HRL 2018 look & feel verification report for Tree Cover Density 2018 Finland

I. Administrative part

HRL	*Tree Cover Density Status 2018*
Verified area, region	Finland
Institution carrying out the work	Natural Resources Institute Finland (Luke)
Overall visual checking done by (name, position and e-mail)	Hanna Huitu, Researcher, hanna.huitu@luke.fi Matti Katila, Researcher, matti.katila@luke.fi
Look & feel verification done by (name, position and e-mail)	Hanna Huitu, Researcher, hanna.huitu@luke.fi
Statistical verification done by	Matti Katila, Researcher, matti.katila@luke.fi
In situ data used	*National Forest Inventory (NFI) field plots, from systematic cluster sampling with NFI field plots 2017-2019 except for northern Lapland (see Fig.7 for sampling regions) 2012-2013. Data set covers national forestry land (larger than FAO forest, n=13496)*
	Finnish multisource-NFI thematic map of canopy cover *Reference years: 2017 and 2019.Resolution: 16 m*
	National Ortho photo database *Natural color/black and white ortho photos* *Resolution: 0.25-0.5m* *Reference years: 2017 - 2019 (partial coverages)*
	Polygon database of forest stands (Finnish Forest Center SMK) *Reference year 2021, partial coverage*
	National high resolution Corine Land Cover 2018 (HR CLC2018) *Resolution 20 m*
	Topographic database of National Land Survey
	In-house data for crown cover based on Lidar data (Finnish Environment institute, partial coverage)
Reporting done by (name, position and e-mail)	Hanna Huitu, Researcher, hanna.huitu@luke.fi Matti Katila, Researcher, matti.katila@luke.fi

II. General overview of the verified data

General overview of the verified data	*Statistical information chart about the verified data.*

High Resolution Layer for Tree Cover Density (2018) is a raster layer in 10 m resolution, a status product that estimates the ratio of the rectangular cell area (0-100 %) of the vertical projection of tree crowns to a horizontal earth's surface. Main aim of this exercise is identification of systematic classification errors, which are eligible for improvement in future product updates

Shares of HRL Tree Cover Density 2018 layer area to no tree cover, low (< 30 %) and high (>30 %) tree cover are shown in Table 1.

Table 1a: Overview statistics – HRL Tree cover density 2018 Finland

HRL TCD18 Finland	Value	Km2	%
(1,30]	Tree cover 1…30	2 717.0	1.3
(30,100]	Tree cover 31…100	208 339.0	98.7
-	***Total area of tree cover***	***211 056.0***	***100***
0	No tree cover	135 973.7	-
255	Outside area (no data)	428 904.3	-

Table 1b: Overview statistics – Ranges of tree cover values and their occurrence

Statistics HRL TCD 2018 Finland

tree cover %	Km2	%
1…10	101.9	0.0
10…20	484.8	0.2
20…30	2 130.2	1.0
30…40	7 572.7	3.6
40…50	19 881.6	9.4
50…60	37 942.3	18.0
60…70	53 646.2	25.4
70…80	51 711.5	24.5
80…90	30 232.5	14.3
90…100	7 352.5	3.5
	211 056.1	100.0

Total area covered by values in HRL Tree Cover Density layer is 211 056 km^2. This is less than estimated by the thematic layers in national data, where total area of above-zero canopy cover is 261 586 km^2

Tree cover in HRL TCD 2018 was overlaid with the national Corine 2018 Land cover / Land use product HR CLC 2018, which is raster layer at 20 m resolution. As the main findings from this analysis, tree cover is situated in reasonable land use classes, and low TCD occurrence for transitional woodland suggests likelihood of omission errors.

In this comparison, most Level 1 Urban classes had over 20 % of area with tree cover in HRL TCD. Summer cottages stand out at over 70 % of the area with tree cover. These estimates were as anticipated.
Level 1 Agricultural land has mostly less than 10 % tree covered area in HRL TCD, with higher share of tree cover for arable land outside farming subsidies, natural pastures, and agro-forestry areas. These classes contain extensive agriculture allowing tree growth and estimate seems reasonable.

CLC 2018 classes for broadleaved, coniferous, and mixed forests have more than 90 % of their area classified as tree cover in HRL TCD, when the forests are on mineral soils, on peatland the share is slightly less. In the HR CLC 2018 classification, transitional woodland classes are distinguished by their estimated crown cover. Class with lowest (cc<10 %) tree cover had only for 18 % of their area any crown cover in the HRL TCD classification. HR CLC Classes with estimated 10-30 % crown cover had no tree cover in TCD HRL for 37-67 percent of the total area, suggesting omission errors in HRL TCD layer. Wetlands had mostly < 20 % tree cover with peat bogs. Detailed results are shown in Table 2.

Table 2: Corine Land Cover 2018 compared to tree covered area in HRL TCD18.

HR CLC18 code (Level 4)	HR CLC18 class name	Total area (km2)	Tree covered area (HRL TCD 2018)	Non tree covered area (HRL TCD 2018)
1.1.1.1	Continuous urban fabric	171	**25.4%**	74.6%
1.1.2.1	Discontinuous urban fabric	3 176.1	**39.6%**	60.4%
1.2.1.1	Commercial units	956.6	**26.3%**	73.7%
1.2.1.2	Industrial units	623.9	**27.4%**	72.6%
1.2.2.1	Road and rail networks and associated land	2 378.1	**25.5%**	74.5%
1.2.3.1	Port areas	39.9	**5.8%**	94.2%
1.2.4.1	Airports	77	**11.3%**	88.7%
1.3.1.1	Mineral extraction sites	421.9	**16.7%**	83.3%
1.3.1.2	Open cast mines	28.9	**4.9%**	95.1%
1.3.2.1	Dump sites	134	**8.7%**	91.3%
1.3.3.1	Construction sites	27.5	**13.1%**	86.9%
1.4.1.1.	Green urban areas	33.8	**28.4%**	71.6%
1.4.2.1	Summer cottages	1 367.2	**70.5%**	29.5%
1.4.2.2	Sport and leisure areas	134.9	**19.2%**	80.8%
1.4.2.3	Golf courses	87.1	**22.7%**	77.3%
1.4.2.4	Racecourses	9.9	**9.3%**	90.7%
2.1.1.1	Non-irrigated arable land	21 774.7	**2.7%**	97.3%
2.2.2.1	Fruit trees and berry plantations	62.6	**5.1%**	94.9%
2.3.1.1	Pastures	39.7	**9.0%**	91.0%
2.3.1.2	Natural pastures	93.9	**36.3%**	63.7%
2.4.3.1	Arable land outside farming subsidies	2 125.2	**10.9%**	89.1%
2.4.4.1	Agro-forestry areas	35.3	**24.8%**	75.2%
3.1.1.1	Broad-leaved forest on mineral soil	9 795.5	**91.4%**	8.6%
3.1.1.2	Broad-leaved forest on peatland	562.7	**87.0%**	13.0%
3.1.2.1	Coniferous forest on mineral soil	114 100.1	**93.5%**	6.5%
3.1.2.2.	Coniferous forest on peatland	32 643.2	**86.7%**	13.3%
3.1.2.3	Coniferous forest on rocky soil	3 060.2	**90.1%**	9.9%
3.1.3.1	Mixed forest on mineral soil	36 411.7	**92.0%**	8.0%
3.1.3.2	Mixed forest on peatland	8 723.2	**90.8%**	9.2%
3.1.3.3.	Mixed forest on rocky soil	227.7	**89.1%**	10.9%
3.2.1.1	Natural grassland	107.9	**0.1%**	99.9%
3.2.2.1	Moors and heathland	7 382.0	**18.2%**	81.8%

3.2.4.1	Transitional woodland/shrub cc <10%	8 477.9	**18.5%**	81.5%
3.2.4.2	Transitional woodland/shrub, cc 10-30%, on mineral soil	14 768.9	**51.1%**	48.9%
3.2.4.3	Transitional woodland/shrub, cc 10-30%, on peatland	8 623.5	**32.9%**	67.1%
3.2.4.4	Transitional woodland/shrub, cc 10-30%, on rocky soil	1 542.9	**62.8%**	37.2%
3.2.4.6	Transitional woodland/shrub under power lines	384.3	**25.7%**	74.3%
3.3.1.1	Beaches, dunes, and sand plains	64.1	**10.7%**	89.3%
3.3.2.1	Bare rock	1 779.9	**15.1%**	84.9%
3.3.3.1	Sparsely vegetated areas	541.7	**2.2%**	97.8%
4.1.1.1	Inland marshes, terrestrial	373.6	**31.0%**	69.0%
4.1.1.2	Inland marshes, aquatic	1 066.2	**6.9%**	93.1%
4.1.2.1	Peatbogs	19 087.9	**10.0%**	90.0%
4.1.2.2	Peat production sites	1 026.2	**4.1%**	95.9%
4.2.1.1	Salt marshes, terrestrial	300.6	**20.7%**	79.3%
4.2.1.2	Salt marshes, aquatic	292.2	**2.2%**	97.8%
5.1.1.1	Water courses	1 168.5	**18.6%**	81.4%
5.1.2.1	Water bodies	32 299.1	**1.5%**	98.5%
5.2.3.1	Sea and ocean	52 197.4	**0.0%**	100.0%

Overview map (Figure 1) shows tree cover values over Finland. An overlay example illustrating some differences to national thematic data layer on crown cover is shown as Figure 2.

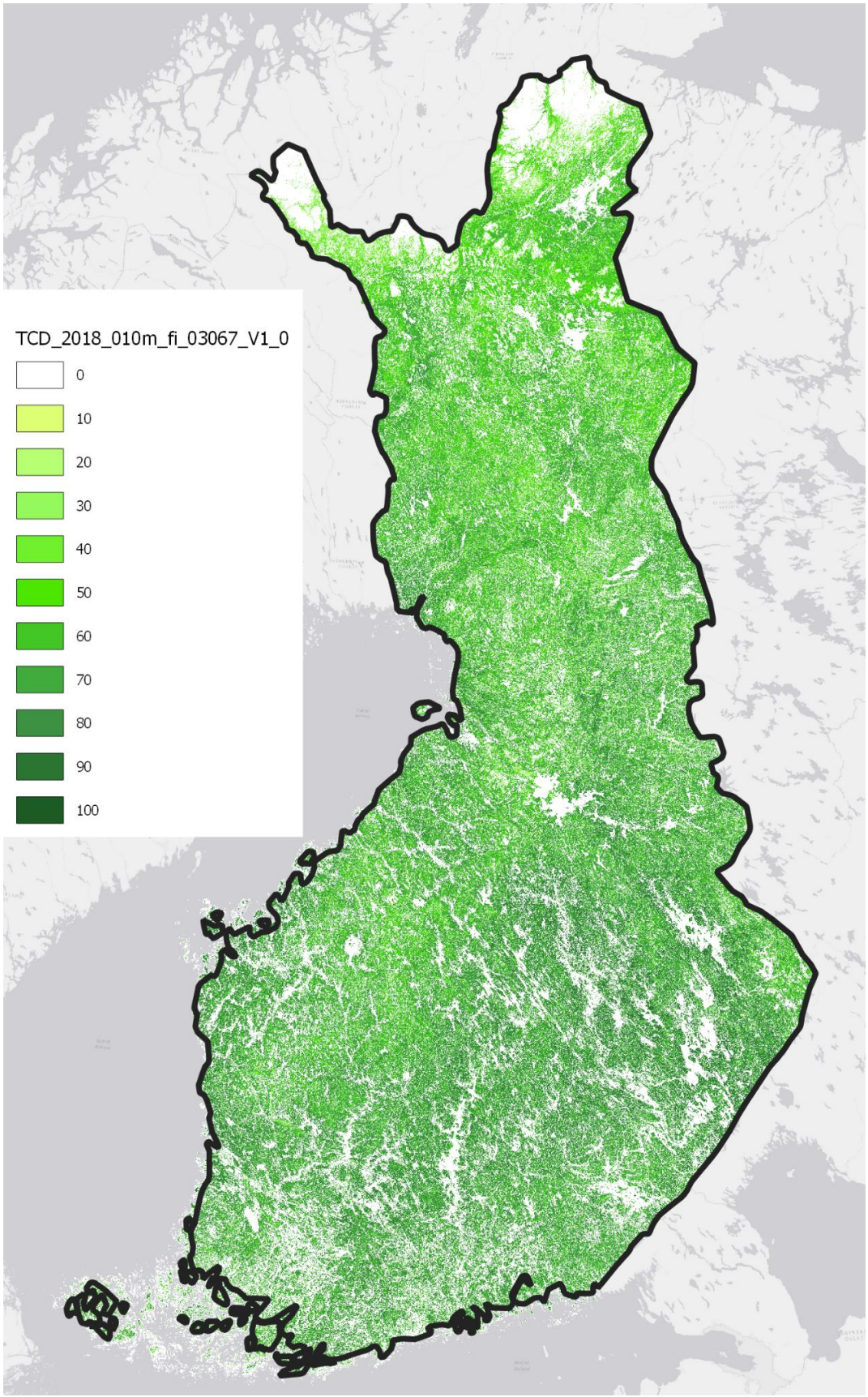

Fig. 1: Overview map - Tree cover density 2018 Finland

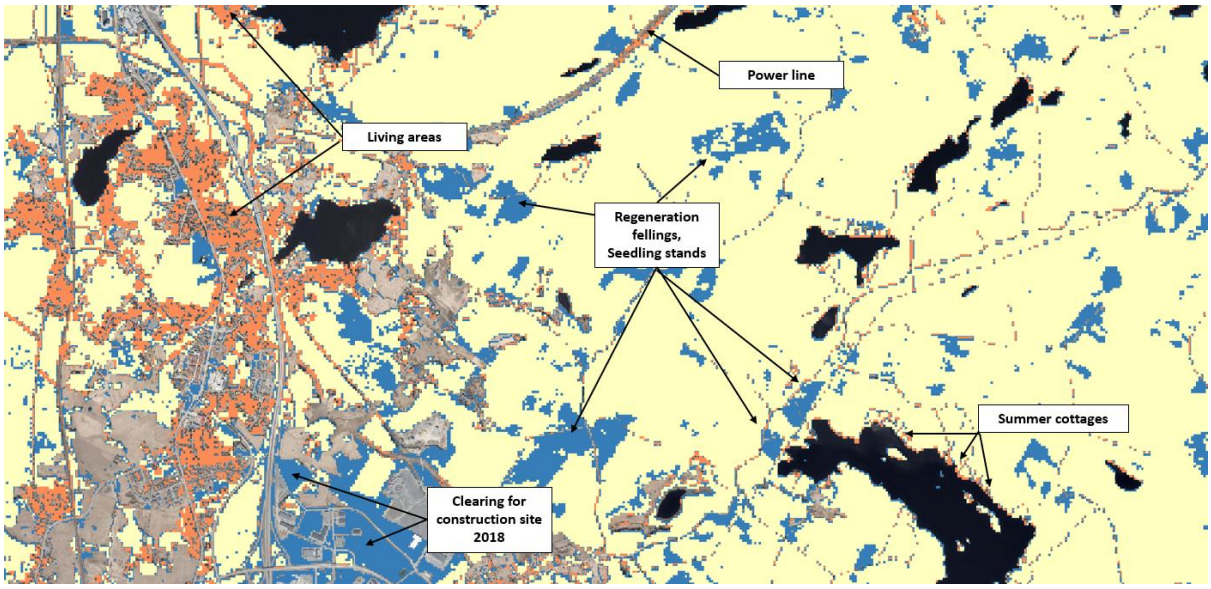

Fig. 2: Overview map - Tree cover density 2018 Finland and MS-NFI 2017 Forest thematic layer for crown cover. Areas in yellow color have crown cover > 0 on both layers. Area in orange color has crown cover >0 on HRL TCD 2018 layer. Area in blue color has crown cover > 0 on MS-NFI 2017 thematic layer. Tree cover in urban living areas is not mapped in MS-NFI 2017.

Summary of experiences about data quality

- Visual scanning of the HRL TCD 2018 layer over MS-NFI thematic layer and ortho-photos showed good consistency in the detailed spatial forest stand structure. Positional errors were not encountered.
- Comparison of HRL TCD 2018 layer to national statistics showed that crown cover in the layer was situated on plausible land use/land use classes (table 2).
- Area of above-zero crown cover in HRL TCD 2018 layer was underestimated when compared to national data (table 2., especially classes 311-324, and table 1b).
- Tree cover density values in HRL TCD 2018 were overestimations (bias of 6 %-units) when compared to NFI field plots as ground truth data and all land use classes were included. Overestimation happened particularly in North of Finland (see table 3. and Fig. 3)
- When NFI field plots on forestry land were used as reference data, HRL TCD underestimated the number of plots with 0-29 % crown cover, and overestimated the number of plots with 30 – 100 % crown cover (see table 4)

III. Overall visual checking

Positional accuracy			
Relative positional accuracy	Quick visual comparison of HRL data with available EO imagery (identifying large positional errors)	*OK*	Large positional errors were not detected in the data.
Thematic accuracy			
Classification correctness	Simple look & feel thematic check (identifying basic thematic mistakes)	*OK*	*Visual comparison of the TCD2018 over MS-NFI crown cover thematic layer and national orthophoto registry shows good agreement of areas with mature forest or closed canopies.* *Thematic agreement is weaker for young forests, or areas where the national thematic layer indicates lower (<30 %) crown coverage.*

IV. Look & feel verification results

Details of look & feel verification

1.Included elements, possible OMISSIONS

Stra-tum	Name of the stratum	Number of samples verified	*Results of the verification by strata*
1	Coastal forests	20	**Acceptable** (3.5). In absence of actual coastal forest biotope, any tree cover along the coastline was selected to represent this stratum
2	Forest along rivers and lakes	21	**Good** (3.8).
3	Forest management features inside forests	11	**Good** (4.1)
4	Forest under development	20	**Insufficient** (2.1) Young trees were often omitted. Omissions in this group were fairly common when compared to national crown cover data.
5	Groups of trees within urban areas	11	**Acceptable** (3.3)
6	Scattered small forest patches on agricultural area	13	**Acceptable** (2.8) Some omissions of small forest patches. MMU of 0.5 ha suggested by table 5.2.2.3.b was not used for sample selection.
7	Trees in sport and recreation areas	17	**Insufficient** (2.5) Sparsely situated, often broadleaved tree cover was often omitted.
8	Transitional woodland, forests in regeneration	10	**Acceptable** (2.6) Omissions in this group were fairly common when compared to national crown cover data.
9	Orchards, olive groves, fruit and other tree plantations	10	**Very poor** (1.0) Almost all fruit tree plantations were omitted
N		133	
Overall evaluation			**Acceptable (3)**
Comments, overview of results			Evaluation was not carried out to these strata: Mountain and lowland forests; Sclerophyllous forests; Dehesa/Montado forest component, and forest damage features inside forest. For forest damage inside forests, number of credible verification data was too small, as damaged parts visible at satellite resolution were also actively felled and hard to verify. In the end this stratum was omitted from results. Other classes did not exist in Finland.

2. Excluded elements, possible COMMISSIONS

Stratum	Name of the stratum (see proposed strata in Tables 5.2.2.x.c)	Number of samples verified	*Results of the verification by strata (excellent, good, acceptable, insufficient, very poor): see chapter 6.3 of the guidelines*
1	Open areas within forests (roads, permanently open vegetated areas, clear cuts, fully burnt areas, other severe forest damage areas, etc.)	11	**Good** (4) The checked locations of open areas within forests seldom had commission errors.
2	Dwarf shrub-covered areas, such as moors and heathland	10	**Good** (4.0)
3	Non-tree woody vegetation (Shrublands)	15	**Acceptable** (3.1) Shrublands as a separate biotope was not identified. Samples for any non-tree woody vegetation was checked for this stratum.
4	Wetland	11	**Good** (3.6)
	Grass fields in sports and recreation area	16	**Insufficient** (1.7) Football fields or sports fields were often classified as tree cover.
N		63	
Overall evaluation			**Acceptable (3)**
Comments, overview of results			Evaluation was not carried out to these recommended strata not found in Finland: Dwarf pine /green alder in Alpine areas, Vineyards, Mediterranean shrublands. Stratum for sports fields was checked here also for commission errors, due to several findings of erroneous classification of tree cover on sports fields.

V. Documentation of errors and critical findings

Please include detailed descriptions, meaningful examples and screenshots of errors, critical findings. Please make sure the nature, location and frequency of the issue is described in some detail. Screenshots should contain ETRS1989 LAEA coordinates.

Tendency of the HRL layer to overestimate tree cover density values (particularly in the north of Finland) when compared to the national product is visible in the Fig.3. The difference image is presented scaled between -50 % to 50 % tree cover density using rainbow colors (blue-green-red) LUT, which means that the green color is approximately near zero difference and red is overestimate and blue is underestimate from the HRL TCD.

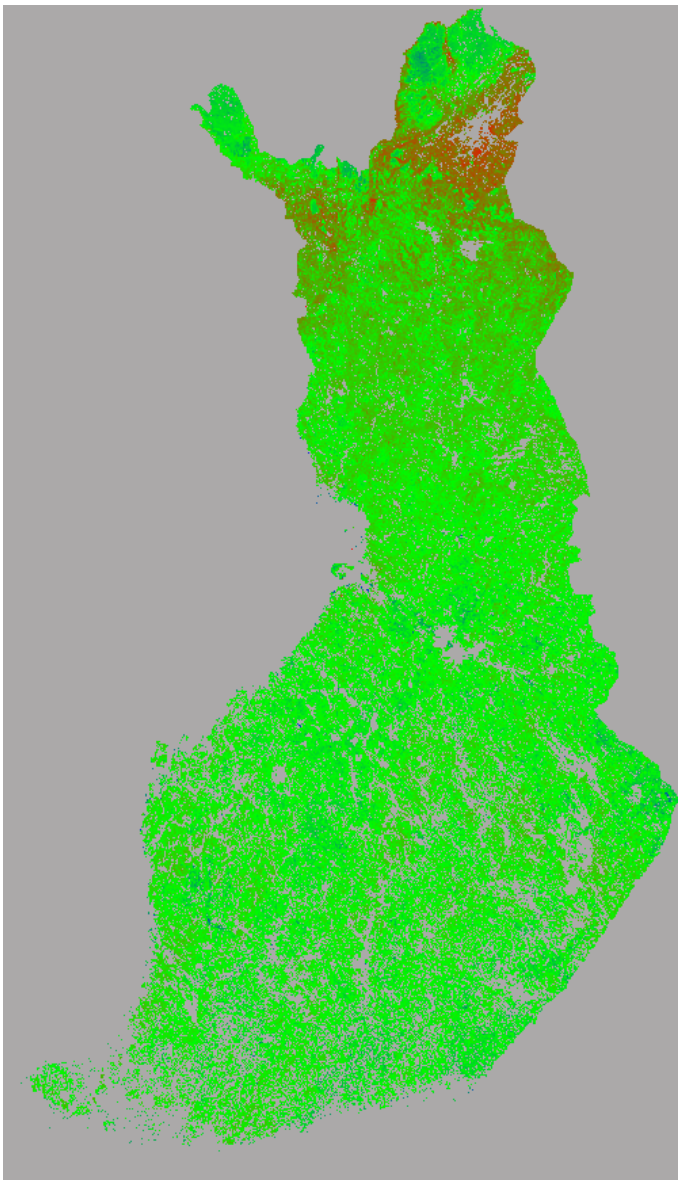

Fig. 3. A difference image between HRL TCD and the MS-NFI-2019 crown cover thematic map (national data) (TCD - MS-NFI-2019). The average value of pixels on joint area covering MS-NFI forest mask and TCD classified area was calculated for each 1200*1200 m2 window. Rainbow colors (blue-green-red) LUT scaled between -50 – 50 %-unit values.

The following examples and screenshots of errors are based on findings in Look and Feel verification. Work was based on the recommended strata (Tables 5.2.2.3.b and 5.2.2.3.c in the Guidelines document). Poor and insufficient classification performance was found on locations where where young tree cover with tree crown was omitted (Forests under development, Transitional woodland, forests in regeneration). Locations to be checked were selected among stands where this error was verified by more than one national datasets. An example of this common error type is given in Figure 4.

Fig. 4. Omission error of young tree covered area. Aerial image with HRL TCD layer laid on top. This is a common error. According to national data (2017 and 2019) crown cover was between 10 – 40 %. Here forest stand has been cut and regenerated before 2015.

Strata for forests along sea, lakes and rivers were overall well included with no relevant errors found. Also, forest management features such as forest roads had seldom errors. Scattered small forest patches on agricultural area were sometimes omitted, an example of this error type is given in Figure 5.

Fig.5. Omission error of small forest patches on agricultural land. Aerial image with HRL TCD layer laid on top. Fairly common error on very small patches.

Orchards with fruit (apple) tree plantations were often omitted, both in cases where trees are planted in grid pattern, and rows of individual trees. Fruit orchards are a marginal land use in Finland due to unsuitable growing conditions for many fruits, so this error has limited effect on overall quality.

Open areas within forests were correctly excluded, as well as moors and heathland. Also, wetlands were mainly correctly excluded. In earlier TCD version (2015) we noted peatland surface pattern being often erroneously classified as tree cover, this error was now very uncommon. An example of this error is shown in Figure 6.

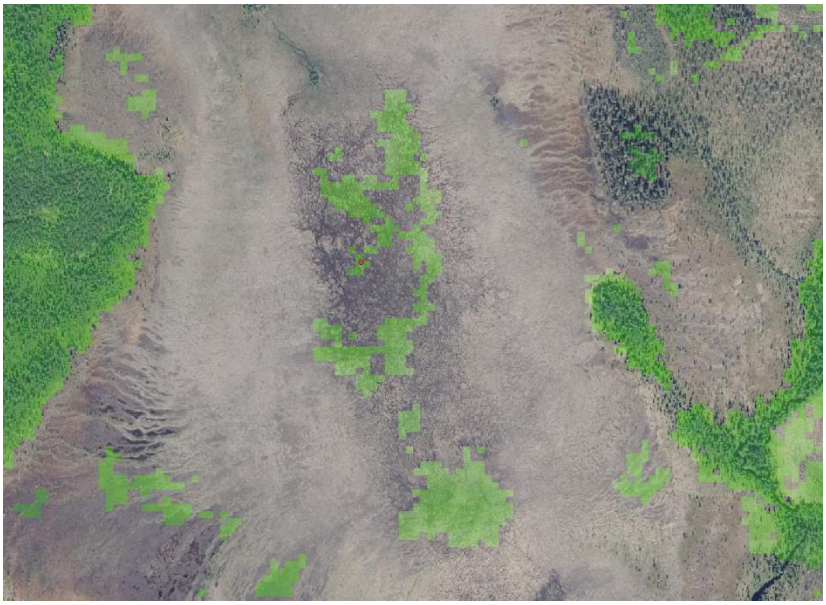

Fig. 6. Commision error on open peatland. Aerial image with HRL TCD layer laid on top Surface pattern in the center of the picture is erroneously translated as 30-50 % crown cover in HRL TCD. Rare error in the present HRL TCD 2018.

A small but often repeating error was found on sports fields, that were completely or partly classified as tree cover. An example of this error type is given in figure 7.

Fig. 7. Omission error of sports and football fields. Aerial image with HRL TCD layer laid on top.

VI. **Statistical verification** (optional)

Description of methodology and software	Describe shortly the methodology and software used for quantitative verification For statistical verification of the HRL forest layers, there is an extensive field sample available based on systematic cluster sampling. The field sample was NFI12 and NFI13 data from years 2017-2019, for which the crown cover was available only for the national forest land field plots. The northernmost Lapland was an exception, the field sample was selected based on double sampling with stratification and originated from the year 2012-2013 (NFI11). The data set contained 13496 field plots on forestry land selected for quantitative verification. All the field plots on land and inland water were included On forestry land, distance to the nearest stand boundary had to be at least 20 m. The radius of the of the NFI12 and NFI13 field plot is 9 m. The forestry land is defined according to national definition, see Tomppo, E., Heikkinen, J., Henttonen, H.M., Ihalainen, A., Katila, M., Mäkelä, H.,Tuomainen, T. & Vainikainen, N. 2011. Designing and conducting a forest inventory - case: 9th National Forest Inventory of Finland. Springer, Managing Forest Eco-systems. Field plots where a drastic change of land cover or a clearcut of forest had occurred between the field measurement date and assumed image acquisition date (30.6.2018 was assumed for the HRL product) were removed using MS-NFI2019 satellite images and land use change monitoring data from Greenhouse gas reporting project. The canopy cover percentage was readily modeled for the field plots on the forest, poorly productive forest land and unproductive land (national land classes) plots (Mäkisara K., Katila M., Peräsaari J. (2019). The multi-source national forest inventory of Finland – methods and results 2015. Natural resources and bioeconomy studies 8/2019. Natural Resources Institute Finland (Luke). http://urn.fi/URN:ISBN:978-952-326-711-4, sect. 3.2.1). Originally, the canopy cover was visually assessed for the NFI10 field plots (for a test of the accuracy of different assessment methods in the field see Korhonen L., Korhonen K.T., Rautiainen M., Stenberg P. 2006. Estimation of forest canopy cover: a comparison of field measurement techniques. Silva Fennica vol. 40 no. 4. https://doi.org/10.14214/sf.315) and predicted for NFI11, NFI12 and NFI13 forestry land field plots using NFI10 data. The canopy cover for deciduous trees was computed from the canopy cover according to the proportion on of deciduous trees in the field plot.
Stratification	*'no stratification'*
Comments	Field measurements from the national forest inventory (NFI) were used as ground truth data in this verification.

	NFI is based on systematic cluster sampling over all land use classes and ownership types, although only plots on forestry land were used for verification of HRL2018. Number of field plots per area decreases towards north. The country is divided into six inventory areas (Fig.7.), and results are presented also for these sub-regions. In Finland, over 78 % of the land area is covered by forestry land. Due to sampling methodology, no stratification was used. Plots where distance to the nearest stand boundary was less than 20 m were excluded from analysis. The error diagnostics of the tree cover density as continuous variable are presented in Table 3 below. The **RMSE** of the TCD is 19 %, which is of the same magnitude as reported for the MS-NFI2011 canopy cover layer (14-20 %) in metadata (http://kartta.metla.fi/). However, the MS-NFI2011 was validated using all the field plots within forestry land which significantly increases the error estimate compared to using only field plots at minimum 20 m from stand boundary in current validation. There is a significant overestimation (**bias**) of tree cover density (percentage units) compared to NFI field plot canopy cover in most sampling regions. There is overestimation, 6 %-units, which increases towards north of Finland (Lappi ja Kuusamo, Ylä-Lappi sampling regions). This systematic error increases also the RMSE values.

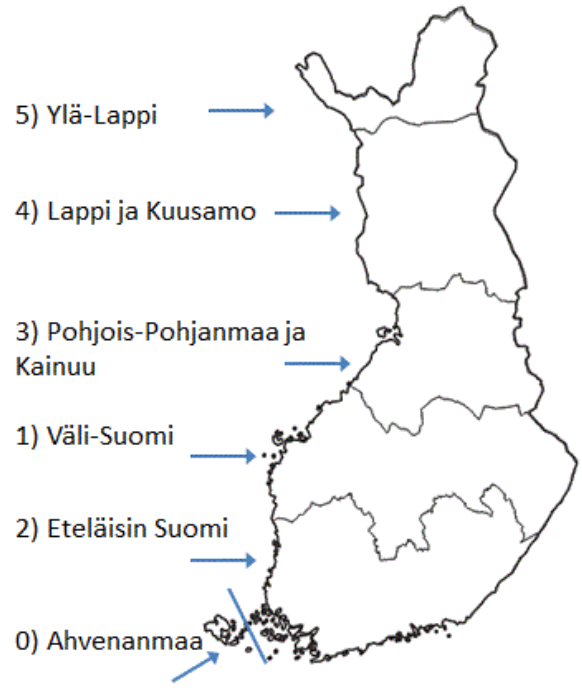

Fig. 7. Sampling region for the Finnish National Forest Inventory.

Table 3. Error diagnostics of the tree cover density as continuous variable, whole country and by inventory regions. The NFI mean, absolute and relative RMSE and bias (TCD – NFICC), the standard error of the bias, the standard deviation of the NFI field variable and R^2 coefficient (the proportion of the variation explained by the classification). (see Katila & Tomppo (2001) http://dx.doi.org/10.1016/S0034-4257(00)00188-7 Table 4 for more explanation).

	No. of	NFI	RMSE		BIAS		2*stdE	NFI	
Region	plots	mea	RMSE	%	BIAS	%	BIAS	st.dev.	R2
Total	*13496*	*46.9*	*19.1*	*40.8*	*5.58*	*11.90*	*0.32*	*26.7*	*0.49*
Ahvenanmaa	*167*	*34.3*	*20.6*	*60.0*	*1.02*	*2.98*	*3.19*	*26.6*	*0.40*
Väli-Suomi	*3825*	*55.5*	*17.1*	*30.8*	*3.01*	*5.42*	*0.54*	*24.3*	*0.51*
E-Suomi	*3361*	*57.8*	*19.1*	*33.1*	*4.23*	*7.33*	*0.64*	*22.4*	*0.28*
Pohjois-Pohjanmaa ja Kainuu	*2547*	*45.8*	*16.8*	*36.7*	*2.64*	*5.76*	*0.66*	*26.5*	*0.60*
Lappi ja Kuusamo	*2618*	*32.4*	*20.2*	*62.5*	*9.87*	*30.50*	*0.69*	*24.1*	*0.29*
Ylä-Lappi	*978*	*19.6*	*27.4*	*139.5*	*17.22*	*87.70*	*1.36*	*15.7*	*-2.06*

Table 4. Classification error matrix for tree cover density using field sample plots of NFI on forestry land (national definition) from years 2017-2019 (except 2012-2013 the northernmost Lapland, Ylä-Lappi).

Confusion Matrix

		Reference Data			
		0-29 %	30-100 %	UserAccuracy	UserAccuracyVariance
Classification Data	0-29 %	2657	502	84,11 %	0,012751
	30-100 %	1038	9299	89,96 %	0,005794
	Weights	3159	10337		
	ProducerAccuracy	71,91 %	94,88 %		
	ProducerAccuracyVariance	0,012052	0,003912		
	PortmanteauAccuracy	88,59 %	88,59 %		
	PortmanteauAccuracyPartial	63,31 %	85,79 %		

OverallAccuracy	**0,885892**
OverallAccuracyVariance	**0,005348**
AllocationDisagreement	**0,074392**
Shift	**0**
Exchange	**0,074392**
QuantityDisagreement	**0,039715**
AMI	**0,338755**
AMIAdjusted	**0,338755**
AMIVariance	**0,015156**
Kappa	**0,699467**
KappaVariance	**0,013937**