Short communication

Changes during twelve years in three mature hemi-boreal stands growing in a radiation model inter-comparison test site, Järvselja, Estonia

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Abstract. In 2007, three mature hemi-boreal stands were selected from Järvselja forest district, South-East Estonia to establish one-hectare-large test plots for the international inter-comparison experiment of radiation models (RAMI). All trees with a stem diameter at breast height greater than 4 cm were mapped and measured in the field. In summer 2019, the forests were inventoried again. Here we present a summary of changes that occurred in the forest structure – mainly growth and mortality. In the birch stand basal area *G* has increased from 23.3 m^2 ha^{-1} to 28.2 m^2 ha^{-1} in the upper layer and the number of trees *N* has decreased from 654 to 565 ha^{-1}. In the upper layer of spruce stand *G* has increased from 30.9 m^2 ha^{-1} to 35.4 m^2 ha^{-1} and *N* has decreased from 774 to 724 ha^{-1} and *N* substantially decreased in the lower layers from 912 to 577 ha^{-1}. In the pine stand *G* has increased from 28.3 m^2 ha^{-1} to 29.1 m^2 ha^{-1} and N decreased from 1116 to 971 ha^{-1}. The three test stands can be used now for validating remote sensing data-based estimates of forest inventory variables at single tree level.

Key words: validation data, remote sensing, single tree measurements, RAMI.

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Introduction

For the fourth international radiation model inter-comparison experiment (RAMI) three forest stands were selected at Järvselja, South-East Estonia (Kuusk *et al*., 2013; Widlowski *et al*., 2015). In each of the three forests a one-hectare-large square-shaped sample plot was established in 2007 and the positions of all trees with stem diameter at breast height *d* greater than 4 cm were mapped. The three sample plots represent typical examples of hemi-boreal forests – birch and spruce stands are growing on fertile soil and the pine stand is located on a transitional bog.

Since 2007, regular measurements of canopy gap fraction have been carried

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out in the stands (Lang *et al*., 2010; Lang *et al*., 2017; Kuusk *et al*., 2018; Lang & Pisek, 2019). There have not been any substantial stand structure alternating disturbances in the stands. Only in the birch stand we removed the understory trees that had *d* less than 4 cm to prepare the site for terrestrial laser scanning experiment in 2018. During the regular visits to the sites we have been observing occurrences of single tree mortality in the stands, changes in canopy conditions and also tree growth. Also, more precise coordinates of sample plot corners can be measured with differential GPS now. Therefore, in the summer of 2019 all three stands were fully inventoried to update the RAMI database, create a checkpoint for modeling experiments and validate remote sensing-based forest structure estimates.

Material and Methods

Stands

The birch stand is located at 58° 16′ 49.81′′ N, 27° 19′ 51.53′ E (Kuusk *et al*., 2013) and was 61 years old in 2019 (photo in Appendix 1). The stand grows on a typical brown soil and the site type according to Lõhmus (2004) is *Aegopodium*. The stand was thinned in September–October 2004 (Kuusk *et al*., 2013). Most of the small trees that formed a dense understorey (consists mainly of *Tilia cordata* Mill., *Prunus padus* L., *Corylus avellana* L., *Acer platanoides* L. and *Fraxinus excelsior* L.) layer were removed from the birch stand after thinning in March 2018 to prepare the site for terrestrial laser scanning. In 2019 about 90 retained trees in the regeneration layer that had grown bigger than 4 cm at breast height were mapped during field inventory in the birch stand.

The spruce stand is located at 58° 17′ 43.0′′ N, 27° 15′ 22.0′′ E (Kuusk *et al*., 2013) and was 71 years old in 2019 (photo in Appendix 1). The stand grows on a Gleyic Ferric Podzol and the site type according to Lõhmus (2004) is *Oxalis-Vaccinium*. Management has not been done in the stand since 2007 and also signs of earlier treatments are absent. The mortality of trees is rather high due to fungi that have infected stems that have had bark stripping damage by *Alces alces.* Another dominant cause of mortality is competition in the second and regeneration layer where many supressed trees were present in 2007.

The pine stand is located at 58° 18′ 40.89′′ N, 27° 17′ 48.41′′ E and was 136 years old in 2019 (photo in Appendix 1). Compared to (Kuusk *et al*., 2013) the sample plot coordinates are corrected based on GPS measurements and the azimuth of the y-axis is 6.25 degrees. The stand grows on a transitional bog where the soil consists of deep (>1.3 m) *Sphagnum* peat. Excess water and poor nutrient availability are the strong growth limiting factors. Tree mortality occurs mainly due to competition. The stand consists almost entirely of Scots pine trees. There has not been any management in the stand.

Mapping

The sample plots were established with a land survey instrument Nikon DTM-332 Total station (Nikon-Trimble Co., Ltd, Tokyo, Japan) in 2007. Corner points of 100 by 100 m square within each stand were marked with metal tubes. In 2014 and 2019, RTK differential GPS was used to measure the corner point coordinates in the Estonian state coordinate system EPSG:3301. In each sample plot nine permanent sampling points L1–L9 were established (Kuusk *et al*., 2013). Tree position coordinates were measured with the Nikon DTM-332 Total station in a local coordinate system with the test site south-west corner as the point of origin (0; 0). Sample plot corner coordinates were later used to convert tree positions to the EPSG:3301 system. Regrowth trees that were included first in 2019 as their *d* exceeded the 4 cm threshold, were positioned by measuring distances from their three closest neighbours.

Forest inventory

In 2007, two perpendicular diameters of tree stems at 1.3 m over root collar were measured with the electronic calliper Masser Racal (Savcor Group Ltd., OY, FIN-50100 Mikkeli, Finland). The average of the two measurements was used as an estimate of *d*. In 2019 we used Haglöf girth tape made of metal which allowed to take readings with a one-millimetre step. If a tree had substantial stem damage at the 1.3 m measurement position (mainly due to stripped bark by moose, *Alces alces*), then readings were taken below and above the damaged part of the stem and interpolated for 1.3 m standard height. Stem diameter measurements of dead trees were made with or without bark according to the remaining stem condition. For trees with a partially decayed stem, we used the *d* value from 2007. In 2007 only alive trees were measured. There are some snags remained from dead trees in 2007 still standing in the pine stand, but these are not included in this report.

The identical sample trees as in 2007 were measured in 2019 to establish upscaling models for tree height, live crown base and tree crown radius. At least two tree and crown base height measurements from different viewpoints were made with Haglöf Vertex IV (Haglöf Sweden AB, Klockargatan 8, 88230, Långsele, Sweden) and the average was calculated. Two perpendicular measurements of the crown projection on the ground were made for crown diameter. An additional set of sample trees were measured to replace dead sample trees and increase the number of observations for model construction. The number of sampled trees for height and crown dimensions was 84 in the spruce stand, 63 in the pine stand and 87 in the birch stand. The upscaling models were created for each tree species in each sample plot, but in the case of an insufficient number of sample trees (e.g., only few spruces in the pine stand) models from other stands were used.

Results

Measurements with differential GPS on the corner points of the test sites provided coordinates that were used to transform tree location maps into the Estonian basic map coordinate system (Table 1). There are small (less than 0.5 m) deviations from the planned ideal 100 by 100 m square which is explained by the decreased precision of GPS under forest canopy and also with small errors made in 2007 when the test sites were established.

Table 1. Corner coordinates (EPSG:3301) of the test sites measured with differential GPS

Tabel 1. Katsealade nurgakoordinaadid Eesti põhikaardi süsteemis

Corner	x_{local}	y_{local}	$x_{EPSG:3301}$	$y_{EPSG:3301}$
Pine1	0	0	693110.5	6468117.1
Pine2	0	100	693121.6	6468216.7
Pine3	100	100	693220.8	6468205.6
Pine4	100	0	693210.1	6468105.9
Spruce1	0	0	690832.1	6466197.9
Spruce2	0	100	690814.5	6466296.3
Spruce3	100	100	690913.1	6466313.8
Spruce4	100	0	690930.6	6466215.4
Birch1	0	0	695299.9	6464769.0
Birch2	0	100	695280.7	6464867.2
Birch3	100	100	695378.8	6464886.6
Birch4	100	0	695397.7	6464788.0

In the birch stand (Figure 1) basal area *G* has increased from 23.3 m^2 ha^{-1} to 28.2 m^2 ha^{-1} in the upper layer and from 4.2 m^2 ha^{-1} to 6.0 m^2 ha^{-1} in the lower layers. The number of trees *N* in the upper layer has decreased from 654 to 565 ha^{-1} and increased in the lower layers from 377 to 401 ha^{-1} (Table 2). In the lower layer the increase in stand density is controlled by the cleaning in 2018, when most of the dense understorey and regeneration was removed. The natural mortality is occurring mainly on smaller trees and mean diameter of the

Table 2. Birch stand summary of forest inventory 2007 and 2019. Notations are explained under table.

Tabel 2. Kaasiku 2007. ja 2019. aasta takseerandmete kokkuvõte.

Species	Code	*N*	*G*	*D*	*H*	L_{cr}	R_{cr}
2007 inventory, upper layer							
Populus tremula L.	HB	78	2.848	21.6	27.5	9.4	1.95
Betula pendula Roth	KS	399	13.44	20.7	26.9	9.4	1.63
Alnus glutinosa (L.) Gaertn.	LM	176	6.921	22.4	23.8	9.8	2.04
Salix spp.	PJ	1	0.044	23.7	24.0	9.9	1.96
2007 inventory, second layer							
Ulmus glabra Huds.	JA	1	0.010	11.3	15.9	8.1	0.99
Betula pendula	KS	66	0.567	10.5	18.2	5.8	0.99
Alnus glutinosa	LM	20	0.271	13.1	17.9	8.5	1.40
Tilia cordata	PN	205	2.622	12.8	16.5	9.0	1.93
Fraxinus excelsior	SA	30	0.281	10.9	17.6	9.2	1.64
Acer platanoides	VA	16	0.159	11.2	16.3	8.5	1.85
2007 inventory, regeneration layer							
Picea abies (L.) H. Karst.	KU	39	0.245	8.9	10.3	4.8	1.16
2019 inventory, upper layer							
Populus tremula	HB	64	4.129	28.7	31.8	10.7	2.30
Betula pendula	KS	342	15.44	24.0	29.4	11.5	1.97
Alnus glutinosa	LM	159	8.654	26.3	26.4	13.1	2.27
2019 inventory, second layer							
Ulmus glabra	JA	1	0.015	13.8	17.3	11.0	2.03
Betula pendula	KS	27	0.275	11.4	19.7	8.0	1.20
Alnus glutinosa	LM	18	0.318	15.0	20.6	10.7	1.65
Tilia cordata	PN	264	4.369	14.5	20.2	13.0	2.13
Fraxinus excelsior	SA	18	0.263	13.6	20.4	12.3	2.12
Acer platanoides	VA	20	0.289	13.6	18.7	12.5	2.16
2019 inventory, regeneration layer							
Picea abies	KU	53	0.511	11.1	13.4	11.6	1.54
2019 inventory, dead trees							
Dead 2007–2019	-	159	1.349	10.4	-	-	-

N – number of trees; *H* – mean tree height, m; *D* – mean tree diameter at breast height, cm;
L_{cr} – mean length of live crown, m; R_{cr} – mean maximum radius of crown, m.

dead trees is 10.4 cm (Figure 2, Table 2). The substantial change in mean tree crown length L_{cr} and crown radius R_{cr} of spruce trees in the regeneration layer is because in 2007 we used a model from the spruce stand, but in 2019 a model based on sample trees from the birch stand was applied. Compared to model prediction the mean value for relative live crown length for spruce sample trees in 2007 was 0.74 (n=3) and 0.87 (n=6) in 2019. As there is sufficient amount of light for Norway spruce regeneration trees in the birch stand, live crown base rise is small and live crowns extend almost to the ground.

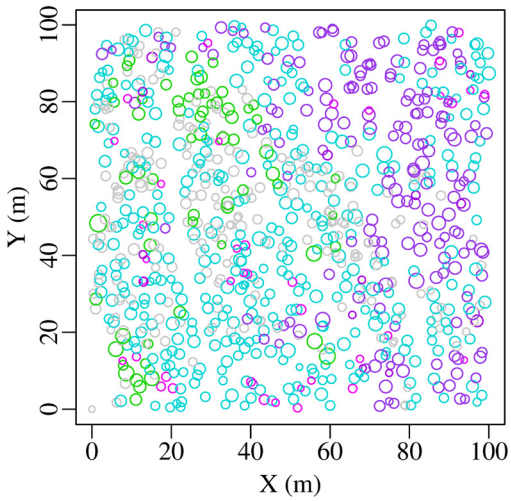


Figure 1. Map of live trees in RAMI birch stand in 2019. The symbols are scaled according to tree size. Cyan corresponds to birch, magenta to spruce, blue-violet to black alder, green to European aspen and grey to other species.

Joonis 1. RAMI kaasiku kasvavate puude kaart aastal 2019. Sümbolid on skaleeritud kujutamaks puude suurust, värvid vastavad metsakorralduse juhendile.

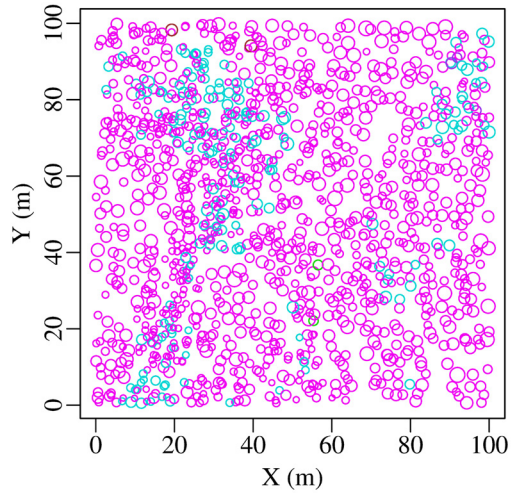


Figure 3. Map of alive trees in RAMI spruce stand in 2019. The symbols are scaled according to tree size. Magenta corresponds to spruce and cyan corresponds to birch.

Joonis 3. RAMI kuusiku kasvavate puude kaart aastal 2019. Sümbolid on skaleeritud kujutamaks puude suurust, värvid vastavad metsakorralduse juhendile.

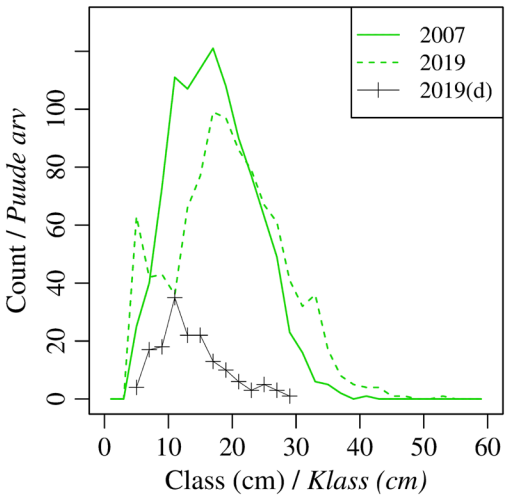


Figure 2. Changes in stem breast height diameter distribution in the birch stand. Label (d) is for the trees that died between two measurements made in 2007 and 2019.

Joonis 2. Kaasiku puude diameetrijaotuse muutus. Ajavahemikus 2007–2019 surnud puud (d) on eraldi välja toodud.

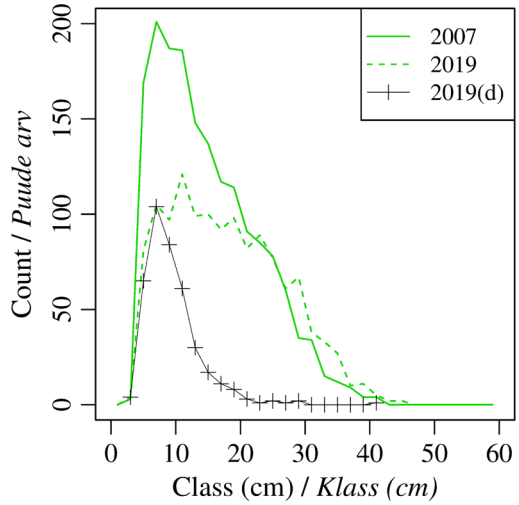


Figure 4. Changes in stem breast height diameter distribution in the spruce stand. Label (d) is for trees that died between two measurements made in 2007 and 2019.

Joonis 4. Kuusiku puude diameetrijaotuse muutus. Ajavahemikus 2007–2019 surnud puud (d) on eraldi välja toodud.

Table 3. Spruce stand summary of forest inventory 2007 and 2019.
Tabel 3. Kuusiku 2007. ja 2019. aasta takseerandmete kokkuvõte.

Species	Code	*N*	*G*	*D*	*H*	L_{cr}	R_{cr}
2007 inventory, upper layer							
Populus tremula	HB	2	0.052	18.2	25.2	7.1	1.51
Betula pendula	KS	143	3.607	17.9	24.7	8.7	1.52
Picea abies	KU	624	27.04	23.5	23.8	12.0	1.81
Alnus glutinosa	LM	3	0.097	20.3	22.6	9.6	2.05
Pinus sylvestris L.	MA	2	0.109	26.3	24.5	10.4	2.11
2007 inventory, second layer							
Betula pendula	KS	152	1.024	9.3	18.1	4.9	0.92
Picea abies	KU	517	5.015	11.1	14.7	6.2	1.17
2007 inventory, regeneration layer							
Picea abies	KU	89	0.188	5.2	5.7	2.8	1.09
Picea abies	KU	157	0.586	6.9	9.1	3.5	1.10
2019 inventory, upper layer							
Populus tremula	HB	2	0.064	20.2	27.3	6.6	1.39
Betula pendula	KS	132	4.489	20.8	28.0	10.2	1.67
Picea abies	KU	585	30.61	25.8	26.7	12.1	1.57
Alnus glutinosa	LM	3	0.111	21.7	24.4	12.3	2.12
Pinus sylvestris	MA	2	0.139	29.7	27.2	13.4	2.70
2019 inventory, second layer							
Betula pendula	KS	45	0.494	11.8	23.1	5.2	0.93
Picea abies	KU	375	4.198	11.9	16.4	7.1	1.04
2019 inventory, regeneration layer							
Picea abies	KU	87	0.248	6.0	7.2	3.2	0.92
Picea abies	KU	70	0.326	7.7	11.7	4.8	0.92
Dead 2007–2019	-	394	1.861	7.8	-	-	-

In the spruce stand (Figure 3) basal area has increased from 30.9 m^2 ha^{-1} to 35.4 m^2 ha^{-1} in the upper layer and from 6.8 m^2 ha^{-1} to 7.1 m^2 ha^{-1} in the lower layers. The number of trees in the upper layer has decreased from 774 to 724 ha^{-1} and substantially decreased in the lower layers from 912 to 577 ha^{-1} (Table 3, Figure 4). We distinguished two separate classes of spruces in the regeneration layer based on their competition status according to the shape of the crown and increment of the top shoot.

While *H* and *G* increased as in the birch stand, the crown radius decreased and live crown length remained almost the same for the spruces in the upper layer and second layer between the two measurements (Table 3). Heights to live crown base were

measured with hypsometer and although random errors are possible, there is probably no systematic error. Measurements of crown diameter are prone to systematic errors as the interpretation of crown projection may have been slightly different in 2007 and 2019. However, it is not excluded that live crown diameter has decreased considering the conical shape of the Norway spruce crown (Kantola & Mäkelä, 2006) and the live crown base rise with stand age (Valentine & Mäkelä, 2005), and that the mean live crown length in the spruce stand remained almost the same as in 2007.

Table 4. Summary of forest inventory 2007 and 2019 of the pine stand.
Tabel 4. Männiku 2007. ja 2019. aasta takseerandmete kokkuvõte.

Species	Code	*N*	*G*	*D*	*H*	L_{cr}	R_{cr}
2007 inventory, upper layer							
Pinus sylvestris	MA	1116	28.25	18	16.1	4.5	1.52
2007 inventory, regeneration layer							
Betula pendula	KS	6	0.014	5.5	4.1	2.9	0.78
Picea abies *	KU	1	0.002	5.0	5.0	1.8	1.09
2019 inventory, upper layer							
Pinus sylvestris	MA	971	29.09	19.5	17.4	4.6	1.53
2019 inventory, regeneration layer							
Betula pendula	KS	6	0.022	6.8	5.0	3.1	0.90
Picea abies *	KU	1	0.003	6.2	6.9	3.8	0.97
Dead 2007–2019	-	145	1.831	12.7	-	-	-

* models from the spruce stand were used.

During preparations for field measurements in the pine stand we identified one tree that was measured in 2007, but due to error had its location coordinates determined outside the test site. The tree was left out from the report by Kuusk *et al*. (2013). Here the tree is included and therefore for 2007 the number of trees in the upper layer is 1116 (Table 1). The pine stand (Figure 5) has the simplest structure of the three stands. There is basically only one layer of Scots pine trees and few small trees that matched the minimum *d* rule. As in the pine and spruce stand, we can see an increase in basal area, mean tree diameter at breast height and stand mean height. The number of trees decreased with smaller trees having a higher probability of dying (Figure 6).

Discussion and conclusion

The three sample plots in Järvselja forest district are similar to the examples in Harvard forest (Eisen & Barker Plotkin, 2015) and to the fiducial reference site in Speulderbos that was established for the validation of satellite measurements-based predictions of forest biophysical variables (Brede *et al.,* 2016). Although for the validation of methods for a wide area map (Dostálová *et al.,* 2018) construction the number of validation observations is more important (Copernicus HRL, 2019) than the sample plot size and tree-level detailed data, large sample plots are better suitable for experiments like RAMI described by Widlowski *et al*. (2015). Large sample plots are the only means to study the impact of

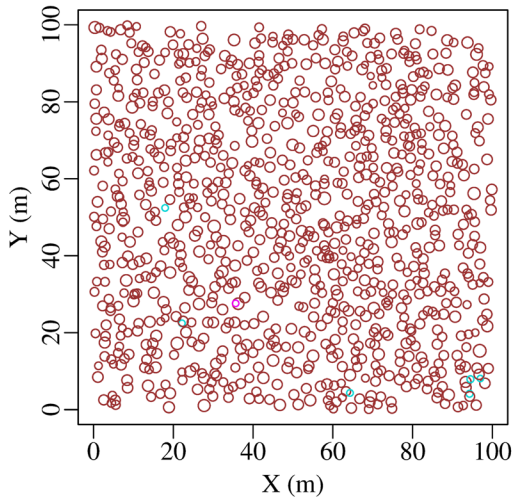


Figure 5. Map of alive trees in RAMI pine stand in 2019. The symbols are scaled according to tree size. Brown corresponds to pine, cyan to birch, magenta to spruce.

Joonis 5. RAMI männiku kasvavate puude kaart aastal 2019. Sümbolid on skaleeritud kujutamaks puude suurust, värvid vastavad metsakorralduse juhendile.

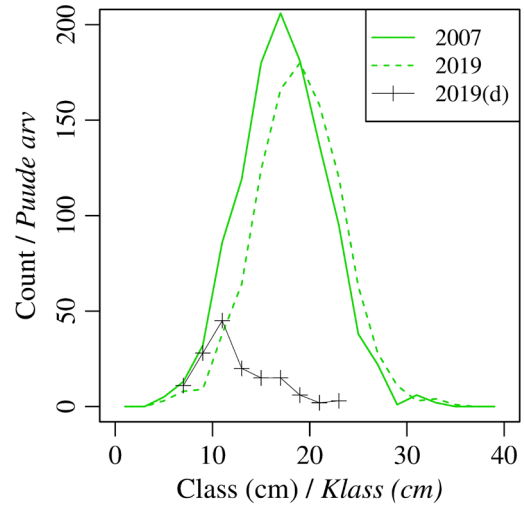


Figure 6. Changes in stem breast height diameter distribution in the pine stand. Label (d) is for trees that died between two measurements made in 2007 and 2019.

Joonis 6. Männiku puude diameetrijaotuse muutus. Ajavahemikus 2007–2019 surnud puud (d) on eraldi välja toodud.

sample plot size on the estimation of forest inventory variables regarding tree location patterns (Maleki & Kiviste, 2015) and also for testing global estimates of forest biophysical products like MODIS BRDF (Pisek *et al.*, 2015).

Our repeated measurements in the three sample plots showed that stand basal area, stand height and mean tree diameter at breast height have been increasing since 2007. The smallest increments were observed in the pine stand which is explained by the poor growth conditions i.e., excess water and limited availability of nutrients in the thick peat soil layer. An interesting finding in the spruce stand was that crown diameter of the spruce trees decreased compared to 2007. As interpretation errors in tree crown outer boundary estimation may be one cause to the result, we expect more solid evidence from terrestrial laser scanning data from 2013 (Kuusk *et al.*, 2015) and 2019 measurements.

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Järvseljal rahvusvahelise kiirguslevimudelite võrdluseksperimendi testalal asuva kolme hemiboreaalse puistu areng ajavahemikus 2007–2019

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Kokkuvõte

2007. aastal rajati Järvseljal kolm ühe hektari suurust katseala, kui kaardistati ja mõõdeti üle kõik puud simulatsiooneksperimentide korraldamiseks (Kuusk, *et al*., 2013; Widlowski *et al*., 2015). Need kolm puistut (vt fotod lisas 1) esindavad tüüpilist liitunud võrastikuga kuusikut, kaasikut ja siirdesoo männikut. Kaasikus oli tehtud 2004. aastal harvendusraie, 2018. aastal puhastati katseala alusmetsast, et valmistada ala ette maapealse laserskanneriga mõõtmisteks. Kuusikus ja männikus teadaolevalt viimase 30 aasta jooksul raieid tehtud ei ole. Katsealade (joonised 1, 3, 5) nurkade koordinaadid on mõõdetud diferentsiaal-GPS meetodiga peale mahamärkimist (tabel 1). 2019. aasta kordusmõõtmiste tulemusena ilmnes, et puistute rinnaspindala, keskmine kõrgus ning keskmise puu rinnasläbimõõt olid kasvanud (tabelid 2–4). Puude arv oli kahanenud kõigis puistutes, välja arvatud kaasikus, kus 2018. aasta puhastusraie käigus jäeti alles selleks ajaks 4 cm rinnasdiameetri saavutanud puud. Kuusikus saadi tulemuseks, et võrade raadiused olid võrreldes 2007. aastaga kahanenud. Kas tegemist on võraprojektsiooni välispiiri erineva tõlgendamise või tegelikult toimunud muutusega, võiks edaspidi selguda 2013. (Kuusk *et al*., 2015) ja 2019. aastal tehtud maapealse laserskanneri mõõtmiste andmete analüüsist.

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Appendix 1. Sample photos of RAMI stands.

Lisa 1. Katsealade puistute fotod.



RAMI birch stand at Järvselja, Estonia
15 August 2018



RAMI spruce stand at Järvselja, Estonia
01 August 2019



RAMI pine stand at Järvselja, Estonia
01 August 2019