Sturm, A., **Drechsler, M.**, **Johst, K.**, **Mewes, M.**, Wätzold, F. (2018):
DSS-Ecopay – A decision support software for designing ecologically effective and cost-effective agri-environment schemes to conserve endangered grassland biodiversity
*Agric. Syst.* **161** , 113 – 116

# DSS-Ecopay – A decision support software for designing ecologically effective and cost-effective agri-environment schemes to conserve endangered grassland biodiversity

**Abstract**

Agri-environment schemes (AES) compensate farmers for applying costly land-use measures that are beneficial to biodiversity. We present DSS-Ecopay, a decision support software for the simulation and optimization of grassland AES. DSS-Ecopay consists of a database capturing the ecological and economic input data, an ecological model for calculating the effect of mowing regimes, grazing regimes and combinations of mowing and grazing regimes on endangered birds, butterflies and habitat types, an agri-economic model for estimating their costs and a simulation and an optimization module for determining ecologically effective and cost-effective AES. DSS-Ecopay is highly flexible and adaptive as it can be applied to different regions and changing economic and ecological circumstances.

**Keywords:** decision support tool, biodiversity conservation, grassland, agriculture

## 1. Introduction

Agricultural intensification and farmers' abandonment of marginal land are key drivers of biodiversity loss in Europe and other parts of the world (Kleijn et al. 2011). In order to halt the loss of farmland biodiversity agri-environment schemes (AES) have been developed. The purpose of AES is to compensate farmers for the adoption of costly land-use measures that benefit biodiversity. Designing ecologically effective and cost-effective AES can be a complex task. The complexity is particularly high if an AES shall protect different species, different land-use measures are available as conservation options, and the costs of these land-use measures as well as their impact on species differ in space and time. In such cases, a software can be a helpful tool to estimate the impact of alternative land-use measures on species and habitat types as well as to identify cost-effective compensation payments to farmers in the context of AES.

Here, we present the decision support software DSS-Ecopay. Its basic components are a database capturing the ecological and economic input data, an ecological model for calculating the effect of land-use measures on endangered biodiversity, an agri-economic model for estimating their costs and a simulation and an optimization module for determining ecologically effective and cost-effective AES. DSS-Ecopay is presently able to calculate the impact of several hundred mowing regimes, grazing regimes and combinations of mowing and grazing regimes (differing, among other aspects, in terms of their timing) on 20 endangered birds, 19 endangered butterflies and 9 endangered habitat types.

DSS-Ecopay is also able to design cost-effective AES. An AES consists of one or several land-use measures and the payments farmers should receive for these measures. DSS-Ecopay includes two cost-effectiveness options.

1) The conservation goal is maximized for a given budget selected by the user. (2) The budget is minimized for certain levels of conservation goals selected by the user. The conservation goals represent the birds, butterflies and habitat types which are selected by the user and weighted in terms of their importance.

DSS-Ecopay is flexible and adaptive and versions exist for the German federal states of Saxony, Schleswig-Holstein and Brandenburg, the region Osterzgebirge in Saxony and the Belgian regions of Noorderkempen, Kust, and Haspengouw. In an ongoing project, it is adapted to support the design of land-use measures in the Aller river valley, Germany.

DSS-Ecopay is based on an ecological-economic modelling procedure (Wätzold et al. 2016). Hence, by developing DSS-Ecopay we are in line with a call by Antle et al. (2017) and Capalbo et al. (2017) who argue for a major effort on the software implementation of agricultural models to increase their relevance for users. In comparison to other decision support software for biodiversity conservation in agricultural landscapes, DSS-Ecopay is novel in several ways. The focus of the software MANUELA (van Haaren et al. 2012) is on the farm level whereas DSS-Ecopay addresses the landscape level.

Similar to DSS-Ecopay, the software INGRID simulates the ecological and economic effects of management decisions in grassland (Rudner et al. 2007) but does not contain an optimisation module. ECOECOMOD (Ulbrich et al. 2008) contains an optimisation module but is limited to one species and a small area. The prominent optimization software MARXAN (Ball et al. 2009) and INVEST (Kareiva et al. 2011) adopt a spatial conservation planning perspective which makes them unsuitable for assessing AES where a software needs to consider the voluntary decision of farmers to adopt a conservation measure which DSS-Ecopay does. A further important novel aspect is that DSS-Ecopay enables the user to take into account explicitly the timing of the land-use measures (i.e., different mowing and grazing dates).

## 2. Description of DSS-Ecopay

### *2.1 Software structure and flexibility*

The structure of DSS-Ecopay is defined by a strict separation of models and input data for the models. The models are implemented in the software, the data set is provided through the database. The database includes region-specific GIS data, all species data, and region-specific as well as general economic and agronomic data and information. The database enables the user to change the required data sets; this makes it possible to apply the software to different regions.

The separation of models and data ensures a high flexibility and transferability. Not only can the software be applied to different regions, but by changing ecologic, economic or agronomic data sets (for example changing the species data under the assumption of global warming) DSS-Ecopay can be adapted to changing circumstances and knowledge and new insights into the design of AES can be gained. Figure 1 provides an overview of DSS-Ecopay structure.

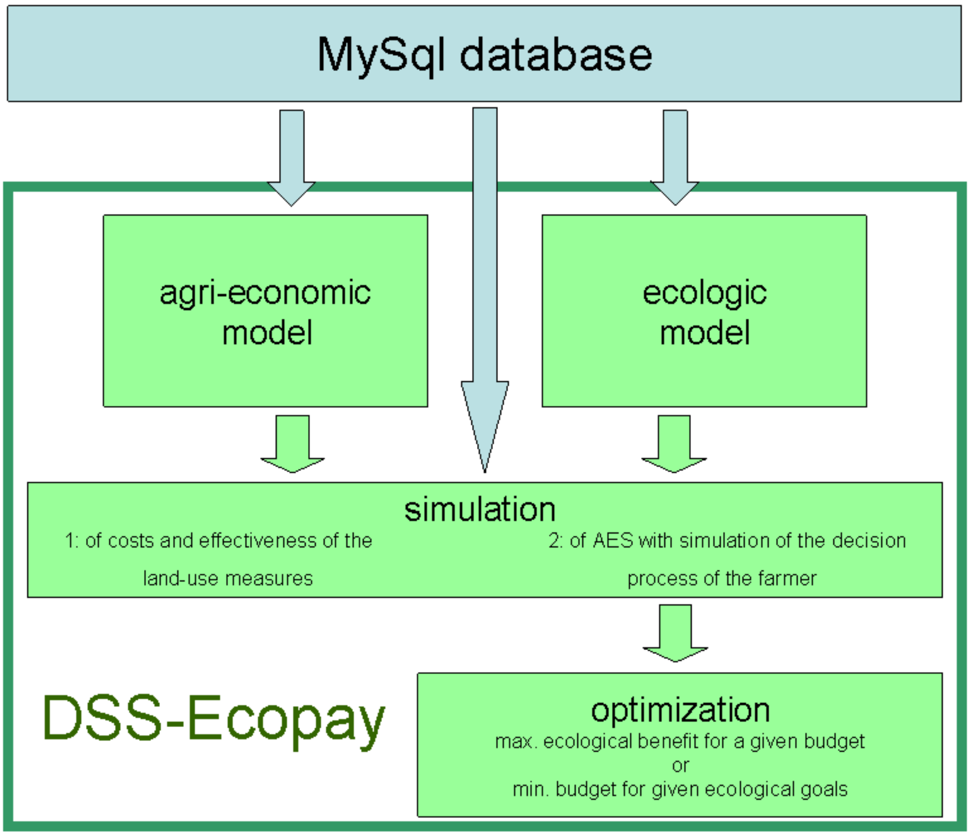


Figure 1: General structure of DSS-Ecopay

### *2.2 Input parameters and data requirements*

The agri-economic and the ecologic models define the software input parameters. The models are spatially and temporally differentiated. The temporal scale is quarter-months (qm); each month is divided in four quarters summing up to 48 quarter-months for the whole year. The spatial scale is a grid cell, the region (e.g. Saxony) is covered by a net of grid cells (e.g. fishnet in ArCGis). The size of the grid cell is user defined depending on the data availability of the user. The grid cell is the smallest spatial unit and cannot be subdivided, e.g. only one land-use measure can be applied on a grid cell at the same time.

Ecological data is needed as input into the ecological model. For birds and butterflies it includes, for example, egg-deposition periods, length of reproduction period, and habitat requirements like soil humidity. Economic and agronomic data is required for the agri-economic model and includes, for example, information on soil productivity of a grid cell, but also digestibility and energy content of the yield.

The structure of the possible land-use measures is pre-defined in the database. The user can alter or add to the set of measures as long as a basic setting is met. The measure has to be mowing, grazing or combination of both including the information whether N-fertilizer is permitted. Moreover, the timing of the first and the temporal distances to further uses have to be defined (for example, mowing with first cut in qm 21, second cut 6 qm and third cut 10 qm later). For grazing the livestock units per ha, the type of livestock and the start and period of the grazing period have to be defined.

The user can display, alter and resave the species data from the database in a window of the software as well as include new species into the database through a window interface. This applies also to the data of the economic model.

### *2.3 Ecological model*

The ecological model estimates the impact of the land-use measures on the species and grassland types. Johst et al. (2015) describes the model in detail, we only give a brief summary here. As birds breed on the ground and butterflies deposit eggs in the grassland, they are impacted during their reproductive period. Therefore, the model considers habitat quality for reproduction as an indicator for the ecological effect of measures. This habitat quality is calculated based on the interference of the type and timing of land-use measures with the reproductive period during which a species is reliant on grassland. The model considers the direct mortality (e.g. eggs are destroyed by mowing machines or trampled by grazers), the habitat suitability related to the varying vegetation height (after cutting or grazing the vegetation regrows) and the local abiotic conditions such as predation pressure**,** soil humidity, the presence of spatial structural elements and the suitability of the grassland type if required (e.g., a certain plant composition necessary for butterflies). The ecological impact of land-use measures on the habitat types is calculated by considering the local abiotic conditions mentioned before and the timing and type of the measures.

### *2.4 Agri-economic model*

The agri-economic model assesses for all land-use measures the opportunity costs of their application. DSS-Ecopay calculates the cost differences for each land-use measure with a profit-maximizing reference scenario defined for each measure (mowing, grazing and combinations of both) for each grid cell. The agri-economic model considers three different types of costs for the farmer: costs that arise because of differences in the quantity and quality of the hay respectively silage from the grass, variable costs for input goods such as fertilizer, and labour costs of the farmer. The administrative costs of the farmer to participate in an AES are not calculated by DSS-Ecopay but are preset and can be changed by the user. Mewes et al. (2015) provides a detailed explanation of how the opportunity costs of the land-use measures are calculated.

### *2.5 Simulation*

The output of the ecological and economic models feed into the simulation. All basic calculations in the software are grid cell wise, i.e. the costs of a measure and its ecological impact are estimated for each grid cell. In the simulation module, this grid cell information is scaled up to the landscape level and to multi-species assessment. The user pre-defines a set of target species and habitat types, a set of land-use measures and selects a region. DSS-Ecopay provides two types of simulations (Fig. 1):

1) Assessment of the costs and the ecological effectiveness of individual land-use measures. One simulation output is the mean cost of each measure in the landscape and the cost span, i.e. the cost of the measure on the cheapest and the most expensive cell. Equivalently, the ecological output is the mean overall habitat quality of each individual measure in the landscape and the habitat quality span that can be calculated for each species or as a mean of multiple species (Johst et al. 2015 provides details).

2) Assessment of the impact of existing or potential AES on user selected species. Here, selection of a measure also includes a predefined payment as input for the explicit simulation of the farmers' decisions determining the resulting land use pattern, i.e. which measure is applied on which grid

cell (see Wätzold et al. 2016 for details). In this pattern, each grassland grid cell has a particular state: either a specific land-use measure is applied or the profit-maximizing reference scenario. A mean habitat quality for each pre-selected species is calculated as well as the number of cells on which individual measures are applied, the required budget for each measure and the overall budget.

### *2.6 Optimization*

The heart of the optimization algorithm is the AES simulation. As the complexity of the optimization does not allow the precise calculation of an optimum we use the heuristic optimization algorithm simulated annealing (Kirkpatrick et al. 1983). In each iteration a solution is generated randomly within a pre-defined neighborhood and compared with the previous best solution. If the new solution outperforms the previous one or is not substantially worse it is chosen for the next iteration; otherwise the previous solution is chosen. Transferring this approach to DSS-Ecopay means the optimization repeats the simulation of AES again and again for different payments for each measure. The simulation results, overall budgets and ecological effects, are compared and evaluated until the cost-effective payments for the measures are found.

### *2.7 Validation*

As field data on the effects of land-use measures on target species and habitat types suitable for a validation of the output of DSS-Ecopay does not exist, we selected an indirect validation approach with several steps. First, we validated the data in the database. This was done for the ecological data through species experts and for the economic data through experts from the agricultural administrations. This validated data was then included in the ecological and economic models. In a second step, we validated output from both models. We simulated particular land-use measures and existing and hypothetical AES and discussed the model output with experts from regional administrations and species experts. Finally, we discussed optimisation results with the experts addressing questions such as whether our results are realistic, and what ecological and economic mechanisms led to the proposed solutions.

## 3. Lessons learned from cooperation with users

For a software to be used and accepted in practise it is important to involve potential users as early as possible in its development process (McIntosh et al. 2011). We involved potential users in the development of DSS-Ecopay and its adaption to a specific region in all regions for which versions of DSS-Ecopay exist. Overall our experience was good, but we encountered also challenges relevant to the development of complex software tools such as DSS-Ecopay. We summarise them as lessons learnt.

(1) It takes time until a complex software such as DSS-Ecopay is understood by users. Understanding this complexity, however, is a pre-requisition for its successful application by users. It is therefore advisable that the same person who is supposed to use the software later is also involved early on in its development respectively adaptation process.

(2) Scientists as software developers and conservation practitioners as users have different time horizons. The duration of research projects is usually 1-3 years whereas practitioners typically have a shorter time horizon. This should be considered early in the software development process.

(3) A careful explanation of the underlying causal relationships of the functioning of the software is important as well as emphasising that it is a decisions aid not meant to replace human decisions. This helps to avoid wrong perceptions of what a software can do. Potential users may be either excessively skeptical about the application of mathematical methods to biodiversity conservation or blindly trust a software without considering its assumptions and limitations.

(4) Calculations with a complex software are time and space consuming, implying that old computers with very small RAM can make a proper use of the software difficult. It is important to ensure that the level of software complexity and the hardware availability of potential users match.

## 4. Software and data availability

DSS-Ecopay is a Windows-based open source C++ software. DSS-Ecopay operates in connection with an Oracle MySQL-database, using the freely available versions of 'MySQL Community Server release 5.1' and C++ connector (version 1.0.5) (see http://www.mysql.com). DSS-Ecopay is open and (including a manual) free for download on the DSS-Ecopay webpage (http://www.inf.fu-berlin.de/DSS-Ecopay/software_eng.html). To run the software an installation of MySQL on the computer is necessary (for example through the open source software XAMPP https://www.apachefriends.org/de/index.html). The software was developed under Windows 7 and tested on Windows 10. As hardware requirement we recommend at least 4GB RAM as the optimization is memory consuming, the size of software itself is only 1.5MB. DSS-Ecopay is joined work of the authors, the corresponding author developed the software code.

## 5. Conclusions

*DSS-Ecopay* is a highly flexible and adaptive decision support software that can be applied to different regions, and under changing economic and ecological circumstances. This flexibility is gained through the separation of data and models, the generality of the ecological and economic models, the explicit simulation of the farmers' decisions and the stable optimization algorithm. If the user is willing to invest some time to understand the complex system behind the software, DSS-Ecopay can provide a much improved understanding of the mechanisms that drive the ecological effectiveness and cost-effectiveness of AES and help to generate more effective and cost-effective AES to conserve biodiversity in grassland.

**_Acknowledgement_**

We gratefully acknowledge financial support by the Deutsche Bundesstiftung Umwelt (project number AZ 29874-33/0).

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