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Impact of forest management intensity on mushroom occurrence and yield with a simulation-based decision support system

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ABSTRACT

Well-researched and sound integration of non-wood forest products into a forest management planning process presents an opportunity to understand the fundamental causative basis of forest dynamics through decision support systems (DSS). The aim of this study is to present a simulation-based mushroom integrated decision support system, ETÇAP*Simulation* model, and forecast the effects of forest management intensity on mushroom productivity and occurrence. This is conducted through five policy sets with different planning scenarios, representing timber-oriented forest management (T1), multipurpose forest management (M1, M4, M6), and no intervention (NI). The study area involves the Kızılcasu Planning unit from the northwestern part of Turkey. The spatial distribution and productivity models of *Lactarius delisiosus* and *L. salmonicolor* generated for the Kızılcasu Planning unit were used in the simulation based model. The results indicated that both minimum harvesting ages and the intensity of forest management interventions are very important for increasing mushroom productivity and occurrence in the case study area. Under the T1 forest management scenario, mushroom productivity is estimated to be approximately 12,469 tonnes. When the planning approach changes to NI, M1, M4 and M6, however, mushroom productivity experiences 86%, 28%, 26% and 33% reduction rates, respectively. Despite these reductions, spatial distribution of mushrooms has been positively affected by forest management interventions.

Simulations with multipurpose management policy would probably lead lower estimations of spatial distribution areas and productivity of mushroom than timber-oriented forest management policy would. Multiple-use planning approach seems to contribute less to mushroom productivity and the occurrence than does timber-oriented approach. In fact, determining optimal harvesting ages and the intensity of forest management interventions for each forest value presents a great challenge for decision makers. The DSS tools like *ETÇAPSimulation* are of great importance to understand the long term effects of various management plans on forest dynamics. Active management of forest resources will be important for achieving simultaneous production of timber products and mushrooms.

1. Introduction

Wild mushrooms are important non-wood forest products (NWFPs) due to their use in medical, nutritional and recreational services. Turkey has an essential market in international mushroom trade with annually millions of tonnes of raw or processed mushrooms (TUIK, 2015). As the economic contribution of mushrooms is worth several million dollars that can be higher than the economic contribution of timber (Alexander et al., 2002; Arnolds, 1991), these products require sound integrated management of resources based on the sustainability concept. Besides, according to the current forest policy in Turkey, the state encourages both the villagers and private companies to utilize potential NWFPs including mushrooms within state forests. Mushrooms in the state forests are considered public goods and the government benefits a very small amount of the stumpage price. However, the state primarily aims to contribute more to rural developments with the intensified production of NWFPs including mushrooms.

While forests have been traditionally managed for just timber production, an increasing interest in NWFPs has created a conflict between the objective of traditional maximum timber production and the maximum production of NWFPs such as mushrooms. Accommodating multiple objectives can be ensured by the multipurpose forest management planning approach (Pilz et al., 1999).

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A good example of the joint production of timber and NWFPs like mushrooms was demonstrated by Palahí et al. (2009) for Catalonian forests. Under the ecosystem-based multipurpose forest management approach, the integration of a number of NWFPs into a forest management plan increases the complexity of forest management planning. In this regard, the models predicting both spatial distribution and productivity of each product with the use of computer-based analytical tools like the Decision Support System (DSS) are indispensable (Eriksson and Borges, 2014).

There are a few forest management planning models in the form of a DSS integrating one or two NWFPs into management plans. Among these models include: EMDS (Reynolds, 2001) accommodating wildlife populations; MONTE (Palahí, 2002; Pukkala, 2003) integrating mushrooms; MONSU (Pukkala, 2004) incorporating mushrooms and berries; PractSFM (Barrett et al., 2006) dealing with woody debris and wildlife populations; ProgettoBosco (Ferretti et al., 2011) taking care of truffles; ToSIA (Tuomasjukka et al., 2013) dealing with pine nut, mushrooms and reindeer, and VDD-Path (Shlisky and Vandendriesche, 2011) incorporating wildlife population by using different simulation and optimization techniques are the most commonly used examples of NWFPs integrated DSS.

In Turkey, a prototype decision support system named ETÇAP was developed to incorporate multiple forest values such as carbon sequestration, soil loss and water production into forest management plans (Baskent et al., 2014; Keleş, 2008). The DSS focuses particularly on the even-aged management system and uses empirical growth and yield models to project forest development over time, accommodating forest management guidelines and regulations that are enforced by the Turkish Forest Service. ETÇAP works both with simulation (ETÇAP*Simulation*) and optimization techniques (ETÇAP*Optimization)* and recently was modified to integrate the mushroom products (Kucuker, 2014).

Previous studies demonstrated that some stand variables such as basal area, stand age and dominant height and climatic parameters such as rainfall, temperatures and topographic characteristics such as elevation, slope and aspect have strong influences on mushroom occurrences and productivity (Bonet et al., 2008, 2010, 2012; Martínez-Peña et al., 2012a, 2012b; Kucuker, 2014; Kucuker and Baskent, 2015a; Tahvanainen et al., 2016). Although climatic and topographic characteristics cannot be changed or modified by forest managers, stand characteristics can be controlled by means of forest management interventions (Pilz et al., 1999; Egli et al., 2010; Bonet et al., 2012). Furthermore, human interventions in the form of forest management practices such as clear-cutting or thinning and some natural disturbances such as wildfire have direct or indirect effects on the occurrence and productivity of mushroom species (Pilz and Molina, 2002). Thus, it can be expected that forest management interventions have an effect on mushroom productivity and emergence with silvicultural interventions such as thinning and clear cutting with different intensities (Bonet et al., 2012). Additionally, these interventions would affect the mycotourism service related to mushroom picking. Thus, forest management interventions with different types and intensities are likely to affect the economic values of forests. However, understanding, as well as analyzing, the tradeoffs and interactions among various forest values such as mushrooms and timber with forest management interventions has been a daunting challenge without the use of a DSS.

Some studies suggest that thinning activities have an effect on mushroom productivity and emergence. Bonet et al. (2012) and Egli et al. (2010) observed an increase in mushroom yield after thinning. Similarly, Egli and Ayer (1997) reported that a 35% reduction in the number of stems had a positive effect on mushroom yield. Ayer et al. (2006) demonstrated that forests with medium stand densities have higher mushroom productivity. However, Kardell and Eriksson (1987) did not observe any clear effects of thinning on the mushroom yields. Some other prominent studies about multipurpose planning incorporated a number of forest values such as soil protection, carbon sequestration and water production into forest management plans and predicted the interactions among the forest values with different multi-criteria decision techniques (Pukkala, 2002; Diaz-Balteiro and Romero, 2003; Backéus et al., 2005; Krcmar et al., 2005; Baskent and Kucuker, 2010; Kucuker and Baskent, 2010, 2015b). Although a limited number of attempts using NWFP integrated DSS have presented the effects of various forest management policies on mushroom production at the stand or regional level (Alexander et al., 2002; Palahí et al., 2009; de-Miguel et al., 2014), very few studies (i.e., Miina et al., 2010) pinpointed on simulating and analyzing the joint production of NWFPs and timber based on optimal stand management.

The primary objective of this study is to introduce the mushroom integrated ETÇAP*Simulation* model that enables integrated planning of mushrooms and timber in addition to other forest values such as soil protection, water production, and carbon sequestration simultaneously. The second objective of the study is to examine the effects of different forest management scenarios on mushroom (*Lactarius delisiosus* and *L. salmonicolor*) productivity and occurrence as well as timber production. ETÇAP DSS was used as a decision making tool to implement the idea of integrating mushroom production with timber production in a case study area of the Kızılcasu Forest Planning unit and capitalizing on forest dynamics. Here, the paper focuses on the evaluation of forest dynamics based on certain forest performance indicators over time at the forest level and does not deal with stand structure with species composition, volume distribution and spatial structure to keep the size and content of the paper more focused.

2. Material and methods

2.1. Description of the mushroom integrated ETÇAPSimulation model

The mushroom integrated ETÇAP*Simulation* model is a unique DSS designed to integrate mushroom products into forest management plans in accordance with the forest management regulations in Turkey. The deterministic model provides opportunities for cross-sectoral assessments of mushroom and the other forest values in addition to timber products. The model is a stand-based DSS and can be used to prepare long term strategic plans with traditional simulation techniques. It facilitates the decision making process based on the combination of stand growth models, mushroom occurrence and yield models. The mushroom integrated ETÇAP*Simulation* model is able to forecast future forest development and analyze the effects of a number of alternative strategies on forest dynamics (i.e., max timber production and even timber flow in each period) with performance indicators, enabling the effectiveness and efficiency of the decision-making processes. This computer-based simulation model remarks with reliability, flexibility and functionality in preparing multiple use forest management plans (Pukkala, 2002; Eriksson and Borges, 2014). Object-oriented programming language used in the model facilitates modular structure to integrate a new application and models. A flexible user interface provides additional functionality for checking data base consistency, revising planning scenarios and reporting the results in a map, tabular and graphical formats (Kucuker, 2014).

The first stage of the mushroom integrated ETÇAP*Simulation* model is a data entry routine for the characterization of a forest ecosystem including initial forest structure, yield tables, economic data, silvicultural regimes and management guidelines (Fig. 1). The next stage lays out management prescriptions depending on

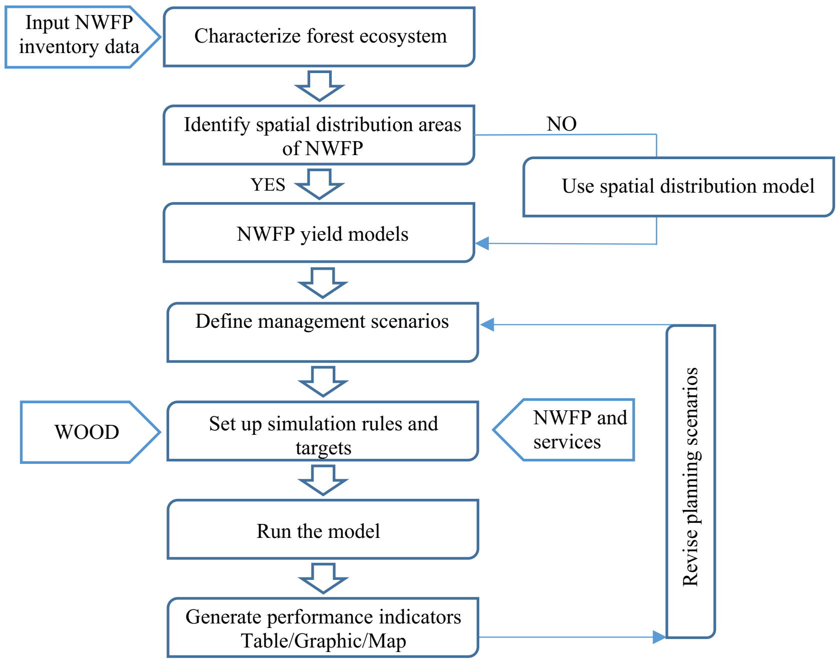

Fig. 1. Flow diagram of mushroom integrated *ETÇAPSimulation* model.

silvicultural treatments applied to each stand type over a planning horizon. Then the users enter all information about non-wood forest products desired to be integrated into the management plan. After selecting the related non-wood forest products and their beneficial parts, users must choose empirical models of spatial distribution areas, yield and calibration among all models because DSS includes some spatial and yield models for the same product. Some regulation factors such as the *p* threshold value (for spatial distribution model), correction factor (for yield model), fresh/dry ratio and rotation time should be provided by users manually. The model estimates the spatial distribution areas of the related NWFP and then the annual yield of the related product in these presence areas is calculated. Thus, the occurrence of mushrooms in each stand is projected to calculate the amount of mushrooms in each period with the DSS. In case there is no spatial model predicting spatial distribution areas of the related product, the product is assumed to be present in each stand of the planning unit.

Given the specification of management scenarios, the DSS generates data of matrices based on a deterministic simulation technique, where stands are forecasted after management interventions period by period, without intertemporal tradeoffs. Although the technique does not assure an optimal solution, it is a widely used quantitative technique to predict long term effects of various management activities on the forest ecosystem values. The DSS also contains a report writer to document the output in the form of a table, graphic and map. The long term effects of forest management interventions on the performance of the mushroom production and mushroom distribution areas as well as wood and other services can also be analyzed.

2.2. Growth and yield projection of timber

An empirical stand simulation model within ETÇAP*Simulation* projects the development of stands over time. Accordingly, the growth of existing stands and the regenerated stands over the following periods were predicted separately by the in-house growth and yield model. The growth of existing stands is predicted based on the relationship between the stand parameters measured from the field inventory and the stand parameters from empirical yield tables (Keleş, 2008). The regenerated stands, however, are assumed to grow according to the empirical yield tables prepared for all commercial tree species available in the study area. The stand growth and yield projection model terminates the growth of stands as soon as they reach the age of mortality and regeneration of stands starts afterwards. In this study, the growth projection of the stand parameters such as basal area, increment, volume, number of stems for each period were determined by the stand simulation model.

2.3. Spatial distribution of mushroom

The mushroom integrated ETÇAP DSS includes a number of spatial distribution models for mushrooms. These are logistic regression models that predict the spatial distribution areas of the related mushroom for each following year. In this study, the following equation was used to predict the spatial distribution of *L. delicious* and *L. salmonicolor* mushrooms (Kucuker, 2014; Kucuker and Baskent, 2015a) (1). In the model, the *p* threshold value was assumed to be 0.5 and thus the stands whose *p* threshold values are equal or higher than 0.5 were assumed to have mushrooms, whereas the stands whose *p* threshold values are lower than 0.5 were assumed not to have any. Table 1 shows the coefficients of categorical variables in the model.

$$P = 1/(1 + e^{-(-0.024-0.054CC+AC-0.036S+0.011Aa+VC+0.353T)}) \qquad (1)$$

where *p* is the occurrence probability of *Lactarius*, *e* is the "euler" number, *CC* is crown closure, *S* is slope, *Aa* is aspect, *AC* is age classes, *VC* is volume classes and *T* is increment per hectare.

2.4. Yield productivity of mushroom

The mushroom integrated ETÇAP DSS predicts the mushroom yield for each following year in the stands where spatial distribution of the mushroom was determined to exist. In this study, the following mushroom yield model was used to estimate the productivity of *L. delicious* and *L. salmonicolor* mushrooms in the

Table 1
The coefficients of categorical variables in the model.

Volume classes		Coefficient	Exp(β)	Age classes		Coefficient	Exp(β)
VC(1)	<200	1.208	3.35	AC1)	<40	2.699	14.87
VC(2)	200–400	1.813	6.13	AC(2)	40–100	0.543	1.72
VC(3)*	>400	0		AC(3)*	>100	0	

* Last category was selected in the analysis as indicator, the coefficient is “0”.

appropriate stands (Kucuker, 2014) (2). The model is multiplied with the Snowdon correction factor (0.667) (Snowdon, 1991) after the exponentiation of the logarithmic model, since only the fixed part of the model is used in this study.

$$ln(y_{ij}) = 2.804 + 0.451Cos(Asp) + 1.339\ln(Ele) + 0.00004d^3 - 0.0312Age + u_i + u_j + \varepsilon_{ij} \quad (2)$$

where y_{ij} is total yield of i plot in year j, Asp is aspect, Ele is elevation, d is stand mean diameter, Age is stand age, u_i is random plot factor, u_j is random year factor and ε_{ij} is residual.

2.5. Financial data

The mushroom integrated ETÇAP DSS uses the Net Present Value economic approach and a flexible discount rate is used to project the total revenues and costs in each period. Although average market sale prices for each timber assortment were entered in the model as the economic revenues of timber, the cost derived from timber harvesting, regeneration, reforestation and thinning and stumpage prices were all used as input data to represent the total costs of timber. The financial data were gathered from the Cide state forest enterprise. The incomes derived from mushroom production were calculated by the average market sale prices for the last 10 years in the study area and the costs were determined according to stumpage price, sale and general expenses such as administration and maintenance costs. In the calculation of the Net Present Value (NPV) of each forest value a 3% interest rate, the generally accepted value in Turkish forestry, was used.

2.6. Study area

The study was conducted in a province of Kastamonu in the Northwestern Plateau of Turkey. The case study area has high mountain forests occupying an area of 9166 ha, 84% of which is forestland. This study area has a rich diversity in terms of composition with a number of tree and mushroom species. Even aged mixed stands of *Fagus orientalis*, *Carpinus betulus*, *Abies bormülleriana*, *Quercus* sp., *Pinus sylvestris*, *Pinus nigra*, *Castanea sativa*, *Fraxinus excelsior*, *Alnus glutinosa*, *Acer* sp. and *Platanus orientalis* cover the study area. The elevation ranges from 350 m to 1350 m a.s.l. and the average slope is about 49%. This wide range of elevation in the area causes sharp changes in temperature and rainfall. Based on long term measurements of about 20 years, mean annual temperature and rainfall are about 13 °C and 1230 mm, respectively (DMİ, 2008).

2.7. Forest management strategies

Five planning strategies based on the combination of various management objectives with a different set of constraints were developed to examine the interactions of forest management interventions. These strategies are designed to reflect no intervention (NI), timber-oriented (T1) and multipurpose (M1, M4, M6) management approaches. The NI strategy includes no harvesting and thinning objectives and no policy restrictions. The other forest management strategies have similar management objectives such as maximum timber production with even timber flow (T1, M1 and M4) and area regulation (harvesting of even amount of area for each period) (M6) among periods (Table 2). The rationale behind the development of strategies is the reflection on the comparative analysis of conventional timber-oriented planning settings and the multiple-use forest management concept including mushroom occurrence and yield over time.

No intervention strategy (NI) means “do nothing” to any of the stands over the planning horizon. Thus, all stands are left to grow without any harvesting or thinning interventions.

Timber-oriented management strategy (T1) principally aims to maximize total timber production. The model assumes that all forested areas are available for timber production and thus subject to harvesting. In this strategy minimum and maximum rotation ages are modified according to the dominant tree species. The minimum rotation age for both Scots pine and Black pine was 140 years and 120 years for hardwood trees such as Beech, Fir and Oak dominated stands. The maximum rotation ages were set to be 180 and 160 for pine and hardwood dominated stands, respectively. Commercial thinning practices were implemented to the stands whose ages range between 30–80 years with a removal rate of 10% and for the stands of 50–80 years with a removal rate of 15% of standing volume for each 10 year-period for the pine and hardwood dominated stands, respectively.

Multipurpose-oriented strategies (M1, M4 and M6) are designed to maximize total timber production by conserving the other forest ecosystem values. Although these strategies seem to be the same with the timber-oriented management strategies, in multipurpose management strategies all stands are not subject to harvesting. In these strategies, forested areas were previously stratified into management units according to land use categories, ecosystem values such as timber production, biodiversity conservation and soil protection, management objectives, dominant tree species, rotation period and site classes. Based on the new planning approach, forests are stratified into appropriate land use categories by applying the criteria and indicators within the management guidelines of Turkish forestry (OGM, 2014). After gathering forest inventory data for timber and biodiversity, the forest stands are primarily grouped into major ecological, economical and socio-cultural values in a participatory approach. Then, under each major land use category appropriate forest values and thus possible management targets are decided by management experts in consultation with major stakeholders in order to determine and finalize the management units.

While timber dominated areas (i.e., management unit) are subject to clear cutting and thinning interventions, conservation dominated areas are just subject to thinning interventions. Thus

Table 2
Alternative forest management strategies tested in the case study area.

Strategies	Objectives	Constraints
NI	No harvesting and thinning	No restriction
T1	Max timber	Even timber flow (415,000 m^3)
M1	Max timber	Even timber flow (310,000 m^3)
M4	Max timber	Even timber flow (320,000 m^3)
M6	Max timber	Area regulation (460 ha)

Table 3
Limits of harvesting and thinning ages in each management unit and for each forest management alternative.

Alternatives	Management unit	Management interventions				
		Harvesting ages		Thinning ages		
		Min	Max	Min	Max	Removal rate (%)
NI No intervention	All area	–	–	–	–	–
T1 Timber oriented	Timber dominated (Scots pine and Black pine)	140	180	30	80	15
	Timber dominated (Beech, Fir and Oak)	120	160	50	80	10
M1–M4, M6 Multipurpose oriented	Timber dominated (Scots pine and Black pine)	140	180	30	80	10–15
	Timber dominated (Beech, Fir and Oak)	120	160	50	90	10–15
	Conservation dominated	200	220	40	120	10–15

silvicultural prescriptions, minimum and maximum rotation ages, thinning ages and ratios were adjusted to each management unit. The minimum cutting age is 140 years for the "Timber dominated-Scots pine and Black pine" management unit, 120 years for the "Timber dominated-Beech, Fir and Oak" management unit and 200 years for the "Conservation dominated" management unit. Maximum harvesting ages are set to be 180, 160 and 220 years, respectively. Commercial thinning practices were implemented for the stands whose ages range between 30–80, 50–90 and 40–120 years in the management units, respectively. The ratio of commercial thinning actions in each management unit is 10% for M1 and 15% for M4 and M6 strategies (Table 3).

A number of assumptions were taken into consideration in the four management strategies. The planning horizon is 100 years and the planning period is 10 years. All stands may be cut when they reach the minimum harvesting age. Regeneration starts immediately after the harvesting of stands without any regeneration lags. Regenerated stands are assumed to follow the same stand type and site index. All stand parameters such as timber production, mushroom production and their monetary values for each subcompartment are calculated separately at the midpoint of each period.

3. Results and discussion

The amount and NPVs of timber and mushroom production for each planning strategy at the end of the planning horizon can be seen in Table 4. The T1 (Timber-oriented) strategy provided the highest amount of total timber, mushroom and timber NPV. In the timber-oriented strategy, total timber production reached 4 million m^3, mushroom production was about 12,469 tonnes and NPV of timber was about $19 million at the end of the planning horizon. Compared to each other, the timber-oriented management strategy (T1) produced about 36%, 49% and 12% more total timber, mushroom and the NPV of timber, respectively, than the other multipurpose-oriented strategy (M6) did (Table 4). The main reason of that is the process of the allocation of forest areas to conservation dominated management units based on the new planning approach. As expected, the scenario analysis showed that the lowest total timber, mushroom and timber NPV were produced by the NI (No intervention) strategy (Table 4). The results indicated that forest management planning strategies with different objectives, constraints and the level of management interventions substantially determine the achievement level of forest values.

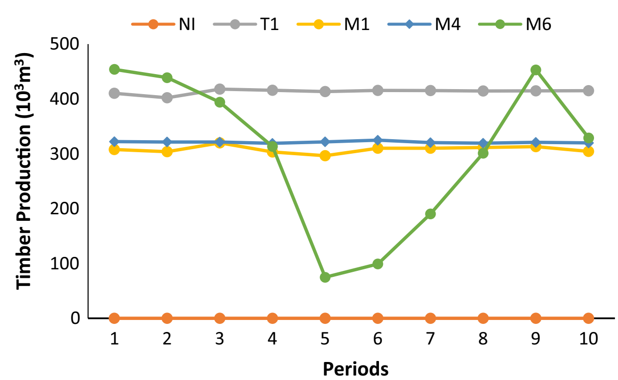

Fig. 2. Total amount of timber over time from all strategies.

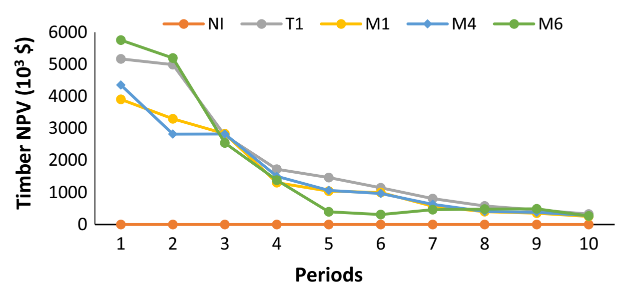

Fig. 3. NPV of timber in successive periods of all strategies.

Even though T1, M1 and M4 strategies have the same maximum timber production objective and even timber flow constraint, T1 produced more timber due to the planning approach that does not include the stratification of forest to various other uses and varying harvesting and treatment limits (Fig. 2). Specifically, the timber-oriented planning approach adopts maximum timber production in all the forest area and all stands are subject to harvesting. The multipurpose-oriented planning approach, however, targets the maximum production of all forest values including timber production. Additionally, strategy T1 uses shorter harvesting ages for each species (Table 3). Since the regular area control constraint limits the model more than the even volume constraint, the M6 strategy produced less amount of timber than the M1 strategy, though both strategies have the same planning approach. However, the M6 strategy contributed more financial income than the

Table 4
The level of forest management objectives for the planning strategies tested.

Strategies	NI	T1	M1	M4	M6
Timber (m^3)	*0*	*4,135,024*	3,080,876	3,211,127	3,048,410
Timber NPV ($)	*0*	*19,426,424*	14,944,075	15,223,273	17,269,745
Mushroom (ton)	*1773*	*12,469*	9032	9249	8357

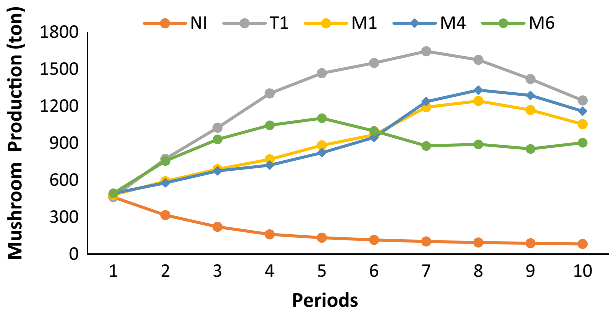

Fig. 4. The amount of mushroom in successive periods of all strategies.

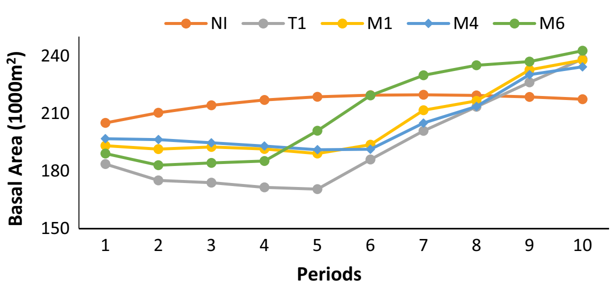

Fig. 5. The periodical change of basal area for each planning strategy.

M1 strategy did as harvesting of the stands, especially in the early periods, contributes more net present value (Figs. 2 and 3). Other similar studies demonstrated that the volume control constraint generally causes a significant reduction in timber NPV given the same initial age class structure (Haight et al., 1992; Baskent and Kucuker, 2010).

At the end of 100 years of planning horizon, NI produced less mushroom (1773 tonnes) than the T1 strategy (12,469 tonnes) and M1 strategy (9032 tonnes) did. This result is encouraged with the previous studies that economically important NWFPs may be better supplied in managed forests than in unmanaged forests (Palahí et al., 2009; Miina et al., 2010). In strategy T1 compared with NI, M1 and M4, total mushroom production decreased by 86%, 28% and 26%, respectively. This is mainly due to the intensity of forest management interventions such as harvesting and thinning based on the forest management approach. Additionally, this result demonstrated that both light silvicultural prescriptions and no interventions in the conservation areas based on stratification process may cause a decrease in the mushroom yield in the long term. Because the model projects stand developments without any harvesting and thinning activities in strategy NI, the age class distribution of the forest develops towards a mature and overmature forest structure and the growing trend of the stands decreases.

It can be seen in Fig. 4 that strategy NI caused a decreasing trend in the mushroom production in successive periods based on inverse relationship with the basal area (Fig. 5). Similarly, Bonet et al. (2008, 2010, 2012) determined that the highest *Lactarius* production occurs at a lower basal area from 10 to 20 $m^2\ ha^{-1}$ in pine stands. The main reason of such a result would be explained with the dynamics of growing stock. Based on the model assumptions, the regenerated stands have an optimal growth trend which has faster growth rates than that of current stands and create a regulated forest structure. Similarly, all M strategies generated less mushroom production than the T1 strategy did depending on a forest management scenario. The probable reason of this low mushroom production may rise from the stratification of forest areas with the multipurpose-oriented strategies (M1, M4, M6) into some other conservation dominated areas. Furthermore, harvesting occurs in those areas in the later development stages than the timber-oriented strategy (T1) does. While the multipurpose management strategies M1 and M4 have the same objective and constraints, the M4 contributed more mushroom yield (nearly 216 tonnes, 2%) than the M1 did. This may well be due to the difference in forest management intensities between the strategies. As far as stand treatment is concerned, the 15% volume removal rate (Scenario M4) caused more mushroom production at the end of the planning horizon than did the 10% removal rate (Scenario M1). As such, it could be stated that the sustainability of forest values such as mushroom and timber may be ensured in the managed forest with increasing forest management intensity compared to unmanaged forests (Bonet et al., 2012; de-Miguel et al., 2014).

The scenario analysis indicated that spatial distribution areas of the mushroom are affected by forest management policies and forest management interventions. Fig. 6 shows the temporal changes in spatial presence and absence areas of mushrooms in each period for each forest management scenario. While in the current

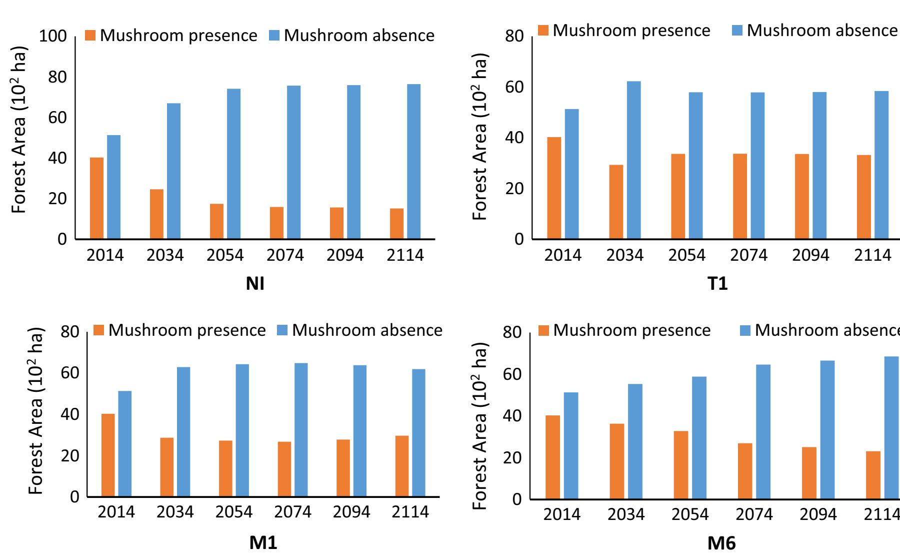

Fig. 6. Temporal evaluation of mushroom occurrence in the study area according to different forest management strategies.

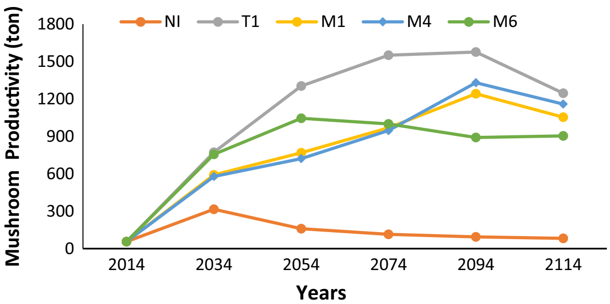

Fig. 7. Temporal changes of mushroom productivity over time under different forest management strategies.

situation (2014) mushroom presence and absence areas in the Kızılcasu planning unit in Turkey are about 4031 ha and 5135 ha respectively, the areas essentially changed based on different planning scenarios. The widest spatial distribution areas (presence areas) of the related mushroom are derived from theT1 strategy for each period, the least presence areas of the mushroom are estimated by the NI strategy. If a forest management action such as harvesting or thinning is not applied over 100 years, the probability of mushroom presence would be rather lower. For example, mushroom presence areas are 1748 ha and 2734 ha for the NI and M1 strategies respectively over 40 years and 1518 ha and 2969 ha over 100 years. Compared to the baseline (in 2014), mushroom presence areas over the planning horizon (in 2114) decreased by 62%, 18%, 26%, 22% and 43% for NI, T1, M1, M4 and M6 strategies, respectively. The results showed that forest management interventions such as harvesting, thinning and shorter rotation ages positively affected the spatial distribution areas in the long term. However, conservation of the forest areas based on stratification process has a negative effect on spatial distribution areas of mushroom in the long term.

The results of the four management strategies showed that various policies and intensities of management interventions affect mushroom productivity. The long term effects of different management scenarios on mushroom productivity can be seen in Fig. 7.

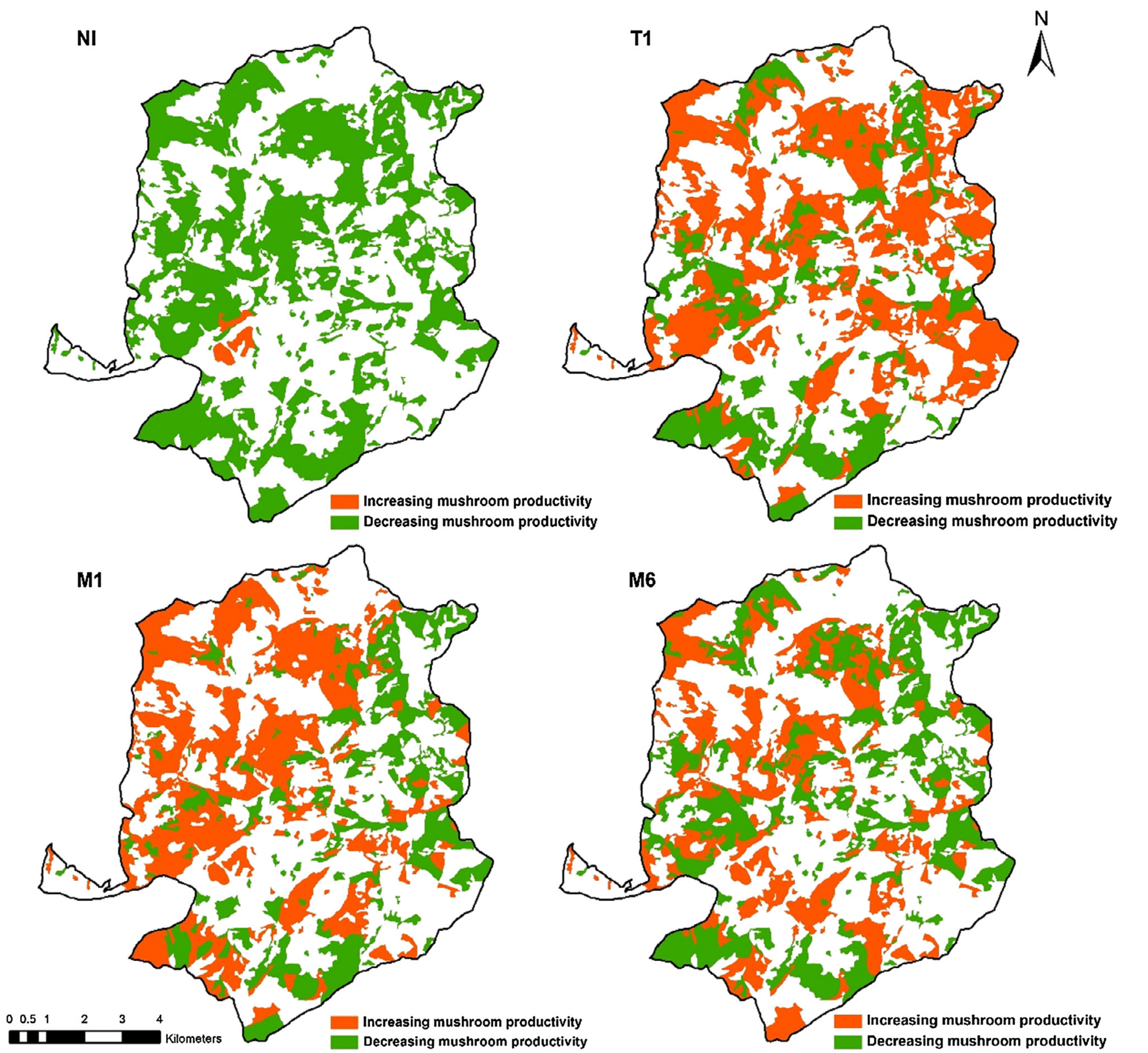

Fig. 8. Temporal changes in mushroom productivity between 2014 and 2114 under different forest management strategies.

Furthermore, mushroom productivity seems to be improved with forest management intensities. While in the current situation (baseline-2014) mushroom productivity in the study area is about 56,165 kg yr^{-1}, the productivity over the 100 year planning horizon greatly increased for each strategy except the NI strategy. In the absence of forest management activities such as harvesting and thinning (NI strategy), while after the first 20 years (2035) an increase in the productivity (about 260 tonnes) could be expected, during the next periods a decreasing trend in mushroom yield was observed. For T1, M1, M4 and M6 strategies, however, a substantial increase in mushroom productivity can be seen as a consequence of the forest management interventions. As a result of simulation, when forests are managed for the maximum timber production (T1 strategy), mushroom productivity is predicted to be more than that of the multipurpose-oriented strategies (M1, M4 and M6). This could also be explained by the longer rotation ages in the conservation dominated areas. The amount of increment in mushroom production between the T1 and M1 strategies is about 182 tonnes (30%), 535 tonnes (70%), 582 tonnes (60%), 334 tonnes (27%) and 192 tonnes (18%) for each 20 year period. The difference in mushroom production between the T1 and M6 strategies is about 17 tonnes (2%), 259 tonnes (25%), 551 tonnes (55%), 685 tonnes (77%) and 343 tonnes (38%) for each 20 year period.

This mushroom integrated ETÇAP*Simulation* model also provides opportunities to show the long term outcomes in a map format. Fig. 8 illustrates the effects of different forest management scenarios between the years 2014 and 2114 based on different forest management intensities on mushroom productivity. These management intensities cause a change in current mushroom production. While the mushroom productivity shows an increment in only 72 ha area between 2014 and 2114, it shows a reduction in approximately 3959 ha area in the NI scenario. On the contrary, in other scenarios the increased amount of mushroom productivity areas was estimated to be 3214 ha, 2863 ha and 2159 ha and the decreased amount of mushroom productivity areas was estimated to be 1609 ha, 1658 ha and 2270 ha for T1, M1 and M6 strategies, respectively.

4. Conclusions

Over the last few decades, forest management planning has evolved from the classical planning approach with only timber production to the multiple-use management approach. While classical planning aims maximum sustainable timber production, the new planning approach accommodates the sustainable management of multiple forest values. In classical planning, as all forest areas are subject to maximum timber production, minimum harvesting ages are decided for each tree species based on site quality. In the multiple-use planning approach, however, forests are stratified into management units according to different forest values or functions such as timber production, soil protection, water production and non-wood forest products (e.g. mushrooms, berries etc). Determining minimum harvesting ages for the sustainable utilization of multiple values is a great challenge in forest management planning. As in the current practice in Turkey, however, longer harvesting ages are generally decided for conservation dominated areas due to the absence of relevant information.

Specifically, the analysis of forest dynamics demonstrated that mushroom occurrence and productivity can be improved with timber-oriented or multipurpose-oriented forest management scenarios by increasing the intensity of forest management interventions. However, the absence of management interventions may cause a great reduction in mushroom occurrence and abundance over a long term projection. Such results mainly correspond to Bonet et al. (2012) who indicated that moderate thinning intensity may immediately increase the productivity of the *Lactarius* group mushroom in *P.pinaster* forests. Also, the study conducted by de-Miguel et al. (2014) showed that low forest management intensities may result in a progressive reduction in mushroom production in pine dominated forests. It is important to note that the forecast of forest dynamics analyzed here is more of a deterministic approach, and thus stochastic events such as fire and storms are not considered within the simulation. In another study, however, such natural disturbances may have to be integrated further into the decision making process to understand the real dynamics of forest ecosystems which happen naturally over time.

In conclusion, this study showed that both minimum harvesting ages and the intensity of forest management interventions are quite important leverages to improve mushroom productivity and occurrence during the integration of mushroom production into forest management plans. Simulations of the multipurpose-based forest management approach would probably lead to lower estimations of spatial distribution areas and productivity of mushroom than the timber-oriented forest management policy would. The multiple-use planning approach seems to contribute less to mushroom productivity and occurrence than the timber-oriented approach does. In fact, determining optimal harvesting ages and the intensity of forest management interventions for each forest value presents a great challenge for decision makers. Furthermore, the DSS tools like *ETÇAPSimulation* are of great importance to understand the long term effects of various management strategies on forest dynamics. In the case of the joint production of timber and mushroom, active management of forest resources seems to be vital in integrated forest management planning.

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