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Assessing costs of multifunctional NATURA 2000 management restrictions in continuous cover beech forest management

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Programmes for forest habitat protection and some certification schemes restrict forest owners' choice of regeneration methods, even in continuous-cover systems such as the use of the shelterwood system in beech (*Fagus sylvatica* L.) forests in Denmark. The aim of this study is to reduce environmental pressure on e.g. groundwater or to protect species dependent on deadwood or undisturbed soils, which is beneficial/important from a welfare economic perspective. Such restrictions come at a cost to both the forest owner and society. Using a case study approach, we investigate the possible financial losses from placing such restrictions on current shelterwood beech management practices. A part of the restrictions implies lower input, intensity and costs in regeneration activities, but this is outweighed by potential future losses arising from incomplete regeneration and prolonged regeneration phases. The cost in terms of present value reductions of a mature stand may be up to 10 per cent (with an interest rate of 3 per cent) but in many cases is much less. Another set of restrictions implies leaving single trees for natural aging and decay, and we estimate the costs of such measures too.

Introduction

In Denmark, like in many other countries, there is an increasing focus on near-natural forestry after several decades of intensifying management (Brunet *et al.*, 2012). What the changed management entails may vary depending on location and aim (Larsen and Nielsen 2007). With society's increased interest in ecosystem services produced by forests, such as protection and recharge of groundwater, species preservation or enhanced recreational opportunities (e.g. Lindhjem 2007; Jacobsen and Hanley 2009; Campbell *et al.*, 2013), there is also an increased public interest in how forests and many other land types are managed, as clearly evident in the European Commission's NATURA 2000 initiatives (European Commission 2009) and also in different forest certification schemes of the private sector.

The implementation of NATURA 2000 programme for habitat protection and enhancement will potentially result in agreements on or requests for restrictions on management practices in forest areas with the designated habitat types. Similarly, private sector certification schemes often require that environmentally benign regeneration policies replace the current practices. In such cases, an obvious question is the size of the costs of transforming current forest management regimes into a regime that is believed to be more 'near-natural' or better able to secure and provide the ecosystem services in demand. This is the question addressed in this paper.

Earlier studies of the economic consequences of various forest transformations have mainly focused on larger types of transformation, involving change of tree species and/or structural changes (Jacobsen *et al.*, 2004; Tarp *et al.*, 2005; Schou and Jacobsen 2012) or analysed the economic performance once transformation has taken place (Nord-Larsen *et al.*, 2003) or dealt with specific aspects like risk (Roessiger *et al.*, 2011). Here we study the economics of a less-embracing transformation of beech management in Denmark, which is a set of restrictions on regeneration intensity and the setting aside of individual trees for aging and natural decay. These restrictions resemble the suggested NATURA 2000 restrictions for some beech forest habitats in Denmark and also reflect aspects of the recently revised PEFC certification criteria (PEFC 2011; Naturstyrelsen 2013). We evaluate the economic consequences of such restrictions in terms of present value of net income forgone as a result of incomplete and prolonged regeneration phases, compensatory measures and volume reductions.

Calculi like those considered in this paper can be used for: (1) a forest owner to evaluate the cost of the changed management (a calculus that must be assumed a part of a profit-maximizing business with continuous changes in growth and policy preconditions, as will be the case in forestry due to the long time horizon), (2) a society that wants to assess the cost compared with the potential benefit in terms of non-marketed environmental services and (3) the government to assess the size of compensation for forest owners if such restrictions are forced upon them.

We find that the reduced costs of regeneration activities following from the restrictions are likely to be outweighed by losses arising from likely prolongations, delays and incompleteness of the regeneration phase. Costs may run as high as 10 per cent of the mature stand's present value, which is comparable with costs of leaving 7–8 mature trees for aging and decay.

The models developed are specific to the silvicultural and forest management practice in Denmark and the way Danish shelterwood beech forests typically are managed. Thus, we start by outlining the current practice and the implications of the restrictions in the next section and then follow sections outlining the method applied and the empirical data and models. Results are presented and followed by a concluding discussion of the findings and the approach.

The case: Danish beech shelterwood management

In Denmark, beech covers 13 per cent of the forest area and is the most frequent naturally occurring species (Nord-Larsen *et al.*, 2010) and a natural climax species on most areas. Wherever possible, beech is managed in a shelterwood regime, with a two-storey structure during the first/last 20–30 years of the rotation and a single-storey structure for the remaining years. This system is economically superior to clear-cutting and planting, mainly due to much lower establishing costs, which in planted stands may be as high as 8000 €/hectare.

Nevertheless, even in the shelterwood-managed Danish beech forests, the regeneration phase has intensive aspects for two reasons. Firstly, Danish beech stands are usually fairly small in area, and to enhance diameter growth, they are also thinned frequently, resulting in low stand density. The implication is that any additional light to the forest floor results in a fast spread of grasses and other fierce weeds. Secondly, the population of Roe deer (*Capreolus capreolus*) is very high in the Danish landscape for hunting reasons, and they browse young beech plants all year. Around 100 000 deer are shot every year (Bregnballe 2003). Therefore, it is normally considered necessary to fence regenerations. For these reasons, pesticides and full-area soil preparations are commonly used to reduce the competition from weeds and damage by mice and to secure as complete regeneration as possible (Henriksen 1988; Dansk Skovforening 2003). Similarly, gaps, which form where the ground is wet or where grasses have taken over, are generally re-treated. Alternatively, seedlings of other suitable species are planted to secure a full and complete regeneration, closing the canopy, and reducing damage from light, competition and browsing.

Approximately 9500 ha of beech forests (Danish Nature Agency 2013 pers. com.) are assigned as NATURA 2000 areas (European Commission 2009) with specific interests in habitat quality and preservation. Furthermore, groundwater production is important under the Danish forests. Groundwater wells in forests are as frequent as outside, and the water quality is often higher (Raulund-Rasmussen and Hansen 2003).

In NATURA 2000 beech forest areas, the suggested management change is to reduce the use of soil preparation measures and prohibit the use of pesticides to protect the groundwater and to avoid disturbing and damaging the soil structure, microorganisms and other effects on flora and fauna on the forest floor or in the top soil. With these restrictions, beech would in most cases still regenerate on most of the area, but the stand would often be quite incomplete and below commercially optimal stocking levels. This implies costs in terms of lost production. Countermeasures may be undertaken, such as prolonging the period where the trees of the upper storey are kept in the stand. Thereby, it is possible to reduce competition from weeds and secure a longer period for regeneration to take place. Finally, as for the standard shelterwood system, it is quite common to plant suitable alternative species in gaps forming on, e.g. wet areas (e.g. *Fraxinus excelsior*, *Picea abies* or *Piceas sitchensis*). While in the long run this may lead to an uneven-aged gap structure as in the semi-natural forests in Denmark (Emborg *et al.*, 2000; Larsen 2005), the structural effects for the nearest tree generations will be smaller.

Even with the countermeasures, the overall effect of the restrictions will be to impose costs – either directly as costs for restocking or indirectly as opportunity costs in terms of prolonged rotations of the upper storey (including risks of quality reductions) and delayed establishment of the new stand, with quality reductions around gaps. The present study presents estimates of the possible range of such costs.

An additional measure likely to be implemented in these NATURA 2000 beech forests is the setting aside of single trees for aging and decay, also requested for, e.g. FSC and PEFC certification. Deadwood is an important source for biodiversity (Koskela *et al.*, 2007). We calculate the opportunity cost of this measure.

Table 1 summarizes the main differences between the current and the restricted management practice.

Method

The approach taken is one of the present value maximization. Thus, we assume that a forest owner will do what is economically superior and maximizes the present value (the expectation value (EV)) of his stand. The EV represents the present value of a given stand as the sum of the discounted value of costs and benefits arising from the future production and associated management actions. Consequently, it varies over time as trees grow larger and therefore revenues get closer (see, e.g. Amacher *et al.*, 2009 for further details), so it is important to compare stands at a similar state. Thus, we base calculations on EV of a mature beech stand just before entering the regeneration phase. We compare the maximized EV of this stand with the EV of the stand under the alternative restricted management scheme as follows:

$$L = \mathrm{EV}_t^{\mathrm{UR}} - EV_t^R = \sum\nolimits_{j=t}^{\infty} \frac{B_j^{\mathrm{UR}} - C_j^{\mathrm{UR}}}{(1+r)^{-t}} - \sum\nolimits_{j=t}^{\infty} \frac{B_j^R - C_j^R}{(1+r)^{-t}}. \quad (1)$$

Here, R refers to management with restrictions and UR to management without restrictions. B_t and C_t are the costs and benefits at a point in time t and r is a real interest rate.

As the management is cyclic – it is repeated after a given number of years – EV can be calculated as in the following equation:

$$\mathrm{EV}_t = \frac{\sum_{\tau=0}^{T} (B_\tau - C_\tau)(1+r)^{-\tau}}{1-(1+r)^{-T}}, \quad (2)$$

where T is the period after which the cycle is repeated. In this paper, natural regeneration is initiated at the ages of 90 or 100 years depending on site class (1 or 3, respectively) and the stand is harvested over a period of 20–30 years. So, $t = T = 90$ for site class 1 and $t = T = 100$ for site class 3.

Table 1 Summary of current and likely restricted forest management practice

	Current management	Restricted management
Use of pesticides	Allowed and practised	Not allowed
Soil preparation	Practised on almost all of the forest floor area when regenerated	Only allowed on up to 1/3 of the forest floor area in the stand
Restocking with plants and planting	Rarely needed	Implemented in persistent gaps, with larger plants in low density (2700 plants/ha in gap)
Rotation length (initiation age/final removal of last upper storey trees)	Site class 1: 90/110 years Site class 3: 100/120 years	As current management except in and around gaps (total of 2× gap size): Site class 1: 90 /120 years[1] Site class 3: 100 /130 years[1] Site class 3: 100 /140 years[1]
Leaving trees to natural decay	Hardly practised	Practised

[1]Prolonged rotation will not occur in the entire stand, but only in gaps and their proximity where regeneration is not successful at first instance

A less-intensive regeneration with no use of pesticides and ground preparation may result in gaps in the regeneration. If a gap appears, the holdovers in the upper storey may be kept longer to enhance possibilities for further regeneration. This prolonged rotation will take place in and around the gap. Thus, we assume that the area affected by prolonged rotation is twice the size of the gap and that there may be restocking with planted seedlings in the gap. Often a gap appears because of local variation, e.g. soil or topography, and therefore, we assume that if gaps appear, they will also appear in the next generation.

To calculate EV for a stand with a gap, we assume that in and around the gap, the trees will follow a different regeneration cost and rotation length model. Thus, to calculate EV, we must distinguish between the upper and under storey as well as between inside and outside the gap. p $(0 < p < 1)$ denotes the size of the gap; T_s, the time interval between initiation of regeneration outside the gap and T_g the initiation of regeneration inside the gap; and α_s and α_g are the corresponding periods with two storeys in the stand. Then, EV for the stand can be calculated as in the following equation:

$$
\begin{aligned}
\mathrm{EV}_t = {} & (1-p)\left(\sum_{\tau=0}^{T_s}(B_\tau - C_\tau)(1+r)^{-\tau} + \mathrm{EV}_s(1+r)^{-T_s}\right) \\
& + p\left(\sum_{\tau=0}^{T_g}(B_\tau - C_\tau)(1+r)^{-\tau} + \mathrm{EV}_g(1+r)^{-T_g}\right) \\
& + (1-2p)\sum_{\tau=T_s}^{T_s+\alpha_s}(B_\tau - C_\tau)(1+r)^{-\tau} + 2p\sum_{\tau=T_g}^{T_g+\alpha_g}(B_\tau - C_\tau)(1+r)^{-\tau}.
\end{aligned}
$$

The managerial differences were summarized in Table 1.

Data

We analyse models for beech forests growing according to site classes 1 and 3 (Statens Forstlige Forsøgsvæsen 1990), corresponding to clay-rich soils in the eastern part of the country ranging from very good-to-somewhat poor soil. We used standardized tables for Danish conditions for even-aged stands (Dansk Skovforening 2003). Regeneration is initiated by harvesting 20 percent of the standing volume. This takes place at the ages of 90 (100) years on site class1 (3). Each decade, 30 per cent of the standing volume is removed continuously, and after 20 years, the remaining holdovers are removed. If rotation is prolonged due to incomplete regeneration, the same harvesting model is used.

Regeneration costs are presented in Table 2. Soil preparation is reduced in the models with restrictions to one-third of the area, but because of economies of scale, we assume that the costs per hectare are the same as if the whole area is treated. Fencing is assumed needed to protect the seedlings, although this does not entirely prevent browsing. Extra fencing costs are included in the restricted management, cf. Table 3, because fences are maintained for a longer period. Because game populations are high, this is considered necessary, also in NATURA 2000 areas. Otherwise, the difference is in the costs of pesticides and restocking with planted seedlings in gaps.

Timber prices are based on average prices reported by the Danish Forest Association for July 2008 to July 2009 (Dansk Skovforening 2009). The choice of real discount rate for this analysis is based on the review by Brukas *et al.,* (2000) and analyses made by Thorsen (2010), who find that equilibrium real rates of return are in the range of 1–3 per cent. We apply 3 per cent in most of the analyses and use 1 per cent for sensitivity analyses.

Examples of the resulting economic model and turn-over balances are presented in Appendix.

Results

Table 3 shows various EVs for the part of a stand where the respective management is practised. Depending on the gap occurrence, the EV of a stand will consist of a mixture of these. Results are shown for two site classes just before initiating regeneration, i.e. at the age of 90 years for site class 1 and of 100 years for site class 3. Thus, within each site class, these EVs are comparable as the forest is identical at the ages of 90 and 100, respectively. As restocking in larger gaps is expensive and takes place early in the rotation, it has a relatively larger impact on EV compared with a prolonged rotation.

The potential losses from the management restrictions will depend on the site class, how large an area is affected by gaps and hence needs restocking and how much rotation ages around gaps are prolonged. The effect on EV of varying these three variables is shown in Table 4.

As is seen, the largest loss in absolute terms occurs on better soil (site class 1), but in relative terms, the loss is potentially larger on

Table 2 Costs of regeneration

Without restrictions/ with restrictions outside gaps/ with restrictions in gaps				
Age, years	0	1–9	10–19	
Plants+ planting			0/0/29 700[1]	
Pesticide	1095/0/0	1095/0/0		
Clearing	1642			
Soil preparation	3831			
Fence	12 405			
Fence repair		973	0/0/973	
Fence removal			2919	
Clearing in track systems		2736		
Precommercial thinning			5777	
Total	18 972	4804	8695	32 471/30 282/60 955

DKK/hectare (DKK 7.5 ∼ €1)
[1]The costs of plants and planting only occur in the gap. Thus, if there is a 20% gap per hectare, 0.2 × 29 700 DKK is spent.

Table 3 EVs (DKK/hectare) for the part of a stand with the respective management regimes

Site class 1. EV at age 0/90, before activity	
Without restrictions, rotation 90–110	1 57 034
With restrictions, no restocking, rotation 90–110	1 59 226
With restrictions, restocking, rotation 90–110	1 38 058
With restrictions, no restocking, rotation 90–120	1 54 106
With restrictions, restocking, rotation 90–120	1 32 938
Site class 3. EV at age 0/100, before activity	
Without restrictions, rotation 100–120	85 496
With restrictions, no restocking, rotation 100–120	87 647
With restrictions, restocking, rotation 100–120	66 878
With restrictions, no restocking, rotation 100–130	86 268
With restrictions, restocking, rotation 100–130	65 499
With restrictions, no restocking, rotation 100–140	84 568
With restrictions, restocking, rotation 100–140	63 800

The EV of a stand is a combination of these, cf. Tables 4 and 5. Age *x/y* refers to the age of the under and upper storey, respectively (DKK 7.5 ∼ €1).

poor soil and increasing to more than 10 per cent for site class 3 when a further prolongation of the rotation age (20 years instead of 10) is implemented.

In the calculations mentioned earlier, we have used an interest rate of 3 per cent, which is considered an upper-end equilibrium return rate for private investors (Brukas *et al.,* 2000; Thorsen 2010). Table 5 shows the results for an interest rate of 1 per cent, which is a lower-end estimate of the equilibrium rate of return for Danish forest enterprises (Thorsen 2010). It shows that the loss is largest in both absolute and relative terms on good soils, whereas it is negative on poor soils. The latter is because the optimal rotation age is longer for the low interest rate, and therefore a rotation age of 100/120 years is not optimal according to the model. The reason why we still choose to operate with this rotation age is to reflect current practice, which also suggests that for these forests, a discount rate of 1 per cent is considered too low by practice.

In current forest management, gaps are filled to secure productivity. However, if a gap forest structure is the aim per se, and if we assume that in due time sufficient regeneration appears in the gap with no losses from economies of scale, from decreased quality of the new stand or from decreased or delayed total production, then the costly restocking with large seedlings may not be needed, and perhaps only prolonged rotations may be needed as a countermeasure. Table 6 shows the EVs and losses corresponding to Table 4, but with no restocking cost, i.e. only the benefit of reduced cost of pesticides and the cost of prolonged rotation are included. It is seen that under these optimistic assumptions, we find aggregate costs only in stands with larger gaps. A gap often appears due to variations in soil conditions or competition from weeds. Practical experience shows that restocking is necessary in larger gaps to secure sufficiently good regeneration (cf. also Henriksen 1988). Therefore, even if a gap structure is pursued, some restocking in large gaps may be needed, in which case the result may be somewhere between those presented in Tables 4 and 6.

Finally, we present the cost estimates of leaving individual trees for natural decay. There is usually no biological reason for picking the commercially most valuable trees in a stand. Therefore, the selected trees often have low economic value (e.g. for fuel wood or industrial uses). The cost of leaving them for natural decay thus consists of the lost value of the wood as well as the opportunity cost of the area that they occupy. Table 7 presents results for various tree sizes, qualities and site classes. A tree of 55 cm in DBH (4.5 m^3) on site class 1 of fuel wood quality represents a net income of approximately DKK 1000. On top of this comes the soil EV of the land it occupies (cf. Koskela *et al.,* 2007), which in this case is DKK 289 with an interest rate of 3 per cent. Thus, the total loss would be DKK 1289 per tree left for natural decay. We note that typically regulations and certification schemes ask for up to 5 trees left per hectare.

Conclusion

This paper has illustrated the potential range of economic consequences for a forest owner who is requested to use less-intensive regeneration in beech managed under shelterwood, e.g. in the context

Table 4 EVs and loss (L) for incomplete stands with different gap sizes, for a real interest rate of 3%

Percentage gap in the stand	0%	10%	20%	30%	40%
Site class 1, 10 years prolongation and restocking in gap					
EV(0/90)	157 034	156 121	153 016	149 911	146 806
L (0/90)	0	913	4018	7123	10 228
Site class 3, 10 years prolongation and restocking in gap					
EV(0/100)	85 496	85 301	82 956	80 610	78 265
L (0/100)	0	195	2540	4886	7231
Site class 3, 20 years prolongation and restocking in gap					
EV(0/100)	85 496	84 970	82 294	79 617	76 941
L (0/100)	0	526	3202	5879	8555

Numbers in parenthesis refer to the age of the lower and upper storey, respectively (DKK 7.5 ∼ €1).

Table 5 EVs and loss (L) for incomplete stands with different gap sizes, for a real interest rate of 1%

	0%	10%	20%	30%	40%
Site class 1, 10 years prolongation and restocking in gap					
EV(0/90)	375 800	377 092	374 774	372 456	370 137
L (0/90)	0	−1292	1026	3344	5662
Site class 3, 10 years prolongation and restocking in gap					
EV(0/100)	204 004	205 562	203 732	201 901	200 071
L (0/100)	0	−1558	272	2103	3933
Site class 3, 20 years prolongation and restocking in gap					
EV(0/100)	204 004	207 105	206 816	206 528	206 239
L (0/100)	0	−3100	−2812	−2524	−2235

Numbers in parenthesis refer to the age of the lower and upper storey, respectively (DKK 7.5 ∼ €1).

Table 6 EVs and loss (L) for incomplete stands with different gap sizes, for a real interest rate of 3% and no cost of restocking

	0%	10%	20%	30%	40%
Site class 1, 10 years prolongation and restocking in gap					
EV(0/90)	157 034	158 170	157 115	156 060	155 004
L (0/90)	0	−1137	-81	974	2029
Site class 3, 10 years prolongation and restocking in gap					
EV(0/100)	85 496	87 312	86 978	86 643	86 309
L (0/100)	0	−1816	−1482	−1147	−813
Site class 3, 20 years prolongation and restocking in gap					
EV(0/100)	85 496	86 981	86 316	85 650	84 985
L (0/100)	0	−1485	−820	−154	511

Numbers in parenthesis refer to the age of the lower and upper storey, respectively (DKK 7.5 ∼ €1).

Table 7 The cost of leaving a tree for natural aging and decay, inclusive of lost value of the land occupied

Diameter (cm)	Site class1		Site class 3	
	Flooring/fuel wood	C-log	Flooring/fuel wood	C-log
55	1289	1496		
50	1209	1368		
45	927	1049	696	788
40	710	804	575	641
35	529	598	415	463
30	393	445	291	325
25			198	221

DKK/tree for varying diameter and site class (DKK 7.5 ∼ €1).

of a NATURA 2000 regulation or a certification scheme. We show that for a real long-term interest rate of 3 per cent, he may lose up to 10 per cent of the EV calculated just before regeneration is initiated on the best soils, but it depends a lot on the size of gaps generated and the compensatory measures employed. On the better soils, regeneration is typically established easily, but at the same time, competition from weeds as well as deer browsing can be massive, so the restriction of no pesticides and reduced soil preparation may have large impacts. Thus, our results here suggest that implications of e.g. NATURA 2000 restrictions or similar are likely not to be trivial for the affected forest owners.

One assumption in the paper is that it is necessary to fence regenerations a long period due to large roe deer populations. It could be argued that such large populations are not required in NATURA 2000 areas and could therefore be reduced in order to reduce regeneration costs. However, hunting constitutes a large income source for forest owners (Lundhede *et al.*, 2009, Meilby *et al.*, 2006). Thus, the forest owner will face a loss if he has to reduce the game population. Furthermore, even if he decided to, it may not be possible to solve the problem due to migration (except for very large forest properties). Therefore, we have decided to keep possible game population changes out of the present analysis. In areas where fencing is not necessary, the cost of implementing NATURA 2000 would therefore be smaller.

Another case-specific assumption that may vary is that the forests analysed are heavily thinned to increase diameter growth, at least compared with what is found in e.g. Germany. The economic consequences of changing thinning practise too is not analysed here and may be ambiguous.

We calculated EV_{90} and EV_{100}, that is, the present value just before initiating the regeneration, because at this point in time the forest would be in the same state regardless of what the treatment would be from there. This means that the consequences of the changed management (e.g. prolonging the final harvest from 20 to 30 years and undertaking more expensive regeneration costs) weigh relatively much compared with stands of a younger age (where the final harvest would lie further into the future). This is an artefact of the use of EV and may have importance for calculus of the size of current compensation to forest owners, which should be taken into account when the restrictions will result in losses.

This example shows a small management change into a silvicultural regime, which is relatively well known. Often when discussing forest transformation, much larger changes are fathomed, and also often into management regimes that are not well known. The same kind of calculus can be applied – taking adequately into account the uncertain outcome of the management, e.g. by the use of Bayesian updating calculus (Yousefpour *et al.,* 2012) in spanning decision trees.

In the calculi, we have assumed that the forest will be managed as a semi-even-aged stand, only having a two-storeyed structure for a given amount of years. We have also assumed that the occurrence of gaps will be the same in the future rotations. The reason for this assumption is that gaps often occur due to specific growth conditions, which will remain the same. It is possible that forcing the forest into a single-storey structure will not be followed in the future, e.g. because a gap structure may provide other benefits too (e.g. recreational benefits, see Nielsen *et al.,* 2007), or because it is more profitable (see also Nord-Larsen *et al.,* 2003 for a discussion hereof) or an advanced system or target diameter harvesting proves superior (Meilby and Nord-Larsen 2012). While this is relevant to study, it is outside the scope of this paper, where we wanted to focus on small changes, likely to be implemented faster and on a larger scale due to current policy developments.

If we look at these calculi from a welfare economic perspective, we may consider using the results from the 1 per cent interest rate scenario to reflect a social discount rate (Hanley and Barbier 2009). The relevant question is whether these costs are lower than the benefits we may obtain. We have deliberately made no attempts to assess that in the above but briefly offer some considerations here. As we assume no structural changes in the forest stand, there will most likely be no or little effects on recreational aspects (Nielsen *et al.,* 2007). Jensen and Skovsgaard (2009) find thinning intensity to affect the recreational value positively in oak (*Quercus robur*), indicating that if in the longer run a multi-layered forest structure is created with lower trans-visibility, an effect may arise.

Groundwater produced under broadleaved forests is usually of high quality. The restrictions here are unlikely to affect the quantity of groundwater recharge under the relevant forest areas. However, the prohibition of pesticide use may reduce the risk of groundwater pollution. Hasler *et al.,* (2007) estimated willingness-to-pay (WTP) for securing clean groundwater for drinking water to be 900–1900 DKK/household/year. However, because pesticides are used so fairly infrequently in forest management (in our model, just a couple of years over a century), the risk reductions are likely to be of little value.

Related to biodiversity, 54 per cent of the red-listed species in Denmark live in forest areas (Stoltze and Pihl 1998), and they may benefit from enhanced levels of deadwood and lower impact forestry. The benefits may be minor if the changes only occur on small areas, but because we analyse changes that are likely to be implemented on a larger scale (NATURA 2000), the impacts may be important. It would be futile to start here guessing the changed survival probability for any number of species resulting from the management changes analysed. However, we may illustrate the scale of the potential benefits *if* survival of a number of species is secured. Campbell *et al.* (2013) found a WTP of ~1200 DKK/household/year to secure the survival of 100 species currently endangered in Danish deciduous forests. With ~2.5 million households in Denmark, this sums to considerable amounts even with all the appropriate assumptions and a smaller number of species saved.

Such benefit estimates, across the range of ecosystem services demanded from the multifunctional beech forest areas, have to be weighed against the costs of the required number of trees left for natural decay, and the costs of reduced forest productivity and prolonged rotations. Furthermore, they should be informed by assessments of the actual benefits to biodiversity from the new forest structure and deadwood levels, as well as, e.g. risk assessment related to groundwater production.

The forest owner will in general not benefit from the restrictions targeting the enhanced provision of ecosystem services from the multifunctional forest regimes – except for possible personal satisfaction and altruistic motive he may have. Therefore, it is no surprise that compensation schemes for forest owners are under development in Denmark as well as in many other European countries directed at the private losses. In this context, calculations as those presented in this paper are useful as a starting point for an informed policy process.

Conflict of interest statement

None declared.

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Appendix. Examples of cash flow and present value sheets for site classes 1 and 3

Cash flows and their present values are shown across the *age* of the trees in the stand. (DKK/hectare).Thus, e.g. for the scheme with regeneration initiating at *time* 0 (upper storey is age 90), the cash flow is the sum of flows at the ages of 0 and 90. This explains the discounting periods from the age of 90 and up (DKK 7.5 ~ €1) (Tables A1 and A2).

Table A1 Soil class 1: natural regeneration in rotation 90–110/90–120

Numbers in parenthesis are extra cost if restocking, numbers in squared brackets are without any restrictions

Age of trees	0	0–10	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90	90–99	00–109	110	110–119	120
Establishment cost	17 877 [18 972]	3709 [4804]	8695 (39 368)	0												
Volume (m^3)			6	29	72	73	73	74	72	68	86	123	105	276/0	0/92	0/242
Diameter (cm)			6	9	13	18	24	28	33	37	44	47	52	55/0	0/57	0/59
Stumpage price (DKK/m^3)			59	104	141	178	213	240	273	300	352	369	393	397/0	0/395	0/387
Income	−17 877 [−18 972]	−3709 [−4804]	−8340/−39 013	3025	10 165	13 007	15 540	17 779	19 667	20 382	30 178	45 362	41 374	109 640/0	0/36 191	0/93 834
Discounting period	0	5	15	25	35	45	55	65	75	85	0	5	15	20	25	30
Present value	−17 877 [18 972]	−3200 [4144]	−5353/−25 041	1445	3613	3439	3058	2603	2143	1652	30 178	39 129	26 556	60 705/0	0/17 285	0/38 658

Table A2 Soil class 3: natural regeneration in rotation 100–120/100–130/100–140

Numbers in parenthesis are extra cost if restocking, numbers in squared brackets are without any restrictions

Age of trees	0	0–10	10–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	100	100–110	110–120	120	120–129	130	130–139	140
Establishment cost	17 877 [18 972]	3709 [4804]	8695 (39 368)	0															
Volume (m^3)				12	31	38	45	45	44	45	52	61	88	75	197	0/66/66	0/175/0	0/0/59	0/0157
Diameter (cm)				6	9	13	17	20	24	28	32	37	39	44	50	50	56	56	59
Stumpage price (DKK/m^3)				70	105	141	172	193	215	238	263	299	316	352	386	0/387/387	0/397/0	0/0/397	0/0/390
Income	−17 877 [−18 972]	−3709 [−4804]	−8695 (−39 368)	845	3268	5365	7750	8673	9447	10 725	13 664	18 120	27 665	26 544	76 256	0/25 594/25 594	0/69 639/0	0/0/23 393	0/0/61 215
Discounting period	0	5	15	25	35	45	55	65	75	85	95	0	5	15	20	25	30	35	40
Present value	−17 877 [18 972]	−3200 [4144]	−5581 (−25 269)	404	1161	1419	1525	1270	1029	869	824	18 120	23 864	17 038	42 221	0/12 224/12 224	0/28 690/0	0/0/8314	0/0/18 766