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Adaptive biodiversity management of semi-natural hay meadows: The case of West-Norway

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ABSTRACT

Worldwide semi-natural habitats of high biological value are in decline. Consequently, numerous Agri-Environment Schemes (AESs) intended to halt biodiversity loss within these habitats have been implemented. One approach has been the application of "adaptive management", where scientific knowledge is applied alongside the traditional ecological knowledge (TEK) of stakeholders in order to establish an integrated approach that is adjusted as outcomes are assessed. In this paper we examine the effectiveness of the adaptive management approach of Norway's Action Plan for Hay Meadows (APHM). Twenty-nine hay meadows from fourteen farms in the county of Møre og Romsdal were ecologically surveyed over a 2 year period. Interviews were also conducted with owners and land managers to explore TEK and management issues. The interdisciplinary study found that the disembedding of hay meadow management from its initial commercial purpose (in particular the loss of much of the livestock from the region) has contributed to a significant loss of TEK – which is now largely limited to knowledge of how the fields were managed recently. While, the APHM is limiting biodiversity decline by promoting traditional practices there were indications that the standardisation of management actions might negatively affect species composition in the long term. More critically, continued farm abandonment within the region means that without alternatives to management by farmers many of these meadows are likely to disappear in the next couple of decades. We conclude that adaptive management provides an effective short-term means of preserving hay meadows, but long term conservation will require a means of addressing the continued decline of local farming communities.

1. Introduction

Since the 1950s the intensification and mechanisation of agriculture has resulted in the worldwide loss of many natural and semi-natural habitats (Emanuelsson et al., 2009; Foley et al., 2005; Sala et al., 2000). In areas of high agricultural value intensive and mechanised production has replaced low impact management while in marginal areas land-abandonment and under-utilisation have also contributed to significant habitat loss (Emanuelsson et al., 2009; Plieninger et al., 2016; Stoate et al., 2009). In the early 1990s international concern for biodiversity loss brought 150 countries together to sign the Convention on Biological Diversity (UN, 1992), a document that detailed national strategies, plans and programs for conservation and sustainable use of biological diversity (Article 6). Since then, numerous Agri-Environment Schemes (AESs) have been implemented throughout the world with the intention of maintaining, conserving and even recreating threatened habitats (see Henle et al., 2008 for a review).

Within Europe, one of the most species rich ecosystems is that of semi-natural grassland (Billeter et al., 2008; Veen et al., 2009) where high biodiversity results from a long history of locally adapted, low intensity, agricultural land use (Küster and Keenleyside, 2009). Of these grasslands, those managed as semi-natural hay meadows contain some of the most species-rich plant communities and provide a key habitat for several species including invertebrates and bird species (Cizek et al., 2012; Pywell et al., 2012). Hay meadows have evolved over the centuries through an intricate management regime of regular mowing, the turning and drying of grass, only light applications of manure and no or only infrequent ploughing (Dahlström et al., 2008; Norderhaug et al., 1999; Norderhaug et al., 2000). While they are now highly valued for their biodiversity, in the past these meadows played a crucial economic

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role in farm management as often the only source of winter feed for livestock. High meadow biodiversity was partly by design as farmers were aware that hay from biodiverse meadows was more nutritious (e.g. Bradley, 1727; McClure, 1909), but predominantly resulted from a shortage of manure in remote areas meaning meadows distant from the farmhouse were rarely fertilised.

Since the 18th Century European hay meadows have been declining as a result of changing agricultural practices such as the advent of the plough culture, increased drainage, and an increasing preference for the production of silage rather than hay. More recently, mechanisation and the increasing availability of cheap mineral fertilisers have resulted in dramatic declines in hay meadow management – particularly the semi-natural meadows that are highly valued for their biodiversity (Halada et al., 2011; Ostermann, 1998). In Norway, the management regimes that were responsible for creating high species diversity are being abandoned, leaving the meadows vulnerable to forest encroachment and biodiversity loss (Norderhaug and Johansen, 2011). Where meadows are managed, new techniques, large machinery, more frequent cutting of the grass and the application of artificial fertilisers – which are potentially damaging to biodiversity in meadows – have meant that the traditional means of meadow management have been largely abandoned (Øien and Moen, 2006). Norway's semi-natural hay meadows are therefore threatened and regarded as endangered (EN) in the Norwegian Red List for Ecosystems and Habitat Types and require conservation (Norderhaug and Johansen, 2011).

Conserving the biological quality of hay meadows can, however, be a challenge. Complex underlying ecological mechanisms (Dallimer et al., 2010; Gabriel et al., 2010; Kampmann et al., 2012), a fundamental lack of historical knowledge concerning hay meadow decline (Riley, 2005), and uncertainty regarding the impact of specific management practices on ecological dynamics (Henle et al., 2008) make it difficult to design programs for their preservation. As a result, applied approaches have often been too simplistic (even where knowledge has been available), resulting in counterproductive outcomes (Henle et al., 2008). Further, as the historical management of each hay meadow has been different, there is no "one size fits all" approach to designing suitable management regimes (Kirkham et al., 2014). While ecologists have established a sizeable knowledge base on the impact of cutting and grazing regimes, fertilization, more general disturbances such as spring raking and letting hay dry in the meadow (Jantunen et al., 2007; Lennartsson et al., 2012; Oostermeijer et al., 2002; Svensson and Carlsson, 2005) and the impact of surrounding landscapes on grassland biodiversity (Evju and Sverdrup-Thygeson, 2016; Wehn et al., 2017), there is still a great deal of uncertainty regarding the long-term and combined effects of new management guidelines.

As part of the cultural landscape hay meadows rely upon continued active use and management by people, rather than the extensive, hands-off approach employed to achieve many other conservation objectives (Halada et al., 2011; Ostermann, 1998; Riley, 2006). Hay meadow conservation or restoration can require a considerable effort on the part of the farmer – particularly in cases where farm practices have already been rationalised through, for example, mechanised silage-making or the abandonment of marginal upland meadows. Conserving semi-natural hay meadows, therefore, requires attention to the "human factor" so that the ecological measures "are palatable to farmers and therefore effective at changing farmer behaviour" (Batáry et al., 2015, p.1012).

This paper examines one potential approach to developing appropriate hay meadow management plans – namely the adaptive management approach of Norway's Action Plan for Hay Meadows (APHM). Adaptive management approaches are based on a combination of scientific knowledge of hay meadow management and traditional ecological knowledge (TEK) of the existing land managers in order to develop appropriate management plans for each individual hay meadow. The paper reports on an interdisciplinary study involving ecologists and social scientists to assess the APHM five years after initiation. It is divided into four main sections. First, a literature review of adaptive management. Second, a description of the case study area and methodological approach. Third, the results section combines ecological and social data to address the issue of whether the adaptive management plans are safeguarding the hay meadows or not. Finally, we conclude with recommendations for policies incorporating an adaptive management approach.

2. Adaptive management and Norway's APHM

Developed initially by Holling and Walters (Holling, 1978; Walters, 1986), Adaptive Management (AM) arose from a desire to move beyond traditional "top-down", expert-led, decision making and planning, and its associated limitations in terms of ecological outcomes (Holling and Meffe, 1996). As Callicott et al. (1999) suggest, it has become one of the" normative concepts" in conservation and has "become something of a mantra among conservation ecologists and natural resource managers seeking to establish "place-based" integrated management of ecosystems" (Karkkainen, 2002, p.945). Whilst there has been some debate in the literature over what is meant by the term (see Rist et al., 2013), its overarching aim is towards an iterative consideration within management whereby learning takes place and management strategies are adjusted accordingly (Williams, 2011) and to include stakeholders outside of conservation organisations in order to broaden the knowledge base and to create "experiments" that can be used to gradually improve management (Stringer et al., 2006). Although there are normative reasons for the participation of wider stakeholders – that is, a suggestion that people have a democratic right to participate in management decisions (Stringer et al., 2006), which in turn has advantages of capacity building and power sharing (Kapoor, 2001) – there has been a more applied concern for how different forms of understanding can be brought into conservation management (Berkes and Folke, 2002). Central to this argument is a belief that community-based management has coevolved with resource use and ecosystem dynamics (Olsson et al., 2004) and that Traditional Ecological Knowledge (TEK) forms a central part of adaptive management. TEK is defined in this context as:

"A cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment." (Berkes et al., 2000, p.1252).

TEK, the adaptive management literature suggests, might offer the potential "to improve the knowledge base to respond to change adaptively" (Gadgil et al., 2003, p.90), with the recognition that people "who retain TEK are holders of a body of knowledge crafted for centuries by the specifics of completing tasks in the environment in which they have been living" (Drew, 2005, p.1287). Alongside this, it has been argued that because TEK is developed iteratively – through trial and error – it can reflect changes in specific environments and cultures (Drew, 2005). As such, where TEK is incorporated into conservation schemes, it has the potential to offer location-specific knowledge, increased knowledge of environmental linkages, and local capacity building and power sharing. Thus, there is a potential for historical observations that may be seen as "natural experiments" where land users can see the outcomes of particular practices, and because "it is difficult to systematically conduct properly planned and replicated experiments in complex systems, local observations of such experiments can be of significant value" (Gadgil et al., 2003, p.205).

Research has shown that such an endeavour is complicated, with the way that knowledge-practice-belief become indistinguishable in TEK seen as a weakness for many scientists who are keen to identify verifiable "facts" (Gadgil et al., 2003). Although debate continues about the limitations of TEK, it is recognised that it may offer a "wealth of detailed context-specific observations of the dynamics of complex ecological systems" (Gadgil et al., 2003, p.206). There have been several analyses of the challenges to adaptive management, with the two most notable being the potential "stalemates" when groups with

Fig. 1. Study area and the farm properties with the studied semi-natural hay meadows.

different motivational values come together (Theberge et al., 2006) and the observation that programmes of monitoring are potentially costly and difficult to implement (Westgate et al., 2013).

Norway's Action Plan for Hay Meadows[1] was published in 2009 and, taking the principles of adaptive management, aimed to develop dynamic cooperation among authorities, researchers and managers to fulfil the overriding objective of preventing biodiversity loss (The Norwegian Environment Agency, 2009). The document stressed the importance of monitoring the biodiversity targets and regularly re-evaluating them in order to adapt the management if necessary and aims to introduce sustainable management of the most biologically valuable semi-natural hay meadows throughout Norway. If farmers or owners are to receive payments through the APHM, the hay meadows have to be of high biological value. Surveys beginning in the 1990s registered 2551 semi-natural hay meadows throughout Norway, ranking these from A (high) to C (lower) according to the biological value with the aim of including all A and B localities within APHM (naturbase.no; March 1 2017). Management plans – a voluntary 5–10 year agreement between the manager and the authorities (The County Governors and The Norwegian Environment Agency) with payments provided for following management guidelines – have been developed for 607 of these sites (http://www.miljostatus.no/slattemark, 2017.06.21).

Norwegian hay meadows were historically cut using scythes in late summer – after seed set for most flowering plants – and most were grazed in autumn (and spring in some cases) (Norderhaug et al., 1999). The plant species distributed in these habitats are low stature species with a low ability to compete for light (Potthoff, 2009) but are often preferred by pollinators (Oostermeijer et al., 2002; Totland et al., 2013). The traditional management regimes of cutting and drying grass and grazing the meadows led to high biological diversity but due to mechanisation and the industrialisation of agriculture these practices have been largely reduced to cutting the meadow only. This can have negative impacts on biodiversity as cutting date and grazing regimes have a major impact on the reproduction and survival of many plant species (Jantunen et al., 2007; Oostermeijer et al., 2002; Svensson and Carlsson, 2005; Wehn and Johansen, 2015), hence in the APHM, it is advised that the histories of the hay meadows are used for the development of conservation recommendations (The Norwegian Environment Agency, 2009).

[1] In 2009 the Norwegian Nature Diversity Act designated hay meadows as one of six "Selected Nature Types" worthy of conservation (Ministry of Climate and Environment (2009)).

3. Case study area and methodological approach

This research is based on a case study of the county of Møre og Romsdal, Western Norway, which contains 320 biodiverse hay meadows (data provided by the Norwegian environmental agency; naturbase.no) – 192 of which were under APHM management as of January 2017 (personal communication with the county governor of Møre og Romsdal). As Møre og Romsdal has a high number of hay meadows with APHM agreements implemented, we selected two regions in this county for the case study (Romsdalen and Storfjorden; Fig. 1). From these two regions, 29 semi-natural hay meadows (properties of 14 farms) managed under the APHM were included in the study.

The APHM, in contrast to most other agri-environmental schemes in Norway does not require that the property is part of an ongoing active farming business. While some of the informants were property owners themselves others (usually neighbours) carried out the management of the meadows for the owners. Of the 14 properties only five had what may be termed agricultural production *per se* independent of the scheme, and only three of those could be characterized as active farm units. All 14 had previously been active farms, but several of them were now used mainly as dwelling places or summer homes. Most of the properties were small (below the national average) and pluriactive – both historically and at present.

3.1. The social survey

The size of the hay meadows in the study area varied from approximately 0.3–3.5 hectare. Payments within the case study area were typically between 16,000 and 20,000 NOK per hectare, depending on local conditions – with payments being made both for meadow management and the removal of encroaching vegetation. In order to address the primary aim of assessing the outcome of the adaptive management plans, interviews were conducted to represent each of the 14 properties with the result that a total 20 interviews were conducted with the owners/managers of the 29 hay meadows. The interviews involved a qualitative approach and a walk-around interview method (after Riley,

2010) to investigate the land manager's historical, floristic and ecological knowledge linked to hay mowing. This involved interviewing respondents within the hay meadows of interest, often with both ecologists and social scientists present. To receive feedback and discuss the information provided during the interviews, two stakeholder meetings were conducted in autumn 2015 with the farm owners and managers as well as municipality and county representatives from environmental and agricultural sector (in total 18 stakeholder participants). References in the text are made to farmers as R or S, with R denoting farmers from Romsdalen and S farmers from Storfjorden.

3.2. The ecological survey

To evaluate the biodiversity within the semi-natural hay meadows, we first did a botanical survey of the entire hay meadow area in each hay meadow and registered all vascular plant species observed. The total number of vascular plant species was 173, while the number in each of the surveyed semi-natural hay meadows ranged from 35 to 76. We next assigned these species as TEK indicators, semi-natural specialists or neither. To identify TEK indicators we used Høeg's (1974) study of farmer's ecological knowledge. This revealed seven vascular plant species that were used as indicators of mowing date in the late 19th century in the county of Møre og Romsdal. These species were red and white clover (*Trifolium pratense* and *T. repens*), yellow rattle (*Rhinanthus minor*), bird's-foot trefoil (*Lotus corniculatus*), bluebell (*Campanula rotundifolia*), timothy (*Phleum pratense*), and common bent (*Agrostis capillaris*). All of the TEK indicators were present in the semi-natural hay meadows in our case study – with all meadows containing at least 4 of the species. Forty-nine species (between 10 and 24 in each of the meadows) were categorized as semi-natural specialists as these species, according Halvorsen et al. (2016), are distributed in semi-natural grassland and do not occur in fertilized or forested land. The species assemblages in which these species coexist are the plant communities the APHM aims to maintain. Hence semi-natural specialist richness indicates the biological value of the hay meadows. Two species – mountain daisy (*Arnica montana*) and the orchid *Pseudorchis albida* – are listed in the Norwegian Red List for Species as vulnerable and threatened, respectively (Henriksen and Hilmo, 2015).

When assessing whether the adaptive management plans contribute to sustainable biodiversity conservation we focused on both species assemblages and the semi-natural grassland specialists within the studied hay meadows. Based on the botanical survey data, species turnover between the hay meadows was assessed by Detrended Correspondence Analysis (DCA) using Canoco 4.0 (Ter Braak and Smilauer, 2002). According to the management plans mowing should take place once each year and not before July 10th in five of the farms, not before July 15th in two of the farms and in the second half of July for the rest of the farms. Because questions have been raised recently concerning the impact of fixed mowing dates (Dahlström et al., 2008) we questioned this standardization and assessed, therefore, the potential consequences of this recommendation on the future biodiversity and in particular on the viability of semi-natural grassland specialists.

As it is advised in the APHM that the histories of the hay meadows are to be used (The Norwegian Environment Agency, 2009), we examined the potential of using the TEK indicators for determining mowing dates. That is, whether the phenological stages of these species correspond to the time when semi-natural grassland specialists are mature. The phenolological stage of the TEK indicators was based on statements provided by Høeg (1974) such as:

"When the red clover is faded it is time to mow", "when the white clover curls it is time to mow", "when the "money grass" is mature it is time to mow", "when the flowers of the bird's-foot trefoil wither, it is time to mow", "when the bluebell flourishes, it is time to mow", "when the timothy flourishes, it is time to mow", and "when the meadow of common bent is in blooms, it is time to mow" (translated from Norwegian by the authors).

The phenological stages of the seven TEK indicators and 29 of the semi-natural specialists were registered in each of the semi-natural meadows the week before the defined mowing dates in 2014 and 2015. In each meadow, plots of 1 m^2 where located where a specialist or TEK indicator was present. Some specialists co-occurred and could be registered in the same 1 m^2 plot, others did not, therefore the number of plots in each hay meadow ranged from 9 to 22 with a total of 435 plots in 2014 and 427 in 2015. For each plot we registered number of ramets, flowers or inflorescences in bloom, and mature flowers/inflorescences of each of the specialists and TEK indicators present, if several species co-existed. This enabled us to calculate, for each plot, the percentage of mature plants of the specialists and percentage of TEK indicators in the TEK stage (based on information provided by Høeg, 1974).

To test for differences in phenology (percentage mature specialists and percentage TEK indicators in the TEK stage – the phenological state used to indicate when to start mowing) between the 2014 and 2015 seasons and between the semi-natural specialist species we used a generalized mixed modelling approach with species and year as fixed effects and species nested in sites as a random effect. The regression coefficients in the model were estimated using the lme4 package (version 1.1–12) in R (R Core Team, 2015). To test for correlations between the phenology of the TEK indicators and the phenology of the semi-natural grassland specialists we performed simple spearman correlation tests as well as graphical interpretations of the estimates using the R software (Bates et al., 2015).

4. An analysis of the successes and failures of the APHM

In this section we combine outputs from the ecological survey with the social survey in order to address four key issues. First, we explore whether the adaptive management plans have been successful in the short term. Second, we deal with the issue of whether the APHM can lead to a revival of historical practices by looking at the impediments to change. Third, we address the ability of the APHM to secure the future of Norway's hay meadows in the long term. Fourth and finally, we look at the role TEK played in the adaptive management approach.

4.1. Is the APHM management approach successful in the short-term?

Farmers/landowners[2] were generally in agreement both with the need for management and the overall rationale of the APHM, and applied the management recommendations suggested in their respective agreements. From this perspective the involvement of land owners and managers in the scheme appears to have been successful. However, in terms of changing farmer's views on hay meadow management the effect has been limited. Farmer's main motivation for engaging with the scheme was not connected with maintaining species diversity but almost invariably with a perceived need to keep the landscape free of encroaching scrub and woodland vegetation - something that farmers considered to be a major problem due to the land abandonment that had taken place in recent years (also see Olsson et al., 2011; Soliva et al., 2008). Responses linked to the wish to maintain the landscape diversity in the cultural landscape are typified in the following observation from farm owner R4b

"*Respondent R4b*: I've told (the tenant) that the fields should be cleared so that they are usable around the outsides – so that it doesn't encroach further and further into the fields. Because I think that is incredibly unattractive.

Interviewer: So that's the most important reason that you continue to cut?

Respondent R4b: Yes it is. It is so that it will not grow again and become forest in the end. There is nothing uglier than a farm that is overgrown."

[2] The owners were not all farmers

As yet, there is no suggestion that the motivation has changed to also include the wish to maintain the species diversity associated with the semi-natural hay meadows. We contend that the likely reason for this is the failure of the scheme to incorporate the meadow management into farm practices in some meaningful way. Beyond the need to cut the meadow there are no additional requirements that might encourage new understandings of meadow management (e.g. how to produce biodiverse quality hay) and, as a result, managers' key concern lies with how to dispose of the hay, rather than how to manage the meadow to achieve biodiversity goals at species level (see discussion Section 4.2.2).

Even if the botanical survey showed relatively high species richness in the semi-natural hay meadows, it is, from an ecological perspective, difficult to judge whether the APHM has had a positive influence on the biodiversity of hay meadows. Analysis of the interviews, however, indicated that the management of the meadows would have been different in many cases without the scheme. While three respondents (R5, R6, S12) indicated that they would have managed it in exactly the same way, the remainder would have managed it differently – i.e., allowing forest incursion and/or abandoning meadow management (R4b, R7, S9, S10), cutting the edges around the meadow less (R1), using fertiliser or not clearing the grass off the cut meadow (R2, S13), using other management tools (R2), choosing different cutting dates (S13), and managing a smaller area of meadow (R3, S8). In this sense, and given the relative scarcity of hay meadows in the district, the scheme is likely to have a significant impact on preserving the biodiversity value of these hay meadows in the coming years.

4.2. The APHM and the revival of historical practices

The importance of practice to the development and maintenance of TEK raises issues concerning the integration of TEK into the wider farm system. Even if the management of hay meadows is returned to its historical state, analysis of the interviews suggested that the economic, structural and social environment within which the hay meadows are managed has changed. Issues arose in two main areas: fragmentation and centralisation of the hay meadows and cessation of animal husbandry.

4.2.1. Fragmentation and centralisation of hay meadows

The agricultural landscapes of Norway have changed radically in the last century with a dramatic decline in extensively managed hay meadows (Norderhaug and Johansen, 2011). This has had the dual effect of fragmenting the semi-natural habitats around the farmstead while, at the same time leading to increased abandonment of remote and marginal areas (Bryn and Hemsing, 2012; Olsson et al., 2000; Penniston and Lundberg, 2014). Our interviews and the stakeholder meetings with farmers and county environmental representatives suggested this has also been the case in Møre og Romsdal, with semi-natural hay meadows now relatively isolated and located around the farmhouses. Of the 14 properties, 7 reported they had practiced mountain summer farming, i.e., grazing and hay cutting in the mountain areas, but these had gradually been given up since the 1940s, with the last one ceasing production in the 1980s. Two farmers reported that they were still grazing the summer pastures, but neither of these were still cutting the hay meadows. This has implications for the qualities of the remaining hay meadows under the APHM. Historically, meadows close to the farm were subject to more intensive management – in particular through the application of farmyard manures (also see Olsson et al., 2000). In addition to the loss of pastures, the fragmentation of hay meadows accompanied by successional change towards forest threatens the community composition of meadows as each meadow becomes smaller and more isolated from other semi-natural meadows – potentially leading to a deterioration of habitat and even local extinction (Hanski and Ovaskainen, 2002).

4.2.2. The lack of livestock and its influence on management

Traditionally livestock were an integral part of hay meadow management, providing small amounts of organic fertiliser, trampling the meadows to control moss[3] and, above all, providing the main reason for the production of good quality hay. However, small scale livestock farming has long been on the decline in Norway (Forbord et al., 2014). Most properties in the study ceased livestock production during the last 40–45 years (giving up dairy production first), leaving livestock on only four of the 14 properties. While most of the farms in the study area traditionally would have a combination of livestock, more recently the need to invest to improve dairy facilities has meant sheep farming has largely replaced dairy production – particularly on the smaller farms. The only remaining dairy farmer in the study had just taken the decision to close down dairy production and increase sheep numbers. From 2000 to 2017 alone the number of farmers keeping sheep in the five municipalities of the study area decreased from 260 to 160. The decrease in total sheep number was less dramatic, with numbers declining from 10,085 to 8876 (over 5300 of these within a single municipality; Statistics Norway, 2017).

Changing economic pressures (and a strong reliance on pluriactivity – all farms had diversified income) has meant that buildings once associated with hay production and storage have been repurposed. For example, farmer S11b observes that the barn that was used for storing hay has been "completely transformed" and thus, even if the hay can be successfully made, "we do not have any place to store it" (S11a). With the diminishing importance of hay, farmers have also ceased investing in machinery for hay-making and, as a result, some were working with aging machinery (e.g. R2, R5). The result of this is that for most farmers there is both limited commercial reason behind the production of hay and limited facilities for its production and storage. This has implications for the management of biodiversity in the meadows. For many farmers the main concern in hay meadow management – besides keeping the land open – was not for the production of hay but rather how the cut grass could be disposed of. Some farmers had informal agreements with actively farming neighbours whereby if the hay crop proved usable the farmer would take the crop – sometimes cutting the field in return for the hay, but often simply taking it as an alternative to dumping. For example:

Respondent R2: "So it lies there for a week and then we gather it in … or not. If we get it in we pass it on to our neighbour and if not we simply rake it away."

Respondent R7: "Of course, if there is no one who wants to cut it then I cut it myself and dump it in the forest."

The reason farmers are required to remove hay from the meadows as part of their management agreement is that for meadow species, maintaining a low-nutrient environment is important. Nitrogen availability in the soil advantages necrophilous species which then will outcompete the semi-natural grassland specialists (Norderhaug et al., 1999). Of the 49 semi-natural specialist species observed in the hay meadows, 15 do not occur in habitats that are manured or artificially fertilized (Halvorsen et al., 2016). The others occur in areas with some signs of fertilization but only at relatively low intensities.

Given that many of the APHM hay meadows have been fertilised in the past, the presence of these fertiliser intolerant species may provide hope for the preservation of biodiversity already lost from the historically abandoned meadows. However, this relationship is not a simple one. Extremely high species richness in east-central European grasslands is argued to be due to the suppression of dominants and support of competitive weak species resulting from mowing in absence of nutrient application (Roleček et al., 2014). A case study from the UK

[3] Historical literature on the control of moss in hay meadows from the UK notes "The production of them [mosses] is also much encouraged in older pastures by eating the grass too bare in August and the early part of September, as also by taking a crop of meadow-hay where the ground is not much trodden upon" (I.R. (1839))

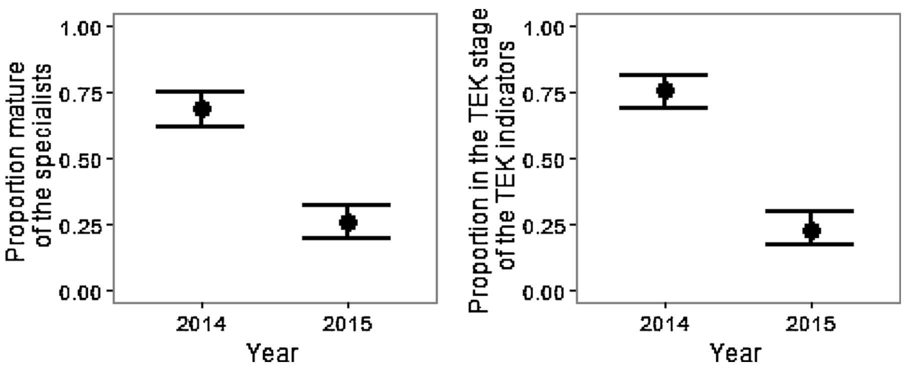

Fig. 2. Proportion (mean and confidence intervals) of a) semi-natural specialists (proportion mature plants) and b) TEK (traditional ecological knowledge) indicators (proportion plants in the TEK stage; the stage used historically to define when to start mowing) in 29 semi-natural hay meadows involved in the Action Plan for Hay Meadows in Norway (APHM) the week before recommended mowing date in the two years of the study.

showed that high levels of both manure and artificial fertilizers results in lower species richness, less biodiverse grassland indicators and more species that impact negatively on plant community quality (Kirkham et al., 2014). However, the authors further argue that species richness might be sustained if low levels of nutrients are added, but only if the system has had a long history of nutrient application.

The hay meadows in our study had a long history of traditional nutrient application. In the past, farmers would keep animals and spread manure on the land close to the farm – even using bucket chains to spread yard-manure on steeper slopes. However, in the case of APHM meadows the only fertilization that is permitted comes from sheep grazing during spring and/or autumn – an event that in all but 3 of the 29 meadows did not occur either because of the lack of livestock on the farm or the labor-intensive and often complex task of transporting animals to the small fields. As a result, the removal of grass coupled by a lack of grazing caused some farmers concern. For example:

Respondent S10: "I have talked with the neighbor, he thinks the same as I do with cutting it and taking it away, it becomes moss. It just depletes the soil."

Respondent S13[4]: "I'm not quite a hundred percent sure about removing the grass (...) Up here it is almost only moss … So I think you impoverish it badly."

This observation is supported by studies that suggest the application of fertilizer has the potential to reduce the cover and richness of bryophytes (Müller et al., 2012; Rusch and Fernández-Palacios, 1995) – however, the increase in moss may also partly result from the abandonment of the traditional practices of spring/autumn grazing and spring raking as noted in one of the focus groups (also Ludvíková et al., 2014; Norderhaug et al., 1999). Thus while the absence of fertilization supports desirable plant species, the removal of fertilizer and trampling creates a problem for the APHM meadows as the resulting increase in moss cover can influence species richness (Losvik, 2006) by acting as a barrier to germination (Hovstad, 2007; Jeschke and Kiehl, 2008; Rusch and Fernández-Palacios, 1995).

4.3. Factors affecting long term sustainability of APHM hay meadows

While the APHM appears to be successful in the short term, a more fundamental question is whether they can safeguard Norway's hay meadows in the long term. Two key issues emerged that may influence long term sustainability – one from each of the ecological and social surveys.

4.3.1. The problem with fixed cutting dates

From an ecological perspective there are some worrying signs. Although species richness was high within the meadows, there was also a high degree of homogeneity across the meadows, with each containing broadly the same species. Based on analyses of the species present, we calculated the length of dca axis 1 to be only 2.087 – which is very low (if it is above 4, there is a complete turnover in species composition between hay meadows) and indicates a potential future decrease in species diversity at the landscape scale. The standardisation of cutting date emerged as a possible ecological explanation for this homogeneity. Fixed earliest cutting dates are not part of traditional hay meadow management practices (Dahlström et al., 2008; Burton and Riley, 2018), nor were they part of the TEK of the local farmers who noted cutting date varied depending on, for example, the climatic conditions (e.g. S10 and S11) or species composition of the meadow (farmer S9).

Evidence for the importance of variable cutting dates emerged as a result of the varying climatic conditions in 2014 and 2015. Mean temperature in the region for 2014 was 2.2 °C above average while precipitation was only 88.2% of the average, a warm and relatively dry summer (data provided by yr.no). Mean temperature the following year was 0.2 °C below average and precipitation 103.1% of average. In the warm summer of 2014 a high proportion of the semi-natural specialists had reached the "mature" stage one week before suggested earliest mowing; on average 67% of the specialists. In 2015 however, only a small proportion of the specialists (28%) were mature a week before the prescribed mowing date (see Fig. 2a; $\chi^2 = 91.5$, $p < .001$).

Phenology also varies between species (Svensson and Carlsson, 2005) as does the proportion of mature plants of each specialists ($\chi^2 = 313.45$; df = 28; $p < .001$; Fig. 3a). The species marked in red in Fig. 3, will *rarely* be able to produce seed if cut in the recommended week in July each year. Most are relatively common and can cope with some degree of encroachment (*Succisa pratensis, Galium verum, Polygala serpyllifolia, Solidago virgaurea, Knautia arvensis, Platanthera montana, Viola canina, and Hypochaeris radicata*), which might be an argument for the continuation of the prescribed mowing activities. However, species that are able to reproduce by clonal growth have been shown to resist land-use abandonment for quite some time as their populations are maintained through vegetative reproduction[5]. Therefore, even if these species are presently found in encroached vegetation their populations might disappear in the future because of an extinction debt. If no sexual reproduction takes place the population will eventually disappear. Of the 29 specialists, all but three are reported to reproduce vegetatively (Kleyer et al., 2008; Lid and Lid, 2005). Early mowing of biodiverse hay meadows could ultimately cause these species to disappear from their most important habitat. For *Plantago media*, *Dianthus deltoides*, and *Pimpinella saxifraga* as well as *Arnica montana*, one of the two red listed species, which do not occur outside of semi-natural habitats as they do not cope with encroachment, the situation is even worse.

That species respond differently to different mowing times is not only the case for the plant taxa. The field fauna of semi-natural grasslands show the same pattern (cf. Humbert et al., 2009). Therefore, biodiversity would, for several trophic levels, benefit from a cutting

[4] NB. Farmer S13 is not the neighbour of farmer S10

[5] This has been shown to be a likely outcome for *Knautia arvensis* (Johansen et al. (2016)).

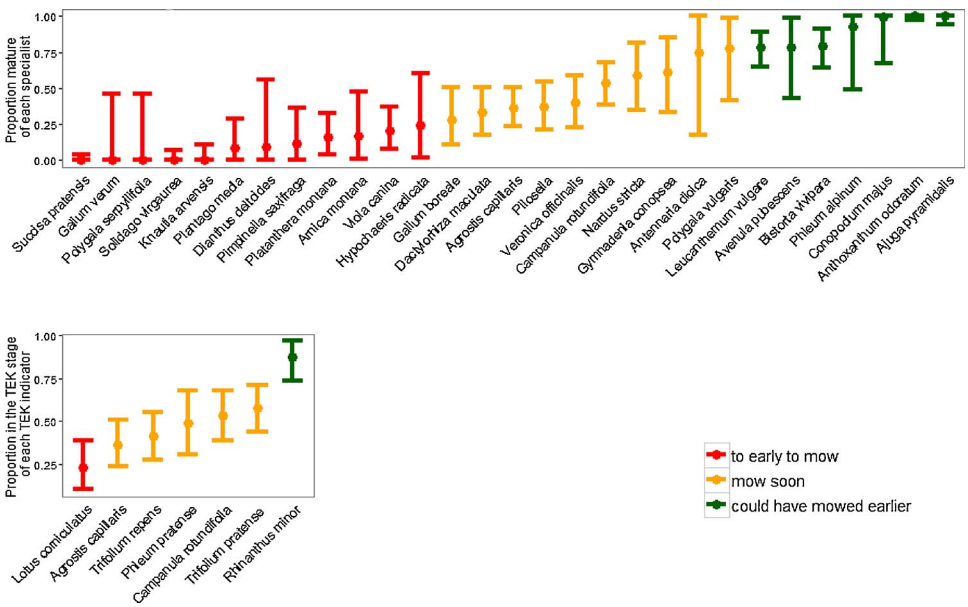

Fig. 3. Mean and confidence intervals of phenological stages of a) semi-natural specialists (proportion mature plants) and b) TEK (traditional ecological knowledge) indicators (proportion plants in the TEK stage; the stage used historically to define when to start mowing) in 29 semi-natural hay meadows involved in the APHM the week before recommended mowing date. If less than 25% of the plants were mature they are marked in red: it is to early to mow for these species to produce seeds. If between 25 and 75% of the plants were mature they are marked in yellow: a mowing can be performed (if hay is let to dry in the meadow such that the seeds can mature). If more than 75% of the plants are mature the mowing could have taken place earlier: marked in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

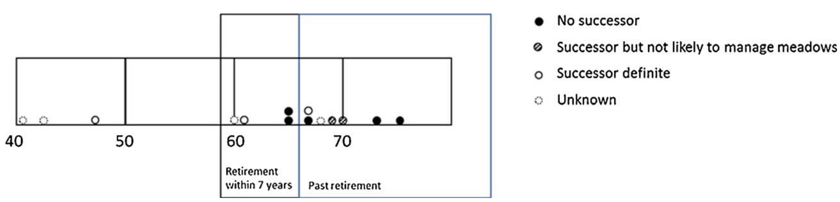

Fig. 4. Age structure of interview farms and presence of successor.

regime that allow cutting dates to vary between years and between hay meadows.

4.3.2. The problem of an aging farming population

While the ecological data suggested future potential biodiversity problems with the APHM managed meadows, a more immediate problem was associated with the changing demographic profile of farmers in the region. In particular, in keeping with general trends in Norway (Forbord et al., 2014), most of the owners/managers interviewed were not young commercial farmers but tended to be older, absentee, part-time or semi-retired (or a combination) – many of whom had no certainty of succession. Fig. 4 depicts the age profile of interviewed farmers along with the potential for the farm to be transferred to the next generation.

Half of the interviewees either knew that they would have no successor, or that the successor was unlikely to carry on with hay meadow management – whereas only three respondents definitely had a successor. Of these three, only one farmer believed his successor might take over the meadow management – and, even then, he notes his son would want to mechanise the process as he did not have the time to “do things the old fashioned way” (R5)[6]. For the sample population as a whole, therefore, the result suggested that within two decades many of the hay meadows could be lost – along with any TEK maintained or developed under the adaptive management approach.

A second potential problem for long-term management emerges from the declining ability of an aging population to manage the meadows. Traditionally, scythes were used to cut the meadows but at the time of the survey only two elderly land owners (R6, S14) were using scythes – something that one of them observed requires “strong legs that have been trained since childhood in this steep terrain and the skills to deal with this hard work” (R6). Cutting hay meadows can be very physically demanding where the terrain is rough (Von Glasenapp and Thornton, 2011), and, even when using motorised equipment, some of the study farmers suggested the physicality of the work made it difficult. For example, seventy year old informant R2 observes how the steep slopes of the farm make mechanical mowing very uncomfortable using his older single axel mower.

"It destroys your arms with all these steep slopes. No, it’s really not nice … if I hold on it rattles my arms apart.”

The problems for older people of managing what are often some of the roughest parts of the farm was also noted by 66 years old owner R4b. She observes of the payments received for the scheme:

“I think it’s a small payment for a large amount of work. It’s OK when the ground is even, as I said, but there are stones in between and there are mounds and it’s steep in some places. So it’s not simple to cut down here.”

One means of resolving the difficulties would be the purchasing of new machinery, however, farmers mentioned two reasons why this was often not possible. First, the payments in the management contracts are not substantial enough to cover the cost of new machinery (farmer R2). Second, as farmer R4a contends “… if I know that there is no one to take over there is no purpose in investing”[7]. With many of the farmers near or past retirement age (see Fig. 4) and having no successor to take over the farm, significant investment in upgrading equipment for hay meadow management is unlikely without additional financial incentive.

[6] Machines such as mowers that tear and mulch instead of cutting the hay are thought to reduce floristic diversity of meadows as seeds are damaged during the process (Tälle et al. (2014)). Even worse affected are insects which suffer high mortality from mulching (Cizek et al., 2012).

[7] An observation also found in the literature where the lack of a successor is known to limit the extent to which farmers are willing to invest in the business (e.g. Fischer and Burton, 2014; Smithers and Johnson (2004)).

4.4. The role of TEK in meeting the ADHM goals

Employing farmer's traditional ecological knowledge within the APHM scheme can be seen as an important part of improving the knowledge base of the scheme using the adaptive knowledge of the current land managers – as well as providing landowners with a say in the management of the scheme in a "bottom up" fashion. However a number of issues associated with TEK use in APHMs emerged from the survey.

4.4.1. A lack of TEK concerning hay meadow management

Given that the adaptive management scheme was predicated on the notion of employing farmer's traditional ecological knowledge in the construction of the agreements, a surprising finding from the interviews was that respondents had very limited TEK of hay meadow management. This is not unique. Grabherr (2009), p.169 observed that herdsmen in the Alps "expressed disappointingly little knowledge of plants" with the focus of their knowledge being noxious or useful plants. Other studies have found similarly disappointing levels of TEK with respect to plant species recognition (e.g. Ianni et al., 2015) and woodland management for charcoal burning (Rotherham, 2007) – with in the latter case, all knowledge being lost only 50 years after the cessation of the practice. One 67 years old respondent in this study suggested that TEK had been lost more than a generation ago, noting "There's a gap between me and my grandfather; that's when it [traditional knowledge] was lost" (S11). In a number of cases farmers suggested they had never known of any indicator species for meadow mowing (R1, R2, R7, R3, S9, S14). The following dialogue between the interviewer and a farmer in her 40s who maintained a strong interest in cultural landscape management illustrates the limited knowledge of younger farmers:

Interviewer: Do you look for any signs?

Farmer R1: No.

Interviewer: Species?

Farmer R1: None that I know of.

Interviewer: Red clover was one of those species they looked for – when it turned brown. Did you know that?

Farmer R1: No.

A potential explanation for this lack of knowledge of indicators can be found in the lack of a commercial use for hay. Based on information provided by Høeg (1974), knowledge of at least seven species was used historically to determine cutting dates (see Section 4.3.1). Two of the seven species (Campanula rotundifolia and Agrostis capillaris) are categorized as semi-natural grassland specialists. However, two species (Rhinanthus minor, Lotus corniculatus) can cope with some level of fertilization and the remaining three species (Trifolium pratense, T. repens, and Phleum pratense) have their main distribution in more intensively used grasslands and are often seeded (Halvorsen et al., 2016). The indicator species' resistance to fertilisers suggests that they are more likely associated with estimating the nutritional value of hay and seeking to obtain maximum production from meadows than attempting to maintain biological diversity *per se*. As a result, the use of these indicator species may have become of limited importance once the commercial value of the hay diminished.

4.4.2. TEK's use in the creation and adaptation of management plans

The lack of TEK among owners/managers of the hay meadows raises the issue of the extent to which TEK could have been incorporated within the initial management plans and what role it can perform in any future adaptive management process. A number of farmers commented during the interview that they had been unable to contribute significantly to the construction of the management agreements. Respondent S9s comments are relatively typical in this respect:

Interviewer: Did you have any input to the management plan? (abridged)

Respondent S9: No … not that I noticed. They came around here and asked about different things, sure. And then they came up with this plan, and we looked over it. It was of course, not just a signature, one has to read through before signing. So it seemed straightforward enough.

Limited contribution to the initial establishment of the management plan led some farmers, after a few years of experience with the scheme, to feel that the results of the management regimes were not as they had expected. The disputed need for fertiliser provided one key area of knowledge conflict. For others the act of managing the hay meadows appeared to be leading to the endogenous development of new knowledge. For example, in the general guidance of the management agreements low intensively spring and autumn grazing by livestock is recommended, but if species vulnerable to such grazing are present, it is recommended not to graze during the period when these species bloom (such spring flowering and vulnerable species are extremely rare). Respondent S10 initially agreed to limit spring grazing but, with experience, now believes more grazing is required:

Respondent S10: "One sees in hindsight that it should grazed a bit more in the early spring. And then it should be grazed right down in the autumn (…)

Interviewer: Have you discussed this with people?

Respondent S10: They've been here, and I've said that it is entirely wrong to cut and take hay away without adding anything (…) it comes down to the fact that if you had sheep that grazed a bit, then they would fertilize a bit.

Interviewer: What does it say in your contract then? … It says that you can use sheep here.

Respondent S10: Yes, but preferably not during spring."

This presents a challenge to scheme managers. While the APHM agreements will be re-evaluated and new agreements signed at intervals of 5–10 years (The Norwegian Environment Agency, 2009), a question will emerge as to what extent the new knowledge farmers develop as a result of participation will be incorporated into the new plans. TEK is developed through iterative practice and observation (Berkes et al., 2000; Drew, 2005) and failing to allow its development (e.g. not authorising spring grazing in order to enable the farmer to observe the outcome) would interfere with the development and transmission of TEK. On the other hand, providing farmers the ability to adjust schemes at will could create an opportunity for the misuse of the process and thus potentially compromise the ecological outcome.

4.4.3. The possible use of recorded TEK

Although the interviewees' knowledge of TEK was sparse, Høeg's (1974) study (based on interviews performed during the period from 1925 to 1973) illustrates that some decades ago TEK had a greater presence in the local region. As the TEK indicators identified by Høeg are common species and easily recognizable, we argue that these species could still be used as indicators, however, for biodiversity production and not, as historically, for agricultural production. We found that, as with the semi-natural grassland specialists, the phenology of the TEK indicator species varied between the two years ($\chi^2 = 93.65$; $p < .001$; df = 1; Fig. 2b) and among the TEK indicators ($\chi^2 = 37.67$; $p < .001$; df = 6; Fig. 3b). The responses were comparable with the semi-natural grassland species (Fig. 2), even if we found only a few significant correlations between the phenology of the TEK indicators and the phenology of the semi-natural grassland specialists (see Table 1). Mowing dates for specialists that tolerate relatively early cutting dates could be indicated by *Rhinanthus minor*, specialists requiring intermediate cutting dates by five of the TEK species (including *Agrostis capillaris*), and specialists requiring late cutting dates by *Lotus corniculatus* (see Fig. 3). *Agrostis capillaris* correlated with several of the specialists and is one of the few plants still used as an indicator today (Respondent S10).

Table 1
Relationship between the proportions of each TEK indicator in the phenological state used to indicate when to start mowing (TEK stage) and the proportion of mature plants of each of the semi-natural specialists the week before defined mowing date. The Spearman correlation coefficients are only shown for those species which showed significant correlations (p > .05).

Specialists:	TEK indicators: *Agrostis capillaris*	*Campanula rotundifolia*	*Phleum pratense*
Agrostis capillaris	1	0.52	0.67
Campanula rotundifolia	0.52	1	—
Dactylorhiza maculata maculata	0.61	0.48	—
Dactylorhiza maculata fuchsii	0.84	0.7	—
Galium boreale	0.61	0.51	—
Gymnadenia conopsea	—	0.87	—
Pilosella sp.	0.35	—	—
Platanthera montana	0.52	—	—
Polygala vulgaris	0.95	—	—
Rhinanthus minor	—	—	—
Rumex acetosella	−0.64	—	—
Veronica officinalis	—	0.41	—

5. Conclusion

In this study we have examined the application of TEK to adaptive management of hay meadows in Møre og Romsdal, Norway. What we found is a cultural landscape that has been largely devoid of hay meadow related TEK for decades, if not generations, and one within which the socioecological context of agriculture has changed so significantly that any attempts to reintroduce traditional approaches are likely to meet considerable obstacles. These range from the aging and increasingly isolated farming population (and their lack of physical efficacy), to the lack of purposed buildings, the lack of livestock to perform critical management roles, and, importantly, the lack of a market for hay to make quality of hay a consideration in decision-making. Attempts in the APHM to return hay meadow management to a more traditional approach are likely to prove difficult not because the practices in the management agreements are ecologically inappropriate or historically inaccurate – nor because the remaining farmers are unwilling to participate – but rather because the structure of the farm and farming community has changed to the extent that the historical TEK is not adapted to current socioecological conditions. From an ecological perspective there are also problems – in part created by the fixing of cutting dates and the impact this might have on species composition in the long turn, but also as a result of a lack of species turnover across the remaining meadows. This is an issue that the APHM, in focusing on contracts and species diversity in individual meadows, does not readily address.

For both ecological and demographic reasons, there are thus likely to be problems with the long term success of the APHM as it currently stands. In the case of the need to vary cutting dates, this could be relatively easily addressed by altering the scheme. Given that the idea of adaptive management is to enable farmers to experiment and adapt to conditions, providing them with the ability to vary the cutting dates seems like a relatively minor alteration – and one that is in keeping with historical cutting regimes. However, there are many reasons farmers may have mown late in the past that do not exist now. These include labour availability due to co-incidence with other farm tasks, the need to improve meadow condition, the targeting of specific hay markets, the intended use of the aftergrass, and the occasional need to gather seed (see Burton and Riley, 2018) – issues that mechanisation, loss of animals, and the lack of a market for hay (or hay seed) have rendered largely irrelevant. Thus, even if land managers were permitted to select the cutting dates, these are unlikely to have the same variance as historical dates as the historical structural drivers are simply not there.

Demographically, the problem of an aging and declining farming population is much more problematic. This issue is not unique to Norway. Some of the most prized cultural landscapes in Europe are under threat from changes in the population structure of their resident rural communities. The Pyrenees National Park in France/Spain (Marín-Yaseli & Martínez, 2003; Mottet et al., 2006), the Burren in Ireland (O'Rourke, 2005), the Lake District National Park in the United Kingdom (Burton et al., 2009; Harvey et al., 2013), and the Massif Central in France (André, 1998; O'Rourke, 2006), are all experiencing the same problem – the declining number of farming families managing the landscape is affecting their ability to apply traditional management approaches. In the case study area, it may already be too late. Research suggests the iterative process of socialising a farm successor and developing a farm such that it is likely to attract a successor is begun in early childhood (Brandth and Overrein, 2013; Fischer and Burton, 2014). Measures to make management easier such as increasing the access to new equipment may assist in keeping the meadows managed for longer than would otherwise be the case but do not address the succession issue.

The Norwegian APHM has undoubtedly helped perserve the biodiversity of hay meadows in Møre og Romsdal in the short term, and, from that perspective, it is a success. However, ecological issues such as the fragmentation of the hay meadows, changes in the landscape surrounding the grasslands, potential problems caused by perhaps too simplified management schemes and social/managerial issues such as the lack of livestock and market incentives for producing biodiverse hay meadows raise issues concenrning long-term success. The evidence presented highlights that the culture in which the hay meadows where formed has irrevocably changed, which poses significant challenges for the likely longer-term success of APHMs and lead us to four main recommendations for action in the short term.

First, to return the hay meadows to their historical state requires the return of livestock to the region. The lack of livestock both creates problems with the non-utilisation of hay (and thereby interest in hay composition) and controlled fertilisation/trampling of the meadows – which can be connected to the rise in moss cover and has longer-term implications for the biological diversity of meadows.

Second, more could be done to create a market for hay. This would provide a motivation for managing the hay meadows which could, in turn, lead to an increase meadow area, an increase in investment in machinery and storage facilities, and make a better regional environment for hay meadow species. Further, if hay from good meadows was marketed as a quality product with "medicinal properties" as some of the informants suggested, then farmers would have a clear incentive to manage the meadows in a manner that promotes biodiversity and learn more about the plant species and their management – effectively promoting the creation of new TEK.

Third, there is a need for farmers to be active participants in adaptive management which, in turn, requires the APHM to be flexible and allow experimentation. As TEK is developed through a process of trial and error, failing to allow experimentation would end the iterative process of action and observation – preventing farmers from adapting to the changing social, economic and ecological environment. In this case, the ability to experiment is even more important as the initial management plans for the meadows were established largely without TEK input from the landowners.

Fourth, and most importantly, the issue of who will manage meadows in the long term needs to be addressed. If it is to be farmers then serious consideration needs to be given to how to encourage young people to remain in rural areas and manage the land for agriculture. However, realistically, without considerable change in the socio-economic condition of the region any measures short of a massive increase in the already high agricultural subsidies could slow the speed of decline, but not prevent or reverse it. Thus consideration needs to be made for alternatives relatively soon. One possibility is for hay meadows under the APHM to be managed by community groups – which is occasionally done but should perhaps be encouraged to a greater extent as town populations grow and rural populations decline.

A final observation concerns the availability of new sources of TEK for use in creating adaptive management plans. Although it is generally assumed that TEK is transferred by (often oral) cultural transmission, the fact that Høeg's (1974) study provided a more informed source of TEK than the remaining land owners and managers raises the issue of the use of written sources of TEK – particularly in cases where TEK is either limited or missing entirely. A recent study by Burton and Riley (2018) found that digitised online libraries provided by Google Books offer a comprehensive source of freely available historical agricultural literature from the 16th to 20th centuries. While their study focused on the English literature, the authors found similarities between hay meadow management practices in 18th Century England and practices revealed in contemporary TEK studies in Romania – suggesting that agricultural TEK in Europe may not be endogenously developed but may have been part of a Europe wide knowledge network prior to industrialisation. They also note that these potential sources are available in a number of European languages. Given the lack of TEK in the sample, the utility of Høeg's study, and the free availability of historical reports (albeit with patchy coverage) this historical literature may prove a useful addition for the creation of adaptive management plans for European hay meadows.

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