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Finnish Forest Act as a conservation tool in protecting boreal springs and associated bryophyte flora

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To halt the loss of biodiversity, serious conservation measures are needed. Recently, key habitat approach has been adopted in all Nordic and Baltic countries. In Finland, conservation of Forest Act Habitats (FAHs) is the main instrument. We assessed whether FAHs have the potential to conserve the unique bryoflora of springs by studying 58 spring complexes, 8 of which included a predetermined FAH. FAHs had more pool surface and colder water than other springs. Our results suggest that a clear bias towards protecting certain types of springs exists, and that a significant number of FAHs have not yet been found. Moreover, our species data did not support the assumption that FAHs are of special importance: richness of bryophytes, specialists or red-listed species were not higher in FAHs. We conclude that the high demand of naturalness and the bias towards aesthetically appealing springs can lead to an ecologically crippled network of protected areas.

Introduction

We are at the verge of a major biodiversity crisis. Never before has the degradation of natural ecosystems caused by man been as fast and as extensive as now. Negative effects on biodiversity have been substantial and largely irreversible (Wilson 1985, Pimm 1995, Novacek and Cleland 2001, Millennium Ecosystem Assessment 2005, Fisher *et al.* 2007). In order to halt the unfavorable trend, international agreements (United Nations 1992, 2002) must be converted into national conservation policies. Due to socioeconomical limitations, large nature reserves are often difficult to establish, and protection of valuable habitats must be integrated into forest management to supplement the existing network of conservation areas (Hanski 2005, Bhagwat *et al.* 2008).

In Finland, the idea of supplementing conservation areas has been enforced by including certain valuable habitats in the Forest Act (Metsälaki/Forest Act 1996), the purpose of which is to promote economically, ecologically and socially sustainable forestry. Seven habitat types regarded especially important in preserving diversity are defined in the Act: (1) springs, brooks, permanent channels of trickling water, small ponds and their immediate surroundings, (2) herb-grass spruce mires, fern spruce mires, thin-peated eutrophic spruce mires and rich fens (south of Lapland), (3) patches of herb-rich forest, (4) small islets of forest in undrained mires, (5) ravines and gorges, (6) steeps and underlying forests, (7) sands, rocky outcrops, stone soils, boulder fields, sparsely wooded mires and shore swamps that are less productive than barren heath forests. When these habitat types are *at or close to natural state* and *clearly delimited from their surroundings* they are protected by the Forest Act (Metsälaki/Forest Act 1996). We call the sites fulfilling Forest Act naturalness and distinctiveness criteria Forest Act Habitats (FAHs) (following Pykälä *et al*. 2006). The fundamental assumption of this key habitat approach is that FAHs are somehow *special* in protecting forest biodiversity: they harbor a larger number of demanding specialist, rare or red-listed species or have more diverse communities than surrounding forests or corresponding non-natural habitats.

Key habitat approach has been enforced in Nordic and Baltic countries for the past 10 years (Tenhola and Yrjönen 2000, Hansson 2001, Andersson and Kriukelia 2002, Svedrup-Thygeson 2002, Andersson *et al*. 2003, Anon. 2005, *see* Timonen *et al*. 2010 for a review and comparison). Results of the current research of flora and fauna of key habitats are somewhat conflicting: others have found support for the assumption of high species richness or high occurrence of red-listed species (Gustafsson *et al*. 1999, Johansson and Gustafsson 2001, Gustafsson 2002, Gjerde *et al*. 2004, Pykälä 2004, 2007), yet others have not (Gustafsson 2000, Svedrup-Thygeson 2002, Gustafsson *et al*. 2004, Hottola and Siitonen 2008) or have questioned the success of implementing the concept into practice (Aune *et al*. 2005, Sippola *et al*. 2005, Junninen and Kouki 2006, Pykälä 2006, 2007). The results are only of minor applicability in Finland because key habitats in most of these studies are not congruent with Finnish FAHs. Junninen and Kouki (2006) stated two main differences: (1) natural forests as such are not FAHs and are protected only if they contain one of the defined FAHs, and (2) the definition of FAH does not include the occurrence of red-listed species. Also, research comparing habitats differing only in naturalness, which is a key factor in determining FAHs, is essentially lacking (but *see* Korvenpää *et al*. 2002).

The most numerous FAH types in Finland are small water bodies consisting of springs, small brooks, rivulets and pools with their immediate surroundings (Yrjönen 2004). The most threatened small water bodies, springs, are defined as endangered (EN) habitats in southern Finland and roughly 89% of all springs are situated outside the existing network of conservation areas (Leka *et al*. 2008). Forestry integrated protection of springs has therefore great potential.

Key habitat protection approach has, in one form or another, recently been adopted in all Nordic and Baltic countries (Timonen *et al*. 2010). In this paper, our main aim is to investigate whether one of the fundamental assumptions of this approach, i.e. that these habitats are somehow special in protecting forest biodiversity, is valid in the Finnish system. This assumption is much debated but empirical evidence for or against it is still far from overwhelming (Timonen *et al*. 2010). Here, we analyze whether FAHs have the potential to be of special importance for protection of springs and associated bryophyte flora. More specifically, we will address the following four questions: (i) Do FAH springs and other springs, not fulfilling Forest Act naturalness and distinctiveness criteria, differ in chemical or structural characteristics? (ii) Are FAH springs closer to natural state than other springs (as they should, by definition)? (iii) Do FAH springs capture most of the red-listed bryophytes occurrences? (iv) Do FAH springs harbour more bryophyte species and have a distinctive community composition as compared with other springs?

Materials and methods

Definition of a spring

Springs are groundwater-affected habitats characterized by constant water temperature and specialized bryophyte flora (Warncke 1980, Eurola *et al*. 1984). Traditionally in northern Europe springs are divided into three main types: helocrenes (seepage springs), rheocrenes (brook springs) and limnocrenes (spring pools) (Warncke 1980, for all-inclusive spring types *see* Springer and Stevens 2008). Rheocrenes and limnocrenes are in general easily recognized by existence of running or bubbling cold spring water. In helocrene springs, instead, the seep-

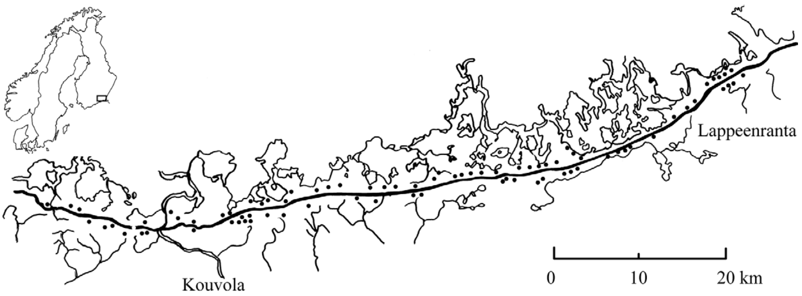

Fig. 1. The study area in Salpausselkä ridge, SE Finland. For clarity, only major bodies of water and highway number six are presented in addition to the studied sites. Modified from Ulvinen (1955).

ing spring water, depending on the intensity of seeping, may be detected only via the presence of distinctive and characteristic mesotrophic and eutrophic intermediate and flark-level species (Eurola *et al*. 1984), notably bryophytes. Pointed springs, namely rheocrenes and limnocrenes, are usually clearly defined meanwhile helocrenes are diffusely delimited (Warncke 1980). Springs exist often as complexes consisting of a varying composition of these three types. Springs are defined in this paper broadly as spring-affected habitats.

Study sites and field methods

The studied springs are located at the outermost Salpausselkä ridge in SE Finland (60–61°N, 26–28°E) in the south-boreal vegetation zone (Ahti *et al*. 1968) (Fig. 1). Salpausselkä is an area of high spring density resulting from large groundwater reserves within the ridge (Raatikainen 1989). Studied springs are mostly surrounded by managed Norway spruce (*Picea abies*) dominated mesic forests and spruce mires.

Selecting of springs was conducted using an old spring-vegetation inventory (Ulvinen 1955) as background information. Each of the springs identified in this inventory were revisited during summer 2006 and all those that could still be found and that were still surrounded by forest were included in the study ($n = 58$ springs). Most of the springs had lost their naturalness to some extent, but a complete series from springs discharging in ditches to springs that are entirely in their natural state was represented (Juutinen and Kotiaho 2009). Study sites are spring complexes consisting varyingly of helocrene, rheocrene and limnocrene springs, helocrenes being most abundant on acreage. Spring area per study site was on average 400 m^2, but ranged between 5 and 3500 m^2.

The chemical and structural characteristics, naturalness and bryophyte flora of the springs were recorded. pH, conductivity and water temperature were measured with a handheld measuring instrument (WTW pH/Cond 340i) in September 2006 during a short, one-week period. Measurements were made directly in the spring as close to the discharge as possible; between every measurement the instrument was calibrated for pH 4 and 7. Other structural characteristics of springs were measured simultaneously to bryophyte sampling. These included percentage of helocrene, rheocrene and limnocrene, size of the spring, basal area of tree stand and the development class of the surrounding forest. Size of the spring was approximated in the field by first drawing the outline of the spring complex on a map (scale 1:16 000) and then — taking into account possible non-spring-affected areas within this outline — calculating the size. Small sites were measured using a pace measure. Total area was subsequently divided into helocrene, rheocrene and limnocrene. Basal area of a tree stand is the cross-sectional area (m^2) of trees at breast height per hectare. It was measured at 1–3 points (depending on the size of the spring) using a relascope. Relascope measure is a widely used variable radius sampling method which can be used as an indirect measure of the stand volume and density. Development class is an ordinal variable measuring forestry stage and it was evaluated using the scale developed by the Finnish Forest Research Institute (Metla 2007): A0 open regeneration area, S0 seed tree stand, T1 young seedling stand, T2 advanced seedling stand, 02 young thinning stand, 03 advanced thinning stand, 04 mature stand and 05 shelterwood stand.

We assessed the natural state of the springs applying a four-class division used by Ulvinen (1955): (1) entirely in natural state, (2) partly in natural state, (3) partly degraded, and (4) entirely degraded. The amount and effect of ditches, effect of forest management, clearing of spring pool or brook, etc. were considered and unambiguous criteria for assessing the natural state of springs were developed (Juutinen and Kotiaho 2009; Appendix 1).

Bryophyte flora (mosses and hepatics) of each spring were sampled using five 1 m × 1 m quadrates stratified representatively in different spring surfaces. Coverage of each bryophyte species from each quadrate was assessed to the nearest 1% and averaged over quadrates to represent the whole spring. Being aware that this sampling effort was not completely adequate in very large spring complexes, all spring-specialist bryophytes and some other bryophytes living outside the quadrates within the spring-affected area were recorded. Overall species richness per spring was calculated in two ways: (1) only species in the quadrates, and (2) species inside and outside the quadrates. (Juutinen and Kotiaho 2009; Appendix 2). In accordance, we calculated also spring specialist richness using either (1) specialists in the quadrates or (2) specialists in the quadrates plus outside the quadrates. Spring specialists — i.e. species regionally confined to springs as in Heino *et al*. (2005) — were determined according to Eurola *et al*. (1984) and Ulvinen *et al*. (2002). We also counted the number of red-listed bryophytes per spring using all our data from and outside the quadrates. In addition to nationally threatened (critically endangered CR, endangered EN, vulnerable VU) species (Rassi *et al*. 2001), the red-listed species are defined here to encompass also regionally threatened (RT) and nationally near-threatened (NT) species (Ulvinen *et al*. 2002). Regionally threatened species are evaluated in Finland applying the same criteria that is used in the nationwide evaluation, and regionally threatened species fulfill regionally CR, EN or VU criteria (Ulvinen *et al*. 2002).

The Forest-Act status of each spring was provided after the data collection by the Forestry Center of South East Finland. The Forest Act status refers here to whether a spring complex includes a FAH predetermined in 1997–2006 by the forestry authorities or not. All springs fulfilling Forest Act criteria are automatically FAHs and need not to be determined as such by the forestry authorities. Here, we only use predetermined FAHs because we want to explore the logic behind how FAHs are determined in practice. Also, these are the springs most likely to be conserved and not to be overlooked in forest management.

Statistical methods

Statistics were conducted using non parametric methods. Differences in chemical and structural characteristics, overall species richness, specialist richness, bryophyte cover and number of red-listed species between FAH springs and other springs were tested using a Mann-Whitney *U*-test. Because species were mapped also outside the quadrates and spring complexes had significant differences in size, we were aware that the size could affect our results. However, there was no difference in size between FAHs and other springs, and thus no need to use size as a covariate in the analyses. The uniformity of distribution of natural classes in FAH springs and other springs was tested using a likelihood-ratio *G*-test. Differences in bryophyte community composition were illustrated graphically with Nonmetric Multidimensional Scaling (NMS) and tested using a Multi-response Permutation Procedure (MRPP) test. Community analyses were run using species abundance data from the quadrates. NMS is an iterative ordination method suited illustrating non-normal and discontinuous data. The method behaves well with zero-truncation problem (McCune and Grace 2002). According to McCune and Grace (2002), "nonmetric multidimensional scaling is the most generally effective ordination method for ecological community data and should be the method of choice, unless a specific analytical goal demands another method". Ordination was run on untransformed data using Sörensen's distance, random starting configuration and procedure recommended by McCune and Mefford

(1999). Success of ordination was measured by stress. Stresses below 10 are considered to be good (McCune and Grace 2002), but stress tends to grow quite fast with growing number of sites (McCune and Grace 2002) and stresses between 15 and 20 are common in data consisting over 50 sites (J. Ilmonen pers. comm.). Statistical significance of ordination was tested using a Monte Carlo permutation with 100 randomized runs. After viewing graphical output of the NMS ordination, the MRPP test was performed in order to test for differences in community composition. MRPP is a non parametric method determining differences in community composition between predetermined groups (McCune and Mefford 2002). MRPP does not require multinormality or equality of variances. MRPP gives an effect size (A) and a p value. Effect size indicates within-group agreement: when $A = 1$, sites within groups are identical; when $A = 0$, variation within group equals variation by chance; and when $A < 0$, within group variation is greater than expected by chance. A robust indicator species analysis (Dufrêne and Legendre 1997) was used to determine species indicating FAHs. The method produces an indicator value (IV, % of perfect indication) and a statistical significance for each species using a Monte Carlo permutation. A perfect indicator (IV = 100%) is always present and abundant at all sites of a group and never appears at other groups sites. All community level analyses were carried out using PC-ORD 4.17 (McCune and Mefford 1999).

Results

Chemical and structural characteristics

In most chemical or structural characteristics, FAH springs did not differ from the other springs (Table 1). However, FAH springs had colder water and a greater percentage of limnocrene surface than other springs. Variation in electrical conductivity was large as compared with previously reported from southern Finland (Ilmonen and Paasivirta 2005, Salmela *et al*. 2007, Ilmonen *et*. *al* 2009). This is probably explained by some springs being heavily affected by leached road salt that is applied during winter to prevent formation of ice on the road surface. Road salt can lead to highly elevated conductivity of the spring water of sites very close to highway number six which is situated all the way along the Salpausselkä ridge (Fig. 1).

Natural state

Natural state did not differ between FAH springs and other springs (G-test: $G = 4.73$, df = 3, $p = 0.193$). Of four springs that we had classi-

Table 1. Means ± SD of chemical and structural characteristics of Forest Act Habitats (FAHs) and other springs, and the results of Mann-Whitney *U*-test for scale variables and *G*-test for nominal variables.

			Mann-Whitney		
	FAHs	Other springs	*U*	*n* (FAH/other)	*p*
pH	6.6 ± 0.4	6.4 ± 0.4	126.5	8/48	0.125
Conductivity (μS cm^{-1})	116.3 ± 43.5	190.0 ± 157.2	141.0	8/48	0.232
Temperature (°C)	7.3 ± 1.8	9.3 ± 2.1	91.5	8/48	0.019
Helocrene (%)	71.3 ± 34.1	86.5 ± 18.0	122.5	8/50	0.079
Rheocrene (%)	6.3 ± 10.1	10.8 ± 16.2	184.0	8/50	0.713
Limnocrene (%)	22.5 ± 36.8	2.64 ± 7.5	111.5	8/50	0.044
Size (100 m^2)	4.8 ± 3.0	4.1 ± 6.0	138.0	8/50	0.160
Basal area of tree stand (m^2 ha^{-1})	17.0 ± 10.0	14.7 ± 6.8	156.0	8/50	0.321
			G-test		
			G	df	*p*
Development class	4.5	4.5	2.776	3	0.427

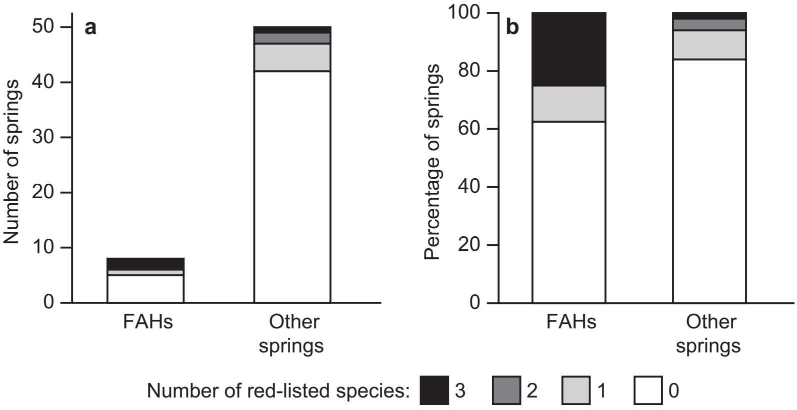

Fig. 2. Number and proportion of springs (**a** and **b**, respectively) harboring red-listed species (CR critically endangered, EN endangered, VU vulnerable, NT near threatened, RT regionally threatened) in Forest Act Habitats (FAHs) (n = 8) and other springs (n = 50).

fied as being entirely in natural state, only one was defined as FAH by the forestry authorities (Table 2). As an anomaly, one of the sites we had classified as entirely degraded and one that we had classified as partly degraded included a FAH.

Bryophyte species richness and composition

There were no differences between FAH springs and other springs in overall bryophyte richness or spring-specialist richness (Table 3). There was, however a tendency for the bryophyte coverage to be greater in FAH springs (Table 3). A considerable number of red-listed species occurrences were found from the other springs and overall there was no difference between FAH springs and other springs in number of springs (Fig. 2a) or proportion of springs (Fisher's exact test: $p = 0.167$; Fig. 2b) harboring red-listed species. There was also no difference in the number of red-listed species per spring between the FAH springs and the other springs (Table 3).

Stress of the best 3-dimensional NMS ordination (Fig. 3) was quite high, 19.76 (Monte Carlo: $p = 0.010$), resulting from the high spe-

Table 2. The naturalness frequency of Forest Act Habitats (FAHs) and other springs.

	Entirely in natural state	Partly in natural state	Partly degraded	Entirely degraded
FAHs	1	5	1	1
Other springs	3	15	23	9

Table 3. Means ± SD of bryophyte species richness [counted from quadrates and quadrates plus outside of quadrates (overall)], coverage (%) and count of red-listed species at Forest Act Habitats (FAHs) and other springs, and the results of the Mann-Whitney *U*-test.

			Mann-Whitney		
	FAHs	Other springs	*U*	*n* (FAH/other)	*p*
Bryophyte richness, quadrates	10.6 ± 2.1	9.8 ± 3.7	159.5	8/50	0.359
Bryophyte richness, overall	10.8 ± 2.3	10.1 ± 4.1	161.0	8/50	0.377
Spring specialist richness, quadrates	5.9 ± 2.1	4.6 ± 2.0	127.5	8/50	0.103
Spring specialist richness, overall	5.9 ± 2.1	4.7 ± 2.1	129.0	8/50	0.113
Bryophyte coverage	62.3 ± 18.2	44.3 ± 24.3	114.5	8/50	0.054
Red-listed species	0.9 ± 1.4	0.2 ± 0.6	151.5	8/50	0.280

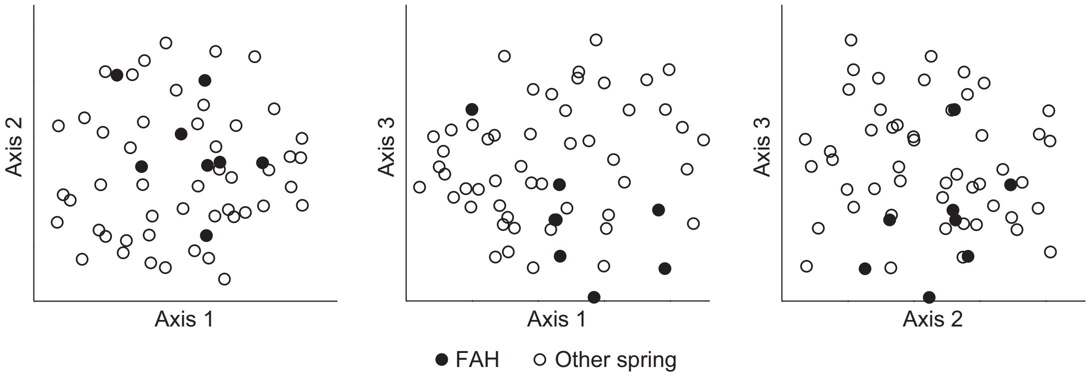

Fig. 3. Three dimensional MNS ordination based on bryophyte abundance data (stress 19.76, $p = 0.010$). Axes representing the three dimensions of the ordination are non-metric, but springs located close to each other have also more similar vegetation than springs located far from each other.

cies heterogeneity among springs. Although FAH bryophyte communities differ significantly from other springs, the difference is extremely small (MRPP: $A = 0.01$, $p = 0.01$). We found three species that were abundant and frequent in FAH springs (i.e. indicators of FAHs). *Calliergon giganteum* (IV = 56.3, $p = 0.001$) and *Fontinalis antipyretica* (IV = 46.4, $p = 0.002$) reflect the differences in spring structure, namely the difference in spring pool proportion to total spring area, while *Straminergon stramineum* (IV = 33.1, $p = 0.028$) is a non-demanding intermediate-flark level species, a result which is harder to explain.

Discussion

On the definitions of Finnish Forest Act

A number of problems with either the definitions of FAHs, i.e. in the Forest Act itself, or application of the Forest Act have been identified (Ohtonen *et al*. 2005, Kotiaho and Selonen 2006, Pykälä 2007). Problematic definitions in the Forest Act are the concepts of naturalness and distinctiveness. It is questionable, if protecting springs that are in or close to natural state is sufficient to preserve specialized spring flora in the long term simply due to the very small number of them (Ohtonen *et al*. 2005). Practically all forests in southern Finland have already been affected by forest management and thus are not in natural state, which makes the application of the naturalness criterion very problematic (Pykälä 2007).

Perhaps even more questionable is the use of naturalness as an indicator of diverse spring flora or occurrence of red-listed species in the absence of proper knowledge of the relationships among them. Correlation between naturalness and bryophyte flora is far from obvious. Indeed, recent research suggests that bryophyte species diversity, coverage or community structure is not related to naturalness of a spring (Juutinen and Kotiaho 2009). Hence, the demand of naturalness in the Forest Act is not easily justified. Another point worth noting is that naturalness of a spring is strongly scale-dependent, that is, whether a spring is regarded as an entity or as a complex of varying naturalness. Most springs in southern Finland are at least partly degraded. Thus, instead of exclusively focusing on springs that are entirely in natural state, conservation effort should also be directed towards spring complexes that contain parts that may be degraded but are still partly in natural state (Ohtonen *et al*. 2005). After all, for conservation measures to be successful, the hydrological nature of springs requires that whole spring complexes rather than small sections of them are conserved.

FAHs are defined as *distinctive and clearly delimited* from their surroundings. Most rheocrene and limnocrene springs fulfill this criterion. Helocrene springs, however, often do not. A significant number of red-listed spring species and often the most diverse bryophyte and tracheophyte communities were found from helocrene springs (data not shown). Thus, it seems that the Forest Act may only be effective in protecting these biodiversity hot spots if they are in connection to rheocrene or limnocrene springs.

According to our findings, in many aspects FAH springs do not differ from other springs. They tend to have colder water and more limnocrene than other springs. This may indicate a bias towards more easily detectable springs, which, in fact, is in accordance with the spirit of the Forest Act. FAH springs have to be easily detectable by non-experts and rheocrene or limnocrene springs usually are. However, a completely different point is whether conservation of only easily detectable springs is ecologically justified.

Ecological justification seems fairly unlikely in the light of the results reported here. Bryophyte richness, cover and community structure did not differ between FAHs and other springs. Not even red-listed species favor FAHs. This may be because of two reasons: first, because less than 80% of FAHs have been detected (Yrjönen 2004, Kotiaho and Selonen 2006), it is possible that springs yet to be identified as FAHs by the forestry authorities obscure the results, or second, FAHs really do not differ significantly from other springs. Whatever the reason, the result is the same: current FAHs are likely to be inadequate in protecting red-listed bryophytes occurring in springs (*see* also Gustafsson 2002). This is because out of the 15 occurrences of red-listed bryophyte species 12 were found from other springs. These springs were all non-pristine, large (several hundred square meters) helocrene springs in mature spruce or pine forests. Thus, it is unlikely for these sites to fulfill either of the criteria given by the Forest Act. Also Pykälä (2007) discovered that most occurrences of threatened vascular plants, bryophytes and lichens were in habitats that failed to fulfill the Forest Act naturalness criteria.

On the application of Forest Act

Problems in the definitions of naturalness and distinctiveness presented above create problems also in the application of the Forest Act. To qualify as a FAH, springs must be at or close to natural state. In practise, however, natural state is not easy to define and detailed guidelines for assessing naturalness are largely absent (but *see* Soininen 2000). As the concept of naturalness is exposed to subjectivity, so is also distinctiveness. This subjectivity in the application requests a lot from the expertise of forestry workers and in an analysis of the quality and reliability of the FAH survey (Kotiaho and Selonen 2007) it has been shown that there is variation in the application of the criteria that is dependent on the people and the institutions that have been conducting the surveys.

The difference in naturalness between FAHs and other springs was nonexistent. The discovery of three natural-state non-FAH sites presumably indicates that those springs were yet to be discovered by the forestry authorities. It has been estimated, that 20% of FAHs have not been found during the nationwide mapping project (Yrjönen 2004), but based on a flaw in the audit methodology this number has been criticized and the true percentage is likely to be much greater (Kotiaho and Selonen 2006). Based on our inventory, it seems that indeed much more than 20% of Forest Act springs of the area have not been discovered. Pykälä's (2007) results from SW Finland show similar discrepancy. Conservation of springs that are not pre-evaluated by the forestry authorities is far from self-evident and the only springs that will, with certain likelihood, remain in natural or near-natural state, are those predetermined by the forestry authorities, even though in principle every spring is automatically protected if it fulfills the Forest Act criteria. Mapping of FAHs is continued along with normal forestry planning (Yrjönen 2004), but it is likely to remain incomplete also in the future. Thus, it would not be fruitful to compare idealistic and perfectly mapped FAHs with other springs because such situation is not likely to happen in reality.

We also found two FAHs that do not fulfill the naturalness criterion of the Forest Act. Forests surrounding both springs had been clear cut less than a year ago. The very narrow, ecologically inadequate buffer strips resulted in a loss of naturalness even though forestry workers had probably operated according to general guidelines. It is likely that the felling took place in between FAH mapping by the forestry authorities and our study.

Two of the three steps towards successful FAH protection, first being successful definitions based on sound scientific evidence and second accurate mapping, were discussed above. The third step, only slightly touched in our study, is application in practice. In order to succeed, the Forest Act needs to be actually taken into account in forestry practices. Problems are related to e.g. inadequate breadth of a buffer strip and regional application of the criteria, both of which can lead to ecologically unsustainably strict definition of FAH (e.g. Kajava *et al*. 2002). Forestry practices permitted in FAHs, according to the Ministry of Agriculture and Forestry (MMM 1997), include for instance cautious felling of timber, felling of individual trees, planting of trees and other practices that do not harm characteristics typical of the FAH in question. It is debatable, however, whether these abovementioned practices harm typical characteristics or not and several researchers have reported negative effects in FAHs in response to forest management practices (e.g. Pykälä 2004, Pykälä 2007, Silver *et al*. 2008, Juutinen and Kotiaho 2009, Siitonen *et al*. 2009).

Conclusions

Our results indicate that the Finnish Forest Act has potential in protecting visually appealing limnocrene springs but value in protecting all spring types and spring bryophytes is limited. For example, the most valuable helocrene spring complexes have no open water and are not easily distinguished from their surroundings and thus, by definition, do not fulfill the Forest Act criteria. Great caution should be taken not only to protect visually appealing large limnocrene springs. Such springs may be very monotonous in respect to bryophyte flora even when in natural state.

The Forest Act seems not to be efficient in protecting rare spring bryophytes which in many cases were situated in springs not fulfilling the Forest Act criteria. In general, it is not adequately acknowledged that springs harboring valuable species can be quite heavily degraded and may seem at first sight not worth protecting. A need to re-evaluate the stringent criteria of naturalness and distinctiveness of the Forest Act is thus obvious and some flexibility should be allowed.

Complementary mapping of Forest Act springs is fundamentally important because the proportion of found FAH springs is probably not as high as previously suggested. Mapping needs to be accompanied by training of forestry workers in recognizing demanding or rare vascular plants and spring bryophytes as well as general factors, other than naturalness, important for spring flora.

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Appendix 1. Guidelines for assessing naturalness class of spring complexes.

GENERAL GUIDELINES

Entirely in natural state (1)
- significant signs of human impact not visible
- immediately surrounding forest in natural state (varying age and species structure), rich in woody debris
- ditching in general not allowed, but single, short and very old ditches and old tracks pass through
- mild edge-effects of surrounding, open regeneration-areas allowed

Partly in natural state (2)
- no ditching, or old ditches not having a significant drying effect
- immediately surrounding forest close to natural state, the amount of woody debris varying
- over 2/3 of the spring complex in natural state, max 1/3 of spring specialist bryophytes in ditches

Partly degraded (3)
- significant signs of ditching-related drying effect
- significant amount of spring specialist bryophytes growing in ditches

Entirely degraded (4)
- spring specialist bryophytes growing exclusively in ditches

Destroyed (5)
- no spring specialist bryophytes to be found
- no obvious points of spring water discharge

When in between classes, the less natural class should be selected.

Naturalness often varies in different parts of a spring complex. In such cases, naturalness should be assessed in each part individually and then weighted-averaged for the area.

FACTORS RAISING NATURNALNESS

extensive natural-like spring and rich fen vegetation in old ditches
natural-like meandering spring brooks in old ditches

SPECIAL CASES

Dammed-up spring pools
- naturalness classes 2–5
- over 50% of the spring complex in natural state (ie. outside dammed pool), no other factors affecting naturalness class 2
- factors lowering naturalness: less than 50% in natural state, immediately surrounding forest not natural, ditching

Spring brooks
- naturalness classes 1–5
- factors lowering naturalness: straightened and deepened brook channel, immediately surrounding forest not natural, ditching

Spring complexes under power lines
- naturalness classes 2–5 (depending on other factors such as ditches and wells)

Appendix 2. Data on the following species were used in the analyses. Spring specialists are set in boldface. Nomenclature as in Ulvinen and Syrjänen (2009). * species recorded outside the quadrates but not included in the bryophyte richness analysis due to insufficient distribution data.

BRYOPHYTA
*_Atrichum tenellum_
*_Atrichum undulatum_
*_Aulacomnium palustre_
Brachythecium rivulare
*_Brachythecium rutabulum_
*_Brachythecium_ sp.
Bryum pseudotriquetrum
Bryum weigelii
*_Bryum_ sp.
Calliergon cordifolium
Calliergon giganteum
Calliergon richardsonii
Calliergonella cuspidata
Campylium stellatum
*_Cirriphyllum piliferum_
*_Climacium dendroides_
*_Dicranum majus_
*_Dicranum polysetum_
*_Dicranum scoparium_
Fissidens adianthoides
Fontinalis antipyretica
Helodium blandowii
Hylocomiastrum umbratum
*_Hylocomium splendens_
Paludella squarrosa
Philonotis fontana
Philonotis seriata
Philonotis tomentella
*_Plagiomnium cuspidatum_
Plagiomnium elatum
Plagiomnium ellipticum
Plagiomnium medium
Plagiomnium undulatum
Plagiothecium denticulatum var. _undulatum_
*_Plagiothecium_ sp.
*_Pleurozium schreberi_
*_Pohlia nutans_
*_Pohlia_ sp.
*_Polytrichum commune_
*_Polytrichum juniperinum_
Pseudobryum cinclidioides
*_Ptilium crista-castrensis_
Rhizomnium magnifolium
Rhizomnium pseudopunctatum
Rhizomnium punctatum
*_Rhodobryum roseum_
*_Rhytidiadelphus squarrosus_
*_Rhytidiadelphus triquetrus_
*_Sanionia uncinata_
*_Sciuro-hypnum oedipodium_
Scorpidium cossonii
Scorpidium revolvens
Scorpidium scorpioides
Sphagnum angustifolium
Sphagnum capillifolium
Sphagnum centrale
Sphagnum girgensohnii
*_Sphagnum magellanicum_
*_Sphagnum papillosum_
*_Sphagnum quinquefarium_
Sphagnum riparium
*_Sphagnum russowii_
Sphagnum squarrosum
Sphagnum teres
Sphagnum warnstorfii
Sphagnum wulfianum
*_Sphagnum_ sp.
Straminergon stramineum
*_Tetraphis pellucida_
Thuidium recognitum
Thuidium tamariscinum
Tomentypnum nitens
Warnstorfia exannulata
Warnstorfia trichophylla

MARCHANTIOPHYTA
Aneura pinguis
*_Calypogeia muelleriana_
*_Calypogeia neesiana_
*_Calypogeia_ sp.
*_Cephalozia_ spp.
Chiloscyphus polyanthos
Harpanthus flotovianus
*_Lepidozia reptans_
*_Lophocolea heterophylla_
*_Lophozia_ spp.
Marchantia polymorpha
Pellia spp.
*_Plagiochila asplenioides_
*_Riccardia latifrons_
Riccardia multifida
Scapania irrigua
*_Scapania mucronata_
Scapania undulata
Trichocolea tomentella