Are agri-environment schemes beneficial to arable specialist bryophytes in Switzerland?

Irene Bisang, **Norbert Schnyder** and **Ariel Bergamini** discuss the implications of their long-term monitoring of arable bryophytes for the conservation of these species in Switzerland.

Humans have cultivated land over thousands of years in Europe and, in doing so, have created and maintained a complex landscape (Price, 2000). Such landscape mosaics, including agricultural habitats farmed at low intensities, sustained a rich and diverse flora and fauna. For example, numerous plant species, many of them introduced, have adapted to regular disturbance through tillage in crop fields. However, the demands of a growing population and technical progress have prompted a dramatic intensification of agricultural practices in the last 100 years. This has led to landscape simplifications and a severe loss of wildlife in the cultivated fields and the environments around them (Emmerson *et al.*, 2016). The arable flora is nowadays considered one of the most threatened plant groups in Europe.

Many bryophytes occur in the European agricultural landscape. Although they rarely form an eye-catching vegetation component, they are, like other organisms, affected by the profound changes in agricultural cultivation. In the European Red List, Hodgetts *et al.* (2019) assessed that about one fifth of the European

◁ Figure 1. Crop rotation, alternating mainly between cereal, grassland (usually mown fodder meadows), root crops and maize, is typically applied in the Swiss Plateau. Ct. Bern, Vechigen, September 2017. *Irene Bisang*

bryophytes are affected by agriculture and forestry management or emissions resulting from nutrient loads and pesticide applications. As the main threat to the European bryophyte flora, Hodgetts *et al.* identified modifications to natural ecosystems, which are often initiated to improve agricultural production. Arable bryophytes have received considerable attention in Great Britain. The pioneer work of Harold Whitehouse was followed by the BBS "Survey of the Bryophytes of Arable Land" project, resulting in several publications (e.g. Preston *et al.*, 2010; Preston *et al.*, 2020), and Ron Porley has taken a lasting interest in the subject (Porley, 2000, 2008). Here we report on our work on arable bryophytes in Switzerland.

Arable bryophytes and agricultural management in Switzerland

In Switzerland, with a high proportion of the country's surface covered by mountains, agricultural land is limited. Roughly one-quarter of the total Swiss surface area is cultivated in one way or another. Arable land, including "fodder meadows" (intensively cultivated, high yielding temporary leys grown to feed cattle as part of the crop rotation), covers just *c.* 4,000 km^2 (*c.* 10% of the Swiss surface area). It is concentrated in the lowlands north of the Alps. Here, in the biogeographic region called Swiss Plateau, with an average altitude of 400 to 600 m, cultivation intensity is highest. Typically, crop rotation has been applied in the area since the second half of the 19th century (Fig. 1). To halt the alarming species decline in agri-ecosystems and to endorse sustainable farming, Switzerland has introduced agri-environment schemes, like many other countries in Europe and globally. For nearly 20 years, the Swiss agri-environment schemes (SAES) have required farmers to achieve pre-defined ecological standards at the farm level to qualify for SAES payments. SAES regulate crop rotation, pesticide and fertiliser application, soil conservation and the maintenance of so-called "Biodiversity Promoting Areas" (BPA), and they are continuously evaluated and modified if necessary to ensure optimal biodiversity promotion. At least 7% of a farm's agricultural area must be managed as BPA. Examples of BPAs linked to arable fields include rotational fallows, wildflower strips or conservation headlands. By 2019, nearly 20% of the arable area was cultivated as BPAs. Finally, the Swiss agri-environmental policy also recognises national priority species of high conservation concern.

We evaluated information in the database of Swissbryophytes (2018; data considered up to October 2019) and identified 46 out of the *c.* 1100 species known to occur in Switzerland that depend on lowland habitats with bare soil (Table 1). These species are either largely confined to, or may more or less regularly occur in, arable fields. Based on these data (>50% of records in arable habitats) and expert consultations, we consider 20 species as arable specialists in Switzerland (Table 1; Fig. 2). Arable bryophyte specialists have adapted to and require habitats that are disturbed regularly, but not too frequently, to find space for germination, establishment, successful growth and reproduction, and to escape competition by crop plants and larger late-successional and/or unspecialised bryophytes (Zechmeister & Moser, 2001). Their ephemeral life span is one or a few years, possibly even compressed to a few months, and most of them are assigned to the Annual and Short-lived Shuttle and Ephemeral Colonist life strategies, which are all characterised by an early

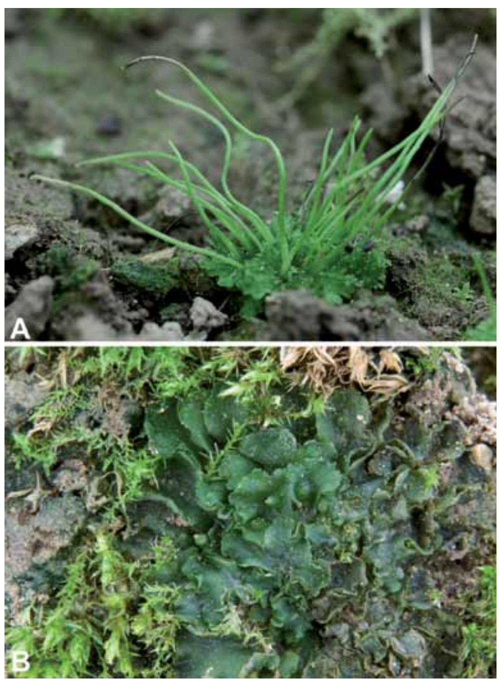
Table 1. Bryophyte species in Switzerland that largely depend on bare soil, with the species' Red List status and population trend or status. Species considered as arable specialists are marked with a bold yes (see text for how the lists were elaborated, based on data from Swissbryophytes, 2018; Kiebacher *et al.*, in prep.; and expert knowledge). Red List status: CR, Critically Endangered; EN, Endangered; LC, Least Concern; NT, Near Threatened; VU, Vulnerable.

Species	Red List status	Population trend or status	Arable specialists
Acaulon muticum	CR	declining	
Anthoceros agrestis	VU	declining	**yes**
Barbula unguiculata	LC		
Bryum argenteum	LC		
Bryum klinggraeffii	LC		
Bryum ruderale	NT	rare	**yes**
Bryum violaceum	LC		**yes**
Ceratodon purpureus	LC		
Dicranella schreberiana	LC		**yes**
Dicranella staphylina	LC		**yes**
Dicranella varia	LC		
Enthostodon fascicularis	VU	declining	
Ephemerum serratum (*E. minutissimum*)	LC		**yes**
Ephemerum stoloniferum	VU	declining	**yes**
Fossombronia pusilla	VU	rare	
Fossombronia wondraczekii	VU	rare	**yes**
Funaria hygrometrica	LC		
Imbribryum (Bryum) subapiculatum	LC		**yes**
Marchantia polymorpha	LC		
Microbryum davallianum	EN	declining	
Phaeoceros carolinianus	EN	declining	**yes**
Physcomitrium eurystomum	EN	declining	**yes**
Physcomitrium patens	VU	declining	
Physcomitrium pyriforme	LC		
Pleuridium acuminatum	LC		
Pleuridium subulatum	LC		
Pseudephemerum nitidum	LC		
Pseudocrossidium hornschuchianum	LC		
Ptychostomum (Bryum) rubens	LC		**yes**
Riccia bifurca	VU	declining	
Riccia cavernosa	EN	declining	
Riccia ciliata	EN	declining	
Riccia glauca	LC		**yes**
Riccia sorocarpa	LC		**yes**
Riccia subbifurca	VU	declining	**yes**
Riccia warnstorfii	VU	declining	**yes**
Sphaerocarpos europaeus (*S. texanus*)	EN	rare	**yes**
Streblotrichum (Barbula) convolutum	LC		
Tortula acaulon (*Phascum cuspidatum*)	LC		**yes**
Tortula caucasica (*T. modica*)	LC		
Tortula protobryoides	LC		
Tortula truncata	LC		**yes**
Trichodon cylindricus	LC		**yes**
Weissia controversa	LC		
Weissia longifolia	LC		
Weissia rostellata	NT	rare	
Number of species	**46**		**20**
Number [proportion] of arable specialists declining			**6 [30%]**

△ Figure 2. Two arable specialists. *Tortula truncata* (A) is common and often forms plenty of sporophytes; *Riccia warnstorfii* (B) is declining in the Swiss Plateau area.
Lars Hedenäs (A), Norbert Schnyder (B)

investment in reproduction (During, 1992). Arable bryophyte species may germinate from spring onward, or only after the crop harvest in late summer. Some species form sporophytes at young ages, such as *Anthoceros agrestis* (Bisang, 2004), while other species soon start producing numerous asexual propagules (for example, rhizoidal tubers in *Ptychostomum (Bryum) rubens*). Both types of diaspores of arable bryophytes may remain viable for several years in a persistent diaspore bank. For example, *Anthoceros agrestis* and *Phaeoceros carolinianus* emerged again from the diaspore bank in sites where no gametophytic populations had been observed for at least three and two years, respectively (Cailliau & Price, 2007; Bisang *et al.*, 2009). Close to one third of the species considered as arable bryophyte specialists in Switzerland have decreased, largely as a consequence of the changes in agricultural practices during the 20th century (Table 1;

▽ Figure 3. *Anthoceros agrestis* (A), with maturing sporophytes; *Phaeoceros carolinianus* (B), with young sporophytes and antheridial chambers.
Irene Bisang (A), Lars Hedenäs (B)



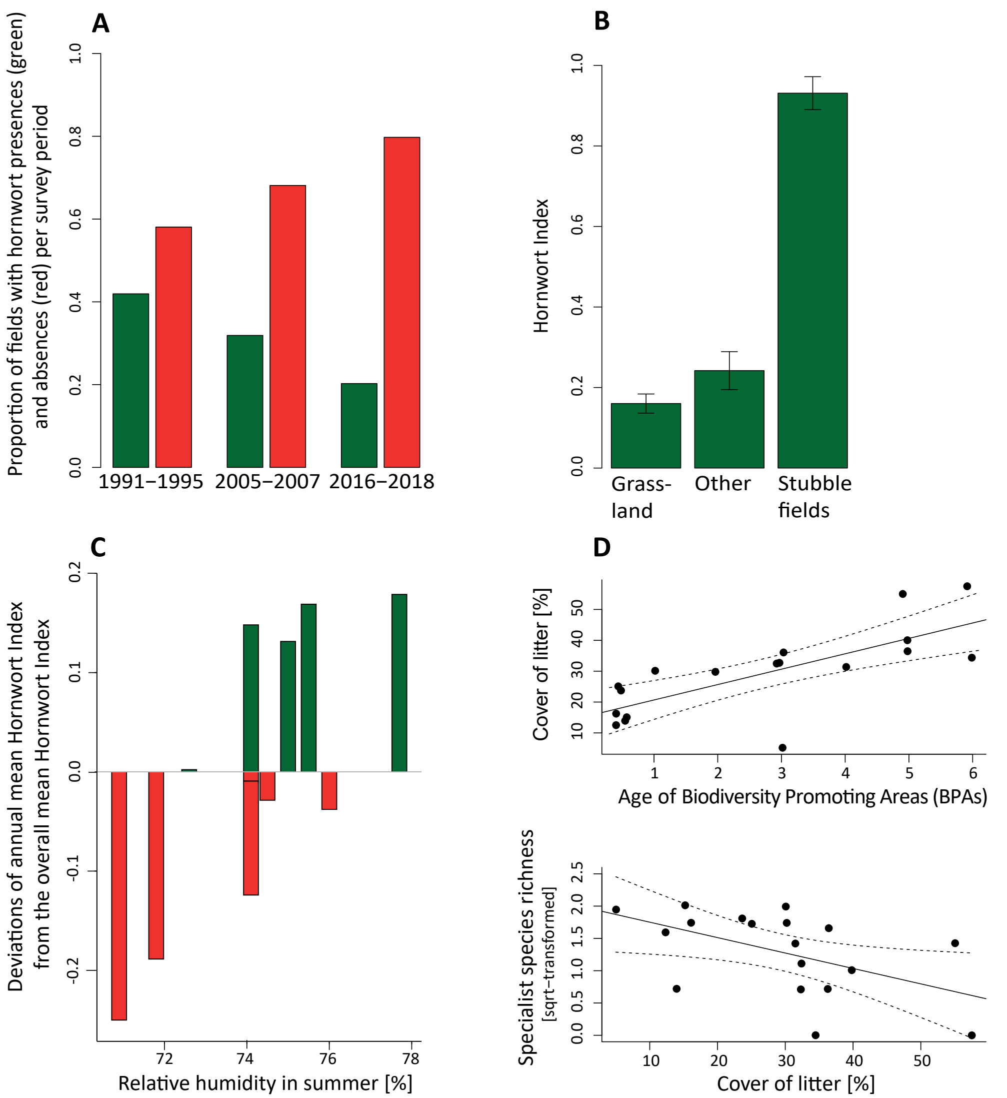
Hofmann *et al.*, 2007; Kiebacher *et al.*, in prep.). For *A. agrestis* and *P. carolinianus* (Fig. 3), the only hornworts that occur in the Swiss Plateau, we have demonstrated that agricultural management was an important predictor of their occurrence (Hofmann *et al.*, 2007; Bisang *et al.*, 2009).

Monitoring hornwort populations in the Swiss Plateau

The objectives of our research were to investigate the effects of crop farming practices, including measures of the SAES, on the specialised arable bryophyte flora in the cultivated area of the Swiss Plateau, and whether weather conditions played a role in its development. We also explored whether Biodiversity Promoting Areas (BPA), a cornerstone of the SAES, were suitable to support arable bryophyte specialist diversity. We selected *A. agrestis* and *P. carolinianus* as target species for one key part of our studies for several reasons. They are characteristic elements of the arable specialist bryophyte flora in Switzerland and in neighbouring countries and their life histories and distribution in Switzerland are well studied (Bisang, 2004; Bisang *et al.*, 2009, and references therein). They develop optimally in non-tilled stubble fields (Fig. 4), and grow preferably on sub-neutral soils (Bisang, 1998). Substrate variability in cultivated fields in the Swiss Plateau is moderate, and the fields are subject to similar climate and weather conditions (Bisang *et al.*, 2009). Both hornwort species are red-listed in Switzerland (Table 1, Kiebacher *et al.*, in prep.), and *P. carolinianus* is one of the Swiss national priority bryophytes bound to the crop habitat type. Finally, hornworts belong to a separate evolutionary lineage and represent a phylogenetically distinct element of the European arable flora. In summary, hornworts are perfectly suited species to address our research questions, and we regard the status of hornwort populations as a useful indicator of the situation of other short-lived arable specialists in the Swiss Plateau.

For nearly three decades, we monitored the occurrence and abundance of hornworts on selected arable fields in the Swiss Plateau, together with field management. The surveys were conducted annually in the autumn, when

▽ Figure 4. Stubble fields that are not managed after harvest nor ploughed until late autumn are favourable habitats for arable specialists, but these have become rare in the Swiss Plateau, Ct. Bern, Ammerzwil, September 2010. *Lars Hedenäs*



△ Figure 5. **A** The proportion of study fields with hornwort populations decreased from 1991 to 2018. **B** The mean Hornwort Index (HI, see text for details) in untreated stubble fields was higher than mean HI in grassland fields and fields with other management. **C** Deviations of the annual mean HI from the overall mean HI (1991–2018) in relation to relative air humidity during summer indicate that HI increases with higher summer air humidity (mean monthly means June to September). **D** Litter cover increases with the age of the fallows that are sown as Biodiversity Promoting Areas (Fig. 6), while the richness of arable bryophyte specialists decreases with increasing litter cover (data from Bisang & Bergamini, 2020; Bisang *et al.*, 2021).

arable bryophytes are best developed in the area, during three periods 1991–1995, 2005–2007 and 2016–2018. We examined each of the 28 designated study fields, in which we had documented hornwort occurrences during exploratory fieldwork from 1987 to 1990, in each survey year. This unique data set spans the period when SAES were initiated (1993), legally formalised (1998) and then gradually modified.

In our monitoring study between 1991 and 2018, we inspected in total 308 fields (11 survey years × 28 study fields), of which 272 were not yet ploughed at the time of the survey, and thus served as potential habitat for arable bryophytes. The proportion of fields holding hornworts (either species) decreased from 42% during the first survey period (1991–1995), to 34% during 2005–2007, and to 20% during the latest period (2016–2018; Fig. 5A). Hornworts have declined in Switzerland, and this happened despite the fact that SAES have been in place since the mid-1990s. Both *A. agrestis* and *P. carolinianus* are affected (Table 1; Bisang, 1992; Hofmann *et al.*, 2007). We further calculated a Hornwort Index (HI) for each field and year, taking into account both occurrence and abundance of the species, which we then related to field management (in terms of management classes) and weather conditions (Bisang *et al.*, 2021). HI steadily decreased from a mean value of 0.36 in the first period, to 0.26 and to 0.13 in the second and third periods, respectively. Hornworts showed a strong affinity to stubble fields, which was demonstrated by a HI for the management class "untreated stubble fields" that was significantly higher than HI for the other management classes, including different types of "grassland" (e.g. fodder meadows, intermediate catch-crops) and other crops (e.g. root crops, oilseeds, stubbles treated with manure and/or herbicide) (Fig. 5B). Finally, HI was positively related to relative air humidity during summer months (Fig. 5C), and negatively affected by high air temperatures during summer. The former is illustrated by the deviations of the annual mean HI from the overall mean HI that are less negative or positive with increasing summer air humidity (Fig. 5C). The analyses that combined management and weather effects on HI clarified that management overall had a much stronger effect than weather conditions on HI (Bisang *et al.*, 2021). However, weather effects varied between years. For example, despite the distinct overall negative trend in HI from the 1991 to 2018, the highest value of HI was recorded in autumn 2007, after an extremely wet and cool summer. We occasionally observed both hornwort species in the Swiss Plateau in spring, as in 2020 (pers. obs. and Swissbryophytes, 2018), indicating that hornwort populations may survive during winter provided temperatures are sufficiently mild. Usually, their frost-sensitive gametophytes die at the beginning of the winter in Central Europe. Higher winter temperatures are predicted for Switzerland (NCCS, 2018), which could possibly prolong the growing season.

Occasionally, we encountered fields that were (partly) treated with broad-spectrum herbicides after harvest. Our field observations suggested that hornwort gametophytes thrived less or were even killed in the sprayed fields compared to non-treated fields. The question whether Round-up herbicides are negative for the arable bryophyte flora has not been experimentally addressed, and our observations remain anecdotal. At least some of the common arable bryophytes seem unaffected, or alternatively, recover quickly from possible damage by herbicide treatment.

The decline of hornworts in the Swiss Plateau is largely attributable to the loss of suitable habitats. Stubble fields that were left untilled after the harvest, the favourable habitat for short-lived arable specialists, have almost disappeared, and over-wintering stubbles are largely gone in the Swiss Plateau (Fig. 4). This is a consequence of several changes in arable practices, such as reduced area of cereal cultivation following market demands or agricultural policy directions, with a 32% fall from 1990 to 2019. High-yield and early-ripening crop varieties allow earlier harvest (by several weeks compared to the early 20th century) and immediate post-harvest cultivation, which are economically favourable for farmers. In 2005, the SAES-directives for soil conservation were amended, which had an obvious effect on stubble tillage. Fields harvested before the end of August must be swiftly sown with a winter crop or with an intermediate crop (also termed "catch-crop"). The aim of this regulation is to minimise the period with exposed bare soil in order to reduce nitrate leaching. This is evidently detrimental to the small arable specialists that are either directly damaged by post-harvest cultivation or prevented from germinating and establishing. As early as 1991, Jones (1991) anticipated a negative impact of a lack of stubbles and early tillage on arable bryophyte specialists in Britain. This was also recognised in other regions (e.g. Jukoniene *et al.*, 2012).

Arable bryophyte specialists in Biodiversity Promoting Areas (BPAs)

We further investigated whether arable bryophyte specialists occurred in different types of BPAs, either above-ground or in the diaspore bank. The existing BPAs are designed to support the diversity of birds, arthropods or flowering plants, or ecosystem services such as pollination or pest control. Across 48 sites with four different fallow-types of different ages (BPA options: annual flower strips, wildflower strips, rotational fallows [Fig. 6], improved field margins), we recorded 44 bryophyte species, of which 13 were arable specialists including both hornwort species (Valentini, 2014; Studer, 2016). All fallow-types harboured bryophytes, and species richness was higher in the fallows than in adjacent conventionally managed fields.

△ Figure 6. A young "Rotational fallow", a type of a Biodiversity Promoting Area, that was sown in the previous year. This includes gaps with bare soil where arable specialists can establish and thrive. However, with increasing fallow age, stand density and litter accumulation increase (see Fig. 5). Swiss Plateau, Ct. Zurich, Neerach. September 2013. *Irene Bisang.*

This indicates a positive influence of BPA directives for bryophytes, although they were not specifically targeted when implementing these BPA options. However, specialist species-richness differed between fallow-types, which was largely due to the time elapsed since sowing of the fallow species mixture. Different fallow options (BPAs) differ in the time they can remain in place. For example, wildflower strips can remain for up to eight years, while conservation headlands are ploughed annually. Specialist species-richness was higher in one- to two-year-old fallows compared to fallows of three and more years. Dense swards, high vegetation cover, accumulating litter (Fig. 5D) and reduced soil disturbance provide unsuitable conditions for non-competitive arable bryophyte specialists (Fig. 6). In the diaspore bank survey, we found 14 arable specialists out of a total of 27 species in the BPAs and the adjacent conventionally cultivated fields. Species richness was higher in the diaspore bank than above ground under all farming regimes, and some species occurred only below ground but not in the surface vegetation. Two of these were red-listed species, *Phaeoceros carolinianus* and *Physcomitrium (Aphanorrhegma) patens* (Table 1). Bryophyte specialist species-richness in the diaspore bank did not differ between fallow-types and the conventionally managed adjacent fields, but it was lower below 15 cm in old fallows. We conclude that BPAs, such as fallows, are potentially beneficial for arable bryophytes. However, for safeguarding specialist species additional measures seem necessary. This is in line with previous findings for other organisms; specialised, rare or endangered species are rarely promoted by standard agri-environmental schemes.

How should we safeguard the arable specialists?

As outlined above, *Anthoceros agrestis* and *Phaeoceros carolinianus* are typical representatives of the arable bryophyte flora in the cultivated fields in the Swiss Plateau. We therefore believe that recommendations based on our findings from the monitoring, combined with the results from the investigations of different BPA fallows, will support other arable specialists in the area. In Switzerland, the need for actions to preserve the arable bryophyte flora is starting to gain some attention, although the concrete implementation may be met with reluctance by farmers. Conservationist colleagues working with arable flora diversity tell us that the enthusiasm for and success of conservation attempts can be improved if attractive segetal flowering plants are included in the measures. The key factor is to maintain suitable habitats, in particular stubble fields, in the intensively cultivated Swiss Plateau. The Swiss agri-environmental policy enables targeted modifications of current SAES directives. Similar to the existing regulations, amended directives are regulated and compensated for in Management Agreements with the farmers. Therefore, we recommend several practices to be implemented in fields with documented occurrences of hornworts or other national priority species of arable fields:

- a high proportion of cereals during crop rotation;
- retention of stubble fields from harvest until end of October or until next spring;
- no application of broad-spectrum herbicides after harvest.

While adhering to the appropriate timing for ploughing, the selected fields should be ploughed at regular intervals. These measures will allow arable specialists to reproduce and to replenish the diaspore bank and, finally, diaspores to re-surface from the reservoir in the soil. Existing directives for BPA fallows that remain for at most two years, such as conservation headlands or annual flower strips, should be modified to include late tillage. Our management recommendations will benefit other organisms that depend on extensively farmed, open and regularly disturbed habitats, i.e. segetal wildflowers, hares, many different arthropods, farmland breeding birds, and migrating amphibians and reptiles. In neighbouring Germany, late tillage and over-wintering stubble fields are widely practiced for the conservation of the segetal flora.

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