Chapter 5
The Status of Arable Plant Habitats in Central Europe

Stefan Meyer

Abstract In Central Europe arable land is the most dominant land use type. This, often intensively managed habitat, is home to about 400 plant species. However, the last decades have seen a dramatic decline in species richness and, in some cases the complete disappearance of arable plant communities. A multitude of comparative studies show that, in the field interiors, the total species number pooled over all samples has declined by approximately one third since the middle of the twentieth century. In the 1950s the first appeals for the protection of these species and their populations were published. Following the establishment of conservation measures in field margins in the late 1970s as a forerunner of the first agri-environment schemes (AES) in the EU, important arable plant areas have been set up. So-called field flora reserves or conservation fields are particularly important for the protection of the rare and highly endangered segetal plants and are managed in accordance with the guidelines agreed with the farmer. As well as the beneficial practices of organic farming, extensification schemes and the use of fallow land or set-aside, rare and endangered arable plants are now being re-introduced on arable land with care being taken to maintain genetic provenance.

Keywords Marginal habitats · Fertilisers · Herbicides · Crop rotation · 100 fields for diversity · Extensification schemes · Conservation guidelines

1 The Change and Impoverishment of the Segetal Flora

As early as 1915, the pharmacist Adolf Andree from Lower Saxony complained that *'one has to travel far to see colourful fields dense with poppies and cornflowers [...]; arable weeds are now rare here'*.

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Arable habitats currently cover about one third of the surface area of Central Europe, and alongside forests are one of the most important ecosystems in the region. This, often intensively managed, habitat is home to about 400 plant species, i.e. slightly more than 10% of the Central European vascular plant flora. Of these, about 150 species are obligate 'segetal' plants, requiring arable habitats to persist. Many of them have evolved under the pressure of land use practices over the course of the roughly 7000-year history of Central European agriculture, and now possess traits adapted to this man-made habitat. Despite the considerable changes in agricultural management during its development from the Middle Ages to the end of the nineteenth century, the arable flora remained relatively stable throughout this period. The three-field-crop rotation with its alternation of winter cereals - spring cereals - fallow was the dominant land-use form in medieval and early-modern Central Europe. Even the widespread shift to the improved three-field-crop rotation (fodder or root crop cultivation instead of fallow land) in the nineteenth century continued to provide the conditions for a species-rich arable flora. The often-quoted statement of Buchli (1936) '*In no other land use system do we find such an abundant and rich segetal flora … as in the improved three-field-crop rotation*' expresses this. Palaeobotanical studies, herbal books and floras, also suggest that the species spectrum did not undergo any fundamental changes until relatively recently, despite the addition of several neophytes especially from the nineteenth century onwards.

The first signs of noticeable declines in the arable flora were at the end of the nineteenth century. This concerned mainly speirochore species (unintentionally spread with the harvested grain) and species with large diaspores, which were disadvantaged by the development of better seed cleaning techniques (e.g. *Adonis* species or Corn cockle, *Agrostemma githago*). Others, like epizoochore species that had been described as 'common, widely distributed' as late as the middle of the nineteenth century also soon became rarities. Bogenhard (1850) mentions the Greater Bur-parsley (*Turgenia latifolia*, Fig. 5.1) and White laceflower (*Orlaya grandiflora*) as field weeds in Thuringia *'which appear in places as a real plague, as a plague of the fields, … known and hated by the farmer*'. Today, they are unknown even to many botanists in Central Europe.

The species spectrum found in arable fields has also shifted with the habitat conditions. In the economically difficult war and post-war years, in which even marginal sites were still cultivated, indicator species of lime and acid conditions were still abundant. In the Thuringian limestone areas, a rich flowering display of arable plants could still be widely experienced in several fields in the 1950s (Hilbig 2007a, Fig. 5.2). But as the area of intensive agriculture with fertile soils and intermediate environmental conditions (not too wet or dry, no extremes in chemical composition etc.) increased in the early twentieth century, so did the dominance of habitat generalist, highly competitive, less herbicide-sensitive species and those adapted to nutrient-rich habitats (Hanf 1937). Numerous floristic and vegetation studies, especially those repeating historical surveys of the segetal vegetation (see the overview in Albrecht 1995; Richner et al. 2014) have highlighted the massive decline and, in some cases the complete disappearance of, the arable plant communities of shallow chalk soils, nutrient-poor acid sandy soils and the wet and

Fig. 5.1 Only three recent arable populations of the Greater bur-parsley (*Turgenia latifolia*) are known in Germany. In Switzerland, Austria and Czechia this plant is either already extinct or only occurs in a few populations. © Stefan Meyer

temporarily flooded sites (Fig. 5.3). In Western Pomerania, the Lamb's lettuce community (Teesdalio-Arnoseridetum) now occurs '*on less than 1% of the arable land on which occurrence would be conceivable according to substrate and climatic conditions*' (Litterski et al. 2005, Fig. 5.4). In contrast to the historical data, arable plant stands tend no longer to be differentiated according to substrate or altitude. Assigning of modern relevés to phytosociological communities is now impossible, and even diagnostic species of higher-level syntaxa are lacking. Character species of the plant communities that were still frequent in the 1920–1950s are now very rare (Meyer et al. 2015; Richner et al. 2017).

Quantitatively, comparative studies show that in the field interiors, total species number pooled over all samples declined by approximately one third since the 1950s/60s and, in some regions like on the Swabian Alb, by up to two thirds (Gerhards et al. 2013). On the plot level (100 m^2), mean species losses were around 45–80% (Kohlbrecher et al. 2012; Meyer et al. 2013a, 2015; Dedek and Wesche 2017; Richner et al. 2017). The cover of segetal vegetation in the field interior is now often less than 3%, in some areas of north-western Germany only 0.5%. Thus, despite early warnings by Tüxen (1962) pointing to the serious destruction of the arable plant communities in Central Europe, it is clear that a widespread collapse of phytodiversity on arable land has taken place in the twentieth century. Consequently, the Red Lists of endangered, lost and extinct plant species have become populated with species of the segetal flora, which is often the group with the highest risk levels.

In summary, several factors have contributed to the great changes in the arable flora over recent decades (Albrecht et al. 2016). The main causes of the decline,

Fig. 5.2 The Kyffhäuser Mountains in Thuringia (Germany) are home to one of the most species-rich and colourful limestone segetal communities in Central Europe. © Stefan Meyer

Fig. 5.3 The Toad rush (*Juncus sphaerocarpus*) used to be found rarely in temporarily flooded arable fields. © Stefan Meyer

Fig. 5.4 The Orange lily (*Lilium bulbiferum* ssp. *croceum*), a former characteristic species of the Teesdalio-Arnoseridetum is very rare today, and is considered to be the queen of the sandy fields in Northern Germany and the Netherlands. © Stefan Meyer

homogenization and endangerment of the segetal flora in Central Europe are the widespread use of herbicides in agriculture, high fertilisation rates resulting in dense crop stands, the abandonment of low-yielding sites or their conversion into grassland, and the disappearance of arable farming in mountain regions (Kohler et al. 2011; Reidl 2015). Furthermore, crop rotations have been simplified, site environmental conditions have been homogenised by soil improvement measures, seed cleaning has been perfected, historical or special crop types (such as emmer) with their adapted species are no longer cultivated and the immediate ploughing of the stubble after harvesting prevents the reproduction of late flowering species (e.g. Gottwald et al. 2018; Seifert et al. 2014; Richner et al. 2014; Meyer et al. 2013a; Storkey et al. 2012).

2 Efforts to Conserve the Segetal Flora

'*... one could now also preserve a field with the old cereal varieties and the former arable plant communities in a museum-like manner...*' (Waldis-Meyer 1978).

The sharp decline in the occurrence of numerous segetal species and species-rich arable plant communities, especially on shallow chalk and acid sandy soils, has led to discussions among conservationists about the protection of these species and their populations. The first calls for the conservation of the segetal flora date back to the 1950s/1960s. The phytosociologist Robert Gradmann wrote as early as 1950 in his very comprehensive work on the flora of the Swabian Alb that '*the flower-decorated cornfields have almost disappeared from our cultural landscape, and soon we will have to set up small protected areas where three-crop rotation farming is carried out with poorly cleaned seeds*' (Gradmann 1950). Militzer (1960) recommended '*to maintain some small fields on marginal soils with low-intensity cultivation. In this way, the species-rich segetal flora … can be preserved in a few examples and protected as important arable plant areas*'. In Germany, the thesis on the protection of arable plants (Hilbig 1986), the Karlstadt position paper (van Elsen et al. 2005), the project '100 fields for diversity' (Meyer and Leuschner 2015) and the review of management options for the conservation of rare arable plants by Albrecht et al. (2016) have made significant contributions to the protection of arable plants and to the requirements for conservation measures of various kinds. Since 2007, an annual 'field conference on the protection of segetal plants has been held in Germany in June, which is increasingly attended by segetal flora specialists from abroad. Consequently, some years ago a bibliography on the 'protection of arable plants' was published by Meyer et al. (2013b). The introduction to this publication outlines the definition, the genesis and the habitat preferences of arable plants in Central Europe, as well as describing the strong decrease of numerous arable plants in recent decades and efforts and conservation measures to protect rare and endangered arable plant species. In the bibliography, all known publications dealing with arable plant conservation are listed. The majority are German texts, but references from other European countries are also included. Altogether, the bibliography cites more than 1700 texts that deal with conservation measures for arable plants and their locations, with special measures for protection and re-establishing of species, with extensification programmes, their successes and their effect on agrobiodiversity. Every citation also includes the country or region of the data source and up to seven additional key words.

Other Central European countries have also seen a sharp decline in the number of arable plants recorded in cultivated fields in recent decades, a trend that continues and is documented in numerous publications (e.g. Richner et al. 2017; Legast et al. 2008; Schopp-Guth et al. 2006; Traxler et al. 2005; Warcholińska 2004). In the former Czechoslovakia, a conference on the protection of plant genetic resources was held around 1980, at which the protection of the arable flora was also discussed (Skalický 1981). Since the 1980s, and increasingly since the 1990s, efforts to protect the phytodiversity in agroecosystems through the conservation of species-rich and typical communities of marginal arable habitats have begun, e.g. for Switzerland (Waldis-Meyer 1986; Waldis 1987) and Poland (Warcholińska 1986). Numerous publications are available on conservation programs in Switzerland, Poland, and Luxembourg (listed in Meyer et al. 2013b). Field flora reserves have been established in Poland (Siciński 1986; Warcholińska 1986), Luxemburg (Lenerz et al. 2017), Austria (Schmid 2008) and Switzerland (Birrer et al. 2018).

For lower Austria, Holzner (1978) had already compiled a list of potential arable protection areas at the end of the 1970s. In the area surrounding Vienna, conservation fields were established where a species-rich segetal vegetation was present (Schmid 2008). A current binational Interreg-project 'Wild and Cultivated' in

Fig. 5.5 Alternatively cultivated vineyard in the district of Kitzingen (Bavaria, Germany) with a large population of Wild tulip (*Tulipa sylvestris*) © B. Blümlein

several biosphere reserves of Bavaria and Austria is dedicated to the propagation of seeds of the regional segetal flora (www.wildundkultiviert.at). One of the project's main goals is the re-establishment of rare and endangered arable plants and their communities. In Switzerland (Halder 1982) special species protection programmes were aimed at preserving the cornflower (*Cyanus segetum*). Brunner and Gigon (2001) described the conservation of bulb-geophytes in Swiss vineyards, which are also highly endangered in Central Europe. Vineyard flora reserves have also been established for the very endangered Geranio-Allietum vinealis community with its magnificent spring geophytes of the genera *Allium*, *Gagea*, *Muscari*, *Ornithogalum* and *Tulipa* and the numerous spring ephemera species (Ehmke 2001; Meyer and Leuschner 2015) (Fig. 5.5).

As long ago as the 1970s, Waldis-Meyer (1978) called for the preservation of examples of the small fields of mountain farmers in the Swiss Valais. Almost 30 years later, this idea was realised and the first plots of land for the conservation of the diverse segetal flora were acquired by Pro Natura Valais (Stipa 2008) (Fig. 5.6). In addition, the 'Resource project for the conservation and promotion of the endangered Swiss arable flora' was implemented in Switzerland between 2012–2018 to preserve existing arable plant communities. By the end of the project in seven cantons, a total of 79 ha of plots were contracted and 60 indicator species of the segetal flora as well as rare arable mosses were secured (Birrer et al. 2018).

Fig. 5.6 Conservation field with rye and saffron cultivation on a south-west facing slope in a mountainous region near Mund/Upper Valais (Switzerland) © Stefan Meyer

Building on this, a project co-ordinated by the HotSpots association in the cantons of Schaffhausen and Zurich is currently underway to promote rare arable plants on suitable arable land. There, at least 20 fields with autochthonous populations of arable plants or that are suitable for reintroduction are to be secured and managed appropriately.

3 Measures and Concepts for the Conservation of Arable Flora

> *'Several possibilities are emerging for creating and maintaining reserves for relics of anthropogenic flora and vegetation. Since the species affected by this are particularly closely linked to the development of land use by man and thus to the history of man himself, all possibilities for the protection of these species and biotopes should be used*'. (Willerding 1986)

3.1 Important Arable Plant Areas, Field Flora Reserves and Conservation Fields

Fields, which have been identified as being particularly important for the protection of the rare and highly endangered segetal plants and included in conservation schemes must be managed in accordance with the guidelines agreed with the farmer. In Baden-Württemberg they were called a field flora reserve ('Feldflorareservat'), a term that was later used by other authors. Hilbig (1985) introduced the term 'Schutzacker' (conservation field). In Poland such conservation fields are called 'agroreserwaty' (agroreserves) (Siciński 1986).

One of the first conservation sites for arable plants in Germany was a field flora reserve on the Swabian Alb (Baden-Württemberg). This has been in existence since 1970 and serves to preserve and demonstrate the diversity of the species-rich field flora of calcareous soils (Rodi and Schill 1982). In the former German Democratic Republic (GDR), intensive research had been conducted since the 1950s on the distribution and environmental requirements of segetal plants, their occurrence in plant communities and on the changes caused by intensive agriculture with large-scale cultivation. According to Hilbig (1978) it was time to '*grant special species protection to the declining arable plants, mostly species of extreme locations*'. Krausch (1978) had already written an '*obituary for an arable plant*' for the corn cockle (*Agrostemma githago*), which was still '*frequent and widespread in cereal fields . . . from the plains to the foothills of the Alps . . . a feared, unwelcome weed*' at the beginning of the twentieth century (Hegi 1910). For knowledge transfer and coordination, and in preparation for the creation of further areas for the protection of the arable flora, a working group 'segetal plant conservation' was founded in 1984 in the former GDR. By the late 1980s, about 25 field flora reserves had been created and some were secured as natural monuments or by integration into a larger nature reserve (Illig 1990; Hilbig 2007b). Various field flora reserves were also established in the federal states of western Germany (for details see Meyer et al. 2013b).

Despite these efforts, the lack of general success in ensuring the long-term conservation of highly endangered arable species led to the development of the '100 fields for diversity' project (Meyer and Leuschner 2015). The aim of this project is to set up a nation-wide network of conservation fields ('Schutzacker'). These arable fields have outstanding plant species inventories and are protected in the long term (up to 25 years or open ended) by appropriate contractual agreements or legal requirements.

The following guidelines are given for the appropriate management of these conservation fields:

- no or only little, mostly organic fertilisation
- no pesticides
- a high proportion of cereals in the rotation, in particular winter cereals, seed preferably uncleaned from the field itself
- late stubble tillage, no catch crops
- only shallow ploughing, no subsoil loosening

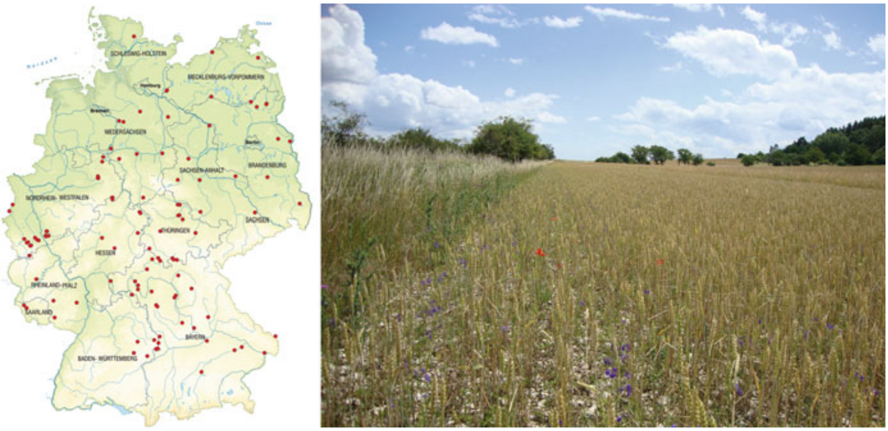

Fig. 5.7 Locations of the 112 conservation fields for arable flora in Germany (left) and conservation field for the segetal flora in the northern foothills of the Harz Mountains (Saxony-Anhalt, Germany) (right). © Stefan Meyer

- no draining or irrigation
- inclusion of old crop types typical for the area
- seeds and plant material of rare arable plant species from the immediate vicinity that have not been identified in the conservation field but are present in the area may be brought in
- the plant species community must be documented at the time of the establishment of the conservation field, as well as its changes over the years, the introduction of species and their development, and the cultivation regime.

Based on a nationwide screening of the floristically most valuable sites for arable vegetation in Germany, 112 important arable plant areas with a total area of around 475 ha had, by 2015, been secured with appropriate low-intensity agricultural practices for at least 10 years (often up to 20–25 years or open ended) by contract. The conservation fields are spread over the whole area of Germany on limestone, sandy or loamy soils with arable communities harbouring many rare and endangered species (Fig. 5.7). A key element is the commitment by the farmer to low-intensity farming practices targeted at promoting endangered species. For this purpose, various instruments for achieving the long-term financial support of conservation management, such as ecological compensation measures and agri-environmental schemes (AES) are used.

3.2 Field Margin Programs

A project creating herbicide-free field margins in the Limestone Eifel begun by Professor Wolfgang Schumacher (University of Bonn) and colleagues in the period 1978–1982 represented a great boost to the protection of segetal plants by integrating the concept of biodiversity conservation into mainstream agriculture (Schumacher 1979). This project was a forerunner of the first agri-environment schemes (AES) in the EU. In the second half of the 1980s and 1990s, the ministries and federal states responsible for agriculture set up special protection programmes for segetal plants and provided funds to support the farmers involved. The field margin programmes attempt to preserve and promote rare arable plants by omitting the chemical weed control methods commonly used today in the headlands and margins of fields (Fig. 5.8). With otherwise the same cultivation, a zone of 3–12(−24) metres of the cultivated area remains unsprayed. Farmers who voluntarily participate in the project receive compensation for reduced yields. In order to promote rare species and to prevent harvesting difficulties caused by the occurrence of problematic weeds, a reduction in fertilization and, on sandy soils, a limitation of lime applications are also recommended. With comparatively little financial outlay, unsprayed field margins can make a major contribution to the medium-term conservation of rare plant species and their animal communities if the areas are carefully selected and targeted based on the presence of endangered species. The effectiveness of the field margin programmes is therefore highly dependent on the commitment of knowledgeable experts on site, who also provide technical support to the participating farmers. These colourful flowering field margins have also increased awareness among the public of segetal flora protection with the help of interpretation boards (Karkow and Gronemann 2005).

Fig. 5.8 Colourful field margin in the district of Goettingen (Lower Saxony, Germany) with flowering poppies. © R. Urner

3.3 Organic Farming

Early comments on the '*impact of alternative land management on vegetation*' are found in Meisel (1978, 1979), who noted '*a positive effect of organic farming*', which was reflected in greater biodiversity on arable land and to some extent also in grassland. In the meantime, numerous comparative studies of biodiversity on organically and conventionally farmed fields, have been published by (among others) van Elsen (2000) and Frieben et al. (2012) for Germany and, more generally by Stein-Bachinger et al. (2020). In the Czech Republic, an analysis of 290 records revealed the abundance of endangered arable species in organically managed fields was 4.5 times higher than in conventional farming (Kolářová et al. 2013). Common to all comparative studies is that - depending on the intensity of cultivation - usually at least 2–3 times more segetal species are found in organically managed fields, ranging from only slightly higher to ten times higher. On an organic farm in the federal state Brandenburg, a total of 21 Red List species of segetal flora were identified (Gottwald 2010, Fig. 5.9). However, even in organic systems, management intensity plays a role, and intensive harrowing or cultivation of grass–clover leys in such systems may be as harmful to threatened species as herbicide application is in conventional systems. Such practices should therefore be limited if management objectives for a given field include preservation of rare arable plants (Albrecht et al. 2016).

3.4 Extensification Schemes and Fallow Land or Set-Aside

Extensification schemes can also contribute to varying degrees to the maintenance of a basic level of arable plant diversity especially on arable land with low productivity. If there is a sufficient soil seed bank, and depending on the location, a few years of extensive cultivation following previous low-input conventional farming is often sufficient to rejuvenate species-rich segetal stands (Litterski and Jörns 2004). A widespread and effective extensification measure is annual rotational fallowing (Hilbig 1998). Here, the favourable effects of the fallow year for the rarer arable plants are maximised when cereal stubble is left over winter: immediate cultivating before the one-year fallow period prevents many positive effects. Which species occur depends on the site conditions, the seed bank and the seed rain from neighbouring areas. Fallow land can, especially on marginal areas, lead to species-rich, colourful vegetation (Fig. 5.10) and to the occurrence of rare, uncompetitive segetal species in the first years. Leaving the field undisturbed for several years, however, leads to successional processes from the initial annual segetal species to increasing numbers of perennial species (Manthey 2003) to ruderal perennial meadows, after which grasses tend to dominate and young tree and shrub saplings start to develop. To promote the competitively weak arable flora, at most a two (to three) year fallow period is suitable. A permanent fallow will eventually kill off a species-rich segetal community. Ritschel-Kandel (1988) wrote in the 1980s of the

Fig. 5.9 Organic cereal cultivation with Field black cumin (*Nigella arvensis*) near Brodowin (Brandenburg, Germany). © Stefan Meyer

Fig. 5.10 Annual fallow fields: on a limestone field on the Franconian Alb (Bavaria, Germany) (*left*) © Stefan Meyer and a colourful annual fallow on a sandy field in the biosphere reserve 'Schorfheide-Chorin' (Brandenburg, Germany) (*right*) © F. Gottwald

'*catastrophic effects on the protection of endangered arable plants of set-aside*'. This phenomenon is mainly due to the fact that farmers used their least productive fields (i.e. remote, sloping, low-yielding, small or stony) for set-aside, which were usually those still supporting a species-rich segetal flora. Especially in such areas, the preservation of arable land with low management intensity is essential for the protection of arable plants and must also be financially supported. In contrast, the extensification or set-aside of highly productive arable land generally does not lead to the occurrence of rare arable plants as the seed banks have been greatly thinned out after decades of intensive cultivation and the seedbank community that will be dominated by common, nitrophilous species. In the interest of preserving a level of arable plant diversity, the following applies to fallow land in general even if this may, however, be in conflict with the protection of animal species on the fallow:

- extensively farmed arable land is better than undisturbed fallow land,
- rotational fallow is better than permanent fallow,
- fallow land is better than seeding,
- the vegetation developing on the fallow land is allowed to grow, it is not flailed and usually develops into a dense sward or it is kept short by flailing (the latter is better for less competitive arable plants) and
- the removal of biomass is better than leaving it lying on the fallow land, as it decreases the nutrient availability and thus promotes less competitive arable plants.

More recently, so-called ‘production-integrated compensation’ measures have been introduced to support biodiversity conservation on arable land in Germany. These measures are financed by developers as ecological compensation for building on farmland (e.g. roads, housing, industrial complexes, wind energy plants) and can be used to promote endangered arable vegetation and other species of arable land through low-intensity production (e.g. skylarks or hamsters) (Druckenbrod and Meyer 2013; Druckenbrod and Beckmann 2018).

3.5 Reintroduction of Rare and Endangered Arable Plants

For about a decade now, the re-establishment of rare and endangered wild arable plants has been tested in Germany on selected sites. Initially, the focus was on projects on organically farmed fields, such as ‘Field flower strips for the integration of autochthonous segetal plants in organically cultivated arable land’ (Hotze et al. 2009) or through ‘Reintroduction of rare and endangered arable wild plants on organic farms’ (Wiesinger et al. 2015; Lang et al. 2016a, b). Field trials showed that early autumn sowing and low competition from crops yielded best results for three rare winter annual species of limestone arable sites (Forking larkspur, *Consolida regalis*, Large Venus’s-looking-glass, *Legousia speculum-veneris* or Field gromwell, *Lithospermum arvense*). For the successful establishment of these rare arable plants, sowing without or with reduced density of winter cereals, such as spelt or rye, by mid-October at the latest is recommended. Sowing rates of 100 seeds/m^2 for *C. regalis* and *L. arvense*, and 50 seeds m^2 for *L. speculum-veneris* are recommended to achieve successful establishment with negligible crop yield losses (Lang et al. 2016b). Grass-clover leys and summer crops like peas allowed little or no emergence of the target species, although they survived to some extent in the seed bank. Seed mixtures were then sown in separate plots and the neighbouring cereal stand and the transfer of topsoil from species-rich areas was tested. In the year of sowing, a proportion of the introduced species developed into adult plants in both methods. This tended to be less successful when competing with cereals. In the following years, some species were again detected in cereal crops; most of the seeds reached deeper soil layers during tillage and enriched the seed bank (Lang et al. 2016a).

According to project team (Bayerische Kulturlandstiftung 2018) the following recommendations should be followed for the reintroduction of rare arable plants:

- there is species-specific variation, with highest success in reintroduction of *L. speculum-veneris*, followed by *C. regalis* and *L. arvense*.
- species lacking a long-term seed bank depend on suitable crop rotations that allow sufficient seed production each year. For winter annuals this means crop rotations containing high percentages of winter cereals, preferably without mechanical weeding.
- seed dispersal by field management is several meters per year. Thus, seeds should be sown on many plots spread over large parts of a reintroduction field.

Currently, several projects (e.g. Lang et al. 2018; Muchow and Fortmann 2019) are trying to establish an economically viable system for producing seeds of regional genotypes with certified provenance. This is especially important for endangered segetal flora species to reintroduce them to areas where they have largely died out and maintain viable populations to preserve them in the long term.

Several essential criteria have been developed for seed collection and sowing. Considering all herbaceous plants in Germany, 22 regions with similar gene pools have been defined. Seed is allowed to be propagated and distributed within these regions, but not between them, in order to prevent the homogenisation of the gene pool. It is important to note that these seed transfer zones are not species-specific, but are, to simplify practical implementation, equally applied to all species. To supply the market with regional seeds adapted to wider range of environmental conditions, the German system requires seeds to be collected from at least five large populations across a region (Prasse et al. 2010). The seed collection should be carried out in a sustainable way - only populations over 100 individuals should be harvested. In order to maintain the genetic diversity of the donor population, the seed collection should be distributed over at least 50 plants per population (Lang et al. 2018). The propagated seeds are available for restoration projects in a given seed zone, or are used for re-establishing another generation of cultivation. This procedure can be repeated for up to five generations, afterwards the seed production must start from a new wild collection (for details see Prasse et al. 2010). To balance the value of local adaptation with the need for future adaptation potential, Bucharova et al. (2019) propose this way of regional provenancing as a compromise strategy. Here, seeds are sourced from multiple populations within the same natural region as the target locality and mixed prior to use. The mixing of seeds will increase the genetic diversity necessary for future adaptation, while restricting seed origins to a regional scale will maintain regional adaptation and reduce the risk of unintended effects on other biota. This approach is feasible in practice and has recently been implemented in Bavaria and North Rhine Westphalia (Lang et al. 2018; Muchow and Fortmann 2019).

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