (1), *Avena* (3), *Bromus* (8), *Cynodon* (1), *Dactylis* (1),*Festuca* (13), *Festulolium* (5), *Hordeum* (3), *Lolium* (2), *Phalaris* (1), *Phleum* (5), *Poa* (15), *Trisetum* (1) |
| Legume (Fabaceae) | 6 | 59 | *Trifolium* (23), *Vicia* (13), *Onobrychis* (1), *Medicago* (5), *Lotus* (5),*Lupinus* (2) |
| Rose (Rosaceae) | 5 | 29 | *Fragaria* (2), *Malus* (2), *Prunus* (7), *Pyrus* (2), *Rubus* (7)[14] |
| Cabbage (Brassicaceae) | 4 | 28 | *Brassica* (3), *Sinapis* (2), *Rorippa* (8), *Raphanus* (1) |
| Carrot (Apiaceae) | 7 | 22 | *Apium* (4), *Anthriscus* (3), *Petroselinum* (2), *Carum* (2), *Foeniculum* (1), *Daucus* (1), *Pastinaca* (1) |
| Onion (Lilliaceae) | 2 | 12 | *Allium* (9), *Asparagus* (1) |
| Poppy (Papaveraceae) | 1 | 11 | *Papaver* (6) |
| Potato (Solanaceae) | 1 | 7 | *Solanum* (5) |
| Currant (Grossulariaceae) | 1 | 6 | *Ribes* (6) |
| Sunflower (Asteraceae) | 3 | 5 | *Cichorium* (1), *Lactuca* (3), *Scorzonera* (1) |
| Lamb's lettuce (Valerianaceae) | 1 | 4 | *Valerianella* (4) |
| Flax (Linaceae) | 1 | 3 | *Linum* (3) |
| Beet (Chenopodiaceae) | 1 | 3 | *Beta* (1) |
| Rhubarb (Polygonaceae) | 1 | 1 | *Rheum* (1 hybrid) |
| Hemp (Cannabaceae) | 1 | 1 | *Humulus* (1) |
| **Totals** | 50 | 303 | |

[13] There is no formally recognised set of English names for plant families. Names used here are chosen to draw attention to economically important members of the family.

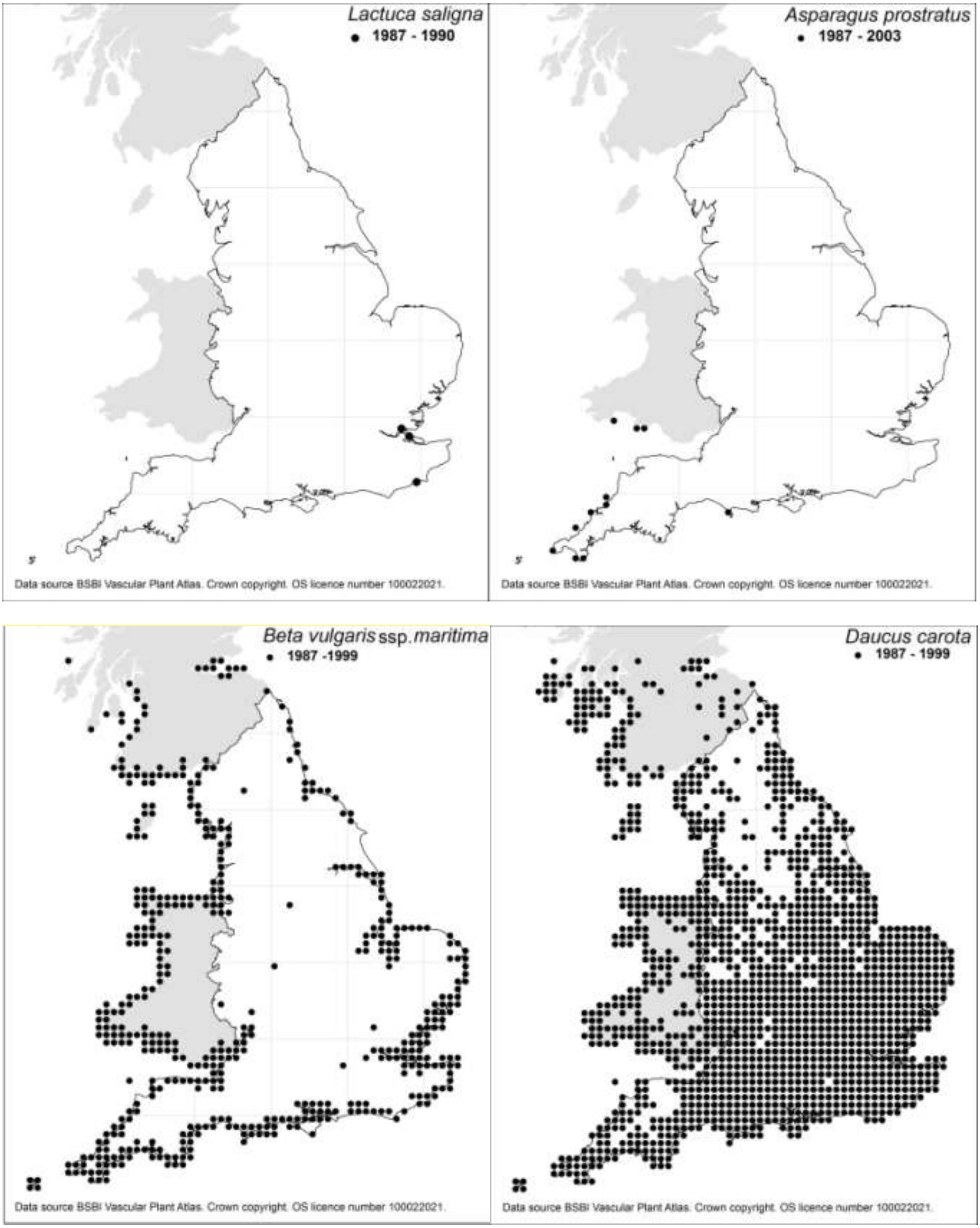
[14] In addition to the species counted here there are also many *microspecies* of *Rubus fruticosus*, i.e. morphologically and genetically distinct "types" which reproduce asexually, that is the type comes true from seed without fertilisation of the seed.

**Table 2** Illustrative Crop Wild Relatives of familiar food plants

| Crop Wild Relative | Food Plant | Status in England (No. of 10km grid squares in Britain 1987- 1999) |
|---|---|---|
| Apple, Crab<br>*Malus sylvestris* | Apple | Widespread in woodlands and hedgerows. (1866) |
| Asparagus,Wild<br>*Asparagus prostrates* | Asparagus | Rare, on sea cliffs. (17) |
| Barley, Sea<br>*Hordeum marinum* | Barley | Local in saltmarshes, brackish marshes, sea walls and open disturbed places by the sea. (63) |
| Beet, Sea<br>*Beta vulgaris* ssp *maritima* | Sugar beet;Beetroot; Fodder beet; Chard | Widespread on the coast. (453) |
| Cabbage Wild<br>*Brassica oleracea* | Cabbage; Brussel sprout; Kale; Kohl rabi | Local on calcareous or otherwise base rich sea cliffs. (62) |
| Carrot, Wild<br>*Daucus carota* ssp *carota* | Carrot | Widespread in grasslands, road verges, quarries and other disturbed places. (1559) |
| Carrot, Sea<br>*Daucus carota* ssp *gummifer* | Carrot | Local in sea cliff grasslands. (88) |
| Celery, Wild<br>*Apium graveolens* ssp *graveolens* | Celery; Celreaic | Widespread, mainly coastal on seawalls, ditches, saltmarshes and disturbed wetlands inland. (307) |
| Cherry, Bird<br>*Prunus avium* | Cherry | Widespread in woodlands and hedgerows. (1920) |
| Chives, Wild<br>*Allium schoenoprasum* | Chives | Rare on rock outcrops and rocky riverbanks. (16) |
| Fennel, Wild<br>*Foeniculum vulgare* ssp *vulgare* | Fennel | Widespread on roadsides, seawalls, and waste places. (810) |
| Flax, Pale<br>*Linum bienne* | Flax; linseed | Local mainly in grasslands and open scrub. (222) |
| Hop<br>*Humulus lupulus* | Hop | Widespread in hedgerows and moist open woods. (1169) |
| Horseradish<br>*Armoracia rusticana* | Horseradish | Widespread in waste places, rocky shores and river banks. (1355) |
| Leek, Wild<br>*Allium ampeloprasum* | Leek | Very local in hedgerows, scrub, rank grassland and marshes often near the sea. (57) |
| Lettuce, Wild<br>*Lactuca serriola* | Lettuce | Widespread in waste and disturbed places. (951) |

**Table continued...**

| Crop Wild Relative | Food Plant | Status in England (No. of 10km grid squares in Britain 1987- 1999) |
|---|---|---|
| Mustard, Black<br>*Brassica nigra* | Mustard | Widespread by rivers, on sea cliffs, shingle, roadsides and waste ground. (757) |
| Parsnip, Wild<br>*Pastinaca sativa* | Parsnip | Widespread in rank swards on neutral / calcareous soils. (830) |
| Pear, Plymouth<br>*Pyrus cordata* | Pear | Extremely rare only two small populations occur in England. (4) |
| Plum, Wild<br>*Prunus domestica* | Plum | Widespread in hedges, woodland borders and scrub. (1476) |
| Turnip, Wild<br>*Brassica rapa* | Turnip | Widespread, often along river and canal banks. (991) |




Least lettuce *Lactuca saligna* and wild asparagus *Asparagus prostratus* are rare coastal plants. In contrast sea beet *Beta vulgaris* ssp. *maritima* is found widely around the coast. Wild carrot *Daucus carota* ssp. *carota* is widespread and common in grasslands, road verges and disturbed places, throughout most of England (although on the coast it is replaced by a much more local sub species, *D. carota* ssp. *gummifer)*.

**Figure 4** Maps of 4 Crop Wild Relatives showing contrasting distribution and abundance in England

# 7 Practical options for the conservation of crop genetic diversity

## *Ex situ* and *In situ* conservation

7.1 There are primarily two technical approaches available for the conservation of plant genetic resources:

- *ex situ* conservation of genetic diversity in "gene banks", where practices for storage of genetic material are well developed; and
- *in situ* conservation, in the environment where the species occurs or occurred in the past and conservation practice is currently less well developed so far as conservation of crop genetic diversity is concerned (Iriondo & De Hond 2008, Maxted & Kell 2009).

### *Ex situ* conservation

7.2 Whether it be for landraces or Crop Wild Relatives, *ex situ* conservation requires surveying to locate populations, sampling to collect an adequate representation of genetic diversity, and transfer of samples for long term storage to specialised facilities. Most often the crop or wild relative is stored as seed but for some species which are propagated as tubers or other vegetative parts (for example, potatoes) frozen tissue is stored. Important *ex situ* collections of crop genetic resources in England occur at the John Innes Centre, Norwich; Warwick HRI, Wellesbourne; Garden Organic's Heritage Seed Library, Ryton-on-Dunsmore and the Millennium Seed Bank, Wakehurst Place. Other germplasm is stored in private collections of commercial breeders and some seed suppliers. Accessions (i.e. samples in storage) of germplasm from England occur in other parts of the world. For example the only known gene bank accession of the Hampshire commons landrace of sainfoin *Onobrychis vicifolia* is in the USA and the pea variety 'Glory of Devon', which was a popular West Country maincrop variety more than 100 years ago, was thought extinct in the England but was recently repatriated from the United States Department of Agriculture (USDA) collection and is now available from Garden Organic.

7.3 Some species are maintained in living collections. This is especially the case with fruits such as at the National Fruit Collection at Brogdale, Kent, where 3,500 named apple, pear, plum, cherry, bush fruit, vine and cob nut varieties are grown (URL: **www.nationalfruitcollection.org.uk/**). For a number of fruits, notably apples and pears, such live collections are the only conservation option as the varieties do not breed true from seed and also seeds soon lose viability in storage in standard (-20°C) storage conditions.

7.4 Such *ex situ* conservation facilities are vitally important because for many commercial cultivated varieties and landraces it is the only way in which they are likely to survive as their commercial production on farms is no longer economic. In the best collections the material is well catalogued and so readily available for use in breeding programs.

7.5 However "gene banks" are not without some drawbacks:

- E*x situ* collections require expert staff and specialist facilities as the stored germplasm needs to be catalogued and kept under controlled environmental conditions, most often as seed kept at low temperature and humidity, including increasingly cryopreservation.
- Long term funding is required and this may be insecure.
- The material stored is a sub-sample of the plant genetic diversity originally found in the field and potentially valuable genes may not have been sampled and stored.

- Over time seeds and other tissues stored lose their viability and need to be regenerated. This is done by growing them on into a new generation and harvesting new seed or other propagules for putting back into storage. Regeneration may result in loss of the genetic diversity as at each generation there is a chance that not all genes will be re-sampled and stored.
- Populations in storage are no longer adapting to environmental change such as climate change and emerging diseases, although it follows that some genes subsequently lost in wild populations due to environmental change may be conserved within stored populations.

## *In situ* conservation

7.6 *In situ* conservation of Crop Wild Relatives involves ensuring their survival in semi-natural ecosystems in which they occur or, in the case of landraces and weedy Crop Wild Relatives, on farms (see Altieira & Merrick 1987, Stolten & others 2006, Maxted & Kell 2009, Veteläinen and others 2009).

7.7 The main approaches identified for *in situ* conservation of crop genetic diversity are:

- **Genetic reserves** – setting up reserves or more often modifying the conservation objectives and management of existing reserves specifically for the purpose of conserving Crop Wild Relatives. This approach is especially suited for conservation of non-weedy Crop Wild Relatives and likely to be a particularly efficient option where protected areas have been established to conserve other aspects of biodiversity and so the additional resource requirements to conserve Crop Wild Relatives may be minimal.
- **On-farm management** – that is the maintenance of traditional farming practices, or potentially modifying the practices of modern agriculture to protect crop genetic diversity, as through agri-environment schemes. This approach in some form or other is required for conservation of landraces and those Crop Wild Relatives which occur as weeds of agriculture.

7.8 Interest in *in situ* conservation has grown since the 1980s as the disadvantages of *ex situ* approaches became more apparent. *In situ* approaches potentially have a number of advantages:

- a much larger part of the gene pool may be conserved;
- there is continuing genetic adaptation to environmental changes such as climate change and emerging diseases;
- there is no requirement for regeneration of stored material; and
- where measures for biodiversity conservation are already in place little additional cost is likely to be required to conserve Crop Wild Relatives.

7.9 *In situ* approaches are most difficult to adopt where they involve the maintenance of traditional farming systems which are no longer adapted to local market conditions and where farmers have begun to adopt new technologies. In addition all types of *in situ* conservation are at risk from:

- changes in land use;
- catastrophic events such as fires or sea water inundation which may destroy the habitats in which the Crop Wild Relatives live; and
- other factors such as climate change and non-native species invasion.

## Integration of *ex situ* and *in situ* conservation

7.10 Whilst some might think there is a simple choice between applying *ex situ* and *in situ* conservation techniques, in fact there is a case for integration of these approaches to gain the benefits of both and reduce the risk of one or the other failing.

7.11 A key practical aspect of *ex situ* conservation of Crop Wild Relatives is that it makes catalogued plant material more readily available to plant breeders than is achievable through *in situ* conservation where availability for a given species may vary from season to season and year to year, potentially delaying breeding activities. However it is essential in both *in situ* and *ex situ* approaches that the genetic resources are adequately documented so that their location and characteristics are made known to plant breeders (Maxted & Kell 2008).

# 8 The future of England's Crop Wild Relatives

## Past change and future prospects

8.1 In the second half of the 20th century 28% of native plants in Britain declined in their distribution (Thomas and others 2004). It has been estimated that on average one plant became extinct every two years in an average county during the 20th century, with the highest extinction rates in lowland counties and in southern and eastern England, where the main concentrations of Crop Wild Relatives are likely to occur. This rate of loss per county also increased during the 20th century reaching a peak in the 1960s (Walker 2003, 2007). Further analysis of the changing status of Crop Wild Relatives in England is required to inform conservation strategy but given that Crop Wild Relatives occur in a wide range of families and genera, have a diverse range of ecological requirements and occur in a wide range of semi natural and highly anthropogenic habitats these analyses suggest that many Crop Wild Relatives have declined in the 20th century. Particularly notable are the steep declines of archaeophytes (plants introduced by humans before 1500) which contain a disproportionately large number of Crop Wild Relatives (Maxted and others 2007).

8.2 Declines in Crop Wild Relatives are likely to continues into the future. Many factors may have adverse impact including:

- Indirect and direct effects on land use of increased demands for food, energy production, housing and water.
- The poorly understood potential impacts on plants of climate change.
- Difficult to predict direct impacts of non-native species including pests and disease (Natural England 2008).

8.3 With these continuing and increasing threats, a more strategic approach to conservation of Crop Wild Relatives is required. Existing mechanisms have had some effect. However in order to secure potentially valuable crop genetic resources requires some modification to the traditional approach to plant conservation which have mainly emphasised the conservation of individuals, populations and species. In the case of the conservation of Crop Wild Relatives it is the conservation of **genetic diversity of genes and their alleles** which is important.

## Genetic conservation of plants

8.4 A strategic approach therefore needs to include not only rare species but also some common species which due to their abundance may be rich reservoirs of potentially useful genetic resources.

8.5 As discussed above (see 6.3 – 6.7), strategic Crop Wild Relative conservation should be informed by genetic analysis of populations. For the great majority of species we lack this knowledge. Recent practice in sampling for *ex situ* conservation has been to use a range of proxy measures intended to capture as complete a range as possible of genetic diversity. For example sampling across the full ecological and geographic range and sampling of the range of morphological variation, including named subspecies and varieties. However research indicates these are not an infallible replacement for conservation strategies based upon genetic analysis of wild populations (for example, Watson-Jones and others 2005, Hargreaves and others 2010).

## Existing conservation mechanisms

8.6 Although their effectiveness in the conservation of Crop Wild Relatives is incompletely known a range of conservation measures are already available. None of these were designed with the conservation of Crop Wild Relatives as an objective. Nonetheless, as most are intended to conserve wild plant diversity they are likely to already play a significant role in the conservation of Crop Wild Relatives.

### Species specific measures

8.7 For the very rarest Wild Crop Relatives a bespoke plan for their conservation may be required. This has already been employed for a species recovery plan aimed at conservation of Plymouth pear *Pyrus cordata* by English Nature and local partners in the1990s ( G. Measures pers. comm.). Only six of the 303 taxa listed by Maxted and others (2007) are currently identified as priority species in the UK Biodiversity Action Plan and targeted for bespoke conservation action. Two species, wild asparagus *Asparagus prostratus* and creeping marshwort *Apium repens* have been the subject of Species Action Plans under the UK Biodiversity Action Plan (Maxted and others 2007).

8.8 Listing as a Red Data Book species, whilst of itself not ensuring conservation, offers protection to the rarest Crop Wild Relatives by drawing attention to their conservation status (but also see **Site Protection Measures** below). Using the most recent assessment of IUCN threat status criteria for vascular plants in the UK (Cheffings 2004) 13 of the 303 agriculturally most important Crop Wild Relatives are listed in the most recent GB Red List (Cheffings and Farrell 2005) and one, interrupted brome *Bromus interruptus,* is now extinct in the wild[15].

8.9 Under the Wildlife and Countryside Act 1981 five of the list of 303 Crop Wild Relatives of highest economic importance identified by Maxted and others (2007) are given strict protection against deliberate picking, uprooting or destruction at all sites where they occur, by being listed on Schedule 8 of the Act. Creeping marshwort *Apium repens,* is also similarly protected through listing under Annexes II and IVb of the EU Habitats Directive, and there are also requirements under the Directive to conserve this species though site designation.

8.10 From time to time these species conservation measures are reviewed and listings amended and it is important that at such time appropriate attention is given to Crop Wild Relative taxa. It is also important that such measures embrace the full genetic diversity of the Crop Wild Relative and this may require an adaptation of existing approaches.

[15] This species has been introduced back into the wild at three sites as part of an ongoing species recovery plan (S. Leach pers. comm.).

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**Plate 3** Fruiting Plymouth pear *Pyrus cordata* in hedgerow near Truro, Cornwall

**Table 3** IUCN threat status, legislative protection and UK Biodiversity Action Plan priority listing for UK Crop Wild Relative taxa (adapted from Maxted and others 2007)

| Taxon name | IUCN status[1] | WCA Schedule 8[2] | UKBAP Priority Species |
|---|---|---|---|
| Creeping marshwort *Apium repens* | CR | WCA-8 | UKBAP |
| Least lettuce *Lactuca saligna* | EN | WCA-8 | UKBAP |
| Viper's grass *Scorzonera humilis* | VU | WCA-8 | |
| Twin headed clover *Trifolium bocconei* | VU | | |
| Large Lizard clover *Trifolium incarnatum* ssp. *molinerii* | VU | | |
| Upright clover *Trifolium strictum* | VU | | |
| Round headed leek *Allium sphaerocephalon* | EN | WCA-8 | |
| Wild asparagus *Asparagus officinalis* ssp. *prostrates* | VU | | UKBAP |
| Interrupted brome *Bromus interruptus* | EW | | UKBAP |
| Bermuda grass *Cynodon dactylon* | VU | | |
| Confused fescue *Festuca lemanii* | DD | | |
| Blue fescue *Festuca longifolia* | VU | | |
| Red fescue *Festuca rubra* ssp. *litoralis* | DD | | |
| Red fescue *Festuca rubra* ssp. *arctica* | DD | | |
| Red fescue *Festuca rubra* ssp. *scotica* | DD | | |
| Wavy meadow grass *Poa flexuosa* | VU | | |
| Plymouth pear *Pyrus cordata* | EN | WCA-8 | UKBAP |
| Broad-fruited corn salad *Valerianella rimosa* | CR | | UKBAP |

[1] EW extinct in the wild; CR critically endangered; EN endangered; VU vulnerable; DD data deficient.

[2] UK legislative protection under the Wildlife and Countryside Act 1981 -Schedule 8.

## Site protection measures

### Site based habitat protection

8.11 Currently the level of protection afforded to Crop Wild Relatives in areas designated for wildlife conservation is incompletely known. Several designations exist to protect biodiversity including Sites of Special Scientific Interest (SSSIs) (the most extensive designation covering approximately 7% of the land area of England), National Nature Reserves (NNRs), and Special Areas of Conservation (SACs) the last under the EU Habitats Directive[16]. The criteria for selection of SSSIs has as an objective to include the best examples, within the full field of ecological variation and geographical range, of all semi-natural habitats in England through selection of a representative series (Nature Conservancy Council 1989). SACs are selected according to criteria set out in Annex III of the Directive in order to protect European priority habitats listed in Annex I of the Directive of which 63 non-marine priority habitats occur in England and are protected by SAC designation. Annex 1 priority habitats containing flowering plants range from intertidal to alpine and cover a wide range of the ecological variation of habitats in England (McLeod and others 2005).

8.12 The habitats included within protected areas are therefore likely to contain a high proportion of all Crop Wild Relatives found in the UK (this may be particularly the case for coastal, grassland and woodland sites) with the possible exception of taxa of highly disturbed anthropogenic habitats such as wild oat *Avena fatua* and wall barley *Hordeum murinum*.

### Site based species protection

8.13 In addition there are guidelines for the selection of SSSIs which conserve the largest populations of certain vascular plants over their geographical range. This includes species listed on Schedule 8 of the Wildlife and Countryside Act, Red Data Book species, endemic taxa, those threatened in Europe as a whole, and micro-species. There are also guidelines for the selection of important assemblages of rare and scarce vascular plant taxa which are likely to afford protection through site designation to a wide range of rare and local Crop Wild Relatives. Nine EU priority species listed in Annex 2 of the Habitats Directive are protected by SAC designation, of which creeping marshwort *Apium repens* is a Crop Wild Relative.

8.14 At sites with particularly important concentrations of Crop Wild Relatives or where unusual genotypes may occur, for example on unusual serpentine soils of The Lizard, Cornwall, more careful planning and management for the conservation of Crop Wild Relatives is appropriate. In 2010 a survey of Crop Wild Relatives was carried out on The Lizard National Nature Reserve (NNR) (Osborne 2010), which holds particularly important concentrations of Crop Wild Relatives (Maxted and others 2007). The survey was carried out with a view to more explicit incorporation of Crop Wild Relative conservation management into the reserve management plan and possible establishment of the site as a genetic reserve for Crop Wild Relatives. The results of The Lizard NNR survey indicate conservation of Crop Wild Relatives is broadly compatible with current management practices and that the main populations documented in the late 1970s persist. It is possible that in many instances only small changes to existing reserve and other protected area management are required to protect Crop Wild Relatives, if any.

[16] Non-marine SACs are also notified as SSSIs and form part of the total area of SSSI in England.

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Asparagus Island occurs in the left foreground of the photo and takes its name from the wild asparagus *Asparagus prostratus* which grows there, and on the cliffs in the background. The Lizard hosts an exceptionally wide range of Crop Wild Relatives including relatives of beet, carrot, chives, leek and flax.

**Plate 4** The Lizard NNR, Cornwall

## Agri-environment schemes

8.15 Currently management agreements funded under the Rural Development Programme for England support conservation of biodiversity and a range of other environmental protection goals. They operate over a large part of the English countryside and are likely to make a significant but currently un-quantified contribution to the conservation of Crop Wild Relatives.

8.16 In 2009 there were more than 58,000 agri-environment scheme agreements in England, covering over 6 million hectares – almost 66% of the agricultural land in England (Natural England 2009). Agri-environment schemes offer further protection to Crop Wild Relatives beyond that of site designation by financially supporting the management of farmed semi-natural habitats, notably hedgerows, grasslands and heathlands. However a class of important Crop Wild Relatives which are likely to be inadequately conserved within protected areas are weedy species and genotypes of arable fields, field margins, and other disturbed habitats of farmland. For example, charlock *Sinapis arvensis*, and wall barley *Hordeum murinum*. There are a range of agri-environment options which support low intensity management of field margins and buffer strips (Natural England 2010a,2010b), which are likely to make a contribution to the conservation of these more weedy Crop Wild Relatives.

## *Ex situ* storage in gene banks

8.17 Even under ideal management conditions external factors such as atmospheric pollution, non-native disease introduction and climate change can cause unavoidable change to Crop Wild Relative status including local and national extinction. The storage in gene banks of seed from wild populations of targeted species and genotypes is therefore desirable as insurance. Currently Crop Wild Relatives are poorly represented in *ex situ* collections However the situation in the UK is more favourable than in some other countries. There is an ongoing programme for the conservation of a small number of seed samples of each UK wild plant species suitable for storage as seed at the Millennium Seed Bank, Wakehurst Place. Whilst this is unlikely to capture the full genetic variation of Crop Wild Relatives, additional samples of rarer species have been taken into the collection in order to capture a wider range of their genetic variation.



**Plate 5** The Kew Millennium Seed Bank, Wakehurst Place, Sussex

8.18 Elsewhere a recent survey revealed only approximately 6% of European Crop Wild Relatives are conserved in European gene banks (Kell & Maxted 2008), many with only one or two accessions, which suggests they do not represent the genetic diversity of the species.

8.19 However for taxa which appear well conserved in *ex situ* collections this may be an inadequate genetic sample. Wild lettuces of the genus *Lactuca* are comparatively well conserved in European gene banks, partly because wild species have already been exploited as sources of genetic disease resistance. However studies of the genetic diversity of accessions of 12 wild *Lactuca* species from 6 European gene banks revealed for some taxa a narrow range of genetic variation in the collections due to the presence of duplicate accessions, as well as evidence of taxonomic mis-identification of some accessions (Rajicic & Dehmer 2008). A strategic approach to the gathering and *ex situ* storage of Crop Wild Relative genetic resources, which compliments the large but poorly quantified amount of *in situ* conservation work being carried out, is clearly required. Such an integrated approach will need to be focussed to make best use of available resources and consider threats to specific populations and species, the genetic analysis of species gene pools where known and the likely future economic value of individual accessions.

## International Co-operation for the Conservation of Crop Wild Relatives

8.20 It is important to see the conservation of England's Crop Wild Relatives in a broader perspective. Over millennia humans have transported crop plants to be grown in new parts of the world, including over oceans to new continents. No country is today self sufficient in genetic resources of the full range of crops it grows. Co-ordinated international action is therefore required, particularly in the conservation of Crop Wild Relatives, which despite their high genetic diversity nearly always survive over a narrower geographical range than the crop plants to which they are related. As a result a number of international instruments set targets to address the problem of co-ordinated action to conserve domesticated and wild crop genetic diversity:

- **Convention on Biological Diversity (CBD) Global Strategy for Plant Conservation 2002**

Target 9:

"*70% of the genetic diversity of crops and other major socioeconomically valued species conserved.*"

- **Convention on Biological Diversity Strategic Plan 2011-2020**

Target 13:

"By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity."

- **European Strategy for Plant Conservation 2008-2014**

Target 9:

"*Establishment of 25 European crop wild relative genetic reserves covering major hotspots of species and genetic diversity.*"

- **International Treaty on Plant Genetic Resources for Food and Agriculture 2001**

Article 5:

"*(Each contracting party shall) survey and inventory plant genetic resources for food and agriculture, taking into account the status and degree of variation in existing populations,* ***including those that are of potential use****, and as feasible asses any threats to them.*"

"*Promote in situ conservation of* ***wild crop relatives*** *and wild plants for food production including in protected areas."*

8.21 England's legally protected Crop Wild Relative populations, protected areas and agri-environment schemes, alongside seed and other accessions in gene banks, have the potential to form a key part of an international framework for conservation of wild and domesticated crop genetic resources.

# 9 Conclusions

9.1 In the 21st century plant breeding is a technology likely to play a central role in ensuring food security. To a significant degree this will depend upon the diversity of genetic resources available. Given the relatively narrow genetic diversity of many crops and the estimated 75% loss of crop genetic diversity in the 20th century, it is likely that wild genetic diversity will play an increasing role. Major advances in breeding of some crops will require a broadening of the genetic base. Crosses between species, including ones in different genera, occurred during the prehistoric development of some crop species and these are increasingly being turned to in scientific breeding programmes using a range of new techniques for genome analysis. There is therefore a strong case for conserving a much wider diversity than those plants which are of the same species as an existing crop plant.

9.2 Although modest by comparison with the world's main centres of crop genetic diversity, nonetheless the flora of England contains a wide range of Crop Wild Relatives in 15 plant families. No country is self-sufficient in crop genetic resources. Conservation of Crop Wild Relatives in England could make a significant contribution to global crop genetic conservation, for which an internationally agreed framework already exists, but has yet to be fully implemented.

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**Plate 6** Genetic reserve near the village of Ham, Lebanon, containing amongst an exceptionally rich assemblage of Crop Wild Relatives relatives of wheat, barley, legumes and onion

9.3 There are several *in situ* conservation mechanisms in place to conserve wild plants in England (legal species protection, site designation, agri-environment programmes) and each is likely to already contribute significantly to conservation of Crop Wild Relatives. However, at present we have an incomplete understanding of which species are benefitting from these conservation mechanisms and do not know if there are significant omissions, not least in conservation of genetically distinctive populations of common plant species. Improving our understanding of where Crop Wild Relatives occur in the field and their wild status is crucial to making appropriate choices about their conservation, including which populations should also be represented in gene banks. Genetic analysis of wild populations, which is becoming less expensive, is highly desirable to guide such decisions. Improving our information about the status and location of wild crop genetic resources is also needed if they are to be made more readily available to breeders, and their economic potential realised.

9.4 Given increasing concern about food security, and the wider recognition of the potential of genes from wild sources to improve many aspects of crop performance, the relatively small amount of conservation activity currently focussed upon Crop Wild Relatives both in England and the rest of the world is of concern. This in part reflects a lack of communication between those working on the conservation and exploitation of agricultural diversity, where the argument for *in situ* and *ex situ* conservation of Crop Wild Relatives has been well rehearsed, and those who work in mainstream biodiversity conservation, who have access to the most important tools for *in situ* plant conservation – species protection legislation, protected areas and agri-environment and similar wider countryside schemes. Given both communities have much to gain from co-operation, as for example in refining our understanding of the use of genetic information to guide conservation planning, it is highly desirable to encourage co-ordinated activities between the two sectors, not least in the areas of research and data sharing.

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# Appendix 1 Crop landraces in England

England historically played a prominent role in the adoption of modern plant breeding techniques. Scientifically bred varieties have been adopted by English farmers from an early date and now dominate commercial production of all major crops. However recent research has revealed landraces of a wide range of vegetables, fruits, fodder crops and cereals have survived in England (Scholten and others 2003; Kell and others 2009). These are primarily associated with niche markets, such as long straw wheat for thatching, or personal commitments, such as Hampshire common sainfoin, grown by a single maintainer, the Cholderton Estate in Hampshire, because of a long-standing family association with the landrace.

Even though initial scoping exercises have been undertaken to map English landrace diversity, there remains very little knowledge of which landraces remain extant today – there is no national inventory of English landrace diversity. We take it for granted that we know the number, distribution, characteristics and often even the population locations of English birds, mammals, butterflies, fish and vascular plants, but we have scant if any knowledge of the traditional crop varieties that have sustained people in England for centuries.

The degree to which those that remain extant are **primary landraces**, which have never been the subject of scientifically based breeding programmes, is also unknown with any certainty. It seems likely that a significant proportion may be **secondary landraces** which are the result of seed saving of obsolete commercial varieties (Stocks 2008). Nonetheless such secondary landraces may possibly contain genetic material of future potential value to breeders which otherwise would have been lost. Also their past commercial role means they may present plant breeders with fewer challenges in exploiting their genetic resources, and therefore be especially valuable as sources of economically useful genes.

English landraces (particularly in the case of vegetables) are maintained in a range of conditions including:

- *In situ* maintenance by growers who practice seed-saving, including commercial farmers, gardeners and allotment-holders (the number of gardeners and allotment holders seed-saving vegetables is imprecisely known).
- *In situ* maintenance by seed companies to supply specialist UK and overseas markets (in some cases this involves bulk production from English genetic stock being carried out overseas). Such companies include: Carroll's Heritage Potatoes, Church of Bures, E.W. King and Co. Ltd., W. Robinson & Son Ltd. and F. Watkin and Son.
- *Ex situ* conservation in gene banks, of which the most significant are at the John Innes Centre, Norwich, Norfolk; Science and Advice for Scottish Agriculture, East Craigs, Edinburgh; University of Warwick HRI, Wellesbourne, Warwickshire; Institute of Biological, Environmental & Rural Sciences, University of Aberystwyth, Wales and Garden Organic's Heritage Seed Library, Coventry (the last is an NGO) or living collection like the National Fruit Collection, Brogdale, Kent.

Although the numbers of landraces are few and shrinking annually, those that remain tend to fill a specific niche market, as well as offering a continued source of genetic diversity for plant breeders. The following examples indicate the range of crop types, numbers and national distribution of English landraces.

## Vegetable landraces

It is believed that by far the largest diversity of surviving landraces in England is of vegetables. Kell and others (2009) identified 569 landrace populations of English and Welsh vegetables belonging to 470 named varieties that were held in UK *ex situ* gene banks and also located an additional 158 landraces held by maintainers and not presently included in *ex situ* collections. Figure A shows the names and locations of some of the commercial companies, NGOs and individuals maintaining vegetable landrace diversity *in situ* in various counties of England and Wales which were identified during the recent vegetable landrace survey of England and Wales (Kell and others 2009).

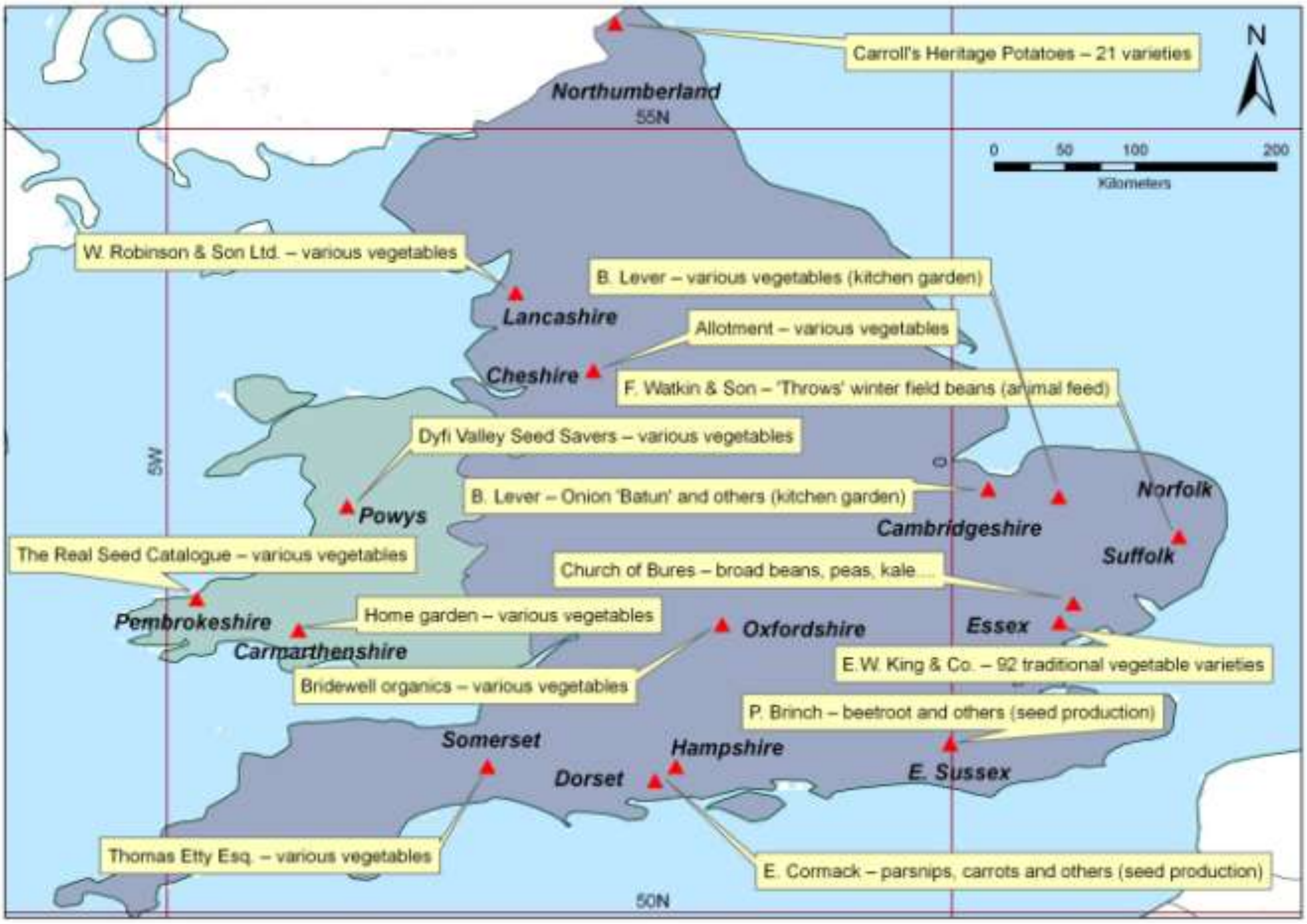


**Figure A** Commercial companies, NGOs and individuals maintaining vegetable landrace diversity in England and Wales (Kell and others 2009)

## Cereal landraces

In southern England the tradition of thatching houses with wheat straw has survived and thus the need for traditional, long-straw wheat varieties (see Table A). Although many are no longer sold commercially and are often selections from landraces in the $19^{th}$ century, they are still necessarily maintained by thatchers. The scale of cultivation is very limited, on average two hectares and this make them very vulnerable to loss, although most are duplicated *ex situ* in the John Innes Centre.

**Table A** Overview of traditional English wheat varieties maintained as landraces (Scholten and others 2010)

| Variety | Pedigree | Seed source | Number of maintainers | Use | Scale (Ha) |
|---|---|---|---|---|---|
| Maris Widgeon | 1960s | National List | 80-110 | Thatch, milling | - |
| Squarehead's Master (Standard Red) | Early 20th century | Majority gene bank | 7 | Thatch | 2 –100 |
| Rampton Rivet | 1939 | Gene bank | 3 | Thatch | 10 |
| April Bearded | Landrace/ selection | Gene bank | 2 | Thatch | 10 |
| Rivet | Landrace | Gene bank | 2 | Thatch | 10 |
| Little Joss | 1908 | Gene bank | 1 | Thatch | 2 |
| N59 | 1950s | Gene bank | 2 | Thatch | - |

## Fodder crop landraces

Grassland covers the largest area of agricultural land in England, the product being forage, fodder or seed crops. Numerous local varieties were maintained by local seed growers associations until the second half of the 20th century (Sneddon 1980), and at least 6 have survived until today (Table B).

Sainfoin has been grown in England since the 18$^{th}$ century and there were two main local sainfoin types: common and giant. Only Cotswold common and Hampshire common could be found in 2003 (Scholten and others 2003). The first is maintained by Cotswold Seed Ltd and used in Conservation Mixtures. The second, Hampshire common, has been continuously grown on the Cholderton Estate in Hampshire since 1730. An overview of current forage seed production is given in Table B.

**Table B** Overview of extant English forage landraces (Scholten and others 2010)

| Local forage Name | Scientific Name | Maintainer | Tonnes/Year 2007 | Number Growers |
|---|---|---|---|---|
| Kent Wild White Clover | *Trifolium repens* L. | KWWCPRG[1] | 0 | 2 |
| Kersey Clover | *Trifolium repens* L. | Church of Bures | Low | Lower |
| Essex Broad Red Clover | *Trifolium pratense* L. | Church of Bures | Low | Lower |
| Kent Indigenous Perennial Rye Grass | *Lolium perenne* L. | KWWCPRG | 15 | 4-5 |
| Hampshire Common Sainfoin | *Onobrychis viciifolia* Scop. | ex-NL | 2 | 1 |
| Cotswold Common Sainfoin | *Onobrychis viciifolia* Scop. | Not NL | Not available | 1 |

[1] Kent Wild White Clover and Perennial Ryegrass Growers

## Fruit crop landraces

Fruits, after vegetables, are likely to be the crop group with second highest number of extant landraces or historical varieties. Although many apple local varieties are conserved *ex situ,* a review estimates that 269 apple varieties were 'at risk' (Palmar, 1999). As such, 1 in 10 of the 2310 apple accessions conserved in the UK National Fruit Collection at Brogdale, Kent are assessed as being 'at risk'. This situation is aggravated by the continuous losses of traditional orchards and the impact of shifting farm subsidies. Neither pear, plum or cherry and none of the ancient fruits (figs, mulberry) or soft fruits (blackberry and other berries, or vines) have been systematically surveyed to date (Scholten and others 2003).

## Conservation and maintenance

It is important to realise the wide range of seed companies, government institutes, NGOs and individuals farmers and even gardeners that play a role in maintaining English landrace diversity. Not least among these are allotment holders. A recent survey of vegetable land races grown in Worcestershire allotments found 34 vegetable land races not present in *ex situ* gene banks, three discontinued varieties and four fruit landraces held by 75 allotment holders.

It has been argued that England's wealth of landraces has not been appreciated as a national resource, they have not been monitored and were falling through conservation net. In fact, Maxted (2008), argued that landraces are the most threatened element of biodiversity in England, as:

- that we have no idea how many landraces of traditional seed-saved varieties are left;
- from the studies that have been undertaken we know the average age of landrace maintainers is 66 and the next generation are not continuing the traditions of landrace cultivation; and
- currently in England no organisation has formal responsibility for their inventory or conservation.

Unless action is taken their loss will continue and is likely to only increase with time.

Natural England works for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas.

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