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Combining spatial prioritization and expert knowledge facilitates effectiveness of large-scale mire protection process in Finland

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Abstract: Conservation resource allocation involves a complex set of considerations including species, habitats, connectivity, local to global biodiversity objectives, alternative protection and restoration actions, while requiring cost-efficiency and effective implementation. We present a national scale spatial conservation prioritization analysis for complementing the network of protected mires in Finland. We show how spatial prioritization coupled with regional targets and expert knowledge can facilitate structured decision-making. In our application, discussion between experts was structured around the prioritization model enabling integration of quantitative analysis with expert knowledge. The used approach balances requirements of many biodiversity features over large landscapes, while aiming at a cost-effective solution. As a special analytical feature, mire complexes were defined prior to prioritization to form hydrologically functional planning units, including also their drained parts that require restoration for the planning unit to remain or potentially increase in value. This enabled selection of mires where restoration effort is supporting and benefitting from the core mire areas of high conservation value. We found that a key to successful implementation was early on structured co-producing between analysts, mire experts, and decision-makers. This allowed effective multidirectional knowledge transfer and evaluation of trade-offs related to the focal conservation decisions. Quantitative trade-off information was seen especially helpful by the stakeholders to decide how to follow the analysis results. Overall, we illustrate a realistic and applicable spatial conservation prioritization case supporting real world conservation decision-making. The introduced approach can be applied globally to increase effectiveness of large-scale protection and management planning of the diverse wetland ecosystem complexes.

Key words: spatial prioritization; trade-offs; implementation; expert knowledge; restoration prioritization, wetlands conservation

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1. Introduction

As human-induced habitat loss, degradation, and fragmentation proceed, and when resources for conservation are limited, prioritization among potential measures and areas to protect biological diversity is needed (Margules & Pressey 2000; Foley et al. 2005; Game et al. 2013; Sinclair et al. 2018). Systematically targeted conservation actions should be implemented to cost-effectively maintain species and habitats that are under pressure (Margules & Pressey 2000; Ferrier & Wintle 2009). These actions need prioritization, which has at least two dimensions. First, the analytical dimension is about effective utilization of knowledge, data, methods and tools (e.g. Game et al. 2013). The second dimension is making analyses operational (e.g. Knight et al. 2008, 2009). While the first dimension may appear logically challenging, the latter meets with cognitive, psychological and societal complexities (Gilbert 2011; Toomey et al. 2016). We need to understand how the most can be gained from the analyses and conversely, how the analyses can be co-produced so that the results are both relevant for the problem at hand as well as perceived legitimate by those affected (Knight et al. 2009; Game et al. 2013; Young et al 2014). Overall, usefulness and implementation of systematic prioritization meets with complex ecological, societal and economic reality (Hirsch et al. 2010; Young et al 2014; Paloniemi et al. 2017; Sinclair et al. 2018). Failing to fill the space between systematic analyses and their implementation to decision-making can lead to biases and opportunism in the decision-making process, decreasing the cost-effectiveness of the use of conservation resources (e.g. Game et al. 2013).

The relevance, legitimacy, credibility, and hence the overall usefulness of systematic conservation planning solutions is enhanced if the knowledge-implementation space is filled with genuine dialogue and co-producing involving analysis providers and decision-makers (Ferrier & Wintle 2009; Young et al. 2014; Toomey et al. 2016; Bertuol-Garcia et al. 2017; Sinclair et al. 2018). Co-producing in the form of joint problem identification, formulation and investigating the solution and the related tradeoffs is strongly emphasized in the systematic conservation planning framework (Margules & Sarkar 2007; Ferrier & Wintle 2009; Knight et al. 2009; Kareksela et al. 2018). In addition to the more general operational model for conservation planning process, specific models exist especially for the implementation of results of conservation science and planning (Knight et al. 2006, 2010) along with e.g. a structured decision-making framework (Keeney & Raiffa 1993, Gregory et al. 2012a) with practical examples (Gregory et al. 2012b; Guerrero et al. 2017).

While the importance of systematic conservation planning or spatial conservation prioritization analyses in providing solutions for wicked problems has been repeatedly demonstrated (Margules and Pressey 2000; Pressey & Bottrill 2008, Game et al. 2013), there are also other sources of information like local social-ecological considerations or expert knowledge that differ from the more systematic nature of spatial conservation prioritization approaches (Cowling et al. 2003, Drescher et al 2013). Considering local stakeholders and expert knowledge is also valuable and often complementary and can influence decisions on social-ecological aspects not easily considered through e.g. more systematical spatial conservation planning approaches (Cowling et al. 2003; Drescher et al 2013). Striking a balance between e.g. expert knowledge and quantitative analysis should be emphasized in decision-making processes (Cowling et al. 2003; Ferrier & Wintle 2009) in order to achieve not only credibility but also relevance and legitimacy of the proposed solutions (Young et al. 2014). Systematic and structured utilization of expert knowledge is not self-evident or easy (Cowling et al. 2003), but it could be enhanced for example by integrating the use of expert knowledge with spatial prioritization analyses in a controlled way, e.g. by following the operational models of the systematic conservation planning and structured decision-making frameworks. The use of expert knowledge is also in a key role in designing the systematic analyses, emphasizing the need for structured multi-way knowledge transfer and co-production between the experts, analysis producers, and decision-makers.

Despite existing operational strategies (e.g. Margules and Sarkar 2007; Knight et al. 2006; 2010; Gregory et al. 2012a) or more thematic approaches to increase the implementation success of the results of systematic analyses or prioritization knowledge in general (Hulme 2014; Toomey et al. 2014; Young et al. 2014; Bertuol-Garcia et al. 2017), there still appears to be a shortage of practical examples on how conservation prioritization analyses and expert knowledge are integrated with on-the-ground decisions (Sinclair et al. 2018), without losing the effectiveness of either one of them. Here we present a spatial prioritization analysis to support decisions about complementing mire protection in Finland. We show how multiple information sources and a relatively complex complementary-based decision support analysis can be systematically integrated to the actual conservation decision-making process. Major contribution of this work is the effective use of the trade-off investigation (e.g. Kareksela et al. 2013, 2018; Kukkala and Moilanen 2013), which is a key component in any structured decision-making process (Gregory et al. 2012a). We describe how information about prioritization trade-offs was used to fill the implementation space by helping to convey the analysis results to the decision-makers in an effective and user-friendly manner. We also provide a method to prioritize diverse mire complexes with restoration considerations. Mires as part of freshwater wetlands have a considerable impact on global biodiversity and ecosystem services and a high need for effective conservation actions (MEA 2005). However, their prioritization as complex hydrological entities is still poorly reported.

2. Methods

2.1. Commissioning and aims of the work

The present prioritization work was commissioned by the working group set by the Finnish Ministry of the Environment to plan complementary expansion of the current network of protected mires in Finland (hereafter the complementary mire protection program, CMPP). The aim of the CMPP was to enhance the protection of a representative network of mires across different vegetation zones in Finland. The initiative for the CMPP and its protection target of approximately 100 000 hectares was set in the government resolution following the Finnish peatland strategy (see e.g. Salomaa et al. 2018). CMPP covered the whole of Finland except for northern Lapland and the Åland Islands in the south-west (Fig 1, Appendix Fig. A1). The program and the spatial prioritization analysis covered 1533 candidate mires (327 300 ha) and 3400 already protected mires (601 700 ha).

The working group comprised 14 stakeholders and experts, including experts of mire ecology, land-use planners, conservation scientists, and representatives of the environmental and forestry administration, the land owner’s association and conservation NGOs. The working group reached a consensus that the added value of including a quantitative analysis to the decision-making process would be a complementarity-based evaluation accounting for many species and habitats. To include ecological connectivity in the evaluation was also seen important. The ecological model for the analysis (Fig. 2) was right from the start designed in close cooperation between the working group (represented here by the authors AA, KA, JSK) and experts in spatial prioritization (SK, AM, JL, NL, NM, TH, ST, RV). In addition to the described complementary based spatial prioritization analysis, the working group also created a scoring system for the candidate sites (including e.g. habitats, species, and naturalness of the mires) that was used to help the expert work. Together the prioritization analysis and the scoring formed a *Structured Decision Making* (SDM) process (e.g. Gregory et al. 2012a) where the problem was formulated, targeted effects of different data and analysis elements (Fig. 2) were heuristically defined, and, following the analysis, related trade-offs were systematically and quantitatively (when applicable) explored.

Decision-making process can have several phases before the areas chosen for example according to a prioritization analysis are set aside and protected in the landscape (Kareksela et al. 2018). Here we consider implementation as the process where the analyses results are integrated to the decision-making, i.e. to the process of choosing mire areas for protection before the process of actually setting the sites aside in the landscape. It should be noted that while the implementation in terms of decision-making process of selecting the sites for protection has been completed (Alanen & Aapala 2015) the final implementation of the complementary expansion of the protected area network in the landscape is still partially to be carried out. A more detailed account of the protection program is given by Alanen & Aapala (2015) and its social-ecological context in Finland by Salomaa et al. (2018).

2.2. Data

Spatial data was based on a comprehensive field survey of the candidate sites, a pre-existing and highly detailed habitat database on protected areas, small water bodies from topographic database (streams and ponds, National land survey of Finland), modelled likelihood for mire bird species territories (based on Breeding Bird Atlas), and species observation data from the Finnish threatened species database HERTTA. Altogether 91 spatial data layers were collated on geomorphological mire complexes (31 layers), mire habitats (39), threatened plants and mosses (3), small water bodies (1), and potential habitats for mire associated birds (17). As condition data for the mires, we used spatial data on ditches on peatlands from topographic database of National Land Survey of Finland. All spatial data were included in analysis as 50-meter resolution raster data layers. See Appendix for more detailed information on the data.

2.3. Prioritization model and analysis structure

We performed the prioritization analysis using the freely available Zonation approach and software (Moilanen 2007; Moilanen et al. 2005, 2014). Zonation is a spatial prioritization framework that can identify areas important for retaining habitat quality and connectivity simultaneously for all biodiversity features in the landscape, thereby indirectly aiming at retaining maximal population sizes and persistence of features (Lehtomäki and Moilanen 2013; Moilanen et al. 2005, 2014). In the ecological sense, Zonation balances the (biodiversity) feature representation in terms of feature quality, amount and connectivity. Simultaneously, ecological considerations can be balanced against multiple direct costs, indirect costs and alternative land uses (Moilanen et al. 2011, Kareksela et al. 2013). Using an iterative process, Zonation produces a balanced priority ranking through the study landscape (Moilanen et al. 2005, 2014). The main outputs of Zonation are the priority rank map and (biodiversity) feature-specific information on what fraction of the original distribution of the feature can be covered (given the Zonation priority ranking) by protecting a given fraction of the landscape.

We constructed the analysis in stages so that we could investigate how different data and analysis approaches affected the priority of areas and that we could modify the analysis where needed. More information on the used analysis approaches can be found in the Appendix and Zonation manual (Moilanen et al. 2014). Concerning the spatial prioritization analysis applied in the present work, following methods were used (see Appendix for details):

1. We weighted the biodiversity features in the analysis based on their Red List status across the whole planning area and more detailed regional Red List statuses (Raunio et al. 2008, Rassi et al. 2010).

2. We used a *hierarchical mask* layer to separate between (prioritize in sequential steps) present protected area network and candidate sites to identify which candidate sites best complement the already protected mire biodiversity (e.g. Mikkonen and Moilanen 2013; Virtanen et al. 2018).

3. We did the analysis on *planning units* (groups of grid cells) to enable prioritization of the mire ecosystem complexes as hydrological entities (spatially defined by mire experts, Appendix, Fig. A3).

4. We applied a *condition layer* to de-emphasize areas where land-use pressure has led to loss of ecological condition and respectively to identify restoration need. Here the use of the condition layer prioritizes sites that include comparatively less damage from drainage (Kareksela et al. 2013, 2018). If partially damaged, the site will only receive high conservation priority in the analysis if its complementary biodiversity value outweighs the lowered condition. The potentially needed

restoration actions at the top priority sites also support the persistence of mires with high complementary biodiversity value, thus also leading to prioritized use of resources for restoration.

5. We used *administrative unit analysis* to allow balancing of local and national scale rarity and weighing of the biodiversity features (Moilanen and Arponen 2011). Heuristically expressed, this type of analysis simultaneously considers both regional and national priorities, leading to more spatially balanced distribution of top priority areas among the considered regions.

6. To emphasize the ecological connectivity of areas we applied *interaction connectivity* (Lehtomäki et al. 2009; Rayfield et al. 2009). This method increases the priority of candidates mires that have other ecologically high-quality areas nearby. Connectivity was emphasized between all mires/peatlands included in the analysis, with higher contributions counted from areas already protected.

2.4. Post processing and integration of expert knowledge

Zonation outputs the priority ranking as geospatial raster data, which can be visualized using any GIS software. In the present case, other main outputs relevant for the working group included a priority listing of the candidate mires (planning units) and information about the representation levels (coverage) of biodiversity features in the solution (sites chosen according to the Zonation analysis, hereafter: the solution). We used the feature-specific representation levels produced by Zonation (Moilanen et al. 2014) to investigate trade-offs between features or groups of features within and between solutions, when the final analysis was iteratively built. Next, we plotted the feature-specific representation levels to produce so-called performance curves to illustrate how the biodiversity coverage of a solution continuously improves when new areas are added into the PA network. Typically, gains are highest with the first additions and level off (saturate) when moving to lower priority additions (Fig 3). This is because the first additions effectively implement gap-filling: they rapidly add coverage for many (comparatively) narrow-range features that have missing or low representation in the existing PA network (Sharafi et al. 2012; Virtanen et al. 2018). This information was useful for the working group in deciding the fraction of new sites (the solution) that should be chosen primarily based on the quantitative Zonation analysis compared to the area that could be primarily chosen based on e.g. the scoring and expert knowledge. We used ArcMap (ESRI 2014) to process the analysis outputs and for the spatial analysis of the results.

The co-production process was centered around the systematic prioritization analysis and carried out without a specific co-production method or model. In other words, building up the model for the prioritization analysis and the expert work for the scoring system (see above) served as a platform for structured decision-making. The stakeholders needed to agree on settings to address the formulated problem, e.g. by defining what elements (data, connectivity, regional priorities etc.) they wanted to include in the quantitative analysis, and how each element was to be emphasized. In addition, the multiphases analysis process (above) served to provide structure for the knowledge use. The co-production and integration of the analysis results was carried out in stages:

1) The stakeholders, mire experts, and analysis experts outlined the detailed targets that would best serve the goal of the program. (It should be noted that the used prioritization method does not require habitat or species-specific targets for biodiversity representation, but it instead aims to cumulative persistence of the most complementary biodiversity features).
2) Alongside with building the model the performance of the analysis was monitored (Fig 3 and 4) as the key parameters were iterated.
3) The working group used the performance curves produced in the final analysis to define complementarity saturation (Fig 3), which was then used to decide how far to follow the prioritization analysis solution (continuous ranking of the candidate mires, see Fig. 1 and above) and how much resources to leave for other prioritization principles, i.e. candidate site scoring and expert knowledge.

4) After deciding how much the analysis priority was followed, the candidate sites suggested according to the analysis results were also qualitatively examined by the working group to, for example, spot major mistakes in data and to make sure that no “strange choices” existed.
5) The actual site selection was then carried out hierarchically, first choosing areas according to the spatial prioritization analysis that best complement the existing protection network, and then complementing this with highest scoring areas within each administrative unit, based on the used scoring method, up to the approx. 100 000 ha total target.

To investigate how restoration need was reflected in the solution we compared the area of the candidate mire sites that needed restoration between all the candidate sites and the candidate sites chosen according to our analysis (the solution). We also calculated the proportion of the area needing restoration that was on sites that hosted the most threatened peatland complexes and habitats and compared this between all the candidate sites and the sites suggested for protection in the solution.

3. Results

3.1. Balanced solution for the complementary expansion

The ecological value of the mire protection area network increased as a function of gradual addition of candidate areas, as shown by the performance curves (Fig. 3). The highest ranked 5% of the analysis area (candidate sites), which corresponds to an approximately 8% increase of protected mire area, would achieve on average a 39% relative increase in the conservation coverage of biodiversity features included in analysis. High cost-effectiveness is primarily achieved via additions for narrow-range features that have missing or low representation in the existing PA network. Coverage of the most threatened features (mire complexes and habitats) improved significantly more than coverage for all features, a 68% improvement for the 8% area increase (Fig. 3).

It is not only conservation coverage of biodiversity features that is increased in this process, but also the balance of coverage across species improves. Because the analysis is based on complementarity, well balanced additions into the network also fix gaps in the ecological coverage of the network (Fig. 4). As shown in Figure 4, the analysis was effective in rising the representation levels of the features with lowest representations at the current network for protected mires. Hence, the analysis can be considered a cost-effective solution for complementing the network for protected mires in Finland.

The performance curves were also used to investigate a potential trade-off between direct biodiversity coverage and spatial connectedness (Fig. 3). They show that additional connectivity consideration did not have a significant negative effect on the static representation of biodiversity in the solution, although it did have an elevated effect for the highest weighted eight features (Fig. 3). This relatively small compromise was nevertheless considered to hold net positive potential for the long-term persistence of biodiversity.

We were also able to achieve a relatively balanced distribution of top priority mires in the solution over the administrative units. Because the priorities (expressed with feature weights) for certain habitats were higher in the south (Appendix, Table A2) and the overall drainage-based degradation of mires is significantly higher in the southern half of Finland, the solution also emphasized more the southern regions, although all the regions included mires in the solution (see Appendix, Fig. A2 for map of the administrative units and solutions spatial distribution). The balance of the distribution of mires over the planning area was further complemented with the protection choices made by the working group.

3.2. Spatial allocation of restoration resources

The area of candidate mires in need of restoration was 29% of the total of candidate sites and 20% of the sites suggested for protection in the solution (the 8% addition to protection). On average 55% of the area on all the candidate mires that needed restoration was on sites that host one or more highest-weighted mire complexes and/or habitats (see methods and Appendix). Of the candidate mires in the solution chosen according to the Zonation analysis, 78% of the area needing restoration was on sites that host these top features. This means that the analysis was effective in choosing areas in good condition, i.e. areas with lower need of resources for restoration, where the still remaining need for restoration efforts was strongly associated to areas with high priority habitats, which increases the cost-effectiveness of potential future restoration efforts on these sites.

3.3. Integration to decision-making

The results described above were presented to the working group, which identified the most cost-effective set of areas that fill gaps in conservation coverage efficiently. Using the graphical illustration of the heuristically defined "saturation of representativeness increase", the analysis providers (SK, AM, JL, NM, NL, RV, ST, TH) were able to produce a recommendation about the number and identity of sites that should preferably be chosen to retain most benefits of the complementary solution. This was approximately 1/3 of the area that could be chosen within the program's area-based target limitation (Fig. 3). The remaining 2/3 of the targeted additional area for protection could then be chosen according to the highest regional scoring points. This approach, along with the connectivity, restoration, and regional considerations (see above) was welcomed and strongly supported by the working group, and it led to successful integration of the analysis results into the decision-making process.

The working group checked prioritization results for top sites to correct any false expectations of ecological value that might have arisen due to problems with data or the ecological model of conservation value. Sites were excluded mainly for practical reasons. For instance, some of the very small or recently drained sites were replaced with more representative candidate sites.

4. Discussion

We were able to produce a cost-effective solution for the complementary network of protected mires in Finland. The analysis results were also successful in facilitating the decision-making process. Through the spatial prioritization analysis, the stakeholder group was able to address a complicated problem involving rarity and Red List status of different biodiversity features, connectivity of areas, and variable restoration need of sites. Even with comparatively small addition to protected area (8%), it was possible to produce a very high increase (20%) in the representation of biodiversity in the PA network. This demonstrates the utility of a systematic analysis in a structured decision-making process, transforming the expert knowledge and stakeholders' goals into effective conservation outcomes (Margules and Pressey 2000, Ferrier & Wintle 2009, Game et al. 2013). The resulting quantitative information of the trade-offs was used to facilitate integration of prioritization results with external decision criteria and expert opinion. We provided information about the characteristics of alternative solutions, allowing well-informed participation in decision-making by people less involved in the prioritization analysis itself.

The analysis presented here was successful both technically and, in its implementation characteristics. The working group was satisfied with clear presentation of the results and how the analysis facilitated the thought processes of the planning group. In other words, the analysis was able to act as a platform for structural decision-making (Gregory et al. 2012a) where the problem formulation and goals for the analysis model were co-produced among the stakeholders and experts. Systematic analysis also provided quantitative comparison of trade-offs, which facilitated the evaluation of the spatial prioritization analysis results and provided more general information on the trade-offs related to the focal conservation task. The role of this trade-off information was imperative in how the prioritization analysis results were implemented: the trade-off investigation offered a way to inspect how much to follow the analysis results and how much freedom for resource allocation for other considerations while still meeting the complementarity targets. This was seen a very useful way by the working group to decide what way and how much to follow the analysis results.

We emphasize the importance of expert knowledge in building the ecological model of conservation value and the analyses it enables. Not only would it be very difficult to build such a model without expert knowledge but engaging with experts and other stakeholders also seems to increase the chances of the results being more relevant for the decisions at hand as well as being perceived more legitimate (i.e. more acceptable). Integration of analysis results with expert knowledge also made the use of the expert knowledge more analytical (Drescher et al. 2013; Drescher & Edwards 2018). All parties involved felt that the rather fluent multidirectional transfer of knowledge resulting from the co-production made a significant difference in how the prioritization analysis was used by the working group to make decisions about candidate sites. We believe this as a result further strengthens the knowledge on the benefits of multidirectional information transfer previously documented in the literature (e.g. Young et al. 2014; Toomey et al. 2016; Bertuol-Garcia et al. 2017). All in all, the structured analysis process with comprehensive involvement of experts and stakeholders seemed very efficient in filling the implementation space with cooperation, analytical information, and knowledge.

Consideration of the restoration needs and hydrological entities in the focal case is a special example of the help systematic spatial analyses can bring to large scale mire conservation globally, complementing the existing methods for conservation planning of wetlands (e.g. Choulak et al. 2019; Reis et al. 2019). Through the analysis methods of *planning units* and *condition layer* we were able to achieve a systematic way to balance the restoration needs with the biodiversity value of the candidate sites as hydrological units (Appendix, Fig. A3). A mire site was chosen into the set of complementary areas (the solution) despite it having lowered condition due to drainage, if its biodiversity value for the solution outbalanced its low condition. In addition, at the mires included in the solution that have lowered condition the need for restoration is linked to core areas of relatively high biodiversity value among the candidate mires, meaning that the restoration of these parts would provide hydrological support for valuable core areas while the core areas act as species sources for the restored parts. This is also a more general example of complexity arising from a need to do conservation decisions with respect to larger entities, based on for example hydrological connectedness. This is likely to apply to many wetland protection projects (Choulak et al. 2019; Reis et al. 2019), in addition to the mires in the focal case. However, although balancing condition with complementary representation of multiple biodiversity features, this was a rather simple consideration of restoration need. While more advanced optimization of restoration and management effects over multiple ecosystem types are likely to be needed in many other cases, it should be noted that they also considerably increase the analysis complexity (Possingham et al. 2009, 2015; Shoo et al. 2017). The introduced approach for mire conservation planning and for the use of trade-off information should have international interest, considering the global need for wetland conservation (MEA 2005). However, the presented approach (as all large-scale planning) is dependent on the availability of reliable quantitative data, that is required for the analyses and is a corner stone of any trade-off evaluation (e.g. Kareksela et al. 2018; Kujala et al. 2018).

Here the data on land acquisition and restoration costs were not fully available at the time of the analysis. Missing the data on economic costs, we used area as a proxy for the cost to be minimized. This has a trade-off of its own by concentrating the solution more on the “hot spots” (high gain with small area) and lowering the probability for potential land-use conflicts in the future (minimizing needed total area) but not minimizing the actual economic resourcing from the society. If full cost information had been available, it could have influenced the relative priority of areas. It should be noted however, that costs did not restrict the protection program, but the societal target was more area-based (the 100 000 ha). As such the analysis could more efficiently fill its role as an information source for cost-effective solution to satisfy the complementarity goal by having the same limiting factor (i.e. area) as the whole decision-making process.

As usual, we lack a reference to be able to say how the results would have been used if the analysis had not been carefully co-produced within the working group. Ultimately, it is nearly impossible to know the impacts of alternative choices and analysis options (Sutherland et al. 2004; Sinclair et al. 2018). Following this problematization, it is difficult to speculate how well for example the structured decision-making process was carried out here, or how much better the prioritization analysis process or results could have been articulated to the stakeholders in the co-production and decision-making phases. Even so, quantitative evaluation of the trade-offs seemed to provide an excellent way to integrate expert knowledge, to evaluate alternative solutions, and to deliver results to decision-makers. In the end, a broad suite of factors was successfully converted into decisions about sites chosen for the protection program.

To conclude, in addition to providing a globally relevant method for effective large scale mire conservation, we were able to identify two major factors helping to fill in the implementation space between analyses and decision-making in a broad context. First, early on structured co-production between analysis experts, ecological experts, and the decision makers facilitates a successful analysis process closely linked to the actual decision-making. Second, systematic use of relevant trade-off information and a multidirectional benchmark process improves a balanced use of multiple information sources. Together, these conclusions strengthen observations made earlier (Hulme 2014; Toomey et al. 2014, Young et al. 2014, Kareksela et al. 2018): open minds, open atmospheres, and open discussions are keys to successful cost-effective conservation.

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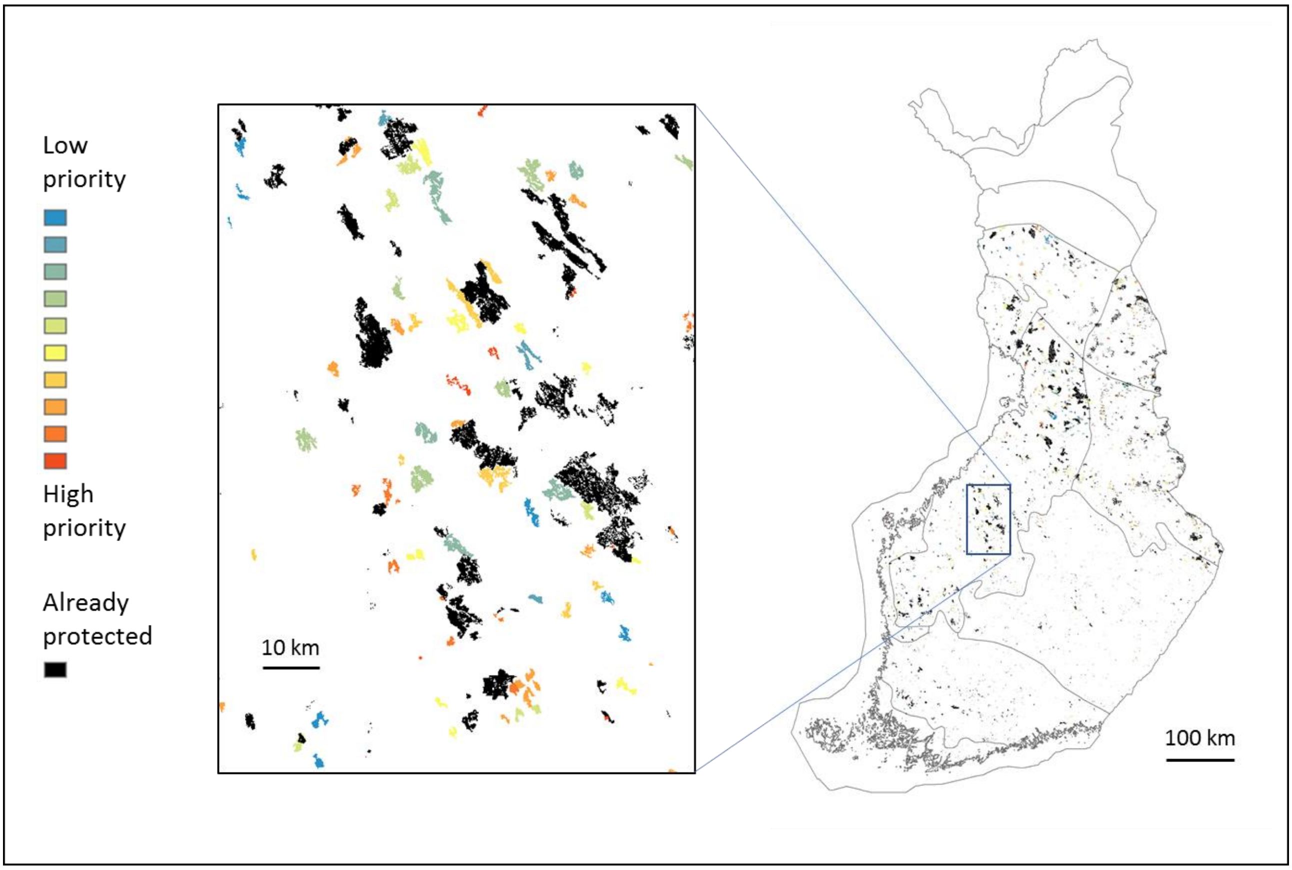

Fig. 1. Analysis area in Finland with administrative unit (forest vegetation zones) borders (see Appendix for further information) and a higher resolution map showing the priorities at the level of individual planning units (hydrological mire entities). Black areas represent the already protected mires and the colored areas from blue (low priority) to red (high priority) represent the prioritized candidate sites.

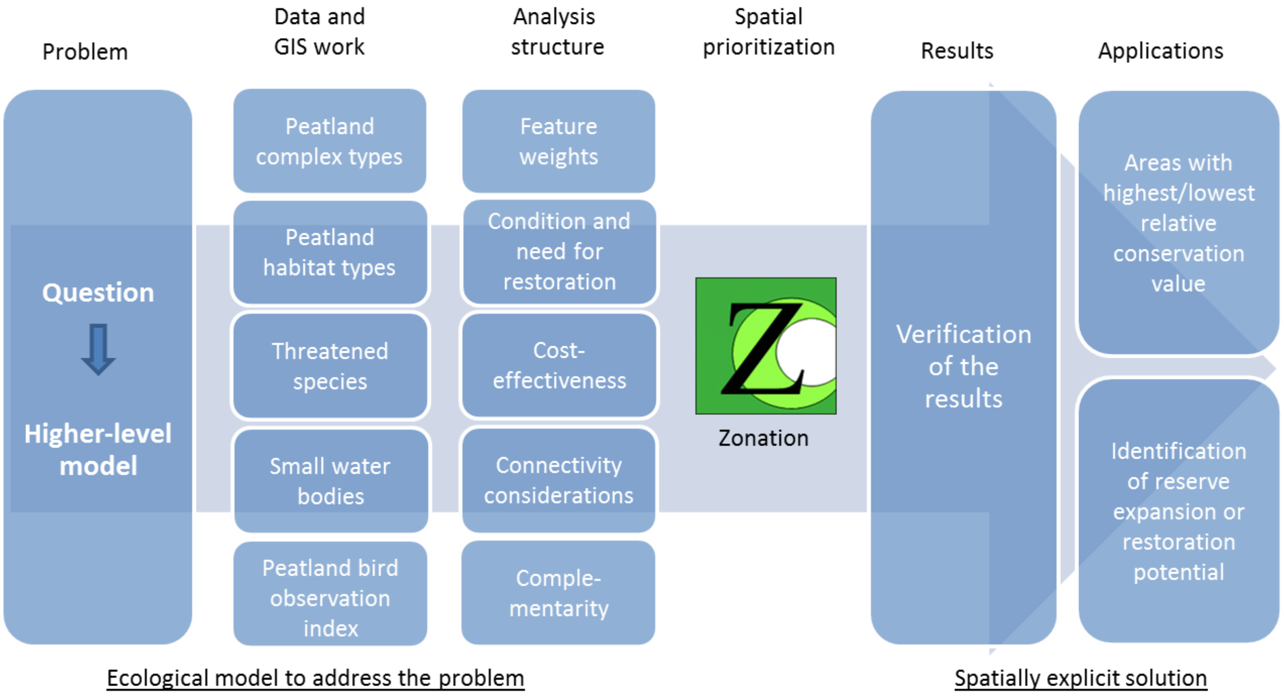

Fig. 2. Flowchart of the complementarity-based analysis implemented using the decision support tool Zonation. All the phases and use of the data elements and analysis approaches were co-planned together by the analysis producers and the mire experts, end-users and other stakeholders in the working group.

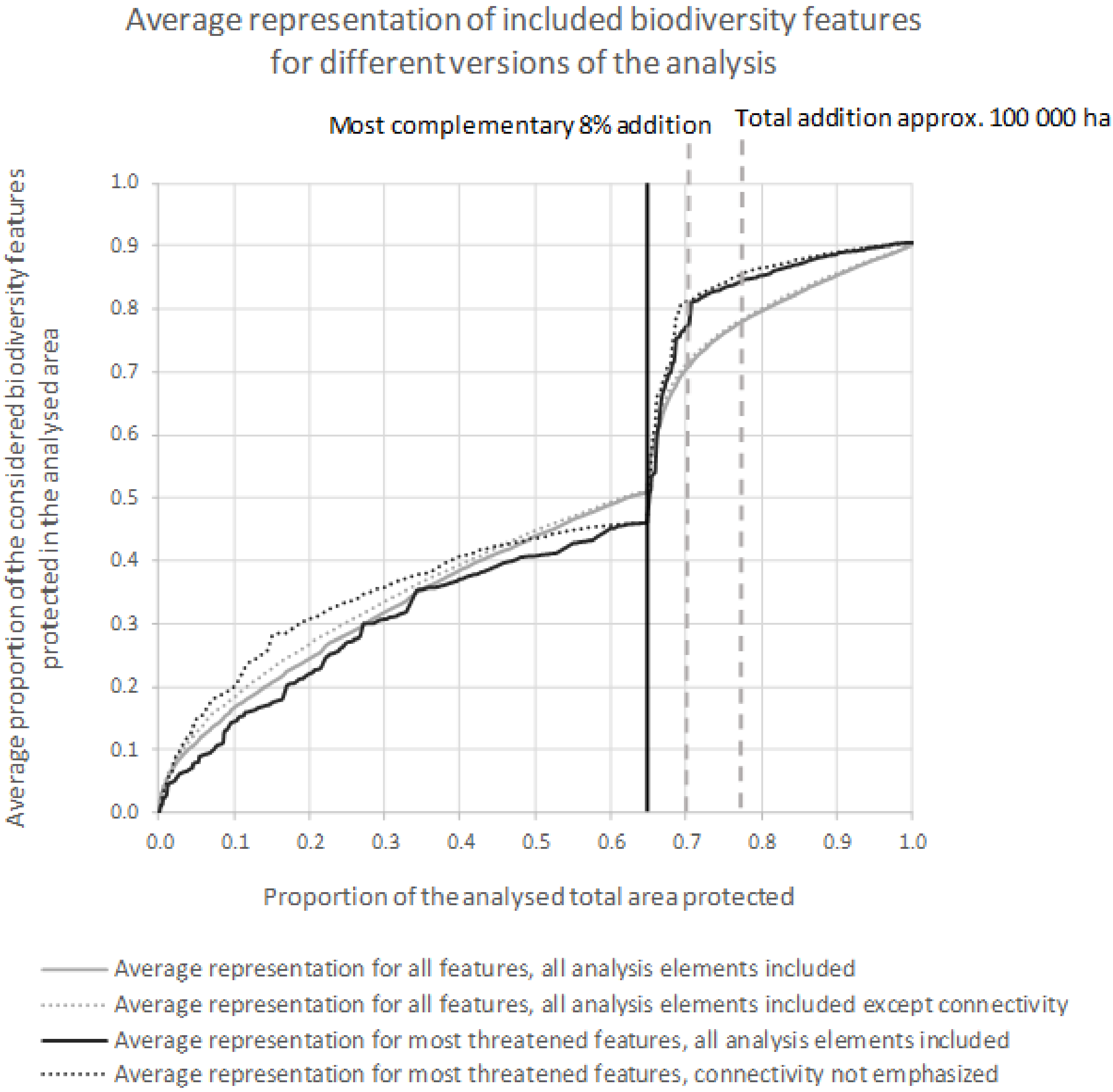

Fig. 3. Performance curves describe how the coverage of biodiversity features changes as function of area added into protection. The black vertical line indicates division between presently protected areas (left from line) and expansion areas (right). The steep rise of the curves to the right of the black line means that some species or habitats are missing or poorly represented within present protected areas (see also Fig. 4), but that the coverage of these features can be improved rapidly with additional sites, until representativeness increase starts to saturate. The dashed gray vertical line on the left shows the amount suggested to be chosen according to the Zonation analysis to ensure complementary solution (the solution of 8% addition to what is already protected), and the dashed gray vertical line on the right marks the total additional area suggested to be protected by the CMPP.

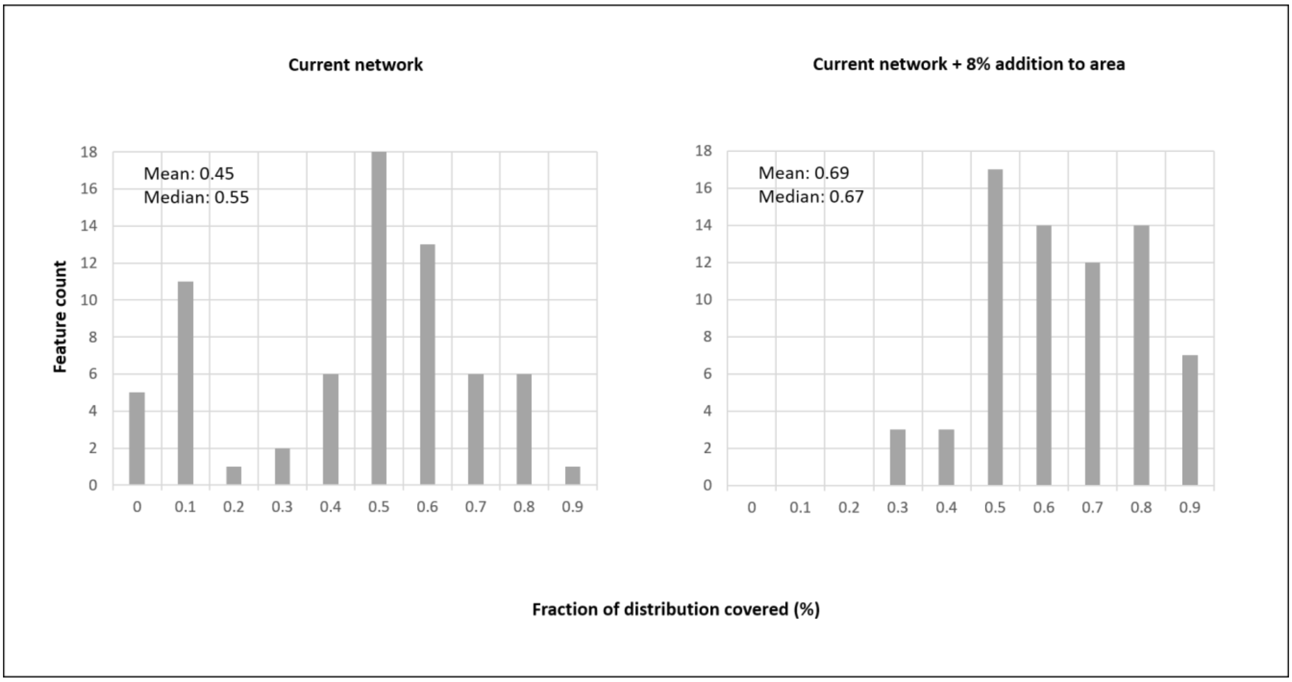

Fig. 4. Histogram of coverage of input biodiversity features (excluding modelled potential distributions for birds and small water bodies) relative to the features' abundances in the current protected areas and candidate areas combined (total analysis area). Comparison of the histograms for current network and with 8 % increase in its area, demonstrate the filling in the biodiversity gaps, i.e. allocating conservation resources for the features least well represented in the current network. Figures on the x-axis show the fraction of a features' analyzed abundance protected currently (left histogram) and in a +8 % situation (right histogram) and the y-axis shows the number of features that have that fraction of its abundance protected. Note that the +8 % represents the mire sites chosen for protection according to Zonation analysis solution (best 8 % addition to the protected landscape) and the final increase in biodiversity representation is higher than shown in the figure, because the addition presented here was approximately 1/3 of the total area chosen for protection. Thus, the presented figure is to demonstrate the "gap-filling effect" of complementarity-based analysis used here.