Review

Set-aside management: How do succession, sowing patterns and landscape context affect biodiversity?

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ABSTRACT

European Union (EU) member states set aside between 5 and 15% of arable land during the last two decades, but abolition of the set-aside scheme in 2008 caused a sudden loss in habitat availability and biodiversity in agricultural landscapes. Management of set-aside has many facets and in this perspective paper we focus on the biodiversity effects of successional age, sowing strategies and landscape context. Young, 1–2-year-old set-asides have been initially considered to be too ephemeral to have any conservation value. However, when a rich seed and bud bank is available, a species-rich natural (secondary) succession can be observed. Arable (annual) weed communities in the first two years of succession can even include endangered plant species with associated rare insect consumers. Furthermore, many bird species benefit from early-successional habitats, whereas small mammal communities are richer in older habitats. If the local plant species pool is poor, sowings of diverse mixtures from regional seed collections can be recommended. Set-aside managers using species-rich sowings often experience that dominant weeds suppress the less competitive annual species. This trend to species-poor communities can be avoided by intraspecific aggregation of competitively weak species. Broadening the spatial scale from the plot to the landscape, efficiency of set-aside is highest in simple landscapes, where set-aside exhibits greatest effect in enhancement of biodiversity and associated services such as pollination and biological control. In complex landscapes, however, additional set-aside does not add much to the high level of biodiversity and ecological processes already present. Twenty percent of semi-natural, non-crop habitat appears to be a rough threshold for enhancing biodiversity and sustaining services such as pollination and biological control, but improved set-aside management should have the potential to reduce the percentage of semi-natural non-crop habitat needed. EU policy should tailor set-aside schemes for the maintenance of biodiversity and also consider that management efficiency is higher in simple than complex landscapes.

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1. Introduction

1.1. Set-aside and agricultural policy changes

Agricultural set-aside schemes were introduced by the Common Agricultural Policy (CAP) of the European Union (EU) in the late 1980s to reduce overproduction and soil erosion, but also to protect farmland biodiversity (ENCA, 2008). In the beginning of the set-aside scheme, the contribution to nature protection was sometimes questioned by conservationists, because of the ephemeral nature of rotational set-aside, which was regarded as an ecological trap without long-term biodiversity benefit. Increasing research on this issue has shown, however, that rotational set-aside contributes to population density of many valuable early successional species in agricultural landscapes (Clarke, 1992; Corbet, 1995; Sotherton, 1998).

Set-aside schemes changed over the decades. In 1988, when the first set-aside scheme was introduced by the EU, most arable land set-aside was left to natural succession. Hence, in the following years, landscapes were characterized by a mosaic of successional stages, including young, 1–2-year old plots dominated by arable weeds, while older stages were dominated by perennial plants (Clarke, 1992; Corbet, 1995). In 1993, set-aside became an obligation for any farmer receiving EU subsidies. Roughly 5–15% of arable land was expected to become rotational set-aside. In contrast to set-aside practices in the early years, farmers in some countries were advised to sow these fallows, thereby avoiding increased weed pressure and facilitating re-cultivation. During this period, landscapes were often colourful, due to set-aside sowings of *Phacelia*, *Trifolium*, *Sinapis* and other plants. From 1995 onwards, farmers increasingly dedicated set-aside to non-food plant production, in particular renewable resources (ENCA, 2008).

After 2006 energy crops (such as oilseed rape) were increasingly sown. In 2008, the abolition of set-aside as an EU-wide instrument to control supply and the rising commodity prices for food and energy crops have led to a widespread loss of set-aside in Europe, with the exception of Switzerland, where farmers are still obliged to set-aside at least 7% of their farmland as ecological compensation areas (ENCA, 2008; Albrecht et al., 2007; Oppermann et al., 2008; Aviron et al., 2009).

1.2. Set-aside and biodiversity conservation

After two decades of set-aside schemes, the political change has led to a sudden decline in fallow land since 2006. The consequences of these changes in set-aside area are pronounced and although there are no published data summarising any biodiversity losses in EU landscapes, there is little doubt about the generally negative effects of set-aside loss on biodiversity (Van Buskirk and Willi, 2004). However, the relative importance of different types of set-aside management, the different responses of species groups and the role of the landscape context for conservation of biodiversity and associated services is still a matter of debate. In this perspective paper, the adverse impact of giving up set-aside on plant, vertebrate and invertebrate communities and associated ecosystem services will be explored, which are in stark contrast to the political objective to halt the decline of biodiversity by 2010 (UNEP, 2002). The review is guided by three hypotheses on the management of set-aside–biodiversity relationships covering less studied aspects on different temporal to spatial scales integrating local and landscape scale management:

(1) From early to late succession, biodiversity displays a hump-shaped pattern from early stages dominated by annual vegetation to perennial stages (e.g., Steffan-Dewenter and Tscharntke, 1997, 2001; Kovács et al., submitted for publication).
(2) Sowing of intraspecifically aggregated wild plants improves conservation value of set-aside (Wassmuth et al., 2009).
(3) Landscape context influences the biodiversity value and ecosystem services of set-aside (Thies and Tscharntke, 1999; Wretenberg et al., 2010).

We conclude with recommendations for improved set-aside management on local and landscape scales.

2. Successional change in naturally developing set-aside fallows

Secondary succession on fallow arable land (old fields) is a subject dominated by plant studies (Glenn-Lewin et al., 1992; Pickett et al., 2009). Also a number of animal studies have accumulated data, and in their meta-analysis Van Buskirk and Willi (2004) showed that age of set-aside generally increases richness of plants and insects, but not birds. However, secondary succession of naturally developed set-aside does not necessarily exhibit steadily increasing species richness with successional age, although this is often expected (Brown and Southwood, 1987).

2.1. Plant and insect diversity through succession

Plant species richness is often closely related to insect richness (Tscharntke and Greiler, 1995). For example, species richness of flowering plants is a good predictor of species richness of bees, whereas the cover of flowering plants is a good predictor of bee abundance (Steffan-Dewenter and Tscharntke, 2001; Batáry et al., 2009). More diverse vegetation supports more diverse insect communities (Strong et al., 1984; Andow, 1991; Siemann et al., 1999), as has also been shown for butterflies (Steffan-Dewenter and Tscharntke, 1997) and trap-nesting bees (Gathmann et al., 1994) on set-aside in Germany.

In a set-aside project located in Germany, species richness of plants, butterflies, beetles, true bugs, parasitoids and bees was highest on 2-year-old set-aside fields in a sequence from 1- to 3-year-old set-aside, in a hump-shaped relationship (Gathmann et al., 1994; Greiler, 1994; Steffan-Dewenter and Tscharntke, 1997, 2001). The most striking pattern was the rapid change from annual vegetation in the first two years of succession to perennial vegetation from the third year onwards. These studies found that in intermediate succession, when annuals were still and perennials already present, species richness of flowering plants was as high as on old low-intensity orchard meadows. Abundance of parasitoids in 2-year-old successional fields, but not of 1-year old or 3-year old fields (Fig. 1), was higher than in crop and *Phacelia* fields, which does not support the hypothesis that the impact of biological control continuously increases with age of succession (Southwood, 1988). These results provide evidence that even young stages of set-aside can serve as significant reservoirs of parasitoids that potentially play a role as biocontrol agents of many plant-feeding insects.
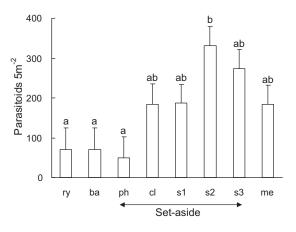
Fig. 1. Parasitoid abundance (mean ± SE) in crop fields, set-aside fields (former cereal fields) and meadows. Results are from 36 fields around the city of Karlsruhe, Germany, in a structurally diverse, species-rich agricultural landscape. Each habitat type was represented by four to five replicates (field type: ry = rye, ba = barley, ph = *Phacelia tanacetifolia*, cl = clover–grass mixture, s1 = 1-year-old, naturally developed successional vegetation, s2 = 2-year-old successional vegetation, s3 = 3-year-old successional vegetation, me = old meadows (>30 years); ANOVA: $F = 3.8$, $N = 36$, $p = 0.006$). Each replicate was based on Univac suction samples on 4 dates (April–August 1991 or 1992) when all insects within a cage ($5 \times 0.25\,m^2$ per date and field) were caught ($5\,m^2$ sample per replicate). Groups differing significantly according to Tukey's Honest Significant Difference-test ($p < 0.05$) are labelled with different letters. Altogether, 6801 specimens from 18 parasitoid families were found (data from Tscharntke, 2000; based on Greiler, 1994).

Young, in particular 2-year-old, set-aside with naturally developed vegetation often supports (i) many annual arable weeds including rare species, (ii) a number of higher trophic level species associated with annual plants including rare butterflies (Steffan-Dewenter and Tscharntke, 1997; Kovács et al., submitted for publication) and rare beetles (chrysomelids and weevils; Greiler, 1994; Tscharntke et al., 1996), (iii) a high density and diversity of potential biocontrol agents such as parasitoids (Tscharntke, 2000) and (iv) farmland birds (see below).

Older successional stages, i.e. older than the three years of succession described above, support usually high biodiversity (Corbet, 1995), including groups such as ants (with soil-inhabiting colonies recovering from ploughing), small mammals and birds (Tscharntke et al., 1996; Jenny, 2000; ENCA, 2008). Highest predator–prey ratios (dominated by spiders) can be usually expected on older, several years old set-asides (Fig. 2; Bayram and Luff, 1993; Denys and Tscharntke, 2002).
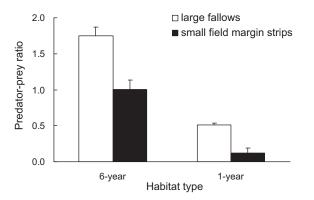

Fig. 2. Comparison of large set-aside fallows ($n = 6$) and narrow field margin strips ($n = 8$), differing in age (6-year-old vs. 1-year-old, naturally developed habitats), with respect to the predator–prey ratio (mean ± SE) of arthropods on mugwort (*Artemisia vulgaris*). In two-way ANOVA predator–prey ratio was significantly related to both area ($F_{2,11} = 25.5$, $p < 0.001$) and age ($F_{2,11} = 73.1$, $p < 0.001$; data from Denys and Tscharntke, 2002).

2.2. Bird and mammal diversity through succession

Firbank et al. (2003) compared rotational with non-rotational, naturally regenerated set-asides and found that breeding birds showed a preference for rotational set-asides, while Kovács et al. (2010) found in a recent Hungarian study that bird numbers and their species richness increase with the age of set-asides (from 1- to 3-year-old sown set-asides). Van Buskirk and Willi (2004), in their meta-analysis on effects of set-asides on biodiversity, showed a negative relationship between the age of set-aside and species richness of birds, but this pattern was not observed for bird abundance. Rotational and young set-asides appeared to provide excellent breeding and feeding sites for several bird species of conservation interest such as skylark (*Alauda arvensis*), corn bunting (*Miliaria calandra*), yellow wagtail (*Motacilla flava*), meadow pipit (*Anthus pratensis*) or grey partridge (*Perdix perdix*) (Berg and Pärt, 1994; Bracken and Bolger, 2006; Oppermann et al., 2008). Somay et al. (2009) found in Hungary that naturally developed old-fields (>5 years) can also support high number of bird species and individuals, although not as many as the nearby semi-natural sandy grasslands.

Species numbers of small mammals begin to increase only after a lag phase on set-asides, as was shown in the case of field vole. Here populations increased only after the second year of establishment, regardless of whether sown or naturally regenerated, when grass and litter cover has become higher in the sward providing shelter from predators (Tattersall et al., 1997, 2000; Vickery et al., 2009). Further, small mammal richness increases with age of succession (Tscharntke et al., 1996). The establishment and management of set-aside fields and field margins affect their suitability as small-mammal habitats, both in terms of food availability and protection from predators (Macdonald et al., 2007).

3. Sowing strategies for set-aside

3.1. The general picture

In the 1990s, set-aside fields were increasingly sown with easily manageable fodder plants to reduce weed pressure (of annuals like *Alopecurus myosuroides* or perennials like *Cirsium arvense* and *Elymus repens*), facilitating re-cultivation of crops and allowing quick establishment of close vegetation cover, which is known to reduce leaching of nitrogen and soil erosion (Tscharntke et al., 1996). During the last years, growing of energy plants (such as oilseed rape and maize) devaluated the character of set-aside as species-rich fallow, because they became an alternative form of crop production, including conventional agrochemical use (ENCA, 2008). Set-asides with naturally regenerated vegetation have been found by Van Buskirk and Willi (2004) to support higher biodiversity than those with sown cover, a meta-analytical result largely driven by the patterns of plant communities. Vickery et al. (2009) analyzed the effects of three types of field margin management on birds: (i) field margins sown with a simple grass seed mix or (ii) with a diverse seed mix including perennial forbs and (iii) naturally regenerated rotational set-aside field margins. Seed and invertebrate food resources were low in the simple grass mixture, but much higher in the diverse seed mix and the naturally regenerated set-aside margins. Two aspects seem pivotal for the effects of sowing on diversity: the plant variety chosen and the role of intraspecific aggregation of competitively inferior species.

3.2. The role of plant variety sown

The value of sown set-aside changes with plant species and varieties sown. Set-aside fields sown with *Phacelia tanacetifolia* (which was common in the early 1990s in Germany) featured low

parasitoid densities, similar to cereal fields (rye and barley). In contrast, clover–grass mixtures and natural successional set-aside supported on average three times more parasitoids (Fig. 1). Potential reasons for low parasitoid density and also for low solitary bee density and diversity in *Phacelia* fields, which are popular nectar-rich 'honey bee plants', include the following (Gathmann et al., 1994; Steffan-Dewenter and Tscharntke, 2001): *P. tanacetifolia* is an introduced plant (from America) with chemical characteristics potentially affecting specialists. *Phacelia* also exhibits a short flowering period (only three weeks in June/July), which is typical for monocultures compared to the continuous flowering of successional fields, thereby reducing nectar and pollen availability to a very short time window. Further, hosts of most parasitoids, e.g. of Poaceae and Brassicaceae inhabiting hosts, are missing from *Phacelia* monocultures.

The selection of plant varieties of fodder grasses and legumes to be sown in set-aside and uncultivated areas can be of crucial importance for enhancing biodiversity and pest enemies. The significance of plant variability and plant cultivars for associated organisms has been known for crops for a long time, including direct resistance mechanisms to herbivores and indirect resistance via attraction (e.g., extrafloral nectaries, volatile emissions) of the herbivores' enemies (Price et al., 1980; Denno and McClure, 1983; Boethel and Eikenbary, 1986; Fritz and Simms, 1992; Bottrell et al., 1998).

Commercially available clover–grass mixtures differ from plants originating from wild seeds sampled in the region of the intended sowing, which is known to affect establishment and restoration success (Vander Mijnsbrugge et al., 2010). Using regional seeds also contribute to conservation of regional genetic structure (Leimu and Fischer, 2008). Such intraspecific differences may cause rather dramatic effects when set-aside fields are sown with varieties that do not support the herbivores, parasitoids and predators known from wild plants (Tscharntke, 2000). Such plant diversity is a misleading predictor of the diversity of the second and third trophic levels (see Fritz, 1992; Hare, 2002). For example, specialised plant hoppers on *Poa pratense* were found to be almost exclusively restricted to wild shoots and not to shoots of commercial varieties; similarly, parasitism of the main parasitoid of a *Tetramesa* gall-maker on the grass *Phleum pratense* was higher in wild than commercial varieties (Fig. 3a). Such specialised species can be expected to suffer from even slight changes in the morphology or chemistry of their host plant (Tscharntke, 2000). In a comparison of plots sown with wild grass seeds with plots sown with commercial seed varieties, predator–prey ratios were significantly higher in the 'wild' grassland plots (Fig. 3b). Hence, the selection of seeds can greatly affect the role of set-aside as source of predators and parasitoids and associated biological-control success. As in other plant families, grasses are known to show intraspecific variation in herbivore resistance, while mechanisms mediated by mechanical or chemical features influencing higher trophic levels are little known (Hare, 2002).

3.3. Enhanced coexistence through intraspecific aggregation

Despite species-rich plant sowings and consideration of regional seed sources, set-asides often have low established richness due to high competitiveness of few, common species (Stoll and Prati, 2001). Wassmuth et al. (2009) found that intraspecific aggregation enables coexistence of subdominant species by alleviating the process of interspecific competitive exclusion (Fig. 4). Consequently, sowing of set-aside fallows designed to preserve and enhance biodiversity should consider small-scale clumping of species (in particular of species with strong response to competition). Aggregated sowing requires the development of new agricultural sowing technologies to successfully cultivate competitively weak and endangered wild plant communities (Wassmuth et al., 2009). Weak competitors may be particularly important for higher trophic levels.
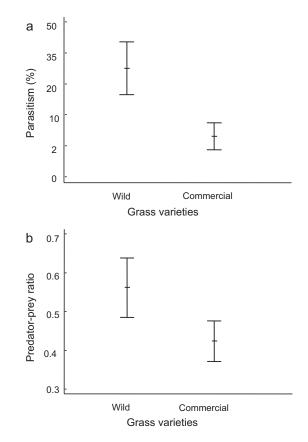
Fig. 3. The impact of natural enemies on grasses grown from wild vs. commercial seeds (Tscharntke, 2000). (a) Differences in percent parasitism by *Eurytoma phlei*, which is the major parasitoid of *Tetramesa* galls on the grass *Phleum pratense*, between wild (regionally collected seeds) and a commercial variety of *Phleum pratense* ('wild' vs. variety 'Tiller'). Arithmetic means of arcsine-transformed percentages $\pm$ SE are given (ANOVA: $F = 5.24$, $N = 8$, $p = 0.06$). 'Wild' stems had higher *Tetramesa* attack rates than 'Tiller' stems (12.6% vs. 7.7%), but percent parasitism of *E. phlei* did not correlate with *Tetramesa* density ($r = 0.264$, $N = 8$, $p = 0.527$). Rate of parasitism was estimated by the dissection of $634 + 841$ shoots (wild + Tiller). (b) The predator–prey ratio on grasses grown from seeds of wild grasses vs. commercial varieties (paired t-test, $t = 2.33$, $N = 20$, $p = 0.04$; arithmetic means $\pm$ SE are given). In 1994, grasses from six species (*Alopecurus pratense*, *Festuca arundinacea*, *Festuca pratensis*, *Lolium perenne*, *Phleum pratense*, *Poa pratensis*) originating from wild seeds and one to two commercial varieties per grass species were sown in 6×5 m plots near Göttingen (Germany), and ten paired samples (wild vs. commercial) were available. Each of the 20 replicates was based on Univac suction samples (following Greiler, 1994); on five dates (May–August 1995) all insects within a cage (4×0.25 m² per date and plot) were caught (in all, a 5 m² sample per replicate). The predator–prey ratio was calculated using all specimens of Homoptera, Lepidoptera, Saltatoria, Thysanoptera, and phytophagous Heteroptera (phytophagous prey) and all specimens of Arachnida, Apocrita, Planipennia, and entomophagous Heteroptera (predators).

For example, species richness of pollinators has been found to be higher in fallows sown with less competitive than with dominant grasses in a field experiment in Finland (Kuussaari et al., submitted for publication).

4. Landscape context of set-aside

Agricultural intensification has caused local habitat simplification (e.g., shortened crop cycles, increased agrochemical use) and landscape-wide habitat simplification through transformation of structurally complex habitat to simple crop systems (including increased field sizes; Tscharntke et al., 2005). The effectiveness of conservation management changes with landscape structure. Duelli and Obrist (2003) argue that success can be expected to be higher in regions where source populations survived in natural or semi-natural habitats, whereas Tscharntke et al. (2005), Rundlöf
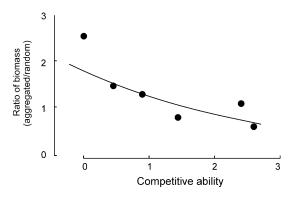
Fig. 4. The competitive ability of six arable weed species (calculated by dividing the biomass in mixture by biomass in monoculture) is negatively related to the ratio of the biomass in intraspecifically aggregated plots and the biomass in randomly dispersed plots (Wassmuth et al., 2009). This figure shows that arable weeds with low competitive ability gain most in biomass when grown intraspecifically aggregated ($R = -0.850$, $p = 0.039$, $n = 6$).

and Smith (2006), Concepción et al. (2008), Isaacs et al. (2009) and Batáry et al. (2010) found the highest effectiveness of conservation management in simple landscapes. They argue that in heterogeneous, structurally complex landscapes with high proportion of non-crop habitat (>20%), biodiversity and associated functioning is at a high level already, so that local conservation management does not result in a recognizable effect. Wretenberg et al. (2010) found that increasing the amount of (mainly non-rotational) set-aside had only positive effects on bird richness in simple landscapes consisting of low to intermediate amounts of forest, but even negative effects in forest-dominated, complex landscapes.

Several papers address the question of how much uncultivated, non-crop area within a landscape is necessary to support a minimum of biodiversity, particularly of endangered species. Banaszak (1992) argues that maximally 75% of the landscape should be under crops if bee species are to be conserved. Kretschmer and Hoffmann (1997) show in a landscape comparison with a range of 5–30% of uncultivated area that bee, carabid beetle, butterfly and bird species diversities respond linearly with no tendency of a saturation curve or threshold. Responses to set-aside can vary widely depending on the organisms' traits and the structure of the surrounding landscape including proximity of colonization sources (Tscharntke et al., 2005).

Agricultural intensification has caused both local and landscape-wide structural simplifications including transformation of complex non-crop habitat to simple crop systems (Tscharntke et al., 2005). Set-aside in species-poor agricultural landscapes can be dominated by very abundant weeds instead of a diverse arable weed community (Denys and Tscharntke, 2002; Gabriel et al., 2005). In England, rarer arable plants can principally benefit from set-aside, but these species are now very localized (ENCA, 2008). In addition to losses in arable plant diversity, population densities of natural enemies of pest insects are reduced and their spillover from non-crop to crop is likely to be diminished in landscapes dominated by arable cropland (Barbosa, 1998; Nentwig et al., 1998; Landis and Marino, 1999). In a review Bianchi et al. (2006) tested the hypothesis that natural pest control is enhanced in complex landscapes with a high proportion of non-crop habitats. Natural enemy populations were higher (74% of all studies) and pest pressure lower (45%) in complex than simple landscapes. In 80% of the cases, herbaceous habitats, which include set-aside fallows, were related to enhanced natural enemy activity and somewhat less often to wooded habitats (71%) and landscape patchiness (70%). Hence, diversified landscapes with high percentages of set-aside hold most potential for the conservation of enemy biodiversity sustaining the pest control function.
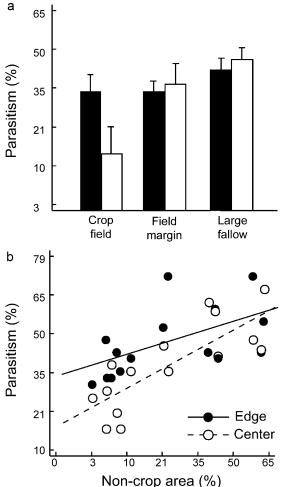

Fig. 5. Parasitism of rape pollen beetle (*Meligethes aeneus*) by ichneumon wasps on oilseed rape (*Brassica napus*) (data from Thies and Tscharntke, 1999). (a) Percentage parasitism in winter rape fields adjacent to cereal crop fields ("crop field"); small (3-m-wide) 6-year-old field margins strips ("field margin") with naturally developed vegetation; and large old set-aside fallows ("large fallow", >1 ha) with naturally developed vegetation. Two-way nested ANOVA: parasitism (%) vs. habitat (crop field/field margin/large fallow: $F = 5.75$, $p = 0.009$, $N = 16$) and sampling site (edge/centre: $F = 2.19$, $p = 0.110$, $N = 32$). (b) Percentage parasitism in relation to the percentage of non-crop area in agricultural landscapes near the edge (1 m from the edge; $F = 5.86$, $p = 0.030$, $R^2 = 0.31$, $N = 15$) and in the centre (10–12 m from the edge; $F = 21.1$, $p < 0.001$, $R^2 = 0.62$) of winter rape fields. The intercepts of these regression lines are significantly different ($F = 4.47$, $p = 0.04$), whereas the slopes do not differ ($F = 1.89$, $p = 0.18$).

In oilseed rape fields, the parasitism of rape pollen beetles (*Meligethes aeneus*) by ichneumon wasps was higher near old set-aside fallows and old field margins than to adjacent cereal crop fields, which was due to increased spillover from set-aside and field-margin habitats (Fig. 5a). Furthermore, parasitism rates of pollen beetles increased with landscape complexity, while oilseed rape damage from this economically important pest decreased (Fig. 5b). In structurally simple landscapes (<20% non-crop habitat), field margins or fallows adjacent to the rape field enhanced parasitism both in the edge and in the centre of the rape field (Fig. 5b; Thies and Tscharntke, 1999). In complex landscapes (>20% non-crop area), the local effect of field margins was absent (no difference in parasitism between the edge and the centre of rape fields, Fig. 5b) and appeared to be superimposed by the landscape-wide enhancement of parasitoid populations due to the high amount of semi-natural habitat. Hence, only in simple landscapes, did creation of set-aside habitat adjacent to crop fields have a significant effect on pollen beetle parasitism (Tscharntke et al., 2002). At less

Table 1
Summary of the effects of set-aside management on plants, insects, birds and mammals. See text for more details and references.

Set-aside management	Effects on plants	Effects on insects	Effects on birds and mammals
Age of natural succession	In complex landscapes, natural succession enhances rare and endangered arable weed species. Arable weeds profit only from early successional, 1–2 years old set-aside.	Rare arable weed species can support rare insects (for example, specialised butterflies and beetles), while older successional stages can harbour more species and a higher predator–prey ratio.	Early successional habitats often benefit birds, whereas small mammal communities are richer in older habitats, in particular in habitats enriched with woody structures such as hedges.
Sowing strategies for set-aside	Regional seeds establish better and conserve regional genetic structure. Intraspecific aggregation helps survival of weak competitors, enhances coexistence and thereby, plant diversity.	Specialised herbivores and solitary bees often do not feed on plants from commercial seeds. Predator–prey-ratios can be higher on regional than commercial grass mixtures, thereby affecting potential biological control. Enhanced plant diversity is usually associated with enhanced insect diversity.	Set-aside with high plant and insect diversity often promotes availability of seed and insect resources for birds and mammals.
Landscape context of set-aside management	In complex landscapes, the large landscape-wide species pool allows high local diversity on set-aside. This is particularly true for arable weeds, but less so for perennial plant communities. Introducing set-aside is more efficient in simple than in complex landscapes.	Complex landscapes harbour a larger insect species pool. Setting crop fields aside and allowing successional fallows is more efficient in simple than complex landscapes.	Complex landscapes support more birds and mammals so that only in simple landscapes conservation management makes a difference.

than 20% non-crop area, rape pollen beetle parasitism dropped to 32–36%, below which a success in classical biological control has never been found (Hawkins and Cornell, 1994). Similarly, cereal aphid population sizes shrunk between wheat flowering and ripening significantly when landscapes were complex, while aphid population growth rate was negatively related to percent aphid parasitism (Thies et al., 2005). In their review, Isaacs et al. (2009) provide more evidence for the concept that creating habitat and flowering plants to enhance biological control in cropland (which could principally be made with set-aside schemes) is more effective in simple than complex landscapes. Plant and bee diversity in Germany was higher in organic than in conventional cereal fields in simple landscapes, but not in complex landscapes (Holzschuh et al., 2007). Also in Sweden, organic farming enhanced bumblebee richness and abundance only in simple landscapes (Rundlöf et al., 2008), and enhanced wild bee diversity can relate into enhanced crop pollination.

These examples show that biodiversity and associated ecological process (for example, pest parasitism and pollination) can be significantly enhanced through introducing local habitat such as set-aside, but only when landscape structure is simple, i.e. landscape composition is dominated by cropland (roughly <20% non-crop habitat).

5. Conclusions

In this review we emphasized the need to consider age of succession, sowing patterns and landscape context for the enhancement of biodiversity on set-aside (Table 1). The loss of set-aside in European landscape means a major loss of biodiversity and associated ecosystem processes (Van Buskirk and Willi, 2004), while the management and type of set-aside greatly affect the biodiversity conservation value. Early successional set-aside can be more attractive for conservation than generally believed, because annual plant communities can harbour endangered species with insect consumer species that are also rare. Sowing strategies may substantially influence the development of set-asides. Sowings should employ seed mixtures of regional seed origin and are particularly relevant when the local (seed and bud) species pool is impoverished. However, establishment of diverse seed mixtures is difficult because of the high competitive ability of a few common

species. This calls for an improved sowing strategy with intraspecific aggregation of subdominant species. Finally, landscape context of set-aside management needs consideration. Efficiency of set-aside is highest in simple landscapes, where improvements have the highest relative effect, whereas in complex landscapes set-asides cannot add much to an already high biodiversity. In simple landscapes, set-aside management can also improve ecosystem services in adjacent crop fields through spillover of pollinators and biological control agents (Thies and Tscharntke, 1999; Thies et al., 2005; Holzschuh et al., 2007). Twenty percent of semi-natural non-crop habitat appears to be a rough threshold sustaining services such as biodiversity conservation (plants, insects, birds) as well as pollination and biological control. However, improved set-aside management, allowing natural succession wherever possible and sowings only with a diversity of regional seeds and intraspecific aggregation should have the potential to reduce the percentage of semi-natural non-crop habitat needed in the landscape (see Holzschuh et al., 2008).

To summarise, the different types of set-aside management support different communities, and only a mosaic of rotational and long-term as well as naturally developed and sown set-aside can increase landscape-wide heterogeneity supporting maximum biodiversity. EU schemes should consider that management efficiency is higher in simple than complex landscapes. The many possible ways of set-aside management, the high geographic, agronomic and socioeconomic variability and the many different, group-specific responses call for target group specific set-aside management in the most responsive landscape. But first of all the demonstrated potential for conservation and ecosystem service benefits demands a revision of EU policy with a set-aside scheme tailored for the maintenance of biodiversity and ecosystem services.

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