Necessity and implementation of micro reserves for the protection of Priority Plant species in the canton of Bern, Switzerland

Master Thesis

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Centaurium pulchellum

Trifolium ochroleucon

Achillea ptarmica

Euphorbia palustris

Odontites vulgaris

Alisma lanceolatum

Gentiana germanica

Gentiana cruciata

Tephroseris helenitis

Rorippa amphibia

Gypsophila muralis

Campanula rhomboidalis

Rumex hydrolapathum

Thalictrum flavum

Callitriche cophocarpa

Rosa sherardii

Content

Abstract

The foundation Info Flora, which documents and promotes wild plants in Switzerland aims to develop a Swiss-wide network of plant micro reserves (PMRs) for the improved protection of priority plant species. Small reserves might have a great potential to protect threatened plant species, as these are sessile and often occur in small populations only. Here, the necessity and implementation of PMRs for the protection of priority plant species in the canton Bern (CH) is assessed by using the Info Flora database and by evaluating the real situation in a field survey. The analysis of the Info Flora database reveals that in the canton of Bern, priority plant species are not adequately protected by already existing reserves, because 44.2% of the priority plant species recorded since 2001 occur outside protected areas. Within the 20x20km study region in the Jura Bernois, this proportion is about 80%, indicating that the situation can be more severe on the regional level. Field visits of recorded priority plant species within the study region show that the real situation is even more dramatic. First, the present rediscovery rate of 51% indicates that priority plant species have disappeared at many locations. Second, the fact that 90% of the newly recorded priority plant species during the field survey in 2018 indicates that the proportion of populations occurring outside protected areas is even larger than represented in the database. Third, the proportion of locally threatened populations within the study region is of about 41% within protected areas. Thus, there is a need of micro reserve implementation for priority plant species within the study region and likely throughout the canton of Bern. Further, the field survey shows that populations are often very small and thus also the size of the potential PMRs, with what their implementation might be more realistic, since they would require the deal with one land owner only. Finally, this study shows that the Info Flora database is a very useful tool to identify potential sites for the development of a PMR network. However, effective PMR implementation requires field surveys to evaluate the situation on site.

Introduction

As a participating state of the convention on biological diversity (CBD), Switzerland undertakes to comply the Aichi and the global strategy for plant conservation (GSPC) targets, which aim at the protection of 17% of the national territory to the benefit of biodiversity and of 75% of the most important areas for plant diversity (Convention on Biological Diversity, 2019). In Switzerland, 44% of the 2700 indigenous plant species are threatened or potentially threatened (Bornand et al. 2016). Plant communities become more and more similar and species compositions impoverish, and forest and nitrogen-loving species increase in their abundance at the cost of species of pastures, meadows and nutrient-poor habitats (BAFU 2017). Main reasons for the decrease in plant diversity in Switzerland are the increasingly intense and similar land use, increasing nitrogen inputs from air and agriculture, as well as climate change and species introductions (BAFU 2017). The proportion of designated areas for the protection of biodiversity currently comes to 12.5% of the Swiss territory (BAFU 2017). These include the national inventories of riparian zones, fens and raised bogs, dry meadows, amphibian spawning areas, water and migratory bird areas, as well as prohibited hunting

areas, forest reserves, the Swiss national park, Smaragd- and Ramsar areas, regional and local reserves, biodiversity promoting areas in arable lands as well as reserves of private persons (BAFU 2017). The "Strategie Biodiversität Schweiz" aims at the construction and expansion of the national ecological infrastructure until 2040, which should ensure the protection of ecologically valuable habitats. To this purpose, the network of protected areas is to expand, which should benefit national priority species in particular (BAFU 2017). The list of national priority species is a complementary instrument to the Red List for the conservation of species at the national level. The list of national priority plant species is a result of the collaboration of the federal office for the environment (BAFU) and the Swiss national species data center (InfoSpecies) and comprises 817 plant species. There are four priority levels (1-4), which result from the combination of the conservation status of each species and the international responsibility of Switzerland for the species (BAFU 2019). The conservation status is based on the red list classification and expressed in the IUCN (International Union for Conservation of Nature and Natural Resources) categories: least concern (LC), near threatened (NT), vulnerable (VU), endangered (EN), critically endangered (CR), regionally extinct (RE) and extinct (EX) (Bornand et al. 2016). Measures in favor of priority species are advisable if their international responsibility of Switzerland is high and/or the threat is acute (BAFU 2019). The existing nature reserves of Switzerland currently protect half of all plant, animal and fungal species with high priority (1 and 2). However, endangered species are regularly lost in protected areas and the protected areas are often inadequately maintained with regard to their purpose (BAFU 2017). Especially among the national inventory of dry meadows, fens and raised bogs, the management is not appropriate to the protection purpose and shifts in vegetation are common (BAFU 2017). Due to this reason and because many priority plant species might occur outside protected areas, priority plant species are considered to be poorly protected in Switzerland (S. Eggenberg, personal communication 2018). Since endangered species often occur only in small areas, plant micro reserves (PMRs) might provide effective protection of national priority plant species in Switzerland (Gigon, unpublished). Studies have consistently shown that small organism such as herbaceous plants and invertebrates need small protected areas in supplement to large protected areas (e.g Moreno et al. 1996; Araujo et al. 2007). The idea of protecting small areas for sessile or small-sized organisms is not new and several studies highlight the potential of small reserves for the protection of vascular plants, as well as of bryophytes and lichen (Gomez-Campo&Herranz-Sanz 1993; Gimeno et al. 2001; Atienza et al. 2001; Laguna et al. 2013; Kadis et al. 2013; Liu et al. 2015). In China, two PMRs have been established to protect orchids (Liu et al. 2015) and in Valencia and Crete, PMR-networks have been established to protect locations with a high plant diversity (Laguna et al. 2013) and locations, where plant species of European community priority occur (Kadis et al. 2013). PMRs are often proposed as conservation strategy as complementation of large reserves, being the only possibility to protect natural fragments surrounded by territory unavailable for conservation actions (Blasi et al. 2011, Volis et al. 2016). Since small and fragmented populations are prone to extinction (Fahrig & Merriam 1994), PMRs might benefit small populations of endangered plant species, especially in a densely populated and intensively used area such as Switzerland. Small protected areas might serve as stepping stones allowing ecological or genetic connectivity (Burkey 1989) by maintaining the ecological niche of the target species. According to Laguna et al. (2013), the surface area of PMRs is suggested to range between 0.1 and 100ha. Within the PMR, the target species can specifically be managed by for instance shrub clearance, herbivore exclusion and population reinforcement (Volis 2016). In contrast to large nature reserves, the planning and management effort as well as financial costs might be low for micro reserves (Gigon 2016).

In Switzerland, there are only a few examples of plant micro reserves established by private persons (Gigon, unpublished; Gnägi, unpublished). Info Flora, the national data and information center about wild plants in Switzerland, plans to list the suitable locations for PMRs for the development of a national PMR-network. This would agree with the purpose of the ecological infrastructure of the state (BAFU 2019). The Info Flora database provides long term records of priority plant species, which can serve as a basis of PMR setting. However, it is still unclear which method should be applied for the development of a national PMR-network. Therefore, the motivation of this study is to design a method to identify sites for potential PMRs with the use of the Info Flora database. The aim is to evaluate whether priority plant species are sufficiently protected through the already existing reserves or whether additional protection through micro reserves is required. Also, the accordance between the database and the real distribution of priority plant species is assessed, to evaluate the potential of the Info Flora database as a tool for PMR implementation. The preliminary analyzation of the Info Flora database allows to assess the distribution of priority plant species within the canton of Bern (CH). To evaluate the necessity of PMRs, records of priority plant species are visited in the field within a 20x20km study region in the Jura Bernois around Moutier (BE). The field surveys document the presence of the species, local threats and population size in order to prioritize sites for PMR implementation within the study region. The specific hypotheses in this study are the following:

1. Priority plant species within the canton of Bern are currently not sufficiently protected through the existing nature reserves.

2. Field work is needed for effective PMR implementation, since there is a lag between the Info Flora database and the real distribution of priority plant species.

3. PMRs might provide effective protection for Swiss priority plant species, however the suitability and necessity for the protection through micro reserves varies among species.

4. Although each potential PMR is an individual case, there are different categories or types of PMRs.

Methods

Spatial analysis and study site selection

All spatial analysis and the selection of the study site were done by using the statistical computer software R 3.5.0 (R Core Team, 2018) and the geographical information system QGIS version 3.2 (QGIS development team 2018). Floristic records of Swiss priority plant species occurring in the canton of Bern were extracted from the Info Flora database (infoflora.ch/de/daten). A record is an observation of a plant individual or a population of a species, made by various botanists. In the database, observations are polygons, whereby coordinates represent the center of this polygon and the inaccuracy of these coordinates the radius of the polygon. Information on (sub-) species identity and identification reliability, on the observation date (day, month, year), as well as on the observer (name) are available for each record. Selected were only records from 2001 or later, with an inaccuracy radius

not exceeding 1000m and coordinated within the canton of Bern. Polygon layers of protected areas were received from the Geographical Information portal of the canton Bern and from the environmental federal agency (BAFU). Following polygon layers were used for the spatial analysis: national nature reserves, biodiversity promoting areas on arable lands, national inventories of riparian zones, of dry meadows, of fens and wet zones, of raised bogs, of spawn areas for amphibians and of reserves for water- and migratory birds, as well as regional forest reserves, low-bog swamps and wet zones of regional importance, the cantonal inventory of wet and dry zones, cantonal nature reserves and ProNatura reserves, as well as the layer containing information about land property, which is in Switzerland organised in parcels. Spatial merging of species records and polygon layers allowed the characterization of each parcel concerning their number of records and species and their presence of protected areas.

In order to prioritize regions for the study site selection, each parcel was scored according the following formula: *Total parcel-score = (Total number of species per parcel * Total number of records per parcel) * protection-score.* The protection-score of a parcel (Table 1) is a combination of whether the parcel contains one or more legally protected area and in the case of one protected area, whether this type of area allows opportunity of action concerning PMR implementation. The opportunity of action of a protected area was estimated by considering the number of people involved in potential PMR implementation. The opportunity of action was considered to be high, when only one single land owner is responsible for a particular type of area (e.g. national inventory of dry meadows), and low, when multiple land owners or political representatives of the municipality, canton or federal government are responsible for the particular area (e.g. cantonal nature reserve including multiple parcels). Thus, parcels with a high total parcel-score include a high number of records of priority plant species and no protected area or a protected area with a high opportunity of action.

Protection score	Protection and Opportunity of action
4	No legally protected area
3	Legally protected area + high opportunity of action
2	Legally protected area + low opportunity of action
1	Multiple legally protected areas

Table 1. The protection score of a parcel is a combination of whether the parcel contains one or more legally protected area, and whether the opportunity of action is high for the presence of only one protected area. Prioritized were parcels with a high protection score and a high number of priority plant species records, which is expressed in the total parcel-score and calculated as follows: *total parcel-score = (Number of species * Number of records) * Protection score*.

In order to select a suitable study site for the case study, a 20x20km moving window was superimposed on all parcels of the canton of Bern. This way, from the 5% of regions with maximum total parcel-score (average of all parcels within the 20x20km region), the ones with maximum variance of total parcel-scores were selected. The variance was considered to find a region that includes both records of priority plant species within and outside of protected areas, in order to evaluate whether legally protected areas provide adequate protection of present priority plant species. The maximum was considered to identify regions, where PMR implementation might be most necessary and easier to enforce. The moving window identified three regions of high priority: the Bernese highlands around Lauterbrunnen, the midland westwards of Bern city, and the Jura Bernois around Moutier. The Bernese highlands have been identified by the moving window because of the large parcels, which often include many records and few protected areas. However, the need of action in the Bernese highlands is low, since the land use is not as intense as in the residual parts of the canton. Due to that

and because of the difficult accessibility, the highlands were excluded. The midlands would probably have been most interesting because of the high need of action and the diversity of different land use types, but the summer period started early in 2018, wherewith a large part of species has already flowered in Mai and June, when the analysis of the Info Flora database was still ongoing. The region around Moutier has a higher elevation (530-1200m versus 550-600m), thus the flowering period was just starting at the beginning of the field survey. Also, the parcels within this region are from different sizes and have diverse states in terms of legal protection. Thus, Moutier and its surrounding area was selected as study site.

Study site

The case study was conducted in a 20x20km area around Moutier in the Jura Bernois (Figure 1). With a mean temperature of 17.4°C, July is the hottest month during the year, with a mean precipitation of 90mm (climate-data.org). The landscape is undulating with an altitudinal gradient of about 900m and consists primarily out of forest and grassland, with a high abundance of dry meadows. Legally protected nature reserves mostly belong to the national inventory of dry meadows.

Figure 1. The study site (red) lies in the western part of Switzerland in the Jura Bernois, close to the border to the canton Jura. (map from geo.admin.ch)

Species selection within the study site

Since there were more records of priority plant species within the study region than feasible to visit in one summer, a species subset had to be selected for the field survey. Primary criteria to select the target species were their priority status, their need of action and their conservation status based on the IUCN red list categories. Secondary criterium was the cantonal responsibility for a species, which is the ratio between the number of records in the canton of Bern and the number of records in Switzerland. As the field work was restricted to a 20 x 20km area within the canton of Bern, cantonal responsibility was more meaningful than national responsibility to prioritize species. When only a few records of a species were provided by the Info Flora database, all of them were visited. When there were more than 15 records of a species provided, a stratified sampling was applied in order to select records for the field visits both within and outside protected areas. For instance, for *Trifolium ochroleucon*, three records each from within and outside the national inventory of dry meadows were randomly selected using the function *sample()* in R version 3.5.0 (R Core Team, 2018). Neighbouring observations of the same species and of others were then added for the purpose of increasing the amount of visits per time.

Field work

250 Info Flora records of Swiss priority plant species were visited on 73 parcels covering a total area of 35.4 ha from June to September 2018. To standardise the monitoring, searching time was limited to 1 hour per record. Time-to-detection models suggest that 30 minutes are required to detect inconspicuous species (Bornand et al. 2014). 1 hour was adequate to deal with the trade-off between

searching effort and quantity of data. Species records were searched with the Swiss map mobile application version 5.71 (powered by Andreas Garzotto GmbH © swisstopo 2009-2018). Species were identified and reported by using the Flora Helvetica application version 2.0 (© by Haupt Verlag AG 2019). The species report included the actual coordinates and their inaccuracy radius. For each rediscovered record, the number of individuals and the coverage (m^2) were identified to assess population size. Potential threats were estimated by observing whether there might be fertilization, mowing or grazing, or shrub encroachment and the probability of competitive exclusion through dominant neighbours. Based on those estimations, records were categorized in being locally threatened or locally not threatened. Depending on the local threat, potential measurements for the protection of the rediscovered records of priority plant species were derived. In the following, the term “rediscovered” is used to indicate that a record of the database was confirmed and the term “rediscovery rate” is applied to express the number of confirmed records relative to the total number of records.

Prioritization of potential locations for micro reserve implementation after the field survey

A selection of suitable potential micro reserves was made from all 250 visited sites. A species-score was calculated based on field work derived parameters, in order to prioritize the visited priority plant species and locations for the suggestion of potential plant micro reserves within the study region. The species-score indicates the species-specific necessity of micro reserve implementation within the study region. This species-score was calculated by taking the sum of the following two proportions for each visited (and rediscovered) species:

(i) Locally threatened rediscovered records of the priority plant species
(ii) Records of the species rediscovered outside of protected areas

The necessity for a priority plant species of micro reserve implementation increases with increasing score. Thus, species with a high proportion of locally threatened rediscovered records and of records rediscovered outside protected areas were prioritized. Locations for potential micro reserves were then selected based on the five highest-scored species. The visualization of the occurrence of these species within QGIS version 3.2 (QGIS development team 2018) was used to select parcels, which included a maximum number of records of these species. In terms of spatial planning, it is beneficial to maximize the number of populations for micro reserve implementation and to minimize the number of affected parcels. Therefore, the five parcels with the maximum number of rediscovered priority plant species were additionally selected for PMR implementation within the study region.

Statistical analysis

The aim of this study was to evaluate the necessity of PMRs within a study region, in order to deliver field work parameters and advices for the development of a Swiss-wide PMR network for the protection of priority plant species. To this purpose, a study region was selected which allowed a high number of field visits of priority plant species records within a small area. This study design had to renounce standardized replicates for the sake of practicability, with what the possibilities of a statistical evaluation were limited.

All statistical analysis were carried out with the statistical computer software R 3.5.0 (R Core Team, 2018). Analysis of variance was used to test whether the number of rediscovered priority plant species was higher in protected areas compared to outside protected areas (non-protected areas). Two proportions z-tests were applied to evaluate, whether protected and non-protected areas (i.e. national inventory of dry meadows) differed in the proportions of rediscovered priority dry meadow species and of locally threatened populations of priority plant species. Generalised mixed effect models were used to assess whether there were differences in the rediscovery rate in respect to plant groups, locations and data characteristics, for instance between protected and non-protected areas. Differences in the rediscovery rate among plant groups might reflect differences in their extinction rates and thus of their protection (Kempel et al., in preparation). For instance, when endangered species are significantly more rediscovered than vulnerable species, they might disappear to a smaller extent, which would indicate that they might be better protected than vulnerable species. Also, the species suitability for PMR-mediated protection might be reflected in the rediscovery rate, for example when geophytes are significantly less rediscovered than hemicryptophytes due to higher spatial movement. Regarding the life forms, micro reserves are expected to be more suitable to protect phanaerophytes and hemikryptophytes with a more stable location than therophytes with higher generation turnover and spatial dynamics. Therefore, life forms (Raunkiaer 1934) were included in the models as well. The basic model had the following structure: *presence ~ time + (1|taxon)*, where time is the scaled time since the initial observation, and *taxon* the species, which was included as random term. Presence refers to the rediscovery rate as response variable in the form of binomial presence-absence data. ANOVA was used to test whether the fixed factors that were excluded from the model had a significant effect on the rediscovery rate. Following factors were included as fixed terms in a series of different models: dry meadow species, national inventory of dry meadows (NIDM), IUCN threat category, accuracy of initial coordinates, plant height (species mean), length of flowering period, life forms (Raunkiaer 1934), ecological strategies (Grime 1979), species habitat type (Delarze et al. 2015) and character species. In addition, following Landolt indicator values (Landolt et al. 2010) were included as fixed terms: moisture (F), reaction (RZ), nitrogen (N), humus (H), light (L), reserve organs (RO), dispersal of diaspores (DA), vegetative dispersal (VA), pollination strategy (BS), mowing compatibility (MV) and dominance at the site (DG). As with the life forms and ecological strategy types, differences in the rediscovery rate depending on for instance VA, MV or DG might indicate different suitability of different plant groups for PMR-mediated conservation. Plant height and length of flowering period was included to test whether tall species and species with a short flowering period are rediscovered more often.

To validate the present rediscovery rate, the rediscovery rate of this case study was compared with the rediscovery rate of one of the largest revisitation studies, in which 8024 records from 1960 to 2001 of 713 plant species of Switzerland including all threatened species were visited in the field to assess their extinction trends (Kempel et al., in preparation). The rediscovery rate of Kempel et al. (in preparation) was 73% for all species and 77% for the species that were revisited in this study. A Welch's two-sample t-test was used to compare the rediscovery rate of exactly the same species of this study and the study of Kempel et al. (in preparation).

Results

Priority plant species in the canton of Bern

According to the Info Flora database, there are 385 priority plant species in the canton of Bern, belonging to 226 genera and 73 families. There are seven species of priority 1 (2%), 49 of priority 2 (13%), 94 of priority 3 (24%) and 235 of priority 4 (61%, Figure 2a). 28 (7%) of these species are critically endangered (CR), 86 (22%) are endangered (EN), 211 (55%) are vulnerable (VU), 30 (8%) are nearly threatened (NT), 26 (7%) are under least concern (LC) and four species (1%) are regionally extinct (RE, Figure 2b). 127 (32%) of the priority plant species of the canton of Bern have a clear need of action, 199 (52%) have an insecure need of action, 52 (14%) have no need of action (Figure 2c) and for 7 (2%) species the knowledge is too little to estimate a need of action. The Info Flora database contains more than 12'000 records of priority species for the canton of Bern since 2001. 56% of these populations occur within some kind of nature reserve, national inventory and/or biodiversity promoting area.

Case study around Moutier, Jura Bernois

Analysis of the Info Flora database: Priority plant species around Moutier

The Info Flora database 3 around Moutier (Jura Bernois). Three species were excluded as falsely recorded since their distribution is restricted to the alpine area which is not represented in the study region (*Thalictrum alpinum, Anthyllis vulneraria subsp. valesiaca* and *Gentiana racemosa*). The number of observations of species varies a lot within the study region. The most abundant priority plant species are *Heracleum sphondylium subsp. alpinum* (220 records), *Gentiana cruciata* (90), *Orchis morio* (76), *Genista pilosa* (50) and *Trifolium ochroleucon* (48). The accuracy of the coordinates reaches from 1 to 1000m, with a median of 7m. The distribution of the priority plant species of different priority-, IUCN threat- and need of action categories is similar in the study region compared to the canton of Bern, however, there is no record of first priority and of regionally extinct (RE) species within the study region (Figure 2a-c).

The cantonal responsibility is low (0.3-25% of the national occurrence) for 47 species (70.3%), for 14 species (21.9%) intermediate (25-50% of the national occurrence) and only for 4 species higher than 50% (*Euphorbia palustris*, *Rosa elliptica*, *Nigritella austriaca* and *Lathyrus cicera,* Figure 2d*)*. In total, 20% of the 778 priority plant species records occur within some kind of protected area, whereby these areas mostly belong to the national inventory of dry meadows. Thus, 80% of the priority species within the study region are recorded outside protected areas (Figure 2e), which is more than the percentage of priority plant species outside protected areas throughout the canton of Bern (44%).

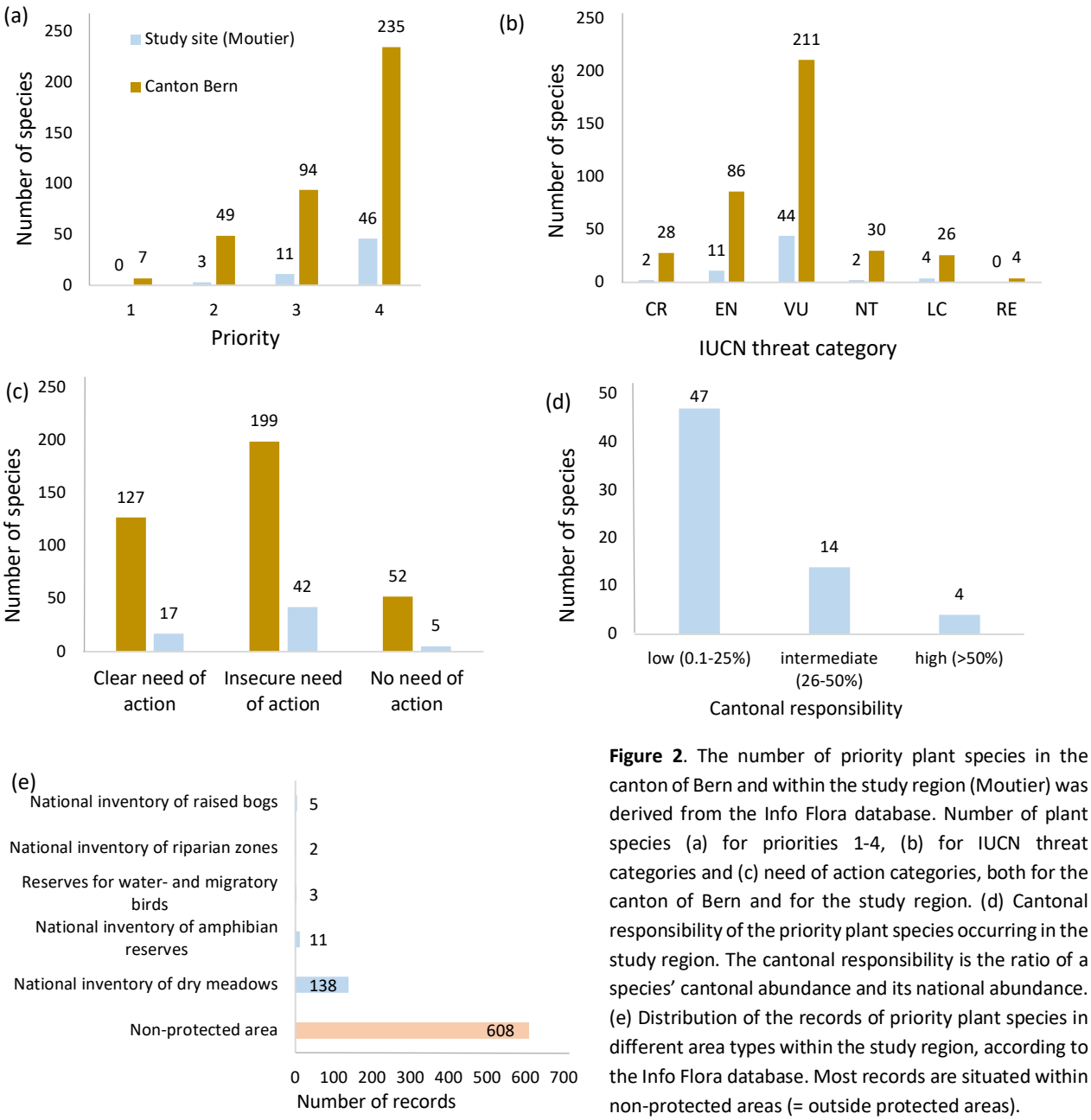

Figure 2. The number of priority plant species in the canton of Bern and within the study region (Moutier) was derived from the Info Flora database. Number of plant species (a) for priorities 1-4, (b) for IUCN threat categories and (c) need of action categories, both for the canton of Bern and for the study region. (d) Cantonal responsibility of the priority plant species occurring in the study region. The cantonal responsibility is the ratio of a species' cantonal abundance and its national abundance. (e) Distribution of the records of priority plant species in different area types within the study region, according to the Info Flora database. Most records are situated within non-protected areas (= outside protected areas).

Field survey: Rediscovered records of priority plant species from the Info Flora database

In total, 250 records (of 788 in total) of 36 different priority plant species were visited within the study region during the field survey in summer 2018 (species list see Appendix). Of that fraction, 128 (51%) were rediscovered during the field survey. The rediscovered observations belong to 17 priority species from 16 genera and 13 families. The rediscovery rate for these species varied between 17% and 100% per species (Figure 3a). Most rediscovered records had a very small population size (1 or 2-10 individuals, Figure 3b). The most abundant rediscovered species were *Gentiana cruciata* (41 observations), *Trifolium ochroleucon* (19), *Odontites vulgaris* (11) and *Rumex hydrolapathum* (10) (Table 2). 17 species (118 observations) could not be rediscovered at the coordinates provided from

the Info Flora database (Figure 4a). Six of these species were recorded only once in the Info Flora database. There were, however, also species that were found despite they showed only one observation in the database. This was true for *Thalictrum flavum*, *Rorippa amphibia* and *Alisma lanceolatum.* These observations were located in protected areas, meaning either in the national inventory of dry meadows, in reserves for water-and migratory birds or in cantonal nature reserves. Species with a rediscovery rate higher than 50% were either tall and/or conspicuous (e.g. *Rumex hydrolapathum*, *Euphorbia palustris*, *Rosa sherardii*) or they were recorded multiple times in the Info Flora database (e.g. *Gentiana cruciata, Odontites vulgaris, Trifolium ochroleucon*).

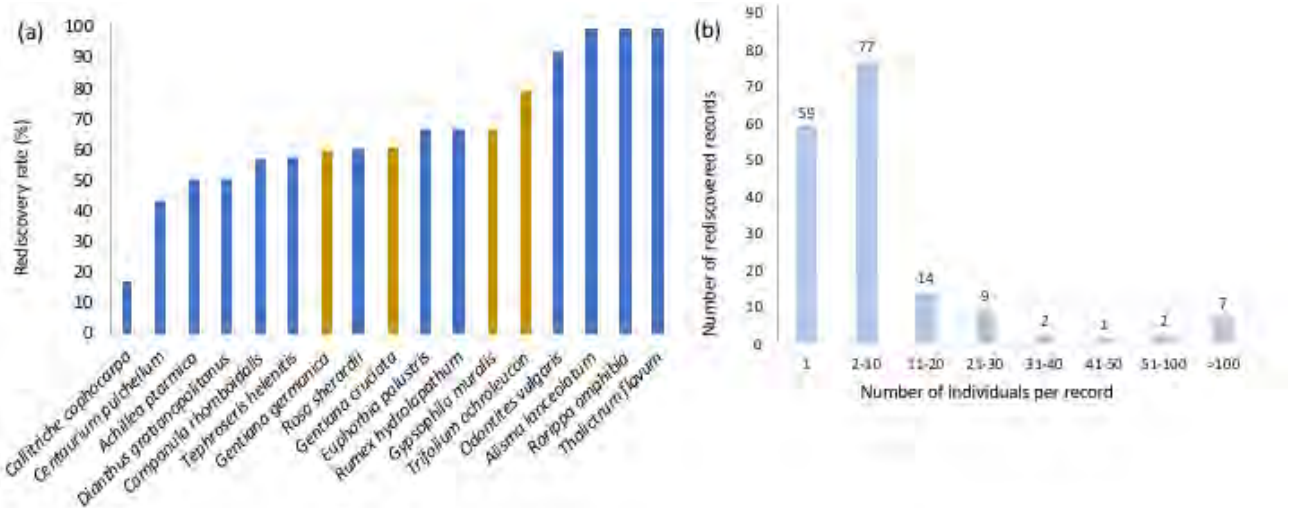

Figure 3. Rediscovery rate and population sizes of rediscovered priority plant species within the study region. (a) Rediscovery rate of the 17 priority plant species within the study region, from which there was at least one rediscovery made during the field survey. The rediscovery rate is calculated by dividing the number of rediscovered records of a species through the total number of visited records of this species. Dry meadow species (Delarze et al. 2015) are marked in yellow. (b) Frequency distribution of population sizes (number of individuals) of the rediscovered records of priority plant species within the study region.

20% of the rediscovered records of priority plant species occurred within the national inventory of dry meadows and 10% within other types of protected areas (e.g. water bird reserve, riparian zone, forest reserve). The remaining 70% of all populations were found outside protected areas (Figure 4b), with what the field survey reflects what the Info Flora dataset of the study region tells – namely that the fraction of populations occurring outside protected areas is much larger than the fraction within protected areas. 29% of all populations are threatened either through mowing, shrub encroachment, fertilizing or through animal or human steps, 71% of the populations are not threatened (Figure 4c). In addition, 80 new observations of the following priority plant species were added to the Info Flora database during the field survey in summer 2018: *Gentiana germanica*, *G.cruciata*, *Rumex hydrolapathum*, *Trifolium ochroleucon*, *Centaurium pulchellum*, *Rosa sherardii*, *Campanula rhomboidalis* and *Heracleum sphondylium subsp. alpinum*. 90% of these new records of priority plant species occurred outside protected areas, 7% occurred within the national inventory of dry meadows and 3% within other types of protected areas (Figure 4d). 20% of the new records of priority plant species were locally threatened, mainly through bush encroachment.

The proportion of locally threatened rediscovered records of priority plant species is 25% outside protected areas and 41% within protected areas. Although this difference is not significant (two-proportions z test, p = 0.15, Figure 4e), it indicates that priority plant species are not sufficiently

protected, not even within legally protected areas. For instance, in the community of Arch (BE) within the study region, a few individuals of *Thalictrum flavum* and *Euphorbia palustris* occurred within an area legally declared as national inventory of riparian zones. These individuals are locally threatened through competitive exclusion through dominant species (e.g. *Calystegia sepium*). Besides these two species, also *Gypsophila muralis*, *Achillea ptarmica* and *Tephroseris helenitis* are 100% locally threatened within the study region, although they occur in cantonal nature reserves or in biodiversity promoting areas. In the case of *G. muralis,* the land owner did not know about the presence of this priority species within his biodiversity promoting area. Similar situations were found within the national inventory of dry meadows, where individuals of *Gentiana cruciata* were partially overgrown by *Rubus fruticosus*. For instance, a parcel belonging to the national inventory of dry meadwos includes 18 individuals of *G. cruciata*, from which one third is locally threatened. Concerning the national inventory of dry meadows, the proportion of rediscovered records within this type of protected area does not significantly differ between dry meadow species and species of other habitats (32% versus 27%, two-proportions z test, p = 0.35, Figure 4f), indicating that the national inventory of dry meadows does not significantly protect dry meadow priority plant species compared to other species.

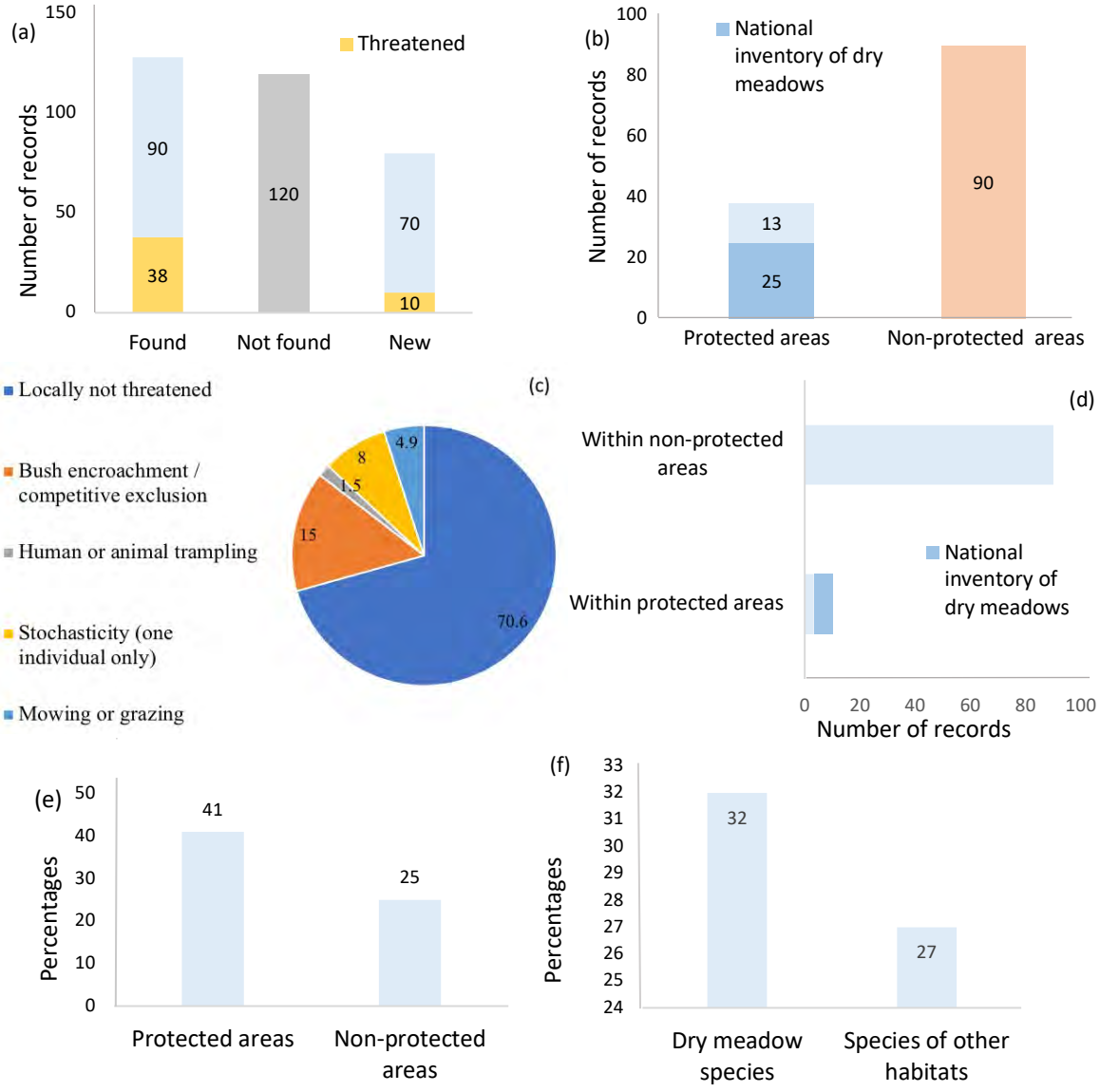

Figure 4. (a) Number of rediscovered records of priority plant species within the study region. "Found" means the number of rediscovered populations during the field survey within the study region, "not found" corresponds to the number of visited locations where the populations could not be rediscovered and "new" indicates the number of newly discovered populations that were not yet recorded in the Info Flora database. (b) Number of rediscovered records of priority plant species within and outside (= non-protected) protected areas in the study region. Most protected areas within the study region belong to the national inventory of dry meadows (dark blue). (c) Percentages of rediscovered priority plant species records in different categories of locally identified threats. Almost one third of all rediscovered records were identified to be locally threatened either through bush encroachment, stochasticity, human or animal trampling or mowing and grazing. (d) Number of newly made records of priority plant species within and outside (= non-protected) areas within the study region during the field visits in summer 2018. (e) Percentages of locally threatened priority plant species records rediscovered in protected and in non-protected areas. The percentage of locally threatened rediscovered records is higher within protected areas, but this difference is not significant (two-proportions z-test, $p = 0.15$). (f) Percentages of rediscovered records of dry meadow priority plant species and priority plant species of other habitats within protected parcels belonging to the inventory of dry meadows within the study region. Dry meadow priority plant species occur more often within the national inventory than priority plant species of other habitats, however, this difference is not significant (two-proportions z-test, $p = 0.35$).

Spatial match between populations recorded from the Info Flora database and rediscovered records during the field survey

From the 128 rediscovered populations, 10 (7.8%) were outside the initial parcel provided by the Info Flora database. Only two of them were supposed to be within a natural reserve, but in reality, they occurred on a neighbouring parcel outside the reserve. This happened for a population of *Campanula rhomboidalis* and a population of *Euphorbia palustris*, which both occurred next to a natural reserve on arable land. *C. rhomboidalis* is listed as a priority plant species, even though it is a rather common fat meadow species in Switzerland. *E. palustris* has only few remaining populations (A. Möhl, personal comment 2018), and the rediscovered individuals were mown during August 2018 (Figure 5a and b). Thus, the spatial shift between the database and field survey was low, in terms of parcels. Nevertheless, there was a pronounced spatial shift in respect to the distance between the initial (database) and the field work coordinated polygon centres of the observed populations. There is an average shift of 40m, with a standard deviation of 72.2m. Only four populations were exactly at the initial position and the largest deviation from the database was 327m. 81% of the populations had a spatial deviation below 50m, 19% of the populations were coordinated more than 50m distant from the initial coordinates. Most populations were rediscovered within a distance of 3-4m from their initial coordinates.

Figure 5. The individuals of *Euphorbia palustris* growing next to a natural reserve (a) have been mown during august 2018 (b).

Table 2. Priority plant species that were rediscovered within the study area around Moutier the Jura Bernois during summer 2018. Percentages of populations within protected areas (PA) and within the national inventory of dry meadows (NIDM) and outside protected areas, as well as percentages of populations locally threatened either through shrub encroachment, fertilizer, mowing, grazing or trampling. The rediscovery rate (RD rate) is the ratio between the number of rediscovered populations and the total number of visited populations. Locations means the number of populations reported from the Info Flora database, which were visited during the field survey. Mean distance = mean spatial deviation between coordinates from the Info Flora database and coordinates where the species has been rediscoverecd during the field visits. Mean population size = mean number of individuals per population of a species. Score = measure of species-specific necessity of micro reserve implementation, calculated by summing the species proportion outside protected areas and the species proportion of locally threatened populations. Species are ordered by decreasing score, i.e. by decreasing necessity of protection necessity through micro reserves.

Species	Within PA (%)	Within NIDM (%)	Outside protected areas (%)	Threatened (%)	RD rate	Observations	Mean distance (m)	Mean population size	Species score
Gypsophila muralis	0	0	100	100	0.7	3	5.5	1	200
Tephroseris helenitis	0	0	100	100	0.57	14	18.3	8.8	200
Euphorbia palustris	50	0	50	100	0.67	3	4.5	2.5	150
Rosa sherardii	0	16.67	83.33	50	0.6	10	36	1	133.33
Gentiana germanica	0	0	100	33	0.6	5	12	1	133
Odontites vulgaris	0	0	100	0.92	12	12	44.4	3.9	100.92
Callitriche cophocarpa	0	0	100	0	0.17	6	3	1	100
Achillea ptarmica	100	0	0	100	0.5	2	58	1	100
Rumex hydrolapathum	0	0	100	0	0.67	15	8.1	1.9	100
Centaurium pulchellum	33	0	67	33	0.43	14	15.7	4.3	100
Thalictrum flavum	100	0	0	100	1	6	6	10	100
Campanula rhomboidalis	11	0	89	11	0.56	16	133	13	100
Dianthus gratianopolitanus	0	0	100	0	0.5	4	8	30	100
Residual species	20.51	6.41	73.08	19.7	0.49	158	40.2		92.78
Trifolium ochroleucon	0	15	85	5	0.79	24	48.7	26.7	90
Gentiana cruciata	0	47.62	52.38	37	0.61	67	33.9	2.1	89.38
Alisma lanceolatum	100	0	0	0	1	4	4	15	0
Rorippa amphibia	100	0	0	0	1	4	50	25	0
Dry meadow species	0	46.29	53.71	15.4	0.59	92	32		
Residual species	20.51	6.41	73.08	19.7	0.49	158	40.2		
Total records	9.7	19.8	70.5	32	0.51	250	40		

Secondary field visits

10 records of 6 species that were not found during the first field visit, were revisited once. In the case of *Alisma lanceolatum, Euphorbia palustris* and *Rorippa amphibia,* the site was not accessible during June due to a flooding event. Later in the season, the swamp dried out and all the populations except one of *E. palustris* were found. *Gentiana germanica* was located during the first visit, but only in its vegetative state, where it can be confused with *G. campestris*. Thus, individuals of *G. germanica* have been visited a second time later in the season when they were flowering to confirm their

identification. *Melampyrum nemorosum* and *Veronica anagalloides* are the only species within the study region with priority 2 and a high need of action, both of which could not be found even after several visits. The former either due to a seasonal mismatch or because it was overgrown by the dense bushy vegetation. The latter has probably disappeared, since its coordinates were placed on a cattle field, which was not especially wet and does therefore not corresponds to the required habitat of this species. In total, 80% of the second visits were successful.

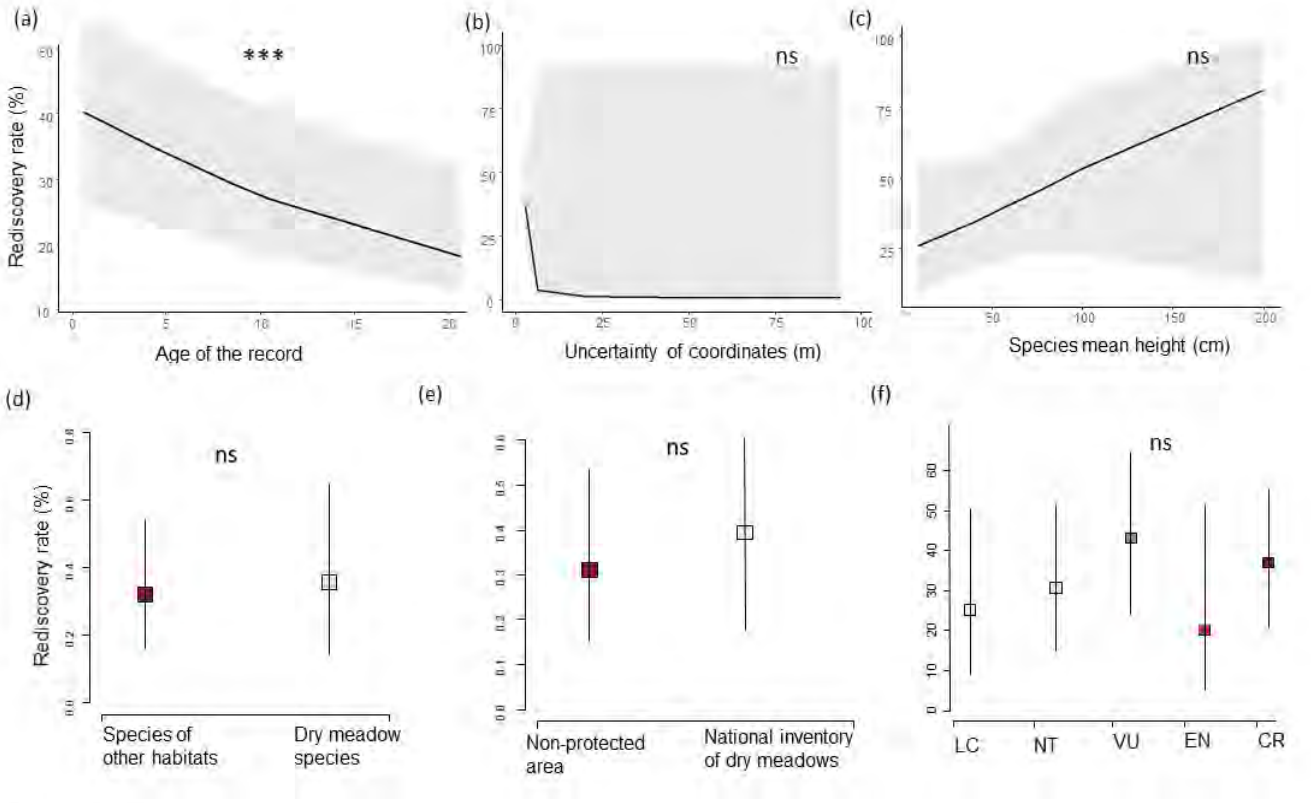

Figure 6. Rediscovery rate (the proportion of rediscovered records of priority plant species within the study region) in relation to data, species and location characteristics. Shown are the generalized mixed effect model outputs, which identified a significant relation only (a) between the rediscovery rate and the age of the record, whereby "ns" corresponds to non-significant. Model predicted relation between the rediscovery rate of priority plant species and (b) the accuracy of coordinated records (= uncertainty of coordinates), (c) species mean height, (d) dry meadow species and species of other habitat types, (e) protected areas (i.e. national inventory of dry meadows) and non-protected areas (= outside protected areas), (g) species threat (IUCN categories); EN = endangered; LC = least concern; NT = near threatened; CR = critically endangered; VU = vulnerable, (f) and life forms according to Raunkiaer (1934); G = geophytes; H = hemicryptophytes; MH = perennial hemicryptophytes; MoH = monocarpic hemicryptophytes; NP = nanophanaerophytes (g).

Rediscovery rate

Similar to the revisitation study of Kempel et al. (in preparation), this study used generalized mixed effect models to assess whether there are patterns in the rediscovery rate of the field surveys in summer 2018. Patterns might indicate for instance, how well protected priority plant species are within protected areas compared to outside protected areas, or which plant groups might decrease in

abundance. In respect to data characteristics, there was a decreasing probability of rediscovery with increasing age of the record ($p < 0.01$, Figure 6a), although only population records after 2001 were used. The inaccuracy of the coordinates did not have a significant effect ($p = 0.097$), but there was a trend towards a decreasing rediscovery rate with decreasing accuracy (Figure 6b). In the field, it was obvious that an observation was much harder to find when the inaccuracy radius was large. According to the experience, one hour searching time was not enough when the radius exceeded 20m, but this also depended on the species size and conspicuousness and the habitat heterogeneity and accessibility. There is a trend towards an increasing rediscovery rate with increasing species mean height, however, this is likewise not significant (Figure 6c). Also, the length of the flowering period did not affect the rediscovery rate.

There was no significant difference regarding the rediscovery rate between species groups (life forms, habitat types, ecological strategy types, character species, dry meadow species, Landolt indicator values). For dry meadow species, the rediscovery rate was slightly higher than for species of other habitat types, but this was not significant (Figure 6d). Regarding location characteristics, there was no significant difference in the rediscovery rate between inside and outside protected areas (Figure 6e). The rediscovery rate was low both within protected (i.e. national inventory of dry meadows) and outside protected areas (38% and 31%, respectively). Like for the rediscovery rate, also the *number* of rediscovered records of priority plant species does not significantly differ between inside and outside protected areas (analysis of variance, $p = 0.25$, Figure 7a). Thus, there is no significant difference between within and outside protected areas regarding the presence of priority plant species and their disappearance.

While the inaccuracy of the coordinates in this study was a maximum of 1km, the related revisitation study of Kempel et al. (in preparation) always examined a whole 1x1km cell according to the species recorded in the Info Flora database. Nevertheless, data of Kempel et al. (in preparation) was used to compare the rediscovery rate of the present rediscovery rate with their rediscovery. A Welch's two-sample t-test of the rediscovery rates of similar species showed that the rediscovery rate of this case study is significantly lower than the one of Kempel et al. (in preparation, 51% versus 77%, $p = 0.00028$, Figure 7b). Thus, there is either a higher percentage of priority plant species that has disappeared in the past in the study region around Moutier (BE) compared to the various regions assessed by Kempel et al. (in preparation) across Switzerland, or there is an unknown percentage of records that could not be found in the study region although they still exist.

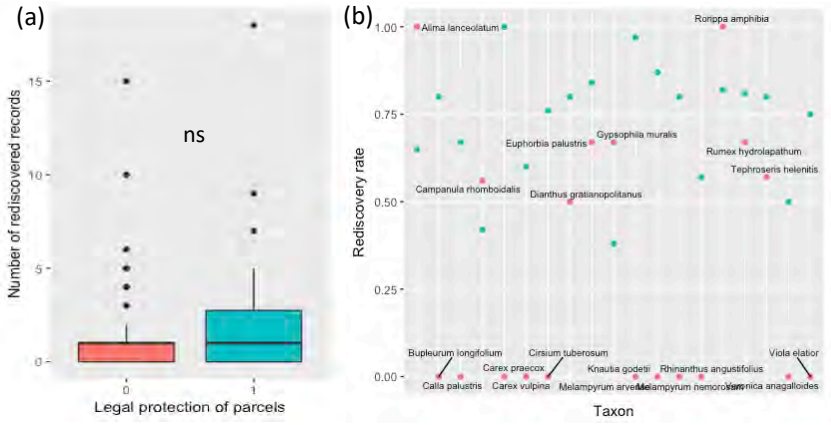

Figure 7. (a) Comparison between the number of rediscovered records of priority plant species within legally protected and outside protected parcels (1=inside, 0=outside; "ns" corresponds to non-significant); (b) Rediscovery rates of the same rediscovered priority plant species within this study (indicated in red) and a study conducted by Kempel et al. (in preparation, indicated in blue), which are significantly different (Welch's two sample t-test, $p = 0.00028$).

The following three reasons could be identified why species could not be rediscovered at specific locations and why the present rediscovery rate of 51% is markedly low. First, the targeted species might have been overlooked when they were in their vegetative form during the field survey. The extreme summer heat in 2018 has probably increased this temporal mismatch. Second, the inaccuracy of the coordinates from the Info Flora database was sometimes resulting in a searching radius of up to 500m and in an exceptional case of 1000m, which strongly impedes the rediscovery, especially when the terrain is heterogenic and (partially) inaccessible. Third, the real disappearance of recorded priority plant species is likely reflected in the low rediscovery rate. Especially in the case of large, conspicuous species as for instance *Gentiana cruciata*, a low rediscovery rate might indicate the regional disappearance of this species. At some locations, it was obvious that the target population must have disappeared (Figure 8), for example when there was a road renovation or a complete shrub encroachment. Most of the time, however, it was not possible to identify the reasons of why a certain population could not be rediscovered at a certain location.

Figure 8. Examples of locations where the priority plant species recorded in the Info Flora database has certainly disappeared. (a) Tar disposal site, probably due to a road renovation, at the location of a recorded *Campanula cervicaria*; (b) landslide at the site of a recorded *Knautia godetii*.

Suggestion of micro reserve implementation around Moutier (BE)

According to the species-score system, species with lowest scores have the highest necessity of local protection within the study region (Table 2). Thus, the following species should be prioritized for the implementation of micro reserves within the study region: *Gypsophila muralis*, *Tephroseris helenitis*, *Euphorbia palustris*, *Rosa sherardii* and *Gentiana germanica*. The populations of these species are distributed across the whole study region, so that 15 PMRs would have to be installed for their conservation. One of them would include not only the target species *G. germanica* but also individuals of *G. cruciata*. In terms of spatial planning, the parcels with the maximum numbers of rediscovered populations should be suggested for the implementation of micro reserves. There are only five parcels which include seven or more populations. Parcel A belongs to the community Sauge and is part of the national inventory of dry meadows. 18 rediscovered individuals of *Gentiana cruciata* occur within this parcel, whereby a third of them is locally threatened through potentially competitive exclusion through *Rubus fruticosus*. Five individuals of *G. cruciata* could not be rediscovered and might have disappeared, thus there is a need of action regarding the priority plant species within this parcel. Parcel B in Moutier includes six populations of *Trifolium ochroleucon* and nine individuals of *G. cruciata*, from which only one is locally threatened through bush encroachment. Parcel C includes seven populations of *T. ochroleucon* and three individuals of *Rosa sherardii*, from which two are locally threatened. Parcel D in the community Crémines covers a large area, thus the occurring populations

of *T. ochroleucon* and *Centaurium pulchellum* could be protected in two separate PMRs. The two populations of *C. pulchellum* occur in a small local reserve within the parcel but are locally threatened through animal or human trampling. In addition, two populations of the same species could not be rediscovered. Parcel E in Lengnau includes four large individuals of *Rumex hydrolapathum* and two locally endangered individuals of *C. pulchellum*. Finally, the combination of the species-score system and the selection of parcels with the maximum number of rediscovered priority plant species (parcels A-E) leads to the suggestion of 18 PMRs on 12 different parcels for priority plant species within the study region (Figure 9, documented PMRs see appendix). Their implementation would protect the following species: *Gentiana cruciata*, *G. germanica*, *Rosa sherardii*, *Euphorbia palustris*, *Tephroseris helenitis*, *Gypsophila muralis*, *Rumex hydrolapathum*, *Centaurium pulchellum* and *Trifolium ochroleucon*. Thus, 9 of 17 rediscovered species would be included in only 18 PMRs with sizes between 0.012 and 4.89 ha.

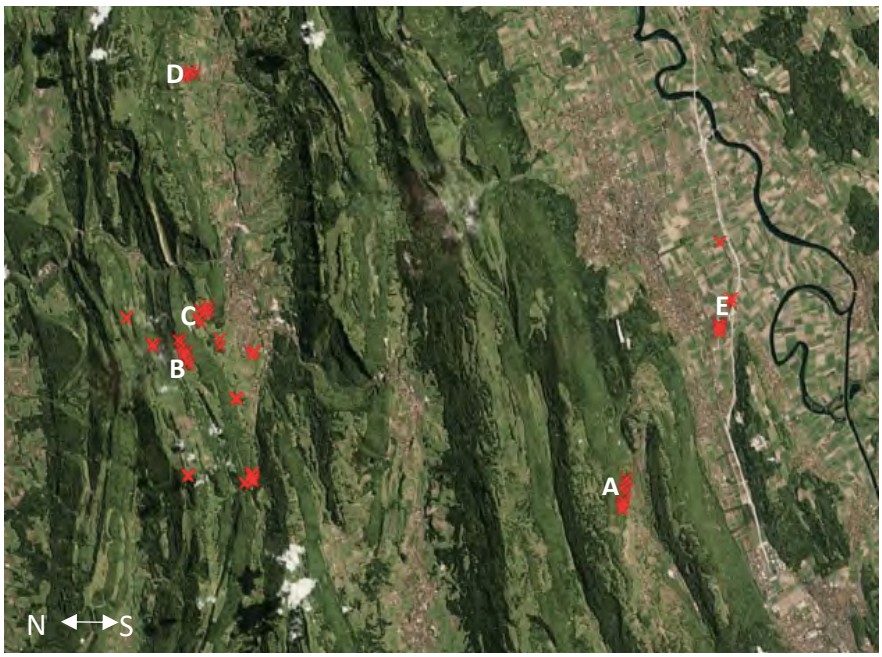

Figure 9. The red crosses represent the 18 suggested plant micro reserves for priority plant species within the study region around Moutier (Bern) (satellite image from Bing aerial).

Discussion

Protection of priority plant species in the canton of Bern

The first hypothesis is supported by the finding that 44% of the priority plant species recorded within the canton of Bern occur outside legally protected areas. The fact that this fraction is 80% within the region assessed in this case study shows that depending on the region, the protection of priority plant species provided by legally protected areas can be very low. In addition, there might be a sampling bias towards national inventories, because their implementation often includes the identification of the present plant species (i.e. in respect to the national inventory of dry meadows), with what the actual fraction of priority plant species outside protected areas might even be larger. This is supported by the results of this study, since 90% of the records of priority plant species that were newly made during the field survey within the study region occur outside protected areas.

The evaluation of the present rediscovery rate of 51% shows that the rediscovery success is enhanced, when the field visits are done by expertized botanists and locations are visited 3-4 times (Kempel et al., in preparation). But even then, the rediscovery rate is not larger than 77% (Kempel et al., in preparation), indicating that there is likely a true disappearance of priority plant species in both study regions. Also, the fact that species conspicuity (species mean height and length of flowering period) did not affect the rediscovery rate, indicates that the fraction of overlooked species might be low. The finding of a significantly lower rediscovery rate with increasing age of the record indicates the real disappearance of priority plant species. Thus, the low rediscovery rate within this study might to a large part reflect the real disappearance of priority plant species within the study region. The disappearance is likely to affect priority plant species regardless of their threat status, as this had no effect on the rediscovery rate.

In addition, the findings of the field survey in this study agree with the presumption that priority plant species are not sufficiently protected even *within* protected areas. Possiel et al. (1995) already stated: "It is not sufficient to establish a conservation area and then assume its biodiversity is automatically protected and without risk". The rediscovery rate within this case study was low both within and outside protected areas without a significant difference, indicating that there might be a disappearance of priority plant species both within and outside protected areas. Within the study region, the proportion of locally threatened populations was larger within than outside protected areas. Even though this difference was not significant, it indicates that priority plant species can be locally threatened both outside and inside protected areas. Examples of rediscovered priority plant species within protected areas show that legal natural reserves do not necessarily promote the protection of included priority plant species. This is in accordance with a study by the BAFU (2017), which reports that lacking financial and personal means are often a reason for the insufficient management of different types of natural reserves in Switzerland. Especially dry meadows of national importance are not used in accordance with the law and bush cover is increasing rapidly in some cases (BAFU 2017). The field survey of this study supports the assumption that especially the inventory of dry meadows does not provide effective protection of habitat specific priority plant species. Dry meadow species were not found more often than species of other habitats, even though most of the protected areas within the study region belonged to the national inventory of dry meadows. This might show that the presence of legally protected dry meadows must not necessarily enhance the protection of dry meadow plant species. Gigon (2016) as well stated that in Switzerland, the legal protection of an area does not mean an effective protection of the included priority plant species. Many reserves are not indicated on site and therefore unidentifiable for visitors, which can lead to trampling or plucking (Gigon 2016). Also, larger reserves in Switzerland often belong to multiple land owners, which can complicate the management (Gigon 2016). Further, the purpose of many reserves is not primarily the protection of priority plant species but of habitats, thus an adequate management of these species is missing (BAFU 2017). Considering this and the results of this case study, it can be stated that within the canton of Bern and probably throughout Switzerland, priority plant species are not adequately protected through existing nature reserves. First, because a large proportion of priority plant species occurs outside protected areas, second, because there is probably a decline in priority plant species and third, because the protected areas do not provide sufficient protection for priority plant species. Thus, there is a need of additional protection of priority plant species within the canton of Bern and the establishment of PMRs within already existing reserves should be considered as well. The pioneer work on the establishment of a PMR network in the Valencian region already includes

PMRs *within* natural reserves, in order to manage the vegetation according to the needs of the target species (Laguna et al. 2004).

Effective micro reserve implementation requires field visits of the potential locations

This study shows that the Info Flora database is a valuable tool for the identification of potential micro reserves. The long-term record of species distributions enables an initial spatial analysis and allows to prioritize locations according to the number of species and records and the presence of different land use- and/or natural reserves types. However, the low rediscovery rate within this study region and the spatial mismatch between coordinated populations from the Info Flora database and from the field survey indicate that there is a gap between the database and the present situation. The field data of this case study show that the rediscovery rate decreases with increasing age of the record (significant) and with increasing inaccuracy of its coordinates (non-significant). The use of the database alone might therefore lead to the proposal of PMRs at locations, where there are ultimately no target populations present, which is in accordance with the second hypothesis. Hence, the planning of a Swiss-wide PMR network should consider only records of priority plant species not older than five years and with an inaccuracy radius not larger than 10 meters. In addition, more reserves should be planned than are ultimately politically feasible, since the on-site inspection will show that some locations are not suitable.

This study shows that field work provides important parameters which help to prioritize locations for PMR setting, such as local threats, verification of presence and spatial accuracy. Also, the investigation of the population size could serve as an additional element for the prioritization of potential locations, although it is not yet clear how to apply population size in priority setting. It might be meaningful both to protect very small populations, since they are prone to local extinction, as well as large populations, because they might turn into a source population in the future. Among the field work derived parameters, the local threat status of priority plant species might be most important for the planning of a PMR network. PMRs should be established primarily, where (small) populations of rare and protected species are acutely threatened (Gigon 2016). The PMR network establishment both in the Valencian region and Crete included the precedential identification of local threats of the target species as a decisive parameter (e.g Laguna et al. 2004; Kadis et al. 2013).

Without field surveys, PMR locations can be prioritized solely based on the spatial distribution of priority plant species. Prioritizations in this case can be made only on the species and on the land-use designation level. The lack of information on local population threats, on population size, the spatial accuracy of coordinates and the question of whether the population still exists, might probably decrease the efficiency of PMR planning. Still, the Info Flora database serves as a very good base for preliminary spatial analyses and the subsequent selection of potential PMR locations. Both studies on PMR networks in the Valencian region and in Crete included field visits before the spatial data analysis, since there was no data on species distribution records available (Laguna et al. 2004; Kadis et al. 2013). Thus, the availability of long-term records of priority plant species saves a lot of work in advance. Nevertheless, field visits of these locations are necessary at the latest when PMR implementation takes place. Otherwise, species and populations presence within the PMR, as well as PMR size and measures remain unknown.

Micro reserves are necessary and need prioritizations

Although the implementation and maintenance of PMRs is expected to require only little financial means due to their small area (Gigon 2016), it is important to prioritize conservation actions in terms of species and locations (Arponen 2012), because the political effort for reserve implementation might be large. In this case study, prioritizations for PMR implementation were done after the field survey on the species and the parcel level. This combination of species- and parcel-based prioritization of locations for PMR implementation might be an effective approach to choose locations that: (i) include populations of species with highest need for protection and (ii) maximize the number of priority plant species populations per area. The final implementation will depend on the acceptance of authorities and land owners and on the availability of financial means.
This study considered the species local threat as the most important argument to evaluate the species necessity for its conservation through small reserves, which is in accordance with Laguna et al. (2013). Besides the necessity, also the suitability for PMR-mediated protection should be considered in order to prioritize species for PMR implementation. However, information about the species suitability for PMR-mediated protection is still missing for the time being. Within the study region, there was no difference in the rediscovery rate among different life forms (Raunkiaer 1934) and strategy types (Grimes 1979). Therefore, nothing can be inferred about the spatial movement and thus about the suitability for the protection of small reserves for different plant groups. In respect to the third hypothesis, it can only be concluded that there is a need of additional protection of priority plant species within the study region and the canton of Bern. The necessity of PMR-mediated protection varies from species to species depending on its local and regional threats, but species-specific suitability for PMR-mediated protection remains unknown. Also, the evaluation whether PMRs provide effective protection for Swiss priority plant species is still unclear, since this requires a regular monitoring of existing PMRs. During the field visits in this case study, however, already existing PMRs established by the community were discovered. These contained dense populations of *Gentiana cruciata*, indicating that appropriate management helps to maintain populations of threatened species within small reserves.

Within this case study, there is an appropriate number of replicates (67 visited records) for *Gentiana cruciata*, which allows to make a reliable estimate of the state of this species in the region around Moutier (BE). The appropriate number of replicates (67 visited records) for *G. cruciata* allows to make a reliable estimate of the state of this species in the region around Moutier (BE). As *G. cruciata* is a conspicuous species and easily to detect also in its vegetative state, the rediscovery rate of 61% indicates that there might be a decline of populations since 2001. A third of all observations occurs outside protected areas, and the same fraction is observed to be threatened either through bush encroachment or trampling, thus there is a need of action. Among the species included in the 18 potential PMRs suggested for the study region, *G. cruciata* is the most abundant. The establishment of a network of micro reserves could help to maintain and even increase the existing populations, which might serve as source for future populations. Large populations of *G. cruciata* are required not only for the conservation of this plant species, but also for the endangered butterfly *Phengaris rebeli* for which *G.cruciata* is the exclusive food host (Kéry et al. 2001). Indeed, 23.5% of the *G.cruciata* individuals showed eggs of *P.rebeli* on the leaf surfaces and the egg-laying butterflies were observed as well (Figure 9). This example shows that the local survival of a rare and endangered plant species might determine the fate of another associated rare species as well (Kéry et al. 2001). Thus, the

knowledge on biotic interactions might be important for conservation prioritisation and the establishment of an effective PMR-network in Switzerland.

Figure 9. *Phengaris rebeli*, lying eggs on its exclusive host plant *Gentiana cruciata*, a priority plant species that occurs relatively abundant within and outside protected areas within the study region.

There are different types of plant micro reserves

Assuming PMRs would be implemented for all rediscovered records of priority plant species within the study region, they would all have to be regarded as individual cases, since they are from different shape, size and content. Nevertheless, the identified sites can be classified into different categories of PMR types, as presumed in the fourth hypothesis. For instance, there are species which occur in small and dense populations or as single individuals only, thus the PMR in this case would have to be rather small (e.g regarding *Achillea ptarmica*, *Trifolium ochroleucon* and *Gypsophila muralis*). Other species occur less densely and more scattered, whereby the PMR would have to be larger (e.g regarding *Gentiana cruciata*, *Centaurium pulchellum*, *Tephroseris helenitis* and *Alisma lanceolatum*). Then, there are species such as *Centaurium pulchellum*, which need a certain level of disturbance to provide a dynamic system, which would have to be maintained by the PMR. Also, there are sites where PMRs would have to be implemented more urgently, because the target species are acutely threatened (e.g small individuals of *Gentiana cruciata* that are almost overgrown by *Rubus fruticosus*). There are PMR types that would protect more than one priority plant species, and PMRs that would protect only one priority plant species but many other plant species as well. Whereas some PMRs would be situated in already existing reserves, others would be situated on arable fields, along hiking trails or road borders. Depending on the location and the land owner (community versus private person), PMRs might also differ regarding their implementation probability and facility. Finally, these observations only give an idea of how PMRs could be categorized in different types and further research would be needed to address this issue in detail.

Establishment of a PMR network in Switzerland

In respect to the development of a Swiss-wide PMR network for the biodiversity infrastructure 2040, the present method could be adapted. Since Swiss politics are structured on the federal, cantonal and community level, the PMR network should probably be developed on the cantonal level. In a first step, for each canton, species could be prioritized based on priority, need of action and suitability. Based on the selected species list, a similar spatial analysis of species distribution could be conducted in a second step, in order to detect hot spots of species and population aggregations. As natural reserves do not necessarily provide adequate protection of priority plant species, also species aggregations within protected areas should be considered for PMR implementation. The parcel-score calculation could therefore be neglected. In a third step, parcels with the maximum number of populations and species should be selected for PMR implementation. If financial means are available, the potential locations should be visited, to ensure whether the populations are present and to take specific measures. The PMR implementation of the finally proposed locations includes the obtaining of

authorization and the information of land owners. The PMR could be delimited with a rope between wood piles 1m above the ground, which has successfully been done in the PMR network of Valencia (Laguna et al. 2013, Gigon 2016). Information boards about the threat, ecology and required management could be installed next to the PMR. The PMR should be managed by the land owner or members of a local association for nature conservation (Gigon 2016).

Conclusion

Priority plant species are insufficiently protected in the canton of Bern, since only 55.8% of the total populations occur in legally protected areas. In addition, populations of priority plant species are often very small, and they are locally threatened even within legally protected areas. The low rediscovery rate of plant populations that were previously recorded in the Info Flora database show the disappearance of priority plant species within the study region. Therefore, there is a necessity of PMR implementation, not only outside but also within already existing nature reserves. This study shows that field work provides important parameters for PMR implementation, such as local threats, population and PMR size, as well as specific provisions. The most important benefit of field work is the verification of a species at a certain location. To circumvent this logistic problem, only very actual and accurate records of priority plant species should be used for PMR setting, and more potential micro reserves should be selected based on the database records than can ultimately be implemented. The Info Flora database is a useful tool for the selection of potential PMRs, however, the data need to be validated by field visits before PMR implementation. Further research is necessary to assess different types of PMRs and the suitability of different species for PMR-mediated protection. In this case study, the implementation of 18 PMRs within the study region (Jura Bernois) would protect populations of 10 locally threatened plant priority species, of which *Gentiana cruciata* is the most abundant.

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References

Arponen, A. (2012). Prioritizing species for conservation planning. *Biodiversity and Conservation*, *21*(4), 875-893.

Araújo, M. B., Lobo, J. M., & Moreno, J. C. (2007). The effectiveness of Iberian protected areas in conserving terrestrial biodiversity. *Conservation Biology*, *21*(6), 1423-1432.

Atienza, V., Segarra Moragues, J. G., & Laguna Lumbreras, E. (2001). Propuesta de microrreservas vegetales: una alternativa para la conservación de líquenes en la comunidad Valenciana. *Botanica Complutensis, 25*, 115-128.

BAFU, in press (2019). Liste der National Prioritären Arten und Lebensräume. Arten mit nationaler Priorität für die Erhaltung und Förderung, Stand 2010. *Bundesamt für Umwelt, Bern. Umwelt-Vollzug*

BAFU (2017). Ausgewiesene Gebiete zum Schutz und zur Förderung der Biodiversität in der Schweiz. Faktenblatt. *Bundesamt für Umwelt (BAFU). Bern.*

BAFU (2017). Aktionsplan des Bundesrates. 2017. Aktionsplan Strategie Biodiversität Schweiz. *Bundesamt für Umwelt (BAFU). Bern.*

BAFU (2017). Biodiversität in der Schweiz: Zustand und Entwicklung. Ergebnisse des Überwachungssystems im Bereich Biodiversität, Stand 2016. *Bundesamt für Umwelt, Bern. Umwelt-Zustand Nr*. 1630: 60 S.

Blasi, C., Marignani, M., Copiz, R., Fipaldini, M., Bonacquisti, S., Del Vico, E., ... & Zavattero, L. (2011). Important plant areas in Italy: from data to mapping. *Biological Conservation*, *144*(1), 220-226.

Bornand, C. N., Kéry, M., Bueche, L., & Fischer, M. (2014). Hide-and-seek in vegetation: time-to-detection is an efficient design for estimating detectability and occurrence. *Methods in Ecology and Evolution*, *5*(5), 433-442.

Bornand, C., Gygax, A., Juillerat, P., Jutzi, M., Möhl, A., Rometsch, S., Sager, L., Santiago, H. & Eggenberg, S. (2016). Rote Liste Gefässpflanzen. Gefährdete Arten der Schweiz. *Bundesamt für Umwelt, Bern und Info Flora, Genf. Umwelt-Vollzug Nr.* 1621: 178 S.

Burkey, T. V. (1989). Extinction in nature reserves: the effect of fragmentation and the importance of migration between reserve fragments. *Oikos*, 75-81.

Delarze, R., Gonseth, Y. & Eggenberg, S. (2015). Lebensräume der Schweiz. Ökologie – Gefährdung – Kennarten. 3. Auflage. *Ott Verlag*.

Fahrig, L., & Merriam, G. (1994). Conservation of fragmented populations. *Conservation biology*, *8*(1), 50-59.

Gigon, A, unpublished (2016). Vorschlag für die Einführung von Pflanzen-Mikroreservaten in der Schweiz.

Gimeno, C., Puche, F., Segarra, J. G. & Laguna, E. (2001). Modelo de conservación de la flora briológica en la Comunidad Valenciana: microrreservas de flora criptogámica. *Botanica Complutensis*, *25*, 221-231.

Gnägi, C., unpublished (2015). Masterplan Orchideenschutz Kt. Bern. Bericht im Auftrag der Abteilung für Naturförderung des Kt. Bern.

Gómez-Campo, C., & Herranz-Sanz, J. (1993). Conservation of Iberian endemic plants: the botanical reserve of La Encantada (Villarrobledo, Albacete, Spain). *Biological Conservation*, *64*(2), 155-160.

Grime, J.P. (1979). Plant strategies and vegetation processes. *John Wiley & Sons*, Chichester.

International Union for Conservation of Nature (2010) Discussion note to accompany IUCN's position paper on the Convention on Biological Diversity (CBD) strategic plan 2011–2020: target 20. IUCN, Cambridge, p5

Kadis, K., Thanos, C. A. & Lumbreras, E. L. (Eds.). (2013). Plant micro-reserves: From theory to practice. *Utopia publishing*.

Kempel, K., Bornand, C., Sager, L., (Bäumler, B.), Gygax, A. & Fischer, M. (in preparation). Nationwide revisitation of threatened plant species of Switzerland reveals considerable local extinction.

Kéry, M., Matthies, D., & Fischer, M. (2001). The effect of plant population size on the interactions between the rare plant Gentiana cruciata and its specialized herbivore Maculinea rebeli. *Journal of Ecology*, *89*(3), 418-427.

Laguna, E., Deltoro, V. I., Pérez-Botella, J., Pérez-Rovira, P., Serra, L., Olivares, A. & Fabregat, C. (2004). The role of small reserves in plant conservation in a region of high diversity in eastern Spain. *Biological Conservation, 119(3),* 421-426.

Laguna, E., Ballestar, G., Deltoro, V., Fos, S., Carchano, R., Oltra, J. E., ... & Pérez-Rovira, P. (2013). A Pioneer Project: The Valencian PMR Network. Plant Micro-Reserves: From Theory To Practice, 13-23.

Laguna, E., Ballester, G. & Deltoro, V. (2013). Plant Micro-Reserves (PMRs): Origin and Technical Concept. Plant Micro-Reserves: From Theory To Practice, 3-12.

Laguna, E., Fos, S., Jiménez, J. & Volis, S. (2016). Role of micro-reserves in conservation of endemic, rare and endangered plants of the Valencian region (Eastern Spain). *Israel Journal of Plant Sciences, 63(4),* 320-332.

Landolt, E., Bäumler, B., Erhardt, A., Hegg, O., Klötzli, F., Lämmler, W., ... & Vust, M. (2010). Flora indicativa: Ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen. Haupt.

Liu, Q., Chen, J., Corlett, R. T., Fan, X., Yu, D., Yang, H., & Gao, J. (2015). Orchid conservation in the biodiversity hotspot of southwestern China. *Conservation Biology, 29(6),* 1563-1572.

Maxted, N., Hawkes, J. G., Guarino, L. & Sawkins, M. (1997). Towards the selection of taxa for plant genetic conservation. *Genetic Resources and Crop Evolution, 44(4),* 337-348.

Moreno Saiz, J. C., Castro Parga, I., Humphries, C. J., & Williams, P. H. (1996). Strengthening the national and natural park system of Iberia to conserve pteridophytes. *Pteridology in perspective*, 101ą123.

Possiel, W., Saunier, R. E., & Meganck, R. A. (1995). In-situ conservation of biodiversity. *Conservation of biodiversity and the new regional planning*, 7-20.

Raunkiaer, C. (1934). The life forms of plants and statistical plant geography. *Oxford University press, London.*

Volis, S. (2016). How to conserve threatened Chinese plant species with extremely small populations? *Plant diversity, 38(1),* 45-52.

Websites:

https://fr.climate-data.org/europe/suisse/berne/moutier-100283/ (2018)

https://www.cbd.int/gspc/strategy.shtml (2019)

https://www.infoflora.ch/de/daten (2019)

https://www.bafu.admin.ch/bafu/de/home/themen/biodiversitaet/fachinformationen/massnahmen-zur-erhaltung-und-foerderung-der-biodiversitaet/oekologische-infrastruktur.html (2019)

Appendix

Species list

Table 3. List of all visited records of priority plant species within the study region around Moutier, Bern. The rediscovery rate is calculated by dividing the number of rediscovered records of a species through the total number of visited records of this species. Records means the total number of visited records of a species. The species priority is derived from the list of national priority species (BAFU 2011), which pools the species threat (IUCN), the international responsibility of Switzerland for this species and the need of conservation action concerning this species. Threat IUCN: LC = least concern, NT = near threatened, VU = vulnerable, EN = endangered, CR = critically endangered. International responsibility: 1 = low, 2= intermediate, 3= high. Need of action: 1 = insecure, 2 = clear.

Species	Rediscovery	Records	Priority	Threat IUCN	International responsibility	Need of action
Achillea ptarmica L.	0.5	2	4	VU	1	1
Alisma lanceolatum With.	1	1	3	EN	1	2
Bupleurum longifolium L.	0	1	4	VU	1	2
Calla palustris L.	0	2	3	EN	1	2
Callitriche cophocarpa Sendtn.	0.166667	6	4	VU	1	1
Campanula cervicaria L.	0	1	3	EN	1	2
Campanula rhomboidalis L.	0.5625	16	4	LC	3	NA
Carex praecox Schreb. s.str.	0	2	3	EN	1	2
Carex pseudocyperus L.	0	2	4	VU	1	1
Carex vulpina L.	0	2	3	EN	1	2
Centaurium pulchellum (Sw.) Druce	0.428571	14	4	VU	2	1
Cirsium tuberosum (L.) All.	0	2	4	VU	1	1
Dianthus gratianopolitanus Vill.	0.5	4	3	VU	2	1
Euphorbia palustris L.	0.666667	3	4	VU	1	1
Genista pilosa L.	0	8	4	VU	1	1
Gentiana cruciata L.	0.61194	67	4	VU	1	1
Gentiana germanica Willd.	0.6	5	4	VU	1	1
Gypsophila muralis L.	0.666667	3	3	EN	1	2
Knautia godetii Reut.	0	1	4	VU	1	1
Melampyrum arvense L.	0	4	4	VU	1	1
Melampyrum nemorosum L.	0	0	2	EN	2	2
Odontites vulgaris Moench	0.916667	12	4	VU	1	1
Ophrys apifera Huds.	0	2	4	VU	1	1
Pedicularis sylvatica L.	0	3	4	VU	1	1
Prunella laciniata (L.) L.	0	2	4	VU	1	1
Rhinanthus angustifolius C. C. Gmel.	0	1	4	VU	1	1
Rorippa amphibia (L.) Besser	1	4	4	VU	1	1
Rosa sherardii Davies	0.6	10	4	NT	2	NA
Rumex hydrolapathum Huds.	0.666667	15	4	VU	1	2
Tephroseris helenitis (L.) B. Nord.	0.571429	14	3	EN	1	2

Thalictrum flavum L.	1	1	4	VU	1	1
Trifolium ochroleucon Huds.	0.791667	24	4	VU	1	1
Veronica anagalloides Guss.	0	1	2	CR	1	2
Veronica scutellata L.	0	1	4	VU	1	1

Plant micro reserve (PMR) suggestions for the study region around Moutier (BE)

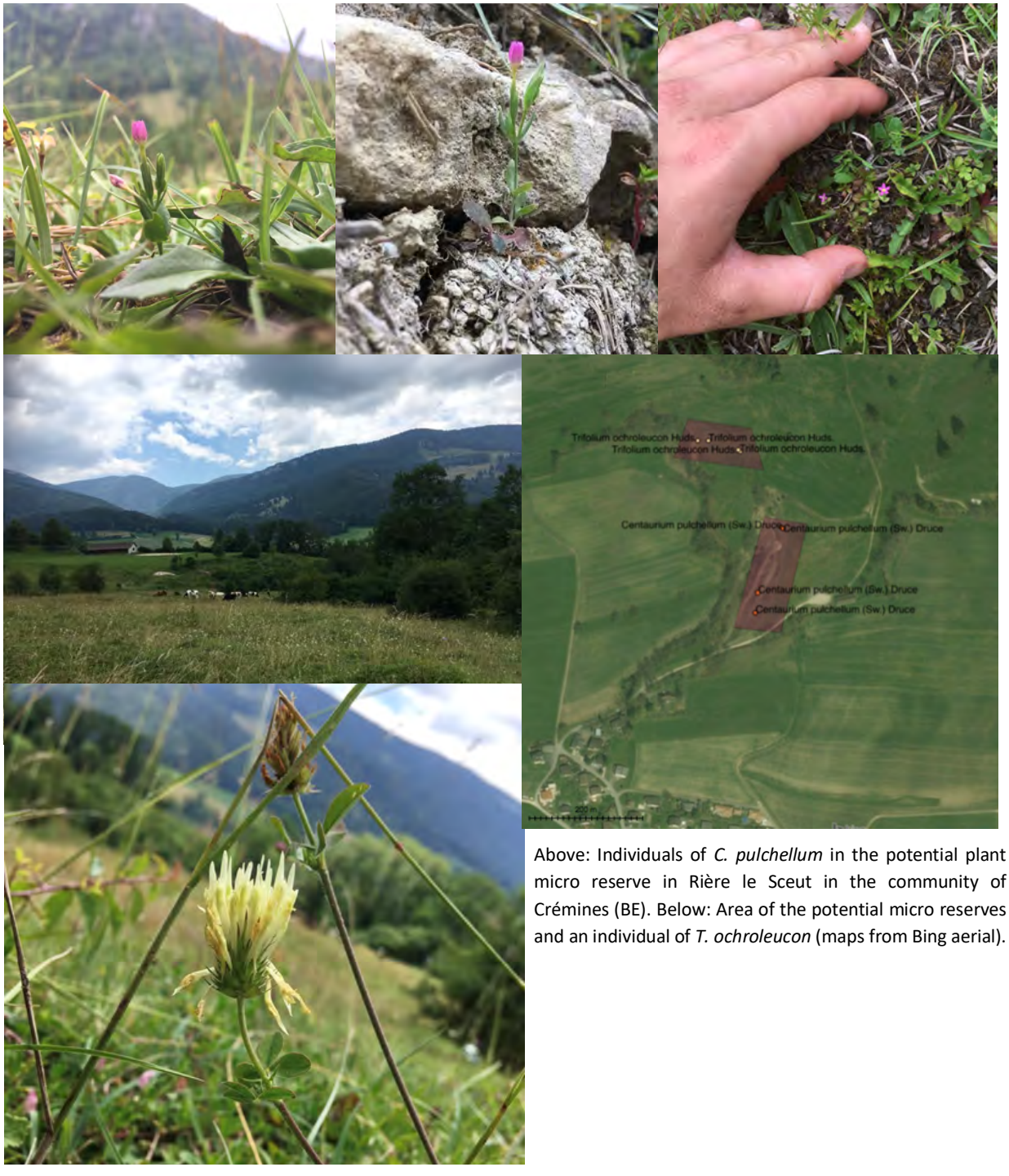
<u>Plant micro reserve number 1: Chlyni Ey, Lengnau (BE)</u>

Size: 0.83 ha
Parcel number: 113697
Coordinated center: 594796 / 224150 (CH1903 / LV03)
Target species: *Rumex hydrolapathum* (VU), *Centaurium pulchellum* (VU)
Local threats: The location belongs to the biosphere "Leugene", an area which is not legally protected but managed as nearly natural habitat since 1988. The four individuals of *R. hydrolapathum* are tall (1.5-2m) and mostly not locally threatened. However, one individual is kinked, and another individual is still small (<1m). There are two individuals of C*. pulchellum* with a size of 3-5cm, which can be overlooked easily and might be locally threatened through trampling.
Measurements: The individuals of *C. pulchellum* could be fenced and marked with a cord. The same could be done for the small and for the kinked individuals of *R. hydrolapathum.* Regular field visits should attest that the small individuals of *C. pulchellum* are free from competitive exclusion.

Left: Potential micro reserve for priority plant species in the area of the "Chlyne Ey" in the community Lengnau (BE) (map from Bing aerial). The target species are located close to the waterbody (map from Bing satellite). Right: Above, flowers of the 1.5-2m tall *R. hydrolapathum*. At the bottom, one of the two individuals of *C. pulchellum*.

Plant micro reserve number 2 and 3: Rière le Sceut, Crémines

Sizes: 0.44 ha and 0.73 ha
Parcel number: 273435
Coordinated centers: 599928 / 237722 and 599994 / 237620 (CH1903 / LV03)
Target species: *Trifolium ochroleucon* (VU), *Centaurium pulchellum* (VU)
Local threats: The three small populations of *T. ochroleucon* are potentially threatened through grazing by cows. The three small populations of *C. pulchellum* are locally threatened through trampling and two populations through bush encroachment.
Measurements: Bush encroachment could be prevented through weeding. The populations could be fenced in order to forestall trampling and grazing.



Above: Individuals of *C. pulchellum* in the potential plant micro reserve in Rière le Sceut in the community of Crémines (BE). Below: Area of the potential micro reserves and an individual of *T. ochroleucon* (maps from Bing aerial).

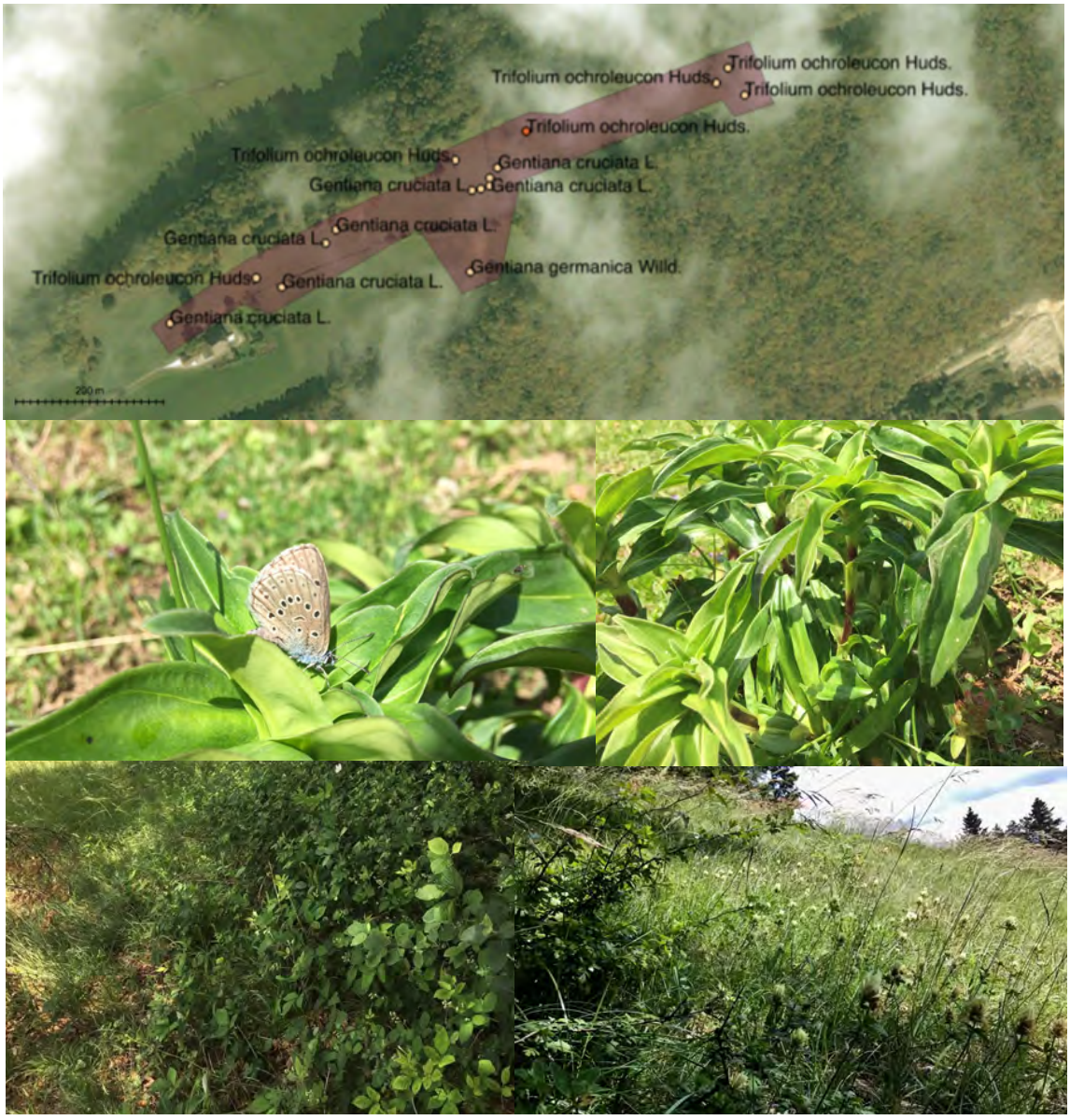
Plant micro reserve number 4, 5 and 6: Patûrage du Droit, Moutier

Sizes: 0.64 ha, 0.57 ha and 2,48 ha
Parcel number: 272025
Coordinated centers: 593882 / 236899, 594580 / 237291 and 594453 / 237492 (CH1903 / LV03)
Target species: *Trifolium ochroleucon* (VU) and *Rosa sherardii* (NT)
Local threats: The populations of *T. ochroleucon* are potentially threatened through grazing by cows and the individuals of *R. sherardii* partially through bush encroachment through *Rubus fruticosus*.
Measurements: The populations could be fenced in order to prevent grazing and *R. fruticosus* could be cut to prevent competitive exclusion.

Above: Area of the three potential plant micro reserves in the "Patûrage du Droit" in the community of Moutier (BE) (map from Bing aerial). Center: Individual of *T. ochroleucon* and grazing cows within the area of the micro reserve number 4. Below: Fruits, leaves and prickles of *R. sherardii*. Characteristic for this species are the remaining and straight caliches of the fruits and the glanded leaves.

Plant micro reserve number 7: Le clos, Moutier

Size: 3.75 ha
Parcel number: 274284
Coordinated center: 593648 / 237806 (CH1903 / LV03)
Target species: *Trifolium ochroleucon* (VU) and *Gentiana cruciata* (VU)
Local threats: The populations of *T. ochroleucon* are large (up to 100 individuals) but partially threatened through competitive exclusion through *Rubus fruticosus* and *Crataegus monogyna*. The individuals of *G. cruciata* are yet not threatened, since the horses and cows on the field specifically avoid this species when they are grazing.
Measurements: *R. fruticosus* and *C. monogyna* should be cut to avoid competitive exclusion of *T. ochroleucon*. The individuals of *G. cruciata* could be fenced in order to promote the dispersal of juveniles.



Above: The area of the potential micro reserve in "Le Clos", Moutier (BE) (map from Bing aerial). Center: Individuals of *G. cruciata* as well as *Phengaris rebeli*, lying eggs on *G. cruciata*, which is its exclusive host plant. Below: A population of *T. ochroleucon* is partially overgrown by *R. fruticosus* and *C. monogyna*.

Plant micro reserve number 8: Sous la Côte, Sauge

Size: 4.89 ha
Parcel number: 154296
Coordinated center: 590400 / 226801 (CH1903 / LV03)
Target species: *Gentiana cruciata* (VU)
Local threats: Seven out of 23 individuals are locally threatened through bush encroaching, mainly by *Rubus fruticosus* and *Crataegus monogyna*. In addition, trampling through cows might prevent seedlings to establish.
Measurements: *C. monogyna* and *R. fruticosus* should be cut and the individuals of *G. cruciata* could be fenced in order to support the local dispersal of juveniles.

Above: Area of the potential plant micro reserve in "Sous la Côte" in the community Sauge (BE) (map from Bing aerial). The parcel legally belongs to the national inventory of dry meadows, however, the management seems to be poor, since large parts of the field are overgrown by *Rubus fruticosus* (right center). Trampling through cows might prevent the local dispersal of *Gentiana cruciata* (left center). Below: Individuals of *G. cruciata,* with eggs from *Maculinea rebeli* on their leaves and partially overgrown by dominant species (right bottom).

Plant micro reserve number 9 and 10: Les Combattes, Moutier

Size: 0.03 ha and 0.028 ha
Parcel number: 274665
Coordinated center: 593593 / 236090 and 593661 / 236032 (CH1903 / LV03)
Target species: *Gypsophila muralis* (EN)
Local threats: Both populations of *G. muralis* are small (<1m2) and grow on biodiversity promoting areas next to arable fields. They might be threatened through mowing, fertilizing of the adjacent fields and/or competitive exclusion through dominant grass species and *Rubus fruticosus*. The land owner did not know about the presence and the rarity of this priority plant species, whereby the inappropriate management of this area might lead to the disappearance of this endangered species.
Measurements: Both populations of G*. muralis* could be fenced and neighbouring dominant species could be cut back.

Above: Location of the two plant micro reserves at the border of the city Moutier (BE) (map from geo.admin.ch). Below: *Gypsophila muralis* grows within a biodiversity promoting area and is partially overgrown through dominant grass species and *Rubus fruticosus.*

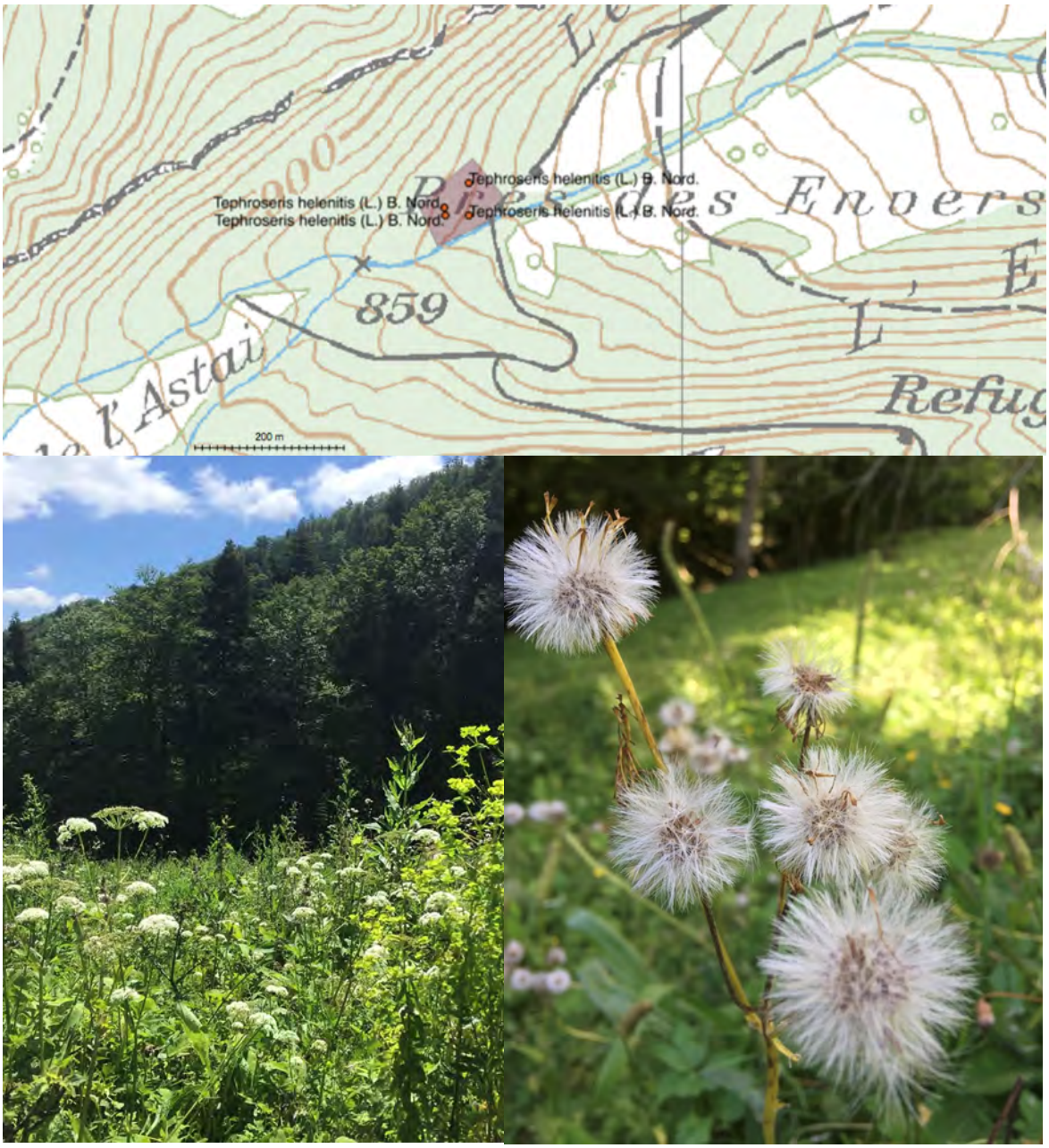
Plant micro reserve number 11: Fond du Clos, Moutier

Size: 0.093 ha
Parcel number: 275177
Coordinated center: 590853 / 237682 (CH1903 / LV03)
Target species: *Tephroseris helenitis* (EN)
Local threats: The population of *T. helenitis* is locally threatened through competitive exclusion through various tall and dominant neighboring species as for instance *Rubus fruticosus* and *Heracleum sphondylium*.
Measurements: The dominant neighboring species could be cut back.

Above: The potential plant micro reserves is located in a small forest in the community of Moutier (BE) (map from Bing aerial). Below: The target species *Tephroseris helenitis* has characteristic spiderweb-like hairs on the leaf surface and on the stem.

Plant micro reserve number 12: Les emenettes, Roches

Size: 0.34 ha
Parcel number: 279286
Coordinated center: 590833 / 237684 (CH1903 / LV03)
Target species: *Tephroseris helenitis* (EN)
Local threats: The population of *T. helenitis* is located on a field with grazing goats and might therefore be threatened through grazing and trampling. In addition, the dense vegetation might potentially lead to competitive exclusion.
Measurements: The populations should be fenced in order to prevent grazing, and dominant neighboring species.



Above: The potential plant micro reserve is located on a field with grazing goats in the community Roches (BE) (map from geo.admin.ch). Below: The target species *Tephroseris helenitis* grows in a dense vegetation and builds a large population with more than 20 individuals.

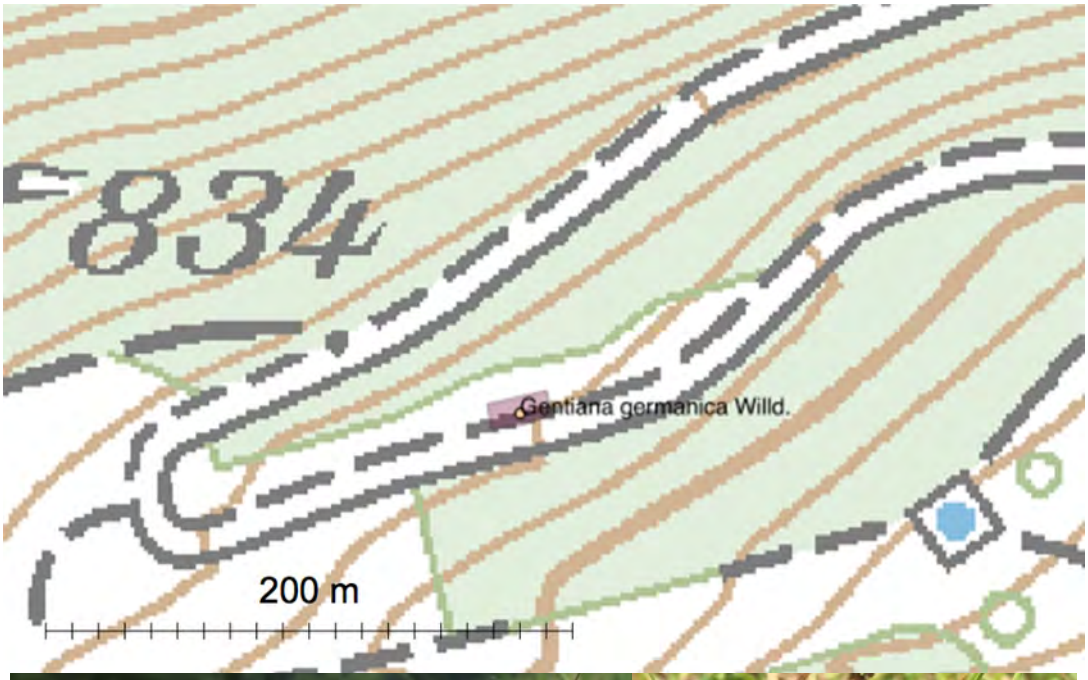
Plant micro reserve number 13: Ey, Lengnau

Size: 0.018km2
Parcel number: 113523
Coordinated center: 596142 / 224417 (CH1903 / LV03)
Target species: *Euphorbia palustris* (VU)
Local threats: The three individuals of this vulnerable species are from a size of 1-1.5m and located at the border of an arable field close to a water shed. A second visit revealed that the individuals are mown during august, which might prevent their dispersal and reproduction.
Measurements: The land owner should be informed about the presence of this priority species in order to prevent the mowing of this small population.

The three individuals of *Euphorbia palustris* grow between a water shed and an arable field (above left) (map from Bing aerial). During June, they were tall grown (above right and below left), however, in august they were mown almost down to the ground (below right).

Plant micro reserve number 14: Roches

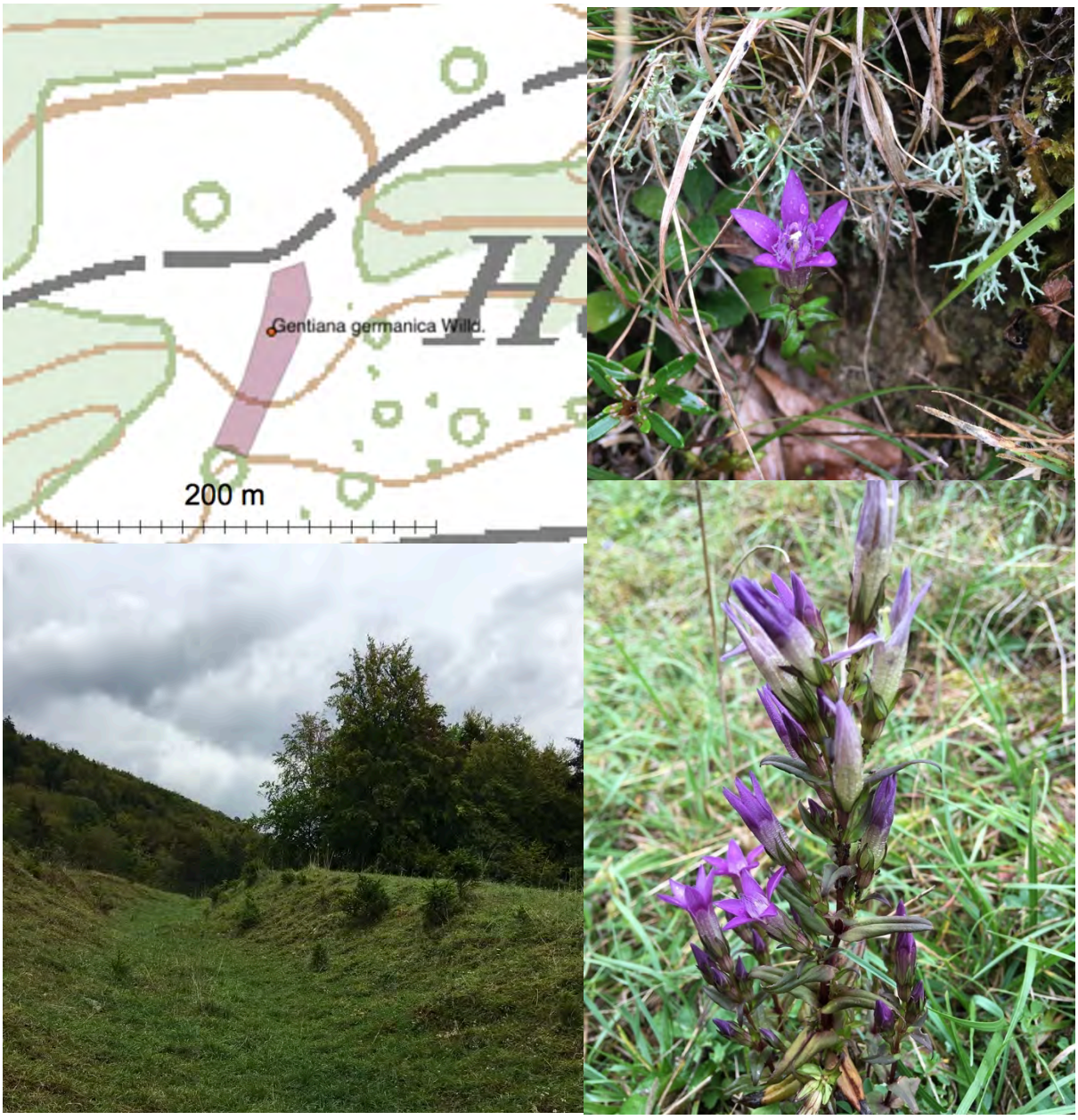
Size: 0.012 ha
Parcel number: 277977
Coordinated center: 594417 / 239208 (CH1903 / LV03)
Target species: *Gentiana germanica* (VU)
Local threats: There is only one individual of *G. germanica,* that grows at the border of a street on a field, which is probably mown regularly during the season. Thus, mowing might lead to the disappearance of this species at this location.
Measurements: the individual of *G. germanica* could be fenced and marked to prevent its mowing.



Above: This is the smallest of all documented potential plant micro reserves, located at the border of a street in the community of Roches (BE) (map from geo.admin.ch). Below: The individual of *Gentiana germanica* grows between fat meadow species on a field that is probably regularly mown.

Plant micro reserve number 15: Perrefitte

Size: 0.075 ha
Parcel number: 277821
Coordinated center: 590794 / 236078 (CH1903 / LV03)
Target species: *Gentiana germanica* (VU)
Local threats: This is the largest observed population of this vulnerable species within the study site, with more than 40 individuals. They grow at the border of a hiking trail and might be plucked by hiking tourists when they are flowering. Also, *Rubus fruticosus*, *Crataegus monogyna* and saplings of *Picea abies* are present on this dry meadow, which could potentially overgrow individuals of *G. germanica*.
Measurements: The population could be fenced with a cord, to prevent potential human or animal disturbance.

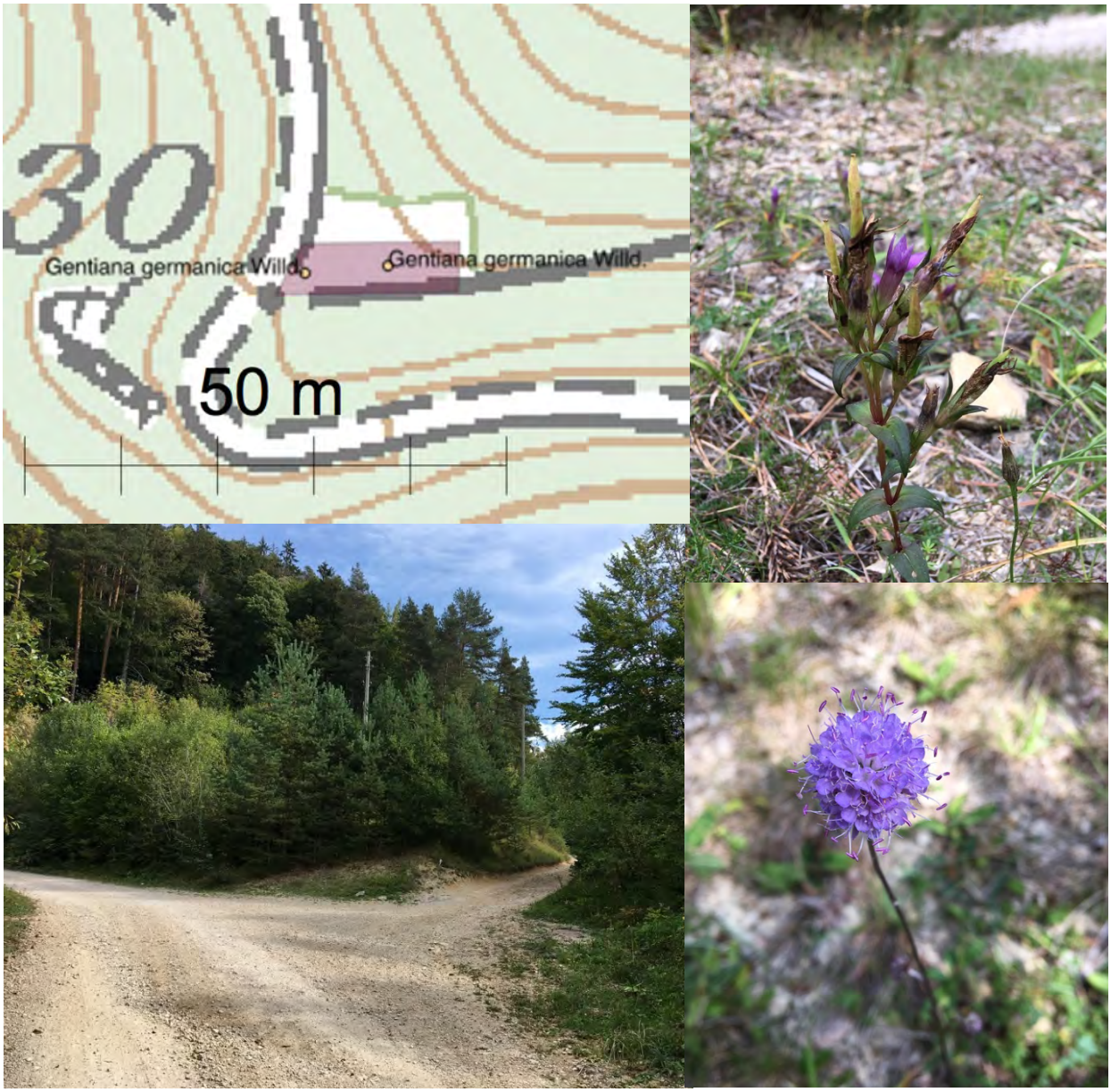


The large population of *Gentiana germanica* is located at the border of a small hiking trail, which is not shown in the map (above left, map from geo.admin.ch). The potential micro reserve would provide the protection of 40 individuals of the vulnerable priority species *G. germanica* (right). Small individuals of *Picea abies* occur at the site, which might become dominant in the near future.

Plant micro reserves number 16, 17 and 18: Perrefitte

Sizes: 0.071 ha, 0.185 ha and 0.059 ha
Parcel number: 277821
Coordinated centers: 590734 / 236074, 590882 / 236116, 590643 / 236282 (CH1902 / LV03)
Target species: *Gentiana germanica* (VU) and *Gentiana cruciata* (VU)
Local threats: The individuals of *G. germanica* and *G. cruciata* in the area of the potential micro reserves number 16 and 17 are mostly threatened through bush encroachment, since the dry meadow is full of large aggregations of *Rosa* sp., *Crataegus monogyna* and *Rubus fruticosus*. Also, trampling through cows might endanger the individuals. The population of *G. germanica* in the potential micro reserve number 18 is located at the border of a forest street between saplings of *Picea abies*, which might become dominant in the future and lead to competitive exclusion of *G. germanica* at this location.
Measurements: The individuals of *G. germanica* and *G. cruciata* in the potential micro reserve number 16 and 17 could be fenced and the dominant neighboring species should be cut back, whenever there is the potential of competitive exclusion. In number 18, the *P. abies* samplings should probably be removed and the population of *G. germanica* could be marked to prevent human plucking and other anthropogenic disturbances.

The potential micro reserves number 16 and 17 (above) include populations of *Gentiana cruciata* (below right) and few individuals of *Gentiana germanica*. Bush encroachment is a major local threat of these priority plant species within this parcel (below left).



The potential micro reserve number 18 is located in the bifurcation of a forest road (left). One of the 18 individuals of *Gentiana germanica*, growing on the stoney border of the road (above right). The potential micro reserve also includes an individual of *Knautia godetii,* a species of priority 4 (VU), which has been newly recorded during the field visits (below right).