

Medicinal Plants in Semi-Natural Grasslands: Impact of Management

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Research

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Abstract

Background: Semi-natural grasslands as valuable ecosystems are significant for their high biodiversity, cultural importance and landscape values. Quantitative information about medicinal plants in semi-natural grasslands facilitates the evaluation of ecosystem services of these plant communities.

Methods: Different literature sources and floristic inventory databases were used to assess the ratio and frequency of medicinal plant species in several Estonian grassland types and the impact of management on these values assessed both in Estonian and Japanese case studies. Lists of medicinal plant species according to different definition scenarios is included as Supplementary Material. Principal Component Analysis was applied for environmental preferences of medicinal plant species compared to other vascular plant species in the semi-natural grasslands.

Results: The ratio of medicinal plant species in local total plant species list was the largest in alvars, followed by floodplain and wooded meadows. The average number of medicinal plant species per study plot in wooded meadows and alvars was about twice that found in naturally growing broadleaved forest (according to the most detailed MP species list 7.2, 7.8 and 4.3, respectively). Fertilization of Estonian wooded meadows had no significant impact on medicinal plant species ratio, but decreased the proportion of medicinal plant biomass in total yield. Estonian coastal meadows had a short list of medicinal plant species and the impact of management quality depended therefore on adopted definition scenario. In Japanese *Miscanthus sinensis* grassland case mowing or burning+mowing combination should be preferred to favor medicinal plant species number. Principal Component Analysis revealed that MP species are more drought-tolerant, common and anthropophyte than the rest of studied grassland species.

Conclusions: Alternative usage of herbaceous plant species from semi-natural grasslands is a promising option to achieve sustainable development goals and increase public awareness. Further close cooperation of ecologists, economists and pharmacists is required to guarantee fair and sustainable trade of this ecosystem service in the future.

Background

Semi-natural grasslands (SNG) as valuable ecosystems have been in focus for several decades due to their high biodiversity, cultural importance and landscape values. Their restoration has been challenging, but this activity has also led to improved knowledge about and opportunities for these unique ecosystems [1, 2]. Typically, biomass production of these areas is lower than that of intensively managed grass and croplands due to restrictions on ploughing, sowing and fertilization and therefore to make extensive management an attractive option for landowners, economic stimulation measures should be adopted. In the EU this problem is partly solved through the agricultural subsidy schemes for NATURA 2000 network areas that should compensate the loss of crop production due to extensive management. Valuable grasslands, however, are not determined by this network only and are found in other locations and geographical regions as well [3, 4]. Recent approaches to evaluation of SNG by the complex list of potential ecosystem services (ES) provides a much more holistic overview and supports sustainable development ideas in different regions by giving a valuable input to the benefits communities can get and share through different provider groups [5, 6]. Different authors point out the wide range of goods and services provided by grasslands, but beside plant species diversity in general all of these assume that SNG are valuable ecosystems for migratory and breeding birds, refuges for pollinators and sources of medicinal plants [2, 3, 6, 7].

Compared with SNG biodiversity or pollinator richness the occurrence, diversity and dynamics of medicinal plants (MP) is less studied. The lack of scientific knowledge about the potential health benefits is an issue while the phytochemical content and pharmacological actions in order to define efficacy and safety have been studied for limited number of species, but this situation may change rapidly [8]. Hitherto, available ethnobotanical reviews focus mainly on the regions where the old traditions and indigenous knowledge have survived globalization tendencies [3, 6, 9, 10]. Application of these databases to any ecological study is disputable as in most cases the native names used in local folklore are difficult to match with scientific plant names in Latin (Sõukand, personal communication). Moreover, the historic records also contain MP species which are no more suggestable due to their severe negative side effects. On the other hand, there are some plant species that are internationally recognized as MP and therefore studied in details for biorefinery purposes. This information allows us to make some assumptions about the environmental factors, that may have an impact on the potential of SNG as a source of medicinal plants. For instance, there are several reports available, demonstrating that medicinal plants take up and accumulate metals from the growing substrate [11, 12] and hence the unfertilized, unploughed SNG may provide plant biomass with higher quality than from traditional agricultural fields where mineral fertilizers are used. The production of compounds that are typically associated with healing benefits are secondary metabolites (alkaloids, glycosides, polyphenols and terpenes) however, is highly dependent on local environment conditions and therefore moderate abiotic stress is assumed to be useful for pharmaceutical purposes [13]. For instance, it has been reported that the monoterpene concentration in *Salvia officinalis* increased significantly during drought stress [14] and that *Glycyrrhiza uralensis* roots contained more useful compounds when grown under a low light intensity regime [15]. Other authors have assumed that the healing, antimicrobial and antitumour effects of MP can be associated with secondary metabolites that protect these plants against free radicals and prevent photosynthetic process damage and demonstrated with their meta-analyses that water scarcity is only one possible factor increasing the ratio of phenolic compounds [16]. The list of environmental factors that may have an impact on useful chemical production also includes soil nutrients and the local agro-climate [17, 18]. Besides abiotic factors the impact of neighboring plants should be also considered for MP quality and MP frequently have a rich rhizosphere community consisting of different arbuscular mycorrhizal fungi genera (Jia et al., 2016). Mutualistic interaction has been demonstrated to increase the concentration of phenolic acids in the roots of model MP *Arnica montana* [22]. Moreover, different endophytic fungi may be linked to the therapeutic activity of the *Asteraceae* family in different parts of the world, but without a host plant they seem to be inactive [23]. Hence it can be assumed that MP that grow naturally in SNG with high biodiversity may provide us with valuable healing compounds. This is already recognized in practice, farmers value species-rich grasslands for these positive effect on livestock health [24]. However, data on the ratio of MP species or their frequency in any European SNG type is limited and consequentially information about the regional potential of MP species is difficult to gather. Such a shortage of knowledge also limits any attempt to quantifying the level of ecosystem services provided by SNG.

Our previous work has provided us with plant biodiversity data from a number of Estonian SNG types with different management regimes (Heinsoo et al. 2020; Kose et al. 2020). These datasets were expanded with information from the Estonian Environment Agency in order to obtain a wider perspective on the variation in each SNG type. Since the historicist botanical database of Estonian folk medicine (herba.folklore.ee) is unsuited to this purpose, we instead, used three different scenarios to define Estonian MP species. The main patterns found in Estonian context were compared with data from one Japanese region, where weather conditions are comparable to those in Estonia.

The main aim of the current study is to quantify the potential of MP as an ecosystem service provided by SNG. For this purpose, we studied the ratio and frequency of MP species in different SNG types and analyzed the impact of different management options (fertilization, infrequent mowing, burning) on these values both in Estonia and Japan. The database of Estonian SNG herbaceous plants has been supplemented with the traits and indicator values of species' environmental requirements (details in [27]), from this data we analyzed whether MP species have any particular environmental preferences compared with other SNG plant species.

Materials And Methods

Medicinal plant species list

We composed the Estonian list of MP species on the basis of three different sources that were created and published for different purposes [28–30]. According to those three sources, different scenarios were implicated in each analysis (Table 1, full lists of MP species by scenarios are available in Appendix A). For the Japanese MP species list we amalgamated information from different officially recognized literature sources [31–34].

The current analyses for Estonia involve herbaceous, low-height shrub plant species (hereby 'plants'). In Japanese case we incorporated non-woody and woody vine species also. Trees and bushes were excluded from the study as their abundance in SNG usually indicates poor management and therefore a negligible provision of ecosystem services from those areas. Low-height shrubs, that tolerate periodic haymaking or grazing were included in the MP species lists as they could include widely popular MP species (e.g. *Oxycoccus palustris* in fens).

Floristic databases

We gathered the information about plant species and their frequency in various SNG from databases that had been collected and explored in a range of studies undertaken for specific purposes. To determine the occurrence and frequency of MP species in various types we scanned the database that included inventory results from 1999–2019 in 82 sites of 12 different NATURA 2000 network habitats (Table 2). The majority of the plant species lists from the plant communities was extracted from the national environmental monitoring information system managed by the Estonian Environment Agency. They initiate biodiversity inventories across a range of valuable habitats, particularly in NATURA 2000 areas and these are supplemented by our previous Data from heaths and old hemi-boreal broad-leaved forests was also included to the study as references in order to evaluate the MP potential of SNG. The floristic database was not balanced; some habitats had been visited more frequently than others and the timespan of inventories varied from unique to multiple visits. However, none of the particular study sites was particularly overwhelming in the habitat and incorporating the habitat data into larger types improved the database quality (Table 2).

The proportion of MP (MP%) was calculated as the ratio between the sums of MP species by particular scenario (MP) and total number of plant species in the sites' (s) plant species lists of all sites of particular type (TP) multiplied by 100 to get %:

$$MP\% = \frac{\sum MP_s}{\sum TP_s} * 100.$$

With such a detailed calculation method, we tried to minimize the impact of one occasional record of any rare species/untypical site and generalize the data obtained from different study sites.

The size of inventory plots in the database varied from 0.2*0.2 to 1*1 m depending of study year/location and the number of plots per site was 10...80 (Table 2). In each plot the occurrence of particular species had been recorded without any additional data regarding its abundance in the plot. Hence, we were not able to detect the abundance of MP in the site/type, only the probability to find these from a plot of a particular type. The number of plots studied per any type was large (280...2800) and therefore we assume this probability to be close to the MP occurrence frequency and use this term as more understandable for ecologists thus the "number of MP species per plot". In practice the average MP frequency (MPfreq) in any type was calculated as the ratio between the sum of the plots per site (s) where this particular MP species was recorded (MPplot) divided by the total number of plots inventoried in this particular type (plot_{tot}):

$$MPfreq = \frac{\sum MP_{plot}}{\sum plot_{tot}}$$

For the analysis on the impact of fertilization on MP species performance we used the dataset of Laelatu wooded meadow, western Estonia, which has been mowed annually for approximately 300 years [35]. The fertilization experiment in this meadow took place between 1961 and 1981 with annual fertilization of PK and two different levels of N in three plots per treatment (details in (Heinsoo et al., 2020)). In order to avoid the annual effect of weather and to minimize the dynamics of vegetation response to treatment change we compared only two periods in our current analyses: the period in which we assume the impact of fertilization was steady (1969–1981) and the period where no further impact of fertilization on biomass production was detected (2005–2016). In this case MP% was calculated as the proportion of MP species in the total plant species list of particular treatment during the same period. The dataset allowed us to calculate the ratio of MP biomass (MPb) per treatment as the sum of the MP dry biomass weights (w) measured in particular treatment plots divided by the sum of all species (tot) dry biomass in the same plots:

$$MPb = \frac{\sum w_{MP}}{\sum w_{tot}}$$

The Estonian case study on management impact was performed on the same data about coastal meadows that were added to the database for SNG types comparison. These data originated from a study of 15 coastal meadows western Estonian coastal meadows. Most of the sites had been annually grazed by cattle and the management varied from permanently managed to recently restored. The division of these sites into three groups based on their management history and vegetation quality has been proved by their plant community characteristics [26] and we therefore continued the current study with the same “very good”, “good” and “poor” management (vegetation quality) classes. MP% in this case was found as proportion of MP species in the total plant species list per management class. MPfreq was calculated with similar algorithm used for detecting Mfreq in different SNG types.

The Japanese floristic data originate from a study on the impact of various management practices (mowing, burning, burning+mowing, and abandoned) in typical *Miscanthus sinensis* semi-natural grasslands. The dataset was collected twice (summer and autumn 2017) from grasslands in Honshu Island, Japan from 1000...1300 m a.s.l.; twelve grasslands with different management traditions were located on the Kaida Plateau of Nagano Prefecture and six grasslands on the north-eastern foot of Mt. Fuji in Yamanashi Prefecture (Table 3). We are not convinced that during one vegetation season we were able to list all the local plant species and therefore only absolute values of MP species were used in this case. The botanical inventory includes the list of all higher plant species from nine 1 m² plots per site (three from the bottom/central/ upper part of each site). Lists of Japanese MP species by studied regions is available in Appendix B.

Statistical analyses

Lists of Estonian MP species depended significantly on the implicated scenario and therefore no further statistical analysis was reasonable for evaluating the impact of different management regimes on MP species occurrence. We compared the general characteristics of MP species and the other SNG plant species with the CANOCO software unconstrained Principal Component Analysis. The not-compositional response data included different Ellenberg values (classes indexed into numbers according to [27], details in Table 4) and theoretical average and maximum heights obtained from the literature [37].

Results

Compiling different floristic lists of Estonian habitat types resulted in 538 plant species and a 10,814 record database that was used for further analyses. The largest list of plant species was obtained from wooded meadows (330) while in the second most diverse SNG type (floodplain meadows) one third fewer plant species (194) were recorded (details in Appendix C). The ratio of MP species in the list depended on the scenario; the biggest differences were detected for the species list of heaths, which was the type with one of the poorest MP species potential according to scenario 1, but best potential according to scenario 3.

A similar pattern was found in the analysis of floristic databases of different type inventories where almost half the recorded plants in different heaths belonged to scenario 3 MP list. In general MP% was larger in natural communities and among SNG the alvars had the largest relative potential of MP species followed by floodplain and wooded meadows (Fig. 1A). Frequency of MP species according to most scenarios was the highest in wooded meadows and alvars followed by broad-leaved forests. In coastal meadows, where the absolute numbers according to species list (S3) was comparable to that of alvars, the frequency of MP was much lower. Among SNG the lowest MPfreq was detected in fens, but that was larger than the values in heaths despite the scenario (Fig. 1B). The other SNG type where MP species were less common, were floodplain meadows.

The analyses of the Laelatu wooded meadow fertilization experiment database revealed that according to two of the three scenarios, the ratio of MP species increased in time. The impact of fertilization on MP species availability on the plots was diminutive and most of the MP species survived the additional nutrient application indicating adaptation and strain of these species (Fig. 2). At the same time, major differences in MPb between fertilization treatments occurred; the proportion of MP biomass during N fertilization decreased significantly and according to scenarios 1 and 3 these differences in the plots with highest additional nutrient application (NPK2) have not reversed even 20 years after the end of the experiment (Fig. 2D and 2F).

The coastal meadows database was difficult to study as among Estonian SNG they seem to be one of the poorest SNG types in terms of MP species numbers (S3). Hence, application of different scenarios caused significant differences in the evaluation of coastal meadow potential in terms of MP species growing type. Good management of coastal meadows tends to decrease the MP ratio in the inventory species list (Fig. 3A). The impact of management of MP species frequency is species-specific and may result in contrasting impacts (Fig. 3B).

In the Japanese dataset the smallest number of MP species was detected from Nagano abandoned sites (on average 3.3 per plot). Both management options and in combination increased the average MP species count. In Yamanashi the number of MP species per plot was larger and here the least MP species were found in sites where annual burning was used as a management option (Fig. 4). Mowing significantly increased the number of MP species here, compared with abandonment or burning. The number of plant species per plot varied between 3 and 28 and on average, almost half of the study site plant species listed were identified as having medicinal potential.

With the Principal Component Analyses of Estonian SNG species we could not identify any clear peculiarities for MP species. Due to gaps in our knowledge about some characteristics only 171 species were included in the analyses and despite the scenario the first two axes did not explain more than 35% of the variation. According to the different scenarios the best correlation was found between MP and its commonness – MP species are more likely available in nature than the rest of the grassland species (Fig. 5). They also tend to be less light-demanding and tolerate drier growing areas. The average and maximum theoretical height does not define MP species; moreover, they do not differ from the rest of the grassland species by their N demand. In addition, the culture relation does not impact significantly on characterizing an MP species status.

Discussion

The longest list of plant species and also the largest number of MP species was obtained for wooded meadow type. This result is in agreement with other reports showing wooded meadows to be the SNG with the largest plant species richness on a small scale [35]. Such a phenomenon can be partly explained by the large variability of environmental conditions inside this particular type and amplified in our study by the inclusion of data from wooded meadow sites with widely differing water availability and tree coverage. The ratio of MP in wooded meadows, however, was modest and can indicate both large ratio of sedge species and grasses with no recognized healing value in Estonia, or the existence of rare species which usage whose medicinal value has not been recorded in any of our scenarios. The ranking by MP species in total type plant species list varied by scenario, but dry types (alvar) included proportionally less MP species than types which are at least partly seasonally flooded or are permanently water-saturated and therefore larger local diversity of environmental factors expected (floodplain meadow). Natural plant communities tended to have a relatively larger number of MP species, but the comparatively short species list in heaths make its position in the ranking list extremely influenced by scenario used.

The average MP% values by types follow a largely similar pattern; the largest proportion of MP species was recorded from natural plant communities and almost half of the heath plant species were mentioned in the World Encyclopedia of Medicinal Plants [30]. Among SNG, however, alvars were the preferred sites according to this criterion, indicating that the MP species in total type list are found in various sites. Wooded and floodplain meadow demonstrated similar MP% despite applied scenario. The smallest MP% was found for fens indicating that the MP species list there included more rare species that are not growing in each studied site. One can also speculate that fens are historic SNG that are difficult to manage due to high groundwater levels found there [38] and therefore the dataset could contain sites with different edaphic conditions and/or management history and therefore variable plant species lists.

The average number of MP per plot (MPfreq) was the largest in wooded meadows and alvars and therefore these plant community types should be preferred regarding MP provision ecosystem service. The quantity of MP species to be found in plots of these types is most probably twice than that of natural broad-leaved forest, which is the future of neglected wooded meadow in the absence of a proper traditional management regime.

Despite the scenario, MPfreq in coastal and floodplain meadows was about half that of preferred sites with more moderate water availability. During their adaptation to water deficit the species growing in alvars and wooded meadows may have increased the production of secondary metabolites that are associated with the pharmaceutical impact [13, 14].

A long-term study of Laelatu wooded meadow demonstrated that continuous management of SNG can be rewarded by additional MP species emergence in the site – in our case even some species from the strictest scenario 3 started to grow in the area. Fertilization of the plots decreased the overall number of species on plots drastically (Heinsoo et al. 2020). According to our calculations, however, MP% changes between control/fertilization during the experiment were insignificant indicating MP species to be vital and as tolerant of environmental change as the rest of the plant community. On the other hand, the aim of the annual fertilization in this experiment was to increase total biomass yield and that target was achieved by between a 250 and 400 % greater annual plant biomass production per area (Heinsoo et al., 2020). The large decrease of MPb of fertilized plots compared with control ones (NPK1 and NPK2 despite scenario) reveals that other plants than MP have caused the production increase. This indicates that MP, growing in control plots, did not suffer from N deficit and therefore N application is not required to increase their yield for economic reasons.

Our previous study has revealed that in coastal meadows plant species number does not increase with long-term management [26] and in comparison with other types studied only a small number of MP species were present here. Therefore, the interpretation of obtained results must be done carefully. A high proportion of MP in sites that are managed for shorter period indicate that the natural communities developing from coastal meadows during natural succession process have longer list of MP species. Moreover, the scenario-dependent effect of management quality on MP frequency in this type can be a result of the dominance of different plant species in groups compared. For instance, MP species list in scenario 3 includes *Phragmites australis*, which is used as an indicator species for detecting poor management of coastal meadows. In scenario 2, on the other hand, MP species list contained more species which probably favored by proper meadow management.

In absolute values between three and nine MP species per plot were found in Japanese SNG, a number that was comparable to Estonian heaths and fens. The comparatively low biodiversity in the Japanese SNG is associated with historical dominance by *Miscanthus* in this plant community type. Abundance of these grassland types results in decreased biodiversity and therefore different traditional management options are favored [39, 40]. According to our study results mowing in Yamanashi region and combination of mowing and burning in Nagano region should be favored instead of burning or abandonment as those region-specific agricultural practices remove nutrients from semi-natural grassland and therefore suppress *Miscanthus* dominance for further biodiversity

This holistic approach to studying MP plant and environment characteristics resulted in PCAs that explained one third of the class variability. According to all the scenarios used the MP species tolerate or prefer dry growing conditions. Such a result is in accordance to our results which showed a greater frequency of MP species in alvars and wooded meadows as compared with floodplain meadows. Both water shortage and shade tolerance of MP species can be linked to the increased synthesis of useful secondary metabolites during environmental stress [15, 41]. MP species also tend to be more common and anthropophyte than the other plant species in the community. The current analysis was only carried out on less than 200 grassland species however, and for a better understanding of the ecological and social patterns of MP species the database should be developed to include all the herbaceous plant species of Estonia regardless of their growing type. Indeed, the trends observed can also be related to historical factors; during the country's oral heritage period common plants around homesteads had a greater probability of being used and the knowledge about their healing properties being transferred to the next generation. If so, one might speculate that the large biodiversity in Estonian NATURA 2000 sites and the currently improving floristic knowledge might lead to a major increase in the wider MP potential of SNG. For instance, in Estonia there is no evidence of use of sedges as MP species, but there is proof from other regions with similar climates that they can have a positive impact on our health [42–44].

In conclusion we find that the MP potential of grasslands today is significantly dependent on cultural traditions and both the available MP species list and local socio-economic situation should be considered while giving a quantified evaluation to this particular ecosystem service in a region or ecosystem type. The risk of MP contamination with zoonotic disease during the grazing period should also be clarified [45] and SNG management plans adopted which

guarantee consumer safety. In addition, there are reports which demonstrate evidence of overexploitation of natural MP resources [46], and therefore both harvest pressure and economic feasibility of MP utilization for local community and landowners should be assessed through further close cooperation of ecologists, economists and pharmacists.

Conclusions

-The ratio of MP species in local total plant species list was the largest in alvars, followed by floodplain and wooded meadows. The average number of MP species per study plot in wooded meadows and alvars was about twice that found in naturally growing broadleaved forest (according to the most detailed MP species list 7.2, 7.8 and 4.3, respectively).

-Fertilization did not decrease MP species ratio in Estonian wooded meadow, but decreased the proportion of MP biomass in total yield.

-The frequency of MP species in Estonian coastal meadows depended on applied MP definition scenario.

-In Japanese *Miscanthus sinensis* grassland case mowing or burning+mowing combination should be preferred to favor MP species number.

-Principal Component Analysis revealed that MP species are more drought-tolerant, common and anthropophyte than the rest of studied grassland species.

Abbreviations

MP – medicinal plants

MPb - the ratio of MP biomass in total biomass

MPfreq – the ratio of plots with particular MP in total number of plots of particular type

MP% - ratio of MP in total plant list

PCA – Principal Component Analysis

SNG – semi-natural grasslands

TP – total number of plants

Declarations

- Ethics approval and consent to participate

Not applicable

- Consent for publication

Not applicable

- Availability of data and materials

We intend to archive all our original data to the digital archive of Estonian University of Life Sciences <https://dspace.emu.ee/> as soon the manuscript gets published. Part of the datasets is already there <https://dspace.emu.ee/handle/10492/6300>. The lists of the medicinal plants from various sites are provided with the manuscript as Supplementary Information files

- Competing interests

The authors declare that they have no competing interests

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- Authors' contributions

Authors' contribution is: MK – PhD student who collected materials from Estonian case studies and responsible for PCA analysis materials, IM – data collection from Estonian Environmental Board, analysis of Japanese medicinal plants, AO and KU – management of fieldworks in different Japanese regions, KH – management of whole project, data analysis, main author of the text.

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Tables

Table 1 Composition of MP species list in each literature source exploited for Estonian MP species lists.

Class	scenario 1	scenario 2	scenario 3
Total number of MP species in list	260	152	>1700
from these domestic	62	113	207
trees&bushes	3	25	27
fungi	3	1	3
vine	1	1	2
lichen	0	1	2
low-height shrubs and herbaceous plants	55	85	174
Main purpose of the list	Import and market control	Growing and gathering	Encyclopaedic knowledge

Table 2. Background information about the dataset used for the study.

Type	Reason	NATURA 2000 habitat[a]	Number of sites	Number of plots
Alvars	SNG	6280* Nordic alvar and precambrian calcareous flatrocks	18	920
Coastal meadows	SNG	1630* Boreal Baltic coastal meadows	14	280
Floodplain meadows	SNG	6450 Northern boreal alluvial meadows	8	640
Fen meadows	Historic SNG[b]	72 Calcareous fens 90; 7160 Fennoscandian mineral-rich springs and springfens	10	900
Wooded meadows	SNG	6530* Fennoscandian wooded meadows	17	2800
Heath	Natural habitat	21 Sea dunes of the Atlantic, North Sea and Baltic coasts 4030 European dry heaths	8	800
Broad-leaved forest	Natural habitat	9010 Western taiga 9020* Fennoscandian hemiboreal natural old broad-leaved deciduous forests (Quercus, Tilia, Acer, Fraxinus or Ulmus) rich in epiphytes 9050 Fennoscandian herb-rich forests with Picea abies 9060 Coniferous forests on, or connected to, glaciofluvial eskers	8	420

Table 3. Number of Japanese SNG sites with different management in two regions.

Management	Nagano	Yamanashi
Mowing	3	1
Burning	3	3[c]
Burning+Mowing	3	0
Abandoned	3	2 ^c

Table 4. Indexes for Ellenberg values in PCA analysis[4].

Characteristic/Class	Abbreviation	1	2	3	4	5	6	7
Sensitivity to human impact	Humimp	Anthropophyte	Apophyte	Hemiradiaphore	Hemerophobe			
Commonness	Commons	Not known	Very rare	Rare	Uncommon	Scattered	Occasional	Common
Life form	Lifeform	Woody chamaephyte	Chamaephyte	Hemicryptophyte	Geophyte	Therophyte	Hydrophyte	
Leaf endurance	Leaf end	Evergreen	Summergreen	Springgreen				
Light	Light	Deep shade plant	Av.	Shade plant	Av.	Semi-shade plant	Av.	plant in well-lit places
Temperature	Temp	Cold, alpine	Av.	Cool, subalpine	Av.	Moderate heat indicators	Av.	Warm
Continentality	Contnent	Euroceanic	Oceanic	Between 2 and 4	Near oceanic	Intermediate	Subcontinental	Av.
Soil moisture	Moisture	Extreme dryness	Av.	Dry-site indicator	Av.	Moist-site indicator	Av.	Dampness indicator
Soil acidity	Acidity	Indicator of extreme acidity	Av.	Acidity indicator	Av.	Indicator of moderately acid soils	Av.	Weakly acid to weakly basic soils
Nutrients demand	Nutrient	Indicator of extremely infertile sites	Av.	Indicator of more or less fertile soils	Av.	Intermediate fertility	Av.	Richly fertile soils
Salinity	Salinity	Slightly salt-tolerant species	Species both in saline and non-saline	Common in coastal sites	Consistent but low salinity	Obligate halophytes	Species of mid-level saltmarsh	Species of lower saltmarsh

Figures

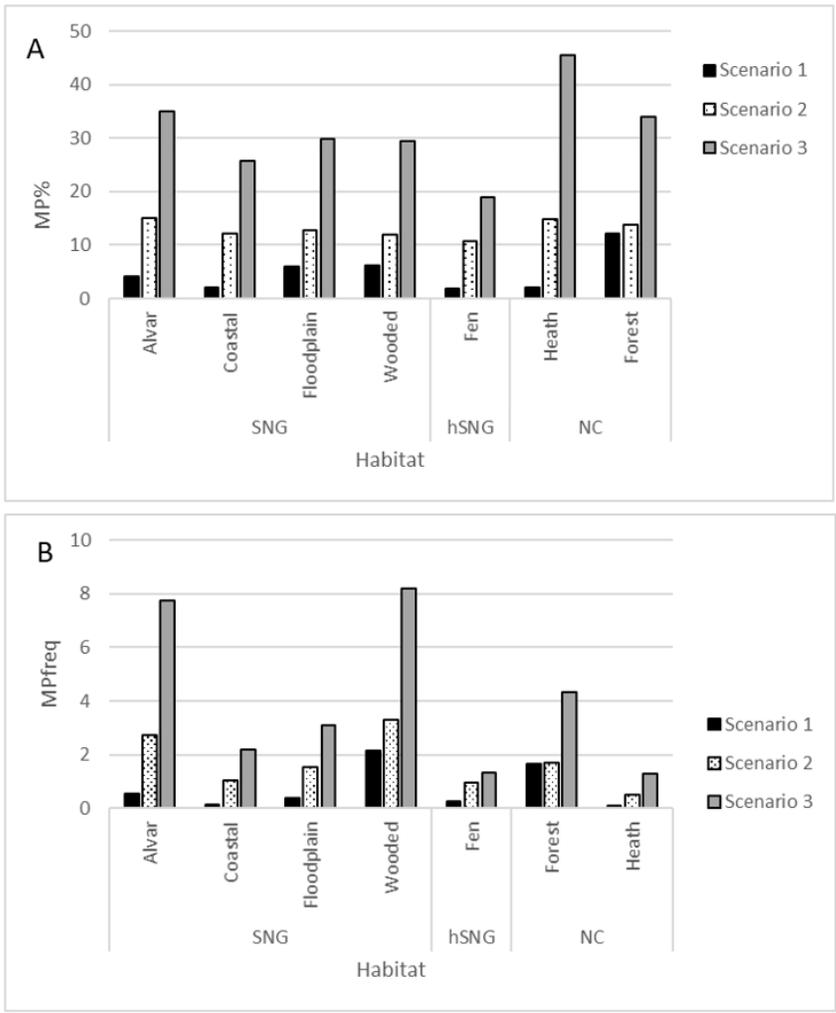


Figure 1

Ratio (A) and frequency (B) of MP species in Estonian plant community types according to different MP species scenarios.

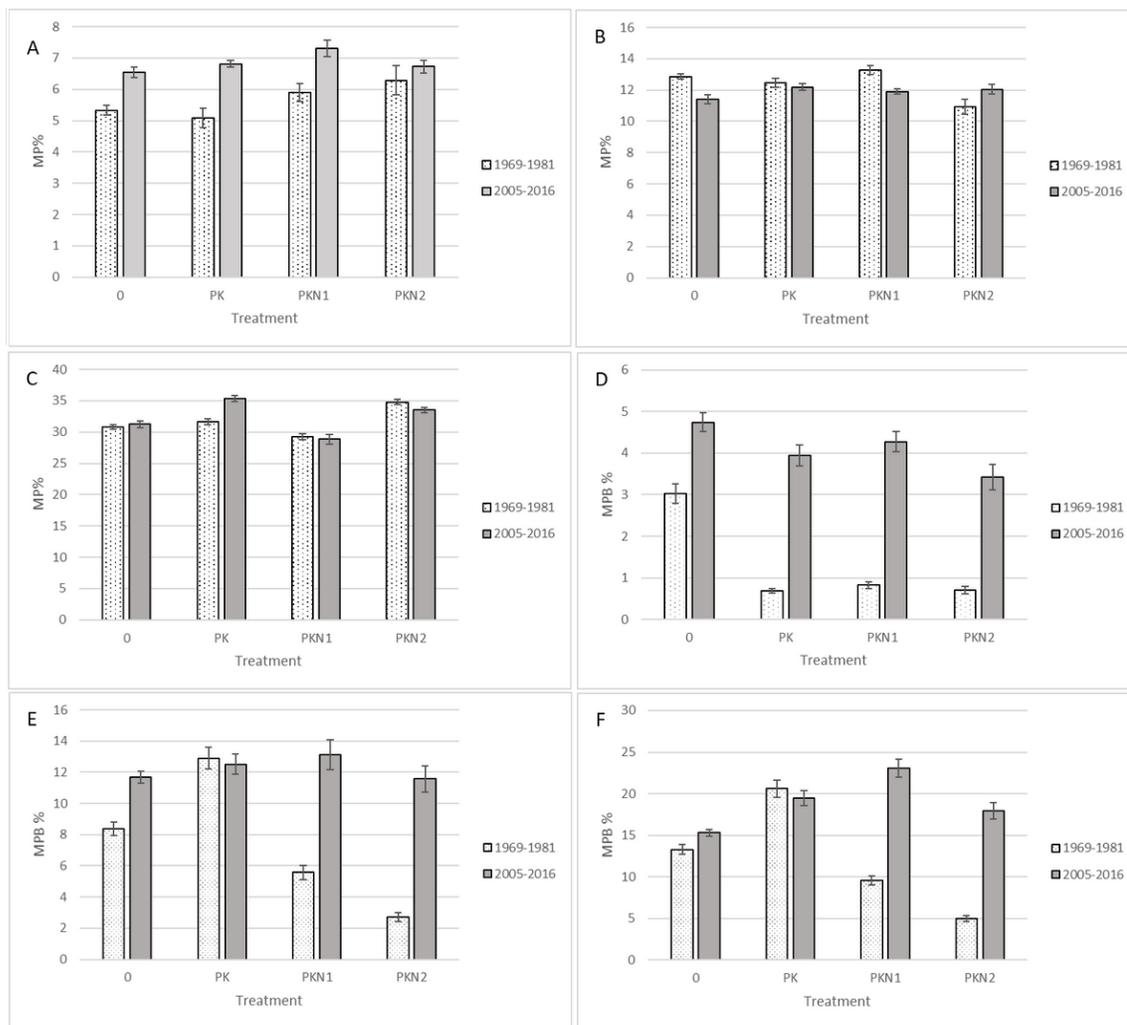


Figure 2
 MP species number (A, B, C) and biomass (D, E, F) ratios in Laelatu wooded meadow during and after the fertilization experiment according to three different MP species scenarios. A, D – scenario 1; B, E – scenario 2; C, F – scenario 3. The vertical bars indicate standard error of average (n=12).

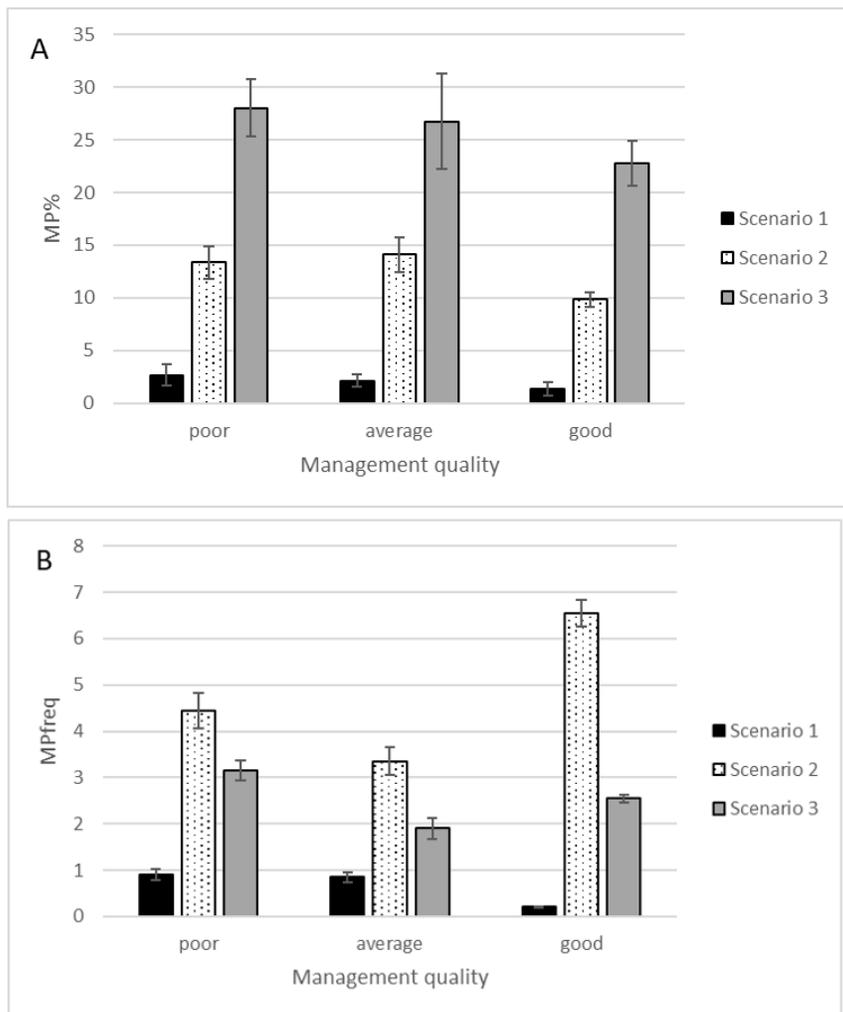


Figure 3
Average ratio (A) and frequency (B) of MP species in plant species lists of coastal meadows with different management quality. Vertical bars indicate standard error of average (n = 3...6).

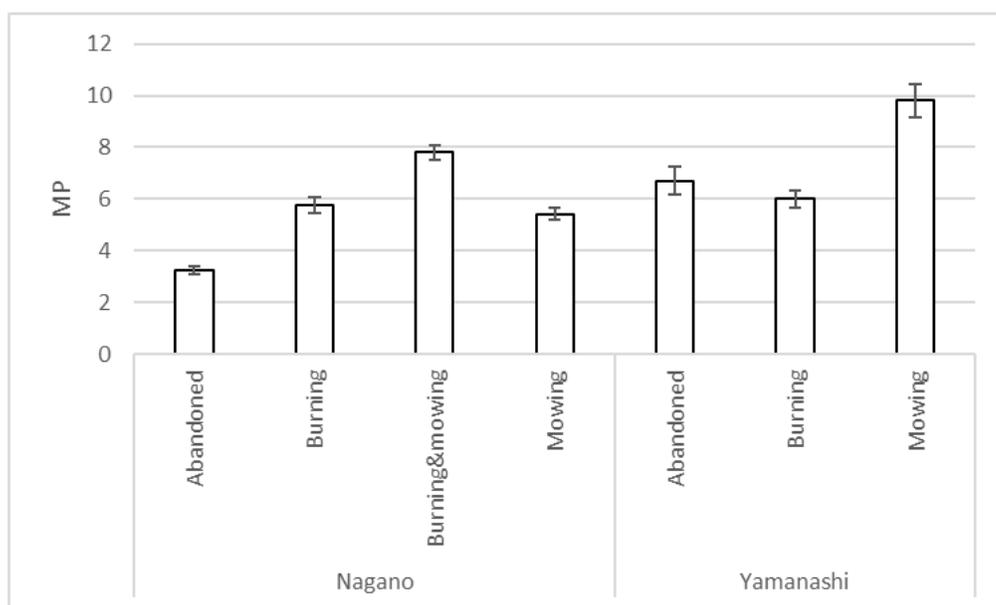
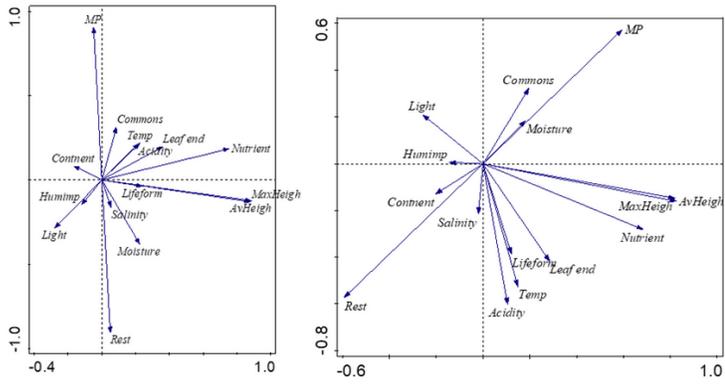
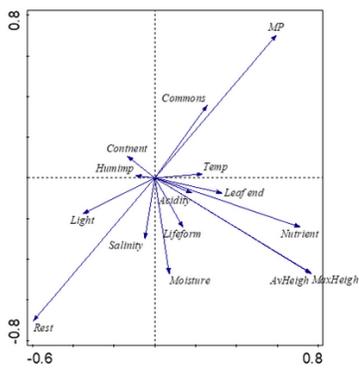


Figure 4
Number of MP species in Japanese SNGs with different management regime in two regions. Vertical bars indicate standard error of average (n = 15...54).



A

B



C

Figure 5

Impact of different plant requirements and characteristics on MP species according to PCA test. A – scenario 1; B – scenario 2; C – scenario 3.

Supplementary Files

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