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Regional Estimation of Forest Stand Parameters

Regionaltarife für die Schätzung von Bestandesparametern

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Summary

This study presents a system which enables the assessment of selected stand characteristics. The system consists of tariffs for dominant height, mean diameter and basal area. The system is based on single eco-regions in Germany but can be applied nation-wide. The tariffs were developed for the tree species spruce, fir, pine, larch, beech, oak, Douglas fir and deciduous trees. The system can be applied to roughly reproduce stand structures at a forest estate and regional level. It enables a comparison of eco-regions in Germany and allows a validation of growth models. For a parameterisation of tariff functions, the data from two different sources was used. Firstly, the tree data of the south-western inventory points from the Federal Forest Inventory (Western Germany) and secondly, the point-related data from forest management records (East Germany). The constructed stand tariffs merely show the statistical relationships between the characteristics of the stands, in contrast to growth models used in forestry (yield tables, forest growth simulators), which describe forest development.

Keywords: regional tariffs, estimation of dominant height, estimation of mean diameter, estimation of stand basal area

Zusammenfassung

In dieser Untersuchung wird ein System für die Schätzung von ausgewählten Bestandescharakteristika vorgestellt. Das System besteht aus Oberhöhen-, Mitteldurchmesser- und Grundflächentarifen. Das System kann deutschlandweit bezogen auf die einzelnen Wuchsgebiete angewendet werden. Die Tarife wurden für die Baumarten Fichte, Tanne, Kiefer, Lärche, Buche, Eiche, Douglasie und sonstiges Laubholz entwickelt. Das System eignet sich für eine grobe Reproduktion von Bestandesstrukturen auf Betriebs- und Regionalebene. Es ermöglicht auch einen Vergleich der Wuchsregionen und erlaubt eine Validierung von Wuchsmodellen. Zur Parametrisierung der Tariffunktionen wurden Daten zweier verschiedenner Datenquellen genutzt. Das sind zunächst die Baumdaten der südwestlichen Inventurpunkte der ersten Bundeswaldinventur (Westdeutschland) und zweitens die punktbezogenen Bestockungsdaten der ostdeutschen Forstdatenbank. Die konstruierten Bestandestarife zeigen im Gegensatz zu den in der Forstwirtschaft genutzen Wuchsmodellen (Ertragstafeln, Waldwachstumssimulatoren), die die Waldentwicklung beschreiben, lediglich die statistischen Beziehungen zwischen den Bestandescharakteristika.

Schlüsselwörter: Regionaltarife, Oberhöhenschätzung, Mitteldurchmesserschätzung, Grundflächenschätzung

1 Introduction

For many years different estimation function (tariffs) and methods based on tariffs have been known in forest science. They were initially developed for forest mensuration practices. Tariffs have always been understood to be a system based on functions and dependent on a single parameter (e.g. diameter at breast height or mean diameter). The first tariffs were constructed for the assessment of tree parameters, later also to assess stand parameters. KRÄUTER (1958), PRODAN (1965) and CONN (1971) reviewed different methods for tariffs. Because they are easy to apply, tariffs were widely used in forest surveys in the past, but have gradually been replaced by more accurate methods. Within the framework of large-scale simulation studies encompassing the entire Federal Republic of Germany, the idea evolved to develop a system of regional functions for the estimation of forest stand parameters (as start values and controlling factors for regionally typical thinning regimes) in situations where the existing information was incomplete. The presented system roughly

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generates a stand structure at forest estate and regional level and enables comparison between the regions, as well as providing a possibility to validate growth models.

A comprehensive database of forest structure and composition was compiled in former West Germany within the National Forest Inventory (BWI; reference period 1987–1990). It was hoped that this national inventory would also provide information about the changes in the condition of forests. Of course, this can only be realised when permanent monitoring is established. These permanent monitoring measurements are very important for forest management and play a decisive role for forestry planning. From the data obtained, it is also possible to deduce the relationships between single characteristics of forest growth and how these vary regionally. For the former East Germany, the forest management database "Datenspeicher Waldfonds" (DSW 1993) was used.

A system for the assessment of forest stand parameters was developed which consists of dominant height tariffs, mean diameter tariffs and basal area tariffs. The tariffs were developed for spruce, fir, pine, larch, beech, oak, Douglas fir and several other deciduous trees. In this study tariffs for spruce are illustrated. The coefficients of the tariffs for the other tree species are available on the author's Internet page http://www.wwk.forst.tu-muenchen.de. The system was developed for all forest eco-regions in Germany (WOLFF 2002).

2 Data for the construction of estimation functions

For a parameterisation of estimation functions data were available from two different sources. One source was the data on trees from the south-western inventory points collected by the BWI[1]. The second source was the point-related data of tree density from the DSW.

From the individual tree data of the BWI, total stand values and mean values were calculated according to a previously devised methodology (BUNDESMINISTERIUM FÜR ERNÄHRUNG, LANDWIRTSCHAFT UND FORSTEN 1990). The data of the DSW were tested for plausibility and were directly used in fitting of models. In total, 10,660 data sets about stands were available. The site-related data were stratified according to tree species composition, and inventory points that had a proportional species representation of higher than 50 % were taken into account. Forest stand characteristics were then re-counted to 100 % representation of a particular tree species. Thus characteristics for pure stands of particular tree species were obtained. As a result, 6,620 data sets with ideal monocultures were available for the development of estimation functions. The available data allowed the construction of estimation functions for spruce, pine, beech and oak at the regional level. For the tree species fir, larch, Douglas fir and other deciduous species trans-regional estimation functions were constructed. The statistical characteristics of the data material for spruce is shown in Table 1.

3 Construction of estimation functions

As the main variable for the individual estimation functions the dominant height was chosen, which in stand assessments is easier to measure than age. This is a stable value that correlates well with site quality. However, this characteristic is not directly available in the DSW data and is also difficult to calculate from the BWI data. Therefore, the approach of KAHN (1994) was used. Based on data from long-term experimental sites,

[1] Within the framework of the project "German Forest Sector under Global Change" only one of four sample plots per inventory grid point of the BWI was supplied.

Table 1. Statistics of data material for Norway Spruce.
(h_g – LOREY's mean height (m); d_g – quadratic mean diameter (cm); G/ha – basal area per hectare (m^2/ha); STD – standard deviation; n – number of observations)

Tabelle 1. Statistische Kennwerte des Datenmaterials für Fichte.
(h_g – Mittelhöhe nach LOREY (m); d_g – Durchmesser des Grundflächenmittelstammes (cm); G/ha – Grundfläche pro Hektar (m^2/ha); STD – Standardabweichung; n – Anzahl)

Nr.	eco-region	h_g			d_g			G/ha		
	(WOLFF et al. 2002)	Mean	STD	n	Mean	STD	n	Mean	STD	n
1	Nordsee – Küstenraum	15.5	5.8	27	21.3	8.2	27	25.1	10.6	22
2	Ostsee – Küstenraum	21.6	5.8	26	28.0	8.1	26	33.8	8.8	26
3	Heide und Altmark	17.1	4.8	18	23.4	12.3	18	28.5	15.8	13
4	Ostdeutsches Tiefland	19.1	7.5	7	20.9	8.5	7	36.9	6.7	4
5	Ostdeutsches Lößtief – und Hügelland	23.2	2.5	123	25.2	4.4	123	33.8	7.6	107
6	Mitteldeutsches Berg – und Hügelland	21.5	7.8	136	27.3	10.9	136	32.3	17.2	124
7	Harz	21.2	5.6	77	26.4	8.3	77	34.3	12.0	69
8	Rheinisch – Westfälische Bucht	19.8	8.3	16	26.7	12.2	16	33.0	15.7	15
9	Rheinisches Schiefergebirge und angrenzende Hügelländer	21.5	7.0	311	28.5	11.4	311	36.3	15.8	281
10	Rheintal und angrenzende Hügelländer	21.7	6.4	15	23.6	7.4	15	38.2	15.9	12
11	Vogelsberg, Odenwald, Spessart	25.2	8.0	81	31.1	12.6	81	36.7	15.9	71
12	Bayerischer-, Oberpfälzer-, Franken-, Thüringer Wald und Erzgebirge	22.1	4.9	550	26.3	8.1	550	32.8	11.8	473
13	Würtembergisches – Fränkisches Hügelland	23.5	7.2	174	28.5	10.6	174	36.7	17.4	141
14	Schwarzwald	24.4	7.9	126	33.3	12.5	126	36.6	18.2	108
15	Schwäbisch – Fränkische Alb	22.6	7.4	138	28.0	11.0	138	37.2	17.6	111
16	Alpenvorland	25.1	6.8	309	30.8	10.5	309	46.4	17.8	291
17	Schwäbisch – Bayerische Jungmoräne und Molassevorberge und Bayerische Alpen	24.8	6.6	101	37.0	12.6	101	41.7	19.6	87

KAHN investigated the relationship between dominant height (h_{100}) and mean height (h_g) and deduced the function of the difference between the dominant and the mean height in dependence on mean height and number of stems per hectare:

$$h_{100} = h_g + e^{a_0 + a_1 \cdot \ln(h_g) + a_2 \cdot \ln(N) + a_3 \cdot \ln(h_g \cdot \ln(N))} \quad (1)$$

where

h_{100} : dominant height
h_g : mean height
N : number of stems per hectare
a_1–a_3 : tree species specific coefficients
e : EULER's value.

Table 2 shows the parameters deduced by KAHN (1994) for the tree species spruce, pine, beech, oak and Douglas fir. Using these parameters, it is possible to estimate the maximum height for each inventory point dependent upon the mean height and number of stems per hectare.

Table 2. Parameters of the dominant height model after KAHN (1994). (a_0 – a_3: coefficients)

Tabelle 2. Parameter zur Schätzung der Oberhöhe nach KAHN (1994). (a_0 – a_3: Koeffizienten der Funktion)

	a_0	a_1	a_2	a_3
Beech	−28.142	−20.923	−2.550	22.077
Oak	−46.530	−41.665	−5.893	43.209
Douglas Fir	−17.902	−13.383	−1.459	13.998
Spruce	−8.253	0	0.625	0.933
Pine	−16.875	−8.273	−0.633	9.436

3.1 Estimation function for dominant height

The tariffs for dominant height play an important role, since they are necessary for assessing the value of stands. The assessment of quality is defined here as an assignment of a stand to a corresponding relative tariff. For the parameterisation of the estimation functions for dominant height, only the inventory points with a proportion of tree species larger than 30 % were used, and then fictive developments of the age-dependent dominant height were constructed. The construction is based on the following principles:

- Parameterisation of the relationship between dominant height (h_{100}) and age (t) in single eco-regions (Figure 1 A) where

  $$h_{100} = A \cdot (1 - e^{-k \cdot t})^p \qquad (2)$$

  where A, k and p are the regression coefficients.
- Statistical division of the data material into three tariff groups (Figure 1 B): maximum (O), mean (M) and lower (U). In tariff group O (upper) all inventory points are included that show a dominant height (h_{100}) larger than $h_{(pred)} \cdot (1 + t_{\alpha;f} \cdot s_{y.x(rel)})$, with $t_{\alpha;f}$ being the critical value of the Student's t-distribution (P = 68 %) and $s_{y.x(rel)}$ the relative standard error of equation 2. If the dominant height is less than $h_{(pred)} \cdot (1 - t_{\alpha;f} \cdot s_{y.x(rel)})$ the inventory points belong to group U (lower), all others are in group M (mean). With this system tariff zones with identical width were created (tariff bands). The division of the data material required a minimum number of 50 inventory points.
- Construction of an anamorph tariff curve (Figure 1 C). For this the coefficients k and p of the function (2) are adopted and the coefficient A estimated separately for each tariff band. The results of the assessment are summarised in Table 3.

3.2 Estimation function for basal area

The estimation functions for basal area describe the dependence of the stand basal area on the dominant height (h_{100}). The regionally characteristic density is not only dependent on the yield level, but also on the silvicultural treatment of the stands. The yield differences are only slight, because the age-dependent variance within the tariff bands is only small. For the construction, the following assumptions were made:

- With a dominant height of h_{100} = 1.3 m the basal area equals zero
- With increasing dominant height the basal area can also decrease
- In the initial phase an s-shape relationship exists.

In order to meet these conditions, the flexible WEIBULL-Density function in the form proposed by WENK et al. (1990) was applied:

$$G = \frac{c}{b} \cdot \left(\frac{h_{100} - 1.3}{b}\right)^{(c-1)} \cdot e^{-\left(\frac{h_{100} - 1.3}{b}\right)^c} \cdot d \qquad (3)$$

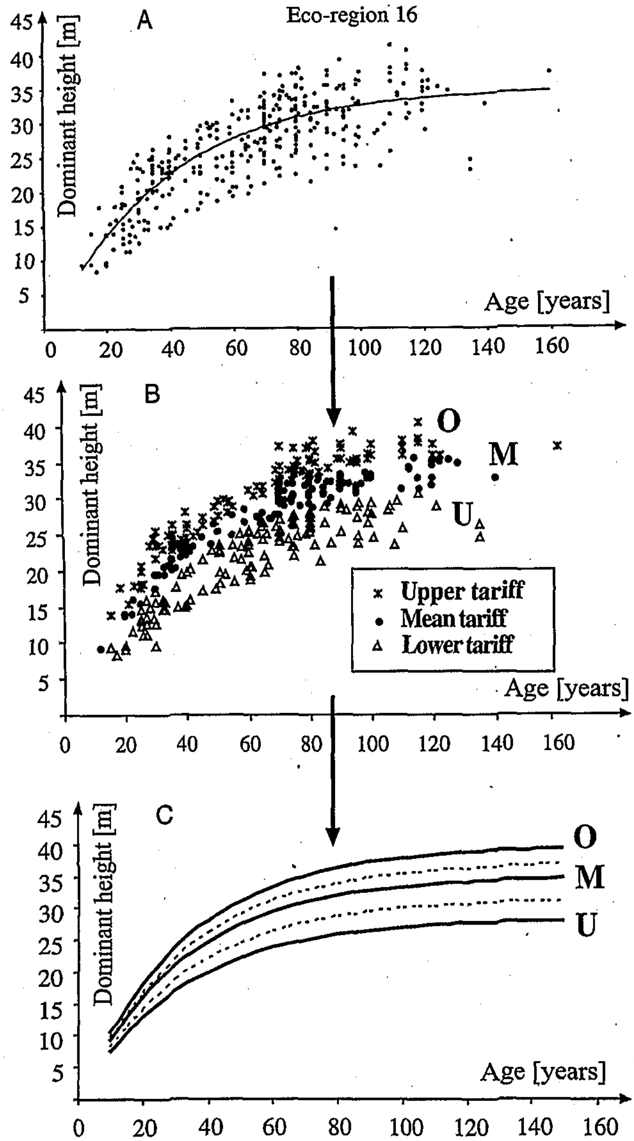

Fig. 1. Diagram showing the construction of an estimation function for dominant height in eco-region 16.

Abb. 1. Darstellung der Konstruktion einer Oberhöhenschätzfunktion für die Wuchsregion 16.

with the variables

G	:	basal area (m^2/ha)
h_{100}	:	dominant height (m)
b, c, d	:	coefficient of the function.

The parameterisation was preceded by covariance analysis (covariates: h_{100}), which was used to investigate differences in the stand density in dependence on the tariff (O, M, U). The analysis has shown that the stand density was dependent on the tariffs (O, M, U) in only a few eco-regions. In these cases, the separate functions were subsequently parameterised for each tariff. The results of the parameterisation are summarised in Table 4. Figure 2 exemplarily shows the tariffs for the basal area of eco-region 16.

Table 3. Coefficients and statistical characteristics of the estimation function of dominant height for Norway Spruce (ER – eco-region; O – upper tariff; M – mean tariff; U – lower tariff; A, k, p – coefficients; n – number; r^2 – coefficient of determination; mse – mean square error; "–" missing data)

Tabelle 3. Koeffizienten und statistische Charakteristika der Oberhöhenschätzfunktion für Fichte (ER – Wuchsregion; O – oberer Tarif; M – mittlerer Tarif; U – unterer Tarif; A, k, p – Koeffizienten; n – Anzahl; r^2 – Bestimmtheitsmaß; mse – mittlerer quadratischer Fehler; „–" fehlende Daten)

ER	O				M				U				O-M-U	O-M-U
	A	n	r^2	mse	A	n	r^2	mse	A	n	r^2	mse	k	p
1	–	–	–	–	28.29	27	0.67	3.53	–	–	–	–	0.02972	1.1000
2	–	–	–	–	30.71	26	0.76	2.98	–	–	–	–	0.03581	1.5288
3	–	–	–	–	21.8	18	0.69	2.75	–	–	–	–	0.09019	4.0064
4	–	–	–	–	29.31	7	0.89	3.12	–	–	–	–	0.05108	5.0000
5	29.93	44	0.64	1.20	26.8	63	0.67	0.71	22.75	87	0.67	2.30	0.03739	1.1000
6	40.04	50	0.95	1.82	34.65	61	0.97	1.17	29.38	63	0.92	1.79	0.02379	1.1000
7	31.93	24	0.92	1.59	27.79	45	0.96	1.02	23.37	31	0.84	1.91	0.04782	3.0706
8	34.16	0	0.76	4.28	34.16	15	0.76	4.28	34.16	0	0.76	4.28	0.02897	1.1000
9	37.41	95	0.92	1.91	32.51	139	0.97	1.04	26.66	113	0.85	2.31	0.03137	1.3268
10	32.7	0	0.75	3.45	32.7	15	0.75	3.45	32.7	0	0.75	3.45	0.03305	1.1000
11	38.9	29	0.97	1.48	35.03	38	0.97	1.05	29.04	44	0.8	2.98	0.03404	1.4595
12	37.43	169	0.85	2.27	31.69	331	0.93	1.02	26.43	286	0.8	2.12	0.02169	1.1000
13	39.38	61	0.92	1.94	33.95	80	0.96	1.10	27.34	87	0.82	2.64	0.02676	1.1000
14	37.08	49	0.94	1.91	32.42	55	0.96	1.13	25.87	49	0.79	2.95	0.04011	1.9039
15	38.52	51	0.96	1.60	33.78	66	0.97	1.00	26.57	72	0.71	3.24	0.02454	1.1000
16	39.6	110	0.94	1.54	34.88	122	0.96	1.10	28.18	123	0.75	2.87	0.02767	1.1000
17	35.59	37	0.87	2.24	28.95	41	0.75	1.68	22.09	39	0.71	2.42	0.03443	1.5886

3.3 Estimation function for mean diameter

The estimation functions for diameter describe the dependence of the mean diameter (dg) on the dominant height (h_{100}) and the respective tariff category (O, M, U). The estimation functions are polymorphic and can be expressed as follows:

$$d_g = b_1 \cdot e^{(b_2 \cdot h_{100})} \quad (4)$$

where b_1 and b_2 are specific coefficients.

The results of the assessment are summarised in Table 5. As an example, the estimation functions for the mean diameter in eco-region 16 are illustrated in Figure 3. The relatively large inaccuracies (as with the basal area tariffs) may be due to yield level differences and thinning effects.

4 Utilisation of estimation functions

The estimation functions presented here describe the relationships between different stand properties. Therefore they are not appropriate for predictions of forest development. However, the estimation functions are very useful in estimating regional stand parameters, which are necessary to generate stand structures as input for forest growth models,especially in cases where large numbers of stands are required. Using this approach it is possible to generate the forest structure of a forest estate, even if exact information (i.e. from forest estate inventories) is not available. In such cases, the tariffs can be used as a basis for a forest estate model in connection with the stand structure generator STRUGEN (PRETZSCH 1993) that was implemented in SILVA 2.2 (KAHN and PRETZSCH 1998). This principle was applied for example by DUSCHL and SUDA (2002), who generated representative forest estate models based on inventory data. These were projected into the future

Table 4. Coefficients and statistical characteristics of the estimation functions of stand basal area for Norway Spruce (ER – eco–region; O – upper tariff; M – mean tariff; U – lower tariff; b, c, d – coefficients; n – number; r^2 – coefficient of determination; mse – mean square error; "–" missing data, h_{100} – dominant height (m))

Tabelle 4. Koeffizienten und statistische Charakteristika der Grundflächenschätzfunktionen für Fichte (ER – Wuchsregion; O – oberer Tarif; M – mittlerer Tarif; U – unterer Tarif; b, c, d – Koeffizienten; n – Anzahl; r^2 – Bestimmtheitsmaß; mse – mittlerer quadratischer Fehler; „–" fehlende Daten, h_{100} – Oberhöhe (m))

ER	tariff	n	r^2	mse	b	c	d	min. h_{100}	max. h_{100}
1	O-M-U	22	0.41	8.55	27.55	2.1213	947.3	6.0	24.9
2	O-M-U	26	0.37	7.22	35.87	2.1341	1498.7	7.0	35.0
3	O-M-U	17	0.54	9.85	27.61	2.7043	989.5	11.6	23.6
4	–	–	–	–	–	–	–	–	–
5	O-M-U	104	0.05	6.68	45.53	2.0748	1984.7	9.0	30.6
6	O-M-U	124	0.36	13.90	40.68	2.3273	1821.1	5.9	38.0
7	O-M-U	69	0.15	11.18	32.90	2.0800	1396.2	8.9	36.9
8	O-M-U	15	0.76	8.41	49.03	2.3398	2767.4	11.5	40.0
9	O	86	0.29	13.81	31.04	2.6817	1459.8	9.6	37.7
9	M	114	0.25	12.18	34.43	2.3691	1558.8	8.9	33.7
9	U	81	0.37	9.45	46.78	1.9971	2000.0	5.7	29.4
10	O-M-U	12	0.21	15.60	40.50	2.3435	2003.3	14.2	33.8
11	O-M-U	71	0.29	13.55	36.20	2.4728	1555.6	9.7	38.8
12	O-M-U	473	0.19	10.60	119.08	1.7876	8665.8	7.5	40.7
13	O-M-U	141	0.42	13.37	39.82	2.6120	1814.9	7.0	39.8
14	O-M-U	108	0.30	15.35	35.22	2.5465	1511.3	7.0	38.1
15	O	42	0.52	11.79	37.09	2.4674	1965.8	8.9	37.9
15	M	43	0.37	13.93	46.68	2.3089	2467.3	11.3	32.6
15	U	26	0.45	11.24	31.41	2.6264	1043.9	9.4	27.1
16	O	105	0.23	13.17	43.75	2.3652	2721.0	15.4	41.2
16	M	104	0.18	15.95	36.30	2.4858	1853.1	9.2	35.5
16	U	82	0.25	13.29	28.44	2.5287	1103.6	8.3	30.5
17	O-M-U	87	0.17	18.09	319.04	1.7242	49771.1	10.6	39.8

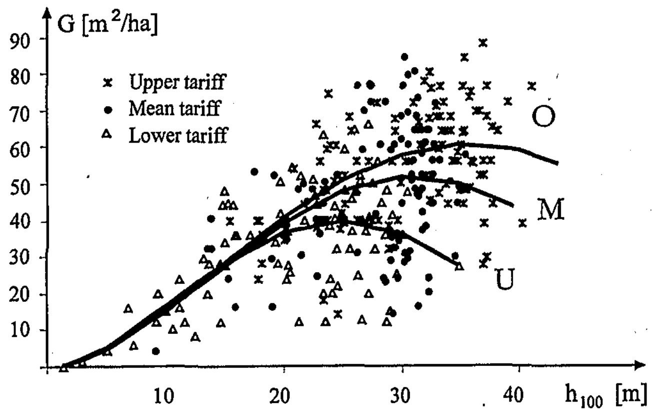

Fig. 2. Estimation function for basal area of stands in eco-region 16.

Abb. 2. Grundflächen-Schätzfunktion für die Wuchsregion 16.

with the forest growth simulator SILVA 2.2 using selected climate scenarios and treatment strategies, and the results were interpreted from a socio-economic perspective. Representative stands were also generated with this method for the sensitivity study presented by PRETZSCH and ĎURSKÝ (2002). Furthermore, estimation functions can be used for the

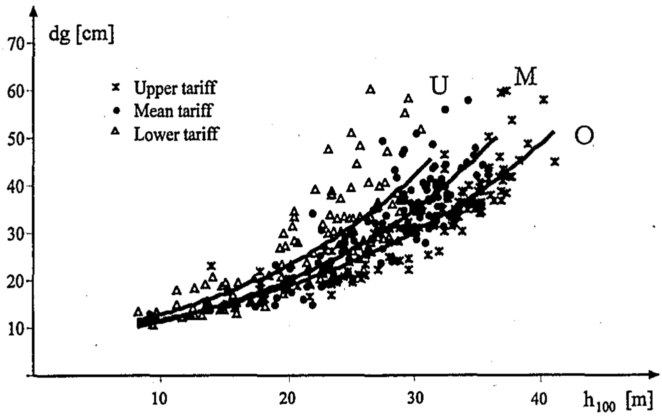

Fig. 3. Estimation function for mean diameter in eco-region 16.

Abb. 3. Mitteldurchmesser-Schätzfunktion für die Wuchsregion 16.

Table 5. Coefficients and statistical characteristics of the estimation function of mean diameter tariffs for Norway Spruce (ER – eco–region; O – upper tariff; M – mean tariff; U – lower tariff; a_1, a_2 – coefficients; n – number; r^2 – coefficient of determination; mse – mean square error; "–" missing data)

Tabelle 5. Koeffizienten und statistische Charakteristika der Mitteldurchmesserschätzfunktion für Fichte (ER – Wuchsregion; O – oberer Tarif; M – mittlerer Tarif; U – unterer Tarif; a_1, a_2 – Koeffizienten; n – Anzahl; r^2 – Bestimmtheitsmaß; mse – mittlerer quadratischer Fehler; „–" fehlende Daten)

ER	tariff	n	r^2	mse	b_1	b_2	ER	tariff	n	r^2	mse	b_1	b_2
1	O-M-U	27	0.8	3.78	7.112	0.0617	11	M	30	0.66	6.89	5.525	0.0610
2	O-M-U	26	0.62	5.11	10.088	0.0432	11	U	27	0.82	5.20	7.350	0.0555
3	O-M-U	18	0.72	6.73	3.274	0.1011	12	O	146	0.76	5.02	6.360	0.0559
4	O-M-U	7	0.94	2.32	5.403	0.0624	12	M	249	0.67	3.84	5.012	0.0685
5	O	36	0.32	4.03	6.610	0.0532	12	U	155	0.51	4.57	6.152	0.0652
5	M	49	0.17	2.60	7.371	0.0500	13	O	55	0.81	5.20	7.016	0.0504
5	U	38	0.26	3.18	12.068	0.0288	13	M	68	0.76	4.60	6.344	0.0571
6	O	46	0.83	5.19	8.603	0.0463	13	U	51	0.53	6.64	9.263	0.0467
6	M	52	0.75	4.93	8.155	0.0495	14	O	41	0.74	6.90	9.008	0.0456
6	U	38	0.79	4.35	8.620	0.0509	14	M	46	0.69	5.87	7.452	0.0542
7	O	23	0.77	4.51	6.182	0.0588	14	U	39	0.8	5.73	6.723	0.0685
7	M	33	0.73	4.25	6.140	0.0627	15	O	46	0.84	4.86	7.157	0.0503
7	U	21	0.55	3.68	9.589	0.0450	15	M	56	0.76	5.31	5.802	0.0616
8	O-M-U	16	0.8	5.59	11.034	0.0382	15	U	36	0.75	4.83	7.404	0.0584
9	O	90	0.82	4.82	7.067	0.0535	16	O	109	0.81	4.42	6.596	0.0505
9	M	128	0.71	6.17	6.800	0.0590	16	M	111	0.72	5.03	7.030	0.0530
9	U	93	0.7	5.61	7.837	0.0584	16	U	89	0.55	7.78	7.400	0.0588
10	O-M-U	15	0.75	3.84	8.348	0.0428	17	O	35	0.49	9.64	12.55	0.0393
11	O	24	0.88	5.04	5.803	0.0556	17	M	35	0.53	6.53	7.045	0.0606
11	M	30	0.66	6.89	5.525	0.0610	17	U	31	0.35	9.21	8.758	0.0619

validation of forest growth models on a regional level (PRETZSCH 2002). They define the frames for the probable forecast by forest growth models. This procedure is described by ĎURSKÝ (2000).

Another aspect of the utilisation of estimation functions is the regionalisation of measures for forest stand treatment. However, it must be considered that the stands of different regions vary in structure and above all in density. Using the system of estimation functions it is possible to quantify differences in the density between single eco-regions. Figure 4

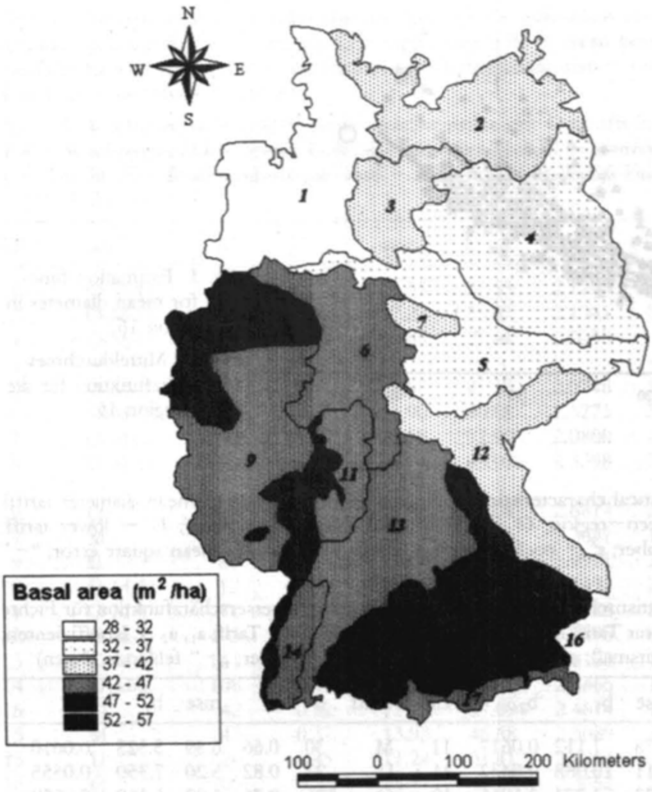

Fig. 4. Mean stand basal area (m^2/ha) for 100-year-old spruce in individual eco-regions of Germany.

Abb. 4. Durchschnittliche Grundflächen (m^2/ha) der Fichte im Alter 100 in den einzelnen Wuchsregionen von Deutschland.

illustrates the comparison of the average stand basal area of 100-year-old spruce stands according to eco-regions.

The estimation functions of dominant height show very good statistical characteristics. This is mainly because of the strong relationship between the height of the stand and its age, but also because the tariff zones were directly derived from the stand height. The coefficient of determination ranges between 0.64 and 0.97 and the mean quadratic error is on average about ±2.34 m. Observation showed a greater variation in the lower tariff range. Diameter estimation functions have relatively high coefficients of determination (0.46 − 0.85) also. The expected allometric relationship between the dominant height and the mean diameter was not confirmed, however it was found at tree level (WENK et al. 1990). This can be explained by the influence of the forest structure on the mean stand parameters. Statistically the results of the basal area estimation functions were not satisfactory owing to the fact that the stand density of the inventory plots is dependent upon site and age, as well as on the treatment of the stand and disturbance events.

In order to utilise the estimation functions two pieces of information are required: age, and mean or dominant height. These two characteristics are needed for the selection of valid tariffs (O, M, U). The procedure described provides the assignment of the tariff level which is necessary for the assessment of basal area or mean diameter.

Age and dominant height are much more difficult to determine from stand measurements than diameter or basal area. Therefore the traditional application of tariffs was to deduce height and stand volume from diameter measurements. The estimation functions developed in this study serve different purposes, which have been already mentioned. They can be adopted where age and dominant height estimates exist from a forest stand survey or from a forest district inventory. Evidently, the accuracy of the estimated forest stand parameters depends on the quality of the input data.

Estimation functions can be applied for stochastic processes by using parameters of variability. Furthermore, utilisation of estimation functions is appropriate for the indirect assessment of stem densities (N/ha). If the values of typical regional stem form factors are known, it is then possible to calculate the growing stock (V/ha).

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