UFZ-Diskussionspapiere

Department of Ecological Modelling
Department of Economics

4/2007

An agglomeration payment for cost-effective biodiversity conservation in spatially structured landscapes

Martin Drechsler, Karin Johst, Frank Wätzold, Jason F. Shogren

March 2007

An agglomeration payment for cost-effective biodiversity conservation in spatially structured landscapes

Martin Drechsler[1], Karin Johst[2], Frank Wätzold[3], Jason F. Shogren[4]

[1] Helmholtz-Centre for Environmental Research – UFZ, Department of Ecological Modelling, Permoserstr. 15 04318 Leipzig, Germany, email: martin.drechsler@ufz.de

[2] Helmholtz-Centre for Environmental Research – UFZ, Department of Ecological Modelling, Permoserstr. 15 04318 Leipzig, Germany, email: karin.johst@ufz.de.

[3] Helmholtz-Centre for Environmental Research – UFZ, Department of Economics, Permoserstr. 15 04318 Leipzig, Germany, email: frank.waetzold@ufz.de

[4] University of Wyoming, Department of Economics and Finance, 1000E. University Avenue, Laramie, WY 82071, USA, email: JRamses@uwyo.edu

Running head: Agglomeration payments for biodiversity

Abstract:

Compensation schemes in which land owners receive payments for voluntarily managing their land in a biodiversity-enhancing manner have become one of the most important instruments for biodiversity conservation worldwide. One key challenge when designing such schemes is to account for the spatial arrangement of habitats bearing in mind that for given total habitat area connected habitats are ecologically more valuable than isolated habitats. To integrate the spatial dimension in compensation schemes and based on the idea of an agglomeration bonus we consider a scheme in which land-owners only receive payments if managed patches are arranged in a specific spatial configuration. We compare the cost-effectiveness of agglomeration payments with spatially homogeneous payments on a conceptual level and for a real world case and find that efficiency gains of agglomeration payments are positive or zero but never negative. In the real world case, agglomeration payments lead to cost-savings of up to 70% compared to spatially homogeneous payments.

Key words: agglomeration bonus, biodiversity conservation, cost-effectiveness, ecological-economic modelling, metapopulation, spatial heterogeneity,

JEL: Q24, Q57

1. Introduction

Compensation schemes in which land owners receive payments for voluntarily managing their land in a biodiversity-enhancing manner have become one of the most important instruments for biodiversity conservation worldwide. In the United States, the US Fisheries and Wildlife Service and over a thousand non-profit land trusts promote habitat conservation by using voluntary incentive mechanisms to elicit the cooperation of private landowners. Based on a survey of state incentive programs, Defenders of Wildlife (2002) found about 400 incentive programs enrolling some 70 million private acres already exist in the 50 states—fifty percent of which were created within the last decade. The typical state offers four to six conservation incentives, usually in some form of direct payment and easement with tax relief (also see the overview in Shogren, 2005). In Europe, farmers receive several billion Euros annually in the context of agri-environmental schemes for applying biodiversity-enhancing farming measures (cf. European Commission 2005). Increasingly, payment schemes for conservation measures are also applied in developing countries (e.g. Landell-Mills and Porras 2002).

These voluntary schemes are needed—they are necessary because property rights are frequently allocated so landowners have considerable latitude to manage their land in their own private interest. Experience with the US Endangered Species Act also demonstrates that forcing owners of land with endangered species to carry out conservation measures might encourage them to eradicate these species to escape the burden of conservation costs (Brown and Shogren 1998).

One key challenge when designing effective biodiversity conservation compensation schemes is to account for the spatial arrangement of habitats. The ecological literature addresses how specific habitats should be spatially allocated to maximise the targeted ecological benefit, such as population size, species viability, and so on (see, e.g, McDonnell et al., (2002), Frank and Wissel (2002), Drechsler et al. (2003)). The design needs to consider that the contribution of a habitat to an overall conservation objective depends on both its spatial extent and its location relative to other patches. In spatially structured landscapes, species populations exist as so-called *metapopulations*, which consist of subpopulations each of which inhabits a habitat patch. If individual members of the species can move between patches, the subpopulations interact. In general, this exchange of individuals is beneficial for the survival of the metapopulation[1], resulting in the general rule for given total habitat area connected habitats are ecologically more valuable than isolated habitats (e.g., Simberloff 1988; Hanski 1999).

Given the voluntary nature of payment schemes, the question is how to induce land-owners to select land for conservation so that habitats are connected? Many payments are spatially homogeneous – every land-owner receives the same payment for a particular conservation measure. Such homogeneous payment schemes generate an ecologically valuable spatial configuration only if it contains the least costly patches. In contrast, Parkhurst et al. (2002) suggested an alternative scheme—the 'agglomeration bonus.' The agglomeration bonus provides an incentive to land-owners to generate a valuable configuration. The idea of an agglomeration bonus is that a premium, a bonus, is paid on top of a standard payment for managing land in a biodiversity-enhancing manner if the managed patches are arranged in a specific spatial configuration.

Such an incentive structure leads to higher ecological benefits but it can also lead to higher costs. It may be necessary to include costly patches to achieve a desired spatial configuration. This suggests a trade-off exists between maximising total habitat size with inferior spatial configuration and optimising spatial configuration with less habitat size. This raises the open question of the overall cost-effectiveness of the agglomeration bonus idea—does an agglomeration bonus lead to a higher ecological output for a given budget than homogeneous payments?

[1] In some cases, the exchange of individuals among subpopulations may be adverse, e.g., spread of disease.

This paper addresses this question—we compare the cost-effectiveness of an agglomeration bonus against a spatially homogeneous payment. We compare two 'pure' payment schemes: (i) payments are only made when a certain spatial configuration is generated (agglomeration payment), and (ii) payments are made independent of habitat location (spatially homogeneous payment).[2] We first explore a conceptual analysis on a fictitious landscape to gain insight into how economic and ecological parameters affect the cost-effectiveness of an agglomeration payment. We then compare the cost-effectiveness of homogeneous and agglomeration payments for a real conservation problem: the protection of an endangered butterfly species (Large Blue, *Maculinea teleius*) in a region around the city of Landau, Germany.

Our conceptual analysis shows that the cost-effectiveness of agglomeration payments compared to homogeneous payments is determined by the interaction of three effects: The *connectivity effect* captures the ecological benefits of agglomeration payments: spatially aggregated habitats are usually better for species survival than spatially dispersed habitats. In contrast, the *patch selection effect* makes homogeneous payments comparatively more cost-effective. This effect arises because under homogeneous payments the most inexpensive patches in the landscape are selected; whereas with the agglomeration payment the selection is restricted which thereby induces the choice of more costly patches.

Surprisingly, cost differences among patches are not necessarily an argument for homogeneous payments. The reason is that agglomeration payments reduce land-owners' producer surpluses—which leads to the third effect, the *surplus transfer effect*. To generate ecologically valuable spatial configurations, it may require the participation of land-owners who would lose money from participating. Their contribution can only be assured with side-payments from other land-owners, which would reduce their producer surpluses.

---

[2] For the sake of analytical clarity, we do not explore mixed schemes with a space-independent component and an agglomeration bonus.

In our model, the patch selection effect never dominates the other two effects, and agglomeration payments are always more cost-effective than homogeneous payments. In the butterfly case study, we find that cost savings of 30-70 percent can be achieved with agglomeration payments.

2. Introduction of agglomeration payments

Consider a landscape with N habitat patches. Let $\mathbf{r}_i=(x_i,y_i)$ denote the spatial location and a_i the size of patch i (i=1…N) and z_i the land-owner's decision to manage patch i in a species-friendly "green" manner (z_i=1) or conventional manner (z_i=0). The vector $\mathbf{z}=(z_1,\ldots,z_N)$ then characterises the spatial arrangement of green patches. The opportunity cost (per habitat patch) to manage patch i in a green manner is denoted as c_i. For convenience, assume each land-owner possesses one patch so the words 'patch' and 'land-owner' can be used synonymously.

Without a detailed specification, we assume an ecological benefit function $\Gamma(a_i,\mathbf{r}_i,z_i; i=1\ldots N)$ that increases if the distances between the patches, determined by their locations $\mathbf{r}_i$, decrease. A practical way to increase Γ is to increase the density of green patches, ρ, in some part of the landscape, denoted as R. The density of green patches in landscape part R is defined as the total area of green patches contained in R divided by the total area ($|R|$) of R:

$$\rho(R)=\frac{\sum_{\mathbf{r}_i\in R} z_j a_j}{|R|} \tag{1}$$

The sum in Equation (1) runs over all patches contained in R. If R, e.g., is a square of size $|R|$=100 ha and it contains 20 ha of green patches, then ρ=0.2. To achieve a desired green patch density, the conservation manager offers a payment p (money per patch area) to each land-owner who:

(1) manages the habitat patch in a green manner, and

(2) in cooperation with other land-owners produces a density of green habitat patches ρ above a given threshold $\rho_{\min}$. The threshold has to be reached in a certain part of the landscape. For simplicity this landscape part, denoted as R, has a rectangular shape. To ensure that there is a single contiguous large area with the desired density *only one* single rectangle may be formed. The choice of size and location of that rectangle is for the land-owners to decide.

In mathematical terms, a payment p is paid to land-owner i if and only if

z_i=1 and $\mathbf{r}_i \in R$ and

$$\rho(R) > \rho_{\min} \tag{2}$$

A payment scheme is defined by the payment p and the threshold density $\rho_{\min}$. Note for purpose of simplification we assume there is only a payment if the conditions of Equation (2) are met, i.e., no other, space-independent payment is considered.

Land-owner i only participates in the scheme if the profit from participation is positive ($\pi_i > 0$) with π_i being determined by

$$\pi_i = p + s_i - c_i \,. \tag{3}$$

Side-payments s_i arise if the individual profit of land-owner i from scheme participation is negative but her contribution is required to generate a desired rectangle. In this case, s_i>0 means land-owner i receives side payments and s_i<0 means she offers them. We assume land-owners select a rectangle only if the *aggregated* profit from all land-owners is positive ($\Pi > 0$).

They eventually decide so total profit from participation of all land-owners in the landscape,

$$\Pi = \sum_{i=1}^{N} z_i a_i (p - c_i), \tag{4}$$

is maximised[3]. The side payments do not occur in Equation (4) as the sum over all side payments is zero. Having agreed upon a rectangle, the land-owners inform the agency about its location and size as well as the locations of the green patches. The resulting budget that has to be spent is

$$B = \sum_{i=1}^{N} z_i a_i p. \tag{5}$$

The spatial configuration of green patches that maximises Π and thus represents the farmers' choice is determined by forming all possible distinctive rectangles in the landscape (two rectangles are distinctive if they contain a different subset of patches). In each rectangle, profit is maximised under the constraint Equation (2).[4] If the threshold density is too high or p too small compared to c_i, a positive profit may be unachievable. In this case, the maximum profit is zero and is achieved through z_i=0 for all i and the corresponding ecological benefit is zero.

[3] We focus on the agglomeration incentive itself, and we do not address the transaction costs of the negotiation process. Sufficiently large transaction costs serve to reduce the efficiency of any incentive device, including the agglomeration bonus.

[4] Technically this works as follows: Start with all patches in the rectangle participating: z_i=1. Then one by one remove all green patches (i.e. set z_i=0) that have negative profits π_i<0. Start with the patch that has the most negative profit, followed by the one with the second most negative profit and proceed until having either reached the marginal meadow (π_i=-0) or the density threshold ρ_{min}.

3. Functioning of the agglomeration payment

3.1 Illustration of basic principle

To demonstrate the idea behind the agglomeration payment, consider now the artificial landscape in Fig.1, in which all patches have equal size a and are arranged on a regular grid. The numbers in the circles represent the costs c_i. With a payment of p=2.1 and a density threshold $\rho_{\min}$=0 (representing homogenous compensation payments) the three patches with c=2 are turned into green patches for a budget of 6.3. These three patches, however, are distant from each other and it would be desirable ecologically to have them closer together. This is achieved, e.g., by offering a payment of p=3.1 under the constraint that a green patch density of $\rho_{\min}=0.5a/d^2$ is exceeded, where d represents the distance between two adjacent grid points.

A number of possible rectangles R can be formed that fulfil Equation (4). The one that maximises the land-owners' total profit is in the lower right corner with $\Pi=3p$-2-2-3=2.3 (eq. 4). The required budget (eq. 5) for these three green patches is $B=3p$=9.3. It is higher than the budget required for p=2.1 without density threshold, because not the three least expensive patches are selected. We call this budget-increasing impact the *patch selection* effect. In contrast, the connectivity between the patches, and thus the ecological effectiveness, has increased – an outcome we call the *connectivity effect*. Since the two effects point into opposite directions, it is unclear a priori whether the agglomeration payment is more cost-effective than homogenous payments. In the next section we investigate this question in a comprehensive manner on a general model.

3.2 Description of a conservation problem in a fictitious landscape

We now consider the conservation problem in a fictitious landscape which we use to illustrate the cost-effectiveness of an agglomeration payment in a general manner. Defining an ecological benefit function without any loss of generality is impossible; so instead we use a general function to measure the connectivity of green habitat patches:

$$\Gamma = \sum_{i=1}^{N} z_i \sum_{j=i+1}^{N} z_j \exp(-\alpha d_{ij}) \quad \text{with} \quad d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{6}$$

where d_{ij} is the distance between two patches i and j. Equation (6) is based on a standard ecological model for the dispersal of individuals from one habitat patch to another: Usually, if an individual emigrates from a patch i its probability of reaching a patch j at a distance d_{ij} is assumed to be $\exp(-\alpha d_{ij})$, where α measures the dispersal ability of the species. Small α means individuals of the species are able to reach distant patches, while large α means they can only reach nearby patches. From eq. (6) for given α, we see the connectivity Γ increases with increasing habitat area and with decreasing distances between habitat patches. Habitat patches close to a cluster of patches contribute more to connectivity than isolated ones. According to the theory of metapopulations (e.g., Hanski 1999), Γ is a good predictor for the survival probability of a metapopulation inhabiting the landscape.

With this measure of ecological benefit, an agglomeration payment scheme [defined as a combination of payment and density threshold $(p,\rho_{\min})$] is more cost effective than another agglomeration payment scheme if and only if it leads to higher patch connectivity Γ for a given budget. For the general analysis we consider a landscape where the patches are arranged on a regular square grid with length and width given by $dN^{1/2}$ (cf. Fig. 1). Here N is the total number of patches and d is the distance between two adjacent grid points. The costs of patches c_i are drawn randomly from a uniform distribution with mean m_c and width $2\sigma_c$.

We consider a landscape of 100 patches, and we assume two levels of the dispersal parameter α: α_1=1/d for a species with short-range dispersal that cannot travel on average much farther than from one patch to one of its next neighbours; and $\alpha_2=1/(dN^{1/2})$ for a species that can travel a mean distance of $dN^{1/2}$ and thus can reach any patch in the landscape with high and nearly equal probability.

3.3 Analysis of the demonstrational conservation problem

We now define a landscape by the number of patches (N), the distance between grid points (d), patch size (a), and mean and variation of costs (m_c and σ_c). For several different landscapes (see below) we investigate 200 different payment schemes ($p,\rho_{\min}$). For $\rho_{\min}$, we consider values k times a/d^2 with $k\in\{0.0, 0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 0.9, 0.95, 1.0.\}$. At the lowest density level, $\rho_{\min}$=0, all patches that fulfil eq. (3) participate in the scheme. This represents the *homogenous payment scheme* that does not induce any explicit agglomeration. At the highest level of $\rho_{\min}=a/d^2$ each patch in the landscape must be a green patch. Values for the payment p are chosen so they encompass the entire range of costs, $[m_c(1-\sigma_c), m_c(1+\sigma_c)]$. We set these at $p=m_c(1+l\sigma_c)$ with $l\in\{-0.95, -0.9, -0.8, -0.7, -0.6, -0.5, -0.4, -0.3, -0.2, -0.1, 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9\}$. Systematic combination of the 10 levels for k and 20 levels for l leads to the 200 possible payment schemes.

Since the costs c_i are uncertain, for a given payment scheme the size and location of the rectangle R and particularly the resulting connectivity Γ are also uncertain. We account for this by randomly sampling the costs c_i for all patches 100 times. Each of the 100 random sets of costs $\{c_i\}_{i=1\ldots N}$ may be denoted as a “cost landscape”. For each cost landscape $\{c_i\}$ we examine the 200 payment schemes. Means and standard deviations of the resulting connectivity, the corresponding budget and the land-owners' total profit are calculated for each payment scheme over the 100 random cost landscapes.

We restrict the dimensionality of the problem by rescaling some parameters:

1. We measure connectivity Γ (6) in units of a^2, which is achieved by formally setting a=1.
2. We measure density ρ (eq. 2) in units of a/d^2. Together with a=1 this is achieved by formally setting d=1.
3. We measure the budget B in units of the mean cost, m_c, which is achieved by formally setting m_c=1.

These restrictions reduce the dimensionality of the analysis, as the only independent parameters to be varied are now σ_c and α. Starting from a base scenario and varying each parameter independently, we consider the following three scenarios for N=100:

a. σ_c=0.1, α=1/d

b. σ_c=0.1, α=1/($dN^{1/2}$)

c. σ_c=0.5, α=1/d

3.4 Results

Figures 2a-c show the results for the three scenarios. All figures show the connectivity Γ as a function of the budget for various density thresholds $\rho_{\min}$. The *density threshold* $\rho_{\min}$=0 (solid line in Fig. 2) represents homogeneous payments; the expected cost-effectiveness improvements of the agglomeration payment are presented in Fig. 2 for various $\rho_{\min}$.

In all scenarios of Fig. 2 the cost-effectiveness of a payment scheme increases with $\rho_{\min}$, so all agglomeration payment schemes with $\rho_{\min}$>0 lead to efficiency gains compared to homogenous payments. Why is this so, given the patch selection effect increases the cost of the spatially aggregated patch arrangements? The reason is the presence of a third effect that has not been considered yet: a *surplus transfer effect*. The agglomeration payment not only aggregates patches in space but also reduces the producer surplus of the land-owners. Without a density threshold ($\rho_{\min}$=0), only land-owners with positive individual profits, π_i>0, participate. If a positive density threshold is set and only land-owners with positive individual profits participate, their number may be too small to reach the density threshold $\rho_{\min}$>0 and so they may not get any payments at all (eq. 2). To get at least some profit individual land-owners have to sacrifice some of their producer surplus and transfer it through side-payments (eq. 3) to the land-owners whose individual profits would otherwise be negative. Now the density threshold is reached and a positive total profit obtained. To give a numerical example, set *p*=2.6 instead of *p*=3.1 in Fig. 1. The profit maximising patch configuration can be achieved only if the owners of the two (*c*=2)-patches offer a side payment to the owner of the (*c*=3)-patch. Both the required budget (7.8) and the total profit (7.8-7=0.8) are reduced compared to the case of *p*=3.1.

Two questions remain: (i) How does the magnitude of the efficiency gain depend on key model parameters: budget, dispersal range ($1/\alpha$), and level of cost variation (σ)? (ii) Why does the patch selection effect never dominate surplus transfer effect plus connectivity effect? We now address each question in turn.

The effect of the budget on the efficiency gain

Figure 2 shows that high efficiency gains exist only if the budget is below a specific value (Fig. 2a). For instance, in the case of $\rho_{\min}$=0.6 the connectivity (long-dashed line) exceeds the connectivity obtained from homogenous payments (solid line) only for budgets below 80m_c, while for higher budgets both curves are identical, indicating zero efficiency gain. The reason is that at high budgets there are already many green patches in the landscape and selecting one patch instead of another will not increase connectivity considerably (the connectivity effect is small). Furthermore, in such a situation the density threshold can be reached in the entire landscape already with those patches that have $\pi_i>0$. In this case, there is no incentive for the owners of these patches to share their producer surplus (the surplus transfer effect is small). Each of them gains his full amount p-c_i, which is just what one obtains under homogenous payments. Overall, the highest efficiency gain in relative terms occurs with small budgets and decreases with increasing budget.

The effect of the dispersal range

Comparison of Figs. (2a) and (2b) reveals that for species with long-range dispersal efficiency gains are smaller than for species with short-range dispersal. This is plausible given that good dispersers are less dependent on the spatial configuration of habitat than poor dispersers (e.g., Drechsler et al. 2005), which means that for good dispersers the connectivity effect is smaller than for poor dispersers.

The effect of the cost variation (σ)

We find this effect to be ambiguous. For small budgets higher variation in the costs c_i slightly reduces the cost-effectiveness of the agglomeration payment (compare the distances between the solid and dashed lines near the origins of Figs. 2a and 2c) while for high budgets it increases the cost-effectiveness of the agglomeration payment. The reason for the ambiguity is that for small budgets the patch selection effect is relatively strong, because a small budget means that patches that in the case of homogenous payments are dispersed over the entire landscape have to be in a very small rectangle, which leads to a high likelihood that costly patches have to be selected. For increasing budgets the rectangle becomes larger and the patch selection effect decreases to zero (reached when the rectangle covers the entire landscape). The surplus transfer effect, in contrast, increases with the budget and therefore a point exists where both effects have the same magnitude, so that for relatively small (large) budgets the patch selection (surplus transfer) effect dominates and increases (decreases) the costs of the agglomeration payment compared to homogenous payments.

The source of both effects is the variation among the costs (one can show that for uniformly distributed costs with range 2σ the magnitudes of both effects are proportional to σ). Together with the above considerations, this implies that increasing cost variation enhances the dominance of the patch selection (surplus transfer) effect at small (large) budgets and thus reduces (increases) the efficiency gain of the agglomeration payment.

The dominance relations between the three effects

We write the cost-difference between agglomeration payment and homogenous payment as a function $C = C_0 + f(\sigma) + g(\sigma)$ where C_0 represents the cost saving due to the connectivity effect and $f(\sigma)$ and $g(\sigma)$ describe the patch selection and surplus transfer effects. In the previous section we found that that the patch selection effect dominates the surplus transfer effect only at small budgets. However, this dominance cannot be strong, because Fig. 2c shows that in this budget range the impact of σ on the efficiency gain of the agglomeration payment is small. Since the connectivity effect does not depend on σ, this means that the cost difference C is basically unaffected by σ, i.e., $dC/d\sigma \approx 0 \Leftrightarrow C \approx const$. Since this equation holds for all σ, including $\sigma = 0$ where $f = g = 0$, *const* must be equal to C_0. Therefore $C \approx C_0$ for all σ, which implies $f(\sigma) \approx -g(\sigma)$. Altogether, the surplus transfer effect either dominates the patch selection effect or both effects largely cancel each other. Therefore within the parameter ranges considered, the parch selection effect never dominates connectivity effect plus surplus transfer effect and the efficiency gain of the agglomeration payment is either zero or positive.[5]

4. Empirical study: Conserving endangered butterflies with an agglomeration payment

4.1 The conservation problem

We now apply the idea of an agglomeration payment to a case study, the conservation of an endangered butterfly species (Large Blue, *Maculinea teleius*) in an area near the town of Landau in Rhineland-Palatinate, Germany. The butterfly species is highly relevant for conservation as it is protected by the EU Habitats Directive.[6] *M. teleius* is a butterfly that requires the presence of meadows for its survival (see Thomas and Settele 2004 for details of the butterfly's ecology). Each July, the adult butterflies deposit their eggs on the plant *Sanguisorba officinalis*. After a few weeks the larvae fall onto the ground where they are adopted by ants (*Myrmica scabrinodis*) which feed them in their nests over winter. For the survival of the butterfly, it is important when and how frequently meadows are mowed. Mowing may destroy the eggs and larvae on the *Sanguisorba* plant, and the abundance of the plant will be insufficient for egg deposition for the next couple of weeks. Too frequent mowing may also harm *M. scrabinodis.* Mowing is necessary, however, because it avoids succession and preserves an open landscape. Furthermore, rarely mowed meadows become overrun with thick vegetation which is unsuitable for the ants.

[5] We have focused on mean values over 100 random landscapes. How does the variation among these landscapes affect these results? Our work shows that especially for small agglomeration payments the variation in the corresponding budgets and connectivities can be substantial; however, budget and connectivity are almost perfectly correlated. This means that in some landscapes a certain payment may deliver less connectivity than in another landscape, but at the same time the required budget will be smaller by the same factor. So the peculiarity of the landscape affects the effectiveness (connectivity) of the agglomeration payment scheme but not its cost-effectiveness.

[6] We selected this case study given the intersection of data availability and high policy relevance.

The butterfly's dependence on a certain mowing regime explains why *M. teleius* was common in Central Europe until the 1950s, but since then has become endangered. Prior to 1950s, meadows of a region were not mowed all at once; rather mowing took place over the whole summer. Even if some meadows were unsuitable for *M. teleius* at a particular time, there were always other meadows to which butterflies could disperse and deposit their eggs. The development of machinery, however, made it possible to mow all meadows in a region simultaneously twice a year, first at the end of May and second six to eight weeks later. This mowing regime maximises the farmers' profits but is unsuitable for the reproduction of the butterflies as the second mowing date falls into the weeks during which the butterflies deposit their eggs on the *Sanguisorba* plants.

Following the practise of German agricultural policy, we assume property rights are such that farmers cannot be forced to adopt conservation-enhancing mowing practises. This implies a regulator will have to provide compensation to induce farmers to adopt a mowing regime beneficial to the butterflies. The farmers' opportunity costs of mowing at some other date differ depending on the mowing regime. As a general rule, opportunity costs rise with a later mowing-date because the energy content of swath and its quality as fodder decreases.

4.2 Analysis

We identify a cost-effective mowing regime for the region by relying on results from Drechsler et al. (2005). The authors developed an approach to design a cost-effective payment scheme for the conservation of *M. teleius* in the case study region we now consider. The approach integrates an agro-economic cost assessment and an ecological model.[7] The agro-economic cost assessment determines the opportunity costs of the mowing regimes for each meadow in the case study region and the ecological model quantifies the effects of these

[6] See Bergmann (2005) and Johst et al. (2006) for a detailed description of the agro-economic cost assessment and the ecological model.

mowing regimes on the butterfly population on a regional level. By comparing the ecological effects of different mowing regimes, the cost-effective mowing regime and the corresponding payments may be determined as a function of the conservation budget. In line with the current agricultural policy approach in Germany, Drechsler et al. assume for a particular mowing regime payments are not differentiated according to farmers' opportunity costs but every farmer receives the same payment. In the current analysis we extend this work by determining the efficiency gains that can be achieved if the homogeneous payments analysed by Drechsler et al. are replaced by an agglomeration bonus.

For this we consider the most-cost effective mowing regime analysed in Drechsler et al. that is not in conflict with other endangered species (mowing once every second year at the end of August) and compare its cost-effectiveness with a scheme based on an agglomeration payment. The geographic data base for the analysis comes from a digitised satellite image of the case study area (10 by 6 km^2 with a resolution of 20 by 20 m^2). With the image one can distinguish between different landscape types in each pixel. We structure the landscape types into four types as experienced by the butterfly species: meadows, open land (e.g., traffic ways, lakes and rivers, arable land), forests (including shrubland), and settlements. Figure 3 shows the model landscape.

We determine the areas of the individual meadows in the landscape by counting the pixels belonging to each meadow. The location of each meadow is defined by its midpoint such that the x (y) - co-ordinate of a meadow is the average of the x (y) - co-ordinates of all pixels belonging to that meadow. From these x-y locations the Euclidian distances, $d_{ij}=((x_i-x_j)^2+(y_i-y_j)^2)^{1/2}$ are calculated for all pairs (i,j) of meadows. The meadow sizes are required as an input for the ecological model and the cost assessment, and the pair-wise distances are needed for the ecological model.

The opportunity costs of implementing the above introduced mowing regime on the meadows come from Bergmann (2005). Following Drechsler et al (2005) we take into account both opportunity cost and the farmer's administrative costs arising from scheme participation. In addition, farm specific characteristics may differ and different farmers may have different attitudes towards biodiversity conservation and may request slightly higher (if they are opposed) or slightly lower payments (if they are in favour). Assume farm characteristics and personal attitude are random among farmers and uniformly distributed between plus and minus 10% of the real (opportunity plus administrative) costs.[8]

We perform the analysis in the same manner as the general analysis in the previous Section. First we select a critical density $\rho_{\min}$(where $\rho_{\min}$=0 represents the homogenous payment scheme) and determine the number and arrangement of butterfly-friendly mowed meadows that maximise the farmers' profits. Again assume farmers generate rectangles in the landscape and identify the one that maximises their profit. In a real landscape the number of rectangles to be considered would be too large to analyse. Therefore we consider a large subset of rectangles of different sizes, shapes and locations that systematically cover the entire landscape. For this we lay a regular grid with 50 by 50 cells on the entire landscape with the grid cells' north-south and east-west dimension being 120m and 200m respectively. To find the outcome of the farmers' negotiations we form all possible rectangles whose borders lie on the grid lines (which includes all 2500 rectangles made of one grid cell, all 4900 rectangles made of two adjacent grid cells, etc., … up to the largest possible rectangle that includes all 2500 cells). For each agglomeration payment, from these rectangles we determine the one that maximises the farmers' total profit and the corresponding budget and area of meadows occupied by butterflies. The area occupied by butterflies is calculated using a spatially explicit

[8] We only consider medium sized meadows between 0.75ha and 1.5ha. European legislation allows compensation for farmers' administrative costs only as a percentage of opportunity costs and, therefore, the administrative effort to participate in conservation schemes with small meadows may be too high. Large meadows are excluded, because their areas are likely to be overestimated. We do not have data about ownership of meadows and the satellite image which forms the data base of the analysis can depict roads that separate meadows but not fences.

stochastic simulation model (Johst at al. 2006) which considers the life cycle of the species, the dispersal between the meadows, weather fluctuations and the landscape dynamics caused by the mowing events.

As the costs of implementing the mowing regime contain a random element, we consider four different random cost landscapes and determine mean area of occupied meadows and the mean budget.

4.3 Results

Figure 4 shows the efficiency gains achieved by the agglomeration payment compared to a homogeneous payment scheme. The efficiency gain increases with the density threshold ρ_{min}. A maximum of ρ_{min}=0.02 (equivalent to 2 ha of green meadow per km^2) is considered in the figure, as higher thresholds do not lead to further efficiency gains. Efficiency gains of agglomeration payments are substantial for low and medium sized budgets. They range from about 70% for a budget of 3,000€ to about 30% for a budget of 10,000€. Wätzold et al. (2006) found that with 10,000€ the extinction risk of *Maculinea* could be strongly reduced in the case study region.

The observation that efficiency gains are largest for low budgets is in line with results from the conceptual model (cf. section 3.4; Fig.2). The reason is that with low budgets only few meadows are managed in a green manner. Under homogeneous payments these would be dispersed over the entire landscape and agglomerating them strongly increases their connectivity. In contrast, for high budgets there are many green meadows in the landscape whose connectivity would be sufficient even under homogeneous payments.

5. Summary and Discussion

Designing effective compensation payment schemes for biodiversity conservation requires accounting for the spatial configuration of habitat patches. One scheme that has been proposed to generate an ecologically valuable configuration is the *agglomeration bonus* (see Parkhurst et al., 2002). Land-owners receive an agglomeration payment if habitat patches are arranged in an ecologically beneficial configuration. While ecological benefits increase with the bonus scheme, the costs of implementation are expected to increase as more costly patches tend to be selected. This raises the open question of how cost-effective an agglomeration payment is relative to spatially homogeneous payments. Herein we address this question at both a conceptual level and for a specific conservation study – the design of payments for butterfly-friendly grassland management in the region of Landau, Germany. We find the cost-effectiveness of an agglomeration payment is determined by the interaction of three mechanisms: (i) the connectivity effect, (ii) the patch selection effect, and (iii) the surplus transfer effect.

The connectivity effect (i) represents the point that ceteris paribus a spatially aggregated arrangement of habitats usually leads to higher survival rates of endangered species than spatially dispersed habitats und thus the agglomeration bonus increases the ecological effectiveness of the habitat network for a given budget. The ecological reason for this is that the viability of most endangered species inhabiting fragmented landscapes increases when the dispersal of individuals among the habitat patches is increased. The connectivity effect is strongest when the conservation budget or the dispersal range of the species is small, or both. The reason is that in the case of a small budget, only few habitats are created which under homogenous payments are dispersed all over the landscape. The distances between these patches are too large for the species to cross, especially if the species has a small dispersal range. Spatial aggregation of these few patches strongly improves the dispersal among them. The dispersal range of the Large Blue butterfly analysed in the case study is so small (on average ca. 1 km) that for homogeneous payments and small budgets the distances between habitat patches are larger than the species' dispersal distances, and so the connectivity effect is relevant.

The patch selection effect (ii) arises, because different patches are selected under homogeneous payments and under the agglomeration payment. Under homogeneous payments the most inexpensive patches out of all patches in the landscape are chosen while under the agglomeration payment the selection can be made only from the patches contained in a smaller compartment (rectangle R) of the landscape. As a consequence, selecting N patches from the compartment is more expensive than selecting the same number of patches out of the entire landscape. This cost increase, or the patch selection effect, is largest when the cost heterogeneity (σ) among the patches in the landscape is high.

The surplus transfer effect (iii) is a consequence of the density threshold $\rho_{\min}$ that has to be exceeded by the land-owners to receive a payment. Depending on the specific situation, some of the land-owners will be confronted with the choice between not receiving any payment and offering side-payments to farmers whose participation in the programme is necessary to reach the density threshold but whose individual profits would be negative without the side payments. The side-payments reduce the overall producer surplus –an effect that is largest when the cost heterogeneity (σ) among the patches in the landscape is high.

The surplus transfer effect is responsible for the unexpected result that within the scope of our analysis the efficiency gain of the agglomeration payment is always positive (Fig. 2). Without the surplus transfer effect there would be the expected trade-off between connectivity and patch selection effect, and too high cost variation would cause the patch selection effect to dominate the connectivity effect, leading to negative efficiency gains. But since the surplus transfer effect also increases with increasing cost variation but points into the opposite direction, it effectively neutralises the patch selection effect. The connectivity effect prevails and unambiguously increases the cost-effectiveness of the agglomeration payment, especially if the dispersal range of the species is small.

Whether the patch selection effect or the surplus transfer effect dominates depends on various factors, such as the spatial distribution of the costs and the number of habitat patches participating in the scheme. Within our model analysis we found that for small (large) budgets the patch selection effect dominates the surplus transfer effect. As the magnitude of both effects increases with increasing cost variation, increasing cost variation decreases (increases) the cost-effectiveness of the agglomeration payment at small (large) budgets. This may, however, be a consequence of the assumption of the costs being spatially uncorrelated. If there are strong cost gradients in the landscape, the outcome may be different.

The real world case study on the conservation of the Large Blue butterfly confirms the general results. We find efficiency gains of up to 70% may be achieved with agglomeration payments. For the conservation of species with smaller dispersal ranges than the Large Blue efficiency gains may be even larger. Bearing in mind that in Europe and the US several billion Euro and dollars are spent each year on conservation this suggests that significant improvements in conservation management could be made if agglomeration payments are used in practise.

References

Bergmann, H. (2004) Berechnung von Kosten für Maßnahmen zum Schutz von gefährdeten Maculinea-Arten, UFZ discussion paper 2/2004, UFZ Leipzig-Halle GmbH, 61 pp. (http://www.ufz.de/data/ufz-diskussionspapier2-20041180.pdf)

Brown, G.M.Jr., Shogren, J.F. (1998) Economics of the Endangered Species Act. The Journal of Economic Perspectives 12, 3, 3-20.

Defenders of Wildlife (2002) Conservation in America: State Government Incentive for Habitat Conservation. Washington D.C. March.

Drechsler, M., Frank, K., Hanski, I., O'Hara, R. B., Wissel, C. (2003) Ranking metapopulation extinction risk for conservation: from patterns in data to management decisions. Ecological Applications 13, 990-998

Drechsler, M., Wätzold, F., Johst, K., Bergmann, H., Settele, J. (2005) A model-based approach for designing cost-effective compensation payments for conservation of endangered species in real landscapes. UFZ discussion paper 02/2005, UFZ Leipzig-Halle GmbH, 26 pp. (http://www.ufz.de/data/Disk_Papiere_2005-022445.pdf)

European Commission (2005) Agri-environment Measures: Overview on General Principles, Types of Measures, and Application. Study of the European Commission Directorate General for Agriculture and Rural Development, Unit G-4 - Evaluation of Measures applied to Agriculture. (URL: http://europa.eu.int/comm/agriculture/publi/reports/agrienv/rep_en.pdf).

Frank, K., Wissel, C. (2002) A formula for the mean lifetime of metapopulations in heterogeneous landscapes. American Naturalist 159, 530-552

Hanski, I. (1999), Metapopulation Ecology. Oxford University Press, UK, 313 pp.

Johst, K., Drechsler, M., Thomas, J., Settele, J. (2006) Influence of mowing on the persistence of two endangered large blue butterfly species. Journal of Applied Ecology 43, 333-342.

Landell-Mills, N., Porras, I. (2002) Silver Bullets or Fools' Gold? A Global Review of Markets for Forest Environmental services and Their Impact on the Poor. London: International Institute for Environment and Development (IIED).

McDonnell, M. D., Possingham, H. P., Ball, I. R., Cousins, E. A. (2002) Mathematical methods for spatially cohesive reserve design. Environmental Modelling and Assessment 7, 107-114

Parkhurst, G. M., Shogren, J. F., Bastian, P., Kivi, J., Donner, J., Smith, R. B. W. (2002) Agglomeration Bonus: An Incentive Mechanism to Reunite Fragmented Habitat for Biodiversity Conservation, Ecological Economics 41, 305-328.

Shogren, J., ed. (2005). Species at Risk: Using Economic Incentives to Shelter Endangered Species on Private Lands. Austin, TX; University of Texas Press.

Simberloff, D. (1988) The contribution of population and community biology to conservation science. Ann Rev. Ecol. Sys. 19, 437-511.

Thomas, J. A., Settele, J. (2004) Butterfly mimics of ants. Nature 432, 283-284

Wätzold, F., Lienhoop, N., Drechsler, M., Settele, J. (2006) Estimating Optimal Conservation in Agricultural Landscapes when Costs and Benefits of Conservation Measures are Heterogeneous in Space and over Time, UFZ discussion paper 05/2006, UFZ Leipzig-Halle GmbH, 20 pp.

Figure 1: Artificial landscape of patches. For details, see text.

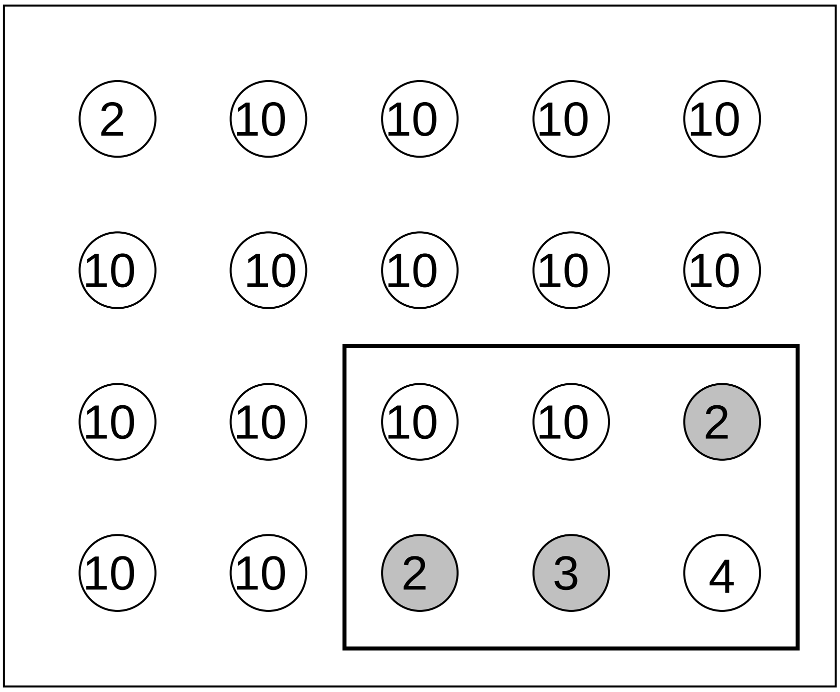


Figure 2: Mean connectivity versus mean budget (measured in units of mean patch cost m_c) for the different levels of ρ_{min}. Solid line: ρ_{min}=0 (homogeneous payments). Dashed lines: ρ_{min} increasing from bottom to top with levels 0.2, 0.3, 0.4, 0.6, 0.8. Panels (a)-(c) represent scenarios (a)-(c). Budget and connectivity are averages over the 100 random cost landscapes $\{c_i\}$.

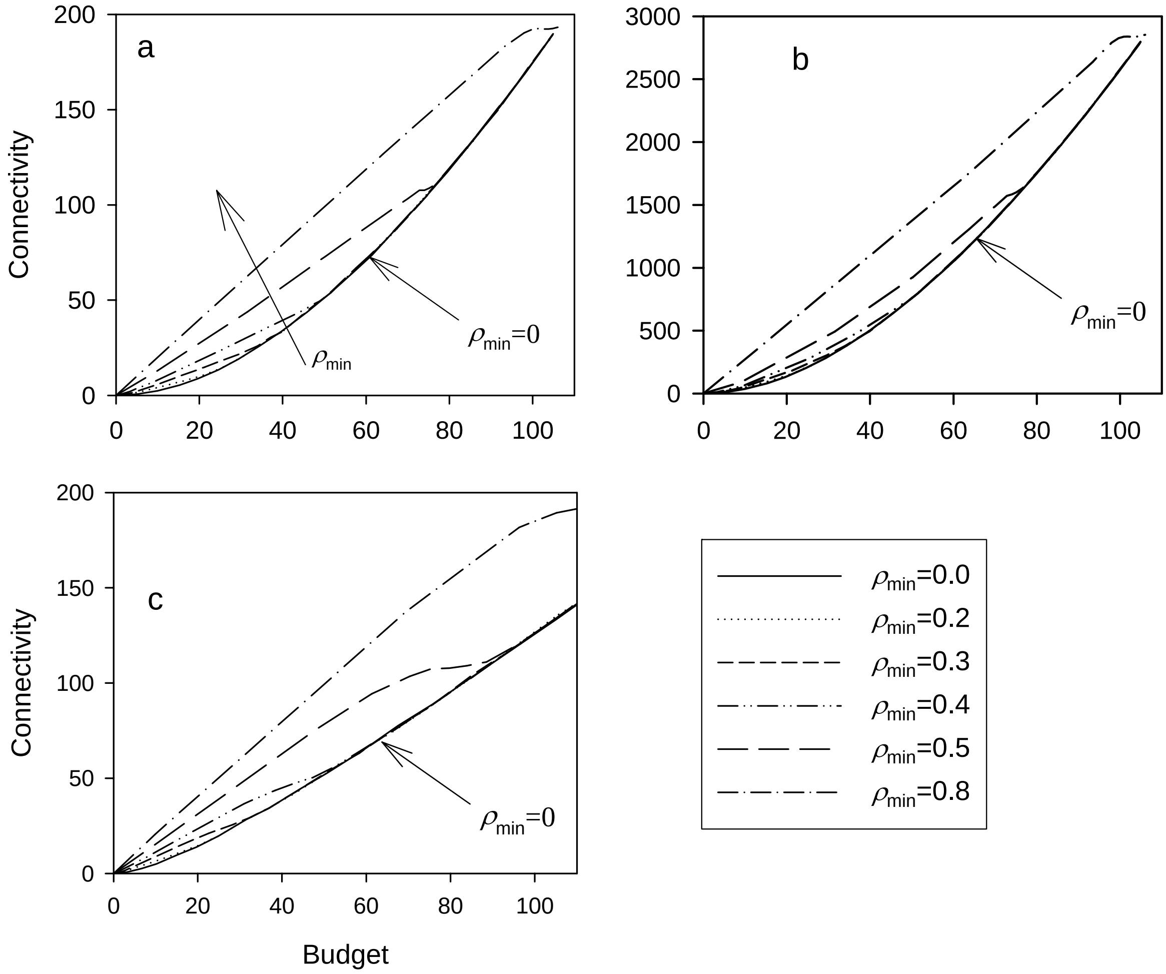
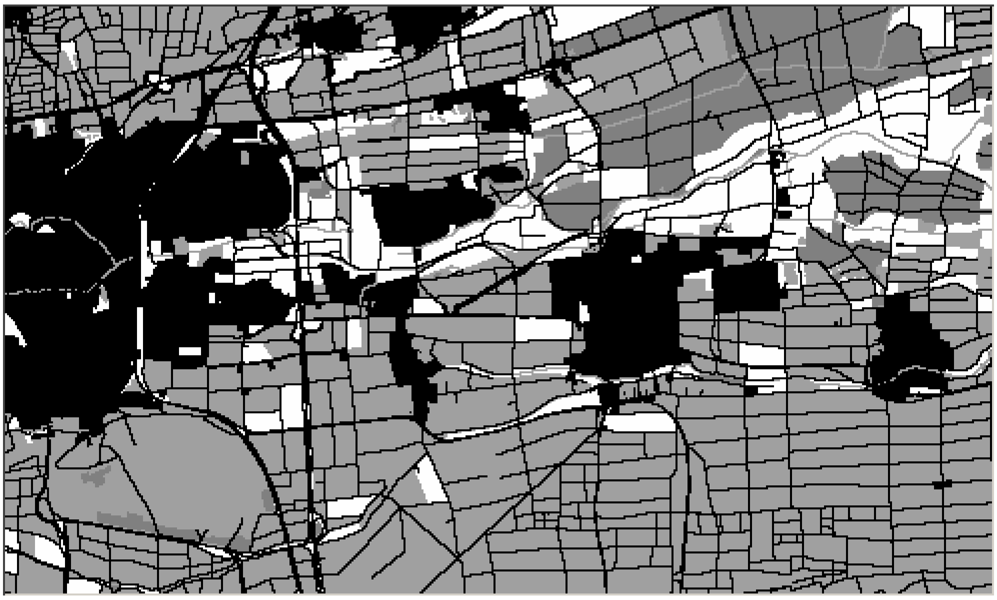


Figure 3: The model landscape (black: settlement/roads; dark grey: forest; light grey: open land, water bodies; white: meadows). The dimension of the map is 10x6 km^2.



Source: Drechsler et al. 2005, p.7

Figure 4: Area of occupied meadows versus budget (means over four random landscapes) for four different density thresholds ρ_{min} (ρ_{min}=0 representing the homogenous payment scheme). The density threshold increases from bottom to top.