UFZ-Umweltforschungszentrum
Leipzig-Halle GmbH
in der Helmholtz-Gemeinschaft

UFZ-Diskussionspapiere

Departments of Ecological Modelling, and Economics, Sociology and Law (OEKUS)

4/2001

An ecological-economic modelling procedure to design effective and efficient compensation payments For the protection of species

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September 2001

Zeitschriftenlesesaal
Reportsammlung

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ISSN 1436-140X

Herausgeber:
UFZ-Umweltforschungszentrum Leipzig-Halle GmbH
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Abstract.

The paper presents an ecological-economic modelling procedure to design compensation payments for species protection. In order to find an ecologically effective and economically efficient design, we choose an interdisciplinary approach that combines both ecological and economic knowledge. We develop our procedure on the example of White Stork protection in a spatio-temporally structured landscape generated by human land use. The proposed procedure is able to solve complex allocation problems such as the spatial and temporal allocation of a budget among more than two areas of any shapes with spatially differing species-specific cost and benefit functions. Furthermore, the procedure delivers the efficient spatio-temporal compensation payments not only qualitatively but quantitatively, and is hence relevant to the implementation of species protection policies.

Key words

ecological-economic modelling, biodiversity, compensation payments, spatio-temporal allocation

1. Introduction

In the past decade, there has been an increasing amount of policies targeted at the protection of species. One example is conservation programmes that include compensation payments to farmers or other landowners who voluntarily introduce protection measures or practise environmentally friendly farming methods (for such measures in the European Union, cf. Nowicki 1997). In connection with compensation payments to protect particular species, one key challenge faced by policy-makers is to design schemes such that they are ecologically effective and economically efficient.

In our paper we develop a simulation procedure which allows effective and efficient compensation payments to be designed at a regional level using the example of a scheme to protect the White Stork. Our approach is interdisciplinary, and combines both ecological and economic knowledge. Based on an ecological simulation model we develop an ecologically effective scheme to increase the breeding success of the White Stork. When the compensation payments needed to induce the required behavioural changes in farmers are calculated, it has to be taken into account that the budget available for such payments is usually limited. By integrating species-specific ecological and economic data into the simulation model, we show how efficient compensation payments must be modified depending on the size of the available budget. A compensation scheme is efficient if the survival probability of the nestlings is maximised with a given (restricted) budget.

The use of purely ecological models for the development of effective conservation programmes to protect endangered species is not new. For example, ecological models have been used to study the influence of habitat fragmentation, habitat destruction and habitat deterioration on species survival (e.g. Gyllenberg and Hanski 1997, Tilman et al. 1997, Frank and Wissel 1998, Drechsler and Wissel 1998). In particular, the problem of whether one single large habitat or several small habitats lead to higher population persistence (the so-called SLOSS problem) has received much attention (e.g. Quinn and Hastings 1987). Aside from these spatial aspects of extinction processes, the temporal aspects have also been studied. For example, human influences may alter the strength and correlation of environmental fluctuations and consequently may increase the extinction risk of populations (e.g. Lande 1993, Foley 1994, Wissel et al. 1994, Johst and Wissel 1997, Heino et al. 1997, Palmqvist and Lundberg 1998).

There are also several studies that address specifically economic aspects of conservation programmes. For example, Bonnieux et al. (1998) investigated what factors influence farmers' decisions to take part in compensation schemes by analysing a case-study of the implementation of an agri-environmental programme in the Cotentin Wetlands in Lower-Normandy (France). Smith and Shogren (1998) analysed the effect of asymmetric information between the regulator and farmers about the abilities of farmers to provide adequate protection measures. They found that in order to obtain the same reserve size, subsidies have to be higher compared to subsidies under perfect information because landowners are able to earn information rents. Choe and Fraser (1998) showed that asymmetric information also leads to higher subsidies because of implementation difficulties. If the enforcement authority is unable to verify with certainty whether a farmer has complied with all the requirements of the scheme, the possibility of unjustified penalties by the enforcement agency might lead the farmer to demand a "risk premium" in addition to the subsidy.

Only a few studies have explicitly integrated both economic and ecological knowledge into their analysis of conservation programmes. Among them, Wu and Bogess (1999) showed that the optimum spatial allocation of conservation funds must take into account the specific shape of the ecological benefit function. An intuitively clear result of their study is that when a threshold in the ecological benefit function exists (i.e. cumulative effects are present), a limited conservation fund should be concentrated on one region in order to exceed the threshold instead of distributing the fund evenly among two regions. Drechsler and Wätzold (2001) systematically examined how the budget size, the shape of the cost function and the shape of the benefit function influence the efficient spatial allocation of conservation funds.

Most of these ecological-economic studies have concentrated on the spatial allocation between two areas within a geographic region and assumed special forms of cost-benefit functions. These relatively simple systems are analytically tractable, contribute to our understanding of the underlying mechanisms, and focus attention on key factors. They reveal how particular shapes of both ecological benefit and economic cost function influence the appropriate spatial allocation. However, it is not always obvious whether the conclusions drawn from these simple models can be applied to specific conservation problems.

Our approach goes beyond the above studies in several respects. Firstly, any species-specific cost and benefit functions can be used and they can differ between the areas. Secondly, any number of areas within a geographic region can be included in the procedure. Thirdly, our procedure is able to quantitatively determine the efficient and effective compensation payments. Fourthly, not only the spatial but also the temporal allocation of a budget can be calculated by our procedure. Thus we explicitly take into account the spatio-temporal dimension of conservation programmes.

2. Ecological modelling to determine an effective protection scheme

2.1. Land use and the conservation of the White Stork

The White Stork (*Ciconia ciconia*) breeding population has decreased in Germany since the mid-20th century, from around 9,000 pairs in 1934 to 4,063 pairs in 1995 (Bairlein 1991, Kaatz 1999). White Storks breed in villages or cities and forage in the surroundings. In the agricultural landscapes of Germany, natural foraging habitats have dwindled and White Storks have progressively switched to foraging on freshly mowed agricultural meadows. Storks prefer freshly mowed meadows because prey are better accessible than in meadows with tall vegetation (Lakeberg 1993). Consequently, food supply for the nestlings and thus the breeding success of the White Stork are increasingly dependent on the temporal and spatial mowing patterns, generating a patchy and dynamic food availability. These patterns have changed in many parts of Germany over the past few decades. Whereas mowing once took place during the whole summer, the mowing period has since been reduced to one short period at the end of May and another short period approximately six to eight weeks later. The reason for this is the increasing use of mowing machines, which allows farmers to mow meadows synchronously across large spatial scales. White Storks suffer from the presently applied mowing patterns as meadows with short vegetation only exist within two short periods in summer and many nestlings die from starvation (Pfeifer and Brandl 1991, Lakeberg 1993, Kaatz 1999). There are two ways of protecting the breeding population of the White Stork: either new natural foraging habitats need to be generated and protected, or farmers must be motivated to change their mowing regime. We will concentrate here on the second option because it can be applied in the present agricultural landscape. However, what mowing regime will maximise the breeding success of the White Stork, i.e. what is the most ecologically effective mowing regime? To answer this question we created an ecological model to study the impact of different mowing regimes on the breeding success of the White Stork. As the details of the model are given in Johst et al. (2001) and here we are primarily focusing on the development of an ecological-economic procedure to design a compensation scheme, below we merely outline how the ecological model works.

2.2. Ecological model

After returning from the wintering areas in Africa, storks start breeding in Germany during the second half of April. A female produces a maximum of six eggs per nest, and there is one breeding attempt per year. Nestlings must be fed in the nest for about 70 days. The ecological model considers food supply for the nestlings during this time span in relation to the dynamics of food availability in the foraging patches (meadows) around the nest and is based on knowledge of the foraging behaviour of the White Stork (Lakeberg 1993, for further references cf. Johst et al. 2001).

The daily food supply for the nestlings is the sum of the food supplied by the foraging trips during the day. Therefore, each foraging trip is considered in detail and includes two foraging decisions: the selection of a foraging patch and the time spent foraging on the patch. The stork embarks on an extra foraging trip if the nestlings' energy requirements have not been met by the preceding trips and there is enough daylight for another foraging trip. Thus, both the duration of a foraging trip and the number of trips per day are related to the energy requirements of nestlings and adults. These possibilities have time limits set by the time budget per trip (around 2 hours) and per day (daylight is necessary for foraging).

The White Stork is a central-place forager and both the quality of the foraging patches (i.e. their food availability) and the distance are important for food supply. Foraging trips do not exceed a radius of approximately 5 km around the nest (Lakeberg 1993). By way of generalisation, we assume a hypothetical landscape with 10 meadows of different distances from the nest ranging from 0.5 to 5 km. These distances determine the flight costs of the stork to the corresponding meadow, whose quality is determined by the vegetation height: vegetation height and food availability are negatively correlated. As a surrogate for the availability of prey (e.g. mice, earthworms) at a given vegetation height, we use the energy intake rate $e_{rate}(t) = q(t) * e_{max}$ (in kJ/h) during foraging on the patch, which depends on the day t after mowing (Johst et al. 2001 and references therein). The quantity e_{max} is the maximum energy intake rate on a freshly mowed meadow, and $q(t)$ describes the decrease in the energy intake rate during the growth of the vegetation (Fig. 1). Thus the farmers' spatial and temporal mowing pattern influences food supply for the nestlings.

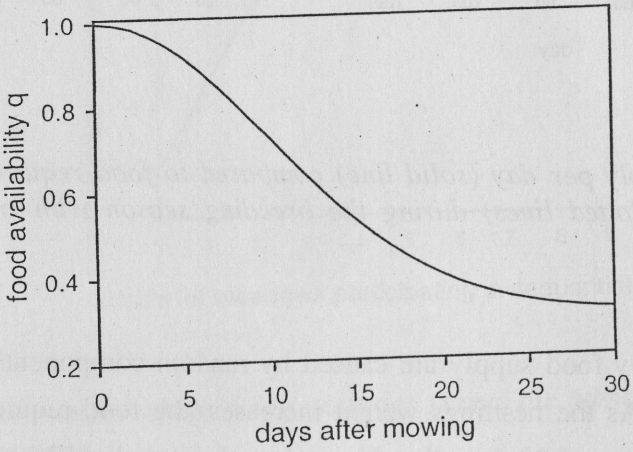

Figure 1: Food availability as a function of time after mowing.

2.3. Ecologically effective land use strategy

As mentioned above, meadows are commonly mowed twice during the breeding season of the White Stork, with the first mowing around hatching, and the second mowing about six to eight weeks later. The exact date of mowing depends on the weather (Pfeifer and Brandl 1991). To investigate the impact of this land use strategy on food supply for the nestlings, we assume that the first mowing of all meadows around the nest occurs within a time span of 14 days during hatching time, and the second mowing occurs seven weeks later, again within a time span of 14 days. The exact date for each meadow is chosen randomly. We call this land use pattern *conventional mowing* because it describes the common usage of meadows by farmers. *Sequential mowing* might be more advantageous for foraging storks. We investigated the effect of a variety of sequential mowing patterns differing in the mowing date and the number of participating meadows. To demonstrate the basic difference between conventional and sequential mowing, Fig. 2 shows the mean daily food supply (solid line) compared to the energy requirements of one to six nestlings (dotted lines) during one simulation run through the breeding season (Johst et al. 2001).

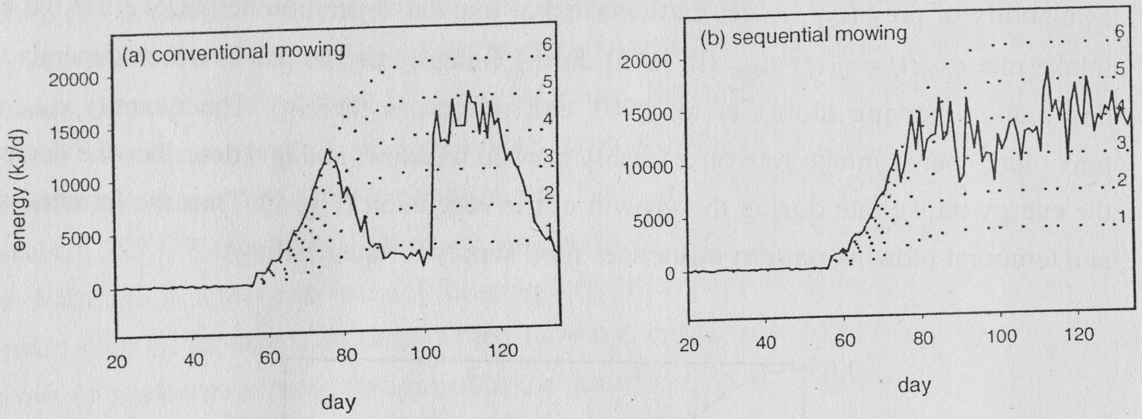

Figure 2: Food supply per day (solid line) compared to food requirements of one to six nestlings per day (dotted lines) during the breeding season with two different mowing regimes.

Variations in the daily food supply are caused by random components in the mowing and foraging behaviour. As the nestlings weight increases, the food requirements increase and reach a plateau at an age of 20 days (hatching takes place on day 57 in Fig. 2). This increase is steeper and the plateau higher when more nestlings are present. The dates of first mowing coincide with the hatching of the nestlings (end of May) and sufficient food is available to meet the increasing food requirements of nestlings (Fig. 2a). However, after conventional mowing the quality of the foraging patches decreases more or less synchronously with the regrowth of vegetation. Thus, between days t = 80 and 100 in Fig. 2a, all nestlings would die of starvation in this simulation run. In Fig. 2b, conventional mowing is replaced by sequential mowing. Here, ten meadows are mowed at intervals of five days and twice per breeding season. Mowing a meadow more often decreases food availability as then prey (e.g. mice) increasingly leave the meadow. Fig. 2b shows that sequential mowing generates a pattern of food availability more appropriate for foraging storks and two to three nestlings may fledge.

Nestlings can survive a short period of food shortage (i.e. when the solid line in Fig. 2b dips below a dotted line). To translate these changes in daily food supply into the mean breeding success, we assume that this period is around 3 days for younger nestlings (up to an age of 20 days) and around 6 days for older nestlings (Lakeberg 1993). If the food shortage persists, a corresponding number of nestlings will die. Consequently, the mean number of surviving nestlings (averaged over 1,000 simulation runs) and thus the breeding success can be calculated for any mowing regime to find the ecologically effective one. Fig. 2b shows only one possibility for mowing the meadows sequentially. As breeding success depends on both the number and the mowing date of the sequentially mowed meadows, we studied a variety of patterns. To achieve the maximum effect of sequential mowing, we checked all possible mowing dates for a given number of participating meadows and selected those with the maximum mean breeding success. The results are shown in Fig. 3.

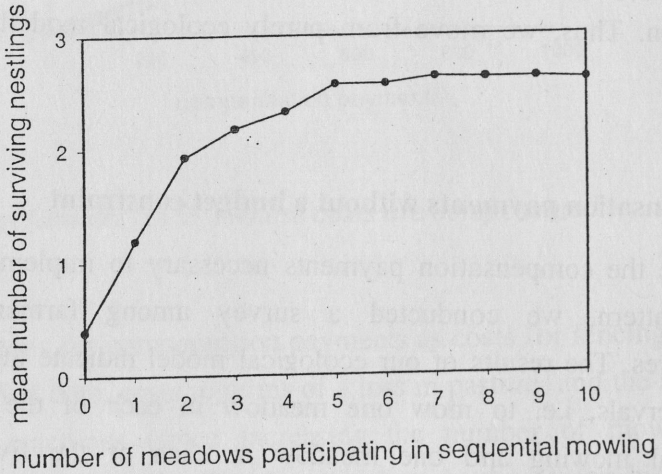

Figure 3: Mean number of surviving nestlings versus the number of meadows participating in sequential mowing.

Breeding success increases as the number of meadows participating in sequential mowing rises. The other meadows are still mowed conventionally. Thus the value zero on the x-axis in Fig. 3 means that all meadows are mowed conventionally. Fig. 3 shows that it is sufficient to mow five meadows at intervals of one week. More meadows with closer mowing dates did not increase breeding success because the storks can to a certain extent compensate for decreasing food availability by more intense foraging. Thus mowing five meadows at intervals of a week twice a season can be considered as an ecologically effective conservation management. The development of the ecological model enables us to calculate not only the effective mowing pattern but also the ecological benefits of other mowing patterns. This is an essential input for our ecological-economic modelling procedure.

3. Compensation payments to implement the protection scheme

3.1. Compensation payments as a policy instrument

In order to induce the behavioural changes in farmers necessary to implement sequential mowing patterns, we need a policy instrument. Often, compensation payments are used to integrate environmental concerns into farming practices. Such payments can be interpreted as the price public authorities pay for purchasing or renting property rights which are implicitly acknowledged as belonging to farmers by the rest of society (Bromley and Hodge 1990). We first show what such a compensation scheme should be like when sufficient financial resources are available to completely implement the effective sequential mowing pattern. Then we introduce a budget constraint and discuss how this affects the design of the scheme. Taking into account a budget restriction requires us to take economic costs into consideration. Thus, we move from purely ecological modelling to ecological-economic modelling.

3.2. Compensation payments without a budget constraint

To estimate the compensation payments necessary to implement the effective sequential mowing pattern, we conducted a survey among farmers based on standardised questionnaires. The results of our ecological model indicate that it is sufficient to mow at weekly intervals, i.e. to mow one meadow in each of the five weeks after the first conventional mowing and one meadow in each of the five weeks after the second conventional mowing (Fig. 3). As conventionally the second mowing in the season occurs six to eight weeks later, we coupled each of the first five weeks with the corresponding week after the second mowing, i.e. the first week after the first conventional mowing with the first week after the second conventional mowing, and so on. This ensures that the whole breeding season of the White Stork can be covered with sequential mowing. Furthermore, the simultaneous consideration of the first and second half of the breeding season simplified the interview, because only five weeks had to be considered explicitly. In the questionnaire, we asked farmers how much they would have to be paid in order to be compensated for the costs caused by the later mowing of a meadow in the vicinity of a nest. This question was itemised for weeks one, two, three, four and five after conventional mowing periods, and we specified the size of the meadow retained for sequential mowing to be approximately one hectare.

The interviews were conducted in February/March 2000 among 92 farmers in the county of Torgau-Oschatz, a rural district in the German state of Saxony with approximately 63% of its area devoted to farming. Fig. 4 shows the amount of money necessary to compensate farmers for mowing a meadow within a given week. The number of farmers whose costs are compensated rises approximately linearly with the level of compensation payment per week. Note that mowing later in the season requires slightly higher compensation than earlier mowing. For example, approximately DM400 is necessary to motivate 50% of farmers to participate in the first week (circles) of sequential mowing, whereas approximately DM600 is necessary to motivate 50% to mow later in the fifth week (squares).

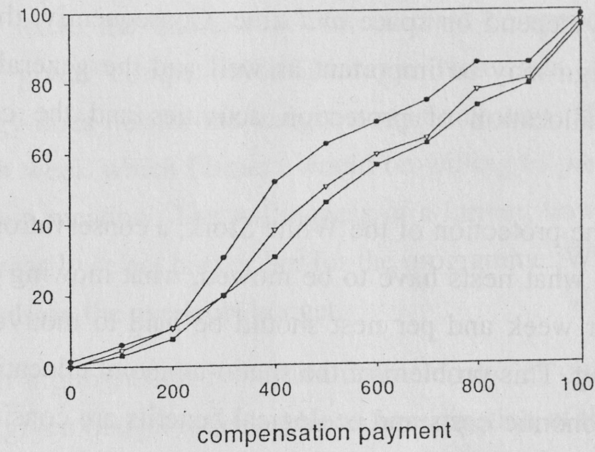

Figure 4: Proportion of farmers (in %) whose costs are compensated.

Farmers listed the reasons for compensation payments as costs for fencing off the area to be mowed at a pre-specified date, costs in terms of a loss in pasture, and the additional input of labour and mowing machines (since increasing the number of mowing dates means economies of scale cannot be used). The fact that later in the season higher compensation payments are necessary was explained by rising opportunity costs for labour and the decreasing quality of grass cut due to lower nutrient levels (protein content). Of course, these costs vary from farmer to farmer depending on farm size, the type of farming, soil quality, etc.

The data contained in Fig. 4 allow the compensation payments necessary to implement the ecologically effective sequential mowing pattern in the county of Torgau-Oschatz to be calculated. Such a scheme would be efficient as compensation payments would ensure that those farmers who are able to carry out the protection measures at the lowest costs will do so. Thus an efficient allocation of protection activities with respect to costs is certain.

However, the situation considerably changes if financial resources are restricted, as the complete introduction of the ecologically effective protection strategy covering the whole region is not feasible. In this case the issue of efficiency has to be considered anew, i.e. under the assumption of a budget constraint.

3.3 General problem of a budget constraint

Funds for the implementation of a particular conservation policy in a certain region are usually restricted. If they are insufficient to completely implement the policy in the whole region, the conservation agency faces the problem of designing compensation payments such that the spatial allocation of protection activities is efficient, i.e. that the ecological benefit is maximised. However, the ecological benefit and the economic costs of conservation management may depend on space *and* time. Consequently, the temporal component of a conservation design may be important as well and the general aim is to find an efficient *spatio-temporal* allocation of protection activities and the corresponding compensation payments.

With respect to the protection of the White Stork, a conservation agency has to decide what meadows around what nests have to be mowed, what mowing dates appropriate, and what compensation per week and per nest should be paid to motivate farmers to participate in sequential mowing. This problem of the spatio-temporal allocation of resources can only be solved if both economic costs and ecological benefits are considered in an integrative way. Therefore, its solution requires ecological-economic modelling.

4. Ecological-economic modelling procedure

4.1. General remarks

Below we present the technique of the ecological-economic procedure. Although it is based on the example of the White Stork in the county of Torgau-Oschatz, it can be applied to many other species and areas. The procedure starts with constructing a model of the region. One possibility would be to consider the exact configuration of all nests and meadows in the region. The analysis of this very realistic landscape model would lead to specific results for the county of Torgau-Oschatz. Alternatively, one may be interested in deriving more general guidelines for the allocation of conservation funds. We choose the second option and create a fictitious landscape with ten nests each surrounded by five meadows available for sequential mowing. Each meadow belongs to one particular farmer whose individual compensation demands for weeks one to five are taken from the questionnaire. For this landscape we want to answer the following questions:

- How much compensation should the agency offer in each of the five weeks?
- What is the efficient spatial and temporal allocation of the budget, i.e. the allocation that maximises the ecological benefit?

First we note that all the farmers have to be treated equally, i.e. they must all be offered the same compensation payments. More precisely, one offer is made for mowing a meadow in the first week, one offer is made for the second week, and so on. The compensation offers for different weeks can be selected independently of each other. We call the combination of the five compensation offers made by the agency a *compensation strategy*. We investigate the above questions not for a single given budget size, but for a continuous range of budget sizes. This allows us to ask the interesting question of whether and (if so) how the efficient compensation strategy and the corresponding spatio-temporal allocation depend on the budget size.

In the first step we leave the question of the efficient compensation strategy open and assume there is a given compensation strategy. Note that considering a particular compensation strategy does not fix the budget size in any way. The compensation strategy only affects in which week which farmers would be willing to participate in the protection programme and mow a meadow. The willingness of a farmer, however, does not mean that the agency will necessarily select him or her for the programme. Whether a willing farmer is selected or not depends on the available budget.

This brief discussion highlights an important characteristic of our procedure: the analysis does not start with a given budget followed by an investigation of the possible choices of the agency (the selection of willing farmers). Instead the analysis is performed the other way round: we investigate the choices of the agency and then determine the agency's resulting expenditure.

Although this approach of not fixing the budget is technically effective and convenient, it does not reflect the real situation in which there is a fixed budget which has to be allocated. This problem can be solved by considering that, assuming the agency always selects the farmers efficiently, there is a unique relationship between the efficient selection of farmers, the level of financial expenditure and benefit. Therefore once all three components and their unique mutual relationships are known, for any given amount of money to be spent by the agency (the budget) we can determine the corresponding efficient selection of the farmers (the efficient allocation of the budget) and the corresponding benefit.

4.2. Description of the procedure

After these introductory remarks, we now turn to the procedure itself (Fig. 5). As mentioned earlier, we start with a single given *compensation strategy* which for reasons given below we choose randomly. For each of the five weeks we randomly draw the compensation in units of Deutschmarks (DM) from a uniform distribution between the limits zero and the maximum amount of money demanded by the farmers in the questionnaire. A compensation offer of zero would mean that only those farmers who do not demand any compensation are willing to participate. A compensation offer equal to the maximum demand would mean that all the farmers are willing.

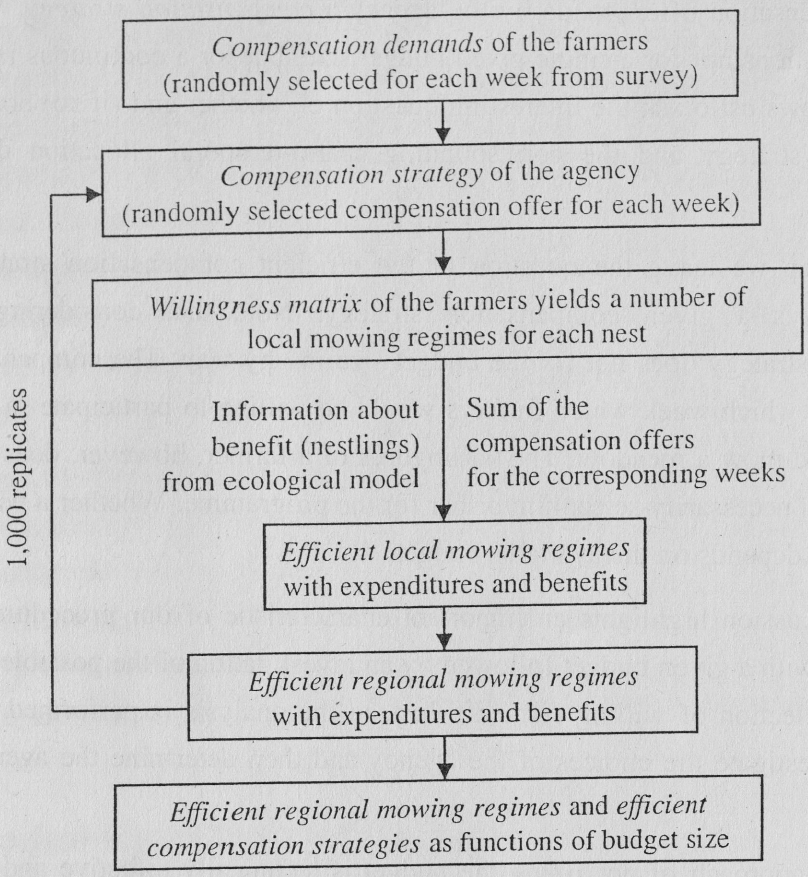

Figure 5: Summary of the ecological-economic modelling procedure.

Now we establish which of the fifty farmers are willing to participate in which week. For this we consider each farmer and for each week compare his/her demand with the compensation offer. If the offer exceeds the demand the farmer will be willing to participate in the particular week. As there are five farmers belonging to each of the 10 nests, for each nest we obtain a matrix with five columns (for the five weeks) and five rows (for the five farmers). Each element of the matrix can be zero or one where an element is one if the corresponding farmer is available in the corresponding week, and zero otherwise. We call this matrix the *willingness matrix* for the nest. Altogether we determine ten willingness matrices, one for each nest.

Each meadow is allowed to be mowed only once within the first and once within the second half of the breeding season. If, however, the compensation offer is high enough, a farmer might be willing to mow his/her meadow more often. In this case the agency has to decide when it wants the farmer to mow the meadow. Furthermore, two farmers may be willing in the same week. Again the agency has to decide which farmer should mow in the particular week. This means that from the willingness matrix of each nest a large number of combinations of up to five farmers, each mowing in one of the five weeks, can be formed. We call these combinations the *local mowing regimes* around the particular nest.

Firstly, we identify the efficient local mowing regimes for each individual nest. Starting with the first nest for each local mowing regime around this nest we calculate the benefit with the help of the ecological model. The total financial expenditure of a particular mowing regime is the sum of the compensation offers to the participating farmers for the corresponding weeks: if, for instance, the compensation offers for the five weeks were DM100, DM200, DM300, DM400 and DM500, respectively, and if we had a feasible local mowing regime in which a meadow is mowed in the first, third and the fifth week, the agency would have to pay the offered compensation for these three weeks and its total expenditure would be DM100 + DM300 + DM500 = DM900. Knowing the expenditure and the benefits for each local mowing regime, we select the efficient ones. A mowing regime is efficient if there is no other mowing regime that has both the lower expenditure and the higher benefit. The set of efficient local mowing regimes and the corresponding benefits and expenditure are identified and recorded for each of the ten nests (Fig. 6).

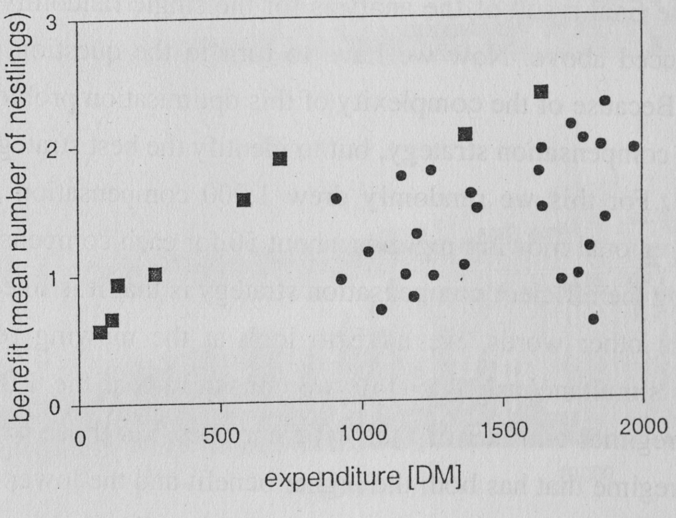

Figure 6: How to identify from all local mowing regimes (dots) the efficient ones (squares). The number of efficient points depends on the compensation strategy and the demands of the farmers belonging to the nest.

Now we have to combine the efficient local mowing regimes to form a *regional mowing regime*. A regional mowing regime is a combination of one efficient mowing regime from each of the ten nests. If there are about 20 different efficient local mowing regimes in each nest, we obtain about 20^{10} different regional mowing regimes, each defined by the decision concerning which of the 50 meadows is mowed and in which week it is mowed, and the total benefit and total expenditure. The total benefit and the total expenditure are the sums of the ten local benefits and their expenditure, respectively. Similar to the local analysis, from these 20^{10} regional mowing regimes we select the efficient ones, i.e. those where no other regional mowing regime yields both higher total benefit with lower total expenditure.

Considering 20^{10} mowing regimes simultaneously is technically not feasible. Therefore we perform the aggregation from the local to the regional mowing regimes in nine steps. In the first step we consider only two nests, which means about $20^2 = 400$ regional mowing regimes and is technically feasible. From these 400 regional mowing regimes we select the efficient ones and obtain a moderate number of efficient mowing regimes. Now we combine these efficient mowing regimes with the about 20 efficient mowing regimes of the third nests. From the resulting mowing regimes we again identify the efficient ones. These are combined with the efficient mowing regimes of the fourth, fifth nests, and so on. This means we never have to consider more than about 1,000 mowing regimes at the same time, and after the procedure we end up with about 50 *efficient regional mowing regimes*. For each one we know whether and which meadow is to be mowed in which week and what the total benefit and the total expenditure (i.e. the size of the budget) are.

This is the final result of the analysis for the single randomly drawn compensation strategy as introduced above. Now we have to turn to the question of the efficient compensation strategy. Because of the complexity of this optimisation problem, we decided not to seek the very best compensation strategy, but to identify the best strategy out of a set of 1,000 random strategies. For this we randomly drew 1,000 compensation strategies and determined the efficient regional mowing regimes, about 50 for each compensation strategy. The problem in identifying the efficient compensation strategy is that it is likely to depend on the size of the budget. In other words, we have to look at the mowing regimes and the compensation strategies simultaneously. For this we consider all of the 1,000 times 50 efficient regional mowing regimes and identify the efficient ones, i.e. those where there is no other regional mowing regime that has both the higher benefit and the lower expenditure. We obtain a total of about 200 efficient regional mowing regimes. For each mowing regime we know which meadow is mowed in which week, the total expenditure and benefits, and the corresponding compensation strategy which by definition is efficient for the particular level of expenditure (i.e. budget size).

The question remains as to whether the efficient compensation strategy was among the 1,000 randomly selected ones. We performed the whole analysis several times and the results varied only marginally, indicating that even though the compensation strategies selected by our procedure are slightly inefficient, they are close enough to the efficient compensation strategy.

4.3. Results for the White Stork

Fig. 7 shows the results of the ecological-economic modelling procedure for the White Stork. Fig. 7a shows how the mean regional breeding success increases with the size of the budget, and Figs. 7b-d show the efficient compensation strategies and spatio-temporal allocation depending on the budget. According to Figure 7d, if the budget is small, all nests have either no or one meadow being mowed. With increasing budget size, one or two meadows are mowed around each nest. This continues until all nests have five meadows being mowed. This means that irrespective of its size, the budget is allocated evenly in space such that all nests receive the same share.

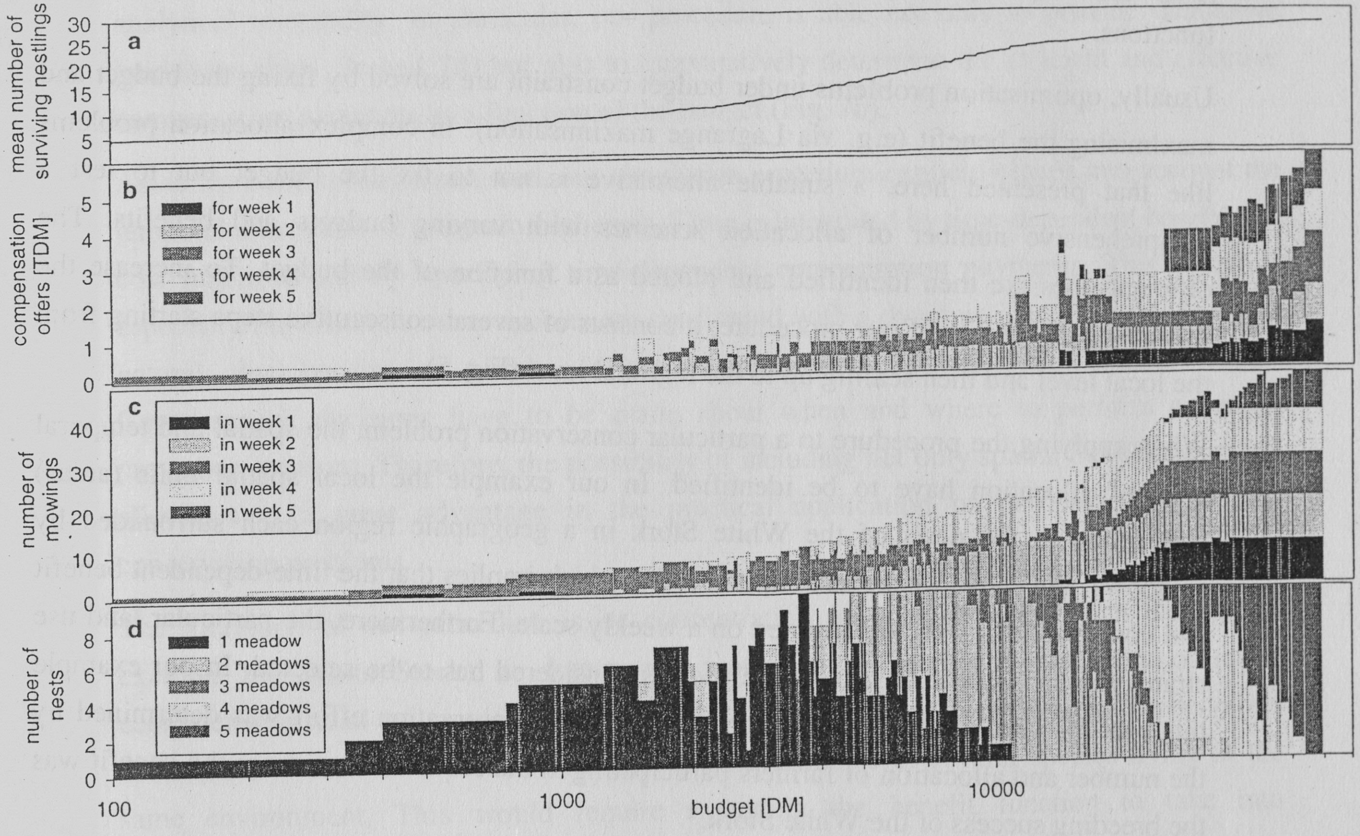

Figure 7: (a) Ecological benefit (mean number of surviving nestlings), (b) compensation payments, (c) efficient temporal allocation, and (d) efficient spatial allocation depending on budget size.

In contrast, the efficient temporal allocation is not even in time (Fig. 7c). If the budget is small, most meadows are mowed in the third week. As the budget increases, meadows are mowed in weeks 2 and 4, then in weeks 2 to 4, and in the end meadows are mowed in all five weeks.

The weekly compensation offers reflect this efficient temporal allocation (Fig. 7b). If the budget is small, compensation should be offered for week 3 only and should have a magnitude of DM500 to motivate enough farmers to participate in the programme. As the budget increases, this would have to be expanded to compensation offers for weeks 2 and 4 and then to all weeks. To motivate all 50 farmers to participate, about DM1,000 has to be offered per week, as shown in Fig. 7b (see also Fig. 4).

5. Discussion

In this paper we have developed an ecological-economic simulation procedure which allows the spatio-temporal allocation of a given budget to be quantitatively determined among a geographic region with a large number of areas and using species-specific cost and benefit functions.

Usually, optimisation problems under budget constraint are solved by fixing the budget and maximising the benefit (e.g. via Lagrange maximisation). In complex allocation problems like that presented here, a suitable alternative is not to fix the budget but to test a comprehensive number of allocation schemes with varying budgets and benefits. The efficient ones are then identified and plotted as a function of the budget. To increase the numerical tractability of our procedure, it consists of several consecutive steps starting from the local level and then scaling up to the regional level (Fig. 5).

When applying the procedure to a particular conservation problem, the spatial and temporal units of allocation have to be identified. In our example the local spatial units (areas) correspond to the nests of the White Stork in a geographic region each surrounded by meadows. We chose weeks as temporal units, which implies that the time-dependent benefit and cost functions were determined on a weekly scale. Furthermore, the particular land use strategy which is able to protect the species considered has to be selected. In our example this was the sequential mowing. Consequently, the conservation effort was determined by the number and allocation of farmers participating in the sequential mowing; the benefit was the breeding success of the White Stork.

Applying our ecological-economic simulation procedure to the example of White Stork protection, we found that if the budget is limited, conservation payments should be allocated evenly across space, i.e. across all nests in the region considered, rather than concentrating them in space on only a few nests. Accordingly, the temporal allocation of conservation payments should be concentrated on only one week or a few particular weeks rather than allocating them evenly in time, i.e. among all the weeks considered.

Wu and Boggess (1999) investigated the spatial allocation of a budget among two areas in a region. In contrast to our results, they found that when the budget is small conservation payments should be concentrated on one area and should not be distributed among the two areas. The difference from our results is due to their sigmoid benefit function, which deviates from our concave benefit function (Fig. 3). This shows that the shape of the ecological benefit and cost functions are crucial elements in the design of efficient land use strategies (Wu and Boggess 1999, Drechsler and Wätzold 2001, and in a more general context Kolstad 1987).

Our ecological-economic modelling procedure goes beyond former studies in several respects. Firstly, species-specific benefit and cost functions can be used and these can differ spatially. The species-specific benefit function can be obtained from ecological modelling (see Fig. 3) whereas the species-specific cost function can be obtained empirically (see Fig. 4). Furthermore, when choosing a simulation approach a relatively large number of areas can be considered in the procedure, as opposed to the usual consideration of only two areas for analytical tractability. In particular, our procedure is able not only to provide qualitative guidelines (Figs. 7c and 7d) but also to quantitatively determine the efficient and effective compensation payments as a function of the budget (Fig. 7b).

Aside from the spatial dimension, our simulation procedure explicitly takes into account the temporal dimension of protection schemes. Time is integrated by time-dependent benefit and cost functions and by specifying time-dependent compensation payments. This aspect is especially important as many species are confronted with a dynamic landscape due to either natural disturbances or human influences (see also Perrings and Walker 1997). Consequently, decisions have to be made about when and where to perform a certain protection measure. Therefore, the possibility of including not only spatial but also temporal allocation is a great advantage in the practical application of the procedure to real conservation problems.

The limitation of our procedure is its concentration on a single species (in the present example the White Stork). In future, the protection of species communities or entire ecosystems instead of single species will become increasingly important. Conservation decisions will then have to take into account the demands of several species living in the same environment. This would require extending the benefit function to take into consideration species communities. Alternatively, the benefit function could focus on habitats rather than species. As conservation decisions often include alternative land use strategies, it could prove necessary to consider more than one land use strategy. For example, to protect the White Stork, the conversion of agricultural areas back to natural foraging habitats would be an alternative to sequential mowing in the existing agricultural landscape. Such alternatives can easily be included in our procedure.

Due to its quantitative output, our procedure is suitable for the development and assessment of conservation programmes. Therefore, one possible avenue for future research is to investigate the efficiency and effectiveness of existing programmes and to identify the potential for improvements.

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