Forest Ecology and Management 318 (2014) 175–182

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

The value of information in conservation planning: Selecting retention trees for lichen conservation

Karin Perhans [a], Robert G. Haight [b], Lena Gustafsson [a,*]

[a] Department of Ecology, Swedish University of Agricultural Sciences, P.O. Box 7044, SE-750 07 Uppsala, Sweden
[b] U.S. Forest Service Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108, USA

ARTICLE INFO

Article history:
Received 21 November 2013
Received in revised form 14 January 2014
Accepted 16 January 2014
Available online 8 February 2014

Keywords:
Biodiversity
Cost-effectiveness
Epiphyte
Forestry
Information cost
Sweden

ABSTRACT

Conservation planning studies at small scales such as forest stands and below are uncommon. However, for retention forestry, developed during the last two decades and with current wide and increasing application in boreal and temperate regions, the need for cost-effective selection of individual trees is evident. In retention forestry certain trees are left at final harvest to promote flora and fauna. There is also a scarcity of studies on information costs and how these relate to the cost-effectiveness of conservation. We addressed both of these issues by studying whether decisions about the retention of aspen *Populus tremula* L. trees can be made more cost-effectively by including information about tree characteristics. We analyzed data from 12 recently harvested stands in middle Sweden containing 131 epiphytic lichen species (a biodiversity proxy) on 360 aspen trees. We related the presence of lichen species to bark and stem attributes and used those relationships to prioritize trees for retention. We estimated the value of using different sets of survey information (lichens, tree characteristics) to select retention trees to achieve various conservation goals. Depending on species or species groups of interest, and the type of tree information being collected, the value of collecting the information is up to 20% of the total value of all potential retention trees, which, given current labor costs, allows up to four hours for planning and selecting the right trees on an average-sized clearcut. The current practice of almost randomly selecting aspen trees to retain at final harvest can be improved by adding easily collected information on tree characteristics, such as black-colored bark, slow tree growth, inclining stems and speckled bark. This can lead to attainment of a given level of a conservation goal (like maximizing the number of lichen species of conservation concern) with fewer retention trees. Inventory of tree information often can be performed quickly, and if part of the gains from using such information to guide tree selection would be spent on additional conservation efforts, this would benefit biodiversity. Studies on more organism groups and tree species are needed to increase the applicability of results.

© 2014 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-SA license.

1. Introduction

The importance of cost-effectiveness in conservation planning and implementation has grown (Bottrill et al. 2008; Ferraro and Pattanayak 2006; Murdoch et al. 2007), reflecting the current pressures on biodiversity and a realization that all species that require conservation investments simply cannot be helped with today's levels of conservation spending. Since there is a trade-off between money spent on collecting data and money used for actual conservation action, finding the appropriate level for biodiversity surveys is an important step in conservation planning. Hitherto, conservation planning studies commonly have been made at a landscape or national scale. Studies at small scales like forest management units, stands and individual trees are not as common (but see Perhans et al. 2011).

Conducting biodiversity surveys to decide where and how to invest in different types of conservation actions is normally regarded as one of the first stages in a systematic conservation planning process (Margules and Pressey 2000). Yet, whether or not to survey and how thorough surveys should be are challenging questions (Possingham et al. 2007). A few studies address these questions by comparing survey benefits and costs. Balmford and Gaston (1999) argue that biodiversity surveys prior to decisions on where to locate new reserves generally allow the selection of fewer, or smaller, areas because the survey data allow selection of areas that complement each other in terms of the conservation features they contain. The cost-effectiveness of surveys depends on this saving in protected area in addition to the costs of land acquisition and

* Corresponding author. Tel.: +46 (0)18 67 27 47.
E-mail addresses: karin.perhans@gmail.com (K. Perhans), rhaight@fs.fed.us (R.G. Haight), lena.gustafsson@slu.se (L. Gustafsson).

http://dx.doi.org/10.1016/j.foreco.2014.01.020
0378-1127/© 2014 The Authors. Published by Elsevier B.V. Open access under CC BY-NC-SA license.

maintenance. They suggest that the break-even survey cost is large enough in both developed and undeveloped countries to make surveys cost-effective in a wide range of applications. Grantham et al. (2008), in a simulation study of reserve selection to protect *Proteaceae* plants in the Fynbos biome of South Africa, determine conservation returns from spending different amounts on surveys prior to selecting reserves. For a given investment in protected area, the incremental gains in species conservation decrease rapidly with increasing amount and cost of surveys. Therefore, contrary to Balmford and Gaston (1999), they argue that with diminishing returns from additional survey information, resources might be better directed toward other conservation actions, depending on their relative costs and benefits.

Here, we conduct a case study to determine how much time and money can be spent on gathering information to help foresters prioritize and select retention trees on clearcuts in a boreal forest landscape in Sweden. To our knowledge, it is the first conservation planning study that addresses the small scale level of individual trees. Retention forestry, which involves leaving trees and dead wood at forestry operations to benefit biodiversity and ecosystem functions, is now practiced widely in boreal and temperate forests, and is increasing in application (Gustafsson et al. 2012; Lindenmayer et al. 2012). In boreal forests, which comprise about 30% of all forests globally (Hansen et al. 2010), retention forestry is used to create a more heterogeneous forest landscape that resembles a landscape shaped by natural disturbances of varying intensity (Lindenmayer and Franklin 2002). Two main approaches are normally used in parallel: single trees dispersed over the clearcut, and trees retained in small, undisturbed forest patches (Lõhmus et al. 2006; Nelson and Halpern 2005). European aspen (*Populus tremula* L) is a frequently used tree species for retention in Sweden (Swedish Forest Agency 2012) since it is a key species for beetles, birds, lichens and bryophytes, including many declining species (Angelstam and Mikusinski 1994; Kuusinen 1996; Siitonen and Martikainen 1994). In Sweden, retention actions are a legal requirement with the same prescriptions irrespective of ownership.

Current guidelines at two of the largest Swedish forest companies (Stora Enso and SCA) for selecting retention trees state that at least 10 trees of high conservation value should be retained per hectare, alone or in patches. Large and old trees shall be prioritized, and in the case of aspens, if there are very few of them, all of them should be retained. In more aspen-rich stands, only a portion of the trees need to be retained. The decision on which solitary trees to retain is normally made by the cutting team, but the guidelines do not include any information on how much time to spend planning per hectare or whether planning must be made prior to cutting or successively while cutting. Thus, basic guidelines for tree selection exist but whether they promote biodiversity better than a random selection has not been rigorously tested.

The aim of our study is to analyze whether aspens to be retained on clearcuts can be selected more cost-effectively than with a random selection, by adding information on tree characteristics. We estimate the value of using different sets of survey information to prioritize and select retention trees to achieve a given level of biodiversity conservation. The value of information is the difference in the cost of a random selection of retention trees without observing tree attributes and a prioritized selection of retention trees based on a set of observed tree attributes. The value of information provides an upper limit for how much time can be spent examining tree attributes and prioritizing trees. Our conservation goal is representation of epiphytic lichens (growing on trees). There are more than 2400 lichen species in Sweden (Gärdenfors 2010) which are symbiotic associations between a fungus and a photobiont (green algae or cyanobacteria). It is a species-rich and well-studied species group with several species considered sensitive to forestry operations (Gärdenfors 2010). Epiphytic species are often used for measuring biodiversity response to retained trees (Rosenvald and Lõhmus, 2008).

2. Methods

2.1. Study clearcuts

The fieldwork was carried out in the summer and autumn of 2009 in the eastern part of the counties of Jämtland and Västernorrland in boreal mid Sweden. The selection of study clearcuts was made from all recently cut stands (between 2005 and 2009) by the forest company SCA and some smaller private forest owners in the region. We selected 12 clearcuts that were harvested 0–4 years earlier and had at least 30 retained living aspen trees (breast height diameter >10 cm) (Table 1). Within each of these clearcuts, 30 aspens (>5 m apart) were randomly selected (from a total number often greatly exceeding 30 aspens per clearcut), using transects with randomly selected starting points, yielding a total of 360 trees. On each tree, all epiphytic lichens on the stem up to a height of 2 m were recorded (presence only) (for data on lichens, see Lundström et al. 2013). The following tree attributes were also recorded on each tree, using a simple and coarse scale from 1 to 3: diameter at breast height, tree age, bark crevice depth, speckled appearance of the bark, black-colored bark, cover of epiphytic bryophytes, tree inclination, size and width of tree crown, branch size, slow tree growth (as evaluated by ocular inspection e.g. of the relationship between diameter and bark texture), and bark damage. For calculation of the economic value of each tree, we also measured the diameter in centimeters, the height of each tree with a digital clinometer, and the amount of wood rot by coring each tree with an increment borer. Aspen wood in this region of Sweden is generally used for pulp, so when calculating the economic value of each tree we used a current price list for pulpwood from the local forest owners association Norrskog, with a price of 236 SEK/m^3. As instructed in the price list, rotten wood was subtracted from the total stem volume up to a level of 67% rotten wood (measured as area at breast height), after which point the tree was considered to have no economic value. No specific permits were required for the described field studies.

2.2. Data analysis

2.2.1. Tree attributes

Generalized linear models were used to analyze the relationship between the tree attributes and (1) the total number of lichen species on each tree, (2) the number of species of conservation concern on each tree (which in this study included red-listed species (Gärdenfors 2010) and indicator species, the latter used to indicate forests of high conservation value in conservation assessments; (Nitare 2000), (3) presence or absence on each tree of the four most frequently occurring lichen species of conservation concern (*Collema furfuraceum* (Arnold) Du Rietz, *Lecanora impudens* Degel., *Leptogium saturninum* (Dicks.) Nyl., and *Lobaria pulmonaria* L. Hoffm. Species number (1 and 2 above) was modeled with a Poisson distribution and with an identity link function to the explanatory variables (tree attributes), while presence or absence of individual species was modeled with a binomial distribution and a logit link function (i.e. logistic regression). The choice of distributions and link functions was based on their fit with the data. Prior to analysis, all explanatory variables were first checked for strong correlations (here >0.6 in a bivariate plot). Where correlations were present, we excluded those variables from further analysis that we judged were of least practical use for identifying retention trees in the field. Tree age, size of branches, and size and width of tree crown were thus excluded due to their strong

Table 1
Description of the 12 study clearcuts in the counties of Jämtland and Västernorrland in boreal Sweden.

	Name	Area (ha)	Cutting year	Mean diameter of surveyed trees (cm)	Mean value of surveyed trees (SEK)	Total value of surveyed trees (SEK)	Number of lichen species	Number of lichen species of conservation concern (red-listed[a]; indicator species[b])
1	Bodmyren	34	2005	33	137	4124	38	6; 6
2	Hällflobrännan	9	2007	32	171	5132	33	3; 5
3	Krogberget	7	2006	36	222	6651	50	4; 4
4	Maskvägen	5	2007	33	213	6394	36	8; 7
5	Ledflon	10	2007	39	139	4169	41	7; 6
6	Hällnäset	21	2007	31	106	3184	46	9; 4
7	Lillgravsberget	19	2009	25	145	4348	62	4; 4
8	Storgravberget	17	2006	33	150	4516	26	4; 8
9	Bockåsen	5.8	2006	47	238	7140	45	6; 6
10	Torråstjärn	13	2006	40	336	10,086	73	8; 8
11	Holkåsen	29	2009	51	344	10,317	43	7; 4
12	Bodsjöberget	4.5	2009	27	81	2426	68	6; 6

[a] According to the 2010 Red List of Swedish species (Gärdenfors 2010).
[b] Species presumed to indicate forest areas of high conservation value (Nitare 2000).

correlation with bark crevices (tree age) and tree diameter (size of branches and size and width of crown). We detected no overdispersion in the Poisson-modeled data.

We used model-averaging to derive parameter estimates for each explanatory variable (see tree attributes in Table 2), to overcome the problem with model selection uncertainty. All possible subsets of models were thus constructed (i.e. 256 models) and we used the second-order Akaike information criterion AIC_C (which penalizes models with many explanatory variables) to calculate relative likelihoods and Akaike weights for all models (Burnham and Anderson 2002). Akaike weights can be interpreted as the probability that each model is the best model, given the data and set of considered candidate models. Model-averaged parameter estimates and associated standard errors and confidence intervals were calculated for all parameters across the models with a $\Delta AIC_C \leqslant 2$ (on average 12 models), which are models that can be said to have "substantial support" (Burnham and Anderson 2002, p. 70; Grueber et al. 2011). To reduce bias in parameter estimates, we denoted the estimate of parameters not included in any given model within the candidate set to zero and thus averaged parameter estimates over all models, not just those containing the parameter (Burnham and Anderson 2002; Lukacs et al. 2010). The statistical software package Statistica was used for all modeling (StatSoft 2011).

2.2.2. Value of information

We estimated the value of using different sets of information to prioritize and select retention trees to achieve three different conservation goals: maximizing the number of lichen species represented on the retention trees on the clearcut, maximizing the number of species of conservation concern represented, and maximizing the probability that a given species of conservation concern is represented on at least one retention tree on the clearcut.

For each conservation goal, we simulated tree selection on each of the 12 clearcuts using different types of information about each tree: (1) A score based on the most important tree attributes (see Table 2), (2) tree diameter (using the coarse 1–3 scale) as a proxy for wood volume and, in turn, economic value of each tree, and (3) the score divided by the diameter, which is a proxy for the conservation return on investment in the tree. To construct the tree score, the values of tree attributes (on a scale of 1–3) with a positive influence (confidence interval entirely above zero) on the lichen species groups were summed, and the values of the attributes with a negative influence (confidence interval entirely below zero) were then subtracted from this sum.

For each clearcut and conservation goal, we produced three rankings of the 30 trees using tree score, tree diameter, and score divided by diameter. Using each ranking, we selected 30 sets of trees, each set containing a successively increasing number of trees from 1 to 30 trees. For each set of selected trees, we computed the performance measure related to the conservation goal as well as the cost of retaining the trees. Since ties occur in the ranking process (e.g. when several trees had the same total score), we repeated the ranking and selection 10,000 times using a random selection of trees with the same rank and then computed the average performance and cost for each of these sets of retention trees.

In addition to using the three rankings to select trees, we performed an optimal tree selection, which serves as a benchmark of "perfect" information related to the conservation goal. For the goals of maximizing the number of lichen species represented or lichen species of conservation concern represented, the optimal tree selection was carried out as a maximal covering problem (Camm et al. 1996; Church et al. 1996). The model objective was to represent as many lichen species as possible on the clearcut for a successively increasing budget, and the model was solved with integer linear programming in Ampl/CPLEX (ILOG 2005). For the goal of maximizing the probability that a given species of conservation concern is represented on at least one retention tree on the clearcut, the optimal selection was performed by ranking the trees on each clearcut according to the species' probability of occurrence on each tree, divided by the cost of retaining each tree. The probabilities were derived from the logistic regression equation for each species, using parameter estimates only for variables with confidence intervals not including zero and tree attribute values for each tree. We then selected 1–30 retention trees according to these values (highest values first).

Finally, as a benchmark of using no information at all, we randomly selected 10,000 sets of a given number of retention trees for each stand and computed the average performance related to each conservation goal over these 10,000 sets.

The result of each tree selection strategy (score-based, diameter-based, score/diameter, optimal, and random) was evaluated as the cumulative number of species represented on the retention trees on the clearcut per level of cumulative cost. For individual species it was evaluated as the resulting cumulative probability of species occurrence on any of the retention trees on the clearcut, calculated from the model-averaged logistic regression equations.

To determine the maximum value of information, i.e. the upper limit for how much money (or time, if converted using standard labor costs) that maximally could be spent on surveying, we compared for each clearcut the different tree selection approaches to

Table 2
Relationship between aspen tree attributes and number of lichen species, number of lichen species of conservation concern, and occurrence of four individual lichen species of conservation concern (tree attributes with confidence intervals of estimates not including zero, indicating an effect on the response variable, are in bold).

Tree attributes	Model-averaged estimate	Model-averaged SE	Lower CI (90%)	Upper CI (90%)
All species				
(Intercept)	0.496	1.164	−1.414	2.405
Diameter	**0.840**	**0.249**	**0.432**	**1.248**
Bark crevices	−0.123	0.228	−0.497	0.250
Speckled bark	**1.938**	**0.341**	**1.378**	**2.497**
Black bark	**0.917**	**0.249**	**0.509**	**1.325**
Bryophyte cover	**−1.572**	**0.543**	**−2.462**	**−0.682**
Tree inclination	**1.997**	**0.328**	**1.459**	**2.535**
Slow-growing trees	**2.178**	**0.374**	**1.565**	**2.790**
Bark damages	−0.483	0.354	−1.064	0.097
Species of conservation concern				
(Intercept)	−0.110	0.555	−1.019	0.800
Diameter	0.174	0.151	−0.074	0.423
Bark crevices	0.148	0.190	−0.164	0.460
Speckled bark	**0.331**	**0.175**	**0.043**	**0.618**
Black bark	**0.304**	**0.127**	**0.096**	**0.512**
Bryophyte cover	−0.136	0.254	−0.553	0.280
Tree inclination	**0.428**	**0.163**	**0.160**	**0.696**
Slow-growing trees	**0.386**	**0.198**	**0.061**	**0.711**
Bark damages	−0.102	0.143	−0.337	0.132
Collema furfuraceum				
(Intercept)	0.132	1.262	−1.938	2.203
Diameter	0.001	0.003	−0.004	0.007
Bark crevices	−0.121	0.212	−0.469	0.227
Speckled bark	0.000	0.000	0.000	0.000
Black bark	0.104	0.168	−0.172	0.380
Bryophyte cover	**−1.862**	**1.036**	**−3.561**	**−0.163**
Tree inclination	−0.292	0.325	−0.826	0.241
Slow-growing trees	**0.537**	**0.257**	**0.115**	**0.959**
Bark damages	−0.011	0.034	−0.066	0.044
Lecanora impudens				
(Intercept)	−1.347	0.967	−2.933	0.239
Diameter	−0.188	0.233	−0.571	0.194
Bark crevices	0.192	0.297	−0.295	0.678
Speckled bark	0.029	0.075	−0.095	0.153
Black bark	**0.860**	**0.216**	**0.505**	**1.215**
Bryophyte cover	−0.269	0.441	−0.993	0.454
Tree inclination	−0.066	0.136	−0.288	0.156
Slow-growing trees	0.033	0.076	−0.093	0.158
Bark damages	**−1.173**	**0.463**	**−1.932**	**−0.413**
Leptogium saturninum				
(Intercept)	0.501	0.737	−0.708	1.710
Diameter	−0.002	0.009	−0.017	0.013
Bark crevices	−0.128	0.208	−0.469	0.213
Speckled bark	0.405	0.300	−0.088	0.897
Black bark	**0.443**	**0.208**	**0.102**	**0.785**
Bryophyte cover	−0.065	0.143	−0.299	0.169
Tree inclination	−0.002	0.012	−0.023	0.018
Slow-growing trees	−0.062	0.122	−0.262	0.137
Bark damages	−0.097	0.167	−0.372	0.177
Lobaria pulmonaria				
(Intercept)	**−3.132**	**0.830**	**−4.493**	**−1.771**
Diameter	0.091	0.139	−0.137	0.319
Bark crevices	**0.764**	**0.278**	**0.308**	**1.219**
Speckled bark	0.046	0.114	−0.141	0.234
Black bark	**−0.433**	**0.187**	**−0.739**	**−0.127**
Bryophyte cover	0.012	0.044	−0.060	0.084
Tree inclination	**0.651**	**0.221**	**0.288**	**1.014**
Slow-growing trees	**0.713**	**0.249**	**0.304**	**1.121**
Bark damages	−0.195	0.269	−0.636	0.245

the random selection of trees. As the starting point for comparison, we used the number of species, or cumulative level of probability, respectively, reached when half of the trees (15 trees) were randomly selected, and we also computed the corresponding total cost of the 15 retained trees. We then computed the total cost and the number of trees needed to attain the same level of species representation, or cumulative probability of occurrence, with the other tree selection approaches. The difference in cost can thus be said to be the economic value of each type of information, and thus, spending more than this amount on surveying and selecting trees would not be cost-effective relative to a random selection of retention trees. The value of information was also converted to maximum surveying time per clearcut and per hectare, in this case assuming a labor cost of 350 SEK/h (1 SEK = 0.11 EUR or 0.14 USD, January 2014) and an average size of a clearcut of 14 ha, as in this study.

3. Results

3.1. Lichen species and value of trees

We found a total of 131 lichen species on the 360 aspen trees in all 12 clearcuts (see also Table 1). Of these, 11 were red-listed species and 12 were indicator species, summing to 22 species of conservation concern (one species (*L. pulmonaria*) belonged to both groups). The mean total species number per tree was 8.9, of which 2.2 were species of conservation concern. The corresponding figures per clearcut were 46.8 and 10.7. The four most common species of conservation concern, *C. furfuraceum*, *L. impudens, L. saturninum*, *L. pulmonaria*, analyzed separately in this study, were present on 17.8%, 19.2%, 76.7%, and 36.7% of the 360 trees in the study, respectively. With a random selection of retention trees among the 30 aspens on each clearcut, on average 17, 28, 2, and 7 trees, respectively, would be needed to be 95% sure to represent each of the four species on at least one tree on the clearcut, reflecting their relative rareness and spatial distribution. To represent 95% of the total number of lichen species present on each clearcut, on average 26 trees would be needed with a random selection of trees, while 25 trees would be needed for species of conservation concern. The mean diameter of the aspen trees was 36.3 cm and the mean economic value 190 SEK. The proportion of trees with more wood rot than 67%, and thus without any economic value, was 12%.

3.2. Tree attributes and tree scores

The tree scores used as an indication of the total number of lichen species were composed of tree diameter, speckled bark, black bark, tree inclination, slow-growing trees (of which all had a positive effect) and bryophyte cover (negative effect; Table 2). For the number of species of conservation concern, the score was similar and composed of speckled bark, black bark, tree inclination, and slow-growing trees (positive effect). For *C. furfuraceum*, slow-growing-trees (positive effect) and bryophyte cover (negative effect) made up the score, while for *L. impudens*, it was black bark (positive effect) and bark damages (negative effect). For *L. saturninum*, only black bark constituted the score (positive effect), while for *L. pulmonaria*, bark crevices, tree inclination, slow-growing trees (all positive effect) and black bark (negative effect) were part of the score.

3.3. Value of information

Selecting trees based on the tree attribute score produced mixed results compared with selecting trees randomly. For two species of conservation concern, *C. furfuraceum* and *L. pulmonaria*, as well as for species of conservation concern as a group, selecting trees based on tree score produced an average (across the 12 clearcuts) economic saving (or value of information) of 730–810 SEK per clearcut, or 14–16% of the total economic value of all 30 trees on the clearcut (Fig. 1 and Table 3). For the total number of species and for *L. impudens*, however, the result from the score-based selection was similar to a random selection of trees. Selecting trees based on their diameter (smallest first, as a proxy for their economic value) always gave a better result than a random selection (except for *L. saturninum*) and resulted in an average saving of 520–1480 SEK per clearcut, or 13–26% of the total economic value of trees. Score-based selection was only better than diameter-based selection for species of conservation concern as a group and for *L. pulmonaria*. Using score divided by diameter improved the result for the total number of species, species of conservation concern, and slightly for *C. furfuraceum* and *L. pulmonaria*, compared to only using the best of either of them alone. For *L. saturninum*, using any kind of information never improved the result compared to a random selection at the level of 15 selected trees because *L. saturninum* is present on most (77%) of the trees.

Across both lichen species groups and the four individual species of conservation concern, slightly (on average 2.8 and 1.5 per clearcut) fewer trees were required to reach the same number of species or probability of species occurrence, respectively, with the score-based or the combined approach than with the random selection of 15 trees. In contrast, the diameter-based selection required on average 0.3 more trees than the random selection.

The average value of information associated with ranking and selecting 15 trees based on their score divided by diameter to attain the maximum number of lichen species represented across the 12 clearcuts was 1339 SEK. Assuming a labor cost of 350 SEK/h, spending up to 3.8 h per clearcut surveying to select the right set of 15 trees would pay off. For the goal of maximizing representation of species of conservation concern, the corresponding figure was 2.8 h per clearcut. To maximize the probability of presence of each of the four species that we analyzed individually, the time that could maximally spent on each clearcut varied from 0 (*L. saturninum*) up to 4.4 h (*C. furfuraceum*). Note that the maximal time increases as species' rarity increases (*L. saturninum* is present on 77% of the trees while *C. furfuraceum* is present on 17% of the trees). For all six species or species groups analyzed in the study, and surveying to get information about both scores and diameter of trees, the average maximum time to spend per clearcut was 2.7 h, or 19 min per hectare, assuming an average clearcut size of 14 ha and selection of 15 retention trees. For information about tree attribute scores alone, on average up to 1.3 h per clearcut can be spent, while 2.4 h can be spent collecting information about the diameter of trees. To get "perfect" information on actual species occurrences and economic values of trees, on average 4.7 h per clearcut could be spent, or 33.6 min per hectare.

4. Discussion

Our study shows that the scope for improvement of the cost-effectiveness when selecting retention aspens for biodiversity conservation often may be quite large. In our case, depending on species or species group of interest and what type of tree information is being collected and used, the value of information is as much as 20% of the total budget for retaining trees, which, given current labor costs, means almost four hours on an average-sized clearcut can be spent on planning and selecting the right trees. Inventory of tree information can most likely often be performed quicker than that, and given a certain budget for conservation action (planning and retaining trees), part or all of these savings could be invested in more retained trees or other conservation efforts, to the benefit of our study group of epiphytic lichens.

For all lichen species taken together, the value of information about tree attribute scores is very low (even slightly negative), and does not follow the same pattern as for species of conservation concern. This is caused by two factors. First, the variability in all species among trees in the score-based selection is lower than the variability in economic values (analysis not shown here) making the economic values stronger drivers of the cost-effectiveness. Second, because their correlation (scores-cost) is positive, trees in a score-based selection have economic values higher than average, an effect of diameter being part of the score (see also Babcock et al. 1997).

Although retention approaches in forestry were introduced only a few decades ago (Gustafsson et al. 2012), a large number of ecological studies have been performed in relation to this practice (Lindenmayer et al. 2012). Reviews of results have also been made,

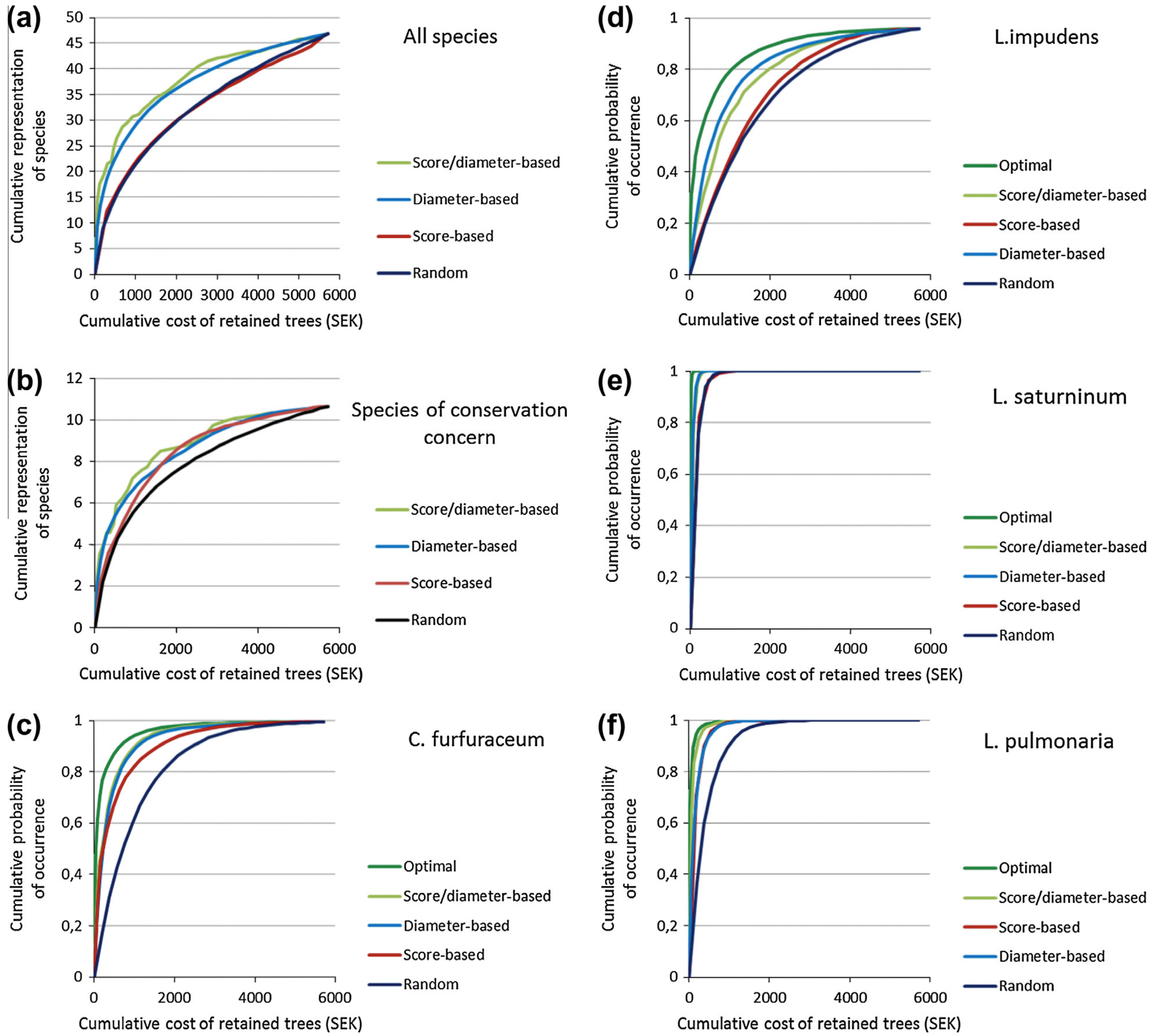

Fig. 1. Cost-effectiveness (averaged over 12 clearcuts) of selecting among 30 candidate retention aspens based on different types of survey information to maximize (a) the total number of lichen species, (b) the number of lichen species of conservation concern; or the probability of presence of (c) *Collema furfuraceum*, (d) *Lecanora impudens*, (e) *Leptogium saturninum*, (f) *Lobaria pulmonaria* on any tree on the clearcut. Note that for all species and for species of conservation concern, the optimal selection could not be averaged between clearcuts as the tree selection was not based on a step-wise increasing tree number; but see Figs. S1 and S2 in Supplementary data for individual plots for each clearcut.

Table 3
Value of information (VOI) about different types of survey data: tree score, tree diameter, score and diameter combined, as well as value of "perfect" information, for each lichen species group or individual lichen species, averaged over the 12 clearcuts.

	Score-based selection			Diameter-based selection			Score/diameter-based selection			Optimal selection		
	VOI (SEK)	VOI (%)[a]	Trees[b]	VOI (SEK)	VOI (%)[a]	Trees[b]	VOI (SEK)	VOI (%)[a]	Trees[b]	VOI (SEK)	VOI (%)[a]	Trees[b]
All species	89	−0.7	−3.5	1050	19.8	0.8	1339	25.0	−1.3	2459	43.4	−9.4
Species of conservation concern	813	14.1	−3.5	523	12.5	2.6	997	19.0	0.6	2509	44.7	−10.8
Collema furfuraceum	803	16.1	−2.5	1479	26.2	−1.7	1557	27.9	−2.3	1935	34.7	−2.6
Lecanora impudens	199	0.7	−1.6	1224	21.2	0.4	820	12.9	−1.7	1807	32.0	−1.5
Leptogium saturninum	0	0	0	0	0	0	0	0	0	0	0	0
Lobaria pulmonaria[c]	732	16.2	−6	691	14.4	−0.5	870	18.6	−4.5	1092	22.5	−3

[a] Expressed as proportion of the total value of all 30 trees on the clearcut.
[b] Difference in number of selected trees compared to a random selection of 15 trees.
[c] The difference in number of selected trees is only based on clearcuts where the probability of occurrence at 15 trees random was <1.

indicating overall positive effects to biodiversity (Gustafsson et al. 2010; Rosenvald and Lõhmus 2008; Vanderwel et al. 2007). Still, the knowledge on links between specific tree properties and tree-associated plants and animals are scarce for retention trees. Our study shows that for aspen, black-colored bark and slow tree growth as well as other features related to tree form and bark texture, are important for the epiphytic lichen flora. Stem shape and bark properties have also been found to be important in other studies on lichen epiphytes in different environments, although their relative importance vary (e.g. Fritz et al. 2009; Ranius et al. 2008). Mechanisms behind the influence of the tree properties seem related to factors like bark chemistry and water-holding capacity (Ellis 2011).

Balmford and Gaston (1999) suggest that the savings in the amount of land to protect that comes from a more efficient, complementarity-based site selection is commonly at least 5%. In our score-based selection, with representation of all species or all species of conservation concern as the conservation goal, 3.5 fewer trees (11.7% of all trees) were needed, supporting their suggestion. Making a selection of the cheapest trees, by prioritizing small diameters, led to more trees, but with lower economic value. Thus, this type of selection, which has been demonstrated also in other studies (see e.g. (Juutinen et al. 2004; Moore et al. 2004; Perhans et al. 2008) could be an alternative strategy. But, it is opposite to current, field-based knowledge from biologists and researchers, who usually view large aspen trees as having special value to epiphytic lichens (e.g. Nitare 2000; Gärdenfors 2010). Importance of large-diameter trees for lichens has been found also for other tree species (e.g. Aragon et al. 2010; Johansson et al. 2007; Thor et al. 2010). Thus, we caution against applying this strategy until more studies have been made on the link between aspen diameter and the epiphytic lichen flora.

Occupancy or representation on the clearcut is a baseline starting point. However, the relationship between occupancy and long-term viability in the landscape is the ultimate response variable or target for conservation, but beyond what could be studied with this dataset. Studies on temporal development of biodiversity related to retained trees are few, which is not surprising since the retention practice was recently introduced. One of few studies was made by Lundström et al. (2013) who found, using an extended version of the dataset analyzed by us, that there was a higher number of aspen-dependent lichen species on retained aspens in stands harvested 10–16 years ago than in stands harvested 0–4 years ago.

It would be interesting to devise a selection procedure that avoids the cumbersome process of first scoring and ranking all the potential retention trees before selecting which ones to retain. For example, each time a potential retention tree is encountered, the forester could calculate its score and decide whether to retain the tree or cut it. This decision may be based on the number and attributes of trees previously selected for retention, and is made to maximize a conservation goal such as the probability of occurrence of a species of conservation concern subject to a cost constraint. Storage of data on tree characteristics could be made in a hand-computer in which logistic equations for a list of key species are stored. The decision to stop accepting more trees for retention could be based on a threshold, e.g. when the probability of occurrence of a species has reached 95%. McDonald-Madden et al. (2008) develop an analogous procedure for dynamic reserve site selection in which the decision maker quickly decides whether to purchase or reject a parcel as it comes on the market.

4.1. Practical implications and ways forward

Our results suggest that a change in current practice from selection of aspens in a more or less random way to a systematic selection based on identification of tree characteristics will benefit epiphytic lichens of conservation concern. Tree variables like black-colored bark, slow tree growth, low cover of epiphytic bryophytes, inclining stems and speckled appearance may then be especially important to measure. The rapidly evolving remote sensing techniques are likely to offer tools that will speed up location of certain tree species like aspen in stands, which would imply shorter inventory times, and thus further increase the cost-effectiveness of this approach. We studied only one organism group and more investigations need to be made on other organism groups in order to increase the generality for biodiversity. To extend the application further, studies on other tree species are also necessary.

Acknowledgements

We are grateful to Fredrik Jonsson who performed the lichen survey and registered aspen characteristics, to Johanna Lundström who assisted with the selection of survey stands, and to Malin Johansson who helped collecting the data on aspen characteristics. We thank Johanna Lundström and Stephanie Snyder for valuable comments on the manuscript. The project was funded by The Swedish Research Council Formas (Grant no. 215-2009-569 to L. Gustafsson).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foreco.2014.01.020.

References

Angelstam, P., Mikusinski, G., 1994. Woodpecker assemblages in natural and managed boreal and hemiboreal forest – a review. Ann. Zool. Fenn. 31, 157–172.
Aragon, G., Martinez, I., Izquierdo, P., Belinchon, R., Escudero, A., 2010. Effects of forest management on epiphytic lichen diversity in Mediterranean forests. Appl. Veg. Sci. 13, 183–194.
Babcock, B.A., Lakshminarayan, P.G., Wu, J., Zilberman, D., 1997. Targeting tools for the purchase of environmental amenities. Land Econ. 73, 325–339.
Balmford, A., Gaston, K.J., 1999. Why biodiversity surveys are good value. Nature 398, 204–205.
Bottrill, M.C., Joseph, L.N., Carwardine, J., Bode, M., Cook, C.N., Game, E.T., Grantham, H., Kark, S., Linke, S., McDonald-Madden, E., Pressey, R.L., Walker, S., Wilson, K.A., Possingham, H.P., 2008. Is conservation triage just smart decision making? Trends Ecol. Evol. 23, 649–654.
Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, second ed. Springer-Verlag.
Camm, J.D., Polasky, S., Solow, A., Csuti, B., 1996. A note on optimal algorithms for reserve site selection. Biol. Conserv. 78, 353–355.
Church, R.L., Stoms, D.M., Davis, F.W., 1996. Reserve selection as a maximal covering location problem. Biol. Conserv. 76, 105–112.
Ellis, E.C., 2011. Anthropogenic transformation of the terrestrial biosphere. Philos. Trans. Roy. Soc. -Math. Phys. Eng. Sci. 369, 1010–1035.
Ferraro, P.J., Pattanayak, S.K., 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. PLoS Biol. 4, 482–488.
Fritz, O., Brunet, J., Caldiz, M., 2009. Interacting effects of tree characteristics on the occurrence of rare epiphytes in a Swedish beech forest area. Bryologist 112, 488–505.
Gärdenfors, U., 2010. Rödlistade arter i Sverige 2010 – The 2010 Red List of Swedish Species. ArtDatabanken, SLU, Uppsala, p. 496.
Grantham, H.S., Moilanen, A., Wilson, K.A., Pressey, R.L., Rebelo, T.G., Possingham, H.P., 2008. Diminishing return on investment for biodiversity data in conservation planning. Conserv. Lett. 1, 190–198.
Grueber, C.E., Nakagawa, S., Laws, R.J., Jamieson, I.G., 2011. Multimodel inference in ecology and evolution: challenges and solutions. J. Evol. Biol. 24, 699–711.
Gustafsson, L., Kouki, J., Sverdrup-Thygeson, A., 2010. Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scand. J. For. Res. 25, 295–308.
Gustafsson, L., Baker, S.C., Bauhus, J., Beese, W.J., Brodie, A., Kouki, J., Lindenmayer, D.B., Lohmus, A., Pastur, G.M., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, W.J.A., Wayne, A., Franklin, J.F., 2012. Retention forestry to maintain multifunctional forests: a world perspective. BioScience 62, 633–645.
Hansen, M.C., Stehman, S.V., Potapov, P.V., 2010. Quantification of global gross forest cover loss. Proc. Natl. Acad. Sci. USA 107, 8650–8655.
ILOG, 2005. CPLEX System 9.1 ILOG. Gentilly, France.
Johansson, P., Rydin, H., Thor, G., 2007. Tree age relationships with epiphytic lichen diversity and lichen life history traits on ash in southern Sweden. Ecoscience 14, 81–91.
Juutinen, A., Mantymaa, E., Mönkkönen, M., Salmi, J., 2004. A cost-efficient approach to selecting forest stands for conserving species: a case study from northern Fennoscandia. For. Sci. 50, 527–539.
Kuusinen, M., 1996. Epiphyte flora and diversity on basal trunks of six old-growth forest tree species in southern and middle boreal Finland. Lichenologist 28, 443–463.

Lindenmayer, D.B., Franklin, J.F., 2002. Conserving Forest Biodiversity. A Comprehensive Multiscaled Approach. Island Press, Washington, DC.
Lindenmayer, D.B., Franklin, J.F., Lohmus, A., Baker, S.C., Bauhus, J., Beese, W., Brodie, A., Kiehl, B., Kouki, J., Pastur, G.M., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J., Wayne, A., Gustafsson, L., 2012. A major shift to the retention approach for forestry can help resolve some global forest sustainability issues. Conserv. Lett. 5, 421–431.
Lõhmus, P., Rosenvald, R., Lõhmus, A., 2006. Effectiveness of solitary retention trees for conserving epiphytes: differential short-term responses of bryophytes and lichens. Can. J. For. Res.-Revue Canadienne De Recherche Forestiere 36, 1319–1330.
Lukacs, P.M., Burnham, K.P., Anderson, D.R., 2010. Model selection bias and Freedman's paradox. Ann. Inst. Stat. Math. 62, 117–125.
Lundström, J., Jonsson, F., Perhans, K., Gustafsson, L., 2013. Lichen species richness on retained aspens increases with time since clear-cutting. For. Ecol. Manage. 293, 49–56.
Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.
McDonald-Madden, E., Bode, M., Game, E.T., Grantham, H., Possingham, H.P., 2008. The need for speed: informed land acquisitions for conservation in a dynamic property market. Ecol. Lett. 11, 1169–1177.
Moore, J., Balmford, A., Allnutt, T., Burgess, N., 2004. Integrating costs into conservation planning across Africa. Biol. Conserv. 117, 343–350.
Murdoch, W., Polasky, S., Wilson, K.A., Possingham, H.P., Kareiva, P., Shaw, R., 2007. Maximizing return on investment in conservation. Biol. Conserv. 139, 375–388.
Nelson, C.R., Halpern, C.B., 2005. Edge-related responses of understory plants to aggregated retention harvest in the Pacific northwest. Ecol. Appl. 15, 196–209.
Nitare, J., 2000. Signalarter. Indikatorarter på skyddsvärd skog. Flora över kryptogamer. Swedish Forest Agency, Jönköping.
Perhans, K., Kindstrand, C., Boman, M., Djupström, L.B., Gustafsson, L., Mattsson, L., Schroeder, L.M., Weslien, J., Wikberg, S., 2008. Conservation goals and the relative importance of costs and benefits in reserve selection. Conserv. Biol. 22, 1331–1339.
Perhans, K., Glöde, D., Gilbertsson, J., Persson, A., Gustafsson, L., 2011. Fine-scale conservation planning outside of reserves: cost-effective selection of retention patches at final harvest. Ecol. Econ. 70, 771–777.
Possingham, H.P., Grantham, H., Rondinini, C., 2007. How can you conserve species that have not been found? J. Biogeogr. 34, 758–759.
Ranius, T., Johansson, P., Berg, N., Niklasson, M., 2008. The influence of tree age and microhabitat quality on the occurrence of crustose lichens associated with old oaks. J. Veg. Sci. 19, 653–662.
Rosenvald, R., Lõhmus, A., 2008. For what, when, and where is green-tree retention better than clear-cutting? A review of the biodiversity aspects. Biol. Conserv. 255, 1–15.
Siitonen, J., Martikainen, P., 1994. Occurrence of rare and threatened insects living on decaying populus-tremula – a comparison between finnish and Russian Karelia. Scand. J. For. Res. 9, 185–191.
StatSoft, 2011. STATISTICA (data analysis software system), version 10. <www.statsoft.com>.
Swedish Forest Agency, 2012. Swedish Statistical Yearbook of Forestry. Official Statistics of Sweden. Jönköping.
Thor, G., Johansson, P., Jonsson, M.T., 2010. Lichen diversity and red-listed lichen species relationships with tree species and diameter in wooded meadows. Biodivers. Conserv. 19, 2307–2328.
Vanderwel, M.C., Maicolm, J.R., Mills, S.C., 2007. A meta-analysis of bird responses to uniform partial harvesting across North America. Conserv. Biol. 21, 1230–1240.