Balancing Forest-Regeneration Probabilities and Maintenance Costs in Dry Grasslands of High Conservation Priority

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Abstract: Abandonment of agricultural land has resulted in forest regeneration in species-rich dry grasslands across European mountain regions and threatens conservation efforts in this vegetation type. To support national conservation strategies, we used a site-selection algorithm (MARXAN) to find optimum sets of floristic regions (reporting units) that contain grasslands of high conservation priority. We sought optimum sets that would accommodate 136 important dry-grassland species and that would minimize forest regeneration and costs of management needed to forestall predicted forest regeneration. We did not consider other conservation elements of dry grasslands, such as animal species richness, cultural heritage, and changes due to climate change. Optimal sets that included 95–100% of the dry grassland species encompassed an average of 56–59 floristic regions (standard deviation, SD 5). This is about 15% of approximately 400 floristic regions that contain dry-grassland sites and translates to 4800–5300 ha of dry grassland out of a total of approximately 23,000 ha for the entire study area. Projected costs to manage the grasslands in these optimum sets ranged from CHF (Swiss francs) 5.2 to 6.0 million/year. This is only 15–20% of the current total estimated cost of approximately CHF30–45 million/year required if all dry grasslands were to be protected. The grasslands of the optimal sets may be viewed as core sites in a national conservation strategy.

Keywords: dry grasslands, expert knowledge, MARXAN, reserve selection, set-covering algorithm

Resumen: El abandono de terrenos agrícolas ha resultado en la regeneración de bosques en pastizales secos ricos en especies en regiones montañosas de Europa y amenaza los esfuerzos de conservación en este tipo de vegetación. Para soportar las estrategias nacionales de conservación, utilizamos un algoritmo para la selección de sitios (MARXAN) para encontrar los conjuntos óptimos de regiones florísticas (unidades de información) que contienen pastizales de alta prioridad de conservación. Buscamos conjuntos óptimos que pudieran acomodar 136 especies importantes en los pastizales secos y que minimizaran la regeneración de bosques y los costos de manejo requeridos para evitar la regeneración de bosques pronosticada. No consideramos otros elementos de los pastizales secos, como la riqueza de especies animales, la herencia cultural y los cambios debido al cambio climático. Los conjuntos óptimos que incluyeron 95–100% de las
especies de pastizales secos comprendieron un promedio de 56–59 regiones florísticas (DE 5). Esto es casi 15% de las aproximadamente 400 regiones florísticas que contienen sitios con pastizales secos y se traduce en 4800–5300 ha de pastizales secos de un total de aproximadamente 23, 000 ha de toda el área de estudio. Los costos proyectados para el manejo de los pastizales en estos conjuntos óptimos variaron entre 5.2 y 6.0 millones de FS (Francos Suizos)/año. Esto corresponde a solo 15–20% del costo total estimado de aproximadamente 30–45 millones de FS/año requeridos si todos los pastizales fueran a ser protegidos. Los pastizales en los conjuntos óptimos pueden ser considerados como sitios núcleo en una estrategia nacional de conservación.

**Palabras Clave:** algoritmo de cobertura de conjunto, conocimiento de expertos, MARXAN, pastizales secos, selección de reservas

### Introduction

In Europe the abandonment of agricultural areas of low profitability is the primary reason traditional agricultural management systems are vanishing (Dullinger et al. 2003; Laiolo et al. 2004; van der Vaart 2005). Abandonment of species-rich, agricultural dry grasslands and subsequent forest regeneration in these areas are associated with considerable loss of species richness (Wallis de Vries et al. 2002; Laiolo et al. 2004; Albert et al. 2008). This loss is particularly evident in mountainous regions, such as Switzerland, where between 1985 and 1997 more than 455 km² of agricultural land was either urbanized (typically lowlands, ~285 km²) or reverted to forest (~170 km²) (van Diggelen et al. 2005; Baur et al. 2006). To prevent further losses of species-rich grasslands, the Biodiversity Policy of the Swiss Confederation has implemented a set of conservation measures that include financial incentives for farmers; conservation agreements through which farmers are under contract to manage the dry grasslands sustainably; and forest clearing and mowing by volunteers and non-governmental organizations. These measures have been undertaken on the basis of a national inventory, carried out in the late 1990s and early 2000s. These data can also be used to find likely ways to maximize conservation of these grasslands at minimum costs.

Efficient conservation efforts ensure that as many attributes of conservation importance as possible are included in the smallest possible number (minimum set) of sites (Kati et al. 2004). Site-selection algorithms that are based on this concept of complementarity (Vanewright et al. 1991) are powerful tools with which to balance the maintenance of species richness and the allocation of management resources. These algorithms use a continuous scale of complementarity in which sites with identical species composition have minimum complementarity and sites with different species have maximum complementarity. These algorithms have been used routinely to identify sets of locations that meet a variety of conservation goals (e.g., Pressey et al. 1997; Kati et al. 2004; Moilanen 2005).

Recently, more attention has been placed on the incorporation of economic costs (Balmford et al. 2001; Moore et al. 2004; Carwardine et al. 2008) and expert knowledge into conservation planning (Cowling et al. 2003). Thus, an effective reserve set not only optimizes conservation at levels from landscapes to individual species, but also is cost-effective and practical to implement.

We devised an optimization framework to identify priority floristic regions to protect 136 plant species (listed on the International Union for Conservation of Nature [IUCN] Red List) that occur on dry grassland sites. Within the framework, we sought to identify a set of sites that would minimize the number of floristic regions, management costs, and the probability of forest regeneration. Including probability of forest regeneration added consideration of temporal change to the site-selection process, which is frequently missing in optimization studies. Including direct economic costs associated with maintenance of each dry grassland allowed for evaluation of the economic resources necessary to maintain this vegetation type. We overlaid all known dry grasslands in Switzerland with the geographical delineation of the 593 official Swiss floristic regions and used the floristic regions as reporting units and conservation features. The spatially explicit floristic regions of Switzerland (Welten & Sutter 1982; Wohlgemuth 1998) are based on topographically defined areas overlain with the distribution atlas of pteridophytes and phanerogams of Switzerland. Of the 593 floristic regions, 350 are below timberline, 215 are above timberline, and 28 are lakes.

### Methods

#### Study Area

Switzerland covers an area of approximately 41,000 km². Roughly 15,000 km² are cultivated, of which 9,000 km² are intensively and 6,000 km² are extensively managed (Leifeld et al. 2005). The dry grasslands we considered (230 km²) are extensively managed. The Swiss climate is generally temperate humid, with some xeric areas in the central Alps. The southern Alps are characterized by relatively mild and dry winters and warm, humid summers (Fig. 1).

#### Dry Grasslands Species and Inventory

Dry grasslands are rich in plant and animal species and are frequently used either as meadow or as pasture. In
Figure 1. Switzerland’s biogeographical zones.

Western Europe they are considered an endangered vegetation type (Wallis de Vries et al. 2002) and have declined in area by about 90% in the past 60 years (Eggenberg et al. 2001). About 40% of the plant species growing in dry grasslands, and in some cases over 50% of the animal species present, are on the IUCN Red List. This high percentage reflects the reduction in extent of dry grasslands.

We used information on the location and area of dry grasslands from an inventory of dry grasslands in Switzerland. This inventory was based on interpretation of 1:5000 scale aerial photographs taken from 1996 to 2004 and transferred as digitized polygons into a geographic information system. Roughly 14,000 dry grassland sites (meadows and pastures) covering 23,000 ha were identified, digitized, and clustered into 3143 polygons of dry-grassland sites. Each dry-grassland site was field validated, and the presence or absence of 2573 dry grassland plant species was determined. In line with expert opinion, we considered the presence of 136 dry-grassland plant species on the IUCN Red List crucial in determining the success of dry-grasslands protection (Supporting Information). Our systematic criteria to select the 136 species were primary occurrence in dry grasslands (Eggenberg 2004); an IUCN Red List species status of critically endangered, endangered, vulnerable, or near threatened (Moser et al. 2002); and occurrence in at least 0.05% of all dry-grassland sites.

We linked the dry-grassland sites and the species they contained to the 593 floristic regions previously defined for Switzerland (Welten & Sutter 1982). We classified a species as present in a floristic region if we found it in at least one of the dry grasslands that intersects with the floristic region. Of the 593 floristic regions, approximately 400 contain dry grasslands (Fig. 2a). These regions were the primary analytical and reporting units in our optimization.

Forest Regeneration Probabilities

We constructed two independent data sets to assess probability of forest regeneration. The first was a spatial delineation (polygons) of all known dry grasslands in Switzerland (hereafter dry-grassland mask) we derived from the dry grasslands inventory (Eggenberg et al. 2001). The second was a grid data set that delineated the locations of different land uses, including the dry grasslands, that changed to other land uses or were unchanged from 1985 to 1997 (hereafter land-transition map). Both the 1985 base data and the 1997 change data were derived from an official land-use survey conducted at a 100-m grid resolution from aerial photographs and field sampling. We categorized each grid cell as closed-canopy forest, open-canopy forest, scrub, extensive agriculture (low or no fertilizer input, not or only occasionally mowed), intensive agriculture (high fertilizer input, often cropped or mowed year-round), and other (Rutherford et al. 2008). The sixth class, other, was excluded from our analyses because it consisted of urban areas, nonvegetated mountains, and glaciers and permanent snow fields. We then tabulated the transitions (1985 vs. 1997) from one class to another with transition matrices. We defined forest regeneration as a transition from intensive and extensive agriculture to open-canopy forest, closed-canopy forest, or scrub. Data from this transition matrix were used to estimate probabilities of forest regeneration. We considered these data an estimate of forest regeneration in response to land-use change in the study region.

We used logistic regression to predict probabilities of forest regeneration for each pixel (grid cell) of the dry-grassland mask. Predictor variables at the pixel resolution were topographic, climatic, and descriptors of local and regional land characteristics, which were all intersected with the dry-grassland mask to yield specific predictor values of forest regeneration for each individual dry-grassland pixel (Supporting Information). Prior to building the logistic model, we used the procedures of Hosmer and Lemeshow (2000) to reduce the number of variables. We eliminated highly positively or negatively correlated (Spearman $r > 0.7$) variables; those retained have the strongest hypothesized relations to the probability of forest regeneration. The response variable had two states (forest regeneration or no forest regeneration). Sample size was 1299 dry-grassland sites. Forest regeneration occurred on 205 (15.8%) sites; 1094 sites (84.2%) did not show forest regeneration. These percentages represent the prevalence of forest regeneration in our sample. To calculate mean forest-regeneration probabilities per floristic region, we averaged the regeneration
probabilities of those 100-m pixels that belonged to the dry-grassland mask.

We used 10-fold cross-validation to estimate model accuracies. Model-accuracy metrics included four threshold-dependent variables, the percentage of correctly classified pixels (PCC), specificity, sensitivity, kappa (Fielding & Bell 1997), and the threshold-independent area under the receiver-operator characteristic curve (AUC) (Hanley & McNeil 1982). We set the classification level for forest regeneration to reflect the prevalence of forest regeneration in our sample following Manel et al. (2001). We used this adjusted threshold to estimate accuracies reflected by PCC, sensitivity, specificity, and kappa. The AUC, as a threshold-independent metric, was largely unaffected by unbalanced frequencies (Cumming 2000).

Maintenance Costs for Dry Grasslands

We based costs on actual maintenance costs. They include the costs of removal of woody plants, but excluded agricultural subsidies. We adapted the cost variables in Schick and Stark (2002) to our study and standardized them across all regions and years. We used the following variables to calculate the costs and benefits of maintaining each dry-grassland site per year: costs for planning and administration (Näf 1988; Moriz & Schick 2007); costs for average use of machines on dry-grassland sites (Möhring et al. 2008); average travel costs for an assumed distance of 1 km to reach dry-grassland sites from nearby villages or farmhouses; costs of one mowing event per year on ungrazed sites (meadows); benefits of potential dry-matter harvest of 200–300 kg/ha on ungrazed sites (Dietl 1986).
and benefits of nonintensive cattle grazing on grazed sites (pastures). The mean required labor for dry grasslands, including planning and administration, was 22.9 hours/ha for grassland meadows and 19.0 hour/ha for pasture (Ismail et al. 2009). We adjusted costs as a function of slope because grassland on steep slopes is harder to maintain (Ismail et al. 2009). The costs of various machines (estimated after Ammann 2007) were set at CHF50/ha for meadows and CHF48/ha for pastures. Total maintenance costs do not include work for the initial, labor-intensive inventory of dry-grassland sites (e.g., field visits, aerial photointerpretation), which was an investment cost paid by Swiss cantons and the federal administration. Removal of woody plants is assumed to occur on all sites every 5 years. It involves removal by hand of early regeneration stages and, if needed, machine-assisted wood removal at an average of 45 hours of labor/ha and machine costs of CHF109/ha (Pfeiffer et al. 2002).

At assumed labor costs of CHF41/hour (Ismail et al. 2009), we estimated the mean annual maintenance costs at CHF827 for a pasture and CHF1143 for a meadow, plus an additional CHF391 for years in which woody plants are removed. We summed costs of maintaining all dry-grassland sites within a floristic region (Fig. 3b). We used this summed cost per floristic region in our optimization analyses. In general total maintenance costs were high in floristic regions with steep sites, low accessibility, and large numbers of dry-grassland sites.

Analytical Framework

We used program MARXAN (Ball et al. 2009; version 1.8.10, Game & Grantham 2008) to optimize the selection of floristic regions across Switzerland. MARXAN has been used extensively for a variety of conservation planning processes, including networks of marine reserves, with...
Table 1. List of input variables in the site-selection algorithm MARXAN.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable description</th>
<th>Value range</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest regeneration per floristic region (Fig. 3a)</td>
<td>mean probabilities of forest regeneration of all dry-grassland sites within a floristic region</td>
<td>0–100%</td>
<td>as low as possible</td>
</tr>
<tr>
<td>Dry-grassland species per floristic region (Fig. 2b)</td>
<td>presence or absence of 136 plant species that occur on the dry-grassland sites in a floristic region</td>
<td>species names</td>
<td>at least 95%, 98%, 100% of species represented within the entire study area (Switzerland) as low as possible</td>
</tr>
<tr>
<td>Dry-grassland maintenance cost per floristic region (Fig. 3b)</td>
<td>mean maintenance costs per floristic region derived from individual maintenance costs of each dry-grassland site (Ismail et al. 2009)</td>
<td>CHF0 – 1.3 million</td>
<td>as low as possible</td>
</tr>
</tbody>
</table>

*The variables were used to select an optimum number of floristic regions that contain dry-grassland sites.

(Klein et al. 2008; Ban et al. 2009) extensive stakeholder involvement; for reserve planning for a variety of terrestrial species and groups (Pearce et al. 2008; Becker et al. 2010); and for evaluating ecosystem goods and services (Chan et al. 2006). The terminology we used follows that of Game and Grantham (2008).

Our objective function was determined by the input parameters (Table 1) and consisted of the total cost of maintaining dry-grassland sites in a floristic region multiplied by the average probability of forest regeneration across all grassland sites in the floristic region. The objective function reflects the fact that all maintenance costs, not just weeding and machine-assisted wood removal, increase as land abandonment and subsequent reforestation increase in a floristic region. This increase in cost is, for example, due to higher transportation costs to the remaining, increasingly distant grassland sites, reduced labor force, and a lack of markets for agricultural dry matter. This combined objective function allowed us to balance cost of maintenance (i.e., maintenance costs including those designed to reduce probability of forest regeneration) with an estimate of the probability of forest regeneration (Table 1).

Our goal was to select an optimum number of floristic regions with grassland sites that contained the 136 dry-grassland plant species on the IUCN Red List. Our targets were set at levels of 95%, 98%, and 100% representation of the entire species list within the entire study area (targets A, B, C, respectively). We did not aim to optimize the spatial arrangement of selected floristic regions across Switzerland.

We did not identify a single best-solution set of floristic region; rather, we determined and report the proportion of times a given floristic region was contained in multiple (n = 100) MARXAN model runs. This proportion can be used as a measure of the conservation priority of a floristic region, assuming that the more frequently a region is contained in a solution, the more it contributes to meeting the identified conservation goals (irreplaceability; Pressey et al. 1994; Carwardine et al. 2007). A full listing of the technical parameter values used to perform the MARXAN analyses are in the Supporting Information.

Results

Probability of Forest Regeneration

We retained 10 of the original 21 predictor variables (Supporting Information) during model building (Table 2). Model fit (adjusted $R^2$) was 81.2. Four predictors were negatively related to the probability of forest regeneration: mean difference (1997–1985) of pixels classified as intensive agriculture surrounding the grasslands; average distance of grassland pixels to the closest pixel classified as scrub; and categories plateau and northern Alps from the nominal variable Bioregions. The remaining predictor variables in Table 2 were positively related to regeneration probability (i.e., average number of pixels classified as extensive agriculture surrounding the grasslands; average number of forest pixels surrounding a grassland site; and categories central and southern Alps from the nominal variable Bioregions). Additionally, slope and average yearly temperature were positively related to probability of forest regeneration.

Resubstitution and 10-fold cross-validation accuracies were 79–81% for PCC and specificity and 75% for sensitivity. Kappa was 0.41–0.42, and AUCs were 0.74. These values are indicative of a model with moderate ability to predict probabilities of forest regeneration. The resulting model predicted forest-regeneration probabilities for each dry grassland site, which we averaged per floristic region (Fig. 3a). In general, probabilities of forest regeneration were relatively low on the plateau, whereas in the Jura Mountains and the Alps probability of forest regeneration was relatively high.

Optimized Selections of Floristic Regions

The mean number of floristic regions required to represent 95–100% of the dry-grassland species ranged from 56 to 59 (SD 5) and encompassed 4800–5300 ha of dry grasslands. These 56–59 floristic regions are roughly 15% of approximately 400 floristic regions that contain dry-grassland sites. The area of dry grassland sites covered in these floristic regions amounts to 21–23% of the dry grassland area in Switzerland. The optimally selected 56–59
floristic regions had estimated maintenance costs of between CHF5.2 and 6.0 million/year, which is 15–20% of the current total estimated cost of CHF30 to 45 million/year to protect all known dry grasslands.

As a rule the site-selection algorithm did not select floristic regions, where dry grasslands had high maintenance costs and high probabilities of forest regeneration (Fig. 4a). The algorithm selected some relatively species-rich, easily manageable low land regions, but excluded many regions with high maintenance costs and high probability of reforestation (e.g., in the Jura Mountains and in the species-rich, xeric southwestern part of Switzerland) (Fig. 4a). The core areas of the selected floristic regions, in terms of area required, were in the central Alps, and there were a few plateau regions selected (Fig. 4b). These regions may be viewed as core sites in a national conservation strategy. Additional floristic regions identified by the algorithm were regions in the eastern part of Switzerland and the Jura Mountains, which have medium species richness and low to medium probabilities of forest regeneration. Floristic regions in the southern Alps contributed marginally to the optimal solutions.

**Discussion**

Various strategies are used in reserve selection (Moilanen 2007) that assign different weights to cost and representation of species (Snyder et al. 1999; Cabeza & Moilanen 2003; Kati et al. 2004) or that prioritize the order in which sites might be conserved (Moilanen 2005, 2007).

We based selection of floristic regions on a minimum-set formulation that identified the minimum number of complementary regions that maximized a specified conservation target (Kati et al. 2004; Moilanen 2005). The method is consistent with the understanding that presence of a species at a given location does not guarantee persistence or ensure protection of ecosystem processes that maintain species richness (Pressey et al. 2008), habitat quality (Cabeza & Moilanen 2003), or viable populations (Haight & Travis 2008).

Our optimization framework accounts for the fact that forests are likely to regenerate in species-rich dry grasslands, threatening conservation efforts in this vegetation type of high conservation priority. Forest regeneration is particularly prevalent in mountainous regions (Dullinger et al. 2003; Laiolo et al. 2004; Bolliger et al. 2007), where it can reduce the long-term effectiveness of site-selection that are based solely on measures of species richness. Social and economic processes, such as willingness of the farmers to do work that is not product oriented, also affect whether conservation objectives are achieved across a set of sites selected solely on the basis of ecological factors (Salomon et al. 2006; Pressey et al. 2008).

Even though basic costs, such as those we presented, are relatively easy to estimate, we recommend they be interpreted in orders of magnitude and as an indication of the likely costs for site management rather than precise...
estimates. Our cost estimates focused on management of dry grassland sites only and did not account for costs of reserve establishment. In addition, decisions at the level of the individual farm regarding abandonment of a site depend not only on money but on the individual farmer and the location of the farm. Our cost estimates were based on averages for different maintenance techniques. In practice, maintenance costs will differ greatly from site to site. Costs to continue protecting all dry-grassland sites in Switzerland (23,000 ha) are estimated at CHF30–45 million annually (Ismail et al. 2009). Our results indicate that in theory the 136 dry-grassland plant species on the IUCN Red List could be protected for about CHF5.2–6.0 million/year. These costs could increase approximately by a factor of 1.5 if current Swiss agricultural subsidies were added. Our cost estimates and the underlying optimum solutions must be interpreted with caution because they are associated with uncertainties inherent to site optimization (e.g., insufficient replication of species occurrence). Although the selected 136 dry-grassland plant species occur in at least 0.05% of all dry-grassland sites, our optimizations could generate occasional solutions in which a species is present only once. To assume a single presence is sufficient to confer a high probability of persistence is optimistic (Pereira & Daily 2006), and it may be better to use the proportion of a grassland site in which a species is present as an optimization variable instead of presence or absence.

We considered floristic criteria only, not elements such as animal species richness or cultural heritage. Their inclusion might change the selection of floristic regions considerably. Thus, our results cannot be viewed as a final conservation plan. In particular, two technical constraints need further elaboration if one were to apply our work. First, the floristic regions are ecological rather than administrative units. This means each region has

Figure 4. Floristic regions in Switzerland selected as representing 100% of the 136 dry-grassland plant species on the International Union for Conservation of Nature Red List (conservation target C): (a) average percentage of 100 runs in which a floristic region was selected and (b) area of dry grasslands in floristic regions that were identified in >50% or 20–50% of model runs (circle size is proportional to the area of dry grasslands within a floristic region).
multiple landowners and heterogeneous governance, which may make them more difficult to protect. Second, we assumed that if a floristic region was selected it would result in the full protection of all dry-grassland sites inside the selected floristic region, which is rather unrealistic in practice. Hence, we suggest our analysis is most useful in identifying areas of high national or regional conservation priority that might be cost-effective to manage in the face of dynamic ecological processes such as forest regeneration.

Forest regeneration as we modeled it is only one of several factors that negatively affect dry grasslands. Others include urbanization and agricultural intensification, each of which could affect floristic species richness in dry grasslands, particularly grassland in the low-cost floristic regions on the plateau. Additionally, MARXAN is a static optimization tool and does not account for changes in conservation targets over time. Our approach to incorporating ecological dynamism by means of forest transition probabilities attempts to make MARXAN temporally explicit. Dynamics that might be useful to consider in future site-selection studies include not only historical probabilities of land-cover change but also hypothesized probabilities of land-cover change in response to social and economic phenomena, short-term ecological processes, or long-term changes, such as climate change.

Supporting Information

A list of plant species identified as conservation targets in dry grasslands (Appendix S1), descriptions of variables used to project the probability of forest-regeneration in current dry grasslands (Appendix S2), and technical parameter values used in the MARXAN runs (Appendix S3) are available as part of the online article. The authors are responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Literature Cited


Conservation of Dry Grasslands


