FOREST CLASSES COMMON IN ESTONIA REFLECTING MILITARY ASPECTS OF A TERRAIN BASED ON THE SIZE OF TREE STEMS AND FOREST DENSITY

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Abstract. Military aspects of a terrain include obstacles, observation or fields of fire, cover and concealment, key terrain, and avenues of approach (OCOKA). These are used for evaluating the conditions of a terrain for battling[1]. Wooded areas are not typical grounds for fighting. Due to longer fields of fire and better mobility, many powerful armies prefer open areas. However, there are always certain reasons to operate in wooded areas. Some of the important forest characteristics for fighting are tree stem diameter and the space between trees. Both characteristics are mainly dependent on the age of a forest but also on forest stand history. In this paper, we examine the formation of the structural parameters of forests in Estonia. We will identify basic forest classes based on the Estonian forest inventory database, and discuss their influence on OCOKA.

Keywords: fields of fire, mobility, cover, concealment, OCOKA, tree stem diameter, space between the trees, tree location pattern, forest stand.

1. Introduction

Historically, and in certain times and places, the links between military action and the forest have been significant. McNeill pointed out that forests have been a direct factor in influencing how wars were fought. He described a few examples from the period of the American Civil War as well as from World War II when underestimating the influence of forested areas remarkably changed the course of battles[2]. According to McNeill, "Clever commanders

[1] This article is composed in the framework of scientific project No. 42O (T-005) "Determination of the mechanical properties of soils in relation to military vehicle trafficability, and development of the mapping tool to visualize the tactical properties of forests" (29.04.2019–01.08.2023).

[2] **McNeill, J. R**. 2004. Forests and Warfare in World History. Georgetown University, pp. 21–22. https://foresthistory.org/wp-content/uploads/2016/12/John-McNeill-Lecture.pdf (16.06.2022). [**McNeill** 2004]

could exploit forest barriers to offset enemy advantages in numbers or firepower."[3]

In modern literature, fighting in wooded areas is treated as military operations under special conditions of a terrain[4, 5, 6]. Different authors underlie the necessity to employ different tactics compared to those used in more open areas[7]. Usually, larger armies possessing a sufficient number of men and high firepower prefer to battle in open areas, not wooded ones, especially when conducting attacks. In Estonia, the coverage of forests and other wooded areas is around 58%[8]. Still, it would be rash to consider half of a country's territory as restricted and assume that these conditions are too complicated for fighting. For planning and conducting operations, an important aspect is the total size of a wooded area surrounded by open type land-use, e.g. cultivated fields and grasslands. More precisely, small wooded areas can be easily bypassed by attacking forces that are using less severe conditions. In addition, from the defensive forces' perspective, a battlespace composed of fragmented landscape with discontinuous woodland does not provide options for safely retreating. From the perspective of an offender, more open areas between forests are favourable for indirect fire. It is difficult to determine a specific size for a "small wooded area" because it depends on the type of operation, firepower and unit sizes, etc. For example, a Russian brigade in combat formation will usually occupy a 5–8 km wide sector[9] and a battalion covers a sector of up to 2 km of width[10]. It could be assumed that, with wider forested areas inside axes of advance, units will have to at least partially deploy tactics that are modified for the forest. It should be taken into account that units

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3 **McNeill** 2004, p. 21.

4 **Datz, I. M**. 2004. Military operations under special conditions of terrain and weather. New Delhi: Lancer Publishers & Distributors, pp. 200–208. [**Datz** 2004]

5 **ATP-3.2.1 = NATO Standard No. 3.2.1**: Allied Land Tactics. Edition B, Version 1, August 2018. NATO STANDARDIZATION OFFICE (NSO), pp. 8.1–8.5. [**ATP-3.2.1** 2018]

6 **Grau, L. W.; Bartles, C. K**. 2016. The Russian way of war. Force structure, tactics, and modernization of the Russian ground forces. Foreign Military Studies Office (FMSO). Fort Leavenworth, KS. https://www.armyupress.army.mil/portals/7/hot%20spots/documents/russia/2017-07-the-russian-way-of-war-grau-bartles.pdf (29.06.2022), p. 108. [**Grau, Bartles** 2016]

7 **Datz** 2004, p. 198.

8 **EUROSTAT** 2020. Agriculture, forestry and fishery statistics. Luxembourg: Publications Office of the European Union. pp 176–177. https://doi.org/10.2785/143455.

9 **Grau, Bartles** 2016, p. 140.

10 Ibid., p. 143.

have some freedom to manoeuver around their axes of advance. Nevertheless, taking into account the rather rigid nature of Russian tactics, freedom is quite limited. In summary, battle planning for terrain requires detailed spatial data, including the size and location of wooded areas and parameters of tree cover.

It is generally recognised that a military view on terrain includes the following aspects: obstacles, observation or fields of fire, cover and concealment, key terrain, and avenues of approach (OCOKA)[11]. An obstacle can be defined in several ways but usually it means an obstacle to movement, i.e., mounted as well as dismounted movement. In wooded areas, three aspects of OCOKA are particularly important: observation, cover and concealment, and mobility. Due to the fact that field of view is very limited in the forest, and visibility can at best reach up to 200 m or even be as short as 10 m, the use of direct fire weapons, but also the control of units, is severely curtailed compared to open areas[12, 13]. Impeded observation possibilities will also significantly influence the speed of movement as tree trunks and undergrowth will affect the selection of a route. In reality, there are a few more aspects that are also worth considering: the existence of landmarks useful for orientating[14], the availability of construction material for engineers, and the restrictive effect of vegetation on communication links[15]. In summary, detailed knowledge of these characteristics in a forested area will determine success.

In this paper, we will discuss forest growth regularities in Estonia and how a natural development combined with forest management influence the structure of a forest. Based on the Estonian forest inventory data, we will determine the forest structure parameters (size of trees, stand density and tree location pattern) that are important for military aspects of terrain and discuss their effects on OCOKA.

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11 **Margiotta, F. D**. 2000 (ed). Brassey's encyclopedia of land forces and warfare. Brassey's Washington: Brassey's Inc., pp. 435–436.

12 **Lang, M.; Vennik, K.; Põldma, A.; Nilson, T**. 2020. Options for estimating horizontal visibility in hemiboreal forests using sparse airborne laser scanning data and forest inventory data. – Forestry Studies / Metsanduslikud Uurimused, Vol. 73, pp. 125–135, here p. 130.

13 **ATP-3.2.1** 2018, p. 8-2.

14 **Kala, V.; Peets, A**. 1995. Sõjatopograafia. Tallinn: Eesti Riigikaitse Akadeemia, lk 7. [**Kala, Peets** 1995]

15 **Tamir, T**. 1967. On radio-wave propagation in forest environments. – IEEE Transactions on Antennas and Propagation, Vol. 15, Issue 6, pp. 806–817, here p. 806.

2. Trees and forest: definition and parameters

2.1. Trees and their parameters

Trees and bushes are plants that have wooden stem(s) and branches. For a tree, we can distinguish three major components: the underground root system, the stem, and the tree crown with branches and foliage[16]. In Estonia, we find mainly deciduous broad-leaved tree species and evergreen coniferous tree species. Trees are usually characterised (Figure 1) by their height h (m), height to live crown base h_{lcb} (m), and stem girth or stem diameter d (cm) at breast height, which is measured at 1.3 m over the tree root collar[17]. From d we can calculate the tree stem basal area as the area of corresponding circle $g = 0.25 \times \pi \times d^2$. The d is usually proportional and linearly related to tree crown diameter d_{CR}.[18, 19] Tree species can be classified as shade tolerant (*Norway spruce*) and light demanding (*Scots pine, Silver birch*), whereas shade tolerant species are able to survive below others, where the availability of solar radiation for photosynthesis is limited.

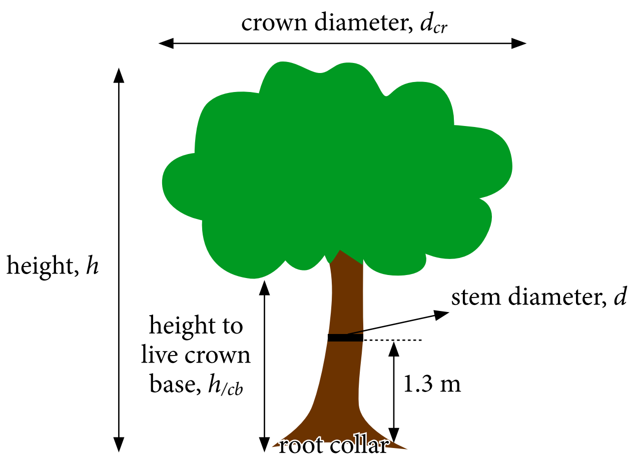

Figure 1. Tree parameters

[16] **Krigul, T**. 1972. Metsatakseerimine. Tallinn: Valgus, lk 11–12.

[17] **Vaus, M**. 2005. Metsatakseerimine. Tartu: OÜ Halo Kirjastus, lk 42–52.

[18] **Spurr, S. H**. 1948. Aerial photography in forestry. New York: The Ronald Press Company, pp. 281–284.

[19] **Hasenauer, H**. 1997. Dimensional relationships of open-grown trees in Austria. – Forest Ecology and Management, Vol. 96, pp. 197–206, here p. 203.

Shade tolerant tree species can also usually grow well in conditions that guarantee full light. Here we see that in a group of trees, each tree requires a certain amount of space determined by the tree size. The number of trees that can survive for several years per unit area N (ha^{-1}) in such a group of trees also depends on soil fertility. A sufficiently large patch of trees covering a certain area is defined as a forest.

2.2. Forest: definition and parameters

Definition and main inventory variables

Almost every country has established its own definition of a forest[20, 21]. Most definitions include criteria for canopy cover (percent of ground covered by tree crown projections), minimum height of trees, and minimum size of the land patch. Forest land is usually divided into sub-units for forest management and management planning. These units are called forest stands. In Estonia, the mean size of a forest stand is currently 1.3 ha[22]. Forest inventory databases describe forest stands by tree layers (dominant, middle, regrowth, understorey). In each layer, the trees of particular species i are usually described by their count per hectare N_i, basal area $G_i = \Sigma (g_i)$ ($m^2\ ha^{-1}$), mean tree (according to g) diameter at breast height D_i, and mean tree height H_i. Here we see that forest stand density is the sum of N_i and stand basal area is the sum of G_i. Stand level D and H are only good descriptor variables for simple single layer stands, otherwise the values are used for each layer of trees separately.

When we observe a unit of forest with a size of one hectare where $N = 1{,}000\ ha^{-1}$ trees grow, and assume a strictly regular rectangular grid pattern of tree locations, then the growth space for each tree s_j is 10 m^2 and the mean distance L between trees is $L_{reg} = 100/\sqrt{N} = 3.16$ m. The need for growth space for a tree is proportional to its size, hence the required distance between trees in younger stands is less than in older stands where trees are bigger and taller.

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[20] **Pulla, P.; Schuck, A.; Verkerk, P. J.; Lasserre, B.; Marchetti, M.; Green, T**. 2013. Mapping the distribution of forest ownership in Europe. – EFI Technical Report 88. European Forest Institute, p. 14.

[21] **FAO 2020**. Global Forest Resources Assessment 2020: Main report. Rome, p. 20. https://www.fao.org/3/ca9825en/ca9825en.pdf (29.06.2022).

[22] **Valgepea, M.; Raudsaar, M.; Sims, A.; Timmusk, T.; Pärt, E.; Suursild, E.; Matson, T**. 2020. Metsavarud. – Aastaraamat Mets 2019. Raudsaar, M.; Valgepea, M. (toim.). Tallinn: Keskkonnaagentuur, lk 83. [**Valgepea et al**. 2020]

Tree distribution pattern (regular, random, clumped)

A strictly rectangular pattern of tree locations can rarely be found in natural stands. Such an arrangement of trees is, however, common to plantations as this pattern provides the maximum mean distance between individual trees and, hence, the most uniform distribution of growth space. Planting or sowing is a common silvicultural task in forest management practice[23, 24] and a regular pattern of locations is preferred. However, ground surface in forest land has much more variation in height, and the soil's chemical and physical properties and water regime are more diverse compared to agricultural land[25, 26]. Additionally, there are stumps, retention trees, rocks, and cutting residuals. Therefore, the tree location pattern in planted stands in forest land also has a random component causing the mean distance to the nearest neighbour tree to decrease. If we have a forest stand where tree location pattern is random, then the expected mean distance from a tree to its nearest neighbour is $L_{rand} = 100/(2\sqrt{N})$, i.e., only half of that found in a strictly regular rectangular pattern. It must be noted that L_{rand} is a mean value and, due to the randomness in the tree location pattern, the individual distances between neighbouring trees vary within a certain range. The point pattern of a stand with a random location of its trees follows the *Poisson* process in which the mean number of trees N_{sample} per sample area $S_{sample} = 10{,}000/N$ (m^2) is equal to the variance of the N_{sample}. We can obtain N_{sample} and its variance by counting trees in a large number of samples, each having the area of S_{sample} taken at random places over the stand area.

If the tree location corresponds to a clustered pattern (Figure 2) then the distance to the nearest neighbouring tree decreases even more (Table 1) compared to L_{rand}, and the variance of tree count in samples (in different locations in the stand) becomes greater than N_{sample} as samples are taken from

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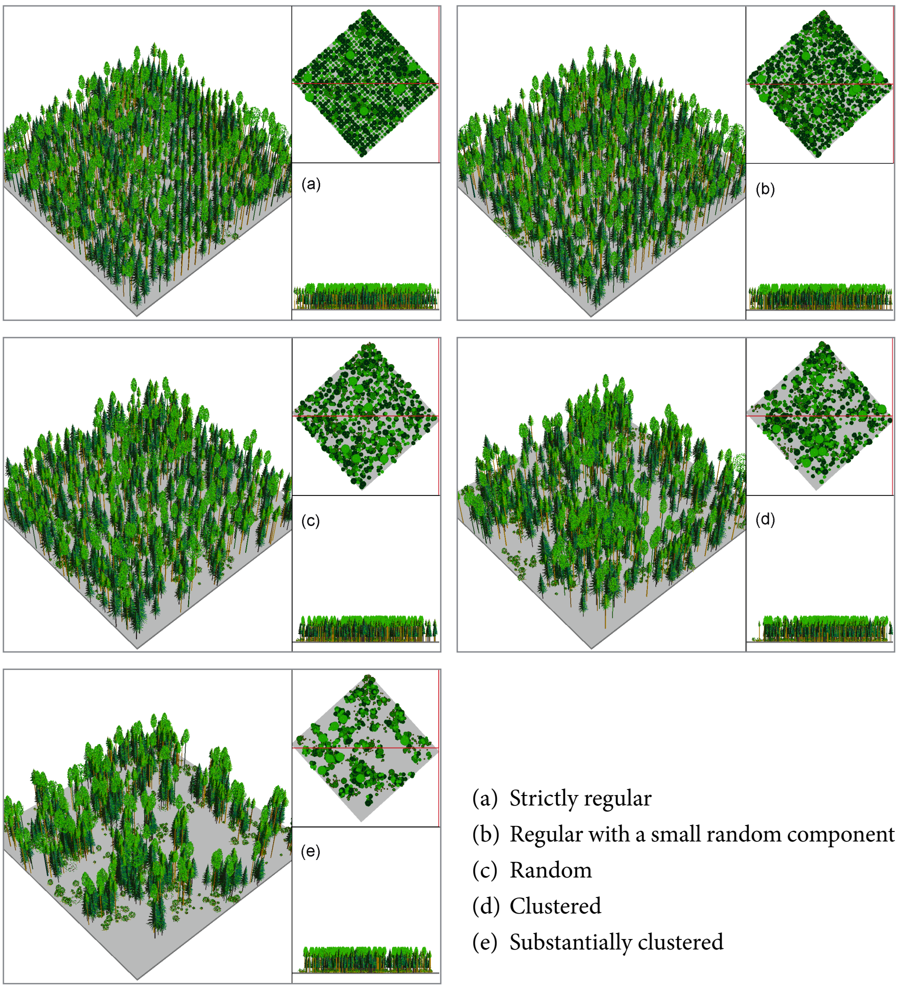
[23] **Tetlov, E.; Valgepea, M**. 2020. Metsauuendamine. – Aastaraamat Mets 2019. Raudsaar, M.; Valgepea. M. (toim.). Keskkonnaagentuur, Tallinn, lk 152.

[24] **Orazio, C.; Freer-Smith, P.; Payn, T.; Fox, T**. 2020. Species choice, planting and establishment in temperate and boreal forests: meeting the challenge of global change. – Stanturf, J. A. (ed.). Achieving sustainable management of boreal and temperate forests. Cambridge: Burleigh Dodds, pp. 397–412, here p. 398.

[25] **Tomson, P.; Bunce R. G. H.; Sepp, K**. 2015. The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. – Landscape and Urban Planning, Vol. 137, p. 60.

[26] **Rannik, K.; Kõlli, R**. 2018. Evaluation of the pedodiversity, agronomical quality and environment protection ability of the soil cover of Estonian croplands. – Estonian Journal of Earth Sciences, Vol. 67(3), pp. 205–222, here p. 217.

all over the stand area. This means that in stands with clustered patterns of tree locations, we have clearly denser groups of trees alternating with more open space. Such clustered patterns can occur in stands that have suffered wind damage or in stands where a patch-type of shelterwood cutting was carried out as treatment for forest regeneration. However, forest thinning usually decreases clustering and modifies the tree location pattern towards regular in order to divide growth space more equally between trees.



(a) Strictly regular
(b) Regular with a small random component
(c) Random
(d) Clustered
(e) Substantially clustered

Figure 2. Examples of dominant layer tree and understorey bush distribution patterns in mixed species mature forest stands

Table 1. Mean distance to nearest neighbour in the simulated stands of different tree location patterns shown in Figure 2. A clustered pattern was always used for understorey bushes in the simulation

Pattern in dominant layer	*Mean distance from a tree to its closest neighbour (m)*	
	Dominant layer (*N* = 361)	Understorey (*N* = 340)
Strictly regular	5.23	2.12
Regular with some randomness	3.77	2.63
Random	2.65	2.00
Random with slight clustering	2.44	2.04
Substantial clustering	1.46	2.08

* *N* is the stand density given as trees per hectare

In the literature dealing with military vehicle mobility through forested areas, we can find controversial numerical values for the required space between tree stems. Rybanský stated that for cross-country mobility, a free manoeuvring of military vehicles requires 5 m of free space, whereas 3 m and less means the terrain is not passable[27]. Again, Peets and Kala described forest conditions with a space smaller than 6 m between trees as not passable[28]. Relating these free space values to the presented mean distances for different tree patterns (Table 1), the no-go conditions for forested areas can generally be deduced if vehicles are to be under the densest tree cover. In addition, Rybanský stated that cross-country mobility is not affected much if the tree stem diameter is smaller than 5 cm; however, when the diameter of stems is greater than 15 cm, it is not possible to travel into the forest[29]. This conclusion relates to the potential of military vehicles to push trees over. Both parameters, i.e., free space between the stems and the effect of tree diameter on military vehicle mobility were studied and experiments conducted by Vennik et al. in 2020[30]. For tracked infantry fighting vehicles, the main findings were that the space between trees is irrelevant in defining mobility. However, for wheeled vehicles, distances smaller less than 4.5 m between tree stems will substantially hamper movement.

[27] **Rybanský, M**. 2007. Effect of the Geographic Factors on the Cross Country Movement during Military Operations and the Natural Disasters. – International Conference on Military Technologies, University of Defence, Brno (Czech Republic), p. 592. [**Rybanský** 2007]

[28] **Kala, Peets** 1995, lk 5.

[29] **Rybanský** 2007, p. 592.

[30] **Vennik, K.; Lang, M.; Piip, K.; Põldma, A**. 2021. Eesti metsade taktikalised omadused: 2020. aasta uuringute kokkuvõte. – EMA Occasional Papers, Vol. 12, lk 45–49. [**Vennik et al**. 2021]

Forest establishment, growth and life cycle of trees

A patch of land can be reforested by planting or sowing, usually aiming for a stand density of 2,000–6,000 ha^{-1} ($1.3 \le L \le 2.2$) when trees reach a height of 1.3 m[31]. The process of growing new trees is uncontrolled in natural regeneration where new trees emerge, depending on the species, from remaining in soil rootsystem sprouts and from the seeds of retention trees. The distance between trees in naturally regenerating stands has a greater variation compared to cultivated stands, and initial densities may be as high as 4 trees per square meter[32]. In some sites, the strong growth of herbaceous vegetation suppresses the establishment of trees completely and the pattern of tree locations in the new stand will be clustered. However, as trees grow, they each try to occupy space proportionally to their size. This causes competition and stand density starts to decrease due to natural mortality. Forest density can also be regulated by thinning. In Estonia, tending and cleaning is typically carried out several times before a stand reaches 10 years of age to regulate first the competition of grasses and then to thin groups of trees. Commercial thinnings are not usually performed in stands over 40–50 years of age[33], with the main aim of selecting 500–800 ($3.5 \le L \le 4.5$) trees for the period until regeneration felling.

At a certain stage in forest stand evolution (about 20–30 years after stand establishment), there is a sufficient amount of light for shade tolerant trees to establish as regrowth. Some of the species remain as forest understorey, and some create a second layer of trees that is eventually able to reach the height of the dominant layer. Estonian forest inventory data (1.14 million stands) indicate that an influence on the distance between trees is notable when the dominant layer trees reach a diameter of about 18 cm (Figure 3) at breast height. At that age, the mean distance between trees, assuming a regular pattern, is about 3 m on average (Figure 3). We have to bear in mind here that L is greatest with a regular pattern and in a real forest, tree patterns always have a random component. There is also a bias in L calculated from forest inventory data because middle and lower layers are only described if

[31] **Pogen, O.; Laas E**. 1989. Metsauuendamine. – Metsamajanduse alused. Taimre, H. (toim.). Tallinn: Valgus, lk 219.

[32] **Kängsepp, V.; Kangur, A.; Kiviste, A**. 2015. Tree height distribution dynamics in young naturally regenerated study plots. – Forestry Studies / Metsanduslikud Uurimused, Vol. 63, pp. 100–110, here p. 102.

[33] **Muiste, L**. 1989. Metsa raiesüsteemid. – Metsamajanduse alused. Taimre, H. (toim.). Tallinn: Valgus, lk 111.

they might have economic value in the future. This means an overestimation of *L*, i.e., we get somewhat longer distances than in nature. Also, during forest inventory, the number of trees is not usually counted but is calculated from stand basal area and mean tree diameter at breast height. In young stands where *D* is less than 6–8 cm, stand densities are usually underestimated in forest management inventory data and *L* is, therefore, overestimated as a result (Figure 3).

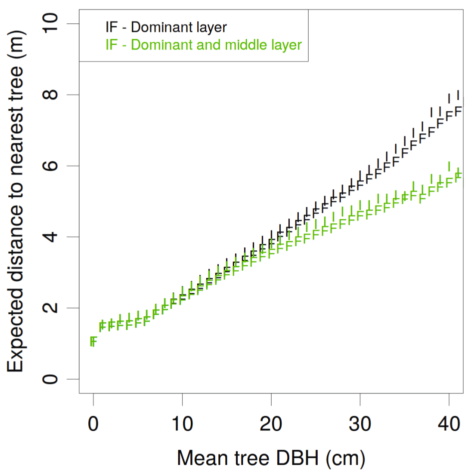


Figure 3. Distance between nearest neighbouring trees depending on the diameter at breast height (DBH) of mean tree in dominant layer. Stand data from Estonian forest register. Distinguished are fertile (F) and less than average fertile (I) sites. A regular pattern is assumed

3. Forested landscapes and their management in Estonia

Estonian landscapes inherit their dominant topographical characteristics from the retreating of the ice shield from about 11,000 years ago[34]. Over the last 100 years, land cover has been strongly influenced by the conversion of forested and wetland areas into agricultural land, and the opposite process of continuous afforestation of small land patches after World War II. Since 1948, the total forest land area has increased[35] from 14.7 thousand km^2 to 23.3 thousand km^2. The area of wooded land is greater than forest land as it

[34] **Arold, I**. 2005. Eesti maastikud. Tartu: Tartu Ülikooli Kirjastus, p. 24.

[35] **Valgepea et al**. 2020, p. 43.

includes bushland and other land with tree cover. Different types of forest management restrictions are imposed on 25.4% of forest land[36]. On that land, forest structure variability increases more over time compared to land where a typical regeneration felling approach (clear-cut) is used.

Forest management is planned and carried out at stand level and the units are typically 0.5–7 ha in size. This also corresponds to a typical regeneration felling area and hints that treeless land patches or areas with some type of forest in the succession have a maximum diameter of 200–250 m. However, according to the Estonian forest inventory database, a typical stand is usually rectangular-shaped, indicating a long management history of forests. In state forest areas we find regular 3–4 m wide skidding roads (narrow strips of land without trees in a forest) which divide state forest land into rectangular blocks of 18–25 ha in size. Inside each block, forest stands are delineated. In private forests such intermediate division is usually absent. Many private forests originate from natural regeneration on abandoned agricultural land that is more fertile compared to historical state-owned forest land.

4. Forest classes in Estonia and their relation to OCOKA

As a result of the previous discussions about forest structure as well as forest growth and management regularities, and using an overview of experiments carried out in the Estonian forest and presented in Vennik et al. (2021)[37], an approach for grouping forest stands in Estonia was developed. For this purpose, the Estonian forest inventory database was also analysed with the aim of determining specific forest stand parameters for each class age, i.e., average diameter of trees at breast height, average height of trees, and average space between trees. This forest grouping system aims to support military battlespace planning at a tactical level, with military aspects of terrain like horizontal visibility, obstacle effect for vehicles and dismounted unit mobility being specified for these groups. Forest classes are presented in Table 2 and discussed in more detail in the following sections.

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[36] **Sims, A.; Raudsaar, M.; Tamm, U.; Timmusk, T**. 2020. Keskkond. – Aastaraamat Mets 2019. Raudsaar, M., Valgepea, M. (toim.). Tallinn: Keskkonnaagentuur, p. 220.

[37] **Vennik, K.; Lang, M.; Piip, K.; Põldma, A**. 2021. Eesti metsade taktikalised omadused: 2020. aasta uuringute kokkuvõte. – EMA Occasional Papers, Vol. 12, lk 45–49. [**Vennik et al**. 2021]

Table 2. Typical forest classes defined by parameters like (D) average diameter of trees at breast height; (H) average height of the trees; and (L) average space between the trees

Forest designation	Condition for designation	Age of forest stand*
Clearing	$H <= 1.5$ m	Dependent on forest stand 0–9 years
Young forest stand	1.5 m < H <= 10 m D <= 10 cm 1 m < L <= 2 m	Dependent on forest stand from 3–9 to 20 years
Pole forest stand	10 m < H <= 15 m 10 cm < D <= 20 cm 1 m < L <= 3 m	20–40 years
Mature forest stand	15 m < H <= 45 m 20 cm < D <= 40 cm 3 m < L <= 7 m Regrowth and understory layer can be very dense or can be completely absent	Over 40 years

* Clear-cut is considered as zero point

Clearing and its parameters relating to OCOKA

In clearings, the most important criterion to be considered is the height of trees. A tree height of less than 1.5 m means that it is possible for a standing man to look over the young trees. There are hardly any forest land sites in Estonia with herbaceous plant cover higher than 1.5 m. For fast-growing deciduous species like silver birch, grey alder or European aspen, a height of 1.5 m can be reached in as little as three to four years. For slow-growing species like pine and spruce, it takes longer—up to nine years depending on site fertility[38, 39]. However, as in the first development stage, deciduous trees normally prevail so it can be assumed that in approx. 5 years, the stated height limit of 1.5 m will already be reached (Figure 4).

Clearings offer a good field of view but cover and concealment are poor. From a mobility perspective, it feels tempting to drive over the clearings; however, the amount of smaller obstacles like stumps, fallen tree stems, dead

38 **Uri, V.; Aosaar, J.; Varik, M.; Kund, M**. 2010. The growth and production of some fast growing deciduous tree species stands on abandoned agricultural land. – Forestry Studies / Metsanduslikud Uurimused, Vol. 52, pp. 18–29, here p. 21.

39 **Tappo, E**. 1982. Eesti NSV puistute keskmised takseertunnused puistu enamuspuuliigi, boniteedi ja vanuse järgi. Tallinn: Eesti NSV põllumajandusministeeriumi informatsiooni ja juurutamise valitsus, lk 27.

retention trees, and piles of twigs seriously hamper free travel. These obstacles are less significant for tracked vehicles compared to wheeled vehicles. In addition, for dismounted movement, these areas are physically difficult to pass due to grass and previously listed visible or hidden obstacles.

Figure 4. Clearings. On the left with deciduous species and on the right with evergreen trees

Young forest stand and its parameters relating to OCOKA

A young forest stand is the densest forest type (Table 2). Slender tree stems are surrounded by just one or two meters of empty space. For a dismounted soldier, the width of the body, a gun and a backpack is approx. 80 cm, hence it is extremely difficult to pass such a thicket. Visibility can be less than 15 metres[40] (Figure 5). Young forest stands offer good concealment, but as the stems here are thinner than a human arm, such a forest provides poor cover. One important aspect here is the fact that movement in this densest forest class may be quite noisy as there is almost no free space, taking tree branches into consideration as well. Both vehicle types—tracked and wheeled vehicles—are able to push away trees and move through the area slowly[41]. Vehicles with a larger total weight will make manoeuvring in this forest type more successful.

Besides wooded areas, shrub land that is normally not defined as woodland may also be considered as belonging to a young forest class. Another issue that influences the density of young forest stands is thinning. Typically, the removal of some plants to make more space for remaining trees to grow is carried out in forests of up to 20 years old. This will produce approx. 2 metres of free space between stems.

[40] **Vennik et al**. 2021, p. 54.

[41] Ibid., pp. 47–49.

Figure 5. Examples of young stands

Pole forest stand and its parameters relating to OCOKA

Approx. 20 years after the establishment of a forest, the next natural stage of development is the pole forest stand (Table 2, Figure 6). During that phase, natural mortality combined with thinning produces more space between stems with the distances ranging between 1–3 m. Thicker tree stems may reach a diameter of up to 20 cm at breast height. Although the obstacle-free space between stems gets larger, entwined lower branches can still impede dismounted movement. Concealment and cover of this type of forest is good. Thicker trees will already provide acceptable cover against automated weapon fire. The horizontal field of view can reach up to 60 m[42]. Tracked vehicles can slowly move but for wheeled vehicles, this type of forest can be described as impassable.

Figure 6. Examples of pole forest stands

[42] **Vennik et al**. 2021, p. 53.

The main reason for this is that wheeled vehicles lack the traction force to push over trees and crawl over fallen ones; nor can these vehicles manoeuver between stems as the space is too narrow.

Mature forest stand and its parameters relating to OCOKA

Regarding tactical operations, significant differences in the structure of forest stands appear at approx. 40 years after forest establishment. Depending on the amount of nutrients in the soil, moisture regime, and terrain location, denser or sparser forest stands evolve. However, it is important to note that the space between the trees of a dominant layer, i.e., the biggest trees in the forest, is quite uniform for all stands—on average from 3–5 m, increasing with stand age. The visual impression of a denser forest is influenced by trees and bushes forming middle and regrowth layers. Tree diameter in mature stands is between 20–35 cm, but the largest trees can even reach 40 cm or more.

The largest obstacle-free space between stems exists in pine forests (Figure 7), seldom in old birch woods. On dry sand soil, visibility in mature pine forests can reach up to 200 m[43]. These are the most sparse forest types in Estonia. Otherwise, extra wide empty space between growing trees may occur due to selective felling. Because of the long field of view, this type of forest supports the use of more long range guns but, on the other hand, cover and concealment is poor. Tracked vehicles are even able to push down trees of over 30 cm in diameter and slowly crawl over the fallen stems. For wheeled vehicles, manoeuvring between trees is preferred.[44]

Figure 7. Examples of old pine forest stands

[43] **Vennik et al**. 2021, p. 52.

[44] Ibid., p. 49.

Due to the existence of trees and bushes in middle, regrowth or understorey layers, other mature forest stands appear to be denser (Figure 8). Mobility for tracked vehicles in mature forest stands depends mainly on soil strength. The interaction between dry ground and tracked vehicles—i.e., tanks and infantry fighting vehicles—will produce enough traction to overcome standing as well as fallen trees. Soft and wet ground does not support manoeuvring[45]. Wheeled vehicles are less powerful, and even dry and strong forest ground does not support pushing over multiple trees simultaneously. Normally, such vehicles do not penetrate mature stands more than just a few meters. A dismounted soldier's speed of movement is significantly influenced by the density of regrowth and understorey layers. Horizontal visibility in mature stands is very variable, ranging from 8 to 150 meters[46].

Figure 8. The density of a mature forest stand: on the left on dry ground and on the right on wet ground

As mentioned above, the rate of construction material provision in a wooded area is equally important for conducting a successful battle. A foxhole can be constructed efficiently with timber with an end diameter of 15–20 cm, and according to FM 5-250, an efficient abatis can be constructed of trees with a diameter of over 60 cm[47]. Although there are no forests in Estonia with trees larger than 60 cm in diameter, information about the location of mature forest stands or the amount of larger trees for timber at a particular point is still needed for survivability and counter-mobility. Moreover, forest stands located on dry ground offer better and simpler logging and timber transportation opportunities.

45 **Vennik et al**. 2021, p. 47.

46 Ibid., p. 53

47 **FM 5–250 = U.S. Army Field Manual No. 5-250**. Explosives and demolitions. Headquarters Department of the Army, Washington DC, 15 June 1992. https://www.bits.de/NRANEU/others/amd-us-archive/fm5-250%2892%29.pdf (29.06.2022), p. 3–7.

While larger homogeneous patches of forest may be preferred as a first choice for tactical operations, there is one more aspect to consider. Movement to a new determined position through a forest requires situation awareness, and soldiers often use global positioning systems devices. However, recent conflicts have proven that the signal from navigational satellites can be effectively jammed with and suppressed[48]. When using hardcopy maps for orienteering purposes, it quickly becomes clear that the frequent presence of different forest stands is very beneficial. Forest boundaries of different age and size classes provide useful landmark lines for soldiers navigating through wooded areas.

5. Summary

Even though, depending on the army and its power, wooded areas are not a preferred fighting ground, one should not completely pass over and ignore these areas. Forested landscapes are not homogeneous areas with uniformly spaced trees with the same mean parameters. The existence of parameters like tree diameter and space between trees in the dominant layer, lower layer trees and bushes, and the level of moisture in the ground significantly affect OCOKA and how battles are conducted. The regularities of forest growth, management routines, soil type and age serve as more or less suitable areas for certain military actions and, thus, as battle areas in Estonia. Altogether, five different forest age classes have been determined here, with their parameters defined and their effect on OCOKA described.

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[48] **Marzal, C.; Colom-Piella, G**. 2021. Russian electronic warfare capabilities and their implications for European strategic stability: A case study of the Syrian conflict. – Strategies XXI-Security and Defence Faculty, Vol. 17(1), pp. 80–87, here p. 80.