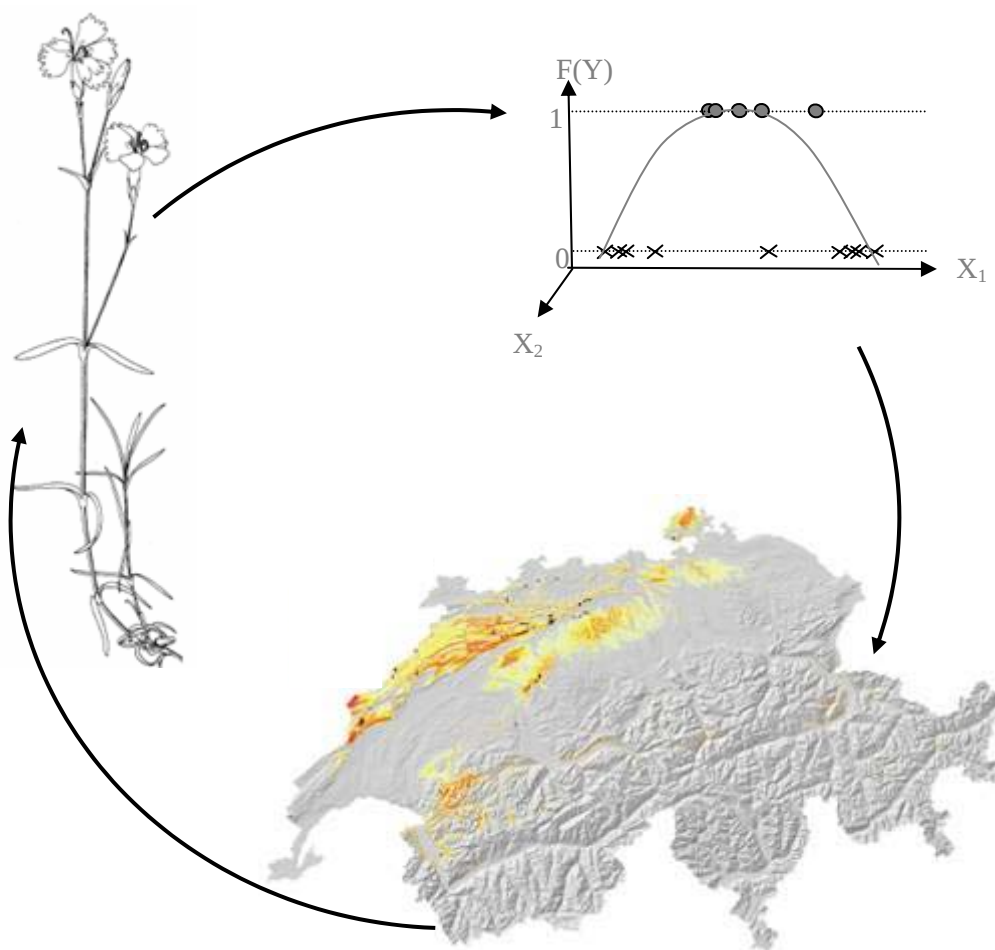


Modelling the potential distribution of rare and endangered plant species



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Abstract

A rising number of studies dealing with species distribution modelling have been conducted in recent years. This was enabled by a tremendous increase of computer performances, which in turn allowed powerful statistical analysis. A common practice is to model species distribution by relating known species distributions to the spatial distribution of environmental predictors. This static approach is used in Generalised Additive Models (GAM), one of the most commonly employed models in vegetation modelling. This model requires presence/absence data. Unfortunately, presence/absence data are often unavailable since gathered during expensive and time consuming field surveys. Therefore, GAMs using presence-only data are generally fitted with computer generated 'pseudo absences'. Many data available today consists of presence-only data sets collected by volunteers and stored in herbarium and museum databanks. This study attempt to establish a general and efficient framework for modelling the distribution of rare and endangered plant species on the basis of presence-only data from a herbarium database. As a preliminary study, three ways of using 'pseudo absences' in GAMs were tested and compared with 'pseudo absence' derived from a preliminary ENFA model. The weighted absence method - a procedure that include all 'pseudo absences' available and that ensures a balanced influence of presences and absences during calibration process - was chosen as the most efficient way of using 'pseudo absences'. The proposed framework is applied to twelve endangered meadow species using presence-only data from the Swiss Floristic Network Data Center over the Swiss landscape. Probability maps resulting from the models were filtered by land use and rocks categories on which species never occurred. The modelling of endangered meadows species provided high accuracy (mean $D^2 = 0.88$) and validation values (mean ROC-CV = 0.96). Indices of precipitations and average temperature of July were shown to have the highest mean contributions in models. Probability maps allow comparing the probability of presence to the known occurrence of the species. This comparison permits identifying priority areas where new populations might be found. It also provides technical help to make decision priorities in protecting areas or re-introduction experiments. The framework used in this study can be part of an iterative process: the occurrences suggested by previous models can serve to fit a second generation of model with enhanced accuracy. With such an iterative process, one could hope in a near future to model the distribution of endangered species with enough precision to provide a new efficient tool for plant conservation management.

Un nombre grandissant d'études traitant de la modélisation de la distribution de plantes a été réalisé ces dernières années. Cet essor a été rendu possible par une augmentation importante de la puissance de calcul des ordinateurs, permettant d'effectuer des analyses statistiques plus puissantes. Une pratique courante pour modéliser la distribution d'une espèce est de mettre en relation sa distribution connue avec la distribution spatiale de variables environnementales. Cette approche statistique est utilisée avec les GAM (Generalised Additive Models), un des modèles les plus souvent employés en modélisation végétale. Ce model requière des données de présence/absence. Malheureusement, les données de présence/absence sont souvent non disponibles car récoltées durant de longs et coûteux échantillonnage sur le terrain. De ce fait, les GAM utilisant des données de présence uniquement sont généralement ajustés avec des 'pseudo absences' générées par ordinateurs. Beaucoup de données disponibles aujourd'hui sont des données de présence uniquement récoltées par des naturalistes volontaires et stockées dans des bases de données floristiques. Cette étude tente d'établir une méthode générale et efficace pour modéliser la distribution de plantes rares et menacées à partir de données de présence uniquement provenant d'une base de donnée floristique. Comme étude préliminaire, trois méthode d'utilisation de 'pseudo absences' dans des GAM ont été testées et comparées avec des 'pseudo absence' dérivées d'un model ENFA préliminaire. La méthode 'weighted' – une procédure incluant toutes les 'pseudo absences' disponibles et assurant une influence équilibrée entre présences et absences dans le processus de calibration du modèle – a été choisie comme la meilleur façon d'utiliser les 'pseudo absences'.

La méthode générale proposée a été testée avec douze plantes rares et menacées de prairie sur une zone d'étude couvrant l'ensemble du territoire suisse en utilisant des données de présences provenant du Centre du Réseau Floristique Suisse. Les cartes de probabilité résultant de la modélisation ont été filtrées par les catégories de roches et d'utilisation du sol sur lesquelles la présence de l'espèce n'était jamais observée. La modélisation de ces espèces rares et menacées a donné des valeurs d'évaluation très élevées (D^2 moyen = 0.88) et des valeur de validation très élevées également (ROC-CV moyen = 0.96). Les indices de précipitation saisonnières et la température moyenne de juillet ont été montrées comme ayant la contribution la plus importante dans les modèles. Les cartes de probabilité permettent de comparer les probabilités de présence aux occurrences connues de l'espèce. Cette comparaison permet d'identifier les zones prioritaires où chercher de nouvelles populations. Il s'agit également d'un outil d'aide à la décision pour choisir des zones de protection ou de réintroduction. La méthode générale utilisée dans cette étude peut être incluse dans un processus itérative : les occurrences suggérées par les models peuvent servir pour ajuster une seconde génération de modèles plus précis. Avec un tel processus itératif, on peut espérer dans un proche avenir, modéliser la distribution de plantes menacées avec assez de précision pour constituer un nouvel outil efficace pour la conservation de plantes.

1. Introduction

Over the past two decades, increases in computer capabilities have enabled the rise of new powerful statistical techniques and GIS tools. These advances have led to the development of predictive habitat distribution models, by relating known species distributions to the spatial distribution of environmental predictors (for a review see Franklin 1995, Guisan and Zimmermann 2000). Models of species distribution are potentially important tools for the management of wildlife populations. These techniques enable to predict the probability of presence of a species in a location where no species information is known. This is particularly helpful in the field of species management where species data sets are often limited or lacking.

Static distribution models are developed from simple statistically derived response surfaces. They automatically assume pseudo-equilibrium (Lischke et al. 1998) between the environment and the observed species patterns. This limitation is not too restrictive for species which are relatively persistent or react slowly to variability in environmental conditions. It is compensated by large-scale prediction with less effort and the advantage that no detailed knowledge of the physiology and behavior of the species involved is necessary. However one must be aware that effects of habitat disturbance, species competition or species dispersal rates may introduce bias in such models (Brzeziecki et al. 1993, Guisan et al. 1999, Lees and Ritman 1991, Zimmermann and Kienast 1999). Two of the most commonly employed statistical techniques are generalised linear modeling (GLM; McCullagh and Nelder 1989) and generalised additive modeling (GAM; Hastie and Tibshirani 1986 see Guisan et al. 2002). GAM models are a non-parametric extension of GLM models that fit predictor variables independently by smooth functions rather than by assumed linear or quadratic relationships, as is the case in GLM. One special case of GLM and GAM is logistic regression applied to presence/absence data. This is by far the most frequent situation when GLM are used to model species distribution based on robust and consistent data (Yee et al. 1991, Austin et al. 1994 -1995, Austin and Meyers 1996, Leathwick et al. 1996, Leathwick and Rogers 1996, Ferrier and Watson 1997, Bio et al. 1998, Franklin 1998, Lehmann 1998, Bio 2000, Pearce and Ferrier 2001, Lehmann et al. 1997).

Unfortunately, presence/absence data is often unavailable since it is usually gathered during expensive and time consuming field surveys (Austin et al. 1994, Franklin 1998). Much of the data available today consists of presence-only data sets collected by volunteers and stored in herbarium and museum databanks. Because data collection strategies are designed for inventories rather than statistical analysis, volunteers do not gather information about absence of species. Presence-only data sets are then often the only data type currently available for predictive modelling (Araújo and Williams 2000). This type of data is also the most difficult to successfully incorporate into statistical modelling methods. Herbarium presence-only data sets suffer several fundamental drawbacks that limit their validity in models. The most obvious of these is the lack of accurate absence data, which is a necessary component in most modelling methods. The second is the unknown sampling bias: the sample is often dependent upon factors such as distance to cities, pathways or accessibility, rather than on random sampling strategy. A third drawback lies in the unknown sampling bias of rare versus common species (Ferrier and Watson 1997). In Herbarium data a disproportionately high number of occurrences for rare species in comparison to common species is frequently observed. A final drawback also to be noted is plot precision which is often unknown in this kind of data. All these factors make presence-only data sets more difficult to model accurately than most systematically gathered presence/absence datasets as they decrease the interpretability and significance of results. The evaluation of model based on presence-only data is also a particularly difficult problem.

To overcome the drawback of lack of accurate absence data, several modelling techniques have been developed in recent years which incorporate presence only data. Amongst them one can mention environmental envelopes (BIOCLIM; Austin 1994), genetic algorithms (GARP; Peters and Thackway 1998) and ecological niche factor analysis (ENFA; Hausser 1995; Hirzel et al. 2002b) based on Hutchinson's (1957) ecological niche theory. Although several of these modelling methods have been found to appropriately model data sets containing presence-only data (Austin et al. 1994, Ferrier and Watson 1997, Peters and Thackway 1998, Hirzel et al. 2002a), they generally do not surpass the performance of statistical modelling techniques which require data sets gathered from systematic surveys containing both presence and absence data (Austin 1994, Austin et al. 1994, Ferrier and Watson 1997, Zaniwski et al. 2002).

GAM models have also been used to predict plant species distributions from presence-only data sets. In this case, presence-only data are supplemented with a sample of computer-generated 'pseudo-absences' (Ferrier and Watson 1997, Zaniwski et al. 2002). Predicting species distributions from statistical models incorporating presence-only data sets and generated 'pseudo' absences has the potential to be a convenient and useful alternative when systematically gathered presence/absence data is unavailable. GAM has proved to be particularly robust for modelling species presence/absence data) The results by Ferrier (1997) and Zaniwski (2002) showed that although GAM models derived from presence-only data gave weaker prediction results than GAM models derived from presence/absence data, GAM in general do perform better than the BIOCLIM model (Ferrier and Watson 1997) and ENFA models (Zaniwski et al. 2002) which incorporate only presence data.

Important efforts for collecting observations of rare species for conservation purposes mean that rare and endangered species observations have been more exhaustively sampled. This is confirmed by the higher proportion of occurrences for rare species in comparison to common species in herbarium data (Ferrier and Watson 1997). Thus, we can expect known information about endangered plant species distribution to be more representative of their real distribution than that of common plant species.

Rare species with restricted ecological niches bear the greatest risk of becoming extinct (Fiedler and Smith 2001). A study about Rabinovitz rarity type (Rabinovitz 1986) with CRSF species has shown that 82 percent of rare endangered plant species live in restricted habitats (Broennimann unpublished results, Annexes 2 and 3). These two specific features of endangered plant species are expected to be convenient for modelling their distribution. With restricted habitat, potential areas receiving high prediction are expected to be limited in space. In this case, the potential distribution is a powerful tool for conservation: species distribution models can be useful for identifying priority survey sites and suitable but currently unoccupied habitats.

This study will attempt to establish a general methodology for modelling rare and endangered plant species distribution, based on presence-only data. A new method for generating 'pseudo absences' is proposed. Three ways of using these 'pseudo' absences will then be compared with 'pseudo absence' derived from a preliminary ENFA model. The proposed method is applied to 12 endangered meadow species using presence-only data from the Swiss Floristic Network Data Center (CRSF).

2. Material and methods

2.1 Study area

Switzerland is located at the center of Europe, between approximatively 45 and 48° N latitude. It has a total area of 41285 square kilometres including parts of the Jura and Alps mountains, separated in-between by a plateau. Switzerland's climate is subject to Atlantic influences from the west, while continental influences operate from the east. The result of this combination is a constant alternation of sunny and rainy days at all times of the year. Cold winds from the north may blow in at any time. If warm and humid air masses from the Mediterranean region flow towards the southern slopes of the Alps, heavy precipitation results in these regions, while on the northern slopes a warm and drier wind ensures at the same time fine weather and sends the temperatures soaring. When the wind blows from the West or the Northwest, this drier wind blows in the opposite direction on the southern slopes of the Alps. The many factors that shape the climate and the weather interact with Switzerland's finely subdivided relief to produce a generally temperate climate, which can vary within a small area. Some intra-alpine valleys exhibit relatively strong continental characteristics, whereas areas located south to the Alps have an insubrian climate influence. Since Switzerland is a small territory, well sampled and showing varied climatic conditions, it constitutes an ideal study area for testing various predictive modelling approaches on a regional scale.

2.2 Species data

The response variables used in this study are endangered species presence-only data extracted from the CRSF database (CRSF 1999). This database provides Swiss Authorities with technical bases to make decisions for endangered species management. It contains observations of presence for 132 endangered species. For each observation, information on the precision of the geographic localization is also available. Twelve endangered meadow species with more than 29 occurrences at a 25 meter plot resolution were selected. The resulting subset of 12 species (table 1) provided the presence component in the data used for modelling.

Table 1 - Endangered meadow species used for modelling

species	number of observation	habitat (Delarze et al. 98)	Rabinovitz's rarity type	IUCN criteria
<i>Potentilla inclinata</i>	29	4.1	A	EN
<i>Dracocephalum ruyschiana</i>	49	4.3	A	LR
<i>Dracocephalum austriacum</i>	52	4.2	B	VU
<i>Tulipa sylvestris</i>	54	4.2	B	VU
<i>Dianthus gratianopolitanus</i>	77	4.1	C	VU
<i>Androsace septentrionalis</i>	44	4.1	C	VU
<i>Lathyrus sphaericus</i>	67	4.6	D	VU
<i>Valeriana celtica</i>	53	4.3	E	LR
<i>Knautia godetii</i>	59	4.5	E	LR
<i>Carex fimbriata</i>	29	4.3	F	LR
<i>Eryngium alpinum</i>	90	4.3	G	VU
<i>Aquilegia alpina</i>	60	4.3	G	LR

The number of occurrences with an accuracy ≤ 25 m available in the CRSF database is given. Informations about Species habitat, Rabinovitz rarity type (Rabinovitz 1986) and IUCN criteria are also provided (IUCN 1994):

- Habitat (Delarze et al 1998): 4.1 foliate rocks and lapiaz, 4.2 thermophilous dry meadows, 4.3 mountain meadows and unfertilized pasture, 4.5 fertilized meadows, 4.6 gramineous fallow lands
- Rabinovitz's rarity type based on geographical range/habitat rarity/population size dichotomic criteria:
A. wide/common/large, B. wide/common small, C. wide/rare/large, D. wide/rare/small, E. narrow/common/large
F. narrow/common/small G. narrow/rare/large, H. narrow/rare/small
- IUCN criteria: LR (low risk of extinction), VU (vulnerable), EN (endangered)

2.3 Environmental data

A dataset of 23 environmental layers was used to describe each 25 x 25 meter plot of Switzerland (Table 2). It contains topographic layers, climatic layers and distance layers. All derived layers were calculated using ArcInfo or ArcMap (ESRI, Environmental Systems Research Institute 1992-99, Redlands, USA). From the elevation model (DEM25), sine and cosine transformations of slope aspect were derived. These transformations were done in order to obtain aspect information on a continuous scale rather than on a circular. A slope angle layer was also derived. Topographic position layers were calculated in ArcInfo using the following methods: a circular moving-window with fixed radius (100, 200, 500, 1000 and 1500 meters respectively) was applied to the DEM25, and the differences between the average elevation of the window and the center cell of the window were attributed to the center cell and stored in new layers. Positive values (the center cell in the moving window has a higher elevation than the average elevation of the cells in the window) can be interpreted as peaks, while negative values (center cell is of lower elevation than the average elevation of the window) can be interpreted as valley bottoms (Guisan et al. 1999). The climatic layers set was provided by the Swiss Federal Institute for Forest, Snow and Landscape Research (N.E Zimmermann and F. Kienast, unpublished). Information on monthly precipitation and cloudiness was simplified by principal component analysis (PCA) to create indexes of seasonality. An adequate number of principal components were retained in order to have a cumulate explained variance above 99% for both series of predictors. Detailed explanations about interpretations of principal components are given in figure 1. For cloudiness series, only the first principal component was kept in the dataset whereas the first three principal components were kept for monthly precipitation series.

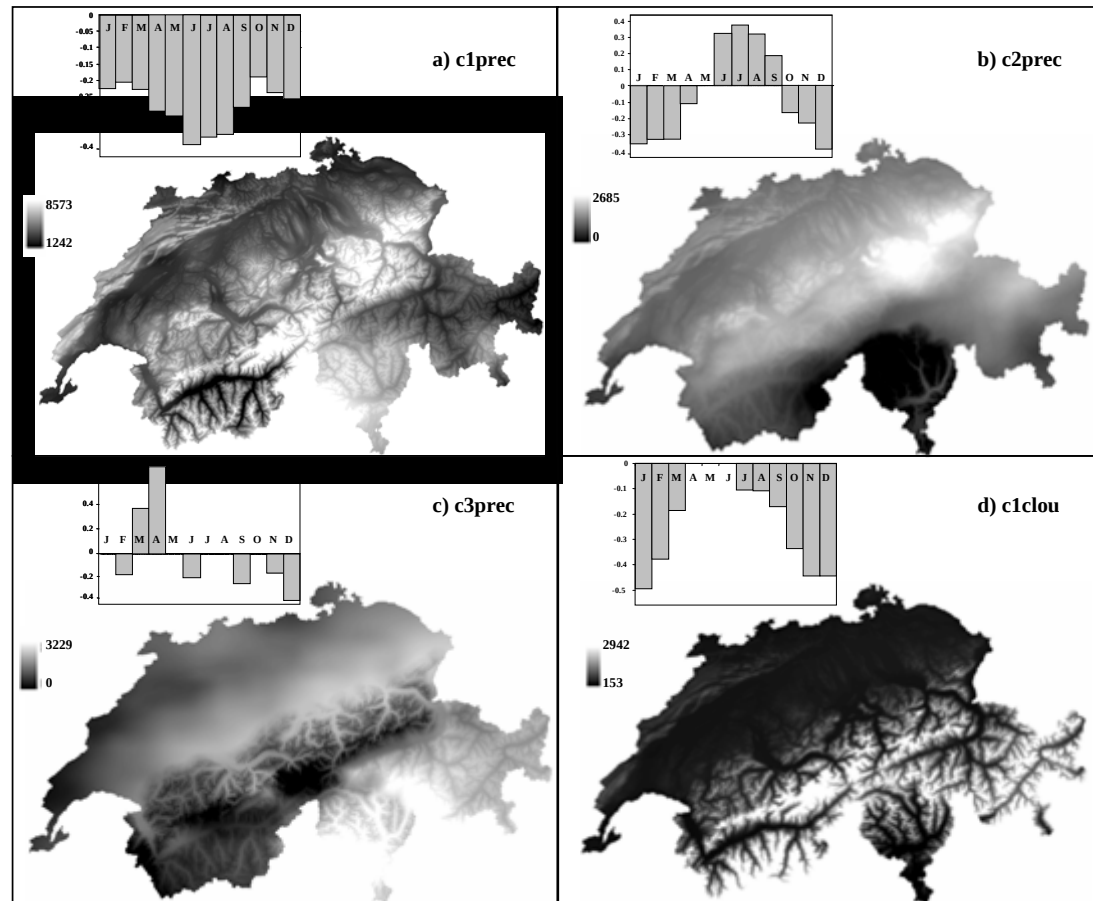


Fig 1 - Result of principal component analysis for monthly mean precipitations and monthly mean cloudiness

Retained predictors derived from the PCA analysis are shown with an enclosed graphic showing monthly eigen vector values. a) first principal component of monthly precipitation (83% explained variance). Values of eigen vector (EV) indicate that the component is an index of relatively higher rainfalls with a predominance of summer rainfalls. b) second principal component of monthly precipitation (16% explained variance). EVs indicate that the component is an index of both relative higher rainfalls in summer and lower rainfalls in winter. Regions with low values are influenced by insubrian climate. c) third principal component of monthly precipitation (1% explained variance). EVs indicate that the component is an index of relative spring precipitations. d) first principal component of monthly cloudiness (99% explained variance). EVs indicate that the component is an index of relatively high cloud coverage especially during winter months.

In addition, two qualitative layers provided information on land-use and soils and rocks (table 2). The distances to rivers, forests and bushes were calculated from land-use layer using the 'distance' function in Spatial Analyst module of ArcMap.

Table 2 – Environmental data

layer	description	unit	interval	source
dem25	elevation	meters	[191:4610]	swisstopo
slope	slope	degrees	[0:88]	calculated
aspectsin	North-South exposition	sin(°)	[-1:1]	calculated
aspectcos	East-West exposition	cos(°)	[-1:1]	calculated
topo100	topographic position in a 100m radius window	meters	[-1960:619]	calculated
topo200	topographic position in a 200m radius window	meters	[-1964:596]	calculated
topo500	topographic position in a 500m radius window	meters	[-1894:664]	calculated
topo1000	topographic position in a 1km radius window	meters	[-1724:833]	calculated
topo1500	topographic position in a 1.5km radius window	meters	[-1636:1061]	calculated
tave7	average temperature of July	°C	[-3.2:21.96]	WSL
ddeg300	sum of annual degreedays with 3° threshold	days x °C	[0:3712]	WSL
sfroyy	annual average nubmer of frost druring growing season	days	[0:81,45]	WSL
pdsum	sum of mean daily precipitations	mm	[20:59]	WSL
c1prec	index of seasonal precipitations	none	[1242:8573]	calculated
c2prec	index of seasonal precipitations	none	[0:3229]	calculated
c3prec	index of seasonal precipitations	none	[0:2685]	calculated
srاد3	March solar radiation	KJ/m2	[2229:25359]	WSL
srاد7	July solar radiation	KJ/m2	[2758:31544]	WSL
swb	soil water budget	mm/yr	[-751,4:150]	WSL
c1clou	index of cloudiness	none	[159:2759]	calculated
gt-ch	simplified geotechnical map (rocks and soils)	qualitative	30 categories	OFS
landuse25	primary surfaces describing the soil use	qualitative	28 categories	swisstopo
dforest	distances to forest	meters	[0:12136]	calculated
dbush	distances to bushes	meters	[0:11649]	calculated
driver	distances to river	meters	[0:4813]	calculated

Names, descriptions, units, intervals and sources for the 23 envirommental data used in this study to describe Switzerland at a 25 meters resolution. dem25 was from swisstopo (Swiss Federal Office of Topography). All climatic layers were from WSL (Swiss Federal Institute for Forest, Snow and Landscape Research). Gt-ch was from Geostat data, OFS (Swiss Federal Statistical Office).

An UPGMA correlation cluster tree including all 23 environmental predictors was calculated (fig. 2) using the R software (v. 1.5.1 (2002), R development Core Team). This tree allowed visual synthesis of environmental correlations between predictors and was meant to support further predictors selection procedures.

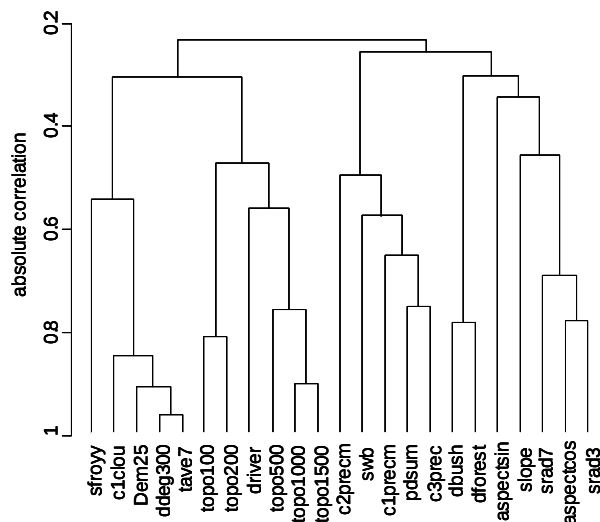


Fig 2 - UPGMA correlation cluster.

The cluster analysis was performed in R with absolute correlation between predictors using the « average» attribute in the hclust function.

2.4 Modelling framework

A general framework (fig 3) is proposed for modelling endangered species distribution with Generalised Additive Models (GAM; Hastie and Tibshirani 1986) using the GRASP package (Lehmann et al. 2002) in the SPLUS software (v. 2000, Mathsoft Inc., Seattle, USA). Depending on the method used to generate absences, some models were performed using the GAM function provided in the mgcv library developed for the R software (v. 1.5.1, R development Core Team 2002).

Since only presence-only data were available, the first step in this framework was to generate ‘pseudo absences’. To examine the most efficient way of creating and using absences in a GAM model, a preliminary study was performed on the *Aquilegia alpina* dataset (see section 2.4.1). Each predictor was tested independently, by considering four ways of introducing absences into models (fig. 4). The method found to be the most efficient and reliable was then used to fit multiple GAMs on presence-pseudo-absence data sets.

A model for each of the twelve endangered meadow species, including an appropriate number of predictors, was built through a stepwise selection of predictors (see section 2.4.2). These multiple models were implemented in a SIG to produce probability maps. Final potential distribution maps were produced by filtering these probability maps with boolean layers excluding landuse and rocks categories on which species never occurred (see section 2.4.3).

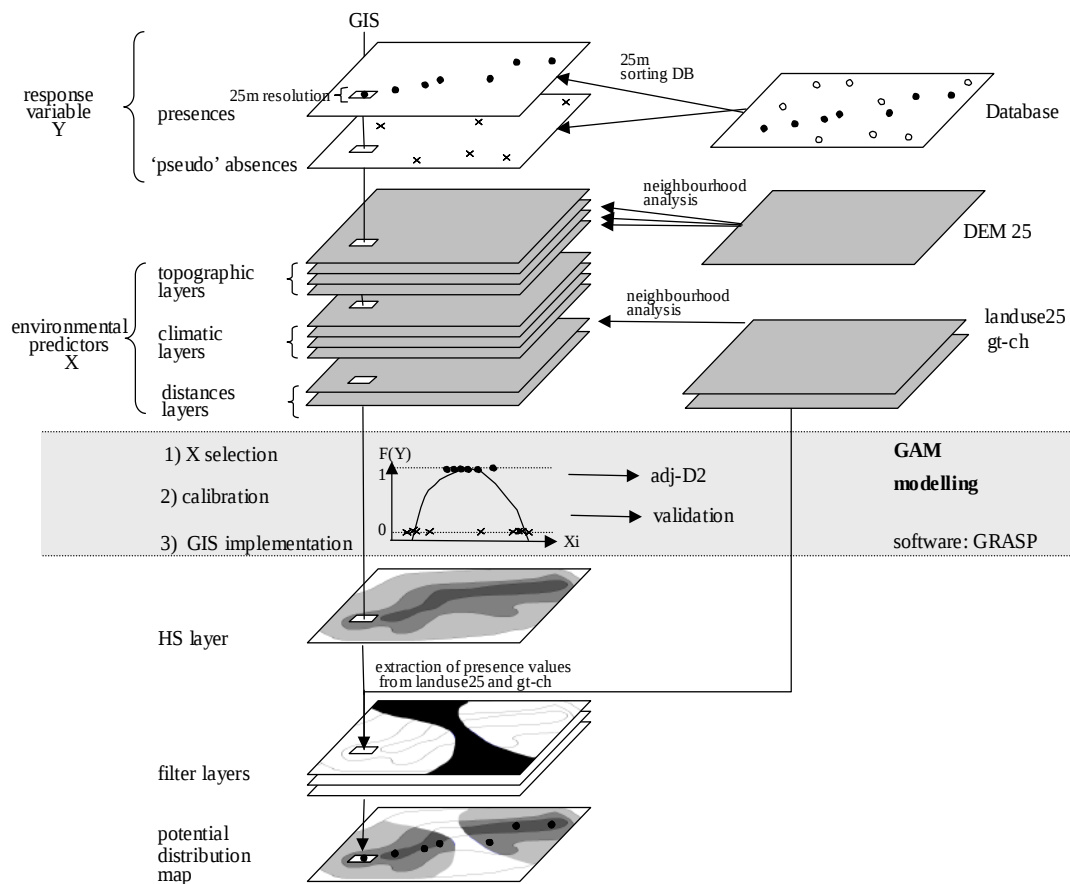


Fig 3- General framework for modelling the distribution of endangered plant species with GAM.

2.4.1 Generating and using absences

Absence data for each of the 12 selected species was derived from the CRSF database in the following manner: considering one species at a time (focal species), all other species occurrences were considered as absences for the focal species. This assumption is reasonable since only data at a 25 meter-plot resolution was used. At this resolution, and considering that volunteers collecting data have generally a rather good knowledge of rare plant species, one can assume that the occurrence of a non-focal species (i.e. an absence for the focal species) could not be noted without as well noticing the presence of the focal species.

The common practice in GAM modelling is to use all available absence data. However, when the data contains more absences than might be predicted by binomial standard error models (McCullagh and Nelder 1989), problems with inference can occur (Barry and Welsh 2002). Four ways of considering absences in the model were tested (fig. 4): i) unweighted method, ii) weighted method, iii) balanced method and iv) ENFA derived method. The unweighted method (i) is the standard method using all absence data available. The weighted method (ii) is an alternative method proposed in the GRASP options module, which consists in recalculating the weight of presences (originally set to 1) to give presences the same weight as absences in the calibration process. The balanced method (iii) consists in randomly selecting the same number of absences than presences. To limit the risk associated with a single random selection, fifty trials of different balanced absence datasets were used instead. In the last case (iv), an ecological niche factor analysis (ENFA) was first performed with the *Aquilegia alpina* presence-only data using the Biomapper software (Hirzel 2002). In the resulting suitability map, areas with a habitat suitability value lower than that corresponding to the lowest prediction for *Aquilegia alpina* occurrences were selected. Random absences were then generated within the selected area, while at the same time ensuring to have an equilibrated number of absences in three equal elevation intervals. As in method (iii), fifty balanced absence datasets were sampled and used to fit as many GAM models.

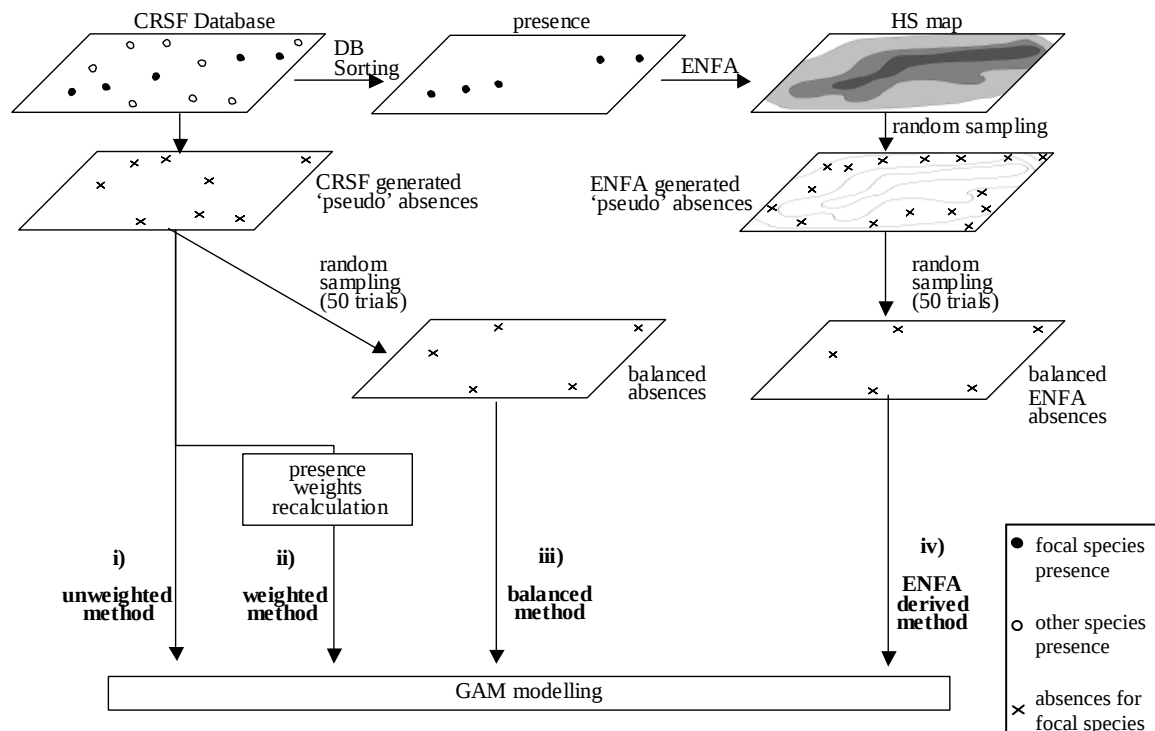


Fig 4 – Presentation of the different methods used to create and to introduce absences in GAM modeling

- unweighted method: other species presences are used as focal species absences. All absences are used in models without presence weight recalculation
- weighted method: other species presences are used as focal species absences. All absences are used in models with presence weight recalculation
- balanced method: other species presences are used as focal species absences. Absences used in models are randomly sampled to have the same number of presence and absence.
- An ENFA is done on the base of presences. Absences are randomly selected in low habitat suitability to have the same number of presence and absence

2.4.2 Statistical analysis

For each species, a multiple GAM was performed using a logistic link and a binomial variance function (i.e. the two parameters one has to specify in a GAM). Predictor selection was performed with an automatic stepwise regression using AIC evaluation criterion (Akaike, 1973). In stepwise procedures, small perturbations of the response data can sometimes lead to vastly different subsets of the predictors. This procedure should hence be used with care (Guisan et al 2002). All models were fitted with all continuous predictor variables using a bi-directional stepwise procedure. Predictor contribution was evaluated by assessing the explained deviance of each predictor independently ('alone' contribution) as well as the variation in residual deviance when other predictor variables were sequentially added and then dropped from the model ('drop' contribution). The stepwise procedure was used to exclude those predictors not significantly reducing the deviance ($\chi^2 = p > 0.01$).

A final model was fitted with a restricted number of predictors (maximum number of predictors $\cong$ 10 percent of the number of observation). This was done in order to maintain an adequate balance between the explained deviance and predictive capability of models (Harrell 2001, p.60-61). Predictors to be included were chosen according to 'drop' and 'alone' contributions: Predictors having a high 'alone' contribution and which kept a high 'drop' contribution in the stepwise procedure were considered as satisfactory predictors and introduced in the final model. When an ambiguity in the choice between two explanatory predictors could not be resolved with this approach, the predictor exhibiting the lowest correlation with other predictors was chosen according to the environmental correlation cluster.

The estimator chosen to test models fit was the adjusted explained deviance ($\text{adj-}D^2$; Weisberg 1980). Two ways were used to evaluate each model. First, a graphical and quantitative comparison of observed values against predicted values was made on all observations. Second, models were evaluated by cross-validation. The ROC-Plot evaluation measure (AUC; Fielding and Bell 1997) was also calculated in each case.

2.4.3 Potential distribution maps

Models were implemented in a GIS using lookup tables in ArcView 3.2 (an ArcView Script is available on the GRASP website). The resulting map indicates the probability of species' occurrence in every 25 m x 25 m plot covering the study area. In order to take into account the information contained in nominal data, boolean layers excluding categories of land use and rocks layers in which the focal species never occurred were produced and multiplied to probability maps in ArcMap. In GAMs, nominal data must have a balanced number of presences and absences in each category, which is rarely the case. Otherwise, problems can be encountered in the calibration procedure. The filtering process mentioned above is therefore a convenient way of using binary or nominal data in GAM modelling.

3 Results

3.1 generating and using absences

The four techniques for generating and using absences (see fig. 4) are compared in figure 5. Methods (iii) and (iv) did not produce significantly different results (Wilcoxon signed rank test: $p = 0.23$). In contrast, every other combination of methods gave significantly different results (signed rank Wilcoxon test: $p < 0.05$, fig. 5). It is to be noted that methods (i), (ii) and (iii) show the same general pattern of explained deviance. The order of explanatory predictors in the increasing explained deviance sequence is always the same. The main difference between methods is the level of explained deviance ($i < ii < iii = iv$). A slightly different pattern is observed with method (iv): explained deviance is higher with low explaining predictors, especially with topo and distances layers. In contrast, there is quite the same pattern with predictors correlated with DEM25.

The method (ii) was used in the following multiple GAMs for several reasons. Firstly, it has the same pattern of explained variance than method (i) which is the standard method. Secondly, it explains deviance at an intermediate level, so models will not be artificially over fitted or underestimated. Finally, it is a convenient method easy to implement in GRASP.

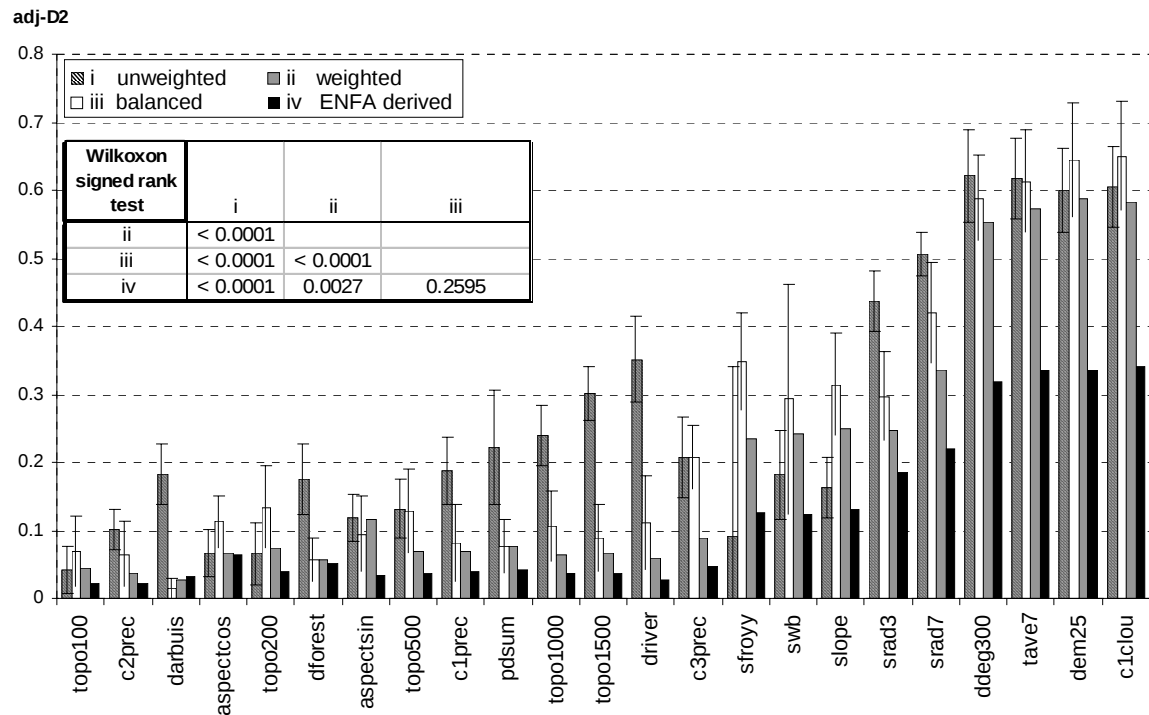


Fig 5 - Results of absences methods

Adj-D² by each environmental variables for the different absence methods (i, ii, iii, iv). Environmental variables are sorted out by increasing mean explained deviance. Results of the Wilcoxon signed rank test is shown two by two for each method in the enclosed table. Pairs of methods with a p -value < 0.05 are providing significantly different results.

3.2 Multiple GAM models

Predictor 'drop' contributions are illustrated in table 3. Only 16 predictors out of 23 were selected at least once and used for fitting multiple GAMs (Table 3 and 4). All predictors explained a significant part of deviance in each related model with p-values inferior to 0.01. The mean contribution for each predictor illustrates which predictors explain the distribution of rare meadow plant species in Switzerland. The first four explanatory predictors are related to precipitations and temperature (0.66 cumulated mean contribution). C3prec has the highest mean contribution (0.26), followed by tave7 (0.2), c2prec (0.12) and c1prec (0.07).

It is to be noted that, in general, neither topographic layers nor distance layers provide useful information to explain species distribution at this scale (except one notable exception for *Dianthus gratianopolitanus*).

Table 3 – Models contributions, accuracy and validation.

species	presences	variables	contrib 1	contrib 2	contrib 3	contrib 4	contrib 5	contrib 6	contrib 7	contrib 8	contrib 9	D2	adj-D2	V	CV
<i>Potentilla inclinata</i>	29	3	sw b 0.48	pdsum 0.27	c2prec 0.25							0.60	0.57	0.95	0.92
<i>Dracocephalum ruyschiana</i>	49	5	tave7 0.76	pdsum 0.09	c1prec 0.07	dforet 0.06	c2prec 0.03					0.67	0.64	0.96	0.92
<i>Dracocephalum austriacum</i>	52	5	c3prec 0.59	c2prec 0.17	tave7 0.12	mnt25 0.07	srاد3 0.05					0.94	0.93	1.00	0.99
<i>Tulipa sylvestris</i>	54	6	c3prec 0.61	c2prec 0.11	ddeg300 0.11	srاد7 0.08	srاد3 0.05	slope 0.04				0.98	0.98	1.00	0.99
<i>Dianthus gratianopolitanus</i>	77	8	topo100 0.18	c3prec 0.18	srاد3 0.13	c2prec 0.11	ddeg300 0.11	mnt25 0.10	srاد7 0.10	pdsum 0.08		0.88	0.87	0.99	0.97
<i>Androsace septentrionalis</i>	44	6	c1clou 0.32	c3prec 0.26	sfroyy 0.15	c1prec 0.15	srاد3 0.08	sw b 0.04				0.94	0.93	1.00	0.99
<i>Lathyrus sphaericus</i>	67	6	c2prec 0.32	slope 0.25	sw b 0.14	topo500 0.10	c1prec 0.10	tave7 0.08				0.96	0.96	1.00	0.95
<i>Valeriana celtica</i>	53	5	c3prec 0.81	c1prec 0.11	pdsum 0.07	tave7 0.01	srاد3 <0.001					1.00	1.00	0.99	0.99
<i>Knautia godetii</i>	59	6	c2prec 0.25	c1prec 0.19	mnt25 0.19	tave7 0.13	pdsum 0.12	sw b 0.11				0.98	0.98	1.00	1.00
<i>Carex fimbriata</i>	29	3	tave7 0.48	c3prec 0.32	slope 0.20							0.92	0.91	0.99	0.92
<i>Eryngium alpinum</i>	90	9	c3prec 0.30	tave7 0.15	c2prec 0.15	c1prec 0.14	pdsum 0.08	sfroyy 0.05	ddeg300 0.05	srاد7 0.05	sw b 0.04	0.95	0.95	1.00	0.99
<i>Aquilegia alpina</i>	60	6	tave7 0.68	c1prec 0.11	c2prec 0.10	sfroyy 0.07	c3prec 0.03	slope <0.001				0.69	0.66	0.96	0.93

For each modelised species the number of presence and the number of environmental predictors kept in final model is shown. Relative 'drop contributions' of predictors are sorted by increasing values. Models accuracy is illustrated with D² and adj-D². Validation is illustrated with ROC validation (V) and ROC cross-validation (CV).

Table 4 – Predictors mean contribution

	c3prec	tave7	c2prec	c1prec	swb	pdsum	slope	srاد3
contribution	0.26	0.20	0.12	0.07	0.07	0.06	0.04	0.03
nb models	7	8	9	6	5	6	3	5
	c1clou	mnt25	ddeg300	sfroyy	srاد7	topo 100	topo 500	dforet
contribution	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01
nb models	1	3	3	3	3	1	1	1

Predictors mean contribution is calculated for every environmental predictor as the average contribution of the focal predictor within all species. The number of models including each predictor is also shown.

High model adequation values were obtained (fig 6) with explained deviance ranging from 0.6 to 1 (0.57 to 1 for adjusted explained deviance). The values obtained for the model validations are also high, with ROC cross-validation values ranging from 0.92 to 1 (0.95 to 1 for ROC validation). Random models would have provided a value of 0.5. Lowest values are obtained for *Potentilla inclinata* and *Dracocephalum ruyschiana* ($D^2 = 0.6$ and 0.67). Note that these species, although on the Swiss red list, would not be considered as rare species according to Rabinowitz (1986) rarity types.

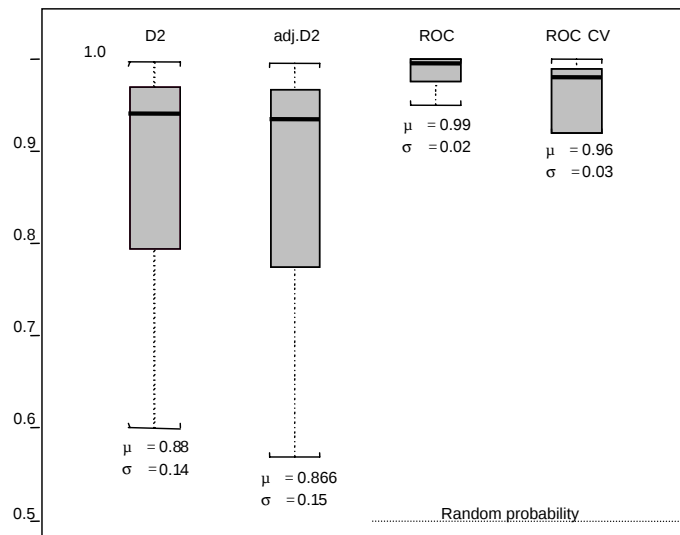


Fig 6 - GAM adequations and validations for the 12 endangered meadow species

boxplot distribution of D^2 and $adj.D^2$ are shown, as well as values of ROC validation and cross-validation. The mean and standard error was calculated for each measure.

Probability maps were filtered in ArcMap by multiplying probability maps layers with boolean layers of categories of land use, rock and soil on which the species never occurs (table 5).

Table 5 – Land use, rock and soil categories on which species were observed at least once

	land use (landuse25)	rocks and soils (gt-ch)	forest	bushes	areas with human impact	landuse25
<i>Potentilla inclinata</i>	1, 16	3, 5, 6, 7, 8, 19, 23, 26, 28	none	present	present	1 other
<i>Dracocephalum ruyschiana</i>	1, 12, 14	3, 6, 7, 17, 18, 19, 20, 22, 23, 25, 26, 28, 29	none	present	none	6 bush
<i>Dracocephalum austriacum</i>	1, 6, 7, 12	3, 6, 7, 19, 20, 21, 22	none	present	none	7 sparse forest
<i>Tulipa sylvestris</i>	1, 12	3, 6, 7, 25, 26, 28	none	present	present	9 swamp forest
<i>Dianthus gratianopolitanus</i>	1, 6, 12, 16	3, 5, 6, 7, 8, 9, 19, 21	present	present	present	10 orchard
<i>Androsace septentrionalis</i>	1, 14	3, 6, 7, 18, 26, 28, 29	none	present	present	12 rock
<i>Lathyrus sphaericus</i>	1, 6, 10, 12, 14, 16	3, 7, 18, 23, 26, 28	none	none	present	14 stone drain
<i>Valeriana celtica</i>	1, 12, 14	3, 7, 28	present	none	none	16 vineyard
<i>Knautia godetii</i>	1, 6, 9	3, 4, 6, 8, 19, 21	none	present	none	
<i>Carex fimbriata</i>	1, 12, 14	2, 26, 30	present	none	none	
<i>Eryngium alpinum</i>	1, 6, 12, 14	3, 7, 14, 17, 18, 19, 20, 21	none	present	none	
<i>Aquilegia alpina</i>	1, 6, 12, 14	3, 5, 6, 7, 8, 19, 23, 26, 28	none	present	none	

gt-ch	
2	glacier
3	sands and silts
4	silt and clay
5-6	gravels and sands
7	blocks (from fall)
8, 9, 14	rocks related to Marl
17	marly Schist
18	calcareous Phyllites
19	massive Limestone
20	sandy Limestone and Limestone
21	Marl and marly Schist
22	Dolomite
23	Granite
25	Quartzite
26	Gneiss with two micas
28	Gneiss
29	green Schists
30	Serpentine

Categories are summarized but full explanations are available on Swisstopo (landuse25) and OFS (gt-ch) websites. Forest, bushes and areas with human impact layers are derived from landuse25. These layers were calculated excluding an edge of 100 m. All categories without observed occurrence were excluded from the probability map.

The modelling and probability map filtration process result in twelve potential distribution maps (Annex 1). Two examples of potential distribution maps are illustrated here with *Dianthus gratianopolitanus* and *Lathyrus sphaericus* (fig 7). For each species, a global map covering the entire study area is shown with a detailed map covering an interesting area. To visually measure the pertinence of the map, observations used for calibration as well as other less precise observations not used for calibration are represented (precision from >25 meters to one kilometre). Since imprecise observations did not enter in the calibration process, they provide an independent control of the model quality. With both illustrated species, imprecise observations are found in high-predicted areas.

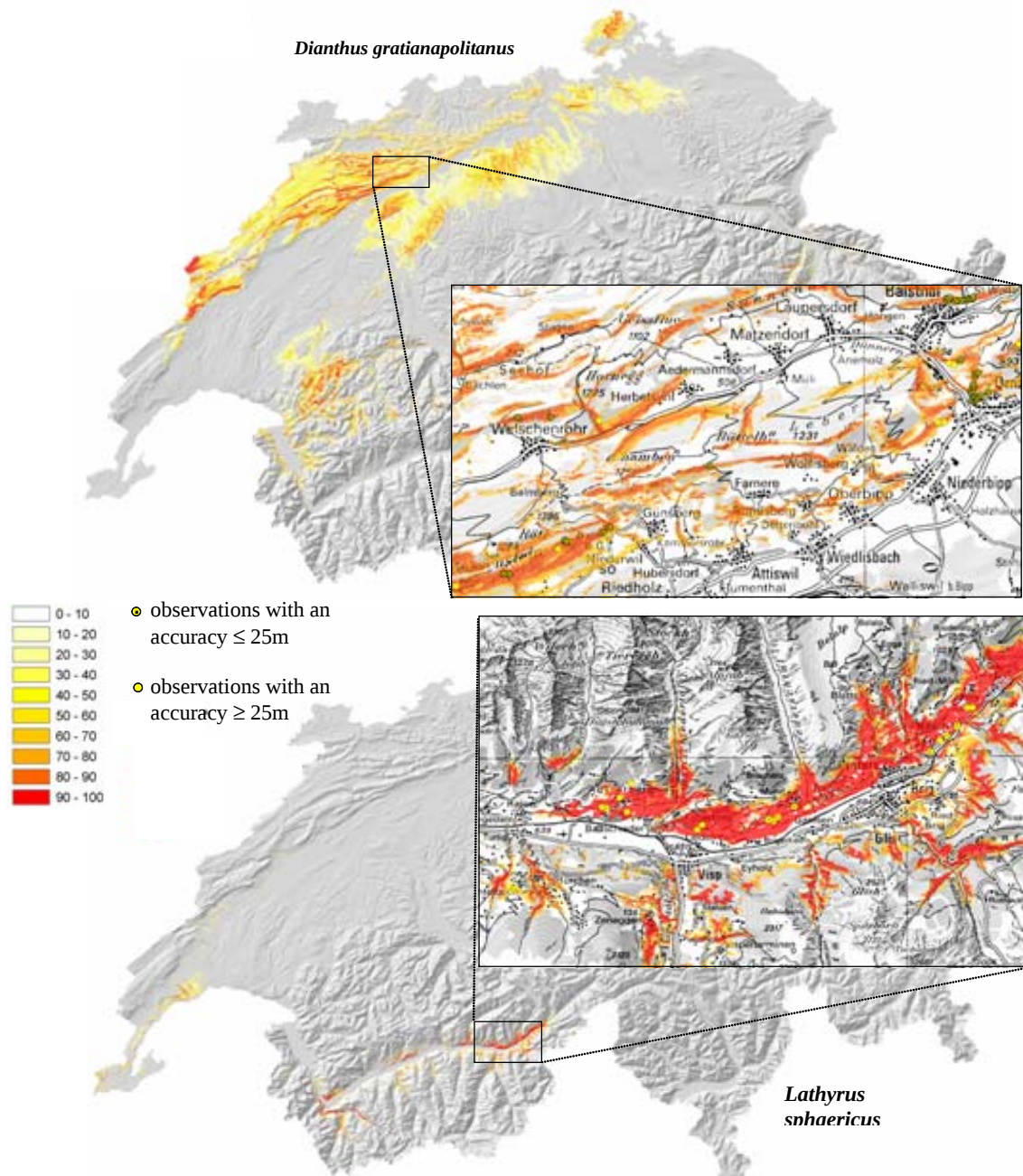


Fig. 7 - Potential distribution maps for *Dianthus gratianopolitanus* and *Lathyrus sphaericus*.
Global and detailed maps contain observations with an accuracy $\leq 25m$ which were used for model calibration. Observations with an accuracy $\geq 25m$ are also shown for qualitative control of model quality

4. Discussion

Generating absence is a particularly hazardous process with GAM modelling using presence-only data (Ferrier and Watson 1997, Zaniwski et al. 2002). The proposed method for generating pseudo-absence, using the multi-species presence data to generate absence for a focal species proved to be reliable and efficient in this study. This method only makes sense if presence data is available at a high precision since, in this case, it is unlikely that the occurrence of a non-focal species could have been noticed in a plot without the presence of the focal species being noticed too. The presences of other species can hence be considered as a reliable indication of absence for a focal species in the case of rare species.

The weighted absence method (ii) was chosen as the most efficient way of using these absences. Compared to the unweighted method (i) it provides a much higher model accuracy. The reason is probably that with a high prevalence of absences when fitting models, the relation between environmental data and species response is biased by the higher weight of absences. The accuracy level of method (iii), which does not recalculate presence weights and use a balanced number of absences and presences, was closer to method (ii) than method (i). It allows concluding that weight recalculation ensures a balanced influence of presences and absences during the calibration process.

Method (iv) provides the same model accuracy level than method (iii) which also uses the same number of presences and absences. This result indicates that the two latter methods for generating absences are valid. However, method (iv) shows a slightly different pattern than methods (i), (ii) and (iii). This is probably because in method (iv), absences are selected only in the ENFA *a priori* high-predicted areas. This process probably overestimates the influence of some predictors, in particular of those predictors explaining a low proportion of deviance.

In this study, the modelling of endangered meadows species provided high accuracy (mean $D^2 = 0.88$) and validation (mean ROC-CV = 0.96) values. One could argue that the overall model quality is biased by the few observations available. Although the number of presences was relatively low (29 to 90 with an average of 55.2 ± 17.6), a low correlation (0.34) was observed between this number and the explained deviance. Furthermore, the worst results are obtained with species that are not considered as rare according to Rabinowitz rarity criteria (Rabinowitz 1986). This suggests that possibilities of modelling are in relation with rarity features. Restricted habitat and important efforts for collecting observation compared to common species could finally lead to defining a more restricted and accurate ecological niche, which in turn could influence the model's accuracy positively. Guisan and Hofer (in review) have already observed this pattern in the case of endangered reptiles.

Indexes of precipitations and average temperature of July were shown to have the highest mean contributions in models of rare and endangered meadow plant species distributions. Precipitations are known to have a significant effect on species distributions (for examples see Austin & Meyers 1996, Austin & al. 1990 Austin & al. 1994, Franklin 1998), through effects on primary production (Prins and Loth 1988). The seasonal distribution of precipitation can strongly affect the severity of drought experienced by the plants (Lauenroth and Sala 92). Performing a principal component analysis on monthly precipitations appears to be convenient because it synthesizes the monthly precipitation variance into a few variables, which in turn simplifies the predictor selection. When predictors are included in a stepwise procedure, perturbations of the response data often lead to very different subsets of the predictors what Guisan et al. (2002) call a "high variance" process. The average temperature of July was retained as an explanatory predictor in eight out of twelve models. Temperature or related predictors have also been extensively used in plant distribution modelling (for example see Austin and Meyers 1996, Austin et al. 1994, Austin 1998, Leathwick 1998, Zaniwski et al. 2002, Austin et al. 1990, Guisan et al. 1998). All plants require a period with temperatures sufficient for growth (Prentice 1992). Low temperatures also affect the survival of plants through different cold tolerance mechanisms (Haxeltine and Prentice 1996). Many authors have emphasized the significance of minimum temperatures in determining species distributions (Sykes et al 1996, Haxeltine and Prentice 1996, Woodward and Rocherfort 1991). In this study, minimum temperatures were not available. The number of degree-days during growing season (deg300) was used as a surrogate predictor of minimum temperatures but did not prove to be the most explanatory predictor related to precipitation. In general, this study confirms the current knowledge about the importance of climatic effects on species distribution (for example see Prentice 1992).

Probability maps only provide the statistical probability of presence of a species in function of available information on the environment. It does not mean that every high-predicted plot will contain the predicted species. Many reasons can lead to a lack of presence in high-predicted areas: strong disturbances, successional dynamics or obstacles to dispersion for example. Among these factors, human influence may play an important role. Human influence was partly taken into account through the land use layer. Categories, on which species never grow were excluded from probability maps. However, some high-predicted areas in which human influence is not inventoried in the land use layer may not host the species.

Despite the potential limitations and bias of this type of models, average prediction success for rare meadow plant species was very high. Hence, they provide a valuable help to the management of rare and endangered species. Special emphasis is also to be given on advantages of modelling with high resolution data. In addition to the advantage of generating absences as mentioned above, probability maps at high resolution provide accurate information to species management teams. Plotted on a detailed map, probability of presence can be compared to known occurrence of the species. This comparison allows identifying priority areas where new populations might be found. It also provides technical help to make priority decisions in protecting areas or reintroducing. Species conservation has to make a trade-off between costs and efficiency. High-predicted areas should be limited in space to avoid time consuming and costly sampling survey. With almost every rare species modeled in this study, probability maps give relatively precise and restricted distributions and pinpoint interesting areas where no population has ever been observed (Fig 8. and Annex 1). A detailed look at these areas, in collaboration with conservation specialists, might form the basis of an efficient field survey.

The models built in this study should allow discovering new populations of the rare and endangered species modelled. There is a very little amount of presence data at high resolution. This lack could be avoided if volunteers collecting data for herbarium or museum databases would sample occurrences of species using a GPS. If these field investigations prove successful, new observations will be available. This data could be introduced in future predictive models and enhance model accuracy. Re-iterating the process until models cannot be improved by new observations would probably permit a considerable improvement in both model quality and population management. With such an iterative process, one could hope in a near future to model the distribution of endangered species with enough precision to provide a new efficient tool for plant conservation management.

5. Conclusions

In conclusion, the following points should be highlighted:

- i) Endangered and rare species presence-only data can be introduced in GAM modelling in an efficient and low time consuming way. GRASP or functions in R packages are particularly well designed for this issue. The model results provide high model accuracy (mean $D^2 = 0.88$) as well as high validation values (mean ROC-CV = 0.96).
- ii) Considering a focal species, working with high resolution (25 meters in this study) multi-species data allows to use the presences of other species as absences for the focal species. This method permits to avoid problems of computer-generated absences usually encountered with presence-only data. The weight of presence data can be recalculated to avoid overestimating the influence of absences in the calibration process.
- iii) Nominal data (for example land use and rock categories) can be taken into account separately from GAM modelling. Creating filter layers excluding categories on which occurrence of the species has never been observed appears to be the most convenient way of using nominal data.
- iv) The probability maps resulting from models provide plant species conservation with a useful tool for identifying priority survey, areas to be protected or sites for re-introduction experiments. These maps are particularly efficient when predicted areas are relatively limited in space, which is the case of rare and endangered meadow species in this study. It avoids time consuming and costly sampling survey.
- v) The framework used in this study can be part of an iterative process. Occurrences suggested by previous models can serve to fit a second generation of model with an enhanced models accuracy.

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7. References

- Akaike H. (1973) Maximum likelihood identification of gaussian autoregressive moving average models. *Biometrika* 60 (2). 255-265.
- Araújo M.B., Williams P.H. (2000) Selecting areas for species persistence using occurrence data. *Biological Conservation* 96, 331- 345.
- Austin M.P., Meyers J.A. (1996) Current approaches to modelling the environmental niche of eucalypts: Implication for management of forest biodiversity. *Forest Ecology and Management* 85 (1-3). 95-106.
- Austin M.P., Nicholls A.O., Doherty M.D., Meyers J.A. (1994) Determining species response functions to an environmental gradient by means of a β -function. *Journal of Vegetation Science* 5. 215–228.
- Austin M.P., Nicholls A.O., Margules C.R. (1990) Measurement of the realized qualitative niche – environmental niches of 5 eucalyptus species. *Ecological Monography* 60 (2). 161-177.
- Barry S.C., Welsh A.H. (2002). Generalized additive modelling and zero inflated count data. *Ecological Modelling* 157. 179-188.
- Bio A. M. F. (2000) Does vegetation suit our models? Data and model assumptions and the assessment of species distribution in space. In Faculty of Geographical Science, Utrecht University. Utrecht, pp. 207.
- Bio A. M. F., Alkemade R., Barendregt A. (1998) Determining alternative models for vegetation response analysis: a non parametric approach. *Journal of Vegetation Science* 9. 5-16.
- Brzeziecki B., Kienast F., Wildi O. (1993) A simulated map of the potential natural forest vegetation of Switzerland. *Journal of Vegetation Science* 4. 499–508.
- Delarze R., Gonseth Y., Galland P. (1998) Guide des milieux naturels de Suisse. Delachaux et Niesté S.A, Lausanne. Switzerland.
- Ferrier S., Watson G. (1997) An evaluation of the effectiveness of environmental surrogates and modeling techniques in predicting the distribution of biological diversity. NSW National Parks and Wildlife Service, New Zealand.
- Fiedler P. , Smith J.P. (2001) *CNPS Inventory*, 6th Edition, California Native Plant Society. Sacramento, CA .USA
- Fielding A.H., Bell J.F. (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. *Environment Conservation* 24. 38-49.
- Franklin J. (1998) Predicting the distribution of shrub species in southern California from climate and terrain-derived variables. *Journal of Vegetation Science* 9. 733–748.
- Franklin, J. (1995) Predictive vegetation mapping: geographic modeling of biospatial patterns in relation to environmental gradients. *Progress in Physical Geography* 19 (4). 474: 499.
- Guisan A., Edwards TC., Hastie T. (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* 157 (2-3). 89-100.
- Guisan A., Theurillat J.-P., Kienast F. (1998). Predicting the potential distribution of plant species in an alpine environment. *Journal of Vegetation Science* 9. 65-74.
- Guisan A., Weiss S.B., Weiss A.D. (1999) GLM versus CCA spatial modeling of plant species distribution. *Plant Ecology* 143 (1). 107-122
- Guisan A., Zimmermann, N.E. (2000) Predictive habitat distribution models in ecology. *Ecological Modelling* 135. 147–186.
- Guisan A., Edward T.C., Hastie T. (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. *Ecological Modelling* 157. 89-100.
- Harrell FE. (2001) *Regression Modeling Strategies*. Springer-Verlag Inc. New York. USA
- Hastie T., Tibshirani R. (1987) Generalized additive models: some applications. *Journal of American Statistical Association* 82. 371–386.
- Hausser J. (1995) Mammifères de la Suisse: Répartition, Biologie, Ecologie. Commission des Mémoires de l'Académie Suisse des Sciences Naturelles. Birkhäuser Verlag, Basel.
- Haxeltine A., Prentice I.C. (1996) Biome3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability, and competition among plant functional types. *Global Biogeochemistry* 10 (4). 693-709.
- Hirzel A.H., Hausser J., Chessel D., Perrin N. (2002) Ecological-niche factor analysis: How to compute habitat-suitability maps without absence data? *Ecology* 83. 2027-2036
- Hutchinson R.E. (1957) Concluding remarks. Cold Spring Harbor. Symp. Quantative Biology 22. 415-427.
- IUCN (1994) IUCN Red list Categories. IUCN Special Survival Commission. Gland, Switzerland
- Lauenroth W.K., Sala O.E (1992) Long-term forage production of North-American short grass steppe. *Ecological applications* 2 (4). 397-403.
- Leathwick J.R., Burns B.R., Clarkson B.D. (1998) Environmental correlates of tree alpha-diversity in New Zealand primary forests. *Ecography* 21 (3). 235-246.
- Lees B.G., Ritman K. (1991) Decision-tree and rule-induction approach to integration of remotely sensed and GIS data in mapping vegetation in disturbed or hilly environment. *Environmental Management* 15, 823–831.
- Lehmann A. (1998) GIS modeling of submerged macrophyte distribution using Generalized Additive Models. *Plant Ecology* 139 (1). 113-124.
- Lehmann A., Jaquet J.-M., Lachavanne J.-B. (1997) A GIS approach of aquatic plant spatial heterogeneity in relation to sediment and depth gradient, Lake Geneva, Switzerland. *Aquatic Botany* 58. 347-361.

- Lehmann A., McC Overton J., Leathwick J.R (2002). GRASP: generalized regression analysis and spatial prediction. *Ecological Modelling* 157. 189-207.
- Lischke H., Guisan A., Fischlin A., Bugmann H. (1998) Vegetation responses to climate change in the Alps- Modeling studies. In: Cebon, P., Dahinden, U., Davies, H., Imboden, D., Jaeger, C. (Eds.), A View from the Alps: Regional Perspectives on Climate Change. MIT Press, Boston, pp. 309–350.
- McCullagh P., Nelder J.A. (1989) Generalized Linear Models, second ed. Chapman and Hall, London. 1–17.
- Pearce J., Ferrier S. (2001) The practical value of modelling relative abundance of species for regional conservation planning: a case study. *Biological Conservation* 1. 33-43.
- Peters D., Thackway R. (1998) A new biogeographic regionalisation for Tasmania. Tasmanian Parks and Wildlife Service GIS Section. Report for the National Reserve System Program Component of the National Heritage Trust. Project NR002, Undertake biophysical regionalism for Tasmania.
- Prentice C., Cramer W., Harrison S.P., Leemans R., Monserud R.A., Solomon A.M. (1992) A global biome model based on plant physiology and dominance, soil properties and climate. *Journal of Biogeography* 19. 117-134.
- Prins H.H.T, Loth P.E (1988). Rainfall patterns as background to plant phenolgy in northern Tanzania. *Journal of Biogeography* 15. 451-463.
- Rabinowitz D., Cairns S., Dillon T. (1986) Seven forms of rarity and their frequency in the flora of the British Isles. p 182:204 in Soule M. Conservation Biology: The Science of scarcity and diversity. Sinauer Associates. Sunderland, MA. USA.
- Sykes M.T., Prentice I.C., Cramer W. (1996) A bioclimatic model for the potential distributions of north European tree species under present and future climates. *Journal of Biogeography* 23 (2). 203-233.
- Weisberg, S. (1980) Applied Linear Regression. John Wiley and Sons, New-York.
- Woodward F.I, Rochefort L. (1991) Sensitivity analysis of vegetation diversity to environmental change. *Global Ecology and Biogeography Letters* 1 (1). 7-23.
- Yee T. W., Mitchell N. D. (1991) Generalized Additive Models in Plant Ecology. *Journal of Vegetation Science* 2 (5). 587-602.
- Zaniewski E.A., Lehmann A., McC. Overton J. (2002) Predicting species spatial distributions using presence-only data: a case study of native New Zealand ferns. *Ecological Modelling* 157. 261-280.
- Zimmermann N.E., Kienast F. (1999) Predictive mapping of alpine grasslands in Switzerland: species versus community approach. *Journal of Vegetation Science* 10. 469–482.

Links to cited web sites:

GRASP web site - <http://www.cscf.ch/GRASP/>
 R mirror web site - <http://stat.ethz.ch/CRAN/>
 Swisstopo web site - <http://www.swisstopo.ch/>
 OFS web site - <http://www.statistik.admin.ch/eindex.htm>
 CRSF web site - <http://www.cjb.unige.ch/rsf/>

8. Annexes

Annexe 1 – Cartes de distributions potentielles

Dans les pages suivantes, les cartes de distributions potentielles pour *Potentilla inclinata*, *Dracocephalum ruyschiana*, *Dracocephalum austriacum*, *Tulipa sylvestris*, *Dianthus gratianopolitanus*, *Androsace septentrionalis*, *Lathyrus sphaericus*, *Valeriana celtica*, *Knautia godetii*, *Carex fimbriata*, *Eryngium alpinum* et *Aquilegia alpina* sont illustrées. Il s'agit, pour les douze espèces, de plantes menacées de prairies et pâturages.

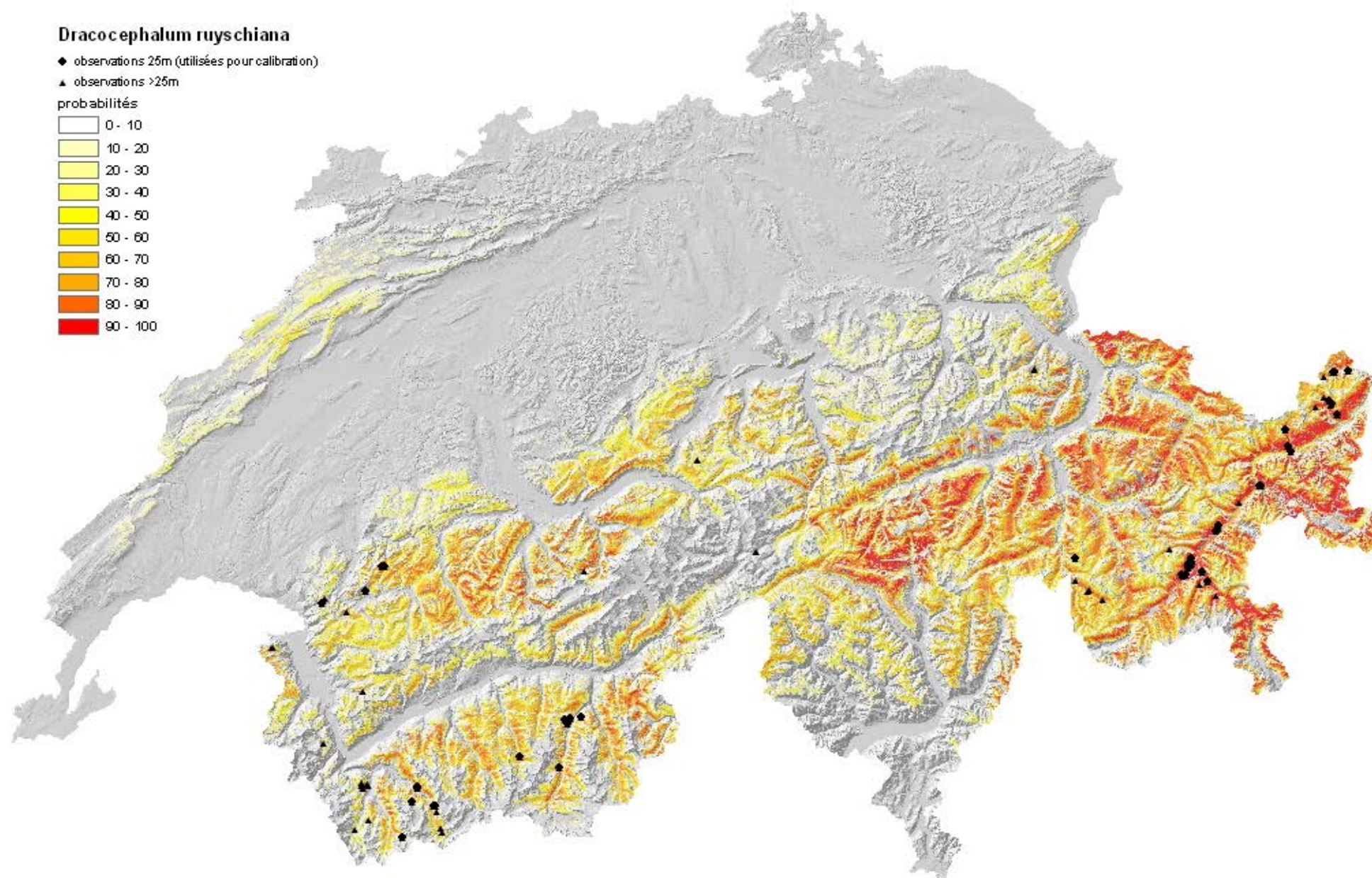
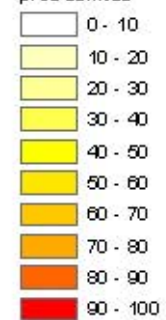
Le dégradé de couleur allant du jaune au rouge représente la probabilité d'accueillir l'espèce modélisée. Les surfaces en rouge indiquent que la probabilité d'occurrence de l'espèce est élevée. Les observations de présence (issue de la base de donnée du CRSF) sont indiquées. Une distinction est faite entre les observations précises (précision inférieur ou égale à 25 m) qui ont servi à calibrer le modèle et les observations moins précises (précision allant de 25 m à 1 Km). Comme ces dernières sont indépendantes du processus de calibration, elles permettent une vérification visuelle de la pertinence des modèles.

Dracocephalum ruyschiana

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

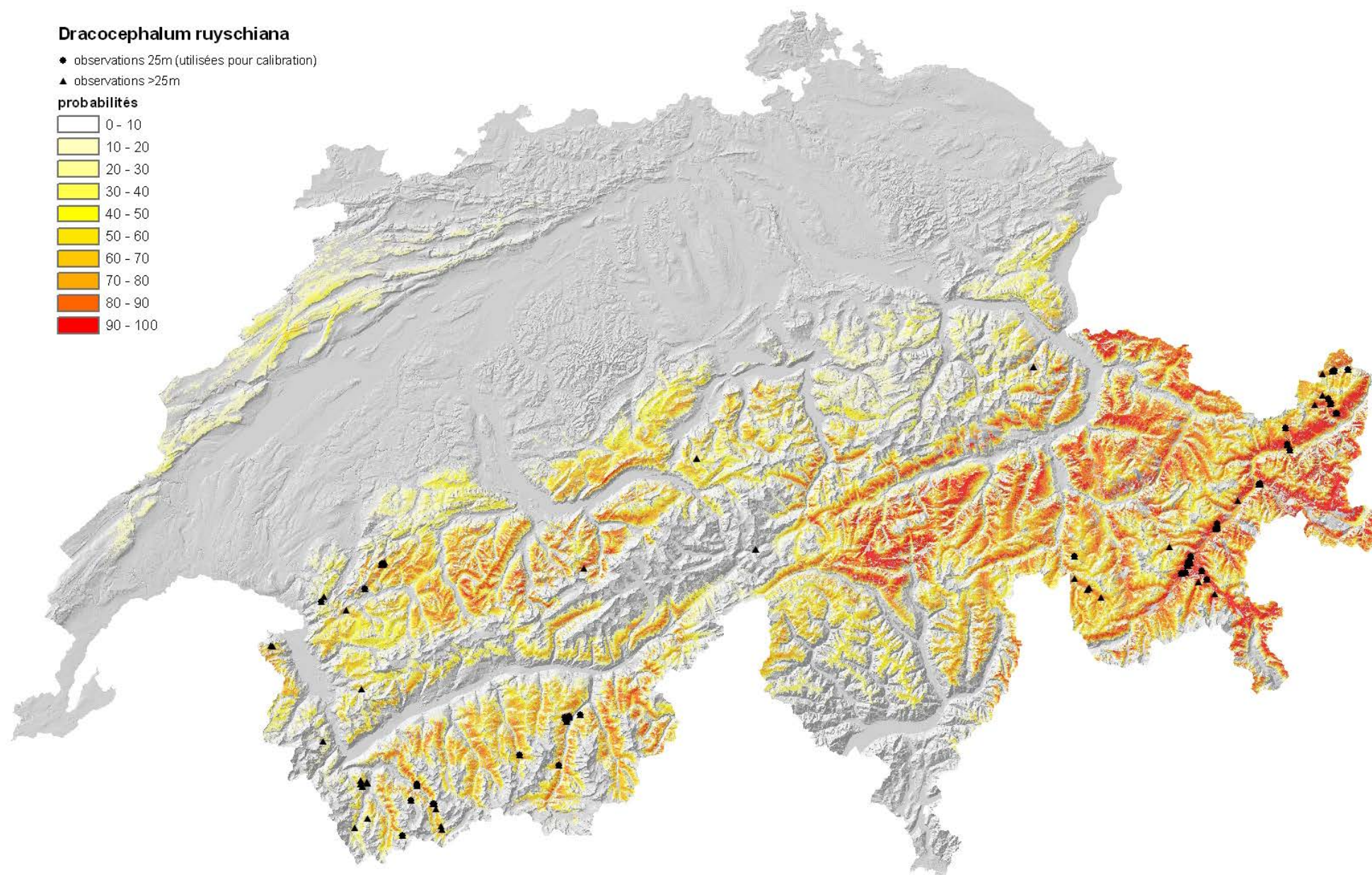
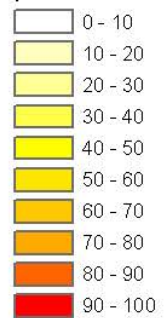


Dracocephalum ruyschiana

● observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

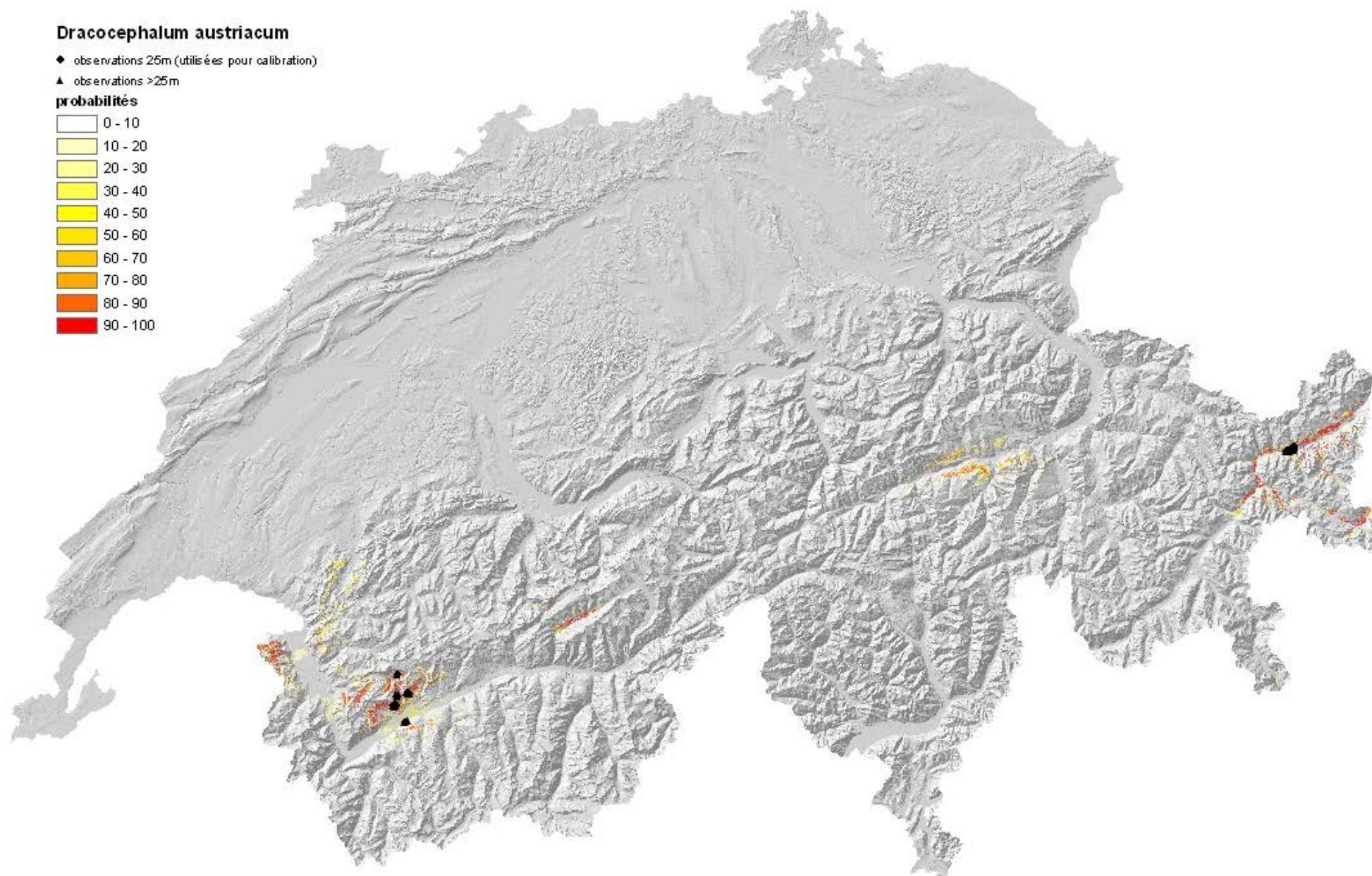
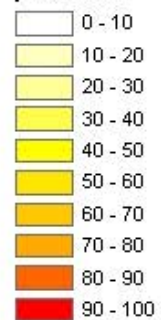


Dracocephalum austriacum

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

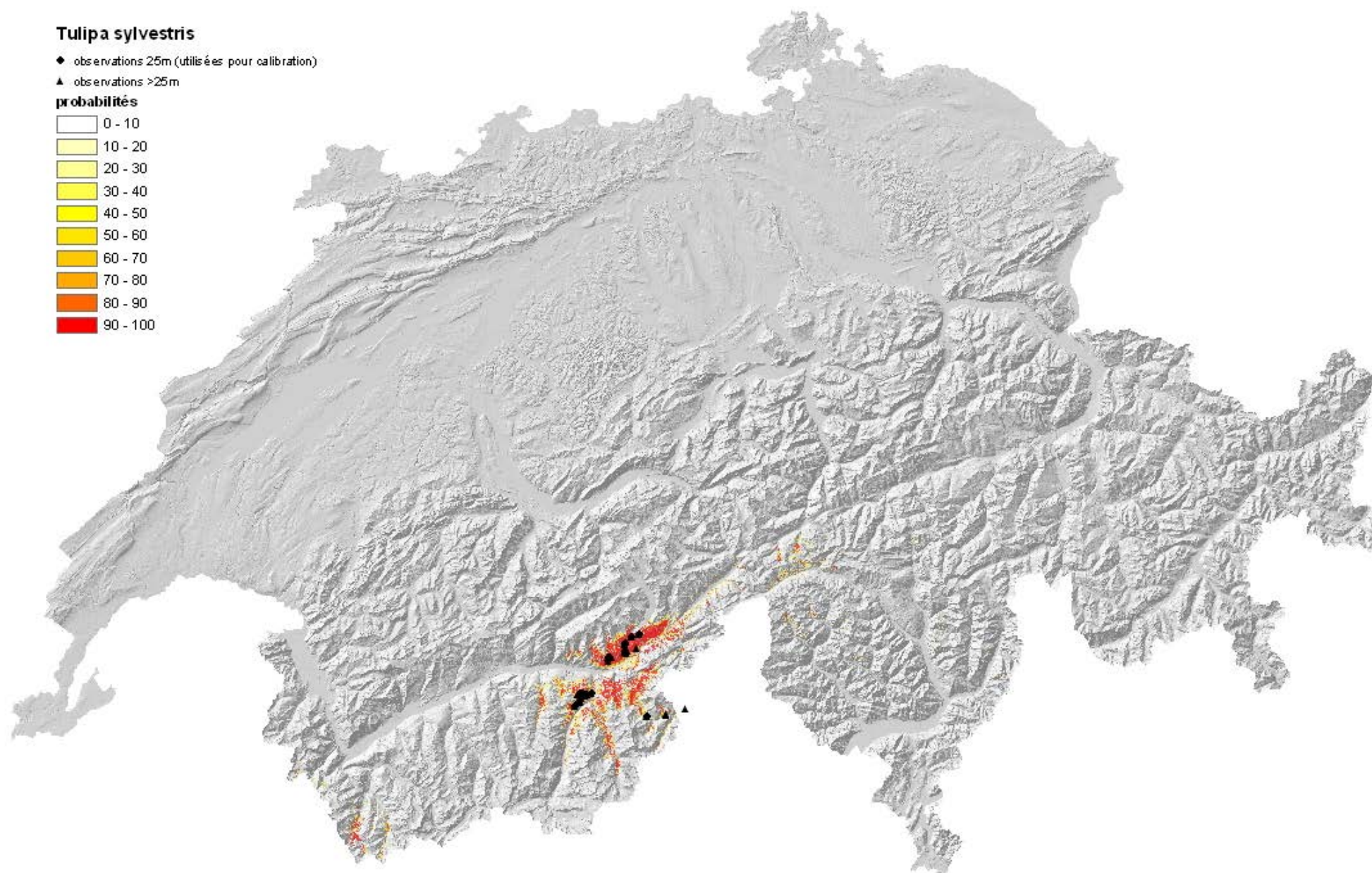
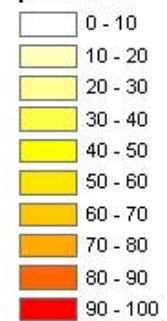


Tulipa sylvestris

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

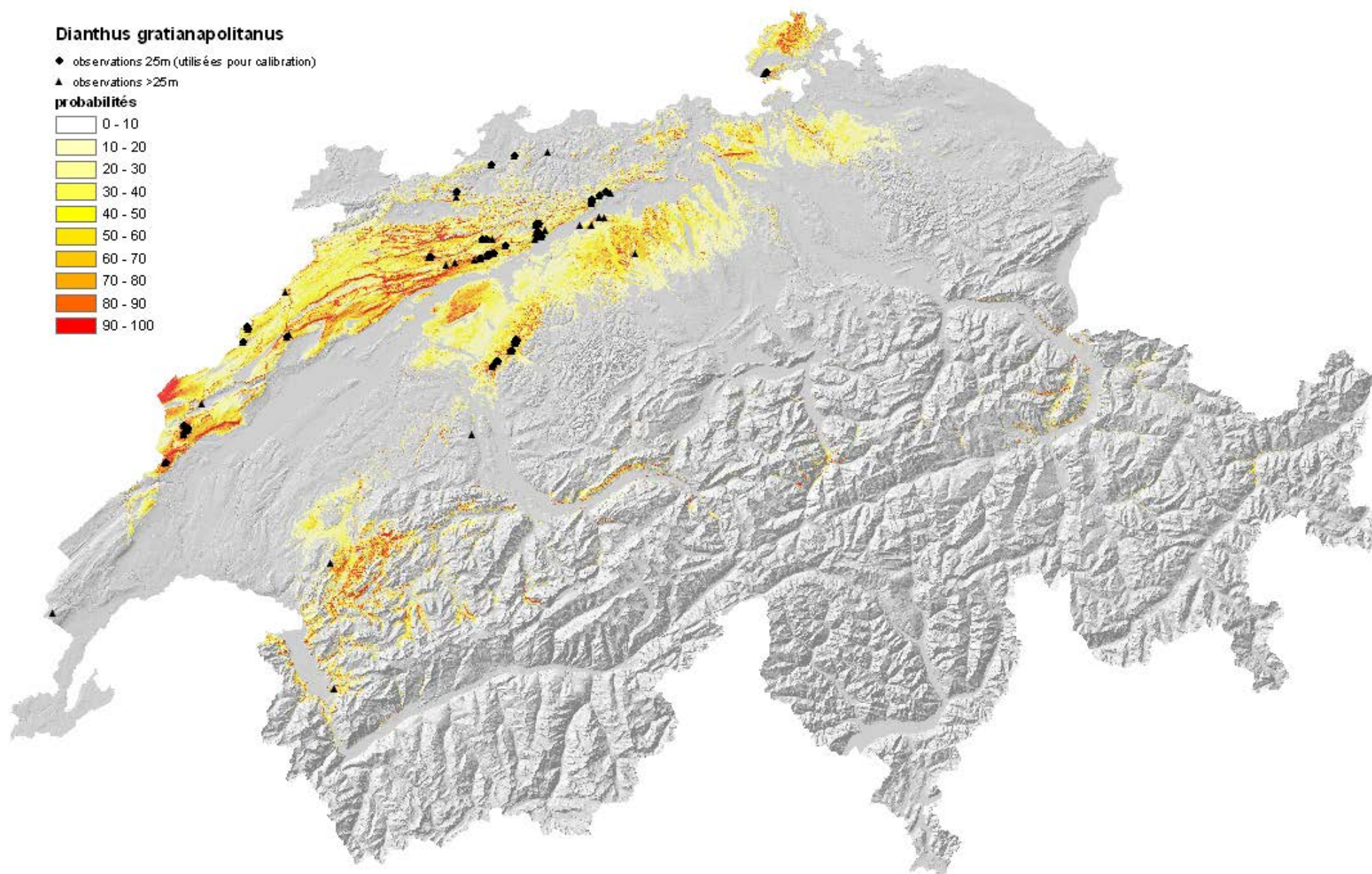
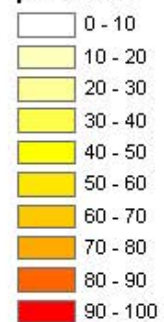


Dianthus gratianopolitanus

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

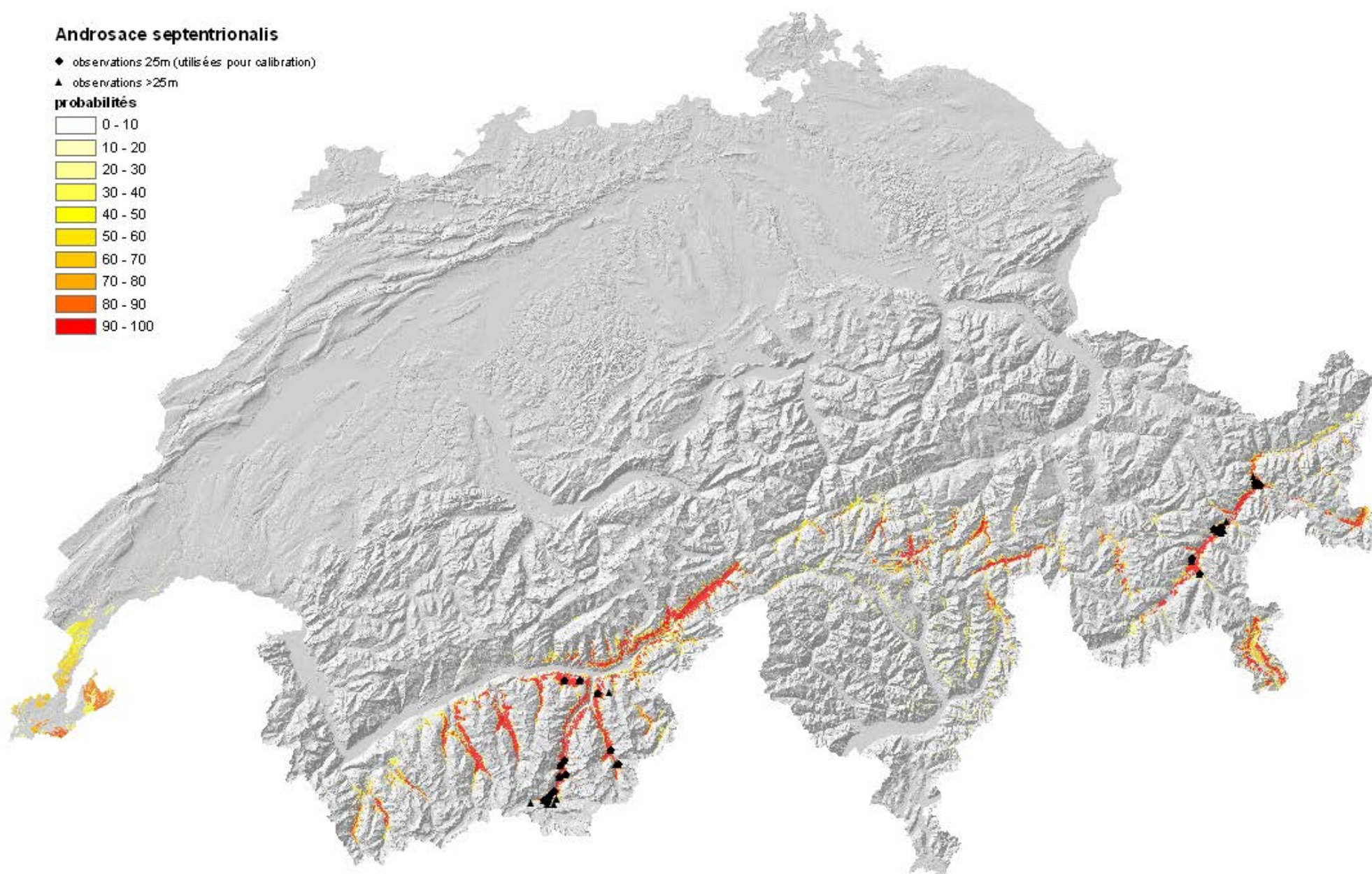
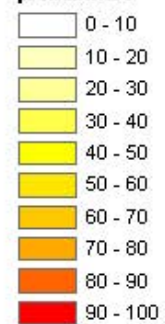


Androsace septentrionalis

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

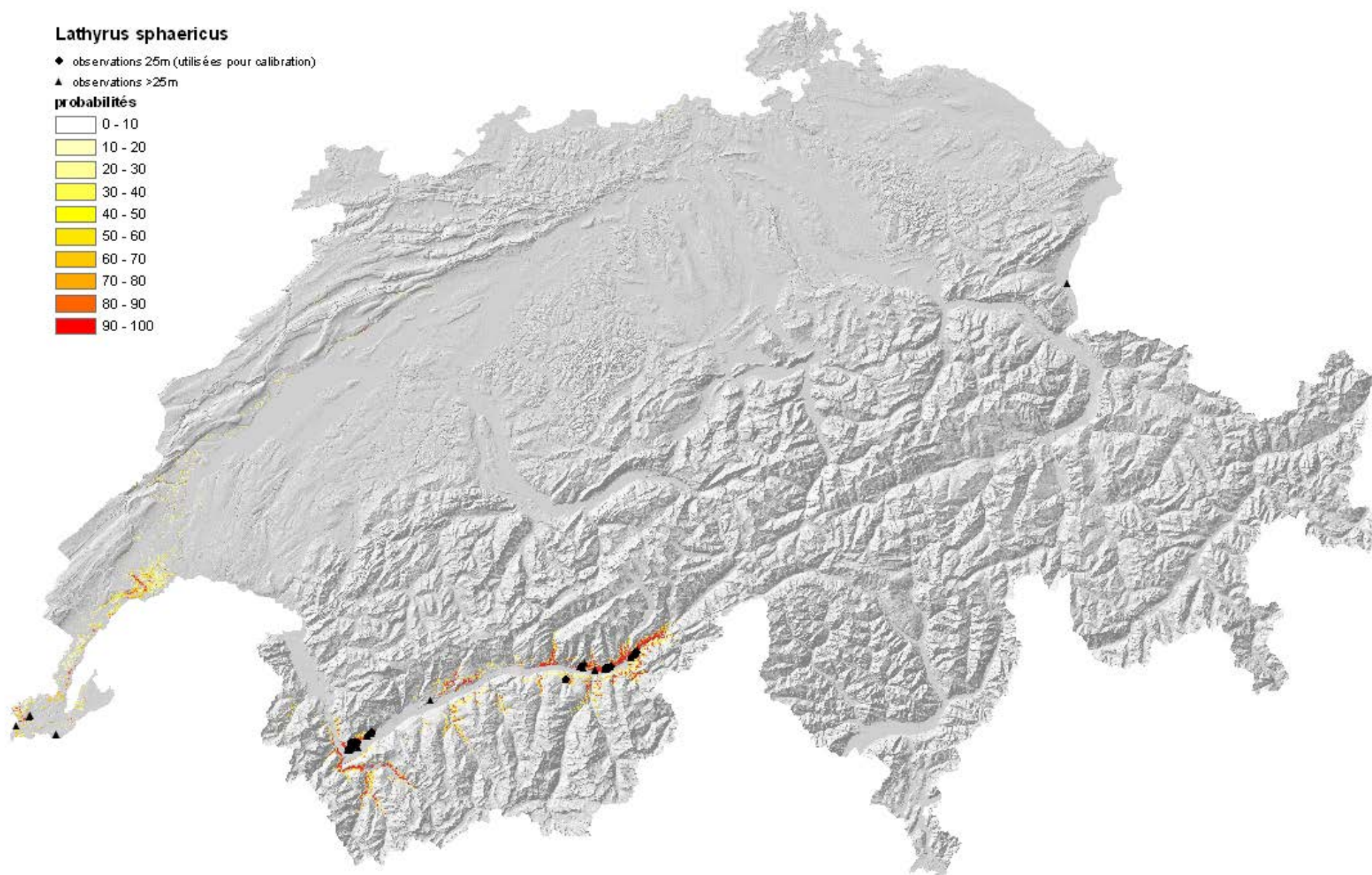
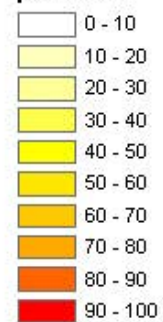


Lathyrus sphaericus

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

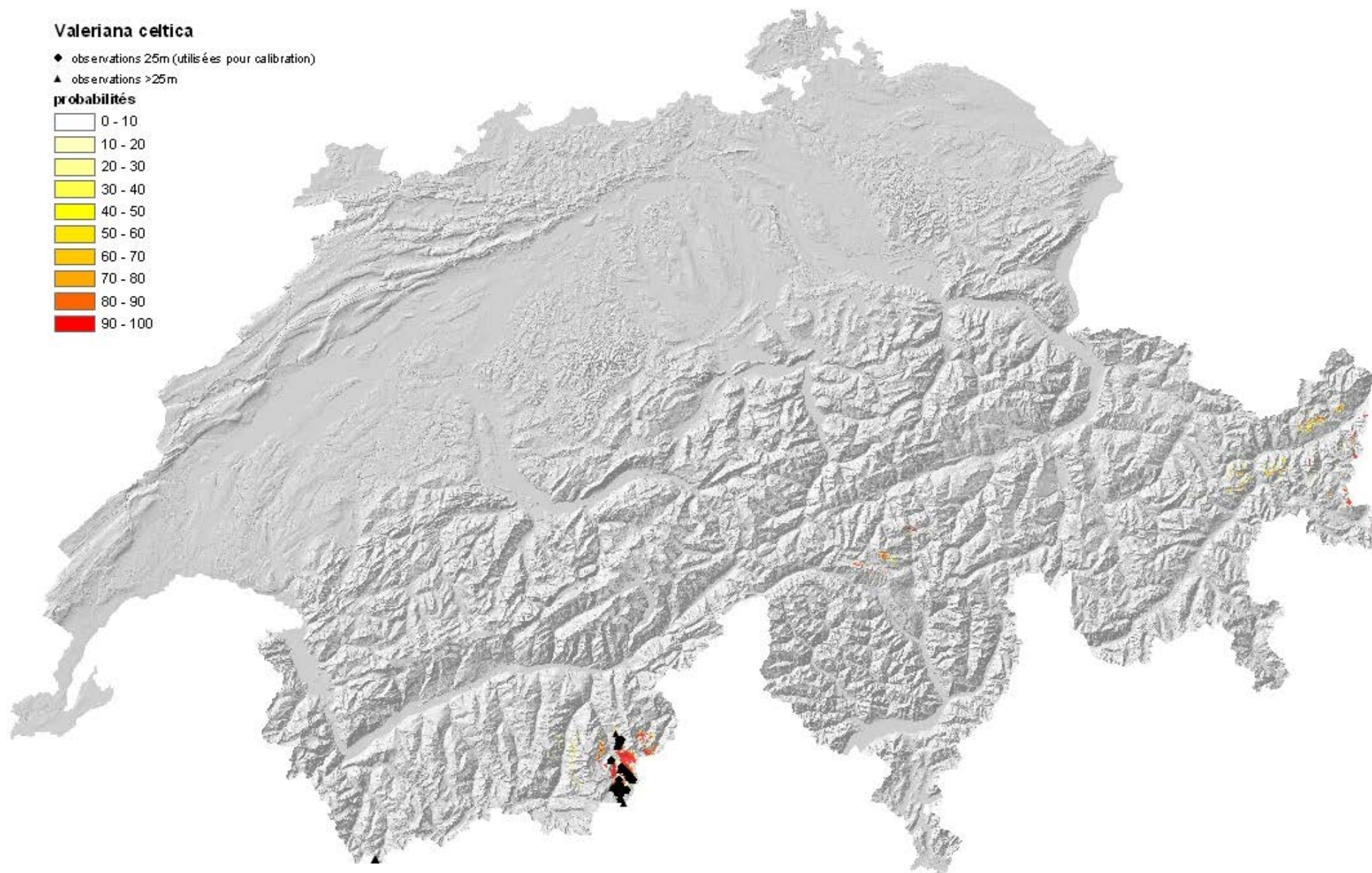
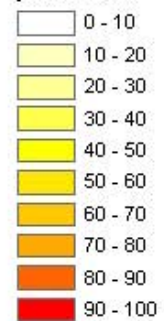


Valeriana celtica

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

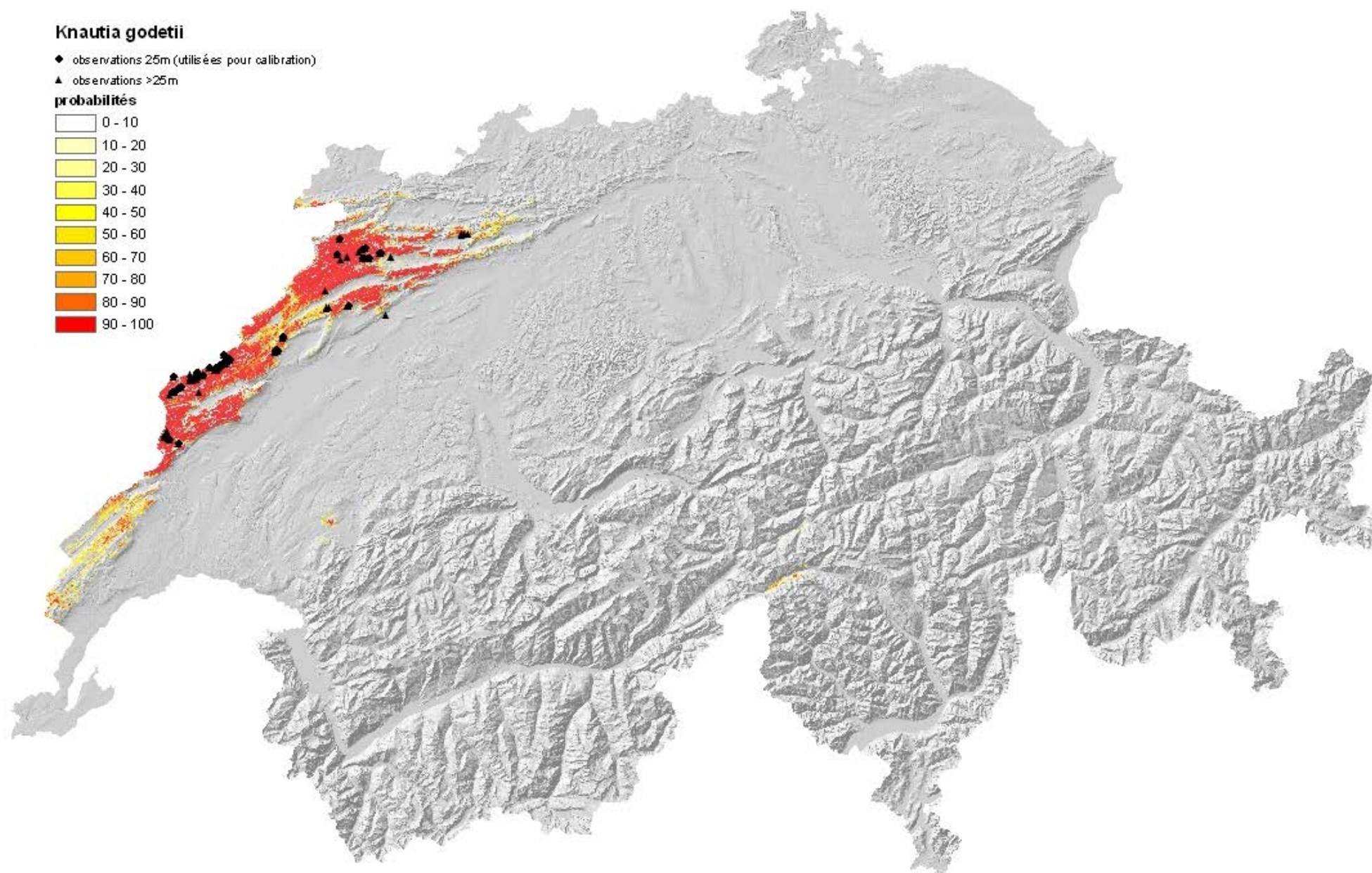
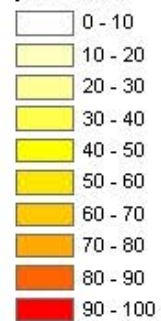


Knautia godetii

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

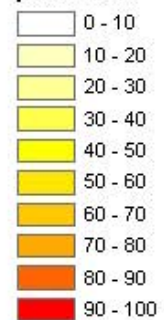


Carex fimbriata

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

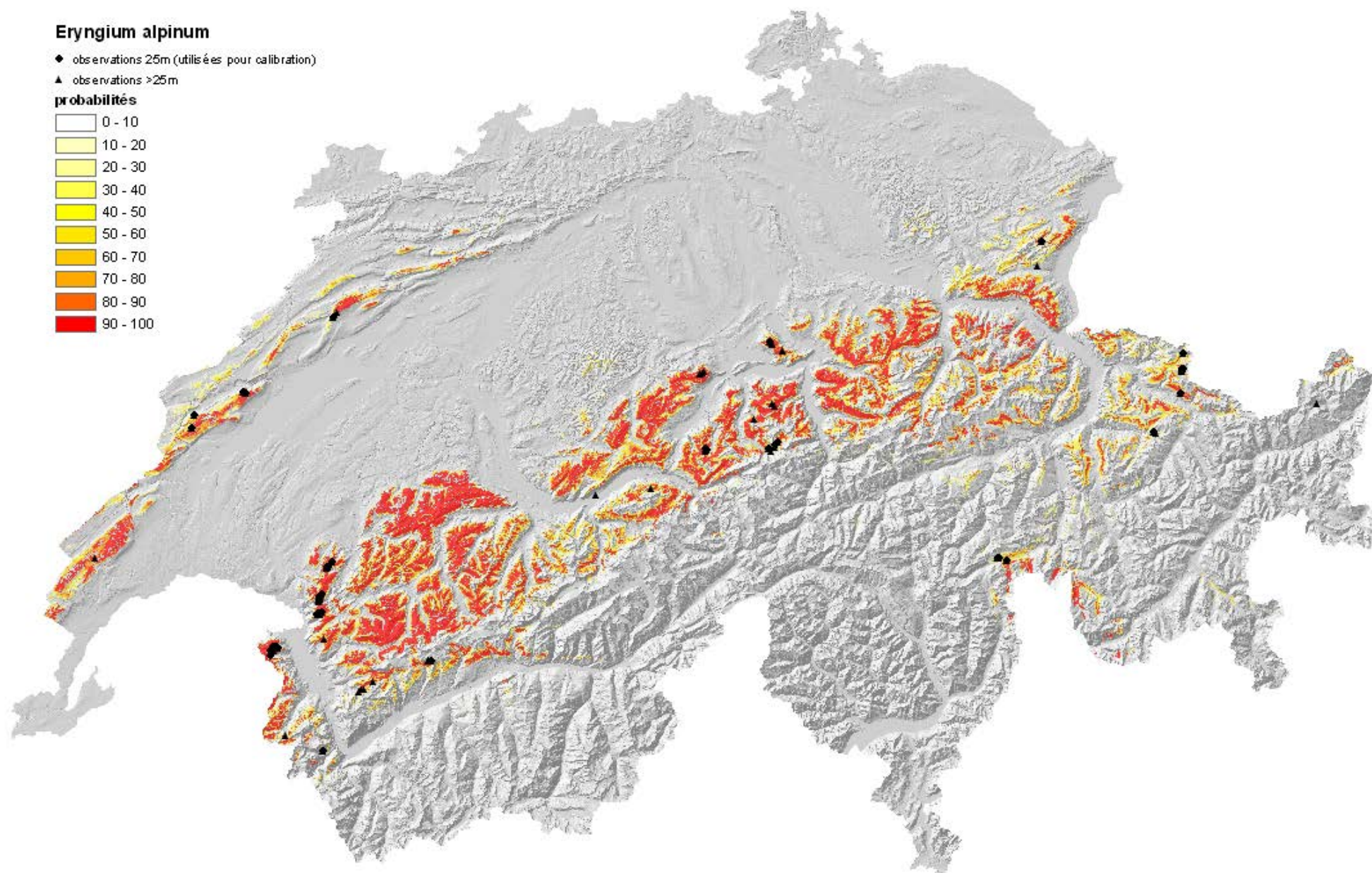
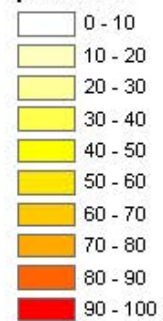


Eryngium alpinum

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités

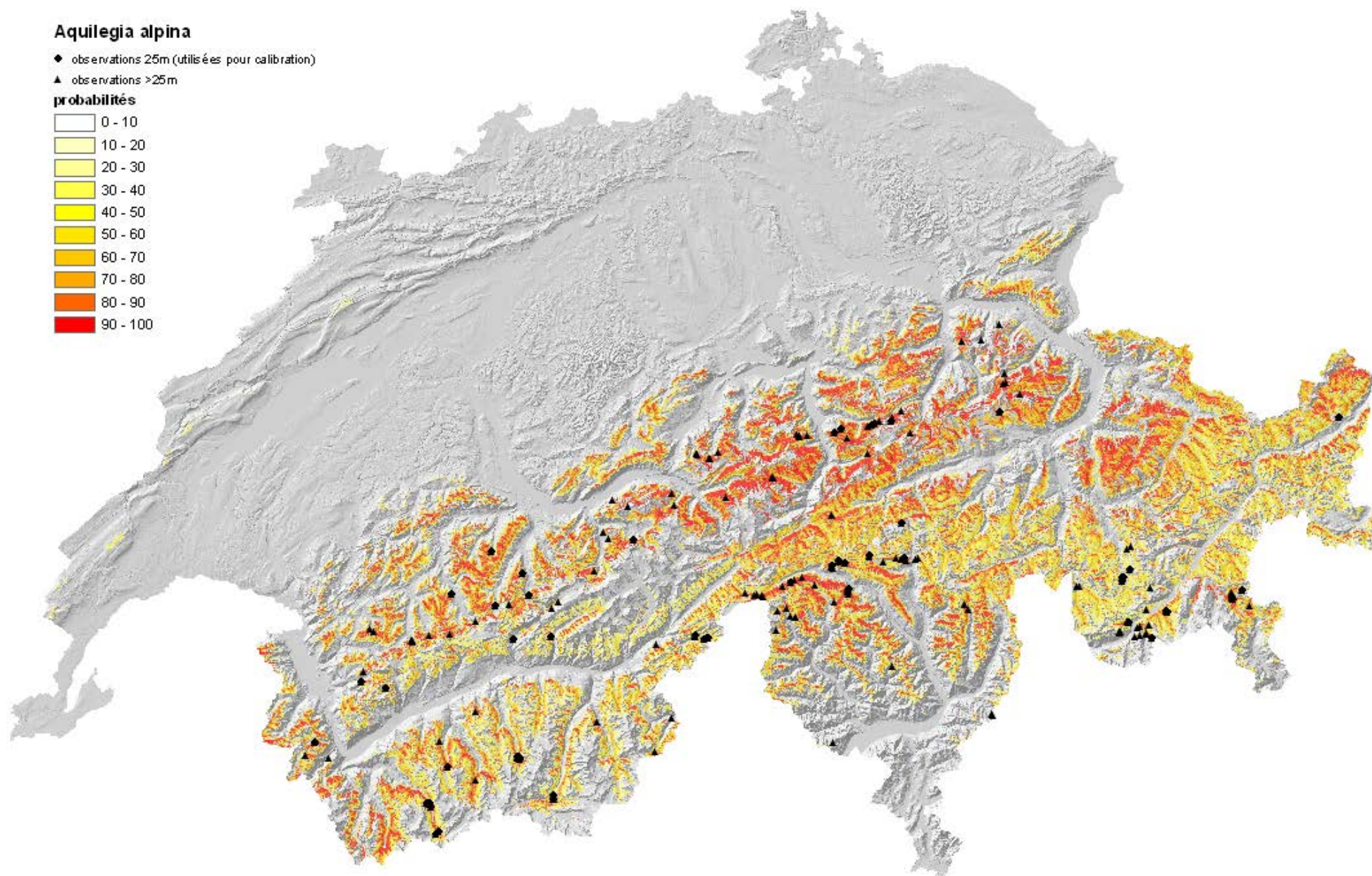
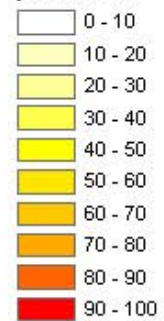


Aquilegia alpina

◆ observations 25m (utilisées pour calibration)

▲ observations >25m

probabilités



Annexe 2 – Description de 123 espèces de plantes menacées issues des « fiches pratiques pour la conservation »

Chaque espèce est décrite par son abondance moyenne au sein des populations, le milieu auquel elle est inféodée, sa distribution suisse et mondiale, son degré de menace UICN (IUCN 1994) et par le type de rareté qu'elle présente (Rabinowitz 86). L'abondance est mesurée par un indice de variant de 1 à 6 (1: <10 individus; 2: 11 à 25 individus; 3: 26 à 50 individus ; 4: 51 à 100 individus ; 5: 101 à 200 individus ; 6: > 201 individus). Deux mesures d'abondances sont illustrées : l'abondance moyenne et l'abondance maximale au sein des populations. Les types et numéros des milieux sont issus du « guide des milieux naturels de suisse » (Delarze et al 1998). L'expertise de la fréquence de ces milieux dans le paysage suisse a été effectuée par Pascal Vittoz sur la base de ses connaissances de terrain. L'étendue de la distribution des espèces en Suisse a été évaluée en dénombrant le nombre de quadrats de 15 x 15 km dans lesquels les espèces ont été observées. La distribution mondiale est résumée à partir des « fiches pratiques pour la conservation » (OFEFP/CPS/CRSF 1999). Les degrés de menace UICN (IUCN 1994) comprennent dans l'ordre croissant de degré de menace : LR (low risk), VU (vulnerable), EN (endangered), CR (critically endangered) , EX (extinct). Les mesures du type de rareté sont basées sur l'étendue géographique de l'aire de répartition de l'espèce, la rareté de l'habitat et l'abondance locale des individus au sein des population (A. répartition étendue / milieu commun / individus abondants localement, B. étendue / commun / dispersés, C. étendue / rare / abondants, D. étendue / rare / dispersés, E. restreinte / commun / abondants, F. restreinte / commun / dispersés G. restreinte / rare / abondants, H. restreinte / rare / dispersés. La première mesure du type de rareté tient compte de l'abondance moyenne alors que la deuxième de l'abondance maximale.

espèce	abondance moyenne	abondance maximale	no milieu	milieu	milieu (commun / restreint)	distrib CH (nb quadrats 15 x 15km)	distribution mondiale	menace UICN	type rareté (a=moy)	type rareté (a=max)
<i>Adenophora liliifolia</i> (L.) A. DC.	2.0	3	2.3.1	molinion	r	1	eurasiatique	EN	D	D
<i>Aldrovanda vesiculosa</i> L.	6.0	6	2.2.1	magnocariçaie	c	2	subméditerranéen-continentale en eurasié (surtout BL,Ukr,RO)	EN	A	A
<i>Allium angulosum</i> L.	4.1	6	2.3.1	molinion	r	24	subméditerranéen oriental(EC→sibérie)	VU	B	B
<i>Allium rotundum</i> L.	1.1	2	8.2.3.2(4.5.1)	panico-setarion	c	2	subméditerranéen oriental et pontique (F→Asie mineure)	CR	C	C
<i>Anagallis minima</i> (L.) E. H. L. Krause	2.5	6	2.5.1	nanocyperion	r	18	européen suocéanique-subméditerranéen (EC→Fennoscandie)	EN	B	B
<i>Anagallis tenella</i> (L.) L.	1.5	2	2.3.1	molinion	r	1	atlantique-ouest.méditerranéen (P,E,F,GB,IR,DK,D,GR)	CR	D	D
<i>Androsace brevis</i> (Hegetschw.) Ces.	2.3	6	4.3.4	elynion	c	1	endémique alpes insubrienne et orobiques(CH,It (100km2))	EN	G	E
<i>Androsace septentrionalis</i> L.	2.2	6	4.1.4(4.2.1.1)	sedo-scleranthion	c	9	eurasiatique et N.Am	VU	C	A
<i>Anemone sylvestris</i> L.	3.0	5	5.1.1	geranion sanguinei	c	2	eurasiatique continentale (F→toute E de l'est)	CR	A	C
<i>Anogramma leptophylla</i> (L.) Link	2.7	5	3.4.1.3	cystopteridion	r	6	subtropical-méditerranéen cosmopolite (Am.C,Af Sud, NZ)	EN	B	D
<i>Apium repens</i> (Jacq.) Lag.	1.0	1	7.1.1	agropyro-rumicion	r	1	ouest-méditerranéen atlantique (F,D,DK,A,CZ,H,PL,P,ES)	EX	D	D
<i>Aquilegia alpina</i> L.	2.6	6	4.3.3(5.4.5)	caricion ferruginae	c	69	endémique ouest alpin (F,I,CH,A)	LR	E	E
<i>Aquilegia einseleana</i> F. W. Schultz	2.7	3	4.3.1/3.3.1.4	seslerion	c	1	est-préalpin endémique (CH,It,Aut,De)	LR	E	G
<i>Artemisia nivalis</i> Braun-Blanq.	2.0	4	3.3.1.3	drabion hoppeanae	c	1	endémique alpes pénniennes(CH)	VU	G	G
<i>Asplenium aduterinum</i> Milde	1.6	5	3.4.2.3	asplenion serpentinii	r	8	euro-préalpin(CH,De,Aut,It,Fr,CZ,PL)	LR	D	D
<i>Asplenium billotii</i> F. W. Schultz	1.4	2	3.4.2.2	androsacion vandellii	c	1	atlantique ouestméditerranéen (toute europe occidentale)	CR	C	C
<i>Asplenium foreziense</i> Magnier	1.5	5	3.4.2.2	androsacion vandellii	c	2	endémique ouest-méditerranéen (Af.N,Es,Fr,It,CH)	CR	C	C
<i>Baldellia ranunculoides</i> (L.) Parl.	2.8	5	2.1.3	littorellion	r	4	ouest méditerranéen et atlantique(GB,Nor,Su,Fr,Tu,Gr)	CR	B	D
<i>Betula humilis</i> Schrank	1.0	1	5.3.7	salicion cinereae	c	1	eurasiatique continentale(PL,Ru,De,CH)	CR	C	C
<i>Blackstonia acuminata</i> (W. D. J. Koch & Ziz) Domin	3.4	6	2.5.1	nanocyperion	r	9	méditerranéen (Po,Es,Fr,Gr,CH,Af.N,De,Aut)	EN	B	B
<i>Botrychium lanceolatum</i> (S. G. Gmel.) Ångstr.	1.0	1	4.3.5	nardion	c	10	circumpolaire (europe,sibérie,Am.N)	CR	C	C
<i>Botrychium matricariifolium</i> (Döll) W. D. J. Koch	1.0	1	5.4.1(4.3.5)	calluno-genistion	r	5	circumpolaire	EX	D	D

Annexe 2 (suite)

espèce	abondance moyenne	abondance maximale	no milieu	milieu	milieu (commun / restreint)	distrib CH (nb quadrats 15 x 15km)	distribution mondiale	menace UICN	type rareté (a=moy)	type rareté (a=max)
<i>Botrychium simplex</i> E. Hitchc.	1.0	1	5.4.1(4.3.5)	calluno-geniston	r	1	circumpolaire	EX	D	D
<i>Botrychium virginianum</i> (L.) Sw.	1.1	2	6.1.3/6.6.2	alnion incanae	r	6	eurosibérien-Am.N	CR	D	D
<i>Bromus grossus</i> DC.	1.0	1	8.2.1.1	aphanion	r	20	médioeuropéen(Be,Lux,Fr,Aut,CZ,It)	CR	D	D
<i>Bufonia paniculata</i> Dubois	3.7	6	8.2.3.4	eragrostion	r	2	nord-ouest méditerranéen(Pyrénée,Fr,It,Gr)	EN	B	B
<i>Cardamine matthioli</i> Moretti	4.0	6	4.5.1	arrhenatherion	c	2	sud-est-européen(It,Ro,Aut,Sk,Si,Se,Gr)	CR	A	A
<i>Carex baldensis</i> L.	4.9	6	4.3.1(6.4.2)	seslerion	c	1	endémique centre et sud est des alpes(CH,It,Aut,De)	LR	E	E
<i>Carex chordorrhiza</i> L. f.	3.3	6	2.2.4	caricion lasiocarpae	r	12	circumpolaire	VU	B	B
<i>Carex fimbriata</i> Schkuhr	4.2	6	4.3.7	caricion fimbriatae	r	3	endémique graipennin(Fr,It,CH)	LR	F	F
<i>Carex hartmanii</i> Cajander	3.9	6	2.3.1	molinion	r	4	eurasiatique continental (Eur.C→fennoscandie,PL,Russie,sibérie)	VU	B	B
<i>Carex heleonastes</i> L. f.	2.4	4	2.2.4	caricion lasiocarpae	r	10	boréal circumpolaire	EN	D	D
<i>Carpesium cernuum</i> L.	1.9	4	5.1.5	aegopodion/alliarion	c	11	subméditerranéen pontique (Es,Fr,De,Aut,Sl,Ukr,Asie mineure)	CR	C	C
<i>Cypripedium calceolus</i> L.	2.1	6	6.2.1(6.4.1)	cephalanthero-fagenion	c	123	eurasiatique continental, subboréal (Es,Eur.C →sibérie,chine)	VU	C	A
<i>Cytisus decumbens</i> (Durande) Spach	1.8	4	5.1.1(4.2.4)	geranion sanguinei	c	3	médio sudest européen(balkans,pyrénées,toscane,abruzzo)	EN	C	C
<i>Cytisus emeriflorus</i> Rchb.	4.2	6	4.3.2	caricion firmae	r	1	endémique insubrien	VU	F	F
<i>Deschampsia littoralis</i> (Gaudin) Reut.	2.2	6	2.1.3	littorellion	r	10	endémique médio européen(De,Aut,CH)	EN	H	F
<i>Dianthus gratianopolitanus</i> Vill.	1.4	4	4.1.1(4.3.1)	alyso-sedion	c	19	endémique subatlantique hercynien	VU	C	C
<i>Diphysastrum complanatum</i> (L.) Holub	2.3	3	6.4.4	dicrano-pinion	r	15	médioeuropéen(GB,Fr,CH,De,Be,CZ,Ukr)	EN	D	D
<i>Diphysastrum tristachyum</i> (Pursh) Holub	2.0	4	5.4.1	calluno-geniston	r	1	circumboréal eurosibérien et américain	EN	D	D
<i>Draba ladina</i> Braun-Blanq.	1.6	3	3.4.1.2	potentillion	c	2	subméditerranéen subatlantique (De,Fennoscandie,PL,Russie)	EX	D	D
<i>Dracocephalum austriacum</i> L.	3.6	6	4.2.1.1(4.2.4)	stipo-poion	r	6	endémique suisse	EN	G	G
<i>Dracocephalum ruyschiana</i> L.	3.4	6	4.3.6/5.1.1(4.3.1)	festucion variae	c	45	sarmatique pontique europe centrale et orientale(CZ,A,SL,H,RO,UK)	VU	B	B
<i>Eriophorum gracile</i> Roth	2.7	6	2.2.4	caricion lasiocarpae	r	22	eurasiatique continental- massif montagneux (pyrénées→carpates)	LR	A	A
<i>Eryngium alpinum</i> L.	2.1	6	4.3.3(5.2.3)	caricion ferruginae	c	34	presque toute l'europe	EN	B	B
<i>Erythronium dens-canis</i> L.	4.0	4	6.3.4(6.3.3)	quecion pubescenti-petraeae	r	7	endémique ouest préalpin (alpes maritimes→alpes juliennes)	VU	G	E
<i>Euphrasia christii</i> Gremli	4.0	6	4.3.6	festucion variae	c	10	eurasiatique(→japon)	VU	B	D
<i>Falcaria vulgaris</i> Bernh.	2.8	6	4.6.1/8.2.1.2	convolvulo-agropyron	r	7	petite aire des alpes occidentales(CH, It)	LR	E	E
<i>Gagea pratensis</i> (Pers.) Dumort.	1.8	6	8.2.3.2	panico-setarion	c	5	méditerranéen moyen oriental(F→asie centrale)	EN	B	B
<i>Galium triflorum</i> Michx.	3.1	6	6.6.2	vaccinio-piceion	c	3	est-sudest-européen (Es,It,Fr,sud.scandinavie)	EN	C	A
<i>Gentiana prostrata</i> Haenke	2.5	6	4.3.4	elynion	c	3	circumboréal	VU	A	A
<i>Gladiolus imbricatus</i> L.	1.9	5	2.3.1(4.2.4)	molinion	r	3	aire mondiale morcelée	EN	A	A
<i>Gladiolus italicus</i> Mill.	1.0	1	8.2.1.2	caucalidon	r	1	est européen sub continental(→iran)	EN	D	D
<i>Gladiolus palustris</i> Gaudin	2.7	6	2.3.1	molinion	r	20	méditerranéen et sudouest-asiatique	CR	D	D
<i>Gratiola officinalis</i> L.	2.9	6	2.3.1(2.1.3/7.1.1)	molinion	r	15	préalpin subméditerranéen continental(Fr→Ukr)	EN	B	B
							eurasiatique (toutes plaines alluviales europe→PL)	EN	B	B

Annexe 2 (suite)

espèce	abondance moyenne	abondance maximale	no milieu	milieu	milieu (commun / restreint)	distrib CH (nb quadrats 15 x 15km)	distribution mondiale	menace UICN	type rareté (a=moy)	type rareté (a=max)
Hammarbya paludosa (L.) Kuntze	1.1	2	2.2.4	caricion lasiocarpae	r	3	circumboréal eurosibérien nord américain	EN	D	D
Helianthemum salicifolium (L.) Mill.	2.8	4	4.1.3	sedo-veronicion	r	1	méditerranéen	EN	B	D
Iberis saxatilis L.	2.0	5	4.1.2	drabo-seslerion	c	2	médio-sud européen	VU	C	C
Inula britannica L.	2.6	6	7.1.1	agropyro-rumicion	r	7	eurasiatique continental et subméditerranéen (Es→extrême orient)	EN	B	B
Inula helvetica Weber	4.4	6	5.1.3	convolvulion	c	18	endémique ouestsubméditerranéenne (Fr,It,CH)	VU	E	E
Inula spiraeifolia L.	2.5	6	4.2.1.2(4.2.2/6.3.4)	cirsion-brachypodion	r	3	subméditerranéen (Fr→HG)	VU	B	B
Isoëtes lacustris L.	4.4	6	2.1.3	littorellion	r	3	médioeuropéen boréal (Groenland→PL)	VU	B	B
Isopyrum thalictroides L.	4.1	6	6.3.3	carpinion betuli	c	4	endémique européen (2 aires de répartition Fr,Es / vénétie→RU)	EN	A	A
Juncus stygius L.	2.2	4	2.2.4	caricion lasiocarpae	r	1	subarctique circumboréal	EN	D	D
Knautia godetii Reut.	3.0	6	4.5.2(4.2.4)	polygono-trisetion	c	9	endémique subatlantique médioeuropéen(Fr,jura suisse)	LR	E	E
Lathyrus bauhini P. A. Genty	2.0	2	4.5.2	polygono-trisetion	c	1	subméditerranéen sudest européen (pyrénées→Ukr,Syrie)	EN	C	C
Lathyrus sphaericus Retz.	2.2	6	4.6.1(4.2/8.2.3)	convolvulo-agropyron	r	5	méditerranéen subméditerranéen(Es,balkans→Su)	VU	D	B
Leucjum aestivum L.	6.0	6	6.1.2	salicion albae	r	2	sudeuropéen-ouest-asiatique(Ir,DK,CZ,Tu,Caucase)	LR	B	B
Linaria alpina subsp. petraea (Jord.) Rouy	2.6	6	3.3.1.5	stipion calamagrostis	c	6	endémique jurassien (Fr,CH)	VU	E	E
Lindernia procumbens (Krock.) Philcox	3.0	3	2.5.1	nanocyperion	r	1	eurasiatique subocéanique-subméditerranéen(→extrême orient)	EX	B	D
Liparis loeselii (L.) Rich.	1.6	5	2.2.3(2.2.4)	caricion davallianae	r	50	circumpolaire (aussi Af.N)	VU	D	D
Littorella uniflora (L.) Asch.	3.3	6	2.1.3	littorellion	r	14	boréal subatlantique	EN	B	B
Lomatogonium carinthiacum (Wulfen) Rchb.	2.9	5	2.2.5	caricion bicolori-atrofuscae	r	5	eurasiatique + Amérique subarctique	VU	B	D
Lysimachia thyrsoflora L.	3.2	6	2.2.1.1	magnocaricion	c	23	circumpolaire (aussi Af.N)	VU	A	A
Marsilea quadrifolia L.	4.5	6	2.1.3(2.5.1)	littorellion	r	2	eurasiatique subméditerranéen subcontinental(→sibérie)	EW	B	B
Melampyrum nemorosum L.	2.0	6	5.1.2(5.1.1/6.3.3)	trifolion medii	c	3	eurosibérien	EN	C	A
Minuartia cherlerioides subsp. rionii (Gremli) Friedrich	2.1	4	3.4.2.2	androsacion vandellii	c	9	endémique alpes centrales (CH,It (mont rose))	LR	G	G
Myosotis rehsteineri Wartm.	3.2	6	2.1.3	littorellion	r	5	préalpin néoendémique(Aut,CH,De)	EN	F	F
Nigella arvensis L.	2.8	6	8.2.1.2	caucalidon	r	9	est-méditerranéen(pyrénées→Asie mineure)	EN	B	B
Notholaena marantae (L.) Desv.	1.8	4	3.4.2.3	asplenion serpentini	r	1	méditerranéen-sudouestasiatique(Es→Ethiopie,Chine)	CR	D	D
Nuphar pumila (Timm) DC.	3.4	6	1.1.4	nymphaeion	r	5	eurosibérien boréal (Fennoscandie→sibérie orientale)	EN	B	B
Orchis laxiflora Lam.	1.5	2	2.2.3/2.3.2	caricion davallianae	r	2	méditerranéen-atlantique (Po→sud Russie, Iran, Af.N)	EX	D	D
Orchis papilionacea L.	2.0	3	4.2.4	mesobromion	c	1	méditerranéen + caucase	EX	C	C
Orchis provincialis DC.	1.3	4	4.2.3(6.3.5/6.3.5)	diplachnion	r	3	méditerranéen (Po,Tu,Af.N)	CR	D	D
Orchis spitzelii W. D. J. Koch	1.0	1	5.4.4	juniperion nanae	c	1	méditerranéen	CR	C	C
Phyteuma humile Gaudin	1.8	5	3.4.2.2	androsacion vandellii	c	3	endémique pennin (mont rose)	LR	G	G
Pilularia globulifera L.	3.5	5	2.1.3(2.5.1)	littorellion	r	1	subatlantique (toute Europe→PL)	EX	B	D
Pinguicula grandiflora Lam. s.str.	3.0	6	2.2.3	caricion davallianae	r	1	atlantique ouestméditerranéen(Es,Fr,CH,Ir)	EN	B	B

Annexe 2 (suite)

espèce	abondance moyenne	abondance maximale	no milieu	milieu	milieu (commun / restreint)	distrib CH (nb quadrats 15 x 15km)	distribution mondiale	menace UICN	type rareté (a=moy)	type rareté (a=max)
Potentilla alpicola Fauc.	2.0	3	4.2.1.1(4.1.4/4.1.3)	stipo-poion	r	9	alpes occidentales et centrales (Piémont, valais, Tyrol sud)	CR	H	H
Potentilla grammopetala Moretti	3.2	6	3.4.2.2	androsacion vandellii	c	6	endémique ouest-alpin(It,CH)	LR	E	E
Potentilla inclinata Vill.	2.7	6	4.1.4(4.2.4/4.5.1)	sedo-scleranthion	c	20	eurasiatique continental(Es→sibérie occidentale)	EN	A	A
Primula daonensis (Leyb.) Leyb.	2.8	6	4.3.7	caricion curvulae	c	2	endémique rhético-alpine (CH,Aut,It (tyrol))	VU	E	E
Pulmonaria helvetica Bolliger	2.1	3	6.1.4/6.2.3	fraxinion	c	5	endémique méditerranéen (CH)	VU	G	G
Ranunculus gramineus L.	2.3	6	4.2.1.1(4.1.3)	stipo-poion	r	4	méditerranéen occidental(Af.N,Es,Po,It,CH)	EN	D	B
Ranunculus pygmaeus Wahlenb.	3.8	6	4.2.2	xerobromion	r	2	arctico-alpin circumpolaire	VU	B	B
Ranunculus rionii Lager	1.7	3	1.1.2	potamion	r	2	cosmopolite hémisphère nord	CR	D	D
Sagina nodosa (L.) Fenzl	3.3	6	2.5.1	nanocyperion	r	6	circumpolaire eurasiatique subocéanique	VU	B	B
Salix myrtilloides L.	2.5	3	5.3.7	salicion cinereae	c	1	eurosibérien	CR	A	C
Saponaria lutea L.	3.5	5	4.3.1	seslerion	c	2	grai-pénin-lépointien (CH (tessin),It)	VU	E	G
Saxifraga diapensioides Bellardi	2.1	6	3.4.1.2	potentillon	c	4	endémique centre alpes occidentales (alpes maritimes→sudouest CH)	LR	G	E
Saxifraga hirculus L.	4.0	6	2.2.4	caricion lasiocarpae	r	1	circumpolaire boréo-arctique	EN	B	B
Scorzonera laciniata L. s.str.	3.0	6	4.6.1	convolvulo-agropyron	r	10	subméditerranéen sarmate(Maroc,Balkan,CZ,Ho,De)	LR	B	B
Sedum rubens L.	3.4	6	4.1.3(7.1)	sedo-veronicion	r	7	méditerranéen (canaries Af.N,Po,Be,Fr,De→Iran)	VU	B	B
Senecio halleri Dandy	3.0	6	4.3.7	caricion curvulae	c	11	endémique grai pennin(Fr,It,CH)	LR	E	E
Senecio incanus subsp. insubricus (Chenevard) Braun-Blanq.	2.9	5	4.3.6	festucion variaae	c	4	central-sudalpin endémique (CH,It)	LR	E	G
Sisymbrium supinum L.	1.3	3	2.5.2(2.1.3)	bidention	c	2	subatlantique-nordouesteuropéen-baltique(nord-ouest Fr,Bénélux,pays Baltes)	CR	C	C
Spiranthes aestivalis (Poir.) Rich.	2.3	6	2.2.3	caricion davallianae	r	36	ouestméditerranéen et atlantique(Fr→Balkan,CZ)	LR	D	B
Teucrium scordium L.	4.5	6	7.1.1(2.2.1.1)	agropyro-rumicion	r	14	européen(Es,asie occidentale,Af.N)	EN	B	B
Thlaspi lerescheanum (Burnat) A. W. Hill	1.8	6	3.3.2.2	androsacion alpinae	c	7	endémique alpes occidentales(Fr,It,CH)	LR	G	E
Trapa natans L.	4.0	6	1.1.4	nymphaeion	r	3	eurasiatique(→Japon)	EW	B	B
Trifolium saxatile All.	2.5	6	3.2.1.1(3.2.2.1)	epilobion fleischeri	c	5	endémique alpes centrales(Fr,CH,It,Aut)	VU	E	E
Trochiscanthes nodiflora (Vill.) W. D. J. Koch	2.3	6	6.2.1	cephalanthero-fagenion	c	5	ouest-alpin et apennin(Fr,It,CH)	VU	G	E
Tulipa sylvestris subsp. australis (Link) Pamp.	4.8	6	4.2.1.1/4.5.2	stipo-poion	r	5	ouest méditerranéen(Pyrénées→proche orient,Af.N)	VU	B	B
Typha minima Hoppe	2.3	6	2.2.3	caricion davallianae	r	20	eurasiatique préalpin méridional continentale très morcelée	CR	D	B
Typha shuttleworthii W. D. J. Koch & Sond.	2.5	6	2.1.2.1(2.2.3)	phragmition	c	34	préalpin (Pyrénée→Anatolie)	VU	A	A
Utricularia bremii Heer	4.2	6	2.1.1	sphagno-utricularion	r	6	subatlantique(europe sans Méditerranée,Balkan,Su,Fin)	EN	B	B
Valeriana celtica L.	3.4	6	4.3.6(4.3.7)	festucion variaae	c	2	endémique grai pennin(Fr,It,CH)	LR	E	E
Veronica austriaca L.	1.7	2	4.2.2	xerobromion	r	1	est-européen(Fr→Sud Ru,Asie mineure)	EN	D	D
Vicia orobus DC.	2.5	3	5.1.2	trifolion medii	c	1	atlantique-ouest européen(Nord Es→Nor)	CR	A	C
Viola elatior Fr.	2.5	5	2.3.1	molinion	r	2	eurasiatique continental(→Ru)	EN	B	D
Viola persicifolia Schreb.	2.8	6	2.3.1	molinion	r	9	eurasiatique	EN	B	B

Annexe 3 - Proportion de chaque type de rareté parmi 123 espèces de plantes menacées issues des « fiches pratiques pour la conservation »

Le nombre d'espèce parmi 123 espèces de plantes menacées issues des « fiches pratiques pour la conservation » OFEFP/CPS/CRSF 1999) correspondant à chaque type de rareté selon Rabinowitz (1986) sont indiquées dans les tableaux, ainsi que le pourcentage qui lui est associé en tenant compte a) de l'abondance locale moyenne ou b) de l'abondance maximale. Les lettres entourées correspondent aux différents types de raretés décrites précédemment dans l'Annexe 2. Les espèces qui n'ont pas pu être traitées dans cette analyse en raison du manque d'information sur au moins un des critères entrant dans la définition des critères de rareté sont *Arenaria gothica* (EX), *Armeria alpina* (EX), *Botrychium multifidum* (EW), *Caldesia parnassifolia* (EX), *Chimaphila umbellata* (EX), *Knautia velutina* (EX), *Najas flexilis* (EX), *Potentilla collina* (CR), *Saxifraga oppositifolia* (EX), *Tulipa didieri* (CR), *Tulipa grengiolensis* (CR). Ces espèces correspondent, dans chaque cas, à des espèces fortement menacées selon les degrés de menaces UICN (IUCN 1994).

a) nombre et pourcentage d'espèces appartenant à chaque type de rareté avec comme critère d'abondance l'abondance moyenne

	large distribution géographique		distribution géographique restreinte	
	milieu commun	milieu rare	milieu commun	milieu rare
localement abondant	13 (10.7 %) (A)	34 (28.0 %) (B)	16 (13.2 %) (E)	4 (3.3 %) (F)
localement dispersé	16 (13.2 %) (C)	29 (23.9 %) (D)	8 (6.6 %) (G)	1 (0.8 %) (H)

b) nombre et pourcentage d'espèces appartenant à chaque type de rareté avec comme critère d'abondance l'abondance maximale

	large distribution géographique		distribution géographique restreinte	
	milieu commun	milieu rare	milieu commun	milieu rare
localement abondant	12 (9.9 %) (A)	38 (31.4 %) (B)	14 (11.5 %) (E)	3 (2.4 %) (F)
localement dispersé	17 (14.0 %) (C)	25 (20.6 %) (D)	10 (8.2 %) (G)	2 (1.6 %) (H)