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Integration of ecological knowledge at a landscape level for conservation policies in agricultural areas

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Abstract

Agricultural landscapes in Europe have been highly fragmented, with habitat loss and degradation of remaining patches as the main consequence. In response to these threats European countries have adopted agro-environmental schemes to protect and enhance biodiversity, but their effects are not always clear. The main objective of this study is to integrate knowledge at a landscape level that could be used as a tool for conservation policies in agricultural areas, taking as an example the perennial herb *Geranium sylvaticum* and the relationship between traditionally managed hay meadows, woodlands and road verges for its survival. An existing model on plants in fragmented agricultural areas will be extended, based on field data and logistic-regression modelling. This paper argues that a more integrative approach is needed for restoration purposes to address the threat of fragmentation on agricultural landscapes. For conservation purposes, this could be achieved taking into consideration not only

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single habitats but a network of associated ones and also reconstructing the historical land-use practices that reflect the landscape dynamics.
Keywords: fragmentation; agricultural landscapes; *Geranium sylvaticum;* hay meadows; woodlands; road verges; holistic approach; habitat networks; conceptual model

Introduction

In the UK, as in many European countries, the decrease of unimproved grasslands has been particularly widespread (Critchley, Burke and Stevens 2004). This is of great concern as most of the European biodiversity is associated with cultural landscapes. The agro-environment schemes were implemented at the European level to ameliorate the problem of habitat loss in agricultural landscapes, and farmers are paid for adopting environmentally beneficial management practices. In the UK, among other schemes, the main one that was introduced in 1987 was the Environmentally Sensitive Areas scheme, in extensive areas of conservation value that were particularly vulnerable. Various studies have been carried out to evaluate the effectiveness of the schemes in general (ADAS 1996; Critchley, Burke and Stevens 2004) but it is still unclear whether AE schemes have been successful in achieving their goal to protect and enhance species-rich grasslands not only in the UK but also in Europe (Kleijn and Sutherland 2003; Kleijn et al. 2001).

The lack of rigorous studies was identified as one of the main causes of this ambiguity, but also the focus of the surveys could have had an important impact in the evaluations. Most of the approaches to evaluate the effectiveness of the schemes compared biodiversity in the agro-environment schemes and control areas at one point in time. In most of the cases the field or farm scales were the only ones that were considered for plants and insects (Zechmeister et al. 2003; Feehan, Gillmor and Culleton 2001) and birds (Bradbury and Allen 2003). None of these studies have acknowledged the importance of the landscape pattern where the field is embedded. This individualistic approach fails to recognize how the landscape determines the persistence of natural populations in organisms, as has been demonstrated in several studies (Ouborg 1993; Harrison and Bruna 1999; Opdam, Verboom and Pouwels 2003; Hanski 1999; Petit and Burel 1998). Fragmentation and biodiversity loss operate at different scales depending on the relationship between fields and the spatial structure of the surrounding habitat.

The objective of this chapter is to incorporate knowledge at a landscape level as a tool for conservation in agricultural areas, thus integrating ecological knowledge and policy for effective conservation; also to broaden existing knowledge of the persistence of plant populations in fragmented habitats. Particularly I will focus on the perennial herb *Geranium sylvaticum* and the habitats where it is found in northern England: woodlands, road verges and especially, traditionally managed meadows, *Anthoxanthum odoratum – Geranium sylvaticum* grasslands, a Priority Habitat in the EU Habitats Directive. The main assumption in this research is that for the persistence of *Geranium sylvaticum* in a fragmented landscape, the relationship between the three habitats is a key aspect that needs to be taken into consideration for conservation and agricultural policies. The concepts developed in the present chapter could be used for conservation purposes and to improve the effectiveness of agro-environment schemes in the area using a more integrative and holistic approach, where not individual habitats are considered alone, e.g. hay meadows, but the quality and the historical land use of the whole landscape is addressed. To develop these ideas, a conceptual model for the population dynamics of *Geranium sylvaticum* will be built from a previous, more general model that will be described in the following section.

Conceptual model for plants in agricultural landscapes

Geertsema et al. (2002) have developed a model for survival of plant populations in fragmented agricultural landscapes (Figure 1), using metapopulation theory (Hanski 1999). The main assumptions of this model are that the stage or phase of a local population in space and time is determined by the presence or absence of plants and/or a seed bank and these in turn are influenced by the quality of the patch. Population dynamics occur mainly by colonizations or extinctions and habitats could have quality changes over time.

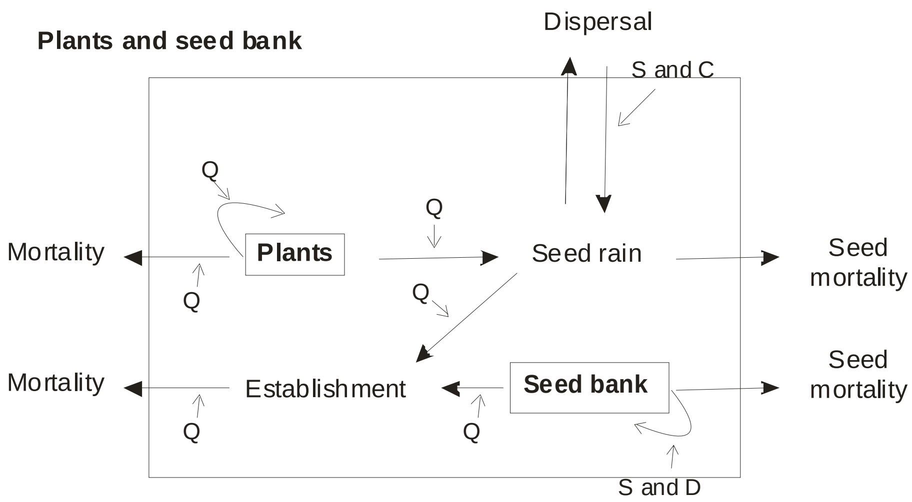

Figure 1. Conceptual model of the population dynamics within patches that are occupied by plants, seed bank and the demographic processes that could be operating. Factors that could influence the demographic processes are Q= habitat quality, D= habitat dynamics, C= habitat configuration, S= species characteristics. Reproduced with permission of Geerstema et al. (2002)

Furthermore, quality and habitat configuration play a major role in the demography of plant populations at a local and landscape scale. Quality enables seeds coming from other patches to establish and, in turn, the plants can produce more seeds or grow in a vegetative way, increasing the population size both above and below ground. Seed banks also are influenced by quality and, together with the species characteristics and the age of the seed bank, could constitute a reservoir of seeds for future non-favourable seasons or to increase the potential density of seed production, causing an increase in the dispersal and gene flow through the landscape. Both patch quality and configuration of the habitat contribute to the spatial cohesion of the habitat network for a species, and processes at the local scale could have implications at the landscape level.

Plant dispersal ability also influences patch (re)colonization and population dynamics through habitat configuration. In the model, Geerstema et al. (2002) particularly emphasize the type of seed banks and dispersal to determine plant strategies in agricultural landscapes. Species could overcome hostile environment in time, by having persistent seed banks and short-distance dispersal, or cross a hostile environment in space, by transient seed banks and long-distance dispersal. However, it is not clear how this model could be applied to plants that do not have either of these strategies and are more stable. In species-rich grasslands, which are one of the most endangered habitats in agricultural landscapes, there are herbs like *G. sylvaticum* that are not successful dispersers and neither have persistent seed banks. They have very local dynamics and they could have evolved in stable environments where they did not have to adapt to (re)colonize empty patches and where the threat of extinction was also low because of the stability of the system (Geertsema, Opdam and Kropff 2002). Thus, it would be useful to know which factors influence their demographic processes.

A case study of fragmentation: *Geranium sylvaticum* and its habitats

Geranium is a perennial plant characteristic of cool and moist climate (Preston, Pearman and Arnold 2002) that is found on neutral to calcareous and moderately mesotrophic soils (Rodwell 1993; 1991). Though it has vegetative reproduction through its rhizomes, which also are used for storage (Schulze 1982), it also has sexual reproduction and produces seeds that are dispersed through ballistic explosion up to several metres. The seeds need a vernalization period to break the dormancy and activate its germination. However, *Geranium* has a transient seed bank (Fitter and Peat 1994) and, thus, there is not a significant contribution to the general meadow seed bank (Smith et al. 2002). For this reason the seed-bank section of the original model will not be taken into consideration. What it is not known is the contribution and importance of seed production for the persistence of *Geranium*, and the precise role of vegetative reproduction.

To investigate the fragmentation pattern of *G. sylvaticum* in road verges, hay meadows and woodlands, vegetation information was recorded in 2002-2003 in the Yorkshire Dales National Park, UK. A re-survey of 120 fields using 1m^2 and 180 point samples of road verges where *G. sylvaticum* used to be present in the past was carried out and the presence and abundance of all vascular species was recorded. Though woodlands were not surveyed, there was past information about their status.

To assess the extent of isolation of hay meadows from meadows, road verges and woodlands in the last 20 years, distance measures (m) were recorded from meadows to the nearest road verges and woodlands using GIS from two periods, 1980-1985 and 2003. In addition buffers from the edge of the fields to 100 and 500 m were set and the area and number of patches of rough, improved, semi-improved and unimproved grassland and woodland present in 1980 were calculated. Logistic-regression models were then constructed for *G. sylvaticum* where the effects of habitat, management and spatial variables were considered.

Preliminary results from meadows demonstrate that *G. sylvaticum* has disappeared from nearly 40% of original sites and that meadows have become ten times more isolated in the last 20 years. However, the distances to road verges and woodlands have remained similar to those in the past, demonstrating that these are more stable habitats. Logistic regressions using stepwise forward selection where the overall presence of *G. sylvaticum* in 2003 was the response variable, showed that field quality and the type of adjacent habitat were important factors affecting the presence of the species in meadows and road verges. Field quality ($B=1.580$, $p<0.0001$), area of unimproved grasslands within 100 m ($B=1.655$, $p<0.0001$) and area of woodland within 100 m (0.001) were the most relevant variables explaining the presence of *G. sylvaticum* in 2003. On the other hand *G. sylvaticum* was not likely to be found in areas of improved grasslands within 100 m ($B=-1.340$, $p< 0.05$).

An important point that needs to be highlighted is that the data of the adjacent habitat were from 1980, more than 20 years ago, giving some indication of a possible time-lag effect in the response of *G. sylvaticum* to landscape changes. Indeed, further analysis indicated that there was a significant positive correlation between the incidence of *G. sylvaticum* in 1980 and the percentage of unimproved grasslands in 1980 (Spearman's rho=0.374, $p<0.05$). However, when the same habitat of 1980 was compared with the incidence of the species in 2003 the correlation was higher (Spearman's rho= 0.583, $p<0.001$).

A new model for habitat integration at the landscape level

From the relationship between *G. sylvaticum*, field quality, adjacent habitat and the relevance of road verges, meadows and woodlands for the dynamics of the species, a new synthesis could be made based on the previous model (Geertsema, Opdam and Kropff 2002), to understand the population dynamics of *G. sylvaticum* in agricultural habitats (Figure 2). Because *G. sylvaticum* has a transient seed bank that may not be important for the survival of the population in the long term, this part of the original model will be excluded. One of the main assumptions in this model is that the relationship between road verges, woodland and meadows is dynamic and could change in time mainly due to management practices, which in turn affects habitat loss and fragmentation.

At high altitudes in the Pennines in the UK, woodland such as the *Fraxinus – Sorbus – Mercurialis* type (Rodwell 1991) was probably the original habitat where *G. sylvaticum* was present, though it may never have reached high levels of dispersion or abundance, being such a light-demanding plant (Hill et al. 1999). Through woodland clearance, meadows and pastures were established locally in the landscape, *G. sylvaticum* itself benefiting from the combination of grazing and mowing associated with the taking of a hay crop in the open environment. The 'park meadows' of Norway and other parts of Scandinavia (Eriksson, Cousins and Bruun 2002) perhaps preserve the kind of agricultural landscape that developed early in the Pennines. Later, enclosure of the better land close to the farmsteads created the pattern of in-bye meadows and pastures that remains largely intact today, eventually providing extensive stretches of fields in the valley-bottom landscape that were a very congenial environment for the frequent and abundant occurrence of *G. sylvaticum* and the associated suite of herbs seen in *Anthoxanthum odoratum – Geranium sylvaticum* grassland (Rodwell 1993).

These hay meadows may provide the ideal condition for *G. sylvaticum* to become a constant and abundant species as the management practices provide the appropriate scenario for its establishment. Light grazing favours *G. sylvaticum* and also controls other more competitive grasses (Smith and Rushton 1994); also the traditional management encourages genetic diversity. Phenological studies of hay-meadow species indicate that the early-flowering species, like *G. sylvaticum*, develop ripe seed mainly during July, which coincides more or less with the existing cutting dates, allowing the bulk of the seed to be shed over this period and outcompeting species whose fruits ripen later (Smith and Jones 1991). Together with hay making, light grazing stimulates the abundance of *G. sylvaticum*, either by seed production or by vegetative growth. By opening the sward, in this way, through the provision of niches for lower-growing species, traditional management encourages the abundance of *G. sylvaticum*, which otherwise would be outcompeted by fast-growing species. However, since the 1940s, these hay meadows have been transformed from low-input and traditionally managed vegetation to high-input and intensively managed swards with the application of chemical fertilizers and herbicides. Now it is believed that the total area of *Anthoxanthum – Geranium* grassland is only 610 ha.

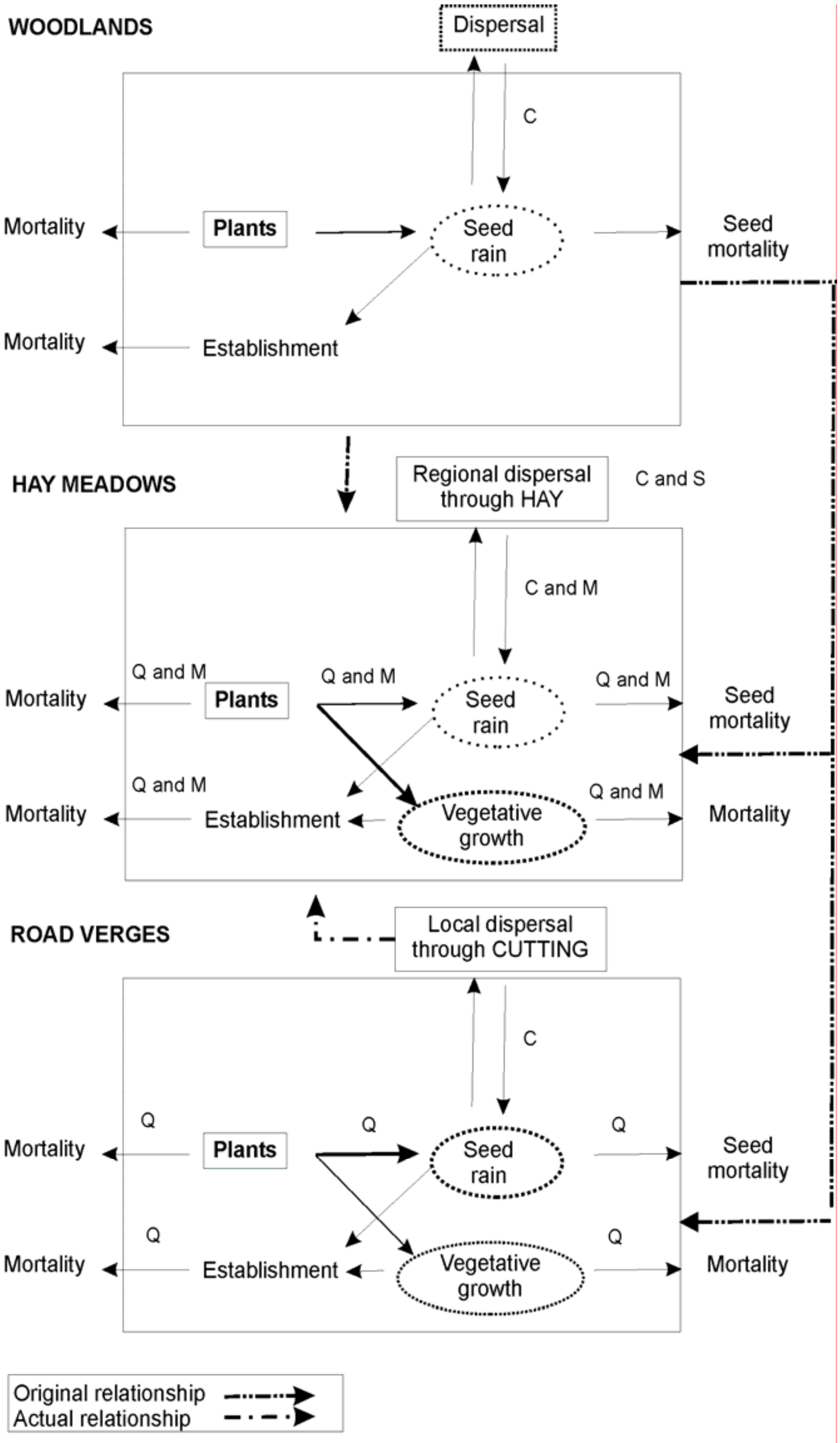

Figure 2. Conceptual model of the population dynamics of *G. sylvaticum* in woodlands, meadows and road verges. Arrows of different thickness indicate demographic processes and their importance. Letters indicate which factors influence these processes. (Q = habitat quality, D =habitat dynamics, C = habitat configuration, S = species characteristics, M = management). Dashed lines indicate processes that are not yet well known

Stretches of land adjacent to early roads and tracks, probably originally grazed and cut for hay, eventually became separated off as verges though they effectively preserved a habitat in which many of the meadow plants could thrive, as nearly 10% of the total hay-meadow flora are thought to be present here. Also the relationship between meadows and verges is further supported by a study on the verges in Cumbria, where in the vicinity of meadows, road verges had similar species. Verges could be regarded as marginal areas, once belonging to meadows and woodlands, which were afterwards isolated when fields became enclosed mainly by walls.

Recent studies have showed the importance of verges for the population dynamics of *G. sylvaticum.* Comparison of morphological and phenological characteristics in meadows and verges indicates that road verges are more suitable habitats for *G. sylvaticum.* Plants in road verges were double the height and width of those in meadows. Also the number of closed buds, open flowers and unripe fruit tended to be higher. The lack of grazing may stimulate the early growth of the species. Furthermore, an increase in cover of *G. sylvaticum* has been reported in areas where grazing has been stopped (Krahulec et al. 2001). Thus, plants in road verges may complete the reproduction cycle by the time that the meadow plants have begun to flower so that interbreeding between meadows and plants of road verges may not be possible. This lack of synchronization between populations indicates that these habitats are more isolated than previously believed and rejects previous ideas that meadows and verges might behave as single reproductive units. However, verges could be a reservoir of seeds of *G. sylvaticum* and a refugium when conditions in meadows are not suitable. Verges could be important targets for restoration but they have been generally neglected.

The main unanswered question concerns the dispersal mechanisms of *Geranium,* especially the importance of vegetative expansion versus seed production. What can be hypothesized is that the distribution of *Geranium* now is the result of past events of clearance and extensive management in most of the valley bottoms. What is present today is a remnant of its original distribution and is not related to the dispersal mechanisms of *G. sylvaticum* (Dupre and Ehrlen 2002). The establishment of *G. sylvaticum* in other fields may be due to movement of hay from one field to another, and if the field quality is suitable the species will establish, an important process that has also been reported in Germany (Poschold et al. 1998) and Scandinavia (Eriksson, Cousins and Bruun 2002). The mortality of the species in all stages is mainly affected by changes in management practise that would affect the field or verge quality.

Conclusions

The extension of the existing model of plants in agricultural areas indicates that the landscape is a dynamic entity, which is affected by the physical and biotic environment, and in agricultural areas is mainly influenced by land use and cultural aspects that determined the landscape history. This study provides evidence that the relationships of different landscape elements could change in time mainly due to fragmentation of the original habitat and changes in land use. At first, broadleaved woodlands were abundant and served as a source of seeds and plants for hay meadows, but as this resource became scarcer, other habitats, in this case road verges, replaced woodlands and now could be the reservoir of the hay-meadow flora. The importance of the quality of the surrounding landscape for the presence of *G. sylvaticum* indicates that a more holistic approach is needed where the landscape as a whole is addressed and there is an integration of the ecology of the target species and the different habitats where it is present. There is evidence from other organisms that the spatial structure of the landscape affects the allocation of dispersing individuals to patches of the network (Geertsema, Opdam and Kropff 2002; Opdam and Wiens 2002). The model developed in this chapter and its implications need to be considered in conjunction with conservation policies, through agro-environment schemes, to provide integration of both landscape and ecological knowledge for the preservation of fragmented agricultural habitats.

The agro-environment schemes as the main programme for restoration of semi-improved grasslands in Europe (Kleijn and Sutherland 2003), tried to halt the extensive improvement that has accelerated after World War II and, more intensively, in the 1970s. However, most of the efforts to recreate and restore meadows through agro-environment schemes have relied only on the management practices to enhance their quality (Walker et al. 2004), and this is not the only factor that needs to be taken into consideration, as it has been reported that despite traditional management the area and number of meadows have decreased, for example, in Sweden as a result of modifications at the landscape level (Berlin, Linusson and Olsson 2000).

Furthermore, considering the results of the present research, the focus of conservation in agro-environment schemes should be broadened to consider not only farms but whole landscapes in the near proximity of target meadows. Large-scale habitat schemes could be the most effective approach targeted to carefully selected areas (Sutherland 2002). This landscape approach could be more beneficial than the farm-scale approach used at present as large-scale population processes will also influence local population dynamics for many species (Benton, Vickery and Wilson 2003). Conservation policies like the Common Agricultural Policy have failed to acknowledge the importance of the landscape as still only a whole-farm approach is being considered (Silcock, Swales and Manley 2003).

Another important result of this research that could be used for restoration purposes is the relevance of the time lag that *G. sylvaticum* showed in relation to the past landscape, indicating that ecological processes occur over longer time scales. This time lag could be encountered following a relatively fast landscape change that reduced the equilibrium of a system and where the population may linger near the old equilibrium for a while (Nagelkerke et al. 2002). This could be the case for these hay meadows, as they suffered important landscape changes due to agricultural intensification at a fast pace. The loss of species following a delay after landscape degradation is of major importance because they may determine how much extinction or other ecosystem change is waiting, as there may be ongoing changes whose full effects will be experienced in the future, even though fragmentation events have ceased (Hobbs and Yates 2003). In this respect *G. sylvaticum* is another example of a "ghost of the landscape past" (Nagelkerke et al. 2002) as its distribution is better explained by a prior landscape configuration than it is by the current one, and thus is a species that exhibits a slow response to fragmentation and which is not likely to be in equilibrium with the current landscape configuration. Moreover if species are long-lived or have perennial vegetative structures or perennial seed banks, the true conservation status of many plant species in habitat fragments may be obscured (Hobbs and Yates 2003). This delay in the response of the species to changes in the landscape is a worrying fact that needs to be addressed, especially in these meadows, where herbs with similar characteristics as *G. sylvaticum* are present. The explanation of a time-delayed response to environmental and landscape conditions may explain why in the ESA monitoring (Critchley et al. 2004), despite conservation efforts, meadow quality is still declining. This phenomenon of population decline after landscape degradation has been also documented for carabid beetles (Petit and Burel 1998) and forest plant species (Grashof-Bokdam and Geertsema 1998; Kolb and Diekmann 2004). This factor is of prime importance for policy decisions on conservation issues, and it shows that the habitat is not static and that what is present today and what is the conservation target, may not be in a stable equilibrium.

This approach, integrating the knowledge based on the ecology of a species and its habitats at different spatial and temporal scales, could be used for conservation policies of agricultural areas. For restoration to be successful in hay meadows there is a need to broaden its scope from local processes (e.g. fields) to consider landscape patterns, temporal scales and land-use history, as it was shown that studying a system in one point in time is not enough to understand the processes that are occurring. This information could then be applied to policy and decision-making for sustainable landscape planning.

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