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Different Organizational Models of Private Forest Owners as a Possibility to Increase Wood Mobilization in Slovenia and Serbia

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Abstract

The importance of renewable energy resources has increased over the last decades due to the European Union renewable energy policy and particularly its climate change mitigation objectives. There is a need to mobilize additional wood resources from private forests in order to meet ambitious renewable energy targets and the demand for wood. Due to the conditions prevailing in privately owned forests in Slovenia and Serbia characterized by a large number of still disorganized private forest owners with fragmented and small-scaled forest properties, wood mobilization strongly depends on owners' organization and cooperation. The purpose of this study is to determine the possibilities for wood mobilization from private forest properties in Serbia and Slovenia, and propose organizational models on this basis and experience from the selected case countries. Surveys were conducted in Slovenia (n=622) and Serbia (n=248) on random samples of private forest owners. Analysis of wood mobilization potentials in Serbia and Slovenia showed that the harvesting intensity in private forests is below the potentials, therefore the preconditions to increase the level of wood mobilization exist. The main obstacles to the increase in the current level of wood mobilization in Serbia are biodiversity and the protective forest function, as well as high acquisition costs, also stated as the main obstacle in Slovenia. Moreover, it appeared that the majority of private forest owners in both countries believe that better logistics and infrastructure and interest association of private forest owners are potential solutions leading to an increase in the level of mobilization. Four models of private forest owner organization are proposed and they take into account the characteristics and attitudes of owners as well as activities in supply chain, including timber sales arrangement, construction and maintenance of forest roads, harvesting, measurement and quality assessment of timber, transportation, invoicing and payments.

Keywords: renewable energy resources, wood mobilization, private forest owners, organizational models

1. Introduction

The importance of renewable energy sources has increased over the last decade particularly due to the European Union renewable energy policy and its climate change mitigation objectives. Energy security issues, rural policies as well as income and employment generation related to bioenergy production have all played important roles (Hatemaki et al. 2014).

Renewable energy policies have consequently been developing rapidly, culminating with the European Union (EU) Renewable Energy Directive 2009/28/EC (hereafter EU-RED), which sets mandatory targets to all member states. The EU will have reached a 20% share of energy from renewable sources by 2020 (Directive 2009, Mantau et al. 2010, Blennow et al. 2014, Halder et al. 2014, Posavec et al. 2015). In addition to the EU-RED, the importance of renewable energy sources has also been recognized in the EU Forest Strategy (EC 2013) and Climate and Energy Framework for 2030 (EC 2014). The EU Forest Strategy argues that forest-based biomass »is gaining market interest« providing »opportunities to maintain or create jobs and diversify income in a low-carbon green economy« (EC 2013). Furthermore, it is noted that »according to the National Renewable Energy Action Plans, biomass will still be the main source of renewable energy in 2020« (EC 2013). In addition to other activities, strategic orientations defined by this document include the following: a) the exploration and promotion of a fuller use of wood as a sustainable, renewable, climate and environment friendly raw material and b) the assessment of potential wood supplies and facilitation of increased sustainable wood mobilization (EC 2013).

In order to meet ambitious renewable energy targets, it is necessary to imply a far more intensive use of forest resources (Schwarzbauer 2010) and mobilize additional wood resources (mainly from fragmented private forests) to meet the demand for wood (Rauch and Gronalt 2005, Lindstad et al. 2015).

Based on EU-RED and the recognized importance of renewable energy sources, EU countries (including Slovenia) have developed and implemented their National Renewable Energy Action Plans. In addition to the promotion of production and use of energy wood from forests (Beurskens and Hekkenberg 2011), they include national policies and policy recommendations for the development of renewable resources. Policy recommendations have been successfully converted to measures leading to an increased mobilization of wood. Serbia initiated the process of harmonization of national legislation with the EU policy concerning renewable energy as part of its pre-accession negotiations. Therefore, Serbia adopted the National Renewable Energy Action Plan until 2020 (NREAP 2013), defining clear objectives in terms of conditions for energy production from renewable energy sources. In these strategic plans private forests were addressed in terms of their wood mobilization potentials.

Considering that private forests in Slovenia and Serbia are characterized by a large number of still disorganized private forest owners (hereinafter PFOs) of fragmented and small forest properties and their continuous fragmentation (Glück et al. 2010, Glück et al. 2011, Pezdevšek Malovrh et al. 2011), wood mobilization will strongly depend on owner readiness to supply woody biomass to the energy market (Posavec et al. 2015, Nonić et al. 2015). In addition, Blennow et al. (2014) report that despite great potentials and needs for additional wood mobilization, a growing number of PFOs in Europe (mostly with fragmented forest properties) do not participate in market wood supply. Therefore, PFOs cannot be expected to supply the amounts of woody biomass for energy required to meet the forest biomass share of EU 2020 renewable energy targets. The most important problems affecting wood mobilization are forest property fragmentation, the lack of PFOs organizations and insufficient motivation of PFOs for harvesting (EC 2008). Rauch and Gronalt (2005) state that the problem of low wood mobilisation is the result of structural disadvantages in small-scale forest properties, bad market position of PFOs, the lack of forest management knowledge and experience, low volumes supplied per forest owner, low machine utilisation and difficulties in promotion. Additional reasons for the low level of wood mobilization from small-scale forest properties are the lack of time needed for wood felling (Suda and Warkotsch 2002), the increase of felling costs, the age of PFOs (Bolkesjo and Baardsen 2002), the low level or the lack of profits from forest management, incomes independency from forestry, the lack of knowledge and skills related to forest management and the lack of cooperation among PFOs (Stern et al. 2013). In addition, there are new types of PFOs who do not want to fell trees, since they primarily value their forest as a place for leisure or hunting (Boon et al. 2004, Hogl et al. 2005, Ní Dhubháin et al. 2007, Pezdevšek Malovrh et al. 2015, Živojinović 2015).

Fundamental approaches that can lead to increased wood mobilization are based on PFOs cooperation and the formation of more PFOs associations and cooperatives (Glück 2002, Nichiforel and Schanz 2009, Becker 2010, Schwarzbauer et al. 2010, Mendes et al. 2011). In addition, it is necessary for PFOs to overcome their distrust towards the existing organizations primarily in the new EU member states as a result of past negative experience caused by general collectivism (EC 2008). Schwarzbauer et al. (2010) argue that wood mobilization is particularly high in formal forms of cooperation (different forms of partnerships, associations or PFO cooperatives). Moreover, Becker (2010) highlighted cluster initiative and local forest management cooperatives as forms of PFO organization with the highest significance for wood mobilization. The classification of PFOs into groups, their attitudes (Schaffner 2008) toward wood mobilization (Huber et al. 2013) and motivation have great importance for the solving of this problem.

The aim of this paper is to determine the possibilities for wood mobilization from private forest properties in Serbia and Slovenia on the basis of: 1) PFOs characteristics, 2) wood potential for mobilization as the difference between the increment and harvesting rate and 3) the attitudes of PFOs toward wood mobilization. Based on the results and models existing in the selected case countries, different PFOs organization models are proposed in order to increase wood mobilization. The following activities in the supply chain were analyzed in the determination of the models: timber sales arrangement, construction and maintenance of forest roads, harvesting, measurement and quality assessment of timber, transportation, invoicing and payment.

2. Background

2.1 Brief description of private forests

Private forests are an important resource of national economies in Serbia and Slovenia. Forest cover accounts for 29.1% (2,252,400 ha) of the territory in Serbia, of which 47% (or 1,058,400 ha) are privately owned forests (Banković et al. 2009). Private forests are characterized by small-scale and fragmented forest properties owned by a large number of forest owners (about 900,000). More than 72% of the owners have properties smaller than 1 ha, while the average forest property size reaches 1.27 ha (Glück et al. 2011). Since 2006, some »large« private forest owners (churches and religious communities) have emerged as a result of the restitution process. By the end of 2014, 23,195 ha of forests and forest land were returned to churches and religious communities (Restitution 2014). The process of property restitution to churches, religious communities and physical persons has not been completed yet. In Serbia private forest owners associations (PFOAs) do not have great significance and impact on forest policy. The first PFOAs were established in Serbia with the assistance of FAO projects in 2006 (Nonić et al. 2010). By 2015, 22 PFOAs were established at the local level, as well as the Serbian Federation of Private Forest Owner Associations as the umbrella organization in 2009. However, due to the necessary change in their legal form, only eight PFOAs have continued to be active after 2011.

In Slovenia, forest cover accounts for 58.4% of the territory (1,183,433 ha). According to data from the 2010–2020 forest management plans, Slovenian PFOs control a larger share of the country's forests than in any other country in the region (76% of approximately 1.2 million ha). The property is divided into approximately 314,000 individual plots, owned by roughly half a million owners. Individual properties are mostly small (64% less than 1 ha) and fragmented, while individual owners possess three plots on average (Pezdevšek Malovrh et al. 2010). That situation resulted in an underutilized management of private forests (harvesting rate below potential), which hinders wood mobilization. Although PFOAs started to develop in Slovenia at the beginning of the 2000s, membership is still low (less than 1% of owners are members of PFOAs). Thirty local PFOAs were established by 2015 (Leban 2014). In addition to local PFOAs, the Association of Private Forest Owners was established at the national level in 2006. Its main goals are to promote cooperation among owners, support the establishment of new local associations and facilitate links between the public forest administration and private forest owners (Mori et al. 2006).

2.2 Potentials of wood mobilization from private forests

The potentials of wood mobilization from private forests in Serbia and Slovenia was analyzed on the basis of data obtained from public forest administrations. The realizable potential was calculated as the difference between the annual growth increment and the volume of wood harvested and was presented as the percentage of utilization (Tables 1 and 2).

In the Serbian study area, the overall potential for wood mobilization is 616,689 m^3/yr, and the average utilization amounts to 57% of the annual growth incre-

Table 1 Potentials for wood mobilization from private forests in the Serbian study area

Forest region	Increment, m^3/yr	Annual cut, m^3/yr	Realization, %
Belgrade	2353	656	28
Kučevo	47,970	50,517	105
Boljevac	98,278	49,815	51
Despotovac	26,595	23,820	90
Kragujevac	30,942	7954	26
Loznica	75,849	22,144	29
Užice	30,776	13,750	45
Prijepolje	37,191	19,295	52
Ivanjica	28,875	11,895	41
Raška	22,022	9038	41
Kraljevo	17,257	9398	54
Kruševac	21,900	18,859	86
Kuršumlija	31,129	18,384	59
Niš	21,194	4307	20
Pirot	20,207	17,682	88
Leskovac	61,804	37,897	61
Vranje	42,347	37,917	90
Total	616,689	353,328	Average: 57

Source: PE »Srbijašume« 2013

Table 2 Potentials for wood mobilization from private forests in Slovenia

Regional unit	Increment, m^3/yr	Annual cut, m^3/yr	Realisation, %
Tolmin	467,508	238,086	51
Bled	18,778	187,158	101
Kranj	388,995	263,703	68
Ljubljana	618,765	428,648	69
Postojna	238,533	206,704	87
Kočevje	257,199	185,747	72
Novo mesto	428,966	299,006	70
Brežice	311,833	340,363	109
Celje	365,079	228,999	63
Nazarje	271,003	206,396	76
Slovenj Gradec	236,247	214,013	91
Maribor	460,081	324,307	70
Murska Sobota	126,244	114,705	91
Sežana	239,204	121,154	51
Total	4,594,435	3,358,988	Average: 73

Source: Report of Public Forestry Service of Slovenia about forests for the year 2014, 2015

ment (PE »Srbijašume«, 2013). Based on the data for 2014, the total available potential for wood mobilization in Slovenia is 4,594,435 m^3/yr, and the average utilization amounts to 73% of the annual growth increment (Report of Public Forestry Service of Slovenia about forests for the years 2014, 2015).

3. Methods

3.1 Survey method

Similar representative nationwide surveys were administered to private forest owners in Serbia and Slovenia with some variation in accordance with the country-specific conditions mainly in organization of forestry sector, in order to determine the possibilities for wood mobilization. The questionnaires were developed as a result of literature analyses and previous socio-economic research related to owner attitudes, motivation and behavior related to the management of their forest properties and wood mobilization (Pezdevšek Malovrh 2010, Glück et al. 2011, Pezdevšek Malovrh et al. 2015, Posavec et al. 2015). The survey questioned owners about a range of issues, and several questions were analyzed in relation to the research aims. These were related to the mobilization of wood resources (PFOs attitudes towards mobilization, obstacles or problems that prevent them to increase the level of mobilization), forest management and socio-demographic characteristics of PFOs.

Personal data about PFOs were found in the encrypted relational databases of the Land and Property Register obtained from the Surveying and Mapping authority of the Republic of Slovenia (SMARS 2007) in Slovenia and from the public enterprise for state forest management »Srbijašume« and Republic geodetic authority in Serbia. Therefore, our target population in both countries consisted of individual PFOs.

At the time of the research, 330,949 distinct PFOs were listed in the Slovenian Land and Property Register and the following PFOs were excluded from study population as they were not considered as a part of our target population or could not be used in our study due to the missing of relevant data: co-owners, church, commons, companies, owners younger than 15, and those without an address or living abroad. From the final population, PFOs were selected with a simple random sample. The data were obtained through an email survey. In order to maximize response rates and reduce survey error, the Dillman's Tailored Design Method (TDM) was partly adopted. As recommended by Dillman (2007), the postal and e-mail survey involved a sequence of five contacts, two of which were used in our data collection, including a questionnaire and cover letter with a token incentive and replacement questionnaire 2–4 weeks later. The reply envelopes were enclosed by postal survey to make it easier for the respondent to return the questionnaire.

In Serbia, a stratified random sample was selected from 107,790 PFOs. The criteria for PFOs classification to strata included the existence of PFOAs in the past, as well as the geographical distribution (forest territorial units and cadastral municipalities) and size of forest properties. On the basis of previously mentioned criteria, 10 municipalities were selected as territorial units in four forest areas (Severnokučajsko, Timočko, Južnokučajsko and Podrinjsko-kolubarsko forest area). All PFOs within the territorial units were divided into strata according to their property size (up to 0.99 ha; from 1 to 4.99 ha; from 5 to 9.99; from 10 to 19.99 ha; more than 20 ha). 310 PFOs were selected randomly (confidence level of 95% and confidence interval 5%) within each stratum in order to ensure that all groups are equally represented. The data were collected through personal interviews.

The survey was distributed via email to 2012 PFOs in Slovenia, while in Serbia 310 PFOs were visited for face-to-face interviewees. The total response rate for the survey in Serbia was 80% (248 replies) (Nonić et al. 2013), while in Slovenia it was 30.9% (622 replies). Taking into account the high non-response rate in Slovenia, mainly caused by errors in the national register, the results should be interpreted tentatively. The questionnaire was tested in October 2012 and the survey was carried out in the period from November 2012 to July 2013 in Serbia. The questionnaire test in Slovenia was conducted between February and March 2015 and the survey was conducted from March to May 2015.

Due to confidentiality concerns, non-respondents were not followed further, so the differences among those respondents were not estimated. Representativeness of the sample was checked by inspecting spatial distribution of the respondents to test their random distribution across the country.

3.2 Data analysis

Data analysis in this study was performed in two stages. The first stage involved secondary data analysis to estimate the potentials of wood mobilization from private forests in Slovenia and Serbia. The second stage involved a summary of collected data through the use of frequency distribution and selected location measures (mean). Data analysis was conducted by the SPSS 20 statistical software package.

4. Research framework

As recognized by previous research, efficient PFOs organization at the local level is an important step in solving the problem of wood mobilization from small-scale forest properties (Nonić and Glavonjić 2012, Nonić et al. 2011, Pezdevšek Malovrh 2010, Glück et al. 2011, Weiss et al. 2012).

There are a number of PFOs organization models that can be divided into two major groups: a) organization with a focus on management, marketing support and provision of services such as technical and financial support, as well as knowledge and information exchange, and b) organization focused on gaining political support by including PFOs in the political process, with active participation in the creation of policy frameworks for the forestry sector (Weiss et al. 2012).

According to Rauch and Gronalt (2005), there are two common distinct supply chain types from small-scale forests: a) PFOs with small forest properties that »handle all forest activities including harvest planning, felling and timber haulage by themselves and sell directly to the industry or trader« or b) PFOs who »may be members of a Forest Owner Cooperative, an organization of forest owners that bundles harvested timber and typically sells to the wood processing industry«. Similarly, Mendes et al. (2011) and Glück (2002) consider that resolving the aforementioned issue of wood mobilization can be achieved through the potential of forest cooperatives and associations.

Table 3 Basic characteristics of private forest owners

Characteristics of private forest owners, %	Serbia	Slovenia
Gender		
Male	94.8	65.4
Female	5.2	34.6
Age	n.a	Average 57.5
<30 years	2.8	3.9
30–60 years	69.0	54.1
>60 years	28.2	42.0
Primary occupation		
Farmer	36.7	–
Unemployed	10.1	5.7
Pensioner	22.2	49.5
Student	–	0.4
Employed	19.8	38.5
Other	11.3	5.9
Level of education		
Primary school	41.5	18.4
Secondary school	48.4	59.2
University education	10.1	22.2
The average distance from the residence to the forest property		
≤5 km	65.3	67.9
6–20 km	27.0	18.9
21–100 km	7.7	13.3
Size of forest property	Average: 7.4	Average: 7.5
<1 ha	8.5	35.9
1–5 ha	52.0	40.1
5–10 ha	20.2	8.6
10–20 ha	11.7	5.9
>20 ha	7.7	9.5

In our study, Germany and Austria were chosen as case countries for an overview of existing PFOs organizational models, based on the fact that these countries have a long tradition in PFOs cooperation, which resulted in a high level of exploitation of forest resources. Moreover, due to similar forest sector organization models, these experiences can be applied in the analyzed case countries.

According to research studies conducted in Germany, there are three different PFOs organizational models depending on wood mobilization and the wood supply chain (HAF 2008). »Model I« is an organization of PFOs who independently perform all forest management tasks. According to this model, an association fulfils the role of a coordinator among the PFOs, forest service and the wood processing industry. »Model II« is an administrative version of the association that performs the role of a coordinator between the forest owner and forest service. »Model III« is an association involved only in the coordination of PFOs, while coordination in other areas is carried out by other, larger associations or specialized marketing companies.

In Austria, Rauch and Gronalt (2005) distinguished among four PFOs organizational models, depending on the knowledge related to forest management: 1) the »model of PFOs who are acting independently«, 2) the »Styrian model«, 3) the »individual accounting model« and 4) the »dividend model«. Within the first model, PFOs take the greatest share of responsibility. In the »Styrian model« owners themselves perform the activities of harvesting and transport, while the association sells assortments concludes contracts and sorts the invoices to individual owners. The »individual accounting model« is characterized by joint forest management of several owners, while the income and expenses are calculated independently for each owner. The »dividend model« involves joint forest management of all members, whereby revenues and expenses are associated with a joint account, i.e. there is no individual accounting for each plot.

5. Results

5.1 The basic characteristics of private forest owners

The profiles of PFOs are presented in Table 3. The results show that PFOs in Serbia and Slovenia are mostly males (in Serbia 94.8% and in Slovenia 65.4%), aged between 30–60 (69% in Serbia and 54.1% in Slovenia), mainly with high school education (48.4% in Serbia, and 59.2% in Slovenia). The basic occupation of PFOs in Serbia is farming (36.7%), while in Slovenia most of them are pensioners (49.5%). More than 60% of PFOs in both countries live close to their property (at a distance shorter than 5 km). The average size of a property in Serbia and Slovenia is almost identical (7.4 ha in Serbia and 7.5 ha in Slovenia), with a predominant share of small forest properties of up to 5 ha (60.5% in Serbia and 76.0% in Slovenia).

5.2 Private forest owner attitudes towards wood mobilization

There were eight statements in the survey that measured the PFOs' attitudes related to wood mobilization (opportunities and potential solutions leading to an increase in the level of mobilization), whereby due to the better comparability of the results, responses to the offered statements are recoded into three groups (agreement, disagreement and don't know) (Fig. 1).

It appeares that the majority of PFOs in both countries believe that a better logistics and infrastructure (better openness of forest complexes) are potential solutions leading to an increase in the level of mobilization. Moreover, PFOs in Serbia think that interest association of PFOs (42.3%) and market share and marketing (41.5%) have a decisive impact on the increase in the level of wood mobilization from private forests. PFOs stated that education and training (18.5%), greater involvement of employees in public enterprises (11.3%) and the existence of forest extension services (19.8%) do not have an impact on wood mobilization.

A 52.3% of respondents in Slovenia think that interest association of PFOs and education and training (36.6%) have an important role in solving the problem of insufficient wood mobilization from private forests. Moreover, they also consider that the use of wood for biomass (36.4%), more intensive participation of the state through grants, loans and fiscal policy instruments (34.8%) and more intensive extension service offered by public forestry service (32.3%) can contribute to the solving of the problem.

5.3 Obstacles to the increase in the level of wood mobilization

Approximately a half of PFOs in Serbia (50.4%) think that the level of mobilization is unacceptable with a possibility for improvement, while the situation in Slovenia is the opposite, as 51.5% of PFOs consider the level of mobilization suitable.

PFOs in Serbia consider that conservation of biodiversity and protective functions of forests (52.4%),

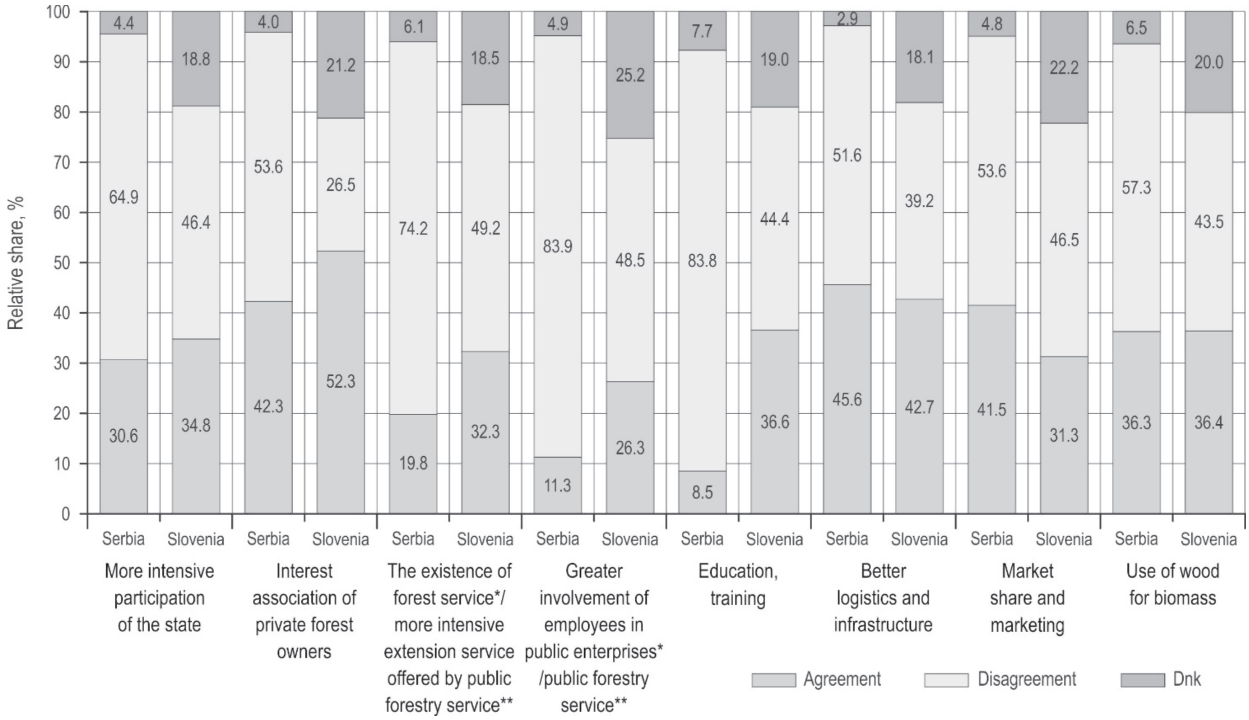

Fig. 1 Attitudes of PFOs towards the opportunities and potential solutions leading to an increase in the level of mobilization. Notes: Agreement = strongly agree plus agree; disagreement = disagree plus strongly disagree; Dnk = Don't know. The original scale and coding was done as strongly agree – 5; agree – 4; I do not know – 3; disagree – 2 and strongly disagree – 1; * Offered response for Serbia; ** offered response for Slovenia (due to different organization of forestry sector)

high acquisition costs (22.6%) and unfavorable technical characteristics of the equipment (18.1%) (Table 4) are the main obstacles to an increase in the level of wood mobilization. In addition, 27% of PFOs consider that there are no obstacles related to wood mobilization from private forests.

Table 4 The main obstacles to an increase in the level of wood mobilization (multiple answers)

Obstacles	Serbia, %	Slovenia, %
Legislation	3.2	13.7
Lack of planning documents*	3.6	6.2
Unfavorable technical characteristics of the equipment	18.1	15.8
Biodiversity conservation and protective functions of forests	52.4	4.9
High acquisition costs	22.6	27.5
Social functions of forests	6.5	6.5
No obstacles	27.0	37.1

* For Slovenia, an offered response was »management plans«

The largest number of PFOs in Slovenia considered that there were no obstacles related to wood mobilization (37.1%), stating that high acquisition costs (27.5%), unfavorable technical characteristics of the equipment (15.8%) and legislation (13.7%) are the main obstacles.

6. Proposed models of private forest owner organization

The cooperation of PFOs is one of the key instruments to increase the level of wood mobilization from private forests as recognized in previous researches (i.e. Rauch and Gronalt 2005, MCPFE, DG AGRI, UNECE/FAO 2010, Becker 2010, Pezdevšek Malovrh 2010, Nonić and Glavonjić 2012, Weiss et al. 2012), whereby the choice of organizational form of cooperation depends on the identified types of PFOs (Schwarzbauer and Stern 2010, Pezdevšek Malovrh et al. 2015, Nonić et al. 2013).

Analysis of wood mobilization potentials in Serbia and Slovenia showed that the harvesting intensity in private forests is below the potentials; therefore, there are preconditions to increase the level of wood mobilization. Moreover, PFOs in both countries think that

Fig. 2 Activities within »Model I«

there are possibilities for improving the level of wood mobilization and that interest association of PFOs can contribute to the solving of the problem. Based on the above facts and the experience from the selected case countries (Austria and Germany), four models[1] of PFOs organization have been proposed to boost the mobilization of wood from private forests. The choice of a particular model depends on the PFOs' experience in the forests management, professional and technical capacity of PFOs, offers of service providers (silviculture, harvesting and transportation), as well as the local market of timber assortments.

»Model I« is proposed for PFOs who possess skills and knowledge in the field of forestry and are full-time engaged in their forest. According to previous research, these owners have been referred to as »active« owners (Pezdevšek Malovrh et al. 2015), »the owners focused on timber production« (Kline et al. 2000, Boon and Meilby 2007), »businessmen« (Mizaraite and Mizaras 2005), »the owners with full-time work in forestry« (Wiersum et al. 2005) or »economically oriented owners« (Loenstedt 1997, Becker et al. 2000, Bieling 2004, Ingemarson et al. 2007). Timber production as the predominant management orientation is of high importance, because they generate economic revenue (Ní Dhubháin et al. 2007, Pezdevšek Malovrh et al. 2015). The income from the forest is largely involved in the total annual household income. Within this organizational model, PFO organization performs the arrangement of timber sales, measurement and quality assessment of timber, invoicing and payment. With timber sales arrangements, the PFOs ensure contract-fixed price of wood throughout the year. PFOs or members of the organization perform timber harvesting and its transportation to the wood processing industry. In addition, PFOs are involved in the measurement and quality assessment of timber. Forest road construction and maintenance is performed by a contractor (entrepreneur) hired by the organization, because of the high initial investments in the purchase of machinery (Fig. 2). The proposed model of PFO organization is similar to cooperatives.

Similar results were reported by Rauch and Gronalt (2005) in the framework of the »Styrian model«, in which owners perform harvesting and supply of wood to the wood processing industry, while other activities are carried out by the employees of the association and representatives of the wood-processing industry. According to a research in Germany, in one of the organizational models, the owners within the association carry out all necessary activities, including forest road construction (HAF 2008).

»Model II« is similar to »Model I« and is proposed for the same group of PFOs with the difference that the transportation of timber is performed by a contractor due to high costs and long amortization period of the transportation vehicles (Fig. 3).

Within »Model II«, activities of the PFOs organization end on a roadside landing or after the measurement, quality assessment and loading of timber. The proposed model of PFOs organization is the same as in Model I (cooperatives).

»Model III« is proposed for PFOs who live close to their forest property, whose main source of income is not related to forestry, which determines their valua-

[1] Based on the experiences from case countries, four models of owner organization are proposed in order to more easily present activities and actors within the model, where the proposed models can also be seen as one model with four different business plans.

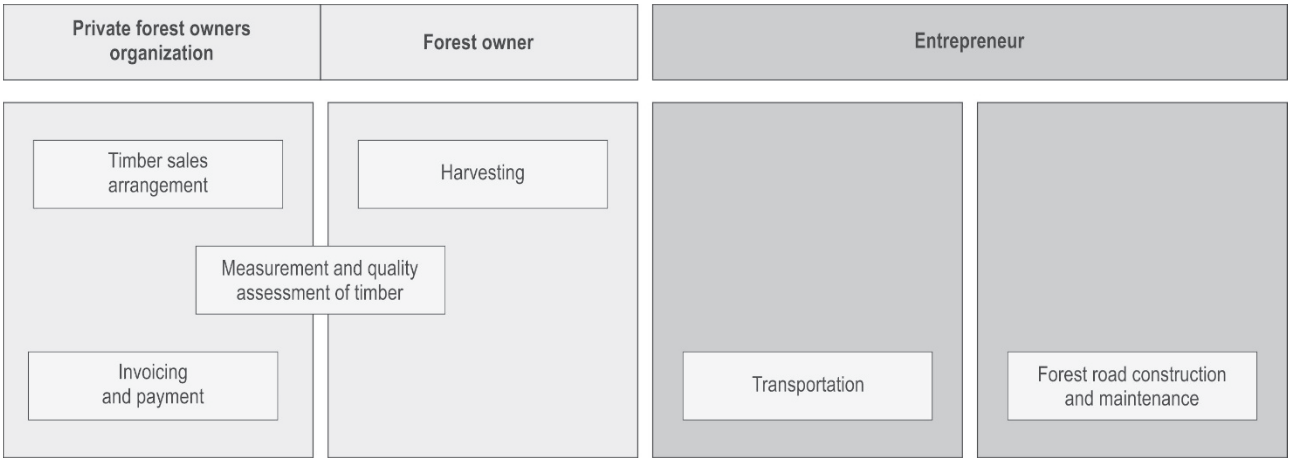

Fig. 3 Activities within »Model II«

tion of production and other forest functions. According to previous research, these owners are referred to as »multi-objective owners« (Kuuluvainen et al. 1996, Karpinnen 1998, Kline et al. 2000, Boon et al. 2004, Mizaraite and Mizaras 2005, Nonić et al. 2013, Pezdevšek Malovrh et al. 2015,) or »multi-functional« owners (Wiersum et al. 2005). Forestry neither affects the total annual household income nor has a small impact on it. They spend little time performing activities in their forests and are, therefore, without experience. A PFOs organization performs timber sales arrangement, measurement and quality assessment of timber, and invoicing and payment to owners. As in the previous models, the arrangement of timber sales ensures a contract-fixed price of wood throughout the year. In addition, the PFOs organization performs tasks such as harvesting and transportation contracts, forest road construction and maintenance contracts, while these works are carried out by a contractor (Fig. 4). In addition, together with PFOs, the association controls all contracted activities.

The »individual accounting model« in Austria and »model II« in Germany have similar characteristics. Within these models, owners do not perform work in their forest and leave these activities to private companies (Rauch and Gronalt 2005). In addition, Lutze (2010) studied the »business manager« model in which employees of the association carry out part of the tasks

Fig. 4 Activities within »Model III«

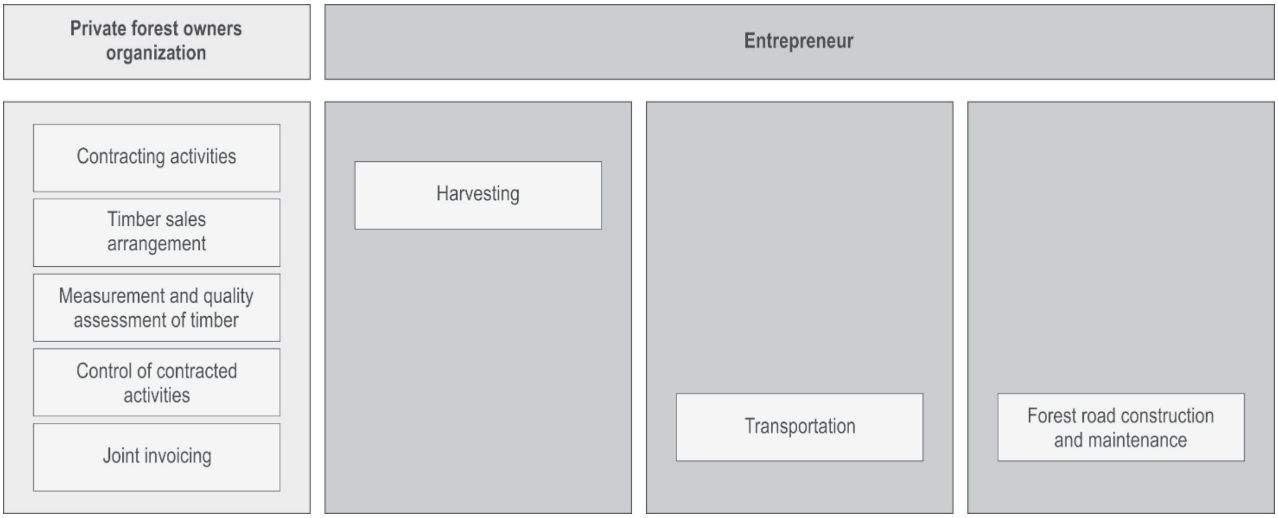

Fig. 5 Activities within »Model IV«

and perform operational management of other activities in the supply chain.

»Model IV« is proposed for absent owners, including owners who live far away and have no contact with their forest property, the ones who live abroad or old owners with no descendants willing to manage their forests. These owners are referred to as »new« or »urban« forest owners (Ziegenspeck et al. 2004, Hogl et al. 2005, Schwarzbauer et al. 2010, Weiss et al. 2012), »resigning owners« (Boon et al. 2004) or »passive« (Kline et al. 2000, Pezdevšek Malovrh 2015) forest owners. The owners have no knowledge and experience in forest management and, therefore, are not interested in the management of their forest property. Moreover, none of the forest management objectives are important to them except ownership and keeping the forest in the family. These owners were created as a result of demographic change, the process of restitution or acquisition of forest ownership through the process of state or social property privatization (Nonić et al. 2013). A PFOs organization acts similarly as in the previous model, except that there is no classification of invoices to the owners individually because of joint forest management. Therefore, both invoices and payments are related to the joint account of the organization (Fig. 5). PFOs are not physically present and do not participate in any of the activities. All activities are arranged and performed exclusively by the organization. Therefore, the PFOs organization arranges harvesting and transportation contracts, forest road construction, maintenance contracts and timber sales, performs the measurement and quality assessment of timber, invoicing and payment to the owners. Measurement and grading is performed while loading on a truck-road. There is no need for an individual measurement for each owner, but only of the total cargo to be shipped.

The management is carried out in the total area, so that every member of the organization receives some income from forests in accordance with the volume and value of timber or their share in the total forest value. In the »dividend model« Rauch and Gronalt (2005) report similar results, according to which joint forest management is carried out and owners receive funding according to their forest property size, i.e. their share in the total managed forest complex.

7. Conclusions

The study explored the potentials of wood mobilization from private forests in Serbia and Slovenia, the characteristics of PFOs, PFOs attitudes related to wood mobilization and the main obstacles.

On the basis of the results, it was established that there are potentials for additional wood mobilization. It was also found that PFOs are mainly representatives of the elderly population, farmers or pensioners with a fragmented forest property. The main obstacles to the increase in the current level of wood mobilization in Serbia are the conservation of biodiversity and the protective forest function, as well as high acquisition costs, also stated as the main obstacle in Slovenia. In addition, about one third of owners in Slovenia considered that there were no obstacles to wood mobilization improvement, and it can be concluded that Slovenian owners seem to be uninterested. This may be a consequence of the 2014 ice break in Slovenia and the resulting increase in the quantity of wood on the market, which was not substantial in Serbia.

Despite the obstacles related to wood mobilization, this paper also presents potential solutions leading to an increased wood mobilization through better logistics and infrastructure, more intensive use of wood for biomass, intense participation of the state (through loans, subsidies and fiscal policy instruments) and PFOs organization.

On the basis of the obtained results and experience from the case countries (Austria and Germany), four models of PFOs organization are proposed, as the cooperation of PFOs is one of the key instruments to increase the level of wood mobilization from private forests. The models take into account the characteristics and attitudes of PFOs, as well as the activities in the supply chain, including timber sales arrangements, construction and maintenance of forest roads, harvesting, measurement and quality assessment of timber, transportation and invoicing and payment. Moreover, models can also be proposed to different types of PFOs. They can be included in the production of business plans and their choice depends on their forest management goals, professional and technical capacities of the owner, local service providers' offer and local market of timber assortments.

The proposed models for active owners with full-time work in forestry provide some security in forest management and business, as the PFOs organization arranges sales and ensures contract-fixed prices of wood throughout the year. In this way, forest owners have secured timber sales and are encouraged to increase wood mobilization.

For PFOs whose main source of income is farming or another economic activity, the presented model of organization enables professionalization of a whole range of forestry services. PFOs without sufficient motivation, time or knowledge required for forestry works have the possibility to delegate forest management activities to relevant professional workers, which could result in the improvement of the existing level of wood mobilization from small forest properties.

For absent owners, the benefits from PFOs organization would be mainly determined by a certain type of security reflected in the sustainable management of their forest by a professional thereby generating certain revenues. An important strategic measure for these owners would be their inclusion in professional networks and information channels, especially if one bears in mind the growing number of these owners and the tremendous potential of wood mobilization from their forests.

In the coming period, it is first of all necessary for state institutions to stimulate wood mobilization from private forests through various (regulatory, economic and informational) policy measures, taking into account different types of forest owners.

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Developing a Volume Model Using South NTS-372R Total Station without Tree Felling in a *Populus canadensis* Moench Plantation in Beijing, China

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Abstract

Volume table preparation using the traditional method and a collection model requires the harvest of approximately 200–300 trees of individual species. Although high precision could be achieved using that method, it causes huge damage to the forest. To minimize these losses, in this study, a South NTS-372R total station with a precise angle and distance measurement mode was used to measure 507 trees of Populus canadensis Moench without single tree felling. Moreover, the C# programming language was used in this study and the collected volume data were inserted in the total station. Using this method, a real-time precise measurement of volume could be achieved. After data collection, the optimal binary volume model of Populus canadensis Moench could be obtained through a comparative analysis. It turns out that the Yamamoto model is the optimal binary volume model (also known as two predictor variable model), with 0.9641 as the coefficient of determination (R^2) and 0.19 m^3 as the standard deviation of estimated value (SEE), which presents a good imitative effect. Moreover, it showed relative stability with the general relative error (TRE) of –0.12% and the mean system error (MSE) of –1.24%. The mean predicted error (MPE) of 1.18% and the mean predicted standard error (MPSE) of 9.25% showed high estimated precision of the average and individual tree volumes. The model has only three parameters, so it is suitable for volume table preparation. Finally, this study will present some new technical methods and means for volume modeling for further application in forestry.

Key words: total station, volume model, Populus canadensis

1. Introduction

Forest volume is a major forest resource indicator, and its estimation is important for forest surveys around the world. Forest production is mainly guided by significant tree volume growth or decline. Volume estimation by scientific and precise methods would be a reliable basis for forest management and planning (Meng 1996).

During a forest volume survey, in most countries, a tree volume table is widely used to improve the work efficiency. The most important and widely used type of tree volume is the trunk volume with bark, which was the research object of this manuscript. Three elements have been considered for developing the regression equation for a volume table, and these are trunk volume with its DBH (diameter at breast height), tree height and stem form. Moreover, three types of volume models with one, two and more than two predictor variables are considered for volume estimation. Consequently, the tree volume tables also could be divided into one-way volume table, binary (standard) volume table and ternary (form class) volume table (Meng 1996, State Forestry Bureau of China 2013). In the case of harvested sample trees, the sectional quadrature method (measurement section method) could be adopted for volume estimation. Generally, 200–300 trees of each species will be randomly drawn

(Meng 1996, Lei 2005, State Forestry Bureau of China 2013 and 1978), and their ground diameter, DBH, tree height and volume of wood will be measured to develop the volume model. Based on comparison and optimization, the optimal volume model could be confirmed for volume table preparation. The precise measurement of the sample volume and the confirmation of the optimal volume model play a decisive role in its accuracy and applicability.

It has been over a century since the binary volume table was developed in 1846 (Meng 1996, Zeng and Tang 2011). Forest scientists have always been engaged in the improvement of the accuracy of the estimation of volume and in the development of various models. At present, more than ten models are commonly used, and those were invented by foresters such as Meyer, Cason, Takada Co-Yan, Meng Xianyu, etc. (Feng 1997, Jin and Ding 2011, Zhong and Zhong 1999). Among these models, the Yamamoto model and the Parabola model are frequently used in China. In 1804, Cotta from Germany made a volume table for beech (Liu and Zhang 1997). In the 1970s, 35 binary volume tables of conifer species and 21 of broadleaf species in a large area were integrated and developed by the Chinese Ministry of Agriculture and Forest (Meng 1996, Zeng 2014). Making the comparison among 3682 tree samples of 14 species, Meng (1982) analyzed the accuracy of a variety of volume equations, which are usually empirical, multivariate or polynomial regression equations and are based on a large amount of experimental data. China has thousands of forest plantations. If the volume tables of all the species need revision, according to the requirements, then for every revision, approximately 300,000 standing trees need to be logged (Meng 1996, Jiao 2013a). This method of calculating the volume table establishes volume equations with relatively high precision, but it causes huge damage to forest resources. Moreover, this method is time-consuming and inconvenient, which is also inconsistent with the purpose of ecological protection.

Based on this concern, Sun et al. (2013) have carried out a study on volume measurement without single tree felling and have used remarkable numbers of advanced instruments to achieve the best results for volume estimation. For that study, volume was measured by using an electronic theodolite on 202 Dahurian larch trees without any tree felling in the Wangyedian Forest Farm, Chifeng, Neimenggu Province. Compared with a traditional volume table, about 85% accuracy was achieved. In another research under a project for the establishment of the volume model in Beijing, the volume of 87 poplars, including *Populus tomentosa* and *Populus canadensis* Moench, both are fast-growing poplar species, had been measured precisely without any tree felling (Jiao et al. 2013a and 2013b). Then, all the 87 poplars were logged and their real volumes measured. Compared with the real volumes, the optimal accuracy of the precision measurements without any tree felling could reach up to 95%. In October 2013, using an electronic theodolite and volume calculation software, Jiao et al. (2013a) measured the volume of 400 groups of 107 poplars. The result of its model prediction achieved by the PSO-SVM algorithm is good. Thus, the function of advanced instruments for conduction measurements, such as precise angle measurement and distance measurement, could be used in the precision measurement of volume without tree felling. However, the major instruments used in these experiments are electronic theodolites that could only achieve angle and distance measurements. Therefore, there is still need for the assistance of relevant software for the volume calculation. Yan et al. (2012) conducted some experiments in Beijing and proved that the more advanced electronic total station could achieve real-time storage and computing of measurement data. This result promotes the possibility of integrating office work and field work in the precision measurement of volume without tree felling.

In this research, the South NTS-372R total station, with precise angle and distance measurement mode and the volume program in the C# programming language inserted in the total station, is used in the real-time precise measurement of the volume of 507 *Populus canadensis* Moench in Beijing without tree felling. After data collection, the optimal binary volume model of *Populus canadensis* Moench could be obtained by comparative analysis, and the model provides new technical methods and tools for further research on volume table preparation.

2. Materials and methods

2.1 Description of sample tree species

Populus canadensis Moench, with its oval and broad crown, taupe, rough bark, caved vertical slits, tall height as well as its large and shining blade, especially in summer, with dense leaves casting green shade, is suitable to be a roadside tree, a shade tree and a tree in shelter-belt plantations. At the same time, it is also a good choice for afforestation in industrial and mining areas and beside houses, villages, roads and water (Fig. 1). The volume table of *Populus canadensis* Moench was prepared in the 1970s during its large scale plantation in Beijing. State Forestry Bureau of China

Fig. 1 Populus canadensis Moench (photographed in 2014)

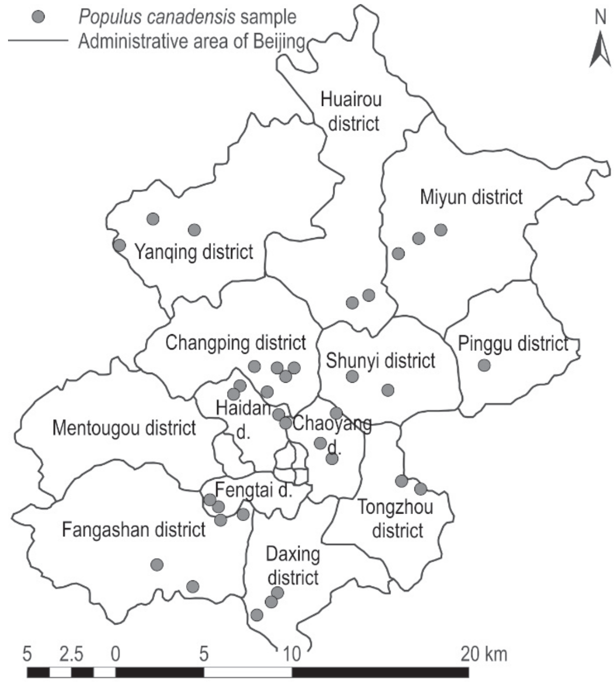

Fig. 2 Distribution of sample collection of Populus canadensis Moench

(1978) and Luo and Kang (2008) realized that those volume tables could not satisfy the current needs and, therefore, needed to be revised. On this backdrop, importance of this research lies in the volume table preparation of *Populus canadensis* Moench using scientific methods and advanced instruments with high precision and accuracy.

In this research, 507 poplars were selected as sample trees, 39 from Daxing District, 25 from Fangshan District, 29 from Fengtai District, 75 from Changping District, 78 from Miyun District, 29 from Yanqing District, 76 from Huairou District, 27 from Chaoyang District, 71 from Tongzhou District and the remaining 58 from downtown and other regions. The sample distribution is shown in Fig. 2. Besides, the sampling scheme of selected trees was as follows:

⇒ all the selected trees were separated according to the DBH class by 2 cm. DBH of sample trees in this research ranged from 8.5 cm to 88.5 cm. In each DBH class, according to height-diameter ratio, the trees with high/middle/low ratio were chosen

⇒ to obtain a standard and precise volume table, the standard *Populus canadensis* Moench with straight trunks were selected and measured

⇒ to carry out of this research, other relevant information of sample areas such as place, terrain, soil, vegetation and forest situation were also investigated and recorded.

2.2 Instrument description

In this study, NTS-372R Total Station, shown in Fig. 3, was used for volume measurement. It is based on the principle of phase method, shooting an extremely narrow and small industrial laser beam on the target without a prism and making use of the diffuse reflection of the target to return the signal. It is a precise

Fig. 3 South NTS-372R total station

instrument, by which some spatial geometric elements, such as the three-dimensional coordinates of the point, its angle and distance, could all be measured. The Nanfang NTS-372R non-prism Total Station is equipped with a 3R-level visible laser, 2″ angular accuracy, 2+2 ppm ranging accuracy with a prism and 3+2 ppm ranging accuracy without a prism. Its measuring time is only 0.5 seconds (Yan et al. 2011). In addition, due to Win CE operating system in this instrument, the C# programming language could be inserted in the system to allow for integrating office and field works for the precision measurement of volume without tree felling.

2.3 Principles and methods

2.3.1 Principles of volume measuring without tree felling

The schematic diagram of volume measurement with no tree felling is shown in Fig. 4. The method needs to take the trunk as the datum formed by the cone in the treetop and several subsequent circular truncated cones and find the sum of their volume, which is the standing tree volume (Xiong et al. 2007, Whitney et al. 2002). The measurement principle and calculation model is:

$$V = V_1 + V_2 + V_3 + ... + V_{\text{treetop}} \qquad (1–1)$$

The formula for the volume of each circular truncated cone is as follows:

$$V_{\text{circular truncated cone}} = \frac{\pi h(D_{\text{top}}^2 + D_{\text{top}} D_{\text{bottom}} + D_{\text{bottom}}^2)}{12} \qquad (1–2)$$

Where:

D_{top} diameter of the upper cross-section
D_{bottom} diameter of the bottom cross-section
H height of any circular truncated cone on the trunk.

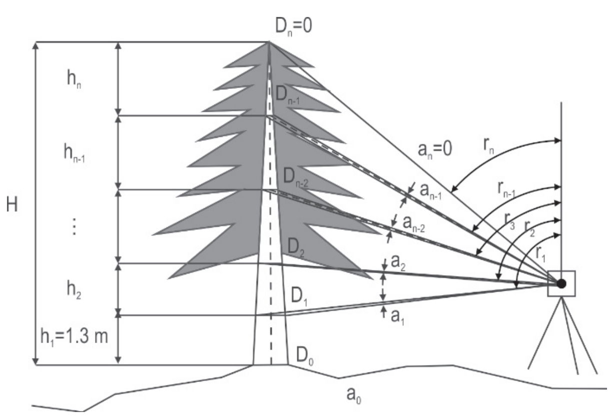

Fig. 4 Schematic diagram of volume measurement

The volume of treetop cone is:

$$V_{\text{treetop cone}} = \frac{\pi h D_{n-1}^2}{12} \qquad (1–3)$$

So, the volume of a standing tree:

$$V = V_1 + V_2 + ... + V_n = $$
$$= \frac{1.3\pi(D_0^2 + D_0 D_{1.3} + D_{1.3}{}^2)}{12} +$$
$$+ \frac{\pi h_2 (D_{1.3}{}^2 + D_{1.3} D_2 + D_2^2)}{12} + ... + \frac{\pi h_n D_{n-1}^2}{12} \qquad (1–4)$$

Wherein, the formulas of:

D_n diameter of any part of the trunk
h_n height of any circular truncated cone, are as follows:

$$D_n = 2L \cdot \sin\frac{a_n}{2} \qquad (1–5)$$

$$h_n = L[\tan(90° - r_n) - \tan(90° - r_{n-1})] \qquad (1–6)$$

$$L = S \cdot \sin r_1 \qquad (1–7)$$

$$S = \frac{\frac{D_{12}}{2}}{\sin\frac{a_{12}}{2}} \qquad (1–8)$$

Among them,

L is the horizontal distance between the center of total station telescope and the central point of trunk, an is the horizontal angle when observing the diameter of any part of the trunk
r_n zenith distance of each observation
D_0 ground diameter of the sample tree
$D_{1.3}$ DBH.

Each value needs 3 precise measurements by a diameter tape and the average value to put in the program. The rest of D_n and h_n can be measured directly by the total station. Then, the precise measurement of the volume without tree felling could be achieved by putting this program into the C# programming language inserted in the total station.

2.3.2 Specific measurement steps

1) Based on the experience of taking measurements, the instrument requires setting at the place where the distance is 1–1.5 times longer than the height of the target tree, which can ensure a moderate observation angle of the total station and is conducive to the stability of observation. The instrument should

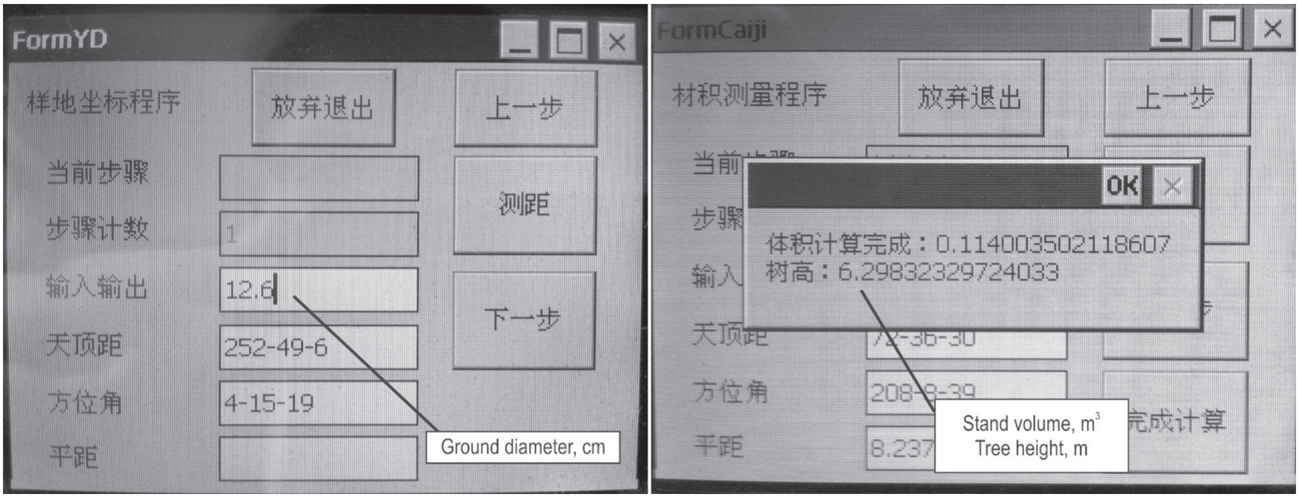

Fig. 5 Interface where the ground diameter of the tree is entered and the volume is calculated by the program

be located at a place with good sight to ensure that more sample trees are observed. When measuring in mountainous areas or slopes, the general principle is to observe from the upper slope to the under slope, which is also convenient for observers to view. In regard to some inclement weather, such as strong winds (over level 4) and heavy rain, the observation should be suspended to ensure the security of the instrument and make the data reliable.

2) With centimetres as the unit of measurement, the diameter tape is utilized in the measurement of ground diameter and the DBH at 1.3 m in height. In terms of the diameter measurement, it needs more than 3 measurements, and the average value is needed for the calculation in the total station (Fig. 5).

3) From the height of 1.3 m to the top of the tree, the instrument needs to aim at the trunk edge of different segments in sequence and to obtain a_1, a_2, a_3,..., the horizontal angles when the total station telescope aims at the left edge and the right edge separately, as well as r_1, r_2, r_3,..., r_n the zenith distance when aiming at the right edge. When the total station measures to the top of the tree, the volume could be obtained and stored in the total station just by pressing the over button (Fig. 5). According to the evaluation of tree height, in general cases, the tree could be divided into 5–10 segments; each of them approximately 0.5–3 m. This decision is based on the conclusion of experiments, which not only ensures the accuracy but also keeps the workload manageable. In each of the upward measurements, the total station needs to select the places where the trunk edge could be seen clearly and avoid scars and branches so that the observation precision could be ensured.

2.4 Selection of volume model

From these research findings, the commonly used binary volume models are as follows (Meng 1996, Zeng 2004, Zeng 2014):

In formulas in Table 1, V represents the standing volume, D is diameter, H is tree height, lg is logarithm, and a_1, a_2, a_3, a_4, and a_5 are model parameters. GAOFS represents the Germany Academy of Forestry Sciences.

Therefore, this research takes the volume of 507 *Populus canadensis* Moench trees as the dependent variable by using 16 commonly used binary volume models and adopting the Marquarat algorithm and the tree height and diameter as the independent variables to fit the volume model. Marquardt algorithm is the most widely used optimization algorithm. It outperforms simple gradient descent and other conjugate gradient methods in a wide variety of problems (Zeng 2014). As a result, the optimal binary volume model, which has small and stable parameters, is selected in this study for its simplicity and effective structures.

2.5 The evaluation of the model

Binary volume models (shown in Tab. 1) are used in this study to develop several regression models. There are many indexes to evaluate models, but under the considerations of all the factors, when evaluating and comparing different volume models, the following six are treated as the basic indexes, namely R^2 is the coefficient of determination, *SEE* is the standard deviation of the estimated value (Kozak and Kozak 2003, Parresol 1999, Zabek 2006, Zianis and Mencuccini 2004, Harmel and Smith 2007), *TRE* is the overall

Table 1 Commonly used volume models

Binary Volume Models	Inventor	Number
$V = a_0 + a_1 D + a_2 D^2 + a_3 DH + a_4 D^2 H + a_5 H$	Meyer W.H.	1–1
$V = a_0 + a_2 D^2 + a_2 D^2 H + a_3 H + a_4 DH^2$	Meng Xianyu	1–2
$V = a_0 + a_2 D^2 + a_2 D^2 H + a_3 H^2 + a_4 DH^2$	Näslund M.	1–3
$V = a_0 D^{a_1} e^{a_2 H - \frac{a_3}{H}}$	Terasaki Wata	1–4
$V = a_0 D^{a_1} H^{a_2}$	Yamamoto	1–5
$V = a_0 (\mathrm{D}+1)^{a_2} H^{a_3}$	Korsun F.	1–6
$V = a_0 + a_1 D^2 H$	Spurr S.H.	1-7
$V = D^2 (a_0 + a_1 H)$	Ogeya N.	1–8
$V = \dfrac{D^2 H}{a_0 + a_1 D}$	Takada Kazuhiko	1–9
$V = a_0 D^{a_1} H^{3-a_2}$	Dwight T.W.	1–10
$V = a_0 (DH)^{a_1}$	Spurr S.H.	1–11
$V = a_0 + a_1 D^2 + a_2 D^2 H + a_3 H$	Stoate T.N.	1–12
$V = a_0 D^2 H$	Spurr S.H.	1–13
$V = a_0 D^2 e^{a_1 - \frac{a_2}{H}}$	Terasaki Wata	1–14
$\lg V = a_0 + a_1 \lg D + a_2 (\lg D)^2 + a_3 \lg H + a_4 (\lg H)^2$	GAOFS	1–15
$V = a_0 D^2 H + a_1 D^3 H + a_2 D^2 \lg D$	Zhao Kesheng	1–16

relative error, *MSE* is the mean system error, *MPE* is the mean predicted error, and *MPSE* is the mean percentage standard error (Zeng and Tang 2011, Zeng et al. 1999, Tang and Li 2002). The expression of these indexes is as follows:

$$R^2 = 1 - \frac{\sum (y_i - \widehat{y}_1)^2}{\sum (y_i - \overline{y})} \quad (2\text{–}1)$$

$$SEE = \sqrt{\frac{\sum (y_i - \widehat{y}_1)^2}{n - p}} \quad (2\text{–}2)$$

$$TRE = \sqrt{\frac{\sum (y_i - \widehat{y}_1)}{\sum \widehat{y}_1 \times 100}} \quad (2\text{–}3)$$

$$MSE = \frac{\dfrac{\sum (y_i - \widehat{y}_1)}{\widehat{y}_1}}{n \times 100} \quad (2\text{–}4)$$

$$MPE = t_\alpha \times \frac{SEE}{\overline{y}} \times \sqrt{n} \times 100 \quad (2\text{–}5)$$

$$MPSE = \sum \left| (y_i - \widehat{y}_1) / \widehat{y}_1 \right| / n \times 100 \quad (2\text{–}6)$$

Where:

- y_i actual observed value
- $\widehat{y}_1$ predicted value of model
- $\overline{y}$ mean value of the sample
- n number of samples
- p number of model parameters
- t_α *t* value when the significance level is 0.05.

Table 2 Actual measurement data of the volume of Populus canadensis Moench

Tree species	Sample	Variable	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation, %
Populus canadensis Moench	507	DBH, cm	38.2	8.5	88.5	12.9	33.77
		Tree height, m	23.8	10.3	35.0	4.6	19.33
		Volume, m^3	1.4022	0.0385	6.1957	0.9999	71.31

In these six indicators, R^2 and *SEE* reflect the goodness of fit of this model. However, these are the most common indicators used to assess regression models. *TRE* and *MSE* are also important indicators to show the fitting effect, and the value of these two indicators is normally less than 3% and 5%, respectively. This value is close to zero, which reflects its effectiveness for volume estimation. The *MPE* reflects the estimated precision of the average volume, and the *MPSE* reflects the estimated precision of a single tree volume.

3. Results and discussion

The measurement results of these 507 *Populus canadensis* Moench, such as DBH, tree height and volume, are imported into the computer. After statistics, the actual measurement data are shown in Table 2.

Based on the 16 commonly used binary volume models mentioned in 1.4, this research takes the actual measurement data of all the 507 *Populus canadensis* Moench as the sample data and adopts the Marquarat algorithm to conduct model fitting. During this process, the 1st Opt15PRO software and formulas are used for calculating various statistical indicators (2–1) ~ (2–6). The results are shown in Tables 3 and 4 and Fig. 6.

From the indicators in Tables 3 and 4, and using 16 binary volume models, the value of R^2 is always over 0.96, which shows that the DBH and tree height have already accounted for 96% of the variation, reflecting the high values of the precision of the average and individual tree volumes. Among them, the 1–1 Mayer model and the 1–15 GAOFS model enjoy the highest correlation. *SEE* takes m^3 as the basic unit and retains two significant figures. Then, except for 1–11 Spurr's

Table 3 Fitting results of the binary volume model of Populus canadensis Moench

Model	Model parameter					
	a0	a1	a2	a3	a4	a5
1–1	–0.161410	0.016783	–0.000177	–0.000285	0.000036	0.00186
1–2	–0.009439	0.000179	0.000024	–0.000626	0.000005	–
1–3	–0.001743	0.000183	0.000024	0.000098	0.000007	–
1–4	0.000674	1.947611	0.025715	5.480645	–	–
1–5	0.000061	1.941859	0.885561	–	–	–
1–6	0.000050	1.981313	0.889570	–	–	–
1–7	0.047941	0.000033	–	–	–	–
1–8	0.000130	0.000028	–	–	–	–
1–9	27719.743170	43.335726	–	–	–	–
1–10	0.000061	1.941859	2.114439	–	–	–
1–11	0.000013	1.672499	–	–	–	–
1–12	–0.075889	0.000141	0.000027	0.004805	–	–
1–13	0.000033	–	–	–	–	–
1–14	3.052688	–7.327658	21.540754	–	–	–
1–15	–3.442538	2.528834	–0.169925	–0.908352	–	–
1–16	0.000032	0.000000	0.000063	–	–	–

Table 4 Statistical results of the binary volume model of Populus canadensis Moench

Model	Statistical indicators					
	R^2	*SEE*/m^3	*TRE*, %	*MSE*, %	*MPE*, %	*MPSE*, %
1–1	0.9643	0.19	0.00	1.33	1.18	11.52
1–2	0.9641	0.19	0.00	–0.38	1.18	9.06
1–3	0.9641	0.19	0.00	–0.53	1.18	9.04
1–4	0.9642	0.19	–0.16	–1.65	1.18	9.53
1–5	0.9641	0.19	–0.12	–1.24	1.18	9.25
1–6	0.9641	0.19	–0.17	–1.68	1.18	9.49
1–7	0.9635	0.19	0.00	–2.42	1.19	10.76
1–8	0.9638	0.19	0.50	0.14	1.18	9.03
1–9	0.9637	0.19	0.24	0.31	1.18	8.96
1–10	0.9641	0.19	–0.12	–1.24	1.18	9.25
1–11	0.9364	0.25	0.42	1.74	1.57	12.32
1–12	0.9640	0.19	0.00	–0.12	1.18	9.58
1–13	0.9635	0.19	1.19	2.59	1.20	9.18
1–14	0.9633	0.19	0.77	2.33	1.20	9.49
1–15	0.9643	0.19	0.00	–0.71	1.18	9.13
1–16	0.9642	0.19	–0.02	–0.56	1.18	8.95

model *SEE* value of 0.25 m^3, the standard deviation of the rest of the models estimated values are all 0.19 m^3, which is attributed to the basic information of calculating the predicted error. The total relative error (*TRE*) and the mean systematic error (*MSE*) range from –0.17% to 1.19% and from –2.42% to 2.59%, respectively. Both of them are under control within ±3%, proving that they have achieved an ideal model fitting effect (Zeng and Tang 2011). The mean predicted error (*MPE*) ranges from 1.18% to 1.57%, indicating that the average predicted precision of the volume reaches over 98%. The majority of the mean predicted standard error (*MPSE*) is lower than 10%, and only the 1–1 Mayer model, the 1–7 and 1–11 Spurr models are a little bit higher, reaching 10.76%, 11.52% and 12.32%, respectively. All the indicators reflect the average level of estimated error of one tree volume.

By comparison, the binary volume model of the 1–15 GAOFS model is titled the optimal model. However, in addition to the optimal precision, the optimal model should also have fewer and more stable parameters with a simple and effective structure. Therefore, the commonly used binary volume models that have fewer than 3 parameters are 1–5, 1–6, 1–7, 1–8, 1–9, 1–10, 1–11, 1–13, 1–14 and 1–16. With further statistical analysis, it is found that the total relative error (*TRE*) and the mean system error (*MSE*) of the models with 3 parameters, namely the Yamamoto model (1–5) and the Dwight T.W. equation (1–10) are, –0.12% and –1.24% respectively, while the first model bears a simple structure. The volume models with 2 parameters also perform well and meet the regulatory requirements, but their precision is

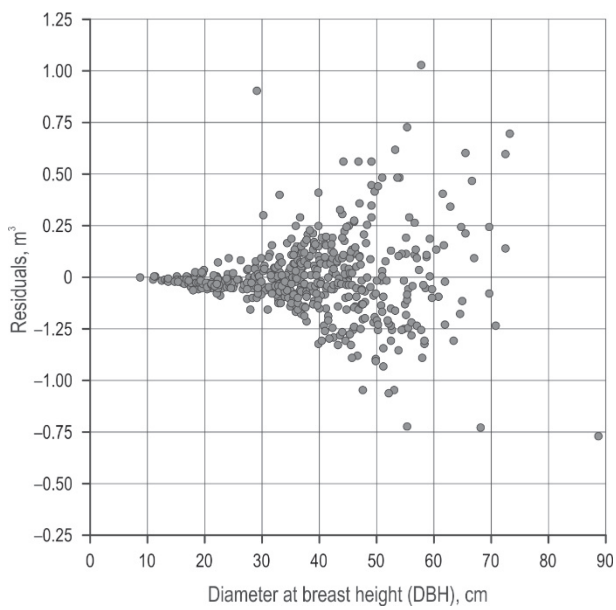

Fig. 6 Distribution of residuals in Yamamoto model

slightly lower than that of the Yamamoto model (1–5) and the Dwight T.W. equation (1–10). The total relative error (*TRE*) and the mean system error (*MSE*) of the 1–13 models with one parameter are 1.19% and 2.59%, respectively, and meet the regulatory requirements.

In summary, the 1–5 Yamamoto model, the most commonly used model in China, is suitable for selection as the optimal binary volume model (3–1). Moreover, this model is to be fitted properly considering its convenient use with few parameters. The Yamamoto model is also known as the standard binary volume model in China (Zeng 2014).

The standard (Yamamoto) binary volume model:

$$V = 0.00006107D^{1.942}H^{0.8856} \qquad (3\text{–}1)$$

The distribution of residuals of the 507 sample trees volume was calculated by determining where the actual observed value was the predicted value of the model (Fig. 6). It was concluded that the positive and negative residuals in each DBH class was almost equal, which shows that the residuals from Yamamoto model was of good randomness and normal distribution.

4. Conclusion

Based on this study and comparison of volume data, an optimal binary volume model of *Populus canadensis* Moench has been finally developed. As shown in the results, the Yamamoto model has proper fit, good stability, and higher precision of both the *MPE* of volume and the *MPSE* of each volume. In addition, the number of parameters is only 3. Considering all of these indicators, this model is found to be the most suitable for volume table preparation.

However, the measurement of data is easy due to the straight trunks with few branches of *Populus canadensis* Moench. Considering coniferous species, a good sight situation could be obtained when measuring the tree volume and more precise result could be measured. On the other hand, for broadleaf trees, it is still worth further study to determine whether this method could achieve the same positive effect.

This research makes use of an advanced instrument which is easy to handle and operate for volume estimation. Most importantly, the application of this method could reduce forest volume losses due to tree felling, as well as provide new techniques for the development of volume models and volume tables. Therefore, this method should be applied and further developed.

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