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NORWAY SPRUCE (PICEA ABIES (L.) Karst.) SMART FORESTS FROM THE SOUTHERN CARPATHIANS

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Abstract

The study begins with a complete analysis of the entire Norway spruce stands (36.183) from the Southern Carpathians. The main characteristics of these stands were analyzed, followed by a classification of their characteristics on favorability classes (from 1 to 5, from the lowest to the highest) based on their framing within the smart forest category. This classification has taken into account both the stand growing characteristics (diameter, height, volume, current growth), as well as some stand qualitative traits (lopping, vitality), forest functions (production/protection subunit, functional group and category) or site characteristics (flora, soil, forest type, station type). This is the first time when stands were classified based on their general adaptability character towards environment conditions, quantifying the notion of smart forests. The most representative Norway spruce smart forests are spread out in Retezat, Ierului, Șureanu and Piatra Craiului Mountains, at altitudes between 1000-1300 meters, on shaded expositions, dystric cambisol soils, in stands aged between 90 and 150 years. The participation percentage of Norway spruce in the stand composition and the field's inclination does not influence the apparition of spruce smart forests. The usage of the term "smart forest" and the classification of stands in this category is a scientific and practical activity for the future.

***Keywords**: Smart forest; Stand; Stand growth; Forest functions; Site characteristics*

Introduction

Numerous authors have studied the adaptation to climate changes in the field of forest management [1-4] or the adaptive capacity of forests to thse pehnomenons [5-8].

If the term "smart agriculture" is already well-known, other terms such as "smart ladscape" [9] or "smart forest" [10] are recent, being used by researchers only during the last four-five years. Some of them use the term of "smart forest" as a novel approach in deploying static and mobile sensors in forests [11-12].

The concept of Climate-Smart Forestry (CSF) tries to translate the concept of Climate-Smart Agriculture (CSA) in the forest domain. CSA was firstly synthetized and stated in 2010 by FAO during The Hague Conference on Agriculture, Food Security and Climate Change. As such, the term integrates the three-dimensions of sustainable development (economic, social and environmental) and aims at sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change and reducing greenhouse gas emission [13].

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Based on this concept, recent studies try to classify the most valuable forests in the above-mebtioned “smart forest” category, based on their adaptation towards climate changes, carbon stock, biodiversity or other synthetic elements.

Experimental

The present study has used the data from forest management plans realized in the period 1980-2008 from national forests [14]. All the forest districts from the Southern Carpathians area were analyzed, taking into account a number of 36.183 sub parcels in which Norway spruce is present (pure or mixed stands). The stands younger than 40 years were not taken into consideration. Each analyzed parameter has received a grade from 1 to 5, namely: 1 = very low; 2 = low; 3 = average; 4 = high; 5 = very high. In total, 16 parameters specific to the stand or station were taken into consideration (Table 1).

Table 1. Grades granted based on the stand’s and site's characteristic

	Characteristic	Grade				
		1	2	3	4	5
1	Looping	0.1; 0.2	0.3; 0.4	0.5	0.6; 0.8	0.7
2	Vitality	5	4	3	2	1
3	Average diameter (cm)*	0-20	21-30	31-40	41-50	51-100
4	Average high (m)*	0-14	15-18	19-25	26-30	31-43
5	Production class	5	4	3	2	1
6	Volume (m^3)*	0-50	51-100	101-200	201-300	301-884
7	Current growth (m^3/an/ha)*	0.1-0.9	1.0-1.9	2.0-2.9	3.0-4.9	5.0-21.0
8	Structure		1	2	3	4
9	Consistency	0.1-0.4	0.5-0.6	0.9	0.7	0.8
10	SUP	O; C	A; D	J, V	G,M	E, K
11	Functional group + Functional category	2,1C	1,4A; 1,4B; 1,4C;1,4D; 1,4E; 1,4F; 1,4I; 1,4J; 1,4K; 1,5L; 2,1B	1,1A; 1,1B; 1,1C; 1,1E; 1,1G; 1,1H; 1,5G; 1,5H	1,2A; 1,2B; 1,2C;1,2E; 1,2F;1,2H; 1,2I;1,2J; 1,2K; 1,2L; 1,5C; 1,5D;	1,3F; 1,3H; 1,3J;1,5A; 1,5B;1,5F; 1,5I;1,5J;
12	Litter	1	2	3	4	5
13	Flora	35; 45; 53; 65; 68	14; 15; 16; 17; 36; 42; 46; 52; 63	12; 22; 23; 32; 34; 44	13; 33; 43; 51; 61	11; 21; 31; 41
14	Soil type	201, 401, 2407, 4104, 4204, 6206, 9102,	1703, 1704, 2205, 2207, 2405, 2501, 3108, 3109, 4103, 4203, 4205, 9101	1701, 1702, 2201, 2401, 3104, 3105, 3107, 3201, 3206, 3307, 4102, 4202	3102, 3302, 3303, 3304, 4201, 5201, 9501	3101, 3301, 4101
15	Forest type	1161, 1162, 5151, 5172, 5211, 5221, 5231, 5241, 5314, 5411	1112, 1122, 1132, 1133, 1142, 1153, 1154, 1172, 1173, 1181, 1341, 1342, 1343, 1431, 4117, 4118, 4151, 4191, 4331, 9821	1113, 1114, 1115, 1116, 1121, 1141, 1241, 1313, 1321, 1331, 1422, 2212, 2213, 2231, 2241, 4112, 4114, 4115, 4131, 4141	1151, 1152, 1171, 2111, 2112, 2211, 2221, 2321, 4111, 9811	1111, 1211, 1311, 1411, 1511
16	Site type	1120, 1310, 1510, 2510, 3120, 4120,	1320, 1330, 2120, 2210, 2311, 2312, 2321, 2331, 3210, 3311, 3321, 3331,	2322, 2332, 2630, 3312, 3322, 3332, 3730,, 4322, 4332, 4420, 5232, 5242	2220, 3220, 3230, 3640, 4323, 4324, 4430, 5243	2333, 2540, 3323, 3333, 3740

* For these characteristics, the entire value range was divided in 5 categories, 1 = the lowest (ex: average diameter between 4-20 cm), 5 = the highest (ex: current growth higher than 5-21 m^3/an/ha) and grades were given based on these categories.

The category division was made so that it will also respect the biometric analyzed characteristics and to ensure a balanced partition as number of values for each category.

The meaning of terms from Table number 1 is rendered below:

Vitality: 1 = very vigorous; 2 = vigourous; 3 = normal; 4 = weak; 5 = very weak

Structure: 1 = even-aged stand; 2 = relatively even-aged stand; 3 = relatively uneven-aged stand; 4 = uneven-aged stand

Production/protection subunits (SUP): A = regular forest, common assortments: wood for timber, constructions, celluloses; C = Conversion; D = regular forest, protection target; E = Reservations for integrally protecting nature; G = selection system forest; J = quasi-selection system forest; K = Seed reservations; M = Forests submitted to exceptional conservation regimes; V = Forests with recreation functions through hunting.

Functional group (GF) and functional category (FCT) (excerpt): 1,1A = forests situated in protection areas for rivers, deposits and mineral, drinkable or industrial waters, exploited or with approval, demarcated by specialty studies; 1,1B = Forests on direct accumulation or natural lake slopes, present or approved; 1,1G = Forests from torrential or excessively alluvial transport basins, determined through hydrological studies, for managing forests or hydrographic basins; 1,2A = Forests situated on cliffs, debris, fields with depth erosion, fields with an inclination higher than 35 degrees, or on flysch, sand or gravel substratum, with an inclination higher than 30 degrees; 1,2B = Forests composed of entire parcels, bordering public roads of high interest or normal railroads from areas with rugged relief (fields with slopes higher than 25 degrees and in danger of landslides); 1,2C = Forest strips from around alpine gaps, with lengths between 100 and 300 meters; 1,2E = Forest plantations realized on degraded fields; 1,3H = Forests situated in areas with a strongly and average polluted atmosphere; 1,4A = Park forests and other recreation forests; 1,4B = Forests from around counties, cities or villages; 1,4E = Forests with a social interest, from around archeological, architectural, historical or artistic monuments; 1,5A = National parks; 1,5B = Natural parks; 1,5C = Natural reservations; 1,5D = Scientific reservations; 1,5F= Natural monuments; 1,5I = Forest areas destined to protecting certain rare indigenous fauna species; 1,5J= Secular forests; 2,1B = Forests destined to produce mainly thick trees with superior timber quality; 2,1C= Forests destined to produce mainly average and slim trees for cellulose, rural constructions and other usages.

Litter: 1 =missing litter; 2 = thin interrupted litter; 3 = thin continuous litter; 4 = normal continuous litter; 5 = thick continuous litter.

Flora: 11 = *Oxalis-Dentaria*; 12 = *Calamagrostis-Luzula*; 13 = *Oxalis-Soldanella*; 14 = *Luzula silvatica*; 15 = *Hylocomium*; 16 = *Vaccinium*; 17 = *Polytrichum comune*; 21 = *Asperula-Oxalis;* 22 = *Luzula albida-Hieracium transilvanicum;* 23 = *Vaccinium;* 31 = *Asperula-Dentaria;* 32 = *Rubus hirtus;* 33 = *Symphytum cordatum-Ranunculus carpaticus;* 34 = *Festuca altissima;* 35 = *Luzula-Calamagrostis;* 41 = *Asperula-Asarum;* 42= *Carex pilosa;* 43= *Rubus hirtus;* 44 = *Festuca altissima;* 45 = *Luzula albida;* 46 = *Vaccinium-Luzula;* 51 = *Asarum-Brachypodium;* 52 = *Carex pilosa;* 53 = *Luzula albida-Carex montana;* 61= *Asarum-Stellaria*.

Soil type (excerpt): 1701 = typical rendzina; 1702b = cambic rendzina; 1703= lytic rendzina; 2201 = typical preluvisol; 2401 = typical luvisol; 2407 = stagnic luvisol; 3101 = typical eutric cambisol; 3301= typical dystric cambisol; 3305 = lytic dystric cambisol; 4101 = typical entic podzol; 4102= lytic entic podzol; 4201 = typical podzol; 9501= typical fluvisol.

Forest type (TP), (excerpt): 1111 = Norway spruce stands with *Oxalis acetosella* or mull flora; 1112 = Norway spruce stands with *Oxalis acetosella* on soils with pronounced gleyzation; 1113 = High altitude Norway spruce stands with *Oxalis acetosella*; 1116 = Norway spruce stands with *Oxalis acetosella* on rake soils; 1121 = Norway spruce stand with green moss; 1131 = Norway spruce stand with *Polytrichum*; 1151 = Norway spruce stand with *Vaccinium myrtillus* and *Oxalis acetosella*; 1153= Norway spruce stand with *Vaccinium myrtillus*; 173 = Norway spruce vista with Sphagnum and *Vaccinium Myrtillus*; 1211 = Normal Norway spruce-fir stand with mull flora; 1231 = Norway spruce-fir stand with *Luzula luzuloides*; 124 1= Norway spruce-fir stand on rake soils; 1311 = Normal resinous and common beech mixture with mull flora; 1321= Resinous and common beech mixture with *Rubus hirtus*; 1331 = Resinous and common beech mixture with *Festuca altissima*; 1411 = Normal Norway spruce-common beech stand with *Oxalis acetosella*; 1422 = Norway spruce-common beech stand with *Vaccinium myrtillus*; 1511 = Norway spruce-larch stand with Oxalis acetosella; 2111 = Normal fir stand with mull flora; 2212 = Fir-common beech stand with mull flora with average productivity; 2251 = Fir-common beech stand with *Vaccinium myrtillus* and moss; 2321 = Mixed mountain common beech stand; 4111 = Normal common beech stand with mull flora; 4114 = Mountain common beech stand on rake soils and mull flora; 4121= Nude mountain common beech stand on moderately acid soils; 4131 = Mountain common beech stand with *Rubus hirtus*; 4151= Mountain common beech stand with Luzula luzuloides; 4161 = Mountain common beech stand with *Vaccinium myrtillus*.

Type of station (TS), (excerpt): 1120 = Mountain subalpine Bi cliff Norway spruce stands with excessive erosion; 1320 = Mountain pre-subalpine Bi podzolic Norway spruce stands with humus and *Vaccinium*; 1420 = Mountain pre-subalpine Bi Norway spruce stands, podzolic cripropodzolic semi-swampy, with *Polytrichum*; 2220 = Mountain Bm(s) Norway spruce stands, rendzina average edaphic, with Oxalis-Dentaria; 2311 = Mountain Bi podzolic Norway spruce stands with raw average and low humus and with *Vaccinium*; 2321 = Mountain Bi low edaphic podzolic-criptopodzolic Norway spruce stands with *Calamagrostis-Luzula*; 2322 = Mountain Bm average edaphic luvisoil Norway spruce stands with *Luzula sylvatica*; 2331 = Mountain Bi low edaphic dystric cambisol Norway spruce stands with *Oxalis-Dentaria* +- acidophilus; 2332 = Mountain Bm average edaphic dystric cambisol Norway spruce stands with *Oxalis-Dentaria* +- acidophilus; 2333 = Mountain Bs dystric cambisol and andosol Norway spruce stands, high and average edaphic with *Oxalis-Dentaria* +- acidophilus; 3210 = Mountain mixtures, Bi low edaphic rendzina; 3311 = Mountain mixtures, Bi low edaphic luvisol with *Vaccinium* and other acidophilus; 3312 = Mountain mixtures, Bm(i) sub-average edaphic podzol with moss and other acidophilus; 3321 = Mountain mixtures, Bi luvisol and low edaphic preluvisol with *Luzula* +- Calamagrostis; 3322 = Mountain mixtures, Bm(i) luvisol and average edaphic preluvisol with *Festuca* +- Calamagrostis; 3331= Mountain mixtures, Bi low edaphic eutric cambisol with *Asperula-Dentaria* +- acidophilus; 3332 = Mountain mixtures, Bm average edaphic eutric cambisol with *Asperula-Dentaria*; 3333 = Mountain mixtures, Bs high edaphic eutric cambisol with *Asperula-Dentaria*; 3640 = Mountain mixtures Bs(m) eutric cambisol and dystric cambisol with average-very high imperfect drainage; 4321 = Mountain-pre-mountain Bi low edaphic dystric cambisol common beech stands; 4322 = Mountain-pre-mountain Bm eutric cambisol common beech stands with average edaphic mull; 4410 = Mountain-pre-mountain Bi low edaphic eutric cambisol common beech stands with *Asperula-Dentaria*; 4420 = Mountain-pre-mountain Bm average edaphic eutric cambisol common beech stands with Asperula-Dentaria; 4430 = Mountain-pre-mountain Bs high edaphic eutric cambisol common beech stands with *Asperila-Dentaria*.

By integrating these values, a total grade resulted for each sub-parcel, based on which the Norway spruce stands from the Southern Carpathians were echeloned.

Results and Discussions

Only the factors that can be found quantified in forest management plans were used. Other factors (such as the distribution of trees on diameter categories, defoliation degree, forest damage, stand stability, tree species composition, introduced tree species, deadwood, genetic resources, threatened forest species or tree crown characteristics) can be used in establishing smart forests in more detailed studies realized on smaller areas.

Figure 1 showcases the number of spruce smart forests distributed on forest districts from the first 100 such stands, while Figure 2 presents the geographic distribution of the first 20 spruce smart forests in the Southern Carpathians.

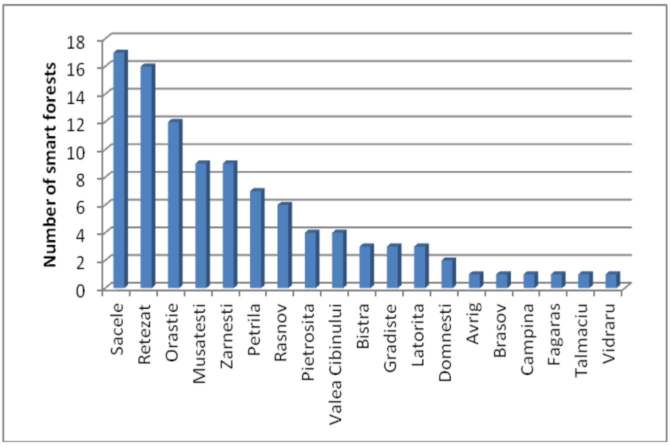

Fig. 1. Distribution of the first 100 spruce smart forests from the Southern Carpathians on forest districts

As such, the majority of spruce smart forests can be found in Săcele (17) and Retezat Forest Districts (16), followed by Orăștie (12) Mușătești and Zărnești (9).

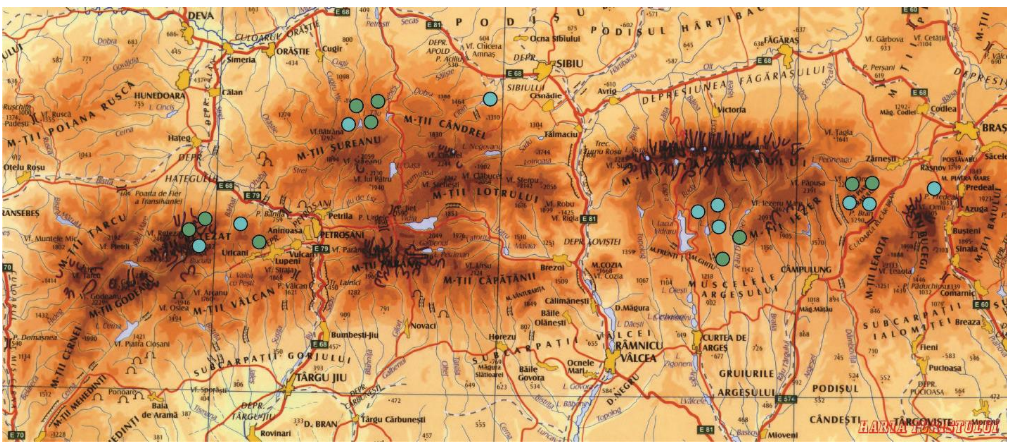

Fig. 2. Distribution of the first 20 spruce smart forests from the Southern Carpathians.

From a geographic distribution point of view, the first 20 spruce smart forests from the Southern Carpathians are located in Retezat, Iezerului, Șureanu and Piatra Craiului Mountains. Other mountain massifs from this Carpathian chain (such as Făgărașului, Lotrului or Căpățânii Mountains) do not exhibit smart forests with high value. The explanation is linked with the difficult climatic conditions from this area in which the Norway spruce resists well but does not present exceptional growth characteristics.

The Norway spruce participation percentage in the composition of smart forests varies from 40% up to 100%. However, this element does not prove to be decisive in the apparition of this forest category. On the other hand, in regard with the age, it can be observed that Norway spruce smart forests are preponderantly old, with ages ranging between 90 and 150 years (it must be taken into account that normally, Norway spruce stands are cut at the age of 110).

Table 2. The characteristics of the first 20 spruce smart stands from the Southern Carpathians

Nr crt	Location	Spruce percentage (%)	Age (years)	Expo sition	Field inclination (%)	Altitude (m)	Soil	Station type	Forest type
1	Orăștie III, 13B	6	95	S	15	1100	Dystric cambisol	4430	4111
2	Zărnești VI, 40C	8	100	NV	23	975	Dystric cambisol	3333	1311
3	Mușătești V, 35C	4	150	SE	32	1450	Dystric cambisol	2333	1111
4	Orăștie III, 159	7	85	NE	23	1225	Dystric cambisol	2333	1111
5	Retezat V, 100A	10	95	NE	10	1200	Fluvisol	2540	1112
6	Domnești II, 101A	8	100	V	10	670	Dystric cambisol	5243	4211
7	Zărnești IX, 113A	9	140	NV	18	1125	Dystric cambisol	3333	1211
8	Petrila V, 103A	5	140	SV	32	1600	Dystric cambisol	2333	1111
9	Retezat V, 151B	4	120	NV	20	1275	Fluvisol	2540	1112
10	Orăștie III, 27C	9	90	NV	20	1330	Dystric cambisol	3333	1311
11	Zărnești VI, 35B	10	95	N	23	1000	Dystric cambisol	3333	1311
12	Domnești II, 102C	9	100	V	10	640	Dystric cambisol	5243	4211
13	Vl. Cibin V, 49C	9	105	NE	25	1338	Dystric cambisol	2333	1111
14	Zărnești V, 65A	6	110	SE	24	1200	Dystric cambisol	3333	1311
15	Râșnov II, 28A	4	150	V	15	1075	Dystric cambisol	3333	1211
16	Retezat III, 130B	4	150	N	42	1190	Dystric cambisol	3333	1411
17	Mușătești V, 35A	4	110	SE	36	1250	Dystric cambisol	2333	1111
18	Mușătești V, 36A	4	110	NE	36	1250	Dystric cambisol	2333	1111
19	Orăștie III, 50H	6	160	N	35	1525	Dystric cambisol	2333	1111
20	Mușătești IV, 26A	6	160	N	36	890	Dystric cambisol	3333	1111

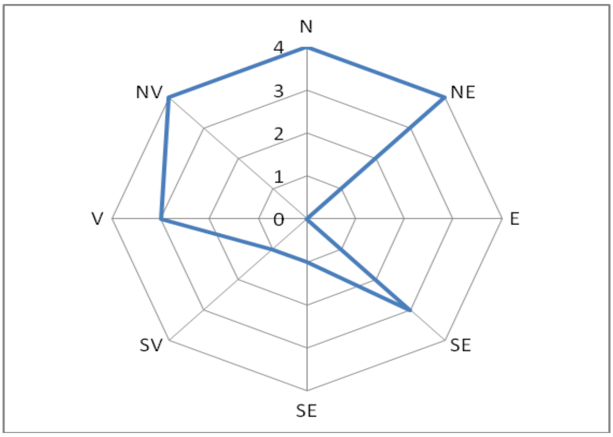

Fig. 3. The distribution of the first 20 spruce smart forests from the Southern Carpathians on expositions

Smart Norway spruce forests are mainly distributed on North slope expositions (N, NE and NW), as can be seen in Figure number 3. This aspect is also confirmed by the specialty literature [15- 17].

Smart Norway spruce forests are distributed on fields with different inclinations, from small inclinations (<10%) to average inclinations (11-20%) up to very strong inclinations (>35%). However, this aspect does not influence the apparition of smart forests. Actually, through its root system [18, 19], and through its mycorrhiza system that it forms [20, 22], Norway spruce can vegetate very well on fields with different slopes.

The altitudes at which the first 20 Norway spruce smart forests are distributed range between 640 and 1600 meters, with the most frequent area of 1000-1330 meters. Indeed, at high altitudes, the Norway spruce does not achieve considerable growths [23, 24], while its introduction at low altitudes represents a failure.

The most spred soil for Noeway spruce is dystruc cambisol. This soil is also the most widespread in Romania's forest area, occupying 35% of its surface [25]. The soil is characterized by richness in humus/organic carbon [26] and has the most appropriate acidity, structure and texture for the Norway spruce [27]. The most optimum stations for the Norway spruce proved to be *Mountain Bs high edaphic eutric cambosol mixtures with Asperula-Dentaria* and *Mountain Bm average edaphic dystric cambisol mixtures with Asperula-Dentaria.* At the same time, the most appropriate forest type proved to be *Norway spruce stand with Oxalis acetosella or mull flora.*

Conclusions

Norway spruce forests from the Southern Carpathians can be situated in the smart forest category, based on the cumulated grades of their characteristics. The forests with the highest score are also the most productive ones, being adapted to environment conditions and representing the most valuable genofund of this arborescent species from this area. They are situated in Săcele, Retezat, Orăștie, Mușătesti and Zărnești Forest Districts, as well as in Retezat, Iezerului, Șureanu and Piatra Craiului Mountains.

The optimal site conditions for the apparition of smart forests in the Southern Carpathians are the following: altitude= 1000-1300 m; exposition = shaded (N, NE, NW); soil =

dystric cambisol; forest type = *Norway spruce stand with Oxalis acetosella or mull flora*; station type = *Mountain Bs high edaphic eutric cambisol mixtures with Asperula-Dentaria*.

Among the optimal stand conditions for the apparition of smart forest in the Southern Carpathians, the most representative one (besides growth) is the age = 90-150 years,

The factors that do not influence the apparition of Norway spruce smart forests are: the percentage of participation in the stand's composition and the field's slope.

The usage of the term "smart forests" proves to be very useful for analyzing different types of stands at a high geographic scale. The classification of forests in this category was realized for the first time in this study and will be useful for forestry research and practice.

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