Efficient Compensation Payments for the Protection of Species: Application of an Ecological-Economic Model

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Abstract: We present 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 ecological knowledge is synthesised in a simulation model, which includes the energy balance of individual storks, and their foraging behaviour to determine the effectiveness of land use practices measured by the number of surviving nestlings. Cost data of different land-use patterns are obtained from an economic survey. The results of the ecological simulation model and the survey are integrated in a numerical optimisation procedure, which determines the efficient land-use patterns. The procedure is able to solve complex allocation problems such as the spatial and temporal allocation of a budget among two or more areas of any shapes with spatially differing species-specific cost and benefit functions. Its modular structure allows its application to many kinds of species and landscapes with different forms of land use. The procedure produces the efficient spatio-temporal compensation payments both in qualitative and quantitative terms, and is hence relevant to the implementation of species protection policies and the resolution of conflicts between species protection and commercial land use.

Key words: ecological-economic modelling; efficiency, compensation payments, species protection, spatio-temporal allocation

1. INTRODUCTION

Necessary conditions for successful species protection include an understanding of the important ecological and economic factors, an ecological-economic evaluation of possible protection measures, and their efficient implementation via a political instrument. The experience is that the use of separate ecological and economic analyses is often limited. Instead, ecological and economic aspects have to be considered in an integrated manner. In this paper we show that ecological-economic modelling is helpful if not indispensable to achieve these goals. The example of White Stork protection is used to investigate how a conservation budget has to be allocated in space and time to maximise the breeding success of the population. This includes the design of an economic instrument that initiates the efficient allocation of the budget.

For the design of this instrument we develop an ecological-economic modelling procedure, which consists of four steps:

1. Identification of the factors threatening species survival and identification of possible protection measures
2. Quantitative evaluation of the effects of identified protection measures on the viability of the population
3. Selection of an appropriate economic instrument to implement the protection measures and gathering of necessary economic information
4. Model-based determination of an effective and efficient protection strategy under budget constraints.

2. THE ECOLOGICAL-ECONOMIC MODELLING PROCEDURE

Step 1: Identification of the factors threatening species survival and identification of possible protection measures

The White Stork populations in Germany have undergone a significant decline in the past few decades, as many of the original breeding habitats no longer provide sufficient food for the production of nestlings [Pfeifer, 1989]. The main reasons are on the one hand the continuing destruction of foraging habitats, e.g., due to the change of meadows into arable land and the expansion of settlements [Kaatz, 1996]; on the other hand agricultural practices have changed dramatically. While in the 1950s, the mowing of all meadows in a region took several months, now modern machines can mow all meadows within two weeks. The stork needs recently mowed meadows where it can find prey, such as worms and mice, better than on meadows with high vegetation [Sackl, 1985]. Therefore modern agricultural practices lead to an abundance of food but only over short periods of time.

Generally, in Germany meadows are mowed twice a year for cattle food production: the first time - in mid till end of May, and the second time - 6-8 weeks later. Intuitively it seems plausible that the stork would benefit, if this modern “conventional” mowing regime was replaced by an alternative regime, that makes meadows with low vegetation available over the entire breeding season of the stork.[1] A detailed spatio-temporal structure of such an ecologically optimal sequential mowing regime cannot be determined by arguments of plausibility but requires the use of a simulation model.

Step 2: Quantitative evaluation of the effect of identified protection measures on the viability of the population

The ecological model used in this study can determine the food supply during the breeding season, and the breeding success depending on the spatio-temporal mowing regime. A detailed description of the simulation model can be found in Johst et al. [2001]. The model is based on knowledge of the feeding ecology of the White Stork, the energy requirements of the nestlings, and on observations regarding the foraging behaviour of the species [Struwe and Thomson, 1991]. The model simulates the individual foraging flights during the 70 days [Bauer and von Blotzheim, 1966] of the breeding season. The White Stork is a central place forager, which means that after each flight it returns to the nest before it flies to the next meadow. The maximum flying range is about 5 km. Each flight considers two foraging decisions: the selection of a foraging patch and the time spent foraging on the patch. The stork embarks on an additional 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.

Each foraging flight implies energy costs, which depend on the distance from the meadow to the nest, and the foraging time. The energy uptake on the meadow depends on the food availability, which is negatively related to vegetation height. The food availability is maximal for about one week after mowing and then exponentially decreases by 70% within the following four weeks.

The availability of mowed meadows and the resulting food supply are calculated as functions of the mowing regime. If the food supply is below the requirements of the nestlings [cf. Brezzel and Brinzinger, 1990] for a certain time, a corresponding number of nestlings die. Since stochastic events influence the survival of nestlings, too, the model is run 1000 times and provides the mean number of surviving nestlings over these runs.

Figure 1 shows the breeding success for mowing regimes, which differ in the total number of meadows participating in the sequential mowing. The total number of meadows considered is 10 with a size of 1 ha each. Each meadow is mowed only twice per breeding season and those meadows which do not participate in the sequential mowing regime are mowed at the

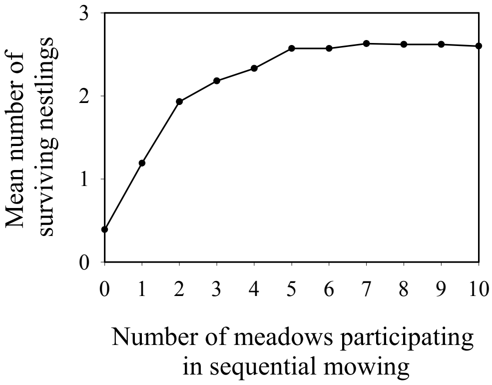

Figure 1. Food availability as a function of time after mowing.

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[1] Observations show that 1 ha patches would be sufficient [Pfeifer, pers. comm.].

conventional dates. In each mowing regime the mowing events are allocated such that for a given number of participating meadows the breeding success is maximised.

One can see that with more meadows participating in the sequential mowing regime the breeding success increases, with a maximum gain achieved initially. The figure further shows that about five meadows are sufficient for the sequential mowing regime, which means that in each of the five weeks between the first and the second conventional mowing, and between the second conventional mowing and the end of the breeding season, one meadow would be mowed.

Step 3: Selection of an appropriate economic instrument to implement the protection measures, and gathering of the necessary economic information

In order to implement the suggested optimal mowing regime an economic instrument is required to stimulate farmers to change the mowing practices. We choose the instrument of compensation payments that go to farmers who mow meadows on dates other than the conventional. This means that the costs of stork protection are born by the society and not by the farmers. It is not a normative decision imposed from without but reflects what is general practice and is widely accepted by the society [Bromley and Hodge, 1990]. Although farmers are obliged to follow certain regulations (such as those concerning the use of fertilisers, pesticides, etc.), they are otherwise free to choose the way they manage their land. For environmental protection measures that go beyond these regulations the farmers are financially compensated. Another advantage of compensation payments is that they guarantee that those farmers participate in the conservation programme who can do so at least costs.

In order to obtain information regarding the costs of a sequential mowing regime, and the corresponding magnitudes of the compensation payments, 92 farmers where interviewed using standardised questionnaires. The survey was conducted in February/March 2000. It included farmers from the district of Torgau-Oschatz in Saxony, who agreed to participate in the survey and owned a meadow in the vicinity of a stork nest. The additional costs of postponed mowing were justified by the diminished quality of hay if grass is mowed at a later date (loss of protein content), by costs of patch preservation (exclusion from grazing), by additional use of labour and machinery, and increased opportunity costs.

The cost data provided by the farmers are very variable among different farmers and range from 0 to €500. In some farmers the costs are constant over the whole breeding season, in others they increase more or less strongly with the time after the conventional mowing date. The percentage of farmers that would be willing to participate in the sequential mowing regime linearly increases with the compensation amount offered. The later the date of the desired mowing event, the higher the compensation required to achieve a given level of participation. For instance, to motivate 50% of all farmers to mow in the first (third/fifth) week after the conventional mowing date, an amount of about €200 (€250/€300) has to be offered per farmer. A payment of €500 will motivate all farmers, regardless of the specified week. Note that although some farmers demand lower compensation payments than others, it is not possible to offer a different payment to each farmer, as this violates the idea of equity and fairness and would reduce the motivation of the farmers to participate in the protection programme immediately!

Step 4: Model-based determination of an effective and efficient protection strategy under budget constraints

The implementation of the ecologically optimal protection scheme requires financial resources that are usually not available. In such a situation the compensation payments have to be designed such that the restricted resources are used efficiently, i.e. lead to maximum benefit (mean number of nestlings) within a given budget. Here a procedure is needed that integrates the ecological model with the cost data.

In the following analysis we assume a model region of ten nests, each surrounded by five 1 ha meadows available for sequential mowing. For a given budget, the nature protection agency now has to choose a compensation strategy and decide simultaneously for the whole region, when and for which nest a meadow should be mowed. A compensation strategy is defined by the combination of payments for the first, second, third, fourth and fifth week after the conventional mowing date. A compensation strategy is efficient if it maximises the mean number of nestlings for a given budget. After the agency has decided on the compensation strategy each farmer decides whether they are willing to participate. That depends on whether the offered compensation exceeds the costs of mowing or not. Then the agency selects from the number of "willing" farmers those that will actually participate in the sequential mowing. Depending on the available budget the number of selected farmers will be larger or smaller.

Usually, one would solve such an optimisation problem by selecting a certain budget and then identifying the compensation strategy and allocation of the budget to maximise the ecological benefit. This is however, difficult for two reasons. First, the cost and benefit functions are discontinuous, as the decision of farmers to participate is binary – either they participate with a whole meadow or not. Second, the budget affects both the compensation strategy and the set of farmers selected for the sequential mowing, which are independent of each other. There is no unique relationship between budget, compensation strategy and mowing pattern.

Due to these difficulties the efficient compensation strategies are not obtained directly but with Monte Carlo simulation by selecting the efficient strategies out of a large number of randomly chosen strategies. The number of 1000 random strategies was found to be sufficient to derive general conclusions. For each compensation strategy the efficient mowing regimes are identified and then the best strategy is selected for a given budget.

Each of the 1000 random compensation strategies is derived and analysed as described below. To obtain a random compensation strategy, the weekly compensation payments are drawn randomly from a uniform distribution where the lower limits are zero and the upper limits are given by the maximum demanded compensation payment from the survey for the corresponding week. To integrate the cost information into the model, each meadow is assigned one of the "cost functions" (i.e., compensation demand as a function of the week) from the survey. For each meadow and each week these compensation demands are compared to the compensation offers (i.e., the payments specified in the compensation strategy), and if the former does not exceed the latter the considered meadow is available for sequential mowing. From this, for each nest a "participation matrix" is established that tells which meadow is available to participate during which week. From this participation matrix, a large number of feasible mowing regimes can be constructed. For each of them the costs are the sum of the weekly compensation payments. The mean number of surviving nestlings is determined from the ecological model.

From this information, for each of the ten nests the efficient mowing regimes are identified, (those that maximise the ecological benefit for a given budget), and arranged in a cost-benefit curve. These ten cost-benefit curves are then combined into a total cost-benefit curve which gives the maximum benefit obtained over the whole region for given costs (budget). Such a regional cost benefit curve contains generally about 150 efficient points (benefit vs. budget), which differ in budget, benefit and mowing pattern. All points of the curve are exactly known and apply to the particular compensation strategy selected above.

Now instead of identifying the efficient mowing regime for a given compensation strategy the goal is to find the efficient compensation strategy itself. Here the Monte Carlo simulation comes into play. The described procedure is repeated for 999 alternative randomly generated compensation strategies. Each leads to a cost-benefit curve with about 150 points. From the approximately 150000 cost-benefit points the efficient ones are identified. Each point corresponds to a particular compensation strategy and to a particular budget, benefit and mowing regime. This might lead to very complicated results, but fortunately, it turns out that although the relationship between budget, compensation strategy and mowing pattern is not unique, under the constraint of efficiency it is, and it is also fairly continuous, as can be seen in Fig. 2.

3. RESULTS

Figure 2a shows the benefit obtained for a given budget if the payments are designed and allocated efficiently. Fig. 2b shows the efficient compensation payments. If the budget is below about €10,000 compensation payments of about €250 should be offered during weeks 2-4. The efficient compensation payments for allocation of a large budget are about €500 and should be offered during all five weeks.

According to Fig. 2c, the mowing events should be allocated evenly over the 10 nests. If the budget is small (e.g., €2,000), about one meadow is mowed at each nest. A medium budget (e.g., €10,000) leads to 2-3 mowing events per nest and at a large budget all meadows are mowed. One may ask whether spatially homogeneous allocation is always superior. Drechsler and Wätzold [2001] showed that in the case of saturating benefit functions (i.e., where marginal benefits decrease) like in Fig. 1, spatially homogeneous allocation of costs tends to lead to maximum benefit.

4. CONCLUSIONS

We presented an integrated model that combines an ecological simulation model with cost data on different spatial and temporal scales. The result is an efficient compensation strategy, i.e. a combination of weekly changing compensation payments that are offered to farmers to mow a meadow in the vicinity of a stork nest during a specified week, such that for a given budget the ecological benefit (number of nestling) is maximised. Apart from the temporal differentiation of the compensation payments, the economic instrument is constant in time, i.e. the payments are selected once and for all. Due to their spatial differentiation and the spatial and temporal dependence of the costs of mowing, however, these payments initiate a spatio-temporal pattern of mowing events in the region and thus spatio-temporal dynamics of the vegetation. The White Storks act in this dynamic landscape, searching for food and raising their young. Their breeding success depends on the availability of food, which depends on the vegetation pattern created by the mowing regime.

The modelling problem is simplified, since costs and benefits are additive in space, i.e. total costs and total number of nestling in the region are the sum of costs and nestlings over the ten nests. Therefore (for a given compensation strategy) we can model costs and benefits separately for each nest and then scale up the results. A particular problem in the identification of efficient compensation strategies is the discontinuity of the cost and benefit functions and the complex and ambiguous relationships between budget (total costs), benefit, mowing regime and compensation strategy.

Despite these technical problems, integrated ecological-economic models seem to be indispensable, as important questions of nature and species protection cannot be solved by ecological or economic research alone. Even if both ecological and economic knowledge exists, for the implementation of species protection it is not sufficient to simply present this knowledge in separate sections to the decision maker and let him or her draw the appropriate conclusions. Instead, it is necessary to integrate ecological and economic knowledge in an interdisciplinary effort.

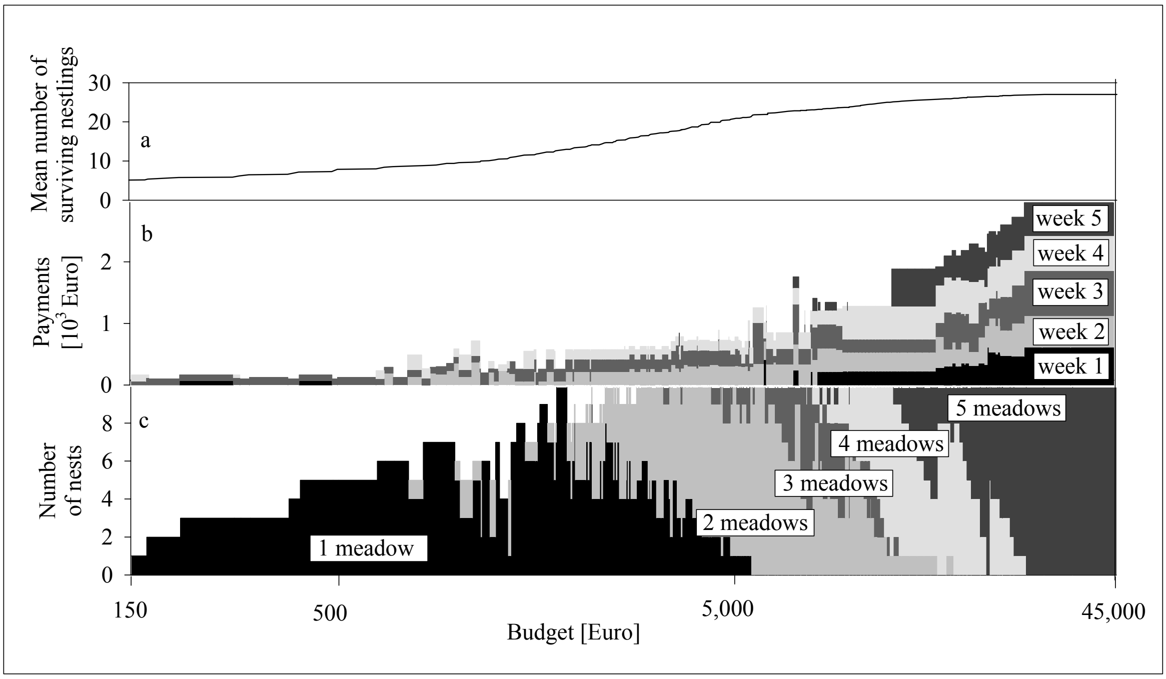

Figure 2. (a) Ecological benefit (mean number of surviving nestlings), (b) compensation payments for weeks 1 to 5, and (c) efficient spatial allocation (number of nests in the region with 1,2,...,5 meadows mowed). All values are given as functions of the budget size. Those in Figs. (b) and (c) are represented by stacked bars.

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6. REFERENCES

Bauer, K.M., and U.N. Glutz von Blotzheim, *Handbuch der Vögel Mitteleuropas.* - Bd. 1, Akademische Verlagsgesellschaft Frankfurt, 1966.

Bezzel, E., and R. Prinzinger, *Ornithologie*, Stuttgart, 1990.

Bromley D.W., and I. Hodge, Private property rights and presumptive policy entitlements: reconsidering the premises of rural policy, *European Review of Agricultural Economics 17*, 197-214, 1990.

Drechsler, M., and F. Wätzold, F., The importance of economic costs in the development of guidelines for spatial conservation management, *Biological Conservation 97*(1), 51-59, 2001.

Johst, K., R. Brandl, and R. Pfeifer, Foraging in a patchy and dynamic landscape: human land use and the White Stork. *Ecological Applications 11*, 60-69, 2001.

Kaatz Ch., Tendenzen der Bestandsentwicklung beim Weißstorch international, im östlichen und westlichen Deutschland sowie im Bundesland Sachsen-Anhalt, in Kaatz, Ch. and M. Kaatz (eds.) *Jubiläumsband Weißstorch, Tagungsbandreihe des Storchenhofes Lohburg im MRLU-LSA*, 3. Tagungsband, 1996.

Pfeifer, R., Zu Nahrungssituation und Bruterfolg des Weißstorches *Ciconia ciconia* an zwei Brutplätzen im Rotmaingebiet, *Anzeiger der Ornithologischen Gesellschaft Bayern 28*, 117-130, 1989.

Sackl, P., Untersuchungen zur Habitatwahl und Nahrungsökologie des Weisstorchs (*Ciconia Ciconia L.*) in der Steiermark, Dissertation, Universität Graz, 1985

Struwe, B., and K.-M. Thomsen, Untersuchungen zur Nahrungsökologie des Weißstorches (*Ciconia Ciconia*, *L. 1758*) in Bergenhusen 1989, *Corax 14*, 210-238, 1991.