Proposal of using GIS for multi-criteria evaluation of environmentally friendly use of skidding technologies in forestry

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ABSTRACT: The aim of the study was to propose and verify a model which, based on multi-criteria evaluation of selected input data, determines the category in terms of the environmentally friendly use of individual skidding technologies for each stand. A farm tractor, skidder, cable system, forwarders, and forwarders in combination with harvesters were selected as model skidding technologies. The selected input parameters included: slope inclination, ground bearing capacity, risk of logging-transportation erosion development, presence and size of obstacles, skidding distance, terrain shape and age of stands. Weights of input parameters for multi-criteria evaluation were defined by means of Saaty's matrix and geometric mean of rows. Stocking and areal representation of spruce and fir were added to the evaluation of forwarder-harvester combination. Different equipment (standard tires, low-pressure tires, wheel tracks) and climatic conditions (dry, wet) were also taken into account in the evaluation of the model. The model was applied to the selected experimental territory in the upper part of the basin of the Oskava River.

Keywords: digital terrain model; technological typification; technological optimization

Utilization of GIS application and method of remote sensing in forestry has a long tradition in the Czech Republic. Forestry has been one of the first pioneers in putting GIS applications and methods of remote sensing into practice. These technologies have become a standard tool for acquiring, updating, analyzing, and presenting spatial data.

Both in the world and in the Czech Republic several technical papers and studies focused on the utilization of GIS technologies for the evaluation of forestry transportation network or for the selection of a suitable skidding technology.

Two main approaches used to be applied in modelling the process of making forests accessible. The first approach is based on solutions for model conditions which are generally applicable to all situations. These procedures are based on theoretical models. The aim of these models is the creation of a generally applicable model that should be independent of real conditions of the territory which are usually simplified in these models. In the Czech Republic, this approach was primarily promoted by Beneš (1991).

The second approach represents solutions which take into account real conditions of the territory, mainly the terrain characteristics. These solutions have gradually prevailed thanks to quick developments in the field of hardware, software, databases, and commercial geographic information systems. The use of digital terrain model (DTM) has enabled modelling real terrain conditions in these models. This category includes for example the models of TERDAS (Shiba 1996), PLANEX (Epstein et al. 2001) or models for the evaluation of skidding and forwarding distance created using the AML programming language (Pacola et al. 1999; Tuček et al. 2003).

GIS are also an integral part of models for automatic localization of new forest roads in forests not yet accessible. These solutions are usually based on economic assessment of their design. The most frequently applied parameters for the evalu-

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ation of suitability of particular designs are costs, profit, mean skidding and forwarding distance, and exploitation index. There are many methods for searching an optimal design of forest road network in forests not yet accessible. GIS are used for assessment of costs and multi-criteria evaluation. Earlier studies on this topic include studies by Liu and Session (1993) or the model of ROADPLAN (Newnham 1995). Among the more recent studies we can mention models by Pacola (2001) or Contreras and Chung (2006).

For completeness, in relation to the overview of using GIS in forest transportation accessibility we have to mention models solving terrain and technological typification. One of the first studies on this topic was a study by Davis and Reisinger (1990), who classified the terrain by slope inclination, ground bearing capacity, and presence of obstacles. These three parameters are also used in later models. Owende et al. (2001) based their classification on similar parameters, namely soil conditions (mainly ground bearing capacity), roughness of the terrain (presence of obstacles (stones and grooves), and slope inclination.

The most commonly used terrain classification in the Czech Republic is the terrain classification of "Lesprojekt 1980" which is also based on three basic parameters: slope inclination, ground bearing capacity, and presence of obstacles. Its undeniable advantage is that it is a part of forest management plans and it is easily accessible. The question is the accuracy of its determination for particular forest stands. The terrain is classified into terrain types which are categorized into five terrain groups labelled from A to E with the appropriate skidding technologies assigned.

Simanov et al. (1993) proposed a new system of the terrain and technological typification for conditions of the Czech Republic. Basic parameters of the terrain classification are slope inclination and edaphic categories derived from forest types. The edaphic category is a source of information on the presence of obstacles, ground bearing capacity, and presence of landslide areas. There are 23 terrain types derived from the combination of input parameters. The last two terrain types are based only on the parameter of slope inclination (over 50%). Suitable skidding technologies are subsequently assigned to each terrain type.

One of the last studies focusing on the terrain and technological typification is a study by Slančík et al. (2008). Terrain typification is carried out on the basis of four parameters: slope inclination, presence of obstacles, ground bearing capacity, and risk of logging-transportation erosion development. Tools of GIS were used in combination with a supportive decision-making system of EMDS which is based on the NetWeaver knowledgebase. Fuzzy logic in the interval of (–1, +1) was used for the evaluation of slope accessibility.

MATERIAL AND METHODS

An area in the upper part of the Oskava river basin, where forests are administrated by Lesy České republiky, s.p., was selected as the experimental territory. The altitude of the area ranges from 340 to 960 m a.s.l. The experimental territory is suitable for multi-criteria evaluation of environmentally friendly skidding technologies due to its geomorphological variability, high percentage of forest cover and high variability of forest types. In the experimental territory, 65 forest types in 16 edaphic categories, including steep slope forest types are represented. With regard to its variety, the experimental territory is well accessible using skidding roads of the density of 19.7 $m \cdot ha^{-1}$. Beneš (1986) recommended the forest road density of 22 $m \cdot ha^{-1}$ for hilly areas and 19 $m \cdot ha^{-1}$ for mountains. There are both of the above types in the experimental territory, so it can be concluded that the forest road density is approaching the optimum.

The latest version of the software named ESRI ArcGIS Desktop, version 10.1 (ESRI, Redlands, USA) was selected for the creation of a model for multi-criteria evaluation of environmentally friendly skidding technologies. Input parameters were selected based on a literature research and with regard to the aim of the study to create a universal dynamic system which will be applied to the whole area of the Czech Republic. The selected parameters have either a nationwide digital layer or can be derived from another nationwide digital layer:

– terrain conditions: slope inclination, terrain shape (concave, convex, combined, flat); presence of obstacles (including singularities),
– soil parameters: ground bearing capacity, risk of logging-transportation erosion development,
– stand: areal representation of spruce and fir, age, stocking,
– technology: climbing ability, nominal ground pressure, ground clearance, skidding and forwarding distance.

Intervals are defined with regard to environmentally friendly use of selected technology for the selected input parameters. These intervals have the following classification:

– fully suitable,
– suitable,
– unsuitable – not excluded,
– unsuitable.

Not all the input parameters have the same weight for particular skidding and forwarding technology. For example slope inclination will have more influence than skidding distance for a farm tractor. Ground bearing capacity will also have higher weight in wet conditions than in dry conditions. Weights of input parameters for multi-criteria evaluation were defined by means of Saaty's matrix and geometric mean of rows (Saaty 1977).

The final weights serve to objectification of basic values of the input parameters (value vs. weight). An independent layer was derived for each defined skidding and forwarding technology. Each stand is classified into one of the categories of environmentally friendly use based on multi-criteria evaluation of the input data (Table 1).

Table 1. Categories of environmentally friendly use

Category	Description
< 1.50	fully suitable
1.51–2.50	suitable
2.51–3.50	unsuitable – not excluded
> 3.50	unsuitable

Terrain conditions. Input parameters of slope inclination and terrain shape were derived from a DTM. Diagrammatic data from the Fundamental Base of Geographic Data (ZABAGED) were used, based on the study by Klimánek (2006), as input data for the creation of DTM. Contour line interval was 2 m and in a small part of the experimental territory 5 m. Apart from contour lines, more data layers were used for creating the DTM from ZABAGED: altitude points, edges, terraces, roads and bodies of water. Singularities, local maxima and local minima were located during the field survey by means of a GPS receiver of GPS Trimble Geo XT 2008. After post processing, these data were used as further input data layers to make the DTM more accurate.

The DTM was constructed in the structures of TIN due to taking into account singularities as compulsory edges. Data layers of slope inclination and curvature were derived from the DTM and subsequently transformed to the raster presentations with resolution of 5 m. The layer of curvature was reclassified then by means of statistical characteristics included in the function of Zonal Statistics. The result of the reclassification was that each stand has only one prevailing terrain shape: flat, convex, concave, or combined.

The presence of obstacles was derived from the edaphic categories of forest types according to the methodology of terrain and technological typification by Simanov et al. (1993). The presence and size of obstacles was verified in selected edaphic categories during the field survey.

Soil parameters. Ground bearing capacity was assessed according to the methodology by Vavříček (2011), who evaluated the ground bearing capacity on the basis of one-time pressed track of LKT 80 skidder with nominal ground pressure of 200 kPa. Ground bearing capacity is evaluated at common moistness of the class of moderately damp soils and also of the class of wet soils for sites influenced by precipitation. Vavříček (2011) defined five resistance degrees of soil in taxonomic units taking into account consistency and temporary hydric influence. The layer of soil resistance degrees was derived from the layer of forest types. Each forest type was assigned a prevailing soil type based on which the appropriate soil resistance degree is derived.

Risk of logging-transportation erosion development was assessed according to the methodology by Macků (2000) created within Project No. VaV/640/3/00 titled "System of complex assessment of forest soils". The assessment includes two steps. The first step is creation of a data layer of the potential development of logging-transportation erosion which is derived from the data layer of forest types. In the second step this data layer is converted into a data layer of the real risk of development of logging-transportation erosion according to the areal representation of broadleaved and coniferous trees by means of the weight of reduction factor. The areal representation of broadleaved and coniferous trees takes into account the changes of natural soil parameters caused by forest management.

Stand. Data on age, areal representation of tree species and stocking which enter the model are taken over from the valid forest management plan for the Janovice forest administration unit. A barrier had to be used for the parameter of areal representation of spruce and fir according to model testing for the combination of harvester with forwarder. This barrier was used for the preference of stands with areal representation of spruce and fir over 60%. The lowest grade 4 was replaced by grade 99.

Technical parameters. Technical parameters of particular skidding and forwarding technologies serve in relation to terrain conditions to set the environmentally friendly use intervals:
– climbing ability in relation to slope inclination,
– nominal ground pressure in relation to ground bearing capacity,

– ground clearance in relation to the presence and size of obstacles.

Assessment of the climbing ability of farm tractor and skidder was taken over from the study by Slančík et al. (2008) without using fuzzy intervals. Assessment of the climbing ability of forwarders and harvesters was carried out according to figures quoted by Neruda (2008).

Figures of nominal ground pressure for farm tractor and skidder were taken over from the study by Simanov (1993). For forwarders and harvesters, figures of nominal ground pressure determined within the ECOWOOD project (Owende et al. 2002) were used.

Skidding and forwarding distance was calculated for each stand by means of the mean geometric skidding and forwarding distance. To recalculate the geometric skidding and forwarding distance into the real skidding and forwarding distance, a formula derived by Beneš (1986) was used. Beneš used this formula to express skidding and forwarding distance in a basin (Equation 1).

$$d_s = d_g \times \sqrt{2} \quad (1)$$

where:

d_s – real skidding and forwarding distance (m),

d_g – geometric skidding and forwarding distance (m).

Ten variants were assessed in the model based on combination of selected skidding and forwarding technologies with different equipment (standard tires, low-pressure tires, wheel tracks) and climatic conditions (dry, wet):

– farm tractor – dry soil (FT–dry),
– farm tractor – low-pressure tires – dry soil (FTLT-dry),
– farm tractor – low-pressure tires – wet soil (FTLT-wet),
– skidder (SK-dry),
– skidder – low-pressure tires – wet soil (SKLT-wet),
– forwarder – dry soil (FW-dry),
– forwarder – wet soil (FW-wet),
– forwarder in combination with harvester – dry soil (FWHV-dry),
– forwarder in combination with harvester – wet soil (FWHV-wet),
– cable system (CS).

The variants of farm tractor and skidder both with standard tires were not considered in the conditions of wet soil. Their respective nominal ground pressure of 160 kPa and 220 kPa fails to correspond even to the highest degree of ground bearing capacity (81–120 kPa) according to Vavříček (2011).

Input parameter weights were defined by means of Saaty's matrix and geometric mean of rows for selected skidding and forwarding technologies (Fig. 1).

Input parameters and their weights were at first processed by means of the function of weighted sum. Parameters of the areal representation of spruce and fir, stocking, age, terrain shape, skidding and forwarding distance were directly defined or converted for particular stands. Other parameters entered the analysis without this con-

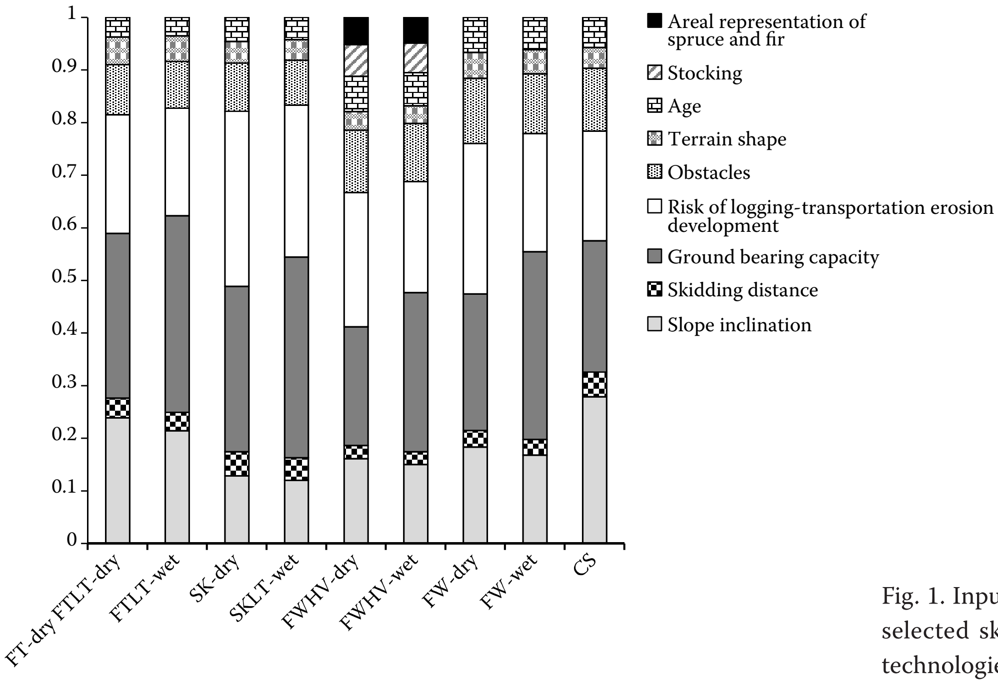

Fig. 1. Input parameter weights for selected skidding and forwarding technologies

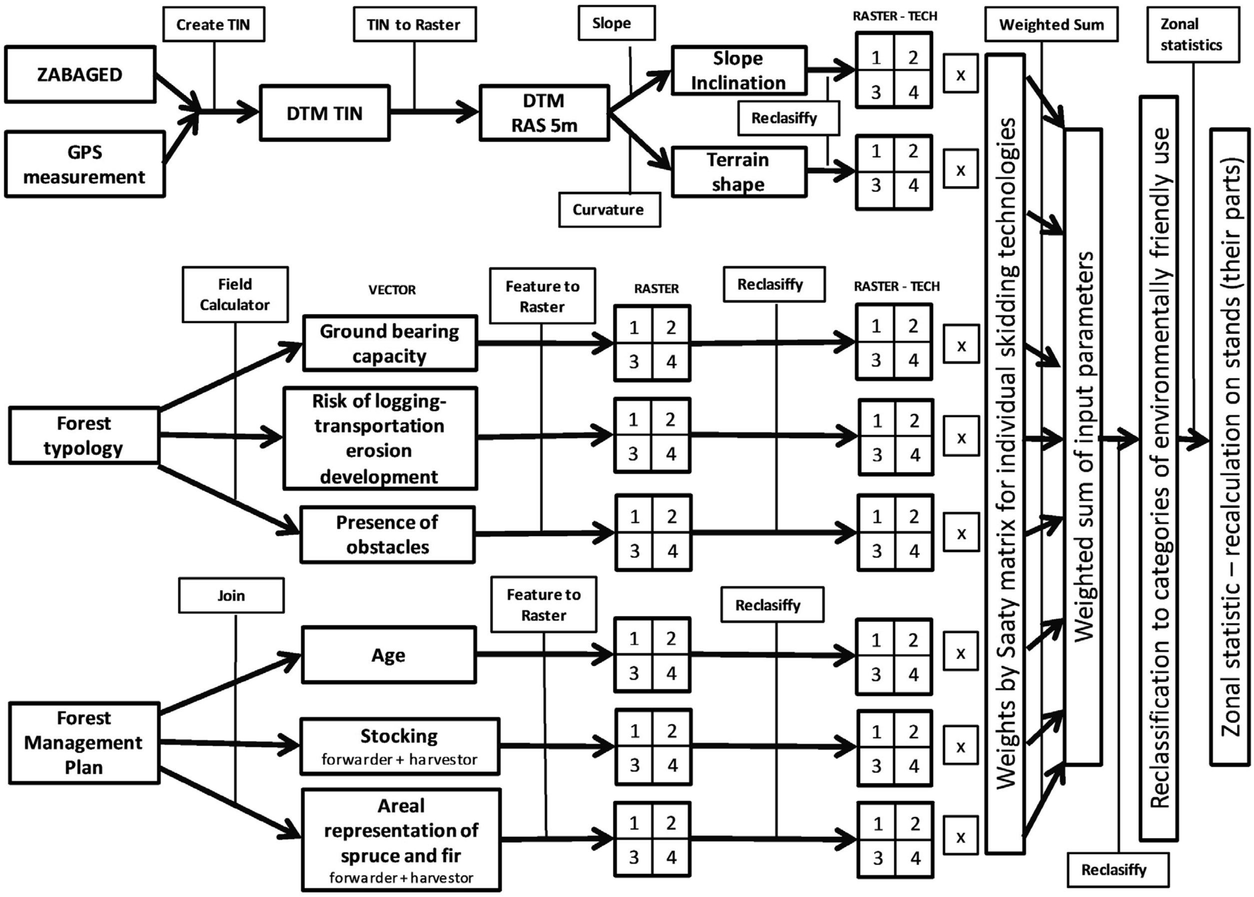

Fig. 2. Scheme of the model

version for stands. The final raster was reclassified to categories of environmentally friendly use. This raster was subsequently processed by means of the function of Zonal Statistics to final values of categories of environmentally friendly use for selected skidding and forwarding technologies for particular stands. Scheme of the model is described in Fig. 2.

RESULTS AND DISCUSSION

The model was applied in the experimental territory of 3,660 ha. A regular grid of points at a spacing of 1 × 1 km was randomly created to verify the results of the model. A buffer zone of 30 m in diameter was then created around each point. Stands for verification of results were selected using spatial intersection of these buffer zones with data layer of the stands. In this manner 70 stands were selected from the total number of 1,551 stands. The number of selected stands represents a share of 4.5% of the total number of stands, but the area accounts for 10.1% of the total forest area within the experimental territory. The input parameters of the model – slope inclination, edaphic category, presence of obstacles, and terrain shape – were verified within a field survey in the selected stands. Evaluation of the category of environmentally friendly use for the selected skidding and forwarding technologies was also verified within the field survey.

The highest variability was shown by the terrain shape during the verification. Assessment of the terrain shape was changed in 8 stands during the field survey. In other 10 stands, it was concluded that the terrain shape was assessed correctly but it was not specific enough to influence the results of the model significantly. The assessment of the parameter of obstacle presence was changed in 5 stands. This parameter depends on the accuracy of determination of forest types in terrain and subsequently on the areal representation of edaphic categories in individual stands. The median value of slope inclination in individual stands was compared with field measurements where a prevailing slope was measured by clinometer. In 10 stands it was found out that there is a difference between the model values and field measurements higher than 5% out of which the slope inclination derived from the DTM was lower than the prevailed slope inclination in the terrain in 7 stands.

Table 2. Farm tractor – different types of tires

Suitability	Whole stands (ha)	Whole stands (%)	Part of stands (ha)	Part of stands (%)	Difference (ha)
Low-pressure tires					
Dry					
0	0.21	0.01	0.23	0.01	0.01
1	12.40	0.34	10.75	0.29	–1.65
2	2,928.29	79.99	2,905.79	79.38	–22.50
3	719.86	19.66	743.99	20.32	24.13
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		
Wet					
0	0.21	0.01	0.23	0.01	0.01
1	0.00	0.00	0.00	0.00	0.00
2	762.17	20.82	787.28	21.51	25.11
3	2,898.38	79.17	2,873.01	78.48	–25.37
4	0.00	0.00	0.25	0.01	0.25
Total	3,660.76		3,660.76		
Standard tires					
Dry					
0	0.21	0.01	0.23	0.01	0.01
1	0.00	0.00	0.00	0.00	0.00
2	1,911.30	52.21	1,925.47	52.60	14.16
3	1,749.25	47.78	1,735.07	47.40	–14.18
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		

The verification of evaluation of the categories of environmentally friendly use for the selected skidding and forwarding technologies showed differences depending only on the accuracy of input parameter determination. If model input parameters corresponded to real terrain conditions, no significant errors in classification of the categories of environmentally friendly use for the selected skidding and forwarding technologies were recorded.

Table 3. Cable system

Suitability	Whole stands (ha)	Whole stands (%)	Part of stands (ha)	Part of stands (%)	Difference (ha)
0	0.21	0.01	0.23	0.01	0.01
1	0.00	0.00	0.00	0.00	0.00
2	87.08	2.38	110.65	3.02	23.57
3	3,562.17	97.31	3,540.96	96.73	–21.21
4	11.29	0.31	8.92	0.24	–2.37
Total	3,660.76		3,660.76		

Results for the selected skidding and forwarding technologies were processed for two variants (Tables 2–8). The whole stands were taken into account in the first variant and parts of individual stands were taken into account in the second variant. More than one third (549) of the total number of stands (1,551) have two or more parts.

As expected, the most environmentally friendly skidding technology, the eight-wheeled forwarder with suitable wheel tracks, has the highest areal representation in the categories of environmentally friendly use 1 and 2. Using this forwarder is suitable in almost 95% of forest area in the experimental territory in wet conditions and in almost 97% of forest area

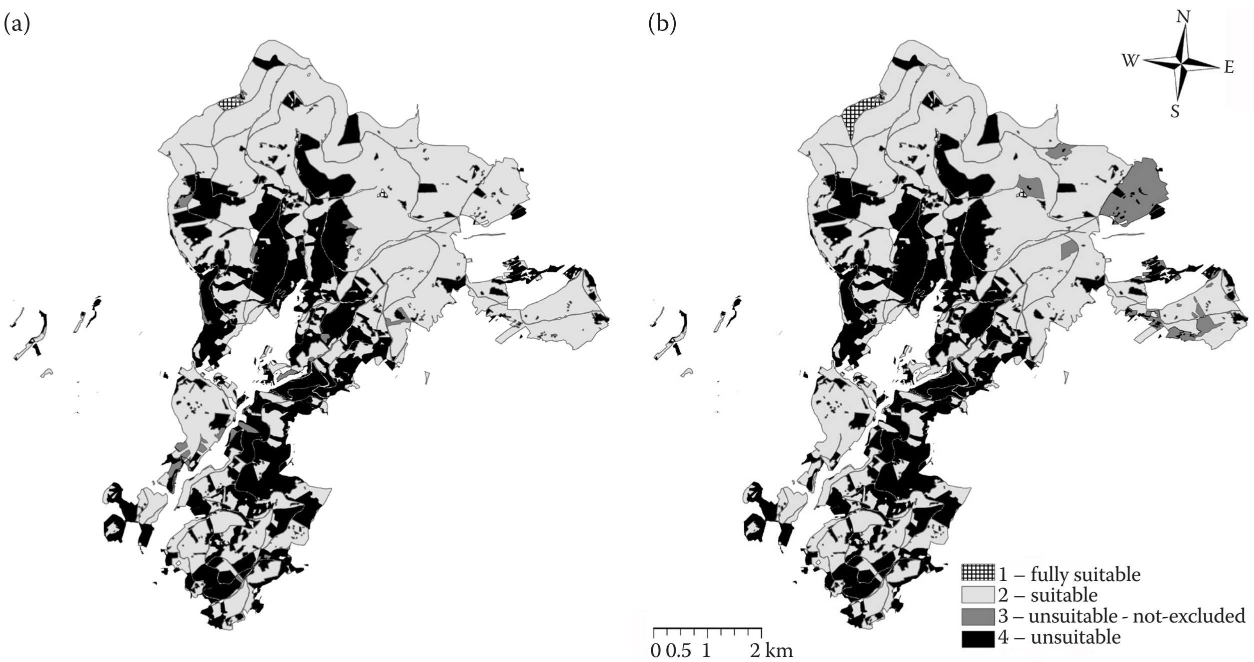

Fig. 3. Forwarder + harvester 8 – wheeled with wheel tracks: dry (a) and wet (b)

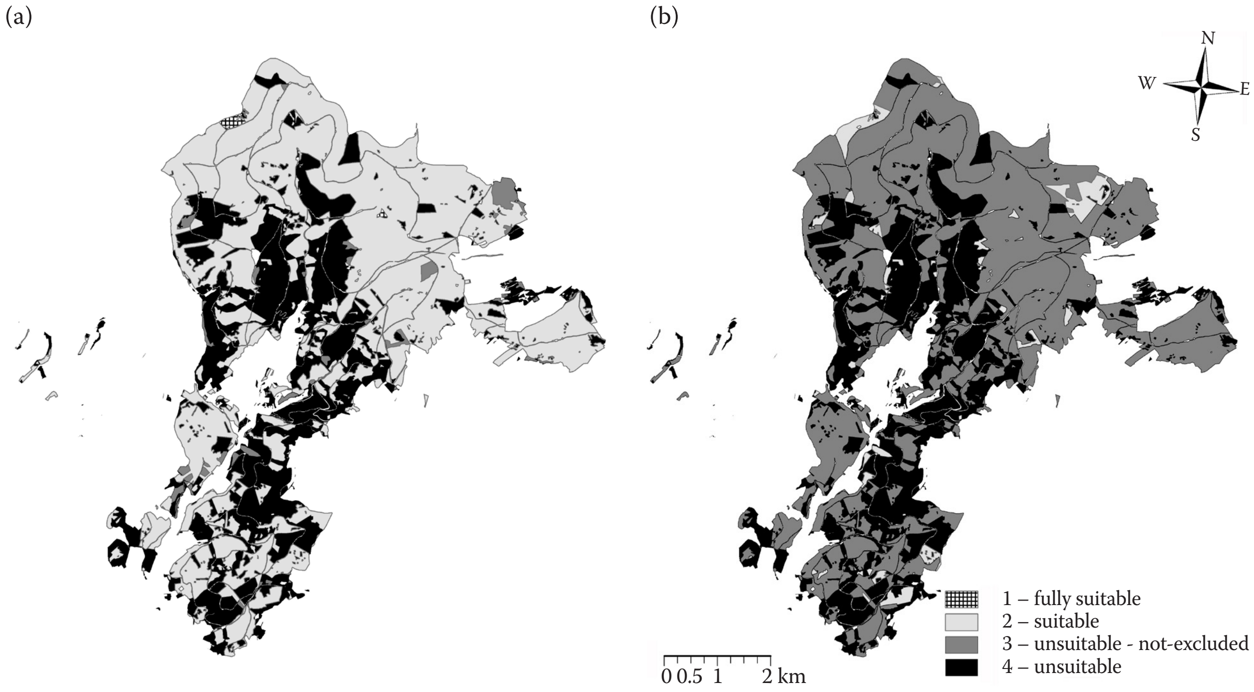

Fig. 4. Forwarder + harvester 4 – wheeled: dry (a) and wet (b)

in dry conditions. Likewise, just a small difference is in using this type of forwarder with an eight-wheeled harvester with suitable wheel tracks. It is 65% of forest area in dry conditions (Fig. 3a) and 62% of forest area in wet conditions (Fig. 3b). There is a big difference in using four-wheeled forwarder in wet or dry conditions. Using this type of forwarder is suitable in almost 95% of forest area in the experimental territory in dry conditions but only in 8% of forest area in wet conditions. Using a combination of four-wheeled forwarder with a four-wheeled harvester is suitable in 64% of forest area in dry conditions (Fig. 4a) but only in 4% of forest area in wet conditions (Fig. 4b).

Significant differences are also in the environmentally friendly use of a farm tractor depending on equipment and climatic conditions. Using a farm tractor with standard tires is suitable in 52% of forest area within the experimental territory in dry conditions. Suitability of using a farm tractor with low-pressure tires is much higher in dry conditions, namely 80% of forest area. However, in wet conditions, even though using low-pressure tires, suitability of using a farm tractor drops to only 21% of forest area.

Significant differences are also recorded in the environmentally friendly use of a skidder depending on equipment and climatic conditions. Using a skidder with standard tires is suitable in 64% of forest area in the experimental territory in dry conditions and only in 29% of forest area in wet conditions, despite of using low-pressure tires.

The model for assessing the environmentally friendly use of a cable system is designed to promote stands where slope inclination, ground bearing capacity, presence of obstacles or combination of these parameters do not allow using wheeled technologies in terms of their environmentally friendly use. Based on these conditions, cable systems are suitable only in 2.4% of forest area if we take into account whole stands and in 3% of forest area if we take into account individual parts of stands. Only one suitable stand was randomly selected for the verification of assessment of environ-

Table 4. Skidder – different types of tires

Suitability	Whole stands		Part of stands		Difference
	(ha)	(%)	(ha)	(%)	(ha)
Standard tires – dry					
0	0.21	0.01	0.23	0.01	0.01
1	9.20	0.25	9.20	0.25	0.00
2	2,339.65	63.91	2,329.76	63.64	–9.89
3	1 311.70	35.83	1 321.58	36.10	9.88
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		
Low-pressure tires – wet					
0	0.21	0.01	0.23	0.01	0.01
1	0.00	0.00	0.00	0.00	0.00
2	1,060.61	28.97	1,066.05	29.12	5.44
3	2,599.94	71.02	2,594.48	70.87	–5.45
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		

Table 5. Forwarder 4 – wheeled

Suitability	Whole stands		Part of stands		Difference
	(ha)	(%)	(ha)	(%)	(ha)
Wet					
0	0.21	0.01	0.23	0.01	0.01
1	0.00	0.00	0.00	0.00	0.00
2	279.80	7.64	304.18	8.31	24.38
3	3,377.19	92.25	3,347.73	91.45	–29.46
4	3.56	0.10	8.62	0.24	5.06
Total	3,660.76		3,660.76		
Dry					
0	0.21	0.01	0.23	0.01	0.01
1	16.16	0.44	16.81	0.46	0.65
2	3,495.63	95.49	3,452.67	94.32	–42.96
3	148.76	4.06	191.06	5.22	42.29
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		

Table 6. Forwarder 8 – wheeled with wheel tracks (WT)

Suitability	Whole stands		Part of stands		Difference
	(ha)	(%)	(ha)	(%)	(ha)
Wet					
0	0.21	0.01	0.23	0.01	0.01
1	93.27	2.55	109.19	2.98	15.92
2	3 367.59	91.99	3 345.63	91.39	-21.96
3	199.69	5.45	205.71	5.62	6.02
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		
Dry					
0	0.21	0.01	0.23	0.01	0.01
1	16.16	0.44	16.81	0.46	0.65
2	3 563.03	97.33	3 527.69	96.36	-35.33
3	81.36	2.22	116.03	3.17	34.67
4	0.00	0.00	0.00	0.00	0.00
Total	3,660.76		3,660.76		

mentally friendly use of cable system, thus other three suitable stands were verified within the field survey (Fig. 5).

CONCLUSIONS

The aim of the study was to create and verify a model for the selection of environmentally friendly skidding technology based on multi-criteria evaluation by means of GIS tools in the selected experimental territory. Verification of model results was carried out in randomly selected stands with the overall area representing more than 10% of the total forest area in the experimental territory.

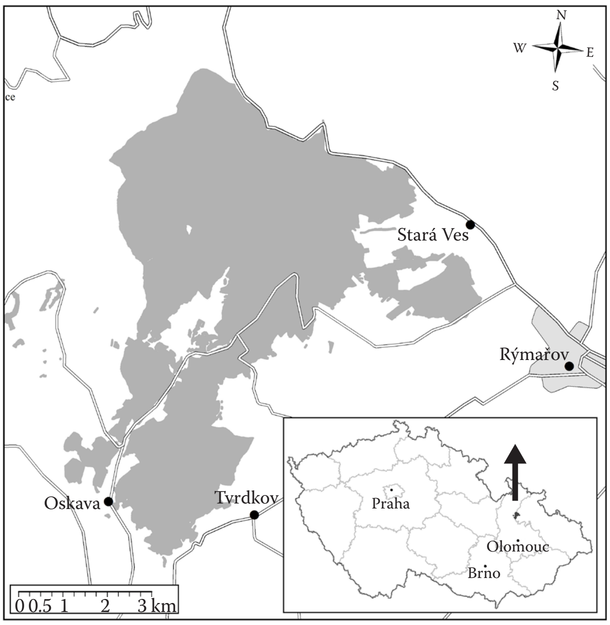

Fig. 5. Overview map

The terrain shape showed the lowest level of reliability among all the input parameters of the model. Its weight ranged from 3 to 5% in the final multi-criteria evaluation, and therefore the incorrect determination of this parameter has a very low influence on the final results of the model. Accuracy improvement of the terrain shape as well as determination of the slope inclination is possible in the next development of the model by using a more accurate DTM. Digital Terrain Model of the Czech Republic – 4th generation (DMR 4G) and later Digital Terrain Model of the Czech Republic – 5th generation (DMR 5G) will be suitable sources for derivation of these two parameters. These two models will be created from laser scanned data. Thanks to this technology

Table 7. Forwarder and harvester 4 – wheeled

Suitability	Whole stands		Part of stands		Difference
	(ha)	(%)	(ha)	(%)	(ha)
Wet					
0	6.33	0.17	0.23	0.01	–6.10
1	0.00	0.00	0.00	0.00	0.00
2	150.71	4.12	157.24	4.30	6.53
3	2,278.97	62.25	2,285.76	62.44	6.79
4	1,224.76	33.46	1,217.54	33.26	–7.22
Total	3,660.76		3,660.76		
Dry					
0	6.33	0.17	0.23	0.01	–6.10
1	9.20	0.25	9.20	0.25	0.00
2	2,333.93	63.76	2,323.16	63.46	–10.77
3	86.55	2.36	110.64	3.02	24.09
4	1,224.76	33.46	1,217.54	33.26	–7.22
Total	3,660.76		3,660.76		

Table 8. Forwarder and harvester 8 – wheeled with wheel tracks (WT)

Suitability	Whole stands		Part of stands		Difference (ha)
	(ha)	(%)	(ha)	(%)	
Wet					
0	6.33	0.17	0.23	0.01	–6.10
1	22.29	0.61	22.29	0.61	0.00
2	2,262.31	61.80	2,272.20	62.07	9.89
3	145.14	3.96	148.50	4.06	3.37
4	1,224.70	33.45	1,217.54	33.26	–7.16
Total	3,660.76		3,660.76		
Dry					
0	6.33	0.17	0.23	0.01	–6.10
1	9.20	0.25	9.20	0.25	0.00
2	2,371.90	64.79	2,368.16	64.69	–3.75
3	48.57	1.33	65.64	1.79	17.07
4	1,224.76	33.46	1,217.54	33.26	–7.22
Total	3,660.76		3,660.76		

both models will have substantially higher altitude accuracy as well as more accurate detection of singularities which have a significant influence on determination of the terrain shape. After adjustment, the total standard error of height in the bare terrain will amount to 0.3 m and in the forested terrain to 1 m in DMR 4G which will be available at the end of 2013. After adjustment, the total standard error of height in the bare terrain will amount to 0.18 m and in the forested terrain to 0.3 m in DMR 5G which will be available in 2015 (Brázdil 2009).

When input parameters corresponding to real terrain conditions were used, no significant errors were recorded in classification of the categories of environmentally friendly use for the selected skidding and forwarding technologies. A small portion of the experimental territory (0.01–0.17%) was classified by grade 0 for all the selected skidding and forwarding technologies. The spatial differences in input data layers are a reason for this classification. Not only this model but also all nationwide data layers and models will be more accurate after creating the unified digital cadastral map of the Czech Republic.

In the next development of the model it seems suitable to take into account the size of the stands, mainly for the cable system. The reason is not to select too small stands or parts of the stands for this type of technology. Stands where the main reason for using the cable system is the ground bearing capacity could be also distinguished because it is possible to use wheeled vehicles when the ground is frozen there.

The model primarily focuses on the stands. More than one third of stands have one or more parts in the experimental territory, thus the results of the model were calculated not only for the whole stands but also for particular parts of the stands and we have obtained more accurate results for the categories of environmentally friendly use. In further development of the model, the categories of environmentally friendly use can be determined with higher accuracy. We propose to determine several categories of the environmentally friendly use of a particular skidding technology for stands or for their parts of an area larger than 1.5 (2) ha. The reason for this division into several categories would be a contiguous area of the suitability category of use larger than 0.5 ha or smaller depending on the requirements of forest management or authorities of nature protection for the size of clearcuts. The final output of the model will be a map of the potential use of selected skidding technologies where information on the environmentally friendly use of particular skidding and forwarding technologies will be directly visualized for particular stands.

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