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Compensation payments for alternative forest management supporting nature conservation – a case study based on SIBYLA tree growth simulator and silvicultural cost model

Kompensationszahlungen für alternative Waldbewirtschaftung zur Unterstützung des Naturschutzes - Eine Fallstudie basierend auf dem SIBYLA Baumwachstumssimulator und einem waldbaulichen Kostenmodell

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Summary

Compensation payments can allow or support nature protection instead of conventional forest management. The Forest Act of Slovakia enables agreement about compensation payments for special purpose forest management. Four management options were simulated for individual stands forming the Great Polom Nature Reserve

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and its buffer zone in northwest Slovakia. Compensation payments were estimated for change from management option "Conventional Management" towards "Alternative Management" meaning transition to selection forests, special "Forest Reserve Management" combining reserve and buffer zones, and "No Management" as a control reflecting just natural processes. Financial single net cash flows of different types of cutting operations was estimated with the single-tree simulator Sibyla. The study integrates a financial silvicultural model for simulation of stand establishment and young stand development including costs for planting and tending. When all stand generations in the study region were considered, afforestation and tending costs reduced compensation payments for managed options compared to the unmanaged option. Assumption for calculation of compensation payment considered only stand generations which were existing at the beginning of the contract period while following generation of young stands regenerated during this period were excluded from the financial calculation. The contract period comprised 45 years. In relation to "Conventional Management", compensation payment was 25 €/ha/year for "Alternative Management" towards selection forest, 70 €/ha/year for change to special "Forest Reserve Management" and 129 €/ha/year for change to "No Management". Only long contract periods enable objective estimation of financial differences between conventional management and alternative opportunities, because short term results were biased by specific developments related to age structure of mature stands. When the contract period is much shorter than rotation, afforestation and tending should not to be carried out to avoid costs, because income from such investments could not be achieved within the contract period. Only cycles of one stand rotation will substantially change age and size structure and therefore can support nature protection.

Zusammenfassung

Eine Kompensationszahlung kann Naturschutz anstelle von konventioneller Forstwirtschaft erlauben oder unterstützen. Das slowakische Forstgesetz ermöglicht eine Vereinbarung über Kompensationszahlungen für eine Forstwirtschaft für spezielle Zwecke. Vier Bewirtschaftungsoptionen wurden für individuelle Bestände simuliert, die das Naturreservat Groß Polom und seine Pufferzone im Nord-Westen der Slowakei bilden. Kompensationszahlungen wurden für den Wechsel von der Bewirtschaftungsoption "Konventionelle Bewirtschaftung" hin zu "Alternative Bewirtschaftung" mit einem Übergang zu einer Einzelbaumnutzung, hin zu einer speziellen "Bewirtschaftung für ein Forstreservat" mit einer Kombination aus Reservat und Pufferzone, und hin zu "Keiner Bewirtschaftung" als Kontrolle mit Berücksichtigung nur natürlicher Prozesse ermittelt. Die Bestimmung der einzelnen finanziellen Netto-Zahlungsströme für die unterschiedlichen Arten der Erntemaßnahmen wurde mit dem Einzelbaumwachstumssimulator Sibyla ausgeführt. Die Studie beinhaltet ein finanzielles waldbauliches Modell für die Simulation der Bestandesbegründung und der Entwicklung des jungen Bestandes einschließlich der Kosten für Pflanzung und Pflege. Wenn alle Bestandesge-

nerationen in der Studienregion berücksichtigt wurden, dann reduzierten die Kosten für Aufforstung und Pflege die Kompensationszahlungen für die bewirtschafteten Optionen im Vergleich zur unbewirtschafteten Option. Die Annahme für die Berechnung der Kompensationszahlungen berücksichtigte nur Bestandesgenerationen welche am Anfang der Vertragsperiode existierten wohingegen die nachfolgende Generationen von jungen Beständen, die während dieser Periode verjüngt wurden, von der finanziellen Berechnung ausgeschlossen wurden. Die Vertragslaufzeit umfasste 45 Jahre. Die Kompensationszahlungen betrugen in Relation zu "Konventionelle Bewirtschaftung" 25 €/ha/Jahr für einen Wechsel zu "Alternativer Bewirtschaftung" im Sinne selektiver Bewirtschaftung, 70 €/ha/Jahr für einen Wechsel zu einer speziellen "Bewirtschaftung für ein Forstreservat", und 129 €/ha/Jahr für einen Wechsel zu "Keine Bewirtschaftung". Nur lange Vertragslaufzeiten ermöglichen eine objektive Bestimmung von finanziellen Differenzen zwischen konventioneller Bewirtschaftung und alternativen Möglichkeiten da in kurzer Zeit die Ergebnisse durch spezifische Entwicklungen verbunden mit der Altersstruktur der ausgereiften Bestände beeinflusst wurden. Wenn die Vertragslaufzeit deutlich kürzer als die Umtriebszeit ist, dann kann die Berechnung Aufforstung und Pflege als nicht ausgeführt berücksichtigen um die Kosten zu vermeiden falls der Mittelrückfluss aus einer solchen Investition nicht innerhalb der Vertragslaufzeit erreicht werden kann. Nur ein langer Zeitraum von einer Bestandesgeneration wird deutlich die Alters- und Größenstruktur verändern und kann so den Naturschutz unterstützen.

1. Introduction

1.1. State of compensation payments for Ecosystem Services

Compensation payments can allow or support nature protection instead of conventional forest management. It opens opportunities for management change when no constraint or prohibition of management should be forced by legislation. Implementation of compensation payments in the sense of trading among property rights and usage rights is only possible when those rights are clearly defined and allocated and there is the possibility for contracts (Coase 1960; Herbert et al., 2010). Individual contracts enable joined benefits for all partners (Hayes et al., 2015) because they allow for individual solutions rather than general anonymous policy instruments implemented by law or demands by interest groups which typically allocate costs only to forest owners (Hahn and Schall, 2013). Another option is to change ownership or forest management to ensure responsibility of the forest area, but in this case the long-time experience and knowledge of the forest owner or forest managers is sacrificed.

Different approaches to estimate the value of ecosystem services exist. Costanza et al. (1997) estimated a value of ecosystem services for different types of ecosystems. Based on an approach of market equilibrium dependent on demand and supply, Zhang and Stenger (2014) demonstrated that results of Costanza et al. (1997) represent "Willingness to pay" on the side of demand but are too high to represent a market volume. Approaches to calculate financial differences between management options and define them as compensation payments represent opportunity costs of supply. Therefore, only the difference in financial value between the ecological and the conventional option can be defined as additional ecosystem service levels compared to conventional options (Wunder, 2005). Often contracts about compensation payments for conservation will be individual agreements, because few markets with prices exist, such as when the supply for ecosystem services is low for a rare and endangered species (Wunder, 2005).

Nevertheless, markets for ecosystem services are evolving. Payments for Ecosystem Services (PES) are used most often in developing countries in the tropics of Asia and South America (Wunder, 2005), but only rarely in Europe. PES can be categorized as a public payment to private land owners (either standardized or individual), formal markets with open trading (regulatory by legislation or voluntary), self-organized private, tax incentives or certification programs (Herbert et al., 2010).

Markets are most developed for carbon pricing to mitigate climate change, with an estimated value of 100 billion US$ in 2008 (Stanton et al., 2010), with only a small portion attributed to forests (Goldstein, 2015). Important markets exist also for water quality protection (9 billion US$ in 2008) (Stanton et al., 2010) and biodiversity (2 to 3 billion US$ annually) (Madsen et al., 2010). Both are related to forestry and characterized by small voluntary markets, but the numbers are rough estimations because the markets are not transparent.

Buyers in forest carbon markets and finance were mainly from Europe and North America and mainly paid in voluntary markets but some also participated in compliance markets (Peters-Stanley et al., 2013). Regional programs for Reduced Emissions from Deforestation and Forest Degradation (REDD), initiated by donor governments, are important activities in Latin America and Africa (Peters-Stanley et al., 2013). Fifty percent of forestry projects were carried out on private lands in 2012 (Peters-Stanley et al., 2013). The majority of market share was certification by Verified Carbon Standard (Peters-Stanley et al., 2013, Goldstein, 2015). In 2014, 700 million US$ related to carbon storage in forests were paid: 260 million US$ were market-based payments, 220 million US$ were non-market-based payments (from government to government), and 230 million US$ were paid within REDD (Goldstein, 2015).

Currently Payments for Watershed Ecosystem Services are typically small-scaled local projects common globally (Stanton et al., 2010). Nowadays real established markets for Watershed Services have the highest practical relevance in the Peoples Republic of China (Zhang et al., 2010; Stanton et al., 2010). Payments in China especially improve water quality by supporting farmers to establish trees on slopes which are characterized by soil erosion (Stanton et al., 2010). Mechanisms to pay are calculated dependent on measured change in water quality standards regarding nitrogen, phosphorus, salinity or temperature. So-called Water Quality Trading exists primarily in the United States (Stanton et al., 2010).

Various schemes for Payments for Biodiversity Services exist or are currently being developed in many countries. Compensatory Mitigation Programs can be classified as Compensation Funds, One-Off Offsets and Mitigation Banking (Madsen et al., 2010). Most advanced markets are in the United States. There, in cases in which developers threaten or endanger species, they have to compensate for their damage, for example, by buying third party credits within Conservation Banking Credit Pricing to protect endangered species elsewhere. Additionally, offset programs exist for wetland mitigation (Madsen et al., 2010). In Europe there is still need to develop programs. Especially within the European Union there are efforts to implement trading systems for biodiversity (habitat banking). The German Program for Impact Mitigation Regulation is largest in Europe, law requires restoration and replacement compensation when impact cannot be avoided (Madsen et al., 2010).

The relevance of compensation payments might increase not only for nature conservation, but also due to increased rates of land use change. For instance, the rate of land use change in Germany is 81 ha per day. It is associated mainly with agricultural land being converted to settlement and traffic purposes, nature protection laws stipulating the need for compensation (BMEL, 2014). Conversely, in developing countries especially in tropical regions there are high losses of forest cover due to conversion into agricultural land (Goldstein, 2015, Kindu et al. 2016). Policy instruments of taxes, unconditional grants or subsides (Herbert et al., 2010) are used to influence market equilibrium. Nevertheless they often lead to unwanted side effects because people might try to reach benefits by other means than those intended (Nürnberger et al., 2013). Therefore, defined goals like the rule of "no net loss" regarding the initial state used for example in the German Impact Mitigation Regulation (Madsen et al., 2010) aims to avoid such shifts. On the global level, nature conservation or bio-economy (in terms of renewable energy) policy must consider the effects of policy instruments on land use change. Instruments might reduce employment patterns and consequently reduce access to sufficient and healthy food, human rights and social standards (BMEL, 2014). Nature protection for biodiversity in a forest will lead to reductions in managed forest area, employment in the forest sector, the amount of harvested timber and trigger an increase in timber prices. Nature conservation and biodiversity protection can conflict with the goal of carbon sequestration as well as the production of renewable energy. Such goal conflicts have to be considered in policy frameworks (BMEL, 2014) as well as by management planning. Therefore, from the forest owner point of view, compensation payments might resolve conflicts over optimal forest management regarding ecological and socioeconomic aspects in opposition to "Conventional management" or financially optimal management. In this study only the forest owners' point of view based on the concept of opportunity costs will be applied, while the concept of "Willingness to pay" will not be considered.

1.2. Legal framework of the common and special forest management in Slovakia

Under the Slovak Forest Act 326/2005 (hereinafter the Act), common forest management is such a way of reforestation, thinning, harvesting, wood transport and other forest management options, which permits in accordance with the principles of sustainable forest management the rational exploitation of all functions of the forest. In fact it is a proposal of management options in forest management plans (targeted primarily at wood production) before applying a special management regime (§ 14 para. 1). The special management regime is defined indirectly in § 14 para. 1: Special purpose forests are forests that have been declared as such and whose purpose is to ensure the specific needs of society, legal entities or persons, and the provision of which significantly changes the way of management compared to common forest management (hereinafter referred to as "special management regime"). The concept of the special management regime is to be prepared by a person licensed for forest management planning or by a professionally qualified member of a nature protection organization in case the special purpose is nature conservation (§ 14 para. 2e of the Act).

If the application for a declaration of special purpose forests is submitted by a person other than the forest owner, the application must include the consent of the owner or forest user with a statement of special purpose forests, and an agreement on determining the amount and nature of compensation for restricting property rights (§ 35 paragraph. 3) due to the special management regime. Compensation for the restriction of property rights is granted on the basis of an agreement determining the rates and the manner of its provision, proposed to the owner or forest user by the person, whose request or proposal limits property rights. If no agreement is reached, the amount or method of providing compensation for restrictions of ownership rights according the Act is determined by the Court (Kulla et al., 2015). The aim of this study is to examine a quantitative approach for calculation of opportunity cost which corresponds to compensation for nature protection by nature conservation (e.g. by state) to the forest owner.

2. Material and Method

2.1. Model territory and management options

The model territory, selected within the “Research Demonstration Area Kysuce”, part Polom (114 ha, 828-1066 m.a.s.l., hereinafter model territory) in northwest Slovakia (Fig. 1), represents a strictly protected forest reserve and adjacent buffer zone with a different degree of forest management restrictions. Forests are dominated by mature even-aged structures, 96% are spruce stands, 52% are more than 85 years old. Several types of management treatments “Shelterwood”, “Clearcut”, “Transition to Selection” and “No Cutting” were simulated for individual stands. Management options of “Conventional Management” (CM), “Alternative Management” (AM), “Forest Reserve

Management" (FRM) and "No Management" (NM) consisted of these stand treatments (Fig. 2).

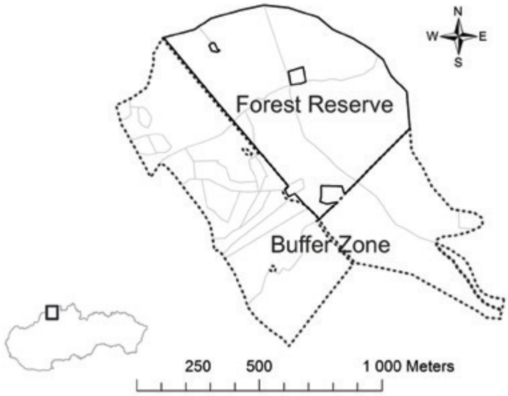

Figure 1: Forest reserve and buffer zone stands in the model territory

Abbildung 1: Bestände des Waldreservates und der Pufferzone im Modellgebiet

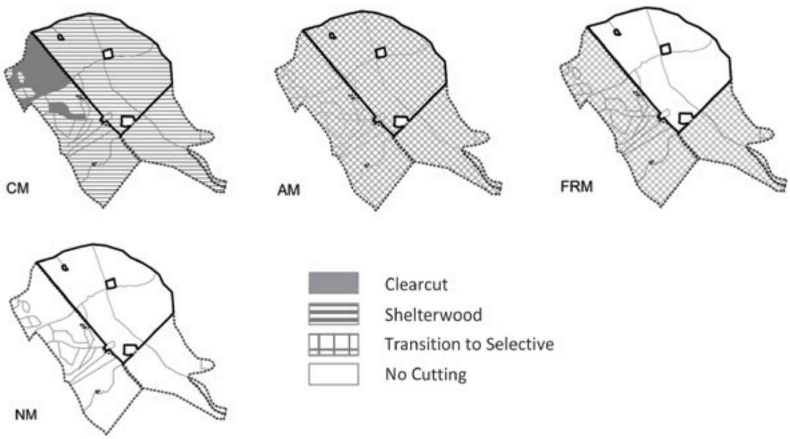

Figure 2: Management treatments according to management options applied for simulations in the model territory

Abbildung 2: Waldbehandlung entsprechend den in den Simulationen angewendeten Bewirtschaftungsoptionen im Modellgebiet

The management program for CM, which is implemented by state approved standard forest management models (FMM) without any restrictions, was applied to all stands as a reference base. The most common CMs in Slovakia are the shelterwood system with application of 2-3 phase shelter cuts, and clear-cut system in specific conditions, both with rotation period of ca 100 – 120 years and most common regeneration period 30 – 40 years. In the model territory, according to FMM shelterwood treatment prevails (102 ha) with only a few stands allowed for clearcut (12 ha). The special management regime, (in our study AM) differs substantially from CM based on approved FMM for given site and stand conditions. The most common special management in Slovakia related to nature protection represents a different level of restrictions from "no management" to "close to nature" forms of management expected to be applied in NATURA 2000 sites. For the purpose of this study, AM "Transition to selection" treatment was applied for all model territory. FRM management option combines treatment "Transition to selection" within buffer zone (67 ha) with "No cutting" within the core part of the forest reserve (47 ha). Additionally, an extreme variant of NM was implemented for the whole model territory to show the development of the forest in case of a total stop of management. Compensation payments were calculated for change from conventional management option CM towards the other management options AM, FRM and NM.

2.2. Financial calculation of compensation payments

Compensation payments were calculated as the difference between annualized net present values (NPV) for management alternatives of different lengths of contract periods (Faustmann, 1849). NPV is calculated as the sum of discounted net cash flows NCFs for each stand age t during rotation period T (Equation 1).

Equation 1:

$$NPV = \sum_{t=0}^{T} NCF_t/(1+i)^t$$

Stands already existed in the model region and, therefore, simulations started with current stand ages t. Therefore, method adapted by holding value (Deegen et al., 2000) was a more appropriate method than *NPV*, because the predefined maximum simulation time *z* of 45 years is too short to cover one complete rotation period *T*. Therefore, adapted method is not able to decide if investment would be beneficial. Additionally, no rotation period *T* exists for *AM* and *NM*, which is needed for accurate *NPV* calculation. For the purposes of this study, adaptation of holding value was used as a concept for an age independent *NPV (AINPV)* also allowing for calculation in case of unknown stand age. *AINPV* was used for the simulation time span of contract period z only rather than *T* and the simulation year *s* instead of a stand age *t*. Instead of expectation value, *AINPV* calculation considers the difference of discounted net stumpage value of the remaining stand (*NVRS*) between final simulation year of contract period *z* minus starting year 0. Additionally, the *AINPV* calculation considered the sum of discounted single *NCF* from the *NPV* approach (Equation 2). Such a concept is a wider interpretation of *NPV* defined by Klemperer (1996) and was applied for uneven-aged forests (e.g. Roessiger et al. 2016). The interest rate used for calculations was 2% which is relatively low but typical for Central European conditions characterized by low growth rates and management restriction by law (e.g. Roessiger et al. 2011, 2013, 2016). *NCF* of all cutting operations was calculated for each stand or its subunit (regeneration unit, *RU*). Hence finite compensation payment (*CP*) corresponds to the sum of discounted differences in *AINPV* between management options for all stands during the defined contract period from simulation year *s* = 0 to *z* (Equation 3).

Equation 2:

$$AINPV = \sum_{s=0}^{z} NCF_s/(1+i)^s - NVRS_0 + NVRS_z/(1+i)^z$$

Equation 3:

$$CP_z = AINPV_{CM,z} - AINPV_{AM,z}$$

Soil expectation value can be converted to an annuity (*ANN*) (Möhring et al., 2006) (Equation 4). *ANN* describes the mean annual payment over longer time periods. Therewith, annuity is a helpful indicator to compare options with different rotation lengths (Heidingsfelder and Knoke, 2004), and was applied in this study. For the purpose of this study we applied in equation 4 *z* instead of *T*.

Equation 4:

$$ANN = AINPV \cdot \frac{(1+i)^z}{(1+i)^z - 1} \cdot i$$

2.3. Combination of two models for financial evaluation

Estimating the financial values of stand development was split and evaluated within two systems (Kulla et al., 2015): The stand establishment phase, pruning and tending of young stands, was assessed within the newly developed silvicultural cost models

(Kovalčík and Kulla, 2015). Growth of older forest, including specific thinning and cutting operations, was simulated with a single-tree simulator Sibyla (Fabrika, 2005; Fabrika and Ďurský, 2005), which was developed from the Silva simulator (Pretzsch et al., 2002). Only thinning and final harvest period were generated and simulated in Sibyla because of its limitations in calculating costs and revenues in stages less than 7 cm diameter at breast height (dbh). Simulation of a point of time of natural regeneration in Sibyla is calculated with the help of random coefficients and therefore does not allow for reproduction within a deterministic approach. Because of these two reasons, young stand establishment and tending period up to this age are skipped in Sibyla; a new stand is generated at initial thinning age only.

The decision of when to change between the two models was the timing of the first thinning. Initial thinning age (*Ai*) was defined as the age at which mean dbh of the tree species in given conditions expressed by site index (*SI*) reaches 10 cm (Halaj and Petráš, 1998). In mixed stands, species proportions were considered. Finally *Ai* was classified in 5 year increments to comply with simulation periods of Sibyla (Equation 5, Table 1).

Equation 5:

$$Ai = a \cdot SI^{b}$$

Table 1: Coefficients to estimate initial thinning age (Ai)

Tabelle 1: Koeffizienten zur Bestimmung des Alters der ersten Durchforstung (*Ai*)

Main tree species	a	b
Spruce	1339.2	-1.07
Fir	1000.8	-0.98
Pine	761.27	-0.954
Oak	454.93	-0.789
Beech	517.13	-0.780

The starting year of simulation for stands older than the initial thinning age (*Ai*) was the first year of the contract period. Simulation started for newly established stands or stands less than *Ai* at the point at which they reached *Ai*.

2.4. Site and growth conditions in Sibyla

Growth characteristics, especially *SI*, were calibrated within Sibyla Localizer by stand characteristics from FMP including forest ecoregion, altitude, aspect, slope and forest site type. *SI* of stands was calculated by Sibyla based on climate, site and soil coefficients (Fabrika, 2005). In the case of differences between *SI* calculated by Sibyla and *SI* defined by *FMP*, conditions in Sibyla were adjusted to fit *SI* according to FMP.

2.5. Generation of already existing older forest stands within single-tree simulator Sibyla

Generation was at the beginning of simulation for existing stands older than initial thinning age, *Ai*. To initialize growth simulation, data about stand characteristics according to the Forest Management Plan (FMP) were entered in Sibyla. Required general data included stand area (ha) and storey (stand layer). Required data for each tree species included stand age, mean dbh, mean height, volume, damage proportion, quality classes A, B or C, and degree of diameter variability. Degree of diameter variability was possible in steps from 1 to 3: 1 in the case of even aged, 2 in the case of partially uneven-aged, and 3 in the case of regularly uneven-aged (according to text description in FMP).

2.6. Generation of young forest stands in the future within Sibyla

In cases of stands younger than initial thinning age *Ai* or stands to be established in the future, stands were generated in the year in which the young stand is expected to reach initial thinning age *Ai*. Tree species composition for the future stand was planned according to FMP or, for long time horizons, not regarded in the FMP according to Remiš et al. (1988) site-specific model. Stand characteristics (mean dbh, mean height and growing stock) were obtained from yield tables (Petráš et al., 1996) for tree species with specific *SI* and common Ai for all tree species in the stand. Damage was set as 0; quality was B (middle). Dbh variability was low in the case of artificial planting and high in the case of natural regeneration. Growing stock of each tree species obtained from yield tables was reduced by the species-specific mean stocking in initial thinning age (STi). Stocking proportion according to the Forestry information system (NFC, 2014) generally is dependent on tree species, age (*A*) and *SI* (Equation 6, Table 2).

Equation 6:

$$St = a - b \cdot LN(A) - c \cdot (d - SI)$$

Table 2: Coefficients to calculate stocking in initial thinning age (STi)

Tabelle 2: Koeffizienten zur Berechnung der Bestockungsdichte im Alter der ersten Durchforstung (STi)

Species	a	b	C	d
Spruce	1.132786	0.089567	0.001987	31.79786
Fir	1.178112	0.103318	0.000667	31.88332
Pine	1.138551	0.088645	0.002464	31.75582
Oak	1.109452	0.072289	0.004057	31.78860
Beech	1.127668	0.081571	0.002533	31.72065

2.7. Simulated thinning operations

During growth simulation, management by cutting operation was applied by Sibyla Cultivator. Nine simulation periods of 5 years each were applied. In each period, options of no harvest, thinning or final harvest were simulated. Between periods trees were removed due to simulated natural mortality, which was based on continuous rates with no large-scale calamities. Only thinning operations for the 1st decade were prescribed by FMP because no further planning was given in the FMP. Intensity of thinning operations in subsequent periods was defined by a special default curve of a decennial thinning percentage by Halaj et al. (1986), specified by tree species, *SI*, and stand density. Frequency of thinning for shelterwood and clearcutting treatment was once per each decennium in which no final harvest was planned. The type of thinning was neutral thinning in case of shelterwood and clearcut management treatments, and intensive thinning from above in the case of transition to selection management.

2.8. Simulated final cuttings

In order to mimic the reality as closely as possible, each stand was divided into a number of RU equal to the number of decades planned for final cutting (regeneration period). Each RU was considered to be one stand for simulation purposes. Each RU was simulated with a representative plot size of 0.25 ha and the results recalculated for the true stand area size according to the FMP. Clearcutting was simulated as removal of all trees on the RU. Age of next stand generation (and all related silvicultural costs taken from silvicultural cost models outside of Sibyla) started immediately after the final cut. Shelterwood was simulated on each RU standardly as a two-phased regeneration cut within ten years. The starting age of the next stand was shifted to the middle of the period between the first and the second shelter cut to consider some delay for natural seeding and artificial regeneration, as underplanting and/or consequent additional planting of missing species. Transition to selection management was simulated as a three-phased shelterwood with a long regeneration period of up to 60 years. The next generation was assumed to be established 5 years after the first regeneration cut.

2.9. Timber prices and harvesting costs

The relation between timber volume harvested or remaining in the stand with financial costs and prices was defined within Sibyla Calculator. Timber prices in €/m^3 for each tree species were derived for quality and diameter classes from the State statistical examination "Forest" executed by the Ministry of Agriculture and Rural Development of the Slovak Republic (2014). Timber prices depend on tree species, quality class, and diameter class, and varied from 27 to 171 €/m^3 for Spruce, 23 to 116 €/m^3 for Pine, 27 to 169 €/m^3 for Fir, 18 to 159 €/m^3 for beech, and 19 to 476 €/m^3 for oak.

2.10. Adjustment of harvesting costs

The Sibyla Calculator used default values of wages, social costs and material consumption instead of costs per cubic meter (m^3). These values were modified based on regulations and localization for the model area in Slovakia to match actual market conditions. Prices for cutting, yarding and conversion wage tariffs were adjusted to 5 €/hour, material consumptions for tractor were 2.15 €/m^3, material consumptions for chainsaw were 1.20 €/reduced normal hour (rNH). Values of other indices were adjusted to 1.30 for Compensation and 0.38 for wage taxation.

Cutting, yarding and conversion cost adjustment was specific to conditions in the case study region. The method of cutting was cutting of stem by chainsaw with removal of branches and tree top including working breaks. Branches of a typical tree covered more than 1/3 of the stem. Detailed criteria for setting the tree class are provided by cutting norms (Nr. 230-2165/234/83-EP) and yarding norms (Nr. 91/1992-230). Regarding norms, specific terrain and stand conditions affected costs and time consumption for operations. Based on these conditions, norms were adjusted for slope steepness and complicated slippery terrain, snow cover and unfriendly weather, regeneration cutting, decay trees, young and dense stands, calamity cuttings for extraction, skidding and unloading. Extraction and skidding distance, slope and skidding direction were taken from the FMP. Calculations considered time for rollout, measuring, cutting, loading and movement.

2.11. Silvicultural cost model for young stands

Scheduling of silvicultural options and costs up to the initial thinning age Ai were implemented outside of Sibyla. Silvicultural models of young stand establishment (*SC1*) and tending (*SC2*) were processed according to optimized technologies proposed by Remiš et al. (1998), which were updated and adapted for current conditions (Kovalčík and Kulla, 2015). Models included costs for planting, pruning and tending. Time schedules and costs for single silvicultural operations are specific for tree species, site, region and management alternative.

For the first phase – establishment, options were differentiated according to site units (combining nutrient status, water regime and AVZ), and processed for the time period since initial stand formation to the expected time of secured young stand establishment according to FMM as silvicultural costs 1 (SC1, Table 3). For the second phase – tending, options were differentiated according to site units and stand type, and processed for the time period since young stand establishment to initial thinning age Ai as silvicultural costs 2 (*SC2*, Table 4). Site unit for each stand was defined according to FMP. Stand type was chosen according to prevailing main tree species in the stand.

Table 3: Silvicultural costs for stand establishment (SC1) in conditions of the model territory in €/ha

Tabelle 3: Waldbauliche Kosten für die Etablierung des Bestandes (SC1) für die Bedingungen des Modellgebietes in €/ha

	Treatment	Clearcut						Shelterwood, Transition to Selection					
Age	Site units	Acidic, 5. *AVZ*			Acidic, 6. *AVZ*			Acidic, 5. *AVZ*			Acidic, 6. *AVZ*		
[years]	Management	A	P	W	A	P	W	A	P	W	A	P	W
1	Area cleaning	1006			1051			1006			1051		
1	Afforestation	2108			1975			2108			1975		
1	Protection, Weeding		127	148		131	132		127			131	
2	Re-afforestation	928			869								
2	Protection, Weeding		127	148		131	132		127			131	
3	Protection, Weeding		127	148		131	132		127			131	
4	Protection, Weeding		127	148		131	132		127			131	
5	Protection, Weeding		127	148		131	132		127			131	
6	Protection, Weeding		127	148		131	132		127	148		131	132
7	Protection, Weeding		127	148		131	132		127	148		131	132
8	Protection, Weeding					131						131	
	Total costs	5971			5867			4301			4338		
	A: Other management related afforestation (Area cleaning; Afforestation; Re-afforestation);												
	P: Individual tree protection against the game; W: Weed and sprout removal												

Table 4: Silvicultural costs for tending (SC2) in conditions of the model territory, age in years, costs in €/ha

Tabelle 4: Waldbauliche Kosten für die Pflege des Bestandes (*SC2*) für die Bedingungen des Modellgebietes, Alter in Jahren, Kosten in €/ha

Stand type	Spruce stand				Beech-fir-spruce stand			
Site units	Acidic, 5. *AVZ*		Acidic, 6. *AVZ*		Acidic, 5. *AVZ*		Acidic, 6. *AVZ*	
	age	costs	age	costs	age	costs	age	costs
	year	*€/ha*	year	*€/ha*	year	*€/ha*	year	*€/ha*
Age establishment	7		8		7		8	
1st tending	16	182	17	182	15	186	15	186
2nd tending	26	182	25	182	22	173	23	173
3rd tending					30	139	30	139
Ai intial thinning age	35		34		38		38	
Total costs [€/ha]		364		364		498		498

3. Results

Compensation payments of management options were based on developing *AINPVs* of stand treatments. When all stand generations (including those expected to be established in the future) in study region were considered, afforestation and tending costs decreased *AINPV* immediately after final cutting of the high proportion of old stands for actively management treatments (Fig. 3). Minimum *AINPV* was reached after simulation year s of 15 years for "Shelterwood", 30 years for "Clearcut" and 40 years for "Transition to Selection". Decreases of *AINPV* for "Clearcut" were large, relative to "Shelterwood" and "Selection Cutting" because additional costs were considered for weed and sprout removal, reforestation and fencing. Decreases of *AINPV* for "Selection Cutting" was slower and lasted longer due to the long regeneration cycle (Fig. 3).

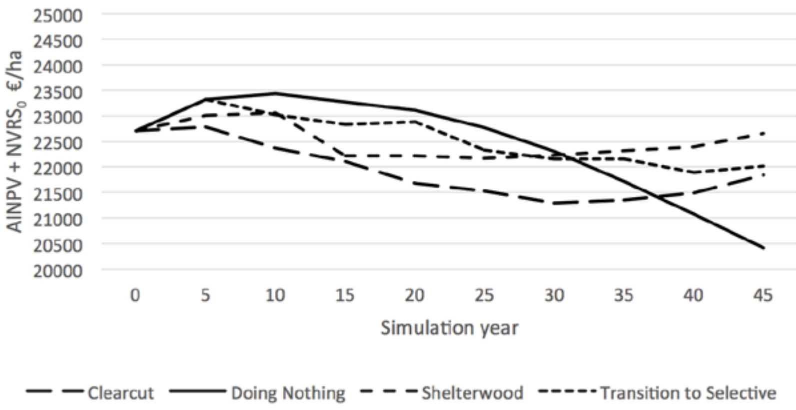

Figure 3: Development of mean AINPV during simulation period s plus NVRS0 in €/ha for reference stand treatments, considering 1st and 2nd stand generation (i.e. including silvicultural costs)

Abbildung 3: Entwicklung des mittleren *AINPV* während der Simulationsperiode s plus NVRS0 in €/ha für die Bestandesbehandlungen, unter Berücksichtigung der 1. und 2. Bestandesgeneration (d.h. einschließlich waldbaulicher Kosten)

In addition to establishing new stands, development of timber stocking and timber values of existing stands differed between treatments. Intensive cutting in "Shelterwood" and "Clearcut" relative to other options in the first two decades temporarily decreased growth potential of standing timber volume and caused lower *AINPV* in this period, relative to "No cutting" and "Transition to Selection". After 10 years, preparatory "Shelterwood" cuts limited stand value growth because stocking density had to be reduced by cutting operations to suboptimal levels. Nevertheless, "Shelterwood" still benefited from additional growth on the remaining stand part which was left after first cut supported by regeneration cuts when compared to "Clearcut" and, therefore, became more profitable financially than "Clearcut". In the long run, "Shelterwood" also was beneficial compared to "Transition to Selection" because AINPV of "Transition to Selection" suffered from the long regeneration cycle, while in "No Cutting", timber quality strongly decreased with time (Fig. 4).

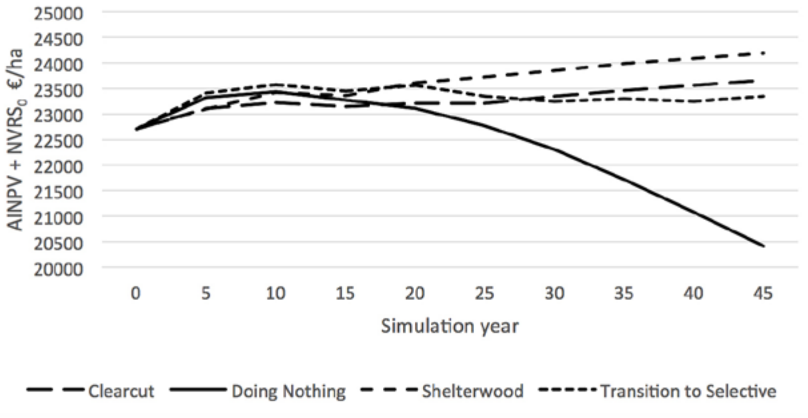

Figure 4: Development of mean AINPV during simulation period s plus NVRS0 in €/ha for stand treatments, considering only already existing 1st stand generation, excluding costs and revenues of 2nd stand generation

Abbildung 4: Entwicklung des mittleren AINPV während der Simulationsperiode s plus NVRS0 in €/ha für die Bestandesbehandlungen, wenn nur die 1. Bestandesgeneration berücksichtigt wird, d.h. ohne Kosten und Erträge der 2. Bestandesgeneration

Compensation payments of management options (Fig. 5 and 6) resulted in differences in *AINPVs* of stand treatments (Fig. 3 and 4), related to specific stand management of management options and transformed to annuities (Kulla et al., 2015). When all existing and newly established young stands in the study region, including afforestation and tending costs, were considered, only contract periods of 35 and more years generated positive compensation payments (Fig. 5).

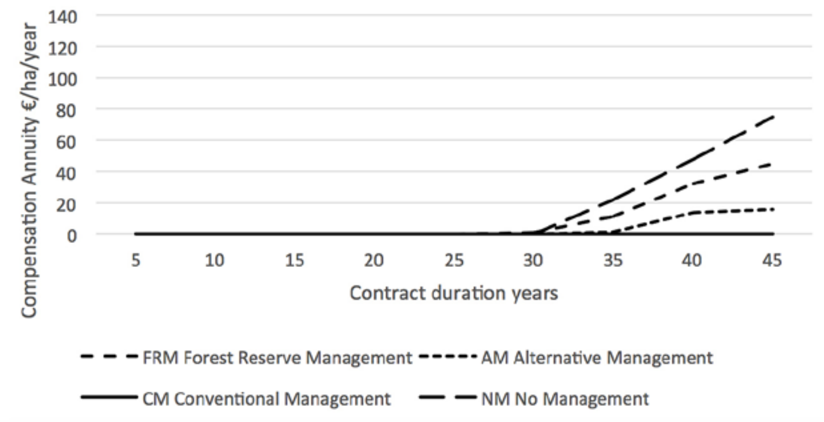

Figure 5: Mean annual compensation payment for management option for different contract period length in €/ha/year, difference to CM, 1st and 2nd stand generation including silvicultural costs considered

Abbildung 5: Mittlere Annuität der Kompensationszahlungen für Bewirtschaftungsoptionen in €/ha/Jahr, Differenz zu CM, 1. und 2. Bestandesgeneration einschließlich waldbaulicher Kosten berücksichtigt

In contrast, contract period of 20 and more years generated positive compensation payments when stand generations were considered, which existed at the beginning of simulation while young stands regenerated during contract period were excluded from financial calculations (Fig. 6). In the second case, in relation to CM, after contract period of 45 years compensation payment was 25 €/ha/year for change to AM towards selection forest, 70 €/ha/year for FRM and 129 €/ha/year for change to NM (Fig. 6). "Transition to selection" seems to be a good alternative how meet economical goals of forest management with relatively low and in time stable loss, quantified as compensation payment for nature conservation.

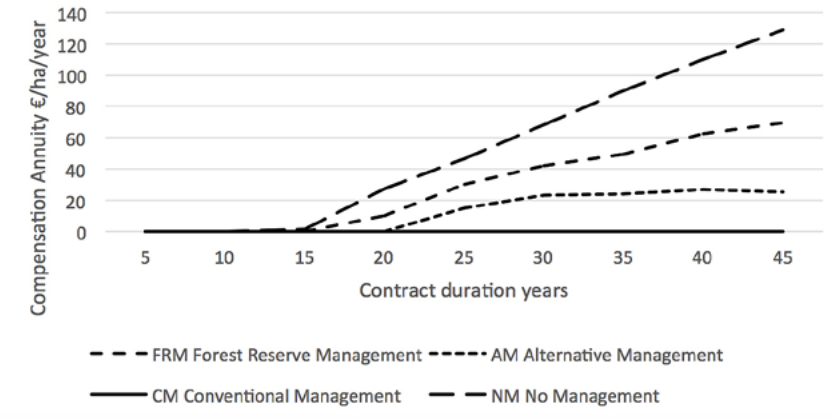

Fig. 6: Mean annual compensation payment for management option for different contract period length in €/ha/year, difference to CM, considered only stand generation existing at the beginning, ignoring costs/revenues of 2nd generation

Abb. 6: Mittlere Annuität der Kompensationszahlungen für Bewirtschaftungsoptionen in €/ha/Jahr, Differenz zu CM, nur am Anfang existierende Bestandesgeneration berücksichtigt, Kosten und Einkommen der 2. Bestandesgeneration ignoriert

Previous results were carried out for mean of all 25 stands for relation with simulation time s. Fig. 7 and 8 enable us follow the composition of total *AINPV* consisting from *AINPV* of 25 single stands displayed according to their stand age t instead of s. *NPV* cannot be derived by *AINPV* because no complete rotation period was simulated. Nevertheless, discounting *AINPV* additionally with simulation year s but also with stand age t in simulation year 0 formed uncompleted untrue time series comparable to *NPV*. As examples, “No Cutting” and “Transition to Selection” treatments were selected to demonstrate influence of passive and active management on *AINPV*. “Transition to Selection” represents actively managed stands, which all are relatively comparable (Fig. 8). Minimum and maximum of *AINPV* trend for all 25 single stands represent variability of growth conditions in the study region (Fig. 7 and 8).

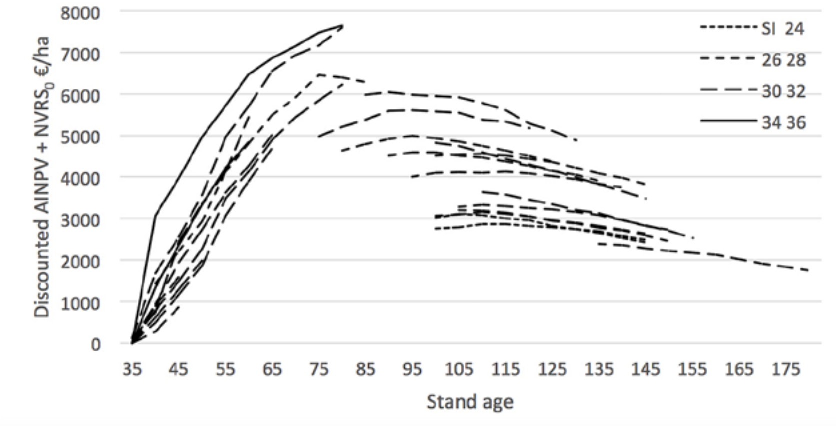

Fig. 7: Development of AINPV plus NVRS0, discounted by stand age in simulation year 0, untrue time series, dependent on stand age t for 25 single stands, stand treatment considering only already existing 1st stand generation, excluding costs and revenues of 2nd stand generation, ages lower than 35 years with 0 €/ha are removed, continuous line: high site index SI, dotted line: low SI, treatment "No Cutting"

Abb. 7: Entwicklung des AINPV plus NVRS0, diskontiert mit dem Bestandesalter im Simulationsjahr 0, unechte Zeitreihe, abhängig vom Bestandesalter t für 25 Einzelbestände, die Bestandesbehandlungen, berücksichtigt nur die 1. Bestandesgeneration, ohne Kosten und Einkünfte der 2. Bestandesgeneration, Alter geringer als 35 Jahre mit 0 €/ha sind entfernt, durchgezogene Linie: hohe Bonität SI, gepunktete Linie: geringer SI, Behandlung "Keine Ernte"

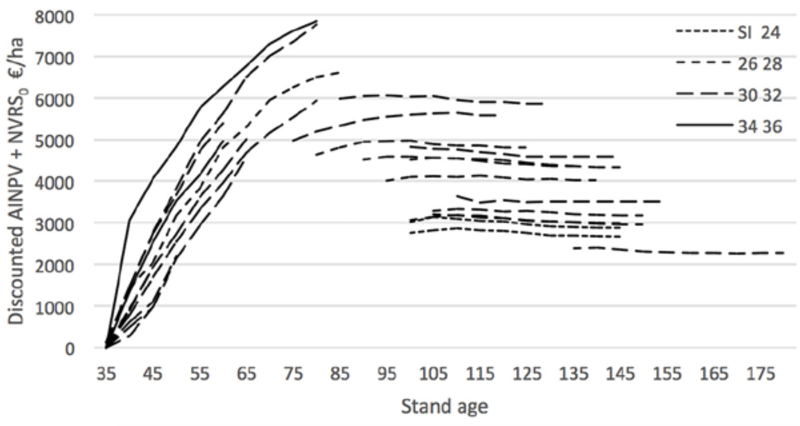

Fig. 8: Development of AINPV plus NVRS0, discounted by stand age in simulation year 0, untrue time series, dependent on stand age t for 25 single stands, stand treatment considering only already existing 1st stand generation, excluding costs and revenues of 2nd stand generation, ages lower than 35 years with 0 €/ha are removed, continuous line: high site index SI, dotted line: low SI, treatment: "Transition to Selection"

Abb. 8: Entwicklung des AINPV plus NVRS0, diskontiert mit dem Bestandesalter im Simulationsjahr 0, unechte Zeitreihe, abhängig vom Bestandesalter t für 25 Einzelbestände, die Bestandesbehandlungen, berücksichtigt nur die 1. Bestandesgeneration, ohne Kosten und Einkünfte der 2. Bestandesgeneration, Alter geringer als 35 Jahre mit 0 €/ha sind entfernt, durchgezogene Linie: hohe Bonität SI, gepunktete Linie: geringer SI, Behandlung: "Übergang zu selektiver Nutzung"

While in Fig. 7 and 8 for young stand ages t from 35 to 80 "Transition to Selection" and "No Cutting" are comparable, for older stand ages t bigger than 80 years for "No Cutting" *AINPV* was reduced caused by decline in timber quality compared to "Transition to Selection" in case of longer simulation ages s. Stands starting simulation beginning from stand age of 35 years or younger are characterized by Sybila with continuous increase in growth potential and can reach high levels of AINPV at age 80. Contrary, stands starting simulation beginning from middle stand ages of 85 years are characterized by much lower starting levels and AINPV stagnates regarding growth potential when discounted with 2% (Fig. 7) or even decreases in case of "No Cutting" (Fig. 8). Differences between minimum and maximum levels in study region (Fig. 7 and 8) are caused by different site index SI, different mixture of tree species and/ or different history of stand management. In future AINPVs are expected to differ but only by little extent caused by different management except of "No Cutting" in case of older stands. Nevertheless, the differences caused by management are still high enough to justify compensation payments.

4. Discussion

Nature conservation can limit forest management options substantially (Kovalčík et al., 2012), but often is not fully compensated. Kovalčík et al. (2012) summarized property losses by management restrictions from nature protection laws, through reductions in timber revenues which correspond to 20 €/ha/year (22 million € per 1.1 million ha) for all levels of protection in Slovakia or 24 €/ha/year (1.6 million € per 68,000 ha) for the strictest level of protection without harvesting. Payments within the Rural Development Programme 2007–2013 for Natura 2000 (strictest level of protection) ranged from 40 to 200 €/ha/year, with a mean of 47 €/ha/year for Slovakia (Kovalčík et al. 2012). Payments differ between states across Europe, ranging from 3 to 220 €/ha/year, with mean of 90 (European Network for Rural Development, 2014, Sarvašová and Kulla, 2015). Options for distributing such compensation payments can be quite different. Small private forests in Southern Finland experienced a wide range of possibilities, for example, including voluntary contracts (Primmer et al. 2013).

Dög et al., (2016) provided a study based on questionnaire and simulation about financial differences of current existing management restrictions regarding protection and recreation as compared to a reference management. Study considering not only current additional expenses but also simulated changes of NCF expected to occur in future on enterprise level. The difference is an annuity of 42 €/ha for private forest enterprises and 35 €/ha for corporate forest enterprises resulting from simulation over 200 years for conditions in German forestry.

Results of study presented in this paper were influenced by limited time horizon and by specific developments related to the age structure of mature stands. Planting, pruning, and thinning decreased AINPV immediately after final cutting. Such future investments will fully prove their benefits for management goals only after one complete regeneration cycle of 100 years or more. Newly established stands with ages from 35 to 40 years not allow for thinning with positive NCF and, therefore, have only negative financial impact on AINPV. Simulation starts mainly with old stands and, therefore, this might explain why NM has higher AINPV in the first 35 years, compared to managed scenarios. In the case of managed scenarios the costs reduced stand value during the development stage characterized by mainly young stands. An owner who knows the length of contract period would not carry out afforestation if he or she is not forced to do so. Positive returns are possible only in the long term, due to positive income from thinning operations and at least with regeneration cut operation of next stand generation benefits of investments in young stands can be realized.

The simulator Sibyla generally assumes natural regeneration while managed options are based on planting. Therefore, the study does not consider differences in stumpage value of young stands between natural and artificial regeneration directly. The stumpage value of managed young stand simulated by Sibyla might be underestimated because silvicultural treatments can improve the financial value of the established stand. To some extent quality differences are reduced by the lower variability of dbh in planted stands.

NPV or holding value reflect positive effects of silvicultural treatments in young stands as they mature. Unfortunately, the AINPV approach used in this study is not able to reflect such effects due to the limited time horizon of the simulations. For these reasons, compensation payments can be calculated without afforestation and tending to avoid costs when income from such investments could not be achieved within the contract period (i.e. when the contract period is substantially shorter than the management rotation length).

Omitting establishment costs for the next stand generation reduced the time until positive compensation payments for managed options appear from 20 to 35 years. The reason for negative compensation in the first 20 years involves the growth dynamics after cutting operations. In the short term, cutting operations will limit stand growth because the RU´s after the final regeneration cut do not contribute to stand value growth, while on the long term cutting allows for positive income beginning with thinning age of the next stand generation. After drop in AINPV during phase characterized by implementation of regeneration, with minimum AINPV from 15 to 40 years for actively managed scenarios, the benefits of these investments in regeneration were realized, indicated by continuous increase in AINPV. Therefore, shorter contract periods do not allow stable differences in stand AINPV. Only long contract periods enable objective estimation of financial differences between CM and alternative opportunities.

Only long cycles of one stand rotation will substantially change age and size structure and, therefore, support nature protection. Compensation payments for such long contract periods can be calculated by the methods for opportunity costs used in this study by considering revenues and costs from planned stand generations. Nevertheless, decisions about management options after very long time periods without management might be very different from previous conventional management because stand age structure, timber quality, natural regeneration, tree species composition and other characteristics might differ strongly from the desired state for financially optimal management. Difference in financial value of remaining stand at the end minus value at the beginning of the contract period do not fully represent expectation value. Forest owners theoretically have the option of reconsidering management options after the end of the conservation contract. For these reasons, a realistic approach for theoretical decision about long term consequences requires NPV or holding value. Such an approach can be applied for compensation payments, but require predefined information about optimal rotation length (Clasen and Knoke, 2013). A fixed rotation length does not exist for management treatments “Transition to Selection” and “No Cutting”. Therefore, a simplified AINPV approach was used, although ignorance of the expected value is a shortcoming but it allows calculation when long-time rotation cycles are not defined. NPV or holding value could be applied for treatments “Transition to Selection” and "No Cutting" when simulation time z can be extended until the desired steady state is reached. Expectation value then could be derived by the steady state. Matrix simulation model (Roessiger et al., 2016) offers evaluation specific for such uneven-aged forest states.

Intense harvest operation, as well as opening of crown cover with sudden light increase, might cause damages, especially in older stands (Griess et al., 2012), possibly reducing timber quality. Destabilization leads to the higher risk of stand failure (Griess et al., 2012) and its consequences of decrease of stand value (Roessiger et al. 2011, 2013). Neither damages nor stand failure were considered in this study.

Spruce forests have declined rapidly in the region of interest due to bark beetles, with the damage on 12% of forest area and the risk of outbreak increasing by 32% of forest area (Hlásny et al., 2010). Decreases can be avoided operationally by active management against bark beetles in the case of calamity, tactically by changing management treatment towards forming more resistant structures, or strategically by changing tree species composition to reduce spruce proportion. Therefore, in the case of NM and FRM there is risk of fast total value decrease of the remaining spruce stands and thus their value might be overestimated.

In contrast to NM, AM allows the introduction of rare tree species and therefore can support change to near-natural tree species composition over long time horizons. FRM only partly allows change of tree species in buffer zones. Avoidance of "Clearcut" reduces costs for stand establishment and allows for benefits from natural regeneration and naturally-driven stand development and therefore can support rare shade-tolerant tree species.

A general debate still exists over whether changes in management from conventional treatments towards selection logging are beneficial, specifically in tropical regions. Brandt et al. (2014, 2016) reported higher deforestation in European concessions in Congo with selection logging according to the FMP. This deforestation rate has been associated with more intense roads network compared to unassigned concessions or Asian concessions without FMP. Conversely, Karsenty et al. (2016) found lower deforestation rates in concessions managed with FMPs compared to those without FMP. They also detected weaknesses in the methodology of Brandt et al. (2014, 2016), especially with excluded and included territory. Such debate calls for more intensive research about single tree selection management and its impact on various ecosystems.

The ownership structure of the study area in Slovakia is dominated by state ownership. In the case of state forests, no real payments can occur as the state will not pay himself. Nevertheless, opportunity costs exist (Kovalčík et al., 2012) and therefore are relevant for political debate and management decisions. While in the private sector, discussions will be between private forest owners and nature protection organizations, there must be public discussion for the state sector, because tax payers and voters have to carry costs and can consume benefits of either forest management or nature protection. Therefore, public forest administration should report and consider real payments as well as opportunity costs to enable public debate about goals of forest management.

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References

BMEL (Federal Ministry of Food and Agriculture), 2014. National policy strategy on bioeconomy, renewable resources and biotechnological processes as a basis for food, industry and energy. http://www.bmel.de/SharedDocs/Downloads/EN/Publications/NatPolicyStrategyBioeconomy.pdf?__blob=publicationFile

Brandt, J.S., Nolte, C., Steinberg, J., Agrawal, A., 2014. Foreign capital, forest change and regulatory compliance in Congo Basin forests. Environmental Research Letters 9 (2014) 044007.

Brandt, J.S., Nolte, C., Agrawal, A., 2016. Deforestation and timber production in Congo after implementation of sustainable management policy, Land Use Policy 52, 15-22.

Clasen, C., Knoke, T., 2013. Site conditions have an impact on compensation payments for the loss of tree species in mixed forests. Forestry 86, 533-542.

Coase, R.H., 1960. The problem of social costs. Journal of law and economics 3, 1-44.

Costanza, R., de Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., et al. 1997. The value of the world's ecosystem services and natural capital. Nature. 387(15), 253–260.

Deegen, P., Stümer, W., Villa, W., Pretzsch, H ., 2000. Zur finanziellen Analyse der Waldpflegeentscheidung bei Berücksichtigung der Biodiversität, dargestellt am Beispiel der Fichte in Sachsen [Financial analysis of the thinning decision with consideration of biodiversity, using the example of spruce in Saxony] Forstwissenschaftliches Centralblatt 119, 226-244 © 2000, Blackwell Wissenschafts-Verlag, Berlin ISSN 0015-8003 [in German].

Dög, M., Seintsch, B., Rosenkranz, L., Dieter, M., 2016. Belastungen der deutschen Forstwirtschaft aus der Schutz- und Erholungsfunktion des Waldes. [Economic burdens for German forestry due to protection and recreation functions of forests]. Landbauforschung - Applied Agricultural Forestry Research 66 (2) 71-92 [In German].

European Network for Rural Development, 2014. Measure 224 – Nature 2000 payments, Rural Development Programmes 2007-2013 Progress Snapshots 2013/ Updated 2014. http://enrd.ec.europa.eu/enrd-static/app_templates/enrd_assets/pdf/measure-information-sheets/C_Infosheet_224.pdf 22.06.2016

Fabrika, M., 2005. Simulator of forests biodynamics SIBYLA. Concept, construction and software solution. PhD thesis, Technical University of Zvolen, 238 pp [in Slovak].

Fabrika, M., Ďurský, J., 2005. Stromové rastové simulátory [Tree growth simulator]. EFRA - Vedecká agentúra pre ekológiu a lesníctvo, Zvolen, 112 s. [in Slovak].

Faustmann, M., 1849. Berechnung des Werthes, welchen Waldboden, sowie noch nicht haubare Holzbestände für die Waldwirtschaft besitzen. [Calculation of the Value which Forest Land and Immature Stands Possess for Forestry]. Allgemeine Forst- und Jagdzeitung 15, 441-451. [In German].

Goldstein, A., 2015. Converging at the Crossroads. State of Forest Carbon Finance 2015. Forest Trends' Ecosystem Marketplace. Available online: http://www.forest-trends.org/documents/files/doc_5020.pdf

Griess, V.C., Acevedo, R., Härtl, F., Staupendahl, K., Knoke, T., 2012. Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. Forest Ecology and Management 267, 284-296.

Hahn, A., Schall, J., 2013. Kosten von Naturschutzauflagen für Waldeigentümer - Bewertungsbeispiele für Mindestvorrat und Flächenstilllegung. [Costs of nature protection requirements for forest owners – evaluation examples for minimum stocking and abandonment of areas]. Allgemeine Forst Zeitschrift für Waldwirtschaft und Umweltvorsorge 68 (21), 8–11. [In German].

Halaj, J., Petráš, R., 1998. Rastové tabuľky hlavných drevín [Yield tables of main tree species]. Slovak Academic Press Bratislava, 325 s. [in Slovak].

Hanewinkel, M., Frutig, F., Lemm, R., 2014. Economic performance of uneven-aged forests analysed with annuities, Forestry 87, 49-60.

Halaj, J., Petráš, R., Sequens, J., 1986. Percentá prebierok pre hlavné dreviny [Thinning percentage for main tree species]. Lesnícke štúdie VÚLH Zvolen, Príroda, Bratislava, č. 40, 98 s. [in Slovak].

Hayes, T., Murtinho, F., Cárdenas Camacho, L.M., Crespo, P., McHugh, S., Salmerón, D., 2015. Can conservation contracts co-exist with change? Payment for ecosystem services in the context of adaptive decision-making and sustainability. Environmental Management 55(1), 69-85. doi: 10.1007/s00267-014-0380-1. Epub 2014 Oct 1.

Heidingsfelder, A., Knoke, T., 2004. Douglasie versus Fichte: Ein betriebswirtschaftlicher Leistungsvergleich auf der Grundlage des Provenienzversuches Kaiserslautern. [Douglas fir versus spruce: A managerial economically comparison of benefit on basis of provenience experiment Kaiserslautern]. Schriften zur Forstökonomie Band 26. Frankfurt: Sauerländer's. [In German].

Herbert, T., Vonada, R., Jenkins, M., Byon, R., Leyva, J.M.F., 2010. Environmental funds and payments for ecosystems Services: RedLAC capacity building project for environmental funds. Rio de Janeiro: RedLAC, 2010.

Hlásny, T., Grodzki, W., Turčáni, M., Sitková, Z., Konôpka, B., 2010. Bark beetle – the main driving force behind spruce forests decline, p. 69-91. In: Hlásny, T., Sitková, Z. (eds), 2010. Spruce forest decline in the Beskids. National Forest Centre – Forest Research Institute Zvolen & Czech University of Life Sciences Prague & Forestry and Game Management Research Institute Jíloviště – Strnady. Zvolen 2010, 182 p.

Karsenty, A., Cerutti, P., Doucet, J.-L., Putz, F. E., Romero, C., Bernard, C., Eba'a Atyi, R., Douard, P., Claeys, F., Desbureaux, S., Ezzine de Blas, D., Fayolle, A., Fomété, T., Forni, E., Gond, V., Gourlet-Fleury, S., Kleinschroth, F., Mortier, F., Nasi, R., Nguinguiri, J.-C., Vermeulen, C., de Wasseige, C., 2016. L'aménagement forestier au Congo engendre-t-il plus de déforestation ? [Do Forest Management Plans in Congo Lead to Greater Deforestation?] (In response to the article by J.S. Brandt, C. Nolte and A. Agrawal, "Deforestation and timber production in Congo after implementation of sustainable management policy" published in Land Use Policy 52, 2016) Downloaded 23.06.2016 http://dpfac.cirad.fr/node/11 [in French].

Kindu, M., Schneider, T., Teketay, D., Knoke, T., 2016. Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. Science of the Total Environment 547, 137-147.

Klemperer, W.D., 1996. Forest resource economics and finance. McGraw Hill, New York.

Kovalčík, M., Kulla, L., 2015. Modely nákladov pestovnŷch činností [Silvicultural costs models], p. 81-93, In: Sarvašová, Z., Kovalčík, M. (eds.): Aktuálne otázky ekonomiky a politiky lesného hospodárstva slovenskej republiky. Zborník z odborného seminára. Zvolen 10. December 2015 [in Slovak].

Kovalčík, M., Sarvašová, Z., Schwarz, M., Moravčík, M. , Oravec, M., Lásková, J., Tutka, J., 2012. Financial and socio-economic impacts of nature conservation on forestry in Slovakia. Journal of forest science 58, 425–435.

Kulla, L., Rössiger, J., Kovalčík, M., Sedliak, M., Fabrika, M., 2015. Aká je cena osobitného režimu hospodárenia v lesoch? [What is the cost of special regime of forest management?], p. 68-80, In: Sarvašová, Z., Kovalčík, M. (eds.): Aktuálne otázky ekonomiky a politiky lesného hospodárstva slovenskej republiky. Zborník z odborného seminára. Zvolen 10. December 2015 [in Slovak].

Madsen, B., Carroll, N., Moore Brands, K., 2010. State of Biodiversity Markets Report: Offset and Compensation Programs Worldwide. Available at: http://www.ecosystemmarketplace. com/documents/acrobat/sbdmr.pdf

Ministry of Agriculture and Rural Development of the Slovak Republic, 2014. State statistical examination "Forest"

Möhring, B., Rüping, U., Leefken, G., Ziegeler, M., 2006. Die Annuität – ein „missing link" der Forstökonomie. [Annuity – a „missing link" in forest economics] Allgemeine Forst- und Jagdzeitung 177, 21-29 [in German].

NFC (National Forest Center), 2014. Forestry information system.

Nürnberger, K., Hahn, A., Rößiger, J., Knoke, T., 2013. Unerwünschte Effekte der Einkommensteuergesetzgebung auf die Wahl waldbaulicher Alternativen: Eine Simulationsstudie aus der Sicht eines risikomeidenden Entscheiders. [Unwanted effects of income tax law on decision about silvicultural alternatives: A simulation study from point of view of a risk-avoiding decision-maker], GEWISOLA 2013, 53. Jahrestagung der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V. AgEconSearch [in German].

Peters-Stanley, M., Gonzalez, G., Yin, D., 2013. Covering New Ground. State of the Forest Carbon Markets 2013. Forest Trends' Ecosystem Marketplace. Available online: http://www.forest-trends.org/documents/files/SOFCM-full-report.pdf

Petráš, R., Halaj, J., Mecko, J., 1996. Sortimentačné rastové tabuľky drevín [Tree species assortment growth tables]. SAP – Slovak Academic Press, Bratislava, 252 pp. [in Slovak].

Pretzsch, H., Biber, P., Ďurský, J., 2002. The single tree-based stand simulator SILVA: construction, application and evaluation. Forest Ecology and Management 162, 3-21.

Primmer, E., Paloniemi, R, Similä, J., Barton, D.N., 2013. Evolution in Finland's Forest Biodiversity Conservation Payments and the Institutional Constraints on Establishing New Policy. Society & Natural Resources: An International Journal, 26, 1137-1154, DOI: 10.1080/08941920.2013.820814.

Remiš, J., Konôpka, J., Lipták, J., Štefančík, L., 1988. Modely a technologické postupy pre fázové výrobky pestovnej činnosti. [Models and technological procedure for production phase of tending activity]. Príroda, Bratislava, 112 s. [In Slovak]

Roessiger, J., Griess, V.C., Knoke, T., 2011. May risk aversion lead to near-natural forestry? A simulation study. Forestry: An International Journal of Forest Research 84, 527-537.

Roessiger, J., Griess, V.C., Härtl, F., Clasen, C., Knoke, T., 2013. How economic performance of a stand increases due to decreased failure risk associated with the admixing of species. Ecological Modelling 255, 58–69.

Roessiger, J., Ficko, A., Clasen, C., Griess, V.C., Knoke, T., 2016. Variability in growth of trees in uneven-aged stands displays the need for optimizing diversified harvest diameters. European Journal of Forest Research: 1-13. doi: 10.1007/s10342-015-0935-6.

Sarvašová, Z., Kulla, L., 2015. Platby NATURA 2000 v lesoch [NATURA 2000 payments in forests], p. 96-104. In: Hajdúchová, I., et al. 2015. Aktuálne problémy financovania lesnícko-drevárskeho komplexu. Zborník vedeckých prác. Technická Univerzita vo Zvolene, Lesnícka Fakulta, Katedra ekonomiky a riadenia lesného hospodárstva.

Stanton, T., Echavarria, M., Hamilton, K., Ott, C., 2010. State of Watershed Payments: An Emerging Marketplace. Ecosystem Marketplace. Available online: http://www.forest-trends.org/documents/files/doc_2438.pdf

Wunder, S., 2005. Payments for environmental services: Some nuts and bolts. CIFOR Occasional Paper No. 42 Center for International Forestry Research, ISSN 0854-9818.

Wunder, S., 2007. The efficiency of payments for environmental services in tropical conservation. Conservation Biology 21(1), 48-58.

Zhang, D., Stenger, A., 2014. Value and valuation of forest ecosystem services, Journal of Environmental Economics and Policy, DOI: 10.1080/21606544.2014.980852.

Zhang, Q., Bennett, M.T, Kannan, K., Jin, L. (Editors), 2010. Payments for ecological services and eco-compensation: Practices and innovations in the People's Republic of China. Proceedings from the International Conference on Payments for Ecological Services, Ningxia Hui Autonomous Region, People's Republic of China, 6–7 September 2009. Mandaluyong City, Philippines: Asian Development Bank, 2010.