

GMES Initial Operations / Copernicus Land monitoring services – Validation of products

Validation Services for the geospatial products of the
Copernicus land Continental and local components
including in-situ data (lot 1)

Open Call for Tenders - EEA/MDI/14/010

**Third Specific Contract - N°3436/R0-
COPERNICUS/EEA.57056**

HRL FOREST 2015

FINAL VALIDATION REPORT



Consortium Partners

Prime Contractor	SIRS SAS (France)
Main Partners	GAF AG (Germany), Joanneum Research (Austria), e-GEOS (Italy)
Experts	Specto Natura (UK), ISPRA (Italy), IGN France International (France), Terranea (Germany), NLSI (Iceland)

Document Preparation and Release

	Affiliation	Name(s)	Date
Author	SIRS	Alexandre Pennec	28/11/2018
Contributions	JR	Janik Deutscher	16/10/2018
Review	SIRS	Alexandre Pennec	07/01/2019
Approval	EEA	Hans Dufourmont	

Document Issue Record

Issue	Date	Author(s)	Description of Change
1.0	05/07/2018	Alexandre Pennec	Document creation
1.1	16/10/2018	Janik Deutscher	Contribution for the response design section
1.2	26/10/2018	Alexandre Pennec	Integration of TCDC results
1.3	07/12/2018	Alexandre Pennec	Thematic accuracy assessment with TCD values regrouped according to the 1% threshold
1.4	03/01/2019	Janik Deutscher	Review
1.5	07/01/2019	Alexandre Pennec	Integration of JR's comments
1.6	25/01/2019	André Stumpf	Review
1.7	28/01/2019	Alexandre Pennec	Integration of GAF's comments

Applicable Documents

ID	Title
AD01	Tender Specifications « Open Call for Tenders n° EEA/MDI/14/010 - Framework service contract for the GMES Initial Operations / Copernicus Land monitoring services – Validation Services for the geospatial products of the Copernicus land Continental and local components including in-situ data (lot 1)”
AD02	Framework service contract No EEA/MDI/14/010
AD03	First Specific Contract N° 3436/B2015/R0-GIO/EEA.56159
AD04	Copernicus Land Monitoring Service – High Resolution Layer Forest: Product Specifications Document, Version 11 of 2018-08-14 (https://land.copernicus.eu/user-corner/technical-library/hrl-forest)
AD05	Second Specific Contract N°3436/R0-COPERNICUS/EEA.56601
AD06	Third Specific Contract N°3436/R0-COPERNICUS/EEA.57056

Executive Summary

This report covers the validation of the High Resolution layer (HRL) on Tree cover Density (TCD), Forest Type (FTY) and Tree Cover Density Change (TCDC).

The **HRL TCD** product was assessed based on a scatterplot as well as applying a threshold to determine its thematic accuracy. Based on scatterplots, it appears that map density values slightly underestimate actual TCD values at very low tree cover density (0-20%) and very high density (>90%). All regression coefficients show very good results with values greater than 0.5 and close to 1; the reference and map information are meant to represent the same information. Regarding the accuracy assessment, results show that the HRL TCD product meets the thematic classification accuracy requirements based on a 1%, 10% and 30% threshold of TCD values. Indeed, at European level, for both blind and plausibility interpretation, the accuracy meets the minimum accuracy requirement (85%) for both user and producer accuracies and the target accuracy (90%) is also met for all the user accuracies and the producer accuracy with a 30% threshold for the plausibility analysis. Nevertheless, there is variability from country to country or based on biogeographical regions.

The main findings and recommendations for the HRL TCD product can be summarised as follows:

1. TCD layer meets the minimum accuracy at pan-European level for omission errors and exceeds the target accuracy for commission errors.
2. The quality of the Tree Cover mask (threshold > 1%) is also very good with a producer accuracy close to 90% and a user accuracy exceeding 90% for both the blind and plausibility approaches.
3. Results provided at lot, bio-geographical regions and country/group of country level should provide a sound basis for further improving the product.
4. Based on the lessons learnt from the previous Specific Contract, the stratification procedure was effective for both commission and omission errors.

At pan-European level, the analysis of the **HRL FTY** product shows that all forest user and producer accuracies values are lower than the minimum accuracy threshold of 85% for the blind interpretation and most of them are lower than these requirements for the plausibility analysis (except the producer accuracy for the Broadleaved class and the user accuracy for the Coniferous class). As previously reported for the first and second Specific Contracts¹, most of the confusion is between the forest classes and not between the forest and non-forest classes. The lowest results are obtained for the mixed forest class with both user and producer accuracies that don't meet the target requirements for nearly all of them (blind and plausibility analysis) at pan-European level and disaggregated levels (country or biogeographical region level). The coniferous forest class meets the target accuracy (90%) for most of the regions and countries in a plausibility approach and the broadleaved forest class shows intermediate results in a plausibility approach.

The main findings and recommendations for the HRL FTY product can be summarised as follows:

1. The FTY layer mainly meets the minimum accuracy requirement for broadleaf and coniferous forest types with respect to omission errors
2. The FTY layer meets the minimum accuracy requirement for coniferous type for commission errors
3. Most of the confusion is between the forest classes and the lowest results are obtained for the mixed forest class
4. The definition of the mixed forest type for the 100m layer purely based on aggregation rules poses a problem and it is suggested to modify the definition or abandon this class.
5. Results provided at bio-geographical regions and country/group of country level, should provide a sound basis for further improving the product.
6. The efficiency of the stratification was also demonstrated for the FTY product.

The results at European level for the **HRL TCDC** show that the accuracy only meets the target accuracy (90%) for both user and producer accuracies of the unchanged area class and for the producer accuracy for both

¹ See <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

Increased and Decreased classes (few omission errors regarding the change in tree cover density). The results show unsatisfyingly low user accuracies for the changed classes (respectively 15.0% and 38.1% for the Increased and Decreased classes for the plausibility analysis) suggesting a very high amount of commission errors (and possibly explaining the few omission errors).

The main findings and recommendations for the HRL TCDC product can be summarised as follows:

1. The TCDC layer only meets the minimum accuracy requirement for increased and decreased changes with respect to omission errors.
2. The TCDC shows very high amount of commission errors which lead to an overestimation of changes.
3. The next exercise for the production of the Forest layer should include the reprocessing of the change layers.
4. Results provided at bio-geographical regions and country/group of country level, should provide a sound basis for further improving the product.
5. The efficiency of the stratification applied for the selection of sample units was also demonstrated for the TCDC product.

Table of Contents

.....	0
1. Validation Framework.....	11
1.1. Products to be validated.....	11
1.2. Validation Criteria.....	12
1.2.1. TCD	12
1.2.2. FTY	14
1.2.3. TCDC	15
2. Validation approach	16
2.1. Completeness	16
2.2. Logical consistency	16
2.2.1. Conceptual consistency	16
2.2.2. Domain consistency	17
2.2.3. Format consistency	17
2.2.4. Topological consistency.....	17
2.2.5. Additional logical consistency checks	17
2.3. Positional Accuracy.....	18
2.4. Thematic Accuracy.....	18
2.4.1. Level of reporting	18
2.4.2. Stratification and sample design.....	21
2.4.3. Response Design.....	29
2.4.4. Estimation and analyses procedures.....	34
2.5. Temporal Quality	35
2.6. Usability	35
2.7. INSPIRE compliant metadata.....	35
3. Validation check list.....	36
3.1. Tree Cover Density (TCD).....	36
3.2. Forest Type (FTY)	41
3.3. Tree Cover Density Change (TCDC)	45
4. Thematic accuracy.....	50
4.1. Tree Cover Density (TCD).....	50
4.2. Forest Type (FTY)	56
4.3. Tree Cover Density Change (TCDC)	60
5. Conclusions and recommendations	63
5.1. TCD.....	63

5.2. FTY.....	64
5.3. TCDC.....	65
Annex 1. Tree Cover Density (TCD) Scatterplot for bio-geographical regions	66
Annex 2. Tree Cover Density (TCD) Scatterplot for countries and group of countries greater than 90,000km ²	77

List of Figures

Figure 1. Level of reporting at pan-European level.....	19
Figure 2. Level of reporting accordingly to the biogeographical regions	19
Figure 3. Level of reporting accordingly to the country or aggregated countries.....	20
Figure 4. Simple random (left) and random systematic (right) sampling designs	21
Figure 5. LUCAS points located on a regular grid.....	22
Figure 6. Number of sample points as a function of the expected error rate for two accepted standard error values (after Wack et al. 2012)	23
Figure 7. Replicates and sub-replicates used on LUCAS grid	24
Figure 8: Example of SSUs organised in a 5x5 20m grid	25
Figure 9: Interpretation tool for reference data labelling (implemented by Joanneum Research).....	30
Figure 10: TCDC validation tool.....	33
Figure 11. Representation of the behaviour of the 95% confidence interval for a 5x5 SSU grid over the whole range of tree cover density values.....	34
Figure 12: Scatterplot of all TCD sample units darker green indicates a greater number of observations, n=15,051, R ² =0.84, Map_Density = 0.8787*Validation_Density+0.9217	50
Figure 13: Error matrices at pan-European level for the HRL FTY product for (a) blind interpretation and (b) plausibility analysis.	59
Figure 14: Scatterplot of all sample units for the Anatolian bio-geographical region HRL TCD, n=1,059, R ² =0.62, Map_Density = 0.9071*Validation_Density+1.3609.....	66
Figure 15: Scatterplot of all sample units for the Anatolian bio-geographical region HRL TCD, n=1,059, R ² =0.62, Map_Density = 0.9071*Validation_Density+1.3609.....	67
Figure 16: Scatterplot of all sample units for the Artic bio-geographical region HRL TCD, n=336, R ² =0.53, Map_Density = 0.6284*Validation_Density+1.7842	68
Figure 17: Scatterplot of all sample units for the Atlantic bio-geographical region HRL TCD, n=2,221, R ² =0.82, Map_Density = 0.8392*Validation_Density-0.1051.....	69
Figure 18: Scatterplot of all sample units for the Black Sea bio-geographical region HRL TCD, n=336, R ² =0.76, Map_Density = 0.8844*Validation_Density+7.9968	70
Figure 19: Scatterplot of all sample units for the Boreal bio-geographical region HRL TCD, n=2,328, R ² =0.86, Map_Density = 0.9207*Validation_Density-1.0176.....	71
Figure 20: Scatterplot of all sample units for the Continental bio-geographical region HRL TCD, n=3,582, R ² =0.89, Map_Density = 0.8851*Validation_Density-0.4069	72
Figure 21: Scatterplot of all sample units for the Macaronesia bio-geographical region HRL TCD, n=25, R ² =0.83, Map_Density = 0.9311*Validation_Density+1.6672.....	73
Figure 22: Scatterplot of all sample units for the Mediterranean bio-geographical region HRL TCD, n=3,053, R ² =0.73, Map_Density = 0.833*Validation_Density+2.689.....	74
Figure 23: Scatterplot of all sample units for the Pannonian bio-geographical region HRL TCD, n=373, R ² =0.89, Map_Density = 0.8884*Validation_Density-0.5606.....	75
Figure 24: Scatterplot of all sample units for the Steppic bio-geographical region HRL TCD, n=95, R ² =0.73, Map_Density = 0.8646*Validation_Density+00.7868	76
Figure 25: Scatterplot of all sample units for AL+ME+MK+RS+XK HRL TCD, n=406, R ² =0.76, Map_Density = 0.8227*Validation_Density+0.9424.....	77
Figure 26: Scatterplot of all sample units for AT+CH+LI HRL TCD, n=322, R ² =0.87, Map_Density = 0.978*Validation_Density+0.9642.....	78
Figure 27: Scatterplot of all sample units for BA + HR + SI HRL TCD, n=324, R ² =0.84, Map_Density = 0.8457*Validation_Density+3.6551.....	79

- Figure 28: Scatterplot of all sample units for BE + LU+ NL + DK HRL TCD, n=288, R²=0.86, Map_Density = 0.8344*Validation_Density-1.9662 80
- Figure 29: Scatterplot of all sample units for BG HRL TCD, n=282, R²=0.88, Map_Density = 0.8859*Validation_Density-0.9186 81
- Figure 30: Scatterplot of all sample units for CZ + SK HRL TCD, n=323, R²=0.94, Map_Density = 0.9749*Validation_Density-2.8284 82
- Figure 31: Scatterplot of all sample units for DE HRL TCD, n=939, R²=0.92, Map_Density = 0.9531*Validation_Density-1.035 83
- Figure 32: Scatterplot of all sample units for EE + LT + LV HRL TCD, n=449, R²=0.88, Map_Density = 0.8958*Validation_Density+0.4239 84
- Figure 33: Scatterplot of all sample units for EL HRL TCD, n=342, R²=0.74, Map_Density = 0.8626*Validation_Density-0.5168 85
- Figure 34: Scatterplot of all sample units for ES HRL TCD, n= 1305, R² = 0,73, Map_Density = 0,8719*Validation_Density + 1.5603 86
- Figure 35: Scatterplot of all sample units for FI HRL TCD, n=872, R²=0.84, Map_Density = 0.8626*Validation_Density+0.7699 87
- Figure 36: Scatterplot of all sample units for FR HRL TCD, n=1402, R²=0.85, Map_Density = 0.8197*Validation_Density+1.1329 88
- Figure 37: Scatterplot of all sample units for HU HRL TCD, n=237, R²=0.88, Map_Density = 0.8921*Validation_Density-0.5518 89
- Figure 38: Scatterplot of all sample units for IE + UK HRL TCD, n=804, R²=0.79, Map_Density = 0.8175*Validation_Density-0.5079 90
- Figure 39: Scatterplot of all sample units for IS HRL TCD, n=325, R²=0,53, Map_Density = 0.6271*Validation_Density+1.8532 91
- Figure 40: Scatterplot of all sample units for IT HRL TCD, n=773, R²=0.78, Map_Density = 0.8668*Validation_Density+3.2402 92
- Figure 41: Scatterplot of all sample units for NO HRL TCD, n=853, R²=0.82, Map_Density = 0.9204*Validation_Density+1.7893 93
- Figure 42: Scatterplot of all sample units for PL HRL TCD, n=810, R²=0.89, Map_Density = 0.8585*Validation_Density+1.6097 94
- Figure 43: Scatterplot of all sample units for PT HRL TCD, n=233, R²=0.66, Map_Density = 0.8406*Validation_Density+1.6119 95
- Figure 44: Scatterplot of all sample units for RO HRL TCD, n=600, R²=0.9077, Map_Density = 0.8809*Validation_Density-1.3879 96
- Figure 45: Scatterplot of all sample units for SE HRL TCD, n=1166, R²=0.84, Map_Density = 0.9352*Validation_Density-0.8252 97
- Figure 46: Scatterplot of all sample units for TR HRL TCD, n=1996, R²=0.76, Map_Density = 0.8691*Validation_Density+2.6184 98

List of Tables

Table 1: Detailed specification of the 100m Tree Cover Density product	13
Table 2: Detailed specification of the 100m Forest Type product.....	14
Table 3: Detailed specification of the 100m Tree Cover Density Change product.....	15
Table 4: Map projection details for LAEA-ERTS89.	18
Table 5: TCD/FTY distribution of sample units per strata and level of stratification.....	25
Table 6: TCD/FTY distribution of sample units per countries or group of them.....	26
Table 7: TCD/FTY weight factors to be applied to each stratum and level of stratification for constructing confusion matrices	26
Table 8: TCDC distribution of sample units per strata and level of stratification.....	27
Table 9: TCDC Weight factors to be applied to each stratum and level of stratification for constructing confusion matrices	28
Table 10: Details of TCD regression line parameter and coefficients and for the whole of Europe cover, per lot, bio-geographical regions and country and group of countries greater than 90,000km ² , n corresponds to the number of observations. Values in green are closest to optimal values (greater than 0.5 for R ² , close to 1 and 0 for slope and intercept respectively)	51
Table 11: TCD product thematic accuracy results for Tree Cover (TC) class for the total European area covered. Values in green indicate accuracies greater than the 85% threshold, yellow greater than 80% and red less than 80% considering the 95% CI (Prod. = Producer) .	52
Table 12: TCD product thematic accuracy results for Tree Cover (TC) for bio-geographical regions. Values in green indicate accuracies greater than the 85% threshold.....	54
Table 13: TCD product thematic accuracy results for Tree Cover (TC) class for countries and group of countries greater than 90,000km ² . Values in green indicate accuracies greater than the 85% threshold, yellow greater than 80% and red less than 80% considering 95% CI.....	55
Table 14: FTY product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km ² and per thematic classes: Non-Forest (NF), Broadleaved (B), Coniferous (C) and mixed (M). Values in green indicate accuracies greater than the 85% threshold, n corresponds to the number of observations	57
Table 15: FTY product thematic accuracy results overall, per bio-geographical region and per country or group of countries greater than 90,000km ² and per thematic classes: Non-Forest (NF) and regrouped Forest (F) classes. Values in green indicate accuracies greater than the 85% threshold, n corresponds to the number of observations	58
Table 16: TCDC product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km ² and per thematic classes: Unchanged areas (UC), Increase (I) and Decrease (D) tree cover density. Values in green indicate accuracies greater than the 85% threshold.	61
Table 17: TCDC product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km ² and per thematic classes: Unchanged areas (UC), Changed areas (C). Values in green indicate accuracies greater than the 85% threshold.	62

List of Abbreviations

BRME	Biogeographical Regions Map of Europe
CLC	CORINE Land Cover
EEA	European Environment Agency
EU-DEM	Digital Elevation Model over Europe
ESA	European Spatial Agency
FAO	Food and Agriculture Organization of the United Nations
FTY	Forest Type
GIO	GMES Initial Operations
GMES	Global Monitoring for Environment and Security
HRL	High Resolution Layer
JRC	Joint Research Centre
LAEA	Lambert Azimuthal Equal-Area
LUCAS	Land Use/Cover Area frame Survey
MMU	Minimum Mapping Unit
MMW	Minimum Mapping Width
PSU	Primary Sample Unit
SP	Service Provider
TCD	Tree Cover Density
UA	Urban Atlas

1. Validation Framework

The validation framework is defined by a comprehensive analysis of the product specifications to determine the criteria to be used for the validation exercise.

1.1. Products to be validated

Pan-European High Resolution Layers (HRL) provide information on specific land cover characteristics, and are complementary to land cover / land use mapping such as in the CORINE land cover (CLC) datasets. The HRLs are produced from 20 m resolution satellite imagery through a combination of automatic processing and interactive rule based classification.

5 themes have been identified so far, corresponding mainly with the main themes from CLC, i.e. imperviousness degree (IMD), tree cover density (TCD) and forest type (FTY), grasslands (GRA), water and wetness (WaW) and small woody features (SWF). Except the SWF product which is produced from VHR imagery, the pixels of 20 by 20 m are aggregated into 100 by 100 m grid cells for final products.

Pan-European wall to wall products cover all EEA39 countries. They were produced in a combined centralized and decentralized approach, involving service industry through market mechanisms and participating countries through grant agreements.

The HRL forest 2015 consists of 3 status layers: **Tree Cover Density (TCD)**, **Dominant Leaf Tree (DLT)** and **Forest Type (FTY)**. and 2 change layers: **Dominant Leaf Type Change (DLTC)** and **Tree Cover Density Change (TCDC)**.

The **Tree Cover Density** dataset is a primary status layer of the HRL Forest products that maps the level of tree cover density in a range from 0-100%, has no MMU (minimum number of pixels to form a patch) and a minimum mapping width of 20 m (20m spatial resolution). The Tree Cover Density product is also available as aggregated version in 100m spatial resolution, fully aligned to the EEA 100m reference grid.

The **Dominant Leaf Tree** product is also a primary status layer of the HRL Forest products that maps the information on the dominant leaf type, either broadleaved or coniferous and which is fully identical in its outline extent with the Tree Cover Density product. The product has also no MMU (minimum number of pixels to form a patch) and a minimum mapping width of 20 m.

The **Forest Type** product allows to get as close as possible to the FAO forest definition. In its original (20m) resolution it consists of two products: 1) a dominant leaf type product that has a MMU of 0.5 ha, as well as a 10% tree cover density threshold applied, and 2) a support layer that maps, based on the dominant leaf type product, trees under agricultural use and in urban context (derived from CLC and imperviousness 2009 data). For the final 100m product trees under agricultural use and urban context from the support layer are removed.

The **Dominant Leaf Type Change** product is a pixel-based 20m layer covering the time period of 2012 (+/- 1 year) to 2015 (+/- 1 year). It is derived by dedicated GIS operations of the primary status layers Tree Cover Density and Dominant Leaf Type for both time steps. It includes 14 thematic classes, thereof 10 change classes. The product presents a 1 ha boundary filter and changes in the tree cover extent and leaf type are indicated whilst considering a Minimum Mapping Unit of 1 ha.

The **Tree Cover Density Change** product is a pixel-based 100m layer based on the aggregated TCD status layers 2012 and 2015. It summarizes the extent and magnitude of tree cover density increases and decreases over time. The product maps the level of tree cover density changes in a range of -30 to -100% and +30 to +100%, has no MMU (minimum number of pixels to form a patch) and a minimum mapping width of 100 m.

For the purpose of this validation exercise, all products at 100m should be validated, these are:

- Tree cover density (TCD), 100m x 100m, European projection, LAEA, version 3.
- Forest type (FTY), 100m x 100m, European projection, LAEA, version 2
- Tree Cover Density Change (TCDC), 100m x 100m, European projection, LAEA, version 4.

1.2. Validation Criteria

For the Forest layers, the main criteria selected for the validation are:

- Completeness, the amount of omission and commission.
- Logical consistency, the adherence to formats, conventions and conceptual aspects.
- Thematic accuracy, the correspondence with reference data.
- Temporal quality, the alignment of the results with the reference year.
- Usability.
- Metadata, the presence of sufficient metadata to describe the product.

Other validations are either not applicable (topological consistency is not relevant for a raster dataset) or being dealt with by other aspects of the project (positional accuracy is an assessment of the image data).

1.2.1. TCD

In the validation framework, the assessment of the thematic accuracy of the Tree Cover Density Layer in 100m spatial resolution for 2015 is done at two levels:

- A scatterplot of the density values extracted from the sample units for both the reference and layer data is made with a view to assess the correlation between reference and map values and identify any systematic bias (slope and intercept of the regression line significantly different for 1 and 0 respectively)
- A threshold applied to the density values for reference and map data to produce binary attributes for both the reference and map data layers. For TCD, no threshold was defined for the validation process. It is suggested that a suitable threshold could be defined based on the regression analysis, but that a starting point would be to assess the tree cover mask by grouping all values from:
 - 1 to 100 (class 1) against 0 (class 0) values corresponding to the forest mask definition.
 - 10 to 100 (class 1) against 0-9 (class 0) values corresponding to the threshold used for the FAO forest definition
 - 30-100 (class 1) against 0-29 (class 0) values corresponding to CLC forest classes definition.

Based on the thematic analysis of products undertaken during the Second Specific Contact², it seems that a 30% threshold produce better results than any other threshold.

No more than 15% error and preferably less than 10% should be present for both omission and commission errors for class 1.

² See <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

The detailed specifications of the Tree Cover Density 100m product is shown below:

Table 1: Detailed specification of the 100m Tree Cover Density product

Tree Cover Density 100m	Acronym	Product category
	TCD	Aggregated status layer
Reference year		
<i>2015 (+/- 1 year)</i>		
Geometric resolution		
<i>Pixel resolution 100m x 100m, fully conform with the EEA reference grid</i>		
Coordinate Reference System		
<i>European ETRS89 LAEA projection</i>		
Geometric accuracy (positioning scale)		
<i>Less than half a pixel. According to ortho-rectified satellite image base delivered by ESA.</i>		
Thematic accuracy		
<i>Determined by the accuracy of the source Tree Cover Density in 20m spatial resolution.</i>		
Data type		
<i>8bit unsigned raster with LZW compression</i>		
Minimum Mapping Unit (MMU)		
<i>Pixel-based (no MMU)</i>		
Tree cover density threshold		
<i>N/A</i>		
Necessary attributes		
<i>Raster value, count, class name, area (in km2), percentage (taking outside area not into account)</i>		
Raster coding (thematic pixel values)		
<i>0: all non-tree covered areas</i>		
<i>1-100: tree cover density values</i>		
<i>254: unclassifiable (no satellite image available, or clouds, shadows, or snow)</i>		
<i>255: outside area</i>		
Metadata		
<i>XML metadata files according to INSPIRE metadata standards</i>		
Delivery format		
<i>GeoTIFF</i>		

1.2.2. FTY

In the validation framework, the overall target thematic accuracy is 90% with 85% considered as absolute minimum accuracy. The 90% accuracy value must be understood as follows: 10% for commission errors and 10% for omission errors for forest classes.

The detailed specifications of the Forest type 100m product is shown below:

Table 2: Detailed specification of the 100m Forest Type product

Forest Type 100m	Acronym	Product category
Reference year <i>2015 (+/- 1 year)</i>	FTY	Aggregated status layer
Geometric resolution <i>Pixel resolution 100m x 100m, fully conform with the EEA reference grid</i>		
Coordinate Reference System <i>European ETRS89 LAEA projection</i>		
Geometric accuracy (positioning scale) <i>Less than half a pixel. According to ortho-rectified satellite image base delivered by ESA.</i>		
Thematic accuracy <i>Determined by the accuracy of the source Forest Type and Forest Additional Support Layer in 20m spatial resolution.</i>		
Data type <i>8bit unsigned raster with LZW compression</i>		
Minimum Mapping Unit (MMU) <i>Pixel-based (no MMU)</i>		
Tree cover density threshold <i>10%</i>		
Necessary attributes <i>Raster value, count, class name, area (in km2), percentage (taking outside area not into account)</i>		
Raster coding (thematic pixel values) <i>0: all non-forest areas 1: broadleaved forest 2: coniferous forest 3: mixed forest 254: unclassifiable (no satellite image available, or clouds, shadows, or snow) 255: outside area</i>		
Metadata <i>XML metadata files according to INSPIRE metadata standards</i>		
Delivery format <i>GeoTIFF</i>		

1.2.3. TCDC

The assessment of the thematic accuracy of the Tree Cover Density Change Layer in 100m spatial resolution for 2012-2015 is done based on thresholds applied to the change density values for reference and map data to produce thematic attributes for both the reference and map data layers. For TCDC, no thresholds were defined for the validation process and it was decided to assess the change layer by grouping all values from:

- -100 to -30 values corresponding to decreased tree cover density
- 0: unchanged areas
- 30 to 100 values corresponding to increased tree cover density

No more than 15% error and preferably less than 10% should be present for both omission and commission errors for the different classes.

The detailed specifications of the Tree Cover Density Change 100m product is shown below:

Table 3: Detailed specification of the 100m Tree Cover Density Change product

Tree Cover Density Change 100m	Acronym	Product category
Reference year <i>2012 (+/- 1 year) to 2015 (+/- 1 year)</i>	TCDC	Change layer
Geometric resolution <i>Pixel resolution 100m x 100m, fully conform with the EEA reference grid</i>		
Coordinate Reference System <i>European ETRS89 LAEA projection</i>		
Geometric accuracy (positioning scale) <i>Less than half a pixel. According to ortho-rectified satellite image base delivered by ESA.</i>		
Thematic accuracy <i>Determined by the accuracy of the source Tree Cover Density 2012/2015 in 20m spatial resolution.</i>		
Data type <i>16bit signed raster with LZW compression</i>		
Minimum Mapping Unit (MMU) <i>Pixel-based (no MMU)</i>		
Tree cover density threshold <i>30%</i>		
Necessary attributes <i>Raster value, count, class name, area (in km2), percentage (taking outside area not into account)</i>		
Raster coding (thematic pixel values) <i>-100 to -30: decreased tree cover density 0: unchanged areas 30-100: increased tree cover density 254: unclassifiable in any of parent status layers 255: outside area</i>		
Metadata <i>XML metadata files according to INSPIRE metadata standards</i>		
Delivery format <i>Geotiff</i>		

2. Validation approach

The validation approach will provide guidance on how the products will be validated by defining suitable indicators or metrics.

Detailed completeness and logical consistency checks are performed as part of the semantic checks undertaken by ETC ULS for most products. Therefore, the aim of this validation exercise is not to repeat these, but to review the existing documentation and perform additional checks if deemed necessary.

The quality assessment is performed according to INSPIRE Data Specifications. The data quality elements considered are: (i) Completeness, (ii) Logical Consistency, (iii) Positional Accuracy, (iv) Thematic Accuracy, (v) Temporal quality and (vi) Usability. Each of them forms a section in the Validation Check list.

Logical consistency checks do not consist in a duplication of Semantic checks but are performed to identify missing information if relevant.

Thematic accuracy will represent the bulk of the work undertaken as part of this validation exercise.

2.1. Completeness

Description: For land cover and land use products (both raster & vector), the notion of completeness in INSPIRE provides an indication of omission and commission errors. Commission - excess data present in the dataset, as described relative to the scope. Omission - data absent from the dataset, as described relative to the scope. This operation will be applied at the dataset level, rather than spatial object, and related to area extent. It can also include attributes and whether they are set etc., but this is actually covered by further checks below.

Indicators: the rate of excess items is used for areas mapped beyond the intended area and the rate of missing items is used to verify gaps in the intended area to be mapped.

2.2. Logical consistency

Logical consistency evaluates the degree of adherence to logical rules of data structure, attribution and relationships. In INSPIRE Data Specifications, Logical Consistency comprises four sub-elements described hereafter: conceptual consistency, domain consistency, format consistency and topological consistency. As the TCD, FTY and TCDC products are in raster format the topological consistency is not relevant.

2.2.1. Conceptual consistency

Description: Conceptual consistency relates to the data structure and follows the data specifications in terms of data model and relationships. It is also related to the adherence to the rules of the conceptual schema.

Indicators: For the TCD, FTY and TCDC layers the properties of conceptual consistency are mainly defined for the 20 m products, with the inference that the same are applied to the versions aggregated to 100 m spatial resolution. The properties appropriate to raster data can be defined as:

- Minimum Mapping Unit (MMU). This is the minimum size a feature may have within the dataset. In the case of raster datasets this is the spatial resolution or grid cell size. For the Forest layers the spatial resolution should be 100 m.
- Coordinate Reference System (CRS): A coordinate-based local, regional or global system used to locate geographical entities and defines a specific map projection. CRS will be dealt with in detail later, but for the Forest layers it is the European LAEA.
- Pixel size and origin
- Compliance between 20m and 100m Forest type and 20 m Additional Support layer (see Verification Guidelines)
- Additional attributes, symbology

2.2.2. Domain consistency

Description: involves the detection of attribute values that are outside the pre-defined range of values. For vector data each attribute has a pre-defined set of range of values. Domain consistency in raster datasets relates to the various range structures for bands and attributes, e.g. number of available bands with their names, the units of measure, the data type and the null value used. Checking domain consistency involves assessing the numbers of bands and the detection of attribute / pixel values that are outside the pre-defined ranges or sets of values. For raster data such as TCD / FTY / TCDC, the correct encoding of data is checked.

Indicator: Value domain non-conformance: number of items not in conformance with their expected value domain.

2.2.3. Format consistency

Description: Format consistency includes detection of file format, file or attribute names or attribute types which do not correspond to the specifications. In addition, for raster data the pixel depth is also considered here. File format, schema, naming conventions etc. Degree to which data is stored in accordance with the physical structure of the dataset, as described by the scope.

Indicators: For the Forest layers which are raster-based products plus documentation, only the following format consistency properties need to be check:

- File format conformance
 - o Raster data is required in the GeoTIFF or TIFF with World file formats.
 - o Compression: It was proposed that the image data should be optimised for storage by use of the LZW compression, which is supported in all image processing and GIS software, including GDAL.
 - o A PDF file providing CRS information, including details of parameters used to transform to ETRS89.
 - o The metadata should be supplied in XML format.
- File name conformance: A set of filename conventions were established in the product specifications.
- Attribute names conformance
- Attribute types conformance

2.2.4. Topological consistency

Description: topological consistency is applicable to vector data and describes the degree of correctness of the topological characteristics described in the product specification of the dataset.

Indicators: Not applicable to raster data

2.2.5. Additional logical consistency checks

There are further logical consistency checks that should be made to make sure the data confirms with the specifications to allow ease of use.

- **Labelling or symbology:** The conformity of a layer with the symbology or style given in the product specifications should be checked. The EEA provided colour tables to be built into raster datasets for all the HRLs.
- **Map projection:** The conformity of the map projection parameters is also checked. The selected projection for the HRL data is the LAEA-ERTS89 (Table 4).

Table 4: Map projection details for LAEA-ERTS89.

European		
Datum	Name	ETRS89 (European Terrestrial Reference System 1989)
	Type	geodetic
	Valid area	Europe / EUREF
Prime meridian	Name	Greenwich
	Longitude	0°
Ellipsoid	Name	GRS 80 (New International)
	Semi major axis	6 378 137 m
	Inverse flattening	298.257222101
Projection		Geographic (Ellipsoidal Coordinate System)

2.3. Positional Accuracy

Detailed positional accuracy as described below is only required for the validation of image mosaics.

Positional accuracy of the HRLs is directly related to the underlying HR imagery.

Visual checks were undertaken in relation to imagery used for validation and during the collection of sample units.

2.4. Thematic Accuracy

2.4.1. Level of reporting

The level of reporting for the validation results is at pan-European level. However, results are also provided at different levels of aggregation (as indicated in the Request for Services for this first specific contracts). The analysis at disaggregated levels will contribute to assess regional differences, if any, and the nature of these differences.

The internal validation needs to find a compromise between the number of sample units and representativeness of the results at sub-European level. Therefore, the envisaged levels of reporting are:

1. Pan-European



Figure 1. Level of reporting at pan-European level

2. Biogeographical regions 2016

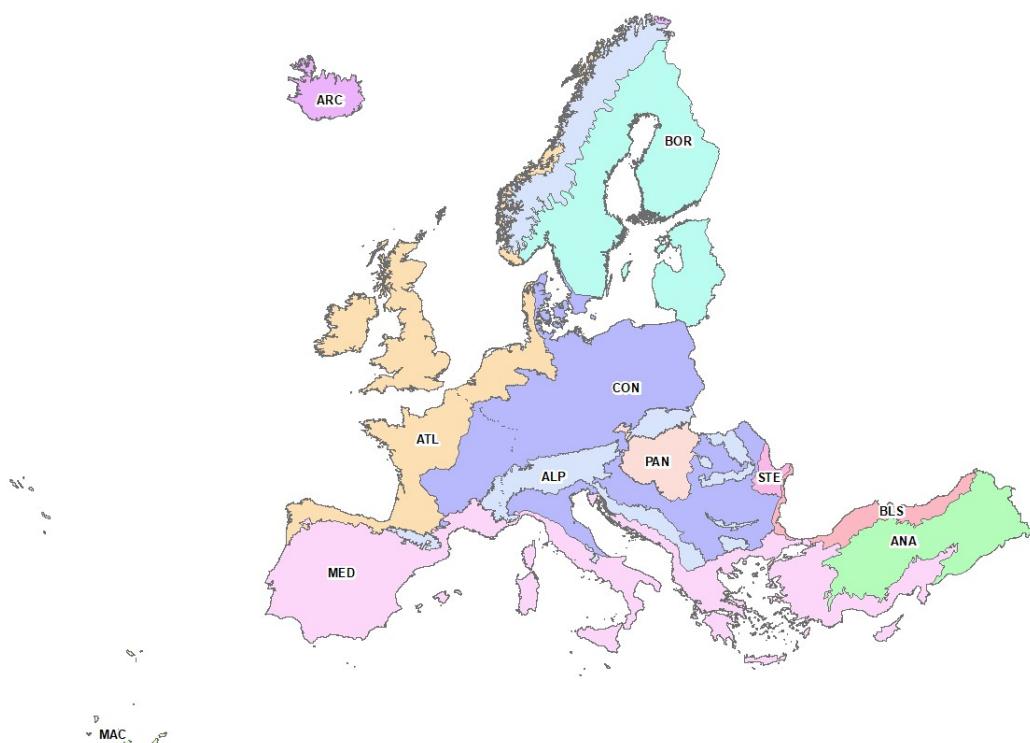


Figure 2. Level of reporting accordingly to the biogeographical regions

3. Country or aggregated countries as described in the previous Specific Contracts in 23 main countries or groups of countries (including French DOMs). Countries < 90,000 km² shall be grouped into contiguous groups of countries > 90,000 km² as much as possible.



Figure 3. Level of reporting accordingly to the country or aggregated countries

2.4.2. Stratification and sample design

The following sub-sections provide a description of the procedure of a scientifically and statistically sound sampling scheme for assessing the thematic quality of the HRL Forest products. This comprises descriptions of the stratification approach, the sample size calculation procedure and of the strategy for ensuring representative sample distribution and sufficient regional spread.

2.4.2.1. Overview

The stratification and the sampling design primarily consists in selecting an appropriate sampling frame and sampling unit. The sampling units can either be “defined on a cartographic representation of the surveyed territory” (Gallego, 2004), in which case it is an area frame, or on a list of the features. According to (Gallego, 2004), area frames give a better representation of the population as the spatial dimension is kept.

In an area frame, sample units can be points, lines (often referred to as transects) or areas (often referred to as segments, described by Gallego, 1995). The first step is to define the geographical area for which the accuracy assessment is to be reported and the type of sample units. For the majority of cases, point samples will be used, but areas or segments may be used in specific cases such as when not only thematic accuracy needs to be reported, but also the geometry of mapped objects. Points are considered as the most appropriate unit for our purpose. Polygons have also the drawback of being specific to a single map. In case of changes, the sample may not be adapted anymore.

Sampling design refers to the protocol whereby the samples are selected. A probability sampling design is preferred for its objectivity. “Simple random, stratified random, clustered random and systematic designs are all examples of probability sampling designs” (Stehman *et al.*, 1998). Even though a simple random design is easy to implement, its main drawback is that some portions of the population may not be adequately sampled. Cluster sampling is often used to reduce the costs of the collection of reference data, but does not resolve geographic distribution problems. A systematic approach would solve this problem, yet it is not appropriate if the map contains cyclic patterns. A stratified approach consists in allocating a pre-defined number of samples per land-cover class. As explained in (Stehman *et al.*, 1998), stratification ensures that each class is represented.

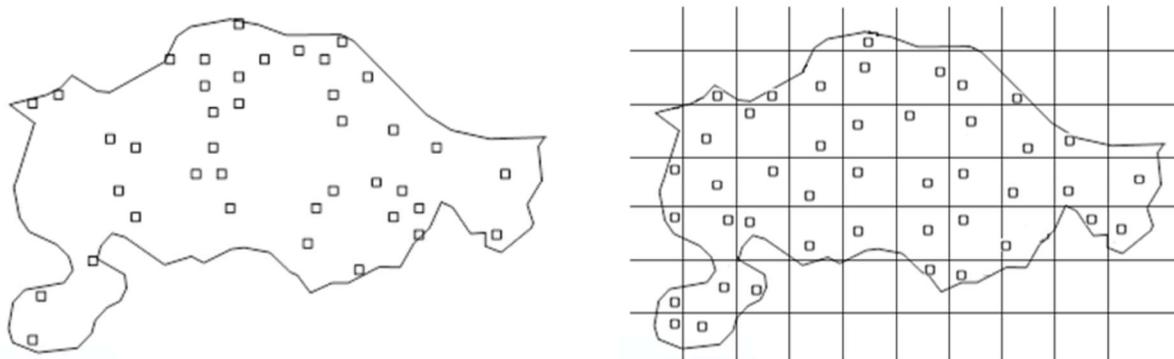


Figure 4. Simple random (left) and random systematic (right) sampling designs

The sampling and stratification design presented below is applicable to all HRL Forest products including change product.

The validation approach of the Copernicus land Lot 1 external validation contract were adopted for the internal validation. It is based on a selected sample design for thematic accuracy assessment and combines systematic and stratified approaches and benefits from the advantages of both of them. It is based on the LUCAS (Land Use/Cover Area frame statistical Survey) sampling approach. LUCAS corresponds to a grid of approximatively

1,100,000 points throughout the European Union where land cover or land use type is observed. Using LUCAS points ensures traceability and coherence between the different layers.

LUCAS points are located every 2 km on a regular grid, as illustrated below. A set of 81 points located on an 18x18 km square constitutes a group in which every point is associated with a number comprised between 1 and 81 (the numbers do not follow each other spatially). The same pattern with the same numbers allocation is repeated all over the grid. A replicate refers to the points with the same number selected on the whole LUCAS grid.

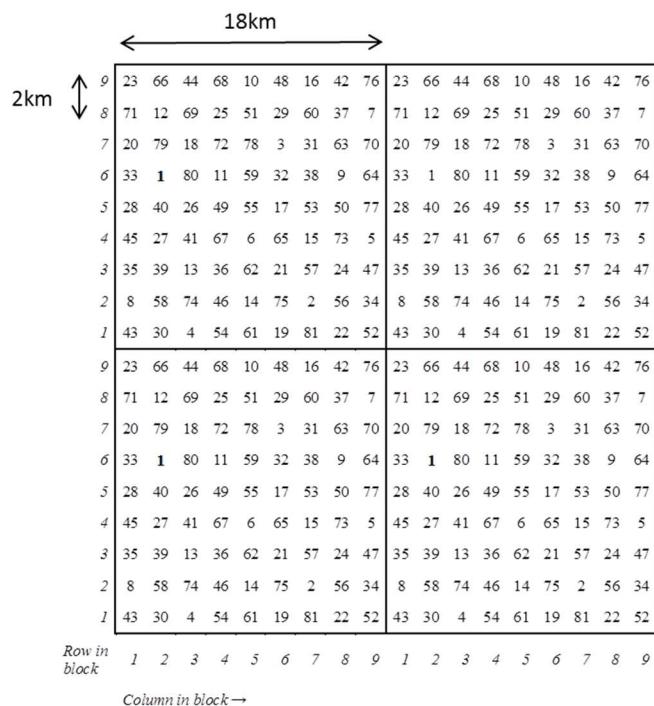


Figure 5. LUCAS points located on a regular grid

At first, the number of samples to allocate to each stratum (or thematic class) is calculated as a function of their area. In this manner the sampling design is not only systematic but also stratified. The number of sample units per stratum is to be defined to ensure sufficient level of precision at reporting level:

The determination of the number of sample units also considers the number of thematic classes.

It is possible to estimate a suitable sample size for each stratum based on the expected acceptable error rate.

The standard error of the error rate can be calculated as follows: $\sigma_h = \sqrt{\frac{p_h(1-p_h)}{n_h}}$ (1) where n_h is the sample size for stratum h and p_h is the expected error rate. This can be reworked to express the sample size n_h as a function of p_h and desired standard error σ_h : $n_h = \frac{p_h(1-p_h)}{\sigma_h^2}$. (2)

From Figure 6 it can be seen that for an expected 50% error rate, within a stratum, 100 sample units would be required to guarantee a standard error of 5%, whereas the number of samples would need to be increased by a factor of four if the accepted standard deviation is divided by a factor of 2. On the other hand if the expected error rate is 15%, only 51 samples would be necessary with a 5% standard error. A similar approach was adopted to determine the sample size for assessing the accuracy of CLC2006 and CLC2000-2006 changes (Büttner *et al.* 2012). This works well to assess commission errors, the definition of an appropriate number of sample units for omission errors is more difficult because it depends on the expected area of the theme to be mapped.

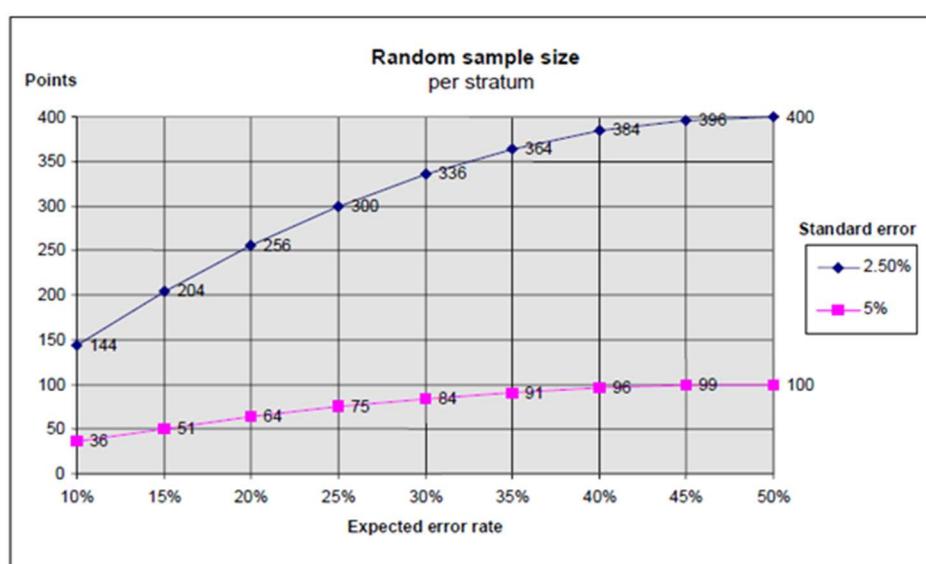


Figure 6. Number of sample points as a function of the expected error rate for two accepted standard error values (after Wack et al. 2012)

When using stratified sampling, the main issue to maximise the efficiency of the stratification (maximise the level of precision) is to optimize the sample allocation per strata. A simple way is the use of equal allocation. Alternatively, the Neyman allocation algorithm is also often used for that purpose:

$$n_h = n * (N_h * \sigma_h) / [\Sigma (N_i * \sigma_i)], \quad (3)$$

where n_h is the sample size for stratum h , n is the total sample size, N_h is the population size for stratum h , and σ_h is the standard deviation of stratum h . According to Stehman (2012), Neyman optimal allocation should be preferred for estimating area of change as well as overall accuracy, whereas equal allocation is effective for estimating user accuracy.

Moreover, in addition to the Neyman sample allocation, a minimum number of sample units per stratum is defined to ensure that even small strata are represented in the sample. As the expected error rate is expected to be less than 10%, a minimum of 50 sample units per reporting stratum should be sufficient.

The number of replicates to be selected for a stratum depends on its area and the number of LUCAS points intersecting the stratum.

For thematic classes covering a large proportion of the study area, 1 replicate may already exceed the defined number of samples for this class. To solve this problem, replicates are split into four sub-replicates, as illustrated by the blue numbers in Figure 7.

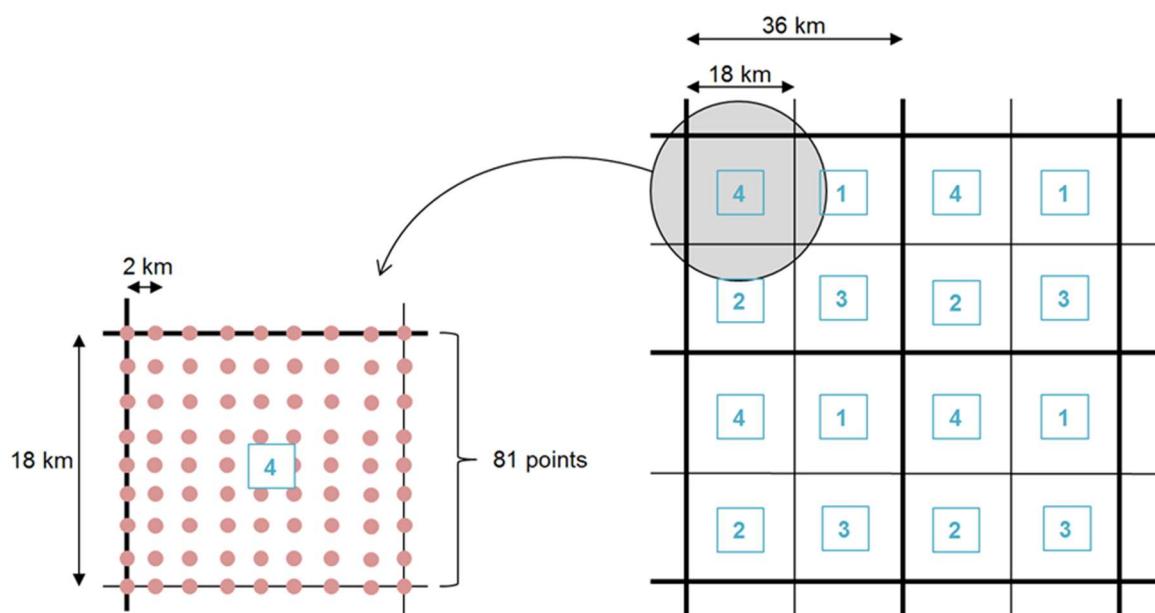


Figure 7. Replicates and sub-replicates used on LUCAS grid

The opposite problem is encountered for land cover classes covering a small proportion of the study area: even by selecting 81 replicates (the maximum number), the intersecting area between the stratum and LUCAS points is too small to reach the required number of samples. Therefore LUCAS grid could be densified by creating one point every 200m.

2.4.2.2. Stratification approach

For the TCD, FTY and TCDC products, a stratification based on a series of omission/commission strata is applied at two levels:

1. at pan-European level then
2. at countries or group of countries with an area greater than 90,000km² level if a minimum sample units of 50 is not reached for one omission/commission strata.

The number of Primary Sample Units (PSUs) per stratum should be such to ensure a sufficient level of precision at reporting level. The minimum number of PSUs per stratum should be set at 75 if possible. Priority is given to strata which are known to be difficult to map: e.g. changes and difficult classes.

The validation exercise covers the whole study area to be valid.

2.4.2.2.1. TCD / FTY

Based on the lessons learnt, from the previous Specific Contracts, the stratification procedure was simplified to only include a commission (tree cover mask 1-100) and an omission stratum (rest of the area) in order to ensure the efficiency of the approach. Stratification is so based on the strata defined as follows:

- Commission: tree cover density 1-100% (minimum of 75 PSUs per country / group of countries)
- Omission: tree cover density 0% (minimum of 75 sample units per country / group of countries)

If the minimum of 75 PSUs per country / group of countries is not reached at the first level of stratification, a second level is applied, per country to ensure the minimum number of PSUs.

Each PSU corresponds to one HRL pixel. Each PSU is then associated to Secondary Sampling Units (SSUs) corresponding to a 5x5 grid with 20m between each SSU (Figure 8). The idea is that each SSU can then be associated with the corresponding HRL 20m layer pixel.



Figure 8: Example of SSUs organised in a 5x5 20m grid

Sampling units will be identical for each forest layer with the same stratification approaches, so the sample locations will be shared thanks to using LUCAS as the basis for selecting sample units for each layer.

Different sampling intensity are applied to focus on strata for which there is a higher probability that errors will be found. Weighting factors will be calculated based on the final sample selected to ensure that the different sampling intensities are accounted for when constructing confusion matrices to avoid the introduction of a bias toward these strata.

There was a total of 15,051 sample units for the TCD and FTY products (Table 5 and Table 6):

Table 5: TCD/FTY distribution of sample units per strata and level of stratification

LABEL		Commission	Omission	Total
Pan-European level		8,081	6,895	14,976
Country level		75	0	75
	IS	75	0	75
TOTAL		8,156	6,895	15,051

Table 6: TCD/FTY distribution of sample units per countries or group of them

LABEL	Commission	Omission	Total
AL+ME+MK+RS+XK	255	151	406
AT + CH + LI	205	117	322
BA + HR + SI	233	91	324
BE + LU+ NL + DK	99	189	288
BG	156	126	282
CZ + SK	180	143	323
DE	513	426	939
EE + LT + LV	263	186	449
EL + CY	222	120	342
ES	739	566	1,305
FI	699	173	872
FR	771	631	1,402
HU	83	154	237
IE + UK	239	565	804
IS	75	250	325
IT + MT	485	288	773
NO	431	422	853
PL	416	394	810
PT	140	93	233
RO	273	327	600
SE	877	289	1,166
TR	802	1194	1,996
TOTAL	8,156	6,895	15,051

In order to ensure that unequal inclusion probabilities are accounted for in the construction of the error matrix, weights are applied to each stratum as shown in (Table 7):

Table 7: TCD/FTY weight factors to be applied to each stratum and level of stratification for constructing confusion matrices

LABEL	Commission	Omission
Pan-European level	1.005049	1.004734
Country level		
IS	0.020715	-

The weights are calculated based on the interpreted sample units, should the number of sample units be modified per stratum following the removal of interpreted sample units classified as uncertain, weights would need to be recalculated. However, if the number of samples removed is small, weight changes should be minimal considering the large sample overall.

The sample units were provided to the bulk interpretation team as two separate shapefiles (one for each delivery batch, according to AD04) in which all the information on strata was removed to ensure the independence of the interpretation.

2.4.2.2.2. TCDC

Stratification is based on a series of omission/commission strata defined as follows:

- Commission 2012-2015: tree cover density 1-100% in 2012-2015 (minimum of 75 PSUs per country / group of countries)
- Omission 2012-2015: tree cover density 0% in 2012-2015 (minimum of 75 sample units per country / group of countries)
- Commission Change 2012-2015 “increase”: increased tree cover density 2012-2015 (minimum of 75 sample units per country / group of countries)
- Commission Change 2012-2015 “decrease”: decreased tree cover density 2012-2015 (minimum of 75 sample units per country / group of countries)
- Omission Change 2012-2015: rest of the area (minimum of 75 sample units per country / group of countries)

If the minimum of 75 PSUs per country / group of countries is not reached at the first level of stratification, a second level is applied, per country to ensure the minimum number of PSUs.

Each PSU corresponds to one HRL pixel. Each PSU is then associated to Secondary Sampling Units (SSUs) corresponding to a 5x5 grid with 20m between each SSU.

Different sampling intensity are applied to focus on strata for which there is a higher probability that errors will be found. Weighting factors will be calculated based on the final sample selected to ensure that the different sampling intensities are accounted for when constructing confusion matrices to avoid the introduction of a bias toward these strata.

There was a total of 15,069 sample units for the TCDC product (Table 8):

Table 8: TCDC distribution of sample units per strata and level of stratification

LABEL	Commission 2012-2015	Omission 2012-2015	Commission Change “increase”	Commission Change “decrease”	Omission Change	Total
Pan-European level	4,412	3,764	565	525	5,490	14,756
Country level	52	0	105	156	0	313
AL+ME+MK+ RS+XK	0	0	8	5	0	13
	0	0	9	14	0	23
	0	0	2	12	0	14
	0	0	13	14	0	27
	0	0	10	19	0	29
	0	0	7	8	0	15
	0	0	0	1	0	1
	0	0	0	13	0	13
	0	0	10	17	0	27
	52	0	20	19	0	91
	0	0	0	7	0	7
	0	0	0	9	0	9
	0	0	0	4	0	4
	0	0	19	4	0	23
RO	0	0	7	10	0	17
TOTAL	4,464	3,764	670	681	5,490	15,069

In order to ensure that unequal inclusion probabilities are accounted for in the construction of the error matrix, weights are applied to each stratum as shown in (Table 9):

Table 9: TCDC Weight factors to be applied to each stratum and level of stratification for constructing confusion matrices

LABEL	Commission 2012-2015	Omission 2012-2015	Commission Change “increase”	Commission Change “decrease”	Omission Change
Pan-European level	0.914997	0.914826	0.426616	0.206463	1.278741
Country level	-	-	-	-	-
AL+ME+MK+RS+XK	-	-	1.387744	2.362557	-
AT + CH + LI	-	-	3.742660	0.801763	-
BA + HR + SI	-	-	12.319837	0.323683	-
BE + LU+ NL + DK	-	-	0.948901	0.284233	-
BG	-	-	0.702052	0.135710	-
CZ + SK	-	-	1.729533	0.709880	-
DE	-	-	-	0.356408	-
EL	-	-	-	0.566850	-
HU	-	-	1.084944	0.350358	-
IS	0.014851	-	0.305175	0.142418	-
IT	-	-	-	0.183795	-
NO	-	-	-	0.120182	-
PL	-	-	-	0.702176	-
PT	-	-	0.513226	4.748353	-
RO	-	-	1.002351	0.381422	-

The weights are calculated based on the interpreted sample units, should the number of sample units be modified per stratum following the removal of interpreted sample units classified as uncertain, weights would need to be recalculated. However, if the number of samples removed is small, weight changes should be minimal considering the large sample overall.

The sample units were provided to the bulk interpretation team as two separate shapefiles (one for each delivery batch, according to AD04) in which all the information on strata was removed to ensure the independence of the interpretation.

2.4.3. Response Design

2.4.3.1. Overview

The sample design is based on the LUCAS sample frame and some sample units will coincide with some LUCAS points. However, the LUCAS points are re-interpreted based on available in situ data. LUCAS thematic information is not used directly.

A blind approach was applied to start with, i.e. the validation is undertaken without considering the map layer information, and then a plausibility analysis was implemented for both layers considering the information of the map layer. This will contribute to provide an in-depth understanding of the causes of classification errors and to account for ambiguous map values at the class borders.

2.4.3.2. TCD

The TCD layer in the 100m product was evaluated according to the following definitions and aggregation rules used (cf. Copernicus Land Monitoring Service – High Resolution Layer Forest: Product Specifications Document, Version 11 of 2018-08-14 available at <https://land.copernicus.eu/user-corner/technical-library/hrl-forest>):

- Tree Cover Density range 0-100%
- 1-100% to be interpreted depending on detail that can be detected from the available 20m raster imagery
- No MMU
- Minimum Mapping Width: 20m

Includes: Evergreen/deciduous broadleaved, sclerophyllous and coniferous trees of any use, forests (grown-up and under development), orchards, olive groves, fruit and other tree plantations, agro-forestry areas, transitional woodland, forests in regeneration, groups of trees within urban areas (alleys, wooded parks and gardens),

Included if tree cover can be detected from the 20m raster imagery per pixel: Forest management/use features inside forests (forest roads, firebreaks, thinnings, etc.); Forest damage features inside forests (partially burnt areas, storm damages, insect-infested damages, etc.)

Excludes (according to FAO): shrubland; Mediterranean bush lands (macchia, garrigue etc.); dwarf pine / green alder in high-mountainous areas; vineyards

Excluded if no tree cover can be detected from the 20m raster imagery per cell: open areas within forests (roads, permanently open vegetated areas, clear cuts, fully burnt areas, other severe forest damage areas, etc.)

A double-blind approach has been applied, where the map information was not available during interpretation. As spatial assessment unit that served as the basis for the comparison of the reference classification and map classification, the 100m by 100m pixel of the TCD High resolution layer was specified. To ensure that the reference classification is of higher quality than the map classification, in addition to the production data, also in-situ data sets were used.

Used reference data which cover the EEA39 area at a wall-to-wall basis:

- HR Image 2015 Coverage 1 CIR imagery with spatial resolution of 10-20m
- HR Image 2015 Coverage 2 CIR imagery with spatial resolution of 20m
- VHR Image 2015 with spatial resolution of 1-2.5m (JP2 pan-sharpened version made available at SIRS)
- HR Image 2012 Coverage 1 CIR imagery with spatial resolution of 25m
- HR Image 2012 Coverage 2 RGB imagery with spatial resolution of 20m
- VHR Image 2012 CIR with spatial resolution of 2.5m (Web map service provided by JRC)
- VHR Image 2012 RGB with spatial resolution of 2.5m (Web map service provided by JRC)

Used reference data which cover parts of the EEA39 area:

- Bing maps (ArcGIS Basemap layer, RGB imagery with varying spatial resolution)
- Arc2Earth imagery (Google commercial ArcGIS plugin, RGB imagery with varying spatial resolution)

- National and regional web map services (RGB and/or CIR imagery with varying spatial resolution)
- Sentinel-2 data via Sentinel-Hub Playground

These comprehensive reference data sets provided a sound basis for the interpretation. For labelling of the reference data, a tool was implemented by Joanneum Research which is shown in the figure below. For estimating the tree crown cover, for each of the 25 sampling points it was interpreted if the point is located above a tree crown. Further, for each of the sampling units, a reliability estimate was assigned by the interpreter. The tool also provided the possibility to record a tree cover density value directly, which explains why validation density values are mostly, but not always in 4% steps.

The following validation procedure for TCD was used:

- i. Assess the TCD in each of the 25 cells using the point approach. Check whether each point is located above a tree crown or not according to the TCD definitions
- ii. Consider the skewness of trees as far as possible using expert knowledge; if not reliable flag reliability=LOW
- iii. Assign value 1 to the cell if it is touching a tree or 0 if it is not touching a tree
- iv. Check if the automatically computed overall tree cover density is correct
- v. After interpretation of the 25 points per plot, check by expert whether the derived average TCD of the plot reflects the “real” TCD in the plot (e.g. in case of obvious over- or underestimation, e.g. line of trees within 100m plot but no point touching a tree), and adjust the overall TCD estimate accordingly if needed.

Flag the quality of the data: for all sampling units for which the interpreter assigned medium or low reliability the interpretation was repeated by a second interpreter. Further, the interpretation cycle included internal quality measures to ensure the quality during the validation process.

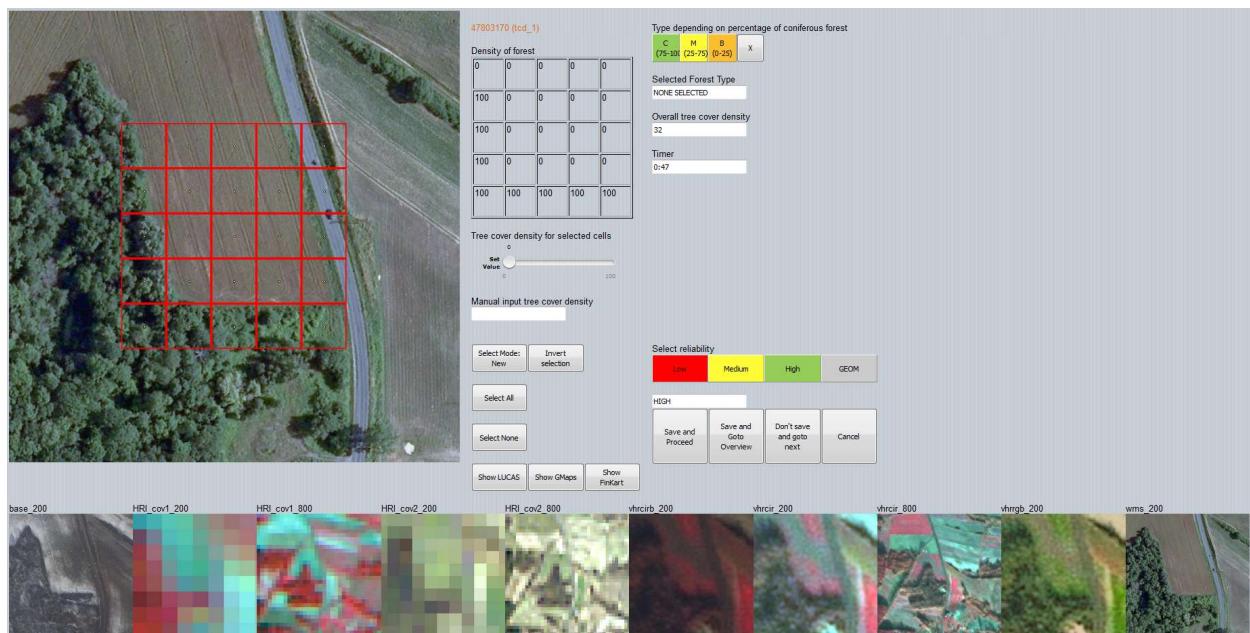


Figure 9: Interpretation tool for reference data labelling (implemented by Joanneum Research)

For TCD, which is a continuous layer with very few exact matches between validation and map layer data, a review of PSUs in disagreement was done as part of a **plausibility analysis**.

2.4.3.3. FTY

The FTY layer in the 100m product must be evaluated according to the following definitions and aggregation rules used (cf. Copernicus Land Monitoring Service – High Resolution Layer Forest: Product Specifications Document, Version 11 of 2018-08-14 available at <https://land.copernicus.eu/user-corner/technical-library/hrl-forest>):

- MMU 0.52 ha (i.e. ≥ 13 20m x 20m cells)
- The smallest forest patch to be mapped will have an area of 13 cells (0.52 ha) in a 4-cell connectivity mode (i.e. only vertical and horizontal pixel neighbourhood is accounted)
- 0-9% TCD = non-forest and TCD 10-100% = forest
- MMW 20m

4 categories:

- Non-forest = 0
- Broadleaved Forest = 1 (0-25% coniferous)
- Coniferous Forest = 2 (75% -100% coniferous)
- Mixed Forest = 3 (26% -74% coniferous)

It **includes** (according to FAO) forest nurseries and seed orchards that constitute an integral part of the forest, as well as forest roads, cleared tracts, firebreaks and other small open areas < 0.5 ha and/or < 20 m width. Forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an area of more than 0.5 ha and width of more or equal than 20 m; plantations primarily used for forestry purposes, including cork oak stands. Tree cover in traditional agroforestry system such as Dehesa / Montado is included.

It **excludes** (according to FAO) land predominantly used for agricultural practices. In this sense fruit trees and olive groves are also excluded. Gardens and urban parks are also not considered as forest.

As for the TCD validation, a double-blind approach for validating the FTY map was applied, where the map information was not available during interpretation. As spatial assessment unit that served as the basis for the comparison of the reference classification and map classification, the 100m by 100m pixel of the FTY High resolution layer was specified. Same validation reference data as used for validating the TCD map was used, which is listed above (2.4.3.2 TCD), which provided a sound basis for the interpretation.

For labelling of the reference data, the tool which is described above was used to assign the categories "coniferous", "mixed", "broadleaved" or "non-forest".

The following validation procedure for FTY was used:

1. Assess the overall forest cover for each of the 25 cells
 - a. Check forest MMU 0.5 ha, MMW 20m and the 4 neighbourhood if visible in HR
 - b. If tree cover ($\geq 10\%$ TCD) is $< 50\%$ per cell then assign this cell to NON-FOREST
 - c. If tree cover ($\geq 10\%$ TCD) is $\geq 50\%$ per cell then assess the type of tree cover for this cell:
 - i. Assign one of the following categories to the cell
 1. Non-forest
 2. Coniferous forest
 3. Broadleaf forest
 4. Broadleaf agricultural
 5. Broadleaf & coniferous urban

d. If more than 50% of all cells (>13 cells) are non-tree, agriculture trees or urban trees, then assign NON-FOREST

e. If more than 50% of the cells (>13 cells) are broadleaf and/or coniferous, then assess and assign the plot forest type

i. Assign one of the following three categories

1. CONIFEROUS (75%-100% coniferous)
2. MIXED (<75% and >25% coniferous)
3. BROADLEAF (25% - 0% coniferous)

2. Flag the quality of the data

For each of the sampling units, the reliability of the interpretation was assigned by the interpreter. For all sampling units for which the interpreter assigned medium or low reliability the interpretation was repeated by a second interpreter. Further, the interpretation cycle included internal quality measures to ensure quality of validation process.

A **plausibility check** was also conducted following the same procedure as above but confronting the validation data PSUs in disagreement with the HRL FTY. The following cases were considered:

1. = both values (product class and bulk interpretation) are plausible => the HRL FTY value is considered correct
2. = Product classification is correct => the HRL FTY value is considered correct
3. = Bulk interpretation is correct => disagreement between HRL FTY and validation is confirmed
4. = Both values are wrong => the correct validation class is re-assigned and disagreement between HRL FTY and validation is confirmed.

In the implementation of the plausibility analysis, attention was given to fully comply with the production aggregation rules to construct the 100m layer (the layer to be validated) from the input 20m layer, especially for the ‘mixed’ class which does not exist at 20m and is an output of the aggregation procedure.

For scenarios 3 and 4, a full interpretation of the Dominant Leaf Type (coniferous or broadleaf) per 20m cell was performed, in order to have an interpretation with higher spatial accuracy for analysing the errors that occurred during map production. The DLT product is only consist of non-forest, broadleaf and coniferous forest, the mixed forest class does not exist. Since the FTY map is an aggregated product of the 20m map, a full 20m interpretation allows analysing the errors already imminent in the 20m product or resulting from the aggregation procedure.

2.4.3.4. TCDC

The Tree Cover Density Change product (TCDC) is a pixel-based 100m layer based on the aggregated TCD status layers 2012 and 2015. It summarizes the extent and magnitude of tree cover density increases and decreases over time. A filtering approach with a 30% density significance threshold has been applied to differentiate between “noise” and the expected real change between both time steps. The TCDC 100m product is evaluated following the definitions and aggregation rules used in the “Copernicus Land Monitoring Service High Resolution Layer Forest Product Specifications” available at <https://land.copernicus.eu/user-corner/technical-library/hrl-forest>):

- 100m spatial resolution
- Tree Cover Density change in range of -30 to -100% and +30 to +100%
- Tree Cover Density significance difference threshold of 30%
- No Minimum Mapping Unit (MMU); pixel-based

The interpretation of TCDC provides binary change information and a change percentage for each plot:

- Binary information: changed/unchanged according to product specifications
- Tree Cover Density change in range of -30 to -100% and +30 to +100%

As for the TCDC validation, a double-blind approach for validating the TCDC map was applied, where the map information was not available during interpretation. As spatial assessment unit that served as the basis for the comparison of the reference classification and map classification, the 100m by 100m pixel of the TCDC High resolution layer was specified. The same validation reference data as used for validating the TCD and FTY map was used, which is listed above (2.4.3.2 TCD), and which provided a sound basis for the interpretation. In addition to the 2015 reference data, also reference data from 2011-2013 was analysed to assess the TCD values of the 2012 reference year. It was available through the same data providers.

For interpreting the reference data, the tool described above was modified to allow for a combined interpretation of 2012 and 2015 reference year image data. By switching from a "NEW" (2015) to an "OLD" (2012) interface the interpreters are able to directly compare the TCD at both reference times. As the correct time of the reference data acquisition is crucial, image acquisition dates are shown in the tool. Interpretation of the TCD values follows the concept of the interpreting 25 20m cells in a binary setup as outlined above (2.4.3.2 TCD). The change values are automatically derived, but in order to eliminate mistakes, the interpreter has to confirm the corresponding change category. If these do not match a warning is shown. The change categories are:

- 1: change 10-29%;
- 2: change $\geq 30\%$;
- 3: no change;
- 4: unreliable

Category 1 was introduced to detect changes that were correctly detected but overestimated in the TCDC layer.

An example of the modified TCDC tool of Joanneum Research is provided in Figure 10.

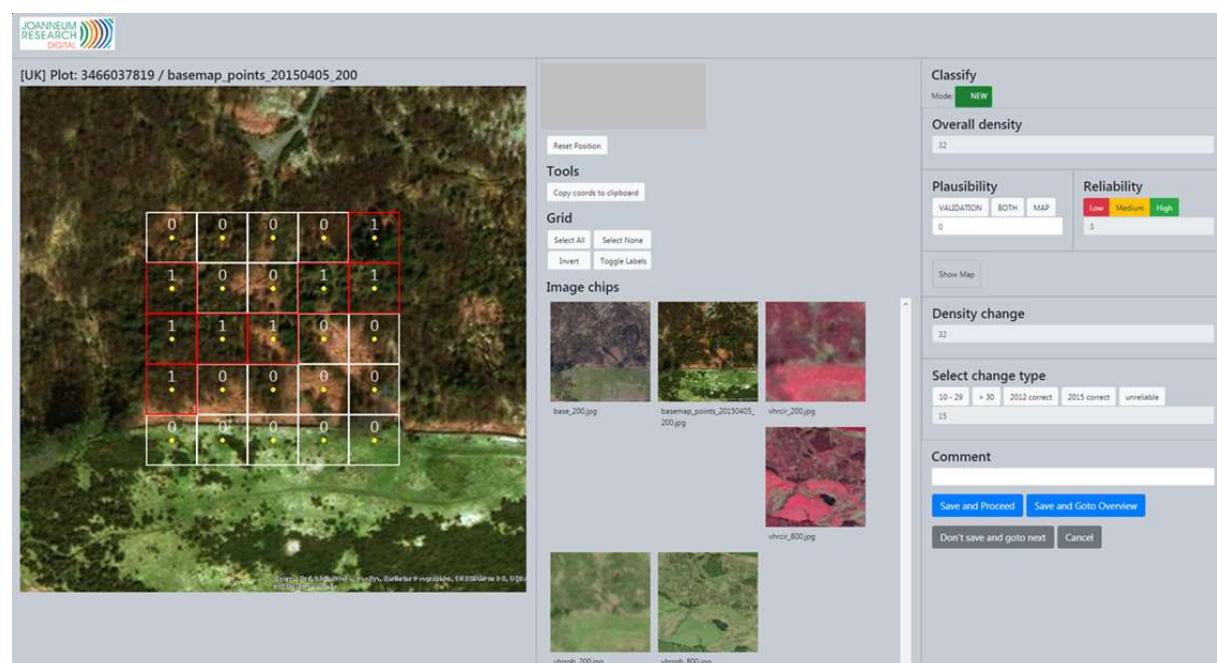


Figure 10: TCDC validation tool

For each of the sampling units, the reliability of the interpretation was assigned by the interpreter. For all sampling units for which the interpreter assigned medium or low reliability the interpretation was checked by a second interpreter. In general, the reliability of the change interpretation is lower than for the status products (TCD, FTY) as reliable reference imagery is needed for two reference times at one plot. The fact, that the production image acquisition dates for the 2015 product were not exactly known to the interpretation team, further reduces the reliability of the change interpretation. Further, the interpretation cycle included internal quality measures to ensure consistent quality during the validation process.

2.4.4. Estimation and analyses procedures

2.4.4.1. Analysis of density values

As described above, density values from the reference data are not directly assessed, but generated from sampled data (SSUs). Therefore, these suffer from sampling error which needs to be considered in the analysis. This makes the use of correlation coefficient difficult to set a suitable threshold above which the correlation is deemed acceptable. If we had a complete information on the cell for our reference data, a reasonable measure of the commission φ and omission ψ errors would be:

$$\varphi = \frac{\sum_i pos(m_i - r_i)}{\sum_i m_i} \quad \psi = \frac{\sum_i pos(r_i - m_i)}{\sum_i r_i} \quad (4)$$

where $pos(x)$ is the positive part, i.e. $pos(x) = x$ if $x > 0$ and $pos(x) = 0$ if $x \leq 0$.

If the map reports a proportion m_i and the reference data give a proportion r_i ,

For each sampling unit of 100 m we have a quantitative value in the map (estimated % in the satellite image classification) and a reference value that is an estimation obtained from a sample of 25 points. The number of forest points that we are using as reference value has a probability distribution due to the within-cell sampling. If the within-sampling is random, the number of points follows a binomial $B(25, p)$. In our case the sampling scheme is systematic, but we use anyhow the binomial as an approximation.

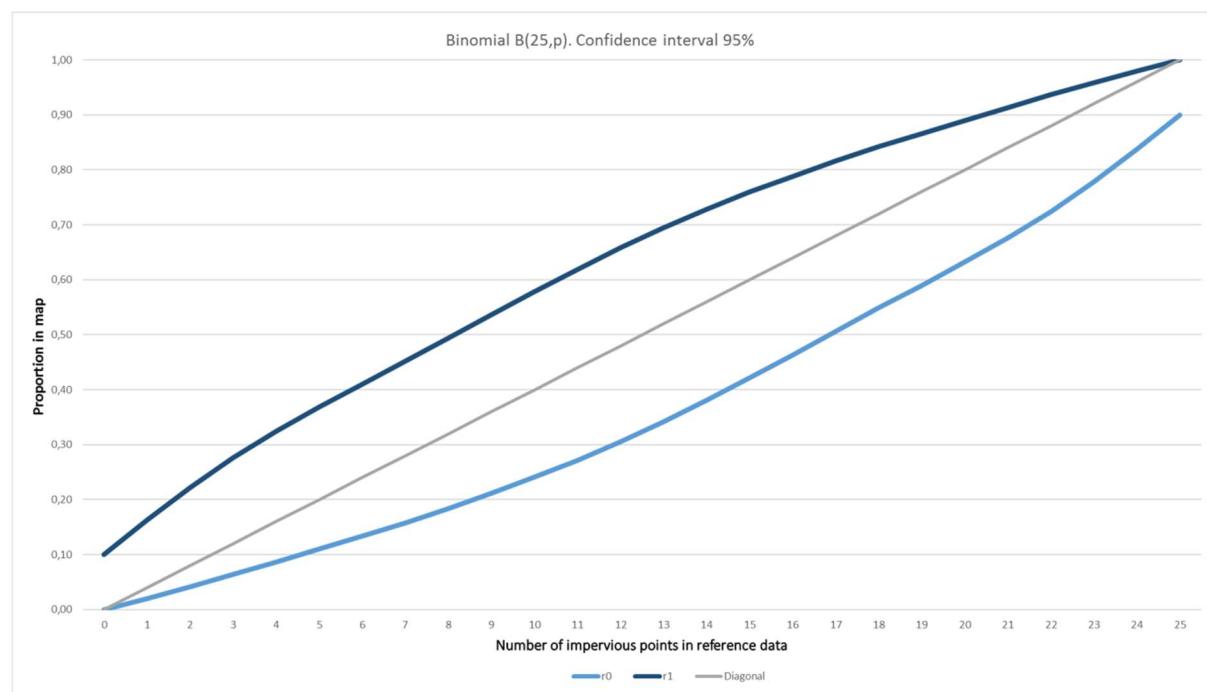


Figure 11. Representation of the behaviour of the 95% confidence interval for a 5x5 SSU grid over the whole range of tree cover density values

Therefore, we cannot say that there is any significant disagreement if m_i lays within (r_{0i}, r_{1i}) a confidence interval corresponding to $B(25, r_i)$. Figure 11 represents the behaviour of the 95% confidence interval for $B(25, r_i)$.

Notice that only for proportions close to 0.5 we can apply the usual Gaussian approximation that leads to an interval approximately $(r_i \pm 2s_i)$, while for proportions close to 0 or to 1 the intervals are strongly asymmetric.

A possible adaptation of the formulas (4) above for the commission φ and omission errors ψ would be:

$$\varphi = \frac{\sum_i pos(m_i - r_{1i})}{\sum_i m_i} \quad \psi = \frac{\sum_i pos(r_{0i} - m_i)}{\sum_i r_i} \quad (5)$$

2.4.4.1. Thematic accuracy

The last step consists in analyzing the samples in order to draw conclusions for the product. This will require applying a threshold to the tree cover density product to convert the continuous density product to a binary mask. For forest, two thresholds of 10% and 30% are usually applied. In addition, the metrics described below are both applicable to status and change layers.

Thematic accuracy should be presented in the form of an error matrix. Unequal sampling intensity resulting from the stratified systematic sampling approach should be accounted for by applying a weight factor (p) to each sample unit based on the ration between the number of samples and the size of the stratum considered:

$$\hat{p}_{ij} = \left(\frac{1}{N}\right) \sum_{x \in (i,j)} \frac{1}{\pi_{uh}^*}$$

Where i and j are the columns and rows in the matrix, N is the total number of possible units (population) and π is the sampling intensity for a given stratum.

Overall accuracy and user and producer accuracy should be computed for all thematic classes and 95% confidence intervals should be calculated for each accuracy.

The standard error of the error rate can be calculated as follows: $\sigma_h = \sqrt{\frac{p_h(1-p_h)}{n_h}}$ where n_h is the sample size for stratum h and p_h is the expected error rate. The standard error is calculated for each stratum and an overall standard error is calculated based on the following formula:

$$\sigma = \sqrt{\sum w_h^2 \cdot \sigma_h^2}$$

In which w_h is the proportion of the total area covered by each stratum. The 95% confidence interval is +/- 1.96. σ .

2.5. Temporal Quality

Temporal quality is evaluated by providing an indication of the closeness of the acquired image data to the reference year, e.g. the percentage area covered outside the accepted reference period as defined in the tender/product specification i.e. 2015 +/- 1-2 year(s).

2.6. Usability

Usability relates to the appropriateness of the metadata description and accompanying documentation to describe the processes and workflows involved in the production of the data. Although it is difficult to describe usability in quantitative terms, it provides a clear evaluation based on objective criteria of any limitation in the intended use of the data.

2.7. INSPIRE compliant metadata

Presence of INSPIRE compliant metadata should be verified.

3. Validation check list

3.1. Tree Cover Density (TCD)

This preliminary validation exercise was performed on the final semantic check report for the full pan-European 100m mosaic integrating some of the comments from the semantic check reports on lot deliveries.

PRODUCT:				HRL Tree Cover Density (TCD)			
VALIDATION LEVEL:				Pan-European			
SERVICE PROVIDER: GAF AG			SERVICE USER: EEA	ISSUE/REVISION:1.0			
VALIDATION DATE: 06/07/2018			REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec			REVIEWED BY: Christophe Sannier	APPROVED BY: Christophe Sannier			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	COMMENTS BY AUDIT TEAM		Draft Audit Conclusion	Final Audit Conclusion
1	Completeness						
1.1	Commission	Rate of excess items	OK				
1.2	Omission	Rate of missing items	OK				
2	Logical consistency						
2.1	Format consistency	File format/readable	OK	GeoTiff Readable in ArcGIS 10.x and QGIS.			

PRODUCT:		HRL Tree Cover Density (TCD)					
VALIDATION LEVEL:		Pan-European					
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0			
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018					
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	Comments by Audit Team		Draft Audit Conclusion	Final Audit Conclusion
2.2	Conceptual consistency	File naming conventions	OK	Corresponds to convention for internal deliveries: THEME_YEAR_RESOLUTION_EXTENT_EPSG_DELIVERY			
2.3		Attributes naming conventions	OK	Value, Count, Class_Name, AREA_KM2, AREA_PERC			
2.4		Attributes types	n/a	n/a			
2.5	Conceptual consistency	Coordinate reference system	OK	European ETRS89 LAEA projection (EPSG 3035)			
2.6		Pixel size and origin	OK	Corresponds to 20m LAEA grid			
2.7		Compliance between 20 m and 100 m Forest type	OK	OK			
2.9		Additional attributes, symbology	OK	Raster value, count, class name, area (in km2), percentage			
2.10	Domaine consistency	Valid Codes	OK	0: all non-tree covered areas 1-100: tree cover density values 254: unclassifiable			

PRODUCT:		HRL Tree Cover Density (TCD)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
3	POSITIONAL ACCURACY					
3.1	Absolute or external accuracy	RMSEP	n/a	This is dependent on the assessment of the CORE001 mosaic.		
3.2	Relative or internal accuracy	RMSEP	n/a	Positional accuracy of TCD/DLT layers was checked against Google Earth imagery and Bing Maps. No large positional error was found.		
4	THEMATIC ACCURACY					
4.1	Classification correctness	Overall accuracy	n/a	Not relevant for this product		
		Min. producer accuracy	OK	See Separate Section 4 below		
4.2		Min. user accuracy	OK	See Separate Section 4 below		

PRODUCT:		HRL Tree Cover Density (TCD)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
4.4		Discrepancies along borderlines	n/a	n/a		
5	TEMPORAL QUALITY					
5.1	Temporal quality	Closeness of the acquired image data to the reference year	OK	The imagery used spans several years (2015 +/- one year)		
6	USABILITY					
6.1	Usability	Usability description	OK	The product is in line with the specification and is based on a clear definition		
7	METADATA					
7.1	INSPIRE compliant metadata	Presence	OK	OK		
7.2		File format	OK	OK		
7.3		File name	OK	OK		

PRODUCT:		HRL Tree Cover Density (TCD)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
7.4		INSPIRE compliance	OK			

3.2. Forest Type (FTY)

This preliminary validation exercise was performed on the final semantic check report for the full pan-European 100m mosaic integrating some of the comments from the semantic check reports on lot deliveries.

PRODUCT:		HRL Forest Type (FTY)					
VALIDATION LEVEL:		Pan-European					
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0			
VALIDATION DATE: 12/07/2018		REVIEW DATE: 12/07/2018					
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY:			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	Comments by Audit Team		Draft Audit Conclusion	Final Audit Conclusion
1	Completeness						
1.1	Commission	Rate of excess items	OK	OK			
1.2	Omission	Rate of missing items	OK	OK			
2	Logical Consistency						
2.1	Format consistency	File format/readable	OK	GeoTiff Readable in ArcGIS 10.x and QGIS			
2.2		File naming conventions	OK	Corresponds to convention for internal deliveries: THEME_YEAR_RESOLUTION_EXTENT_EPSG_DELIVERY			

PRODUCT:		HRL Forest Type (FTY)					
VALIDATION LEVEL:		Pan-European					
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0			
VALIDATION DATE: 12/07/2018		REVIEW DATE: 12/07/2018					
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY:			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	Comments by Audit Team		Draft Audit Conclusion	Final Audit Conclusion
2.3	Conceptual consistency	Attributes naming conventions	OK	OK			
2.4		Attributes types	OK	OK			
2.5	Conceptual consistency	Coordinate reference system	OK	European ETRS89 LAEA projection (EPSG 3035)			
2.6		Pixel size and origin	OK	OK			
2.7		Compliance between 20 m and 100 m Forest type	OK	OK			
2.9		Additional attributes, symbology	OK	OK			
2.10	Domaine consistency	Valid Codes	OK	0: all non-tree covered areas 1: broadleaved trees 2: coniferous trees			
3	POSITIONAL ACCURACY						

PRODUCT:		HRL Forest Type (FTY)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 12/07/2018		REVIEW DATE: 12/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY:		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
3.1	Absolute or external accuracy	RMSEP	n/a	This is dependent on the assessment of the CORE001 mosaic.		
3.2	Relative or internal accuracy	RMSEP	n/a	Positional accuracy of FTY layers was checked against Google Earth imagery. No large positional error was found.		
4	THEMATIC ACCURACY					
4.1	Classification correctness	Overall accuracy	n/a	See Separate Section 4 below		
		Min. producer accuracy	OK NOK	See Separate Section 4 below		
4.2		Min. user accuracy	OK NOK	See Separate Section 4 below		
5	TEMPORAL QUALITY					
5.1	Temporal quality	Closeness of the acquired image data to the reference year	OK	The imagery used spans several years (2015 +/- one year)		
6	USABILITY					

PRODUCT:		HRL Forest Type (FTY)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 12/07/2018		REVIEW DATE: 12/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY:		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
6.1	Usability	Usability description		There seems to be a substantial issue with the definition of the mixed forest class which is the outcome of an aggregation procedure rather than an "mixed" forest class		
7	METADATA					
7.1	INSPIRE compliant metadata	Presence	OK	OK		
7.2		File format	OK	OK		
7.3		File name	OK	OK		
7.4		INSPIRE compliance	OK	OK		

3.3. Tree Cover Density Change (TCDC)

Contrary to TCD / FTY, the preliminary validation exercise and the final semantic check report was not available for the full pan-European 100m mosaic. Nevertheless, some basic verifications have been performed in the validation framework.

PRODUCT:		HRL Tree Cover Density Change (TCDC)					
VALIDATION LEVEL:		Pan-European					
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION: 1.0			
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018					
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	Comments by Audit Team		Draft Audit Conclusion	Final Audit Conclusion
1	Completeness						
1.1	Commission	Rate of excess items	OK				
1.2	Omission	Rate of missing items	OK				
2	Logical Consistency						
2.1	Format consistency	File format/readable	OK	GeoTiff Readable in ArcGIS 10.x and QGIS.			
2.2		File naming conventions	OK	Corresponds to convention for internal deliveries: THEME_YEAR_RESOLUTION_EXTENT_EPSG_DELIVERY			

PRODUCT:		HRL Tree Cover Density Change (TCDC)					
VALIDATION LEVEL:		Pan-European					
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0			
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018					
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier			
No.	Data Quality Sub-	Data Quality Measure	Data Quality Result	Comments by Audit Team		Draft Audit Conclusion	Final Audit Conclusion
2.3	Conceptual consistency	Attributes naming conventions	OK	Value, Count, Class_Name, AREA_KM2, AREA_PERC			
2.4		Attributes types	n/a	n/a			
2.5	Conceptual consistency	Coordinate reference system	OK	European ETRS89 LAEA projection (EPSG 3035)			
2.6		Pixel size and origin	OK	Corresponds to 20m LAEA grid			
2.7		Compliance between 20 m and 100 m Forest type	OK	OK			
2.9		Additional attributes, symbology	OK	Raster value, count, class name, area (in km2), percentage			

PRODUCT:		HRL Tree Cover Density Change (TCDC)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
2.10	Domaine consistency	Valid Codes	OK	100 to -30: decreased tree cover density 0: unchanged areas 30-100: increased tree cover density 254: unclassifiable in any of parent status layers		
3	POSITIONAL ACCURACY					
3.1	Absolute or external accuracy	RMSEP	n/a	This is dependent on the assessment of the CORE001 mosaic.		
3.2	Relative or internal accuracy	RMSEP	n/a	Positional accuracy of TCD/DLT layers was checked against Google Earth imagery and Bing Maps. No large positional error was found.		
4	THEMATIC ACCURACY					
4.1	Classification correctness	Overall accuracy	n/a	Not relevant for this product		
		Min. producer accuracy	OK	See Separate Section 4 below		

PRODUCT:		HRL Tree Cover Density Change (TCDC)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
4.2		Min. user accuracy	OK	See Separate Section 4 below		
4.4		Discrepancies along borderlines	n/a	n/a		
5	TEMPORAL QUALITY					
5.1	Temporal quality	Closeness of the acquired image data to the reference year	OK	The imagery used spans several years (2015 +/- one year)		
6	USABILITY					
6.1	Usability	Usability description	OK	The product is in line with the specification and is based on a clear definition		
7	METADATA					
7.1	INSPIRE compliant	Presence	OK	OK		
7.2		File format	OK	OK		

PRODUCT:		HRL Tree Cover Density Change (TCDC)				
VALIDATION LEVEL:		Pan-European				
SERVICE PROVIDER: GAF AG		SERVICE USER: EEA		ISSUE/REVISION:1.0		
VALIDATION DATE: 06/07/2018		REVIEW DATE: 06/07/2018				
CONDUCTED BY: Alexandre Pennec		REVIEWED BY: Christophe Sannier		APPROVED BY: Christophe Sannier		
No.	DATA QUALITY SUB-	DATA QUALITY MEASURE	DATA QUALITY RESULT	COMMENTS BY AUDIT TEAM	DRAFT AUDIT CONCLUSION	FINAL AUDIT CONCLUSION
7.3	metadata	File name	OK	OK		
7.4		INSPIRE compliance	OK			

4. Thematic accuracy

4.1. Tree Cover Density (TCD)

As indicated in Table 1 and in the Request for Services for this contract, the Tree Cover Density product should be assessed based on a scatterplot as well as applying a threshold to determine its thematic accuracy.

Scatterplots could be constructed with all sample units because of the same sampling intensity for each stratum (Figure 12).

To quantitatively summarise the results displayed in the scatterplots, a linear regression analysis is performed to estimate the relationships between the reference and product information. The analysis produces a coefficient of determination (R^2) which provides information about the goodness of fit of the estimated regression model. Coefficients of determination closer to 1 represent a better fit. In this case as the reference and map information are meant to represent the same information then it is useful to also consider the slope and intercept of the estimated regression model. The slope should therefore approach 1 and the intercept should be close to 0 for the required relations. Deviations from the expected values give an indication of the correspondence of the reference and map data.

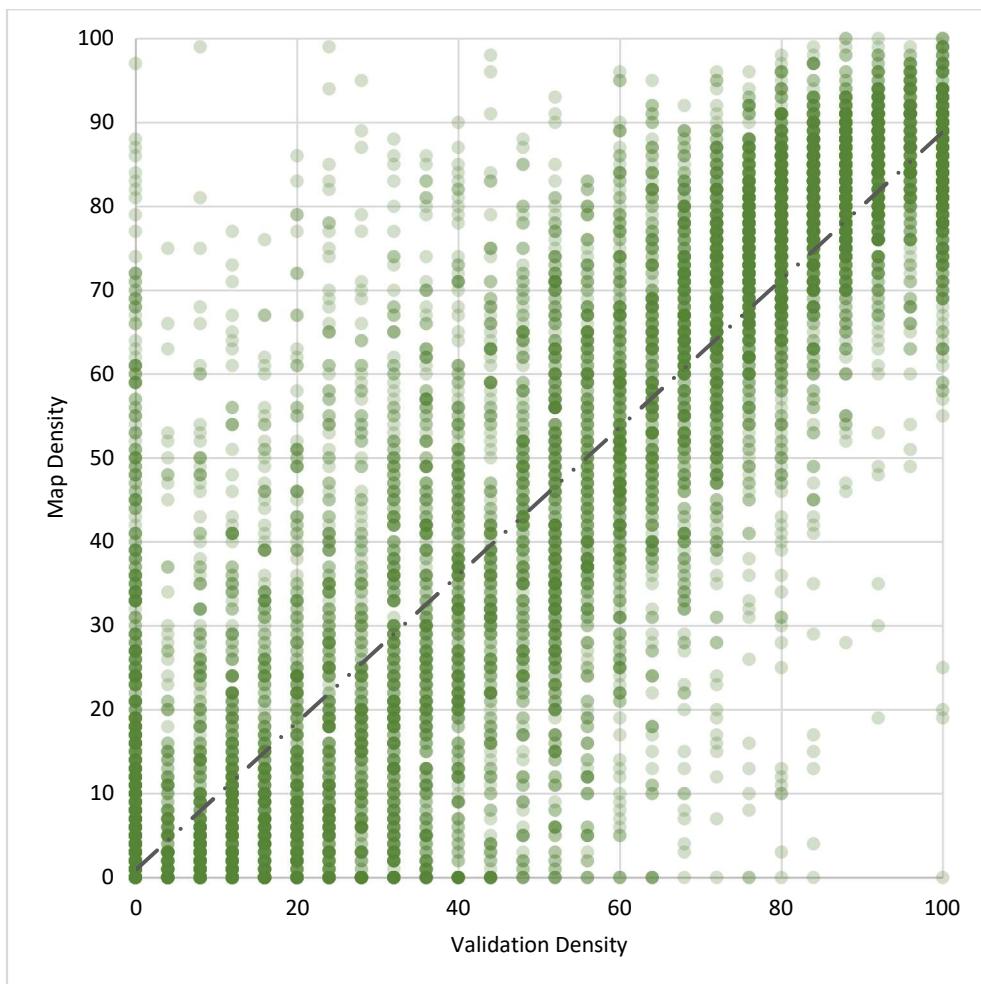


Figure 12: Scatterplot of all TCD sample units darker green indicates a greater number of observations, n=15,051,
 $R^2=0.84$, $\text{Map_Density} = 0.8787 * \text{Validation_Density} + 0.9217$

Figure 12 shows Map density values appear to slightly underestimate actual TCD values at very low tree cover density (0-20%) and very high density (>90%) (with exception of 0% Map Density plots). However, for values close to 100%, it is also possible that these are overestimated in the reference sample due to the sampling

approach (i.e. all SSUs could be labelled as tree covered when the actual tree cover is in fact close to but less than 100%). In addition, there is a not negligible proportion of omission and commission errors which is materialized by values close to 0 and values aligned on the x and y axis. The regression line shown in Figure 12 is strongly influenced by the low TCD values which are not linked to the quality of the TCD calibration but to omission or commission errors. However, it should be stressed that the results obtained are much improved compared to the validation exercise for HRL TCD 2012³

The same approach to Figure 12 was applied for disaggregated geographical units. Detail of regression coefficients as well as the slope and the intercept of the regression are shown in Table 10 for the total European area covered illustrated in Figure 12 as well as production lot, bio-geographical regions and countries and group of countries greater than 90,000km². Corresponding scatterplots are provided in the annexes.

Table 10: Details of TCD regression line parameter and coefficients and for the whole of Europe cover, per lot, bio-geographical regions and country and group of countries greater than 90,000km², n corresponds to the number of observations. Values in green are closest to optimal values (greater than 0.5 for R², close to 1 and 0 for slope and intercept respectively)

	n	R ²	Slope	Intercept
European equal intensity samples	15,051	0.8405	0.8787	0.9217
Alpine (ALP)	1,670	0.8332	0.8919	2.9191
Anatolian (ANA)	1,059	0.6158	0.9071	1.3609
Arctic (ARC)	336	0.5333	0.6284	1.7842
Atlantic (ATL)	2,221	0.8179	0.8392	-0.1051
Black Sea (BLS)	309	0.7550	0.8844	7.9968
Boreal (BOR)	2,328	0.8587	0.9207	-1.0176
Continental (CON)	3,582	0.8860	0.8851	-0.4069
Macaronesia (MAC)	25	0.8317	0.9311	1.6672
Mediterranean (MED)	3,053	0.7318	0.8330	2.6890
Pannonian (PAN)	373	0.8939	0.8884	-0.5606
Steppic (STE)	95	0.7284	0.8646	0.7868
AL+ME+MK+RS+XK	406	0.7570	0.8227	0.9424
AT + CH + LI	322	0.8740	0.9780	0.9642
BA + HR + SI	324	0.8381	0.8457	3.6551
BE + LU+ NL + DK	288	0.8586	0.8344	-1.9662
BG	282	0.8758	0.8859	-0.9186
CZ + SK	323	0.9358	0.9749	-2.8284
DE	939	0.9215	0.9531	-1.0350
EE + LT + LV	449	0.8790	0.8958	0.4239
EL	342	0.7415	0.8626	-0.5168
ES	1,305	0.7300	0.8719	1.5603
FI	872	0.8385	0.8626	0.7699
FR	1,402	0.8520	0.8197	1.1329
HU	237	0.8785	0.8921	-0.5518
IE + UK	804	0.7932	0.8175	-0.5079
IS	325	0.5314	0.6271	1.8532
IT	773	0.7836	0.8668	3.2402
NO	853	0.8177	0.9204	1.7893
PL	810	0.8901	0.8585	1.6097
PT	233	0.6566	0.8406	1.6119
RO	600	0.9077	0.8809	-1.3879
SE	1,166	0.8389	0.9352	-0.8252
TR	1,996	0.7612	0.8691	2.6184

³ <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

All regression coefficients are greater than 0.5 and mainly greater than 0.8. The lowest values are related to regions or countries with very low tree cover or complex landscapes (e.g. Arctic bio-geographical region with Iceland, Mediterranean or Anatolian bio-geographical regions with Portugal, Spain, Greece, Turkey, Italy and the Balkan countries) with a R^2 close to 0.5-0.75. Regression coefficients are generally relatively higher for countries or regions with high tree cover such as Alpine, Boreal or Continental Europe with a R^2 above 0.8. At country level, the highest R^2 are related to eastern countries such as Romania, Poland, Republic Czech and Slovakia with a R^2 greater than 0.9. The central and western countries show a high R^2 greater than 0.8. Iceland shows the lowest R^2 close to 0.5 which is consistent with the result at bio-geographical regions level.

Regression slopes are consistently close to 1 with very few variability (no matter the country or the bio-geographical region) except for the Arctic bio-geographical region (mainly related to Iceland). All slope values are smaller than 1,0 which is mainly a result of commission errors (TCD detected in non-tree covered areas) and a slight underestimation of TCD values at very high tree cover density (>90). The intercept parameter shows good values close to 0 with some of them slightly over 1 which is a result of the commission errors (positive intercept) or omission errors (negative intercept) for the associated bio-geographical region or countries. While optimal value should be close to 0 with a slope close to 1, some results present an intercept around/above 3. The greatest values are related to the Black Sea, Alpine and Mediterranean bio-geographical regions well-known to be especially prone to omission and commissions errors due to a very complex landscape (Macchia, garrigue, alpine shrubs) that are confused with forests. The Atlantic, Continental, Steppic and Pannonic regions show the lowest values close to 0. At country level, the trend is similar with highest values for countries mainly associated to Black Sea, Alpine and Mediterranean bio-geographical region (e.g. Italy, Turkey, Republic Czech and Slovakia, Croatia, Slovenia and Bosnia-Herzegovina) and values close to 0 for countries mainly associated to Continental, Steppic and Pannonic bio-geographical regions (e.g. Austria, Switzerland, Liechtenstein Bulgaria, Hungary, Ireland or United-Kingdom).

TCD values were regrouped according to the thresholds as detailed in section 1.2.1 to perform a thematic accuracy assessment:

- TCD values $\geq 1\%$
- TCD values $\geq 10\%$
- TCD values $\geq 30\%$

The results at European level are shown in Table 11. Accuracy figures were calculated following the procedure described in 0 taking the weight of Table 7 into account. At European level, for both blind and plausibility interpretation, the accuracy meets the minimum requirement (85%) for both user and producer accuracies and the target accuracy (90%) is also met for all the user accuracies and the producer accuracy is also met with a 30% threshold for the plausibility analysis. It should be noted that the quality of the Tree Cover mask (threshold $> 1\%$) is also very good with a producer accuracy close to 90% and a user accuracy exceeding 90% for both the blind and plausibility approaches.

Table 11: TCD product thematic accuracy results for Tree Cover (TC) class for the total European area covered. Values in green indicate accuracies greater than the 85% threshold, yellow greater than 80% and red less than 80% considering the 95% CI (Prod. = Producer)

		Blind Interpretation				Plausibility Analysis			
		Prod TC	95% CI	User TC	95% CI	Prod TC	95% CI	User TC	95% CI
European All Samples	TCD>1%	88,9%	0,3%	92,0%	0,3%	89,0%	0,3%	92,4%	0,3%
	TCD>10%	85,3%	0,4%	93,1%	0,3%	85,6%	0,4%	93,6%	0,3%
	TCD>30%	85,7%	0,4%	91,5%	0,3%	89,7%	0,4%	93,6%	0,3%

The width of the 95% confidence intervals depends on (i) the number of sample units selected, (ii) the accuracy reached and (iii) the efficiency of the stratification. The stratification appears to be very efficient with 95% CI less than 1% achieved at pan-European for assessing commission and omission errors. Indeed, based on the

recommendations made in the Delivery report for the 2012 Forest products⁴, the stratification was simplified to reach this efficiency. There is more variability at bio-geographical region and country/group of countries level, but it is less than 5% with only a few exceptions. This suggests that the stratification is efficiency at disaggregated levels contrary to previous Specific Contracts resulting from the adaptation of the stratification strategy.

The results at biogeographical regions and countries/groups of countries are shown in Table 12. At biogeographical regions, for the plausibility analysis, the weakest results are obtained for the Artic, Anatolian, Mediterranean, Pannonic and, more surprisingly, Atlantic regions with user and producer accuracy mostly under the 85% requirements. If the low results were expected for biogeographical region such as Anatolian, Mediterranean, Pannonic characterized with very complex landscape (Macchia, garrigue, alpine shrubs) or Artic regions with very few forests, the results are very surprising for the Atlantic regions where the producer accuracy is very low suggesting a high amount of omission errors. Iceland is the only country with both user and producer accuracies under the target thresholds. The best results are obtained for the Macaronesia, Boreal, Continental and Black Sea regions for which the accuracies meet the minimum requirements of 85%. At country level, the trend is similar with weakest results for countries mainly associated to Artic, Anatolian, Mediterranean, Pannonic and Atlantic bio-geographical region (e.g. Italy, Turkey, Greece, Portugal, Iceland and especially surprising United-Kingdom and Ireland) and the greatest values for countries mainly associated to Macaronesia, Atlantic, Boreal, Continental and Black Sea regions (e.g. Austria, Switzerland and Liechtenstein, Bulgaria, Republic Czech and Slovakia, Germany, Leetonia, Lithuania and Latvia, Finland, Norway, Sweden, Poland and Romania). United-Kingdom and Ireland, Belgium, Luxembourg, Netherlands and Denmark show unexpected very high amount of omission errors.

⁴ See <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

Table 12: TCD product thematic accuracy results for Tree Cover (TC) for bio-geographical regions. Values in green indicate accuracies greater than the 85% threshold

		Blind Interpretation				Plausibility Analysis			
		Prod TC	95% CI	User TC	95% CI	Prod TC	95% CI	User TC	95% CI
ALP	TCD>1%	92,7%	0,8%	91,4%	1,1%	92,8%	0,8%	91,4%	1,1%
	TCD>10%	90,7%	1,0%	91,6%	1,0%	91,3%	1,0%	91,6%	1,0%
	TCD>30%	88,2%	1,2%	90,8%	1,1%	92,3%	1,0%	92,2%	1,0%
ANA	TCD>1%	84,7%	1,9%	73,4%	1,2%	84,8%	1,9%	73,9%	1,2%
	TCD>10%	77,5%	1,9%	75,9%	1,1%	78,8%	1,8%	76,6%	1,1%
	TCD>30%	72,9%	1,3%	58,0%	1,3%	82,1%	1,2%	62,5%	1,3%
ARC	TCD>1%	34,0%	0,0%	66,7%	0,1%	35,8%	0,0%	72,0%	0,1%
	TCD>10%	72,9%	0,1%	71,4%	0,1%	78,0%	0,1%	79,6%	0,1%
	TCD>30%	51,4%	0,1%	58,1%	0,1%	66,7%	0,1%	77,4%	0,1%
ATL	TCD>1%	80,8%	1,2%	87,1%	0,9%	80,9%	1,2%	87,4%	0,9%
	TCD>10%	73,7%	1,4%	92,1%	0,7%	73,9%	1,4%	92,4%	0,7%
	TCD>30%	77,8%	1,2%	90,7%	0,8%	83,2%	1,1%	92,9%	0,7%
BLS	TCD>1%	93,7%	1,4%	91,9%	2,7%	93,7%	1,4%	92,3%	2,6%
	TCD>10%	92,3%	2,1%	93,2%	2,4%	92,3%	2,0%	93,8%	2,4%
	TCD>30%	94,2%	2,2%	85,8%	3,4%	94,3%	2,2%	88,2%	3,1%
BOR	TCD>1%	95,5%	0,4%	97,3%	0,6%	95,6%	0,4%	97,5%	0,6%
	TCD>10%	92,5%	0,9%	97,9%	0,5%	92,8%	0,8%	98,1%	0,5%
	TCD>30%	89,2%	1,1%	97,7%	0,5%	91,9%	1,0%	98,5%	0,4%
CON	TCD>1%	86,3%	0,8%	93,3%	0,6%	86,4%	0,8%	93,7%	0,6%
	TCD>10%	86,0%	0,8%	95,0%	0,5%	86,3%	0,8%	95,4%	0,5%
	TCD>30%	87,1%	0,8%	95,7%	0,5%	90,0%	0,7%	96,8%	0,4%
MAC	TCD>1%	76,9%	13,7%	100,0%	0,0%	76,9%	13,7%	100,0%	0,0%
	TCD>10%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%
	TCD>30%	83,3%	9,2%	83,3%	9,2%	83,3%	9,2%	83,3%	9,2%
MED	TCD>1%	88,5%	0,7%	90,2%	0,8%	88,7%	0,7%	91,0%	0,8%
	TCD>10%	80,2%	1,1%	88,6%	0,9%	80,7%	1,1%	89,8%	0,8%
	TCD>30%	81,2%	1,1%	82,5%	1,0%	87,8%	0,9%	87,7%	0,9%
PAN	TCD>1%	81,5%	3,3%	89,4%	1,7%	81,6%	3,3%	90,3%	1,6%
	TCD>10%	79,0%	2,9%	93,3%	1,4%	80,0%	2,8%	94,4%	1,3%
	TCD>30%	83,3%	2,1%	95,6%	1,1%	89,2%	1,7%	97,1%	0,9%
STE	TCD>1%	72,2%	8,6%	86,7%	2,3%	72,2%	8,6%	86,7%	2,3%
	TCD>10%	81,8%	2,6%	90,0%	2,0%	83,3%	2,5%	100,0%	0,0%
	TCD>30%	85,7%	2,3%	75,0%	2,9%	87,5%	2,2%	87,5%	2,2%

Table 13: TCD product thematic accuracy results for Tree Cover (TC) class for countries and group of countries greater than 90,000km². Values in green indicate accuracies greater than the 85% threshold, yellow greater than 80% and red less than 80% considering 95% CI

		Blind Interpretation				Plausibility Analysis			
		Prod TC	95% CI	User TC	95% CI	Prod TC	95% CI	User TC	95% CI
AL+ME+MK+RS+XK	TCD>1%	91,9%	1,7%	93,3%	1,9%	92,3%	1,7%	93,7%	1,8%
	TCD>10%	86,4%	2,5%	94,3%	1,7%	87,2%	2,4%	94,8%	1,7%
	TCD>30%	82,4%	2,9%	90,6%	2,2%	88,4%	2,4%	92,8%	1,9%
AT + CH + LI	TCD>1%	95,6%	1,5%	95,6%	1,7%	95,6%	1,5%	96,1%	1,6%
	TCD>10%	93,8%	1,9%	97,8%	1,2%	93,8%	1,9%	97,8%	1,2%
	TCD>30%	86,9%	2,8%	95,4%	1,7%	91,4%	2,3%	96,7%	1,5%
BA + HR + SI	TCD>1%	87,9%	1,8%	93,5%	2,3%	87,9%	1,8%	93,5%	2,3%
	TCD>10%	88,4%	2,4%	91,8%	2,6%	88,8%	2,3%	91,8%	2,6%
	TCD>30%	94,4%	2,2%	91,8%	2,6%	96,6%	1,7%	92,3%	2,5%
BE + LU+ NL + DK	TCD>1%	65,9%	4,2%	86,7%	2,5%	65,9%	4,2%	86,7%	2,5%
	TCD>10%	65,1%	4,5%	97,3%	1,2%	65,1%	4,5%	97,3%	1,2%
	TCD>30%	74,2%	3,6%	96,1%	1,4%	78,1%	3,4%	98,0%	1,0%
BG	TCD>1%	90,1%	2,3%	94,2%	2,1%	91,3%	2,2%	94,8%	2,0%
	TCD>10%	87,4%	2,9%	95,7%	1,8%	89,3%	2,7%	96,4%	1,7%
	TCD>30%	84,1%	3,3%	96,7%	1,6%	92,2%	2,4%	98,3%	1,1%
CZ + SK	TCD>1%	87,1%	2,3%	97,2%	1,4%	87,1%	2,3%	97,2%	1,4%
	TCD>10%	82,4%	3,1%	98,7%	1,0%	82,8%	3,1%	98,7%	1,0%
	TCD>30%	87,4%	2,8%	97,8%	1,2%	91,0%	2,4%	97,8%	1,2%
DE	TCD>1%	85,0%	1,6%	94,1%	1,1%	85,1%	1,6%	94,3%	1,1%
	TCD>10%	85,1%	1,7%	95,6%	1,0%	85,3%	1,7%	95,8%	0,9%
	TCD>30%	90,7%	1,4%	97,4%	0,8%	92,5%	1,2%	98,0%	0,7%
EE + LT + LV	TCD>1%	94,9%	1,2%	91,6%	2,0%	94,9%	1,2%	92,4%	2,0%
	TCD>10%	90,6%	2,0%	96,5%	1,4%	90,7%	2,0%	97,4%	1,2%
	TCD>30%	90,7%	2,1%	97,0%	1,3%	93,0%	1,9%	98,5%	0,9%
EL	TCD>1%	88,3%	2,3%	95,9%	1,6%	88,3%	2,3%	95,9%	1,6%
	TCD>10%	78,6%	3,3%	92,9%	2,1%	78,6%	3,3%	92,9%	2,1%
	TCD>30%	72,9%	3,6%	90,4%	2,4%	81,6%	3,1%	92,0%	2,2%
ES	TCD>1%	87,0%	1,2%	92,2%	1,1%	87,0%	1,2%	92,5%	1,1%
	TCD>10%	78,3%	1,7%	91,0%	1,2%	78,5%	1,7%	91,3%	1,1%
	TCD>30%	80,3%	1,6%	81,7%	1,6%	86,2%	1,4%	87,1%	1,4%
FI	TCD>1%	96,3%	0,5%	97,1%	1,0%	96,3%	0,5%	97,4%	1,0%
	TCD>10%	94,5%	1,2%	97,2%	1,0%	94,6%	1,2%	97,5%	0,9%
	TCD>30%	89,5%	1,8%	97,2%	1,0%	91,8%	1,6%	97,9%	0,9%
FR	TCD>1%	89,6%	1,1%	86,4%	1,3%	89,8%	1,1%	87,2%	1,3%
	TCD>10%	82,5%	1,5%	90,8%	1,1%	82,8%	1,5%	91,8%	1,0%
	TCD>30%	86,0%	1,3%	92,9%	1,0%	89,0%	1,2%	95,3%	0,8%
HU	TCD>1%	82,4%	3,9%	90,4%	2,3%	82,6%	3,9%	91,6%	2,2%
	TCD>10%	78,2%	3,8%	93,8%	1,9%	79,5%	3,7%	95,4%	1,6%
	TCD>30%	84,2%	2,8%	96,0%	1,5%	90,7%	2,2%	98,0%	1,1%
IE + UK	TCD>1%	72,2%	2,6%	85,8%	1,3%	72,3%	2,6%	86,2%	1,2%
	TCD>10%	63,0%	2,8%	90,3%	1,1%	63,0%	2,8%	90,3%	1,1%
	TCD>30%	72,3%	1,9%	87,2%	1,2%	79,7%	1,7%	90,6%	1,1%
IS	TCD>1%	34,0%	0,0%	66,7%	0,1%	35,8%	0,0%	72,0%	0,1%
	TCD>10%	72,9%	0,1%	71,4%	0,1%	78,0%	0,1%	79,6%	0,1%
	TCD>30%	51,4%	0,1%	58,1%	0,1%	66,7%	0,1%	77,4%	0,1%
IT	TCD>1%	84,1%	1,6%	91,7%	1,5%	84,3%	1,6%	92,1%	1,5%
	TCD>10%	86,7%	1,7%	88,1%	1,8%	87,2%	1,7%	89,1%	1,7%
	TCD>30%	85,8%	1,9%	87,6%	1,8%	90,4%	1,6%	91,4%	1,6%
NO	TCD>1%	89,2%	1,4%	90,0%	1,5%	89,2%	1,4%	90,2%	1,5%
	TCD>10%	87,7%	1,6%	88,8%	1,5%	88,0%	1,6%	89,1%	1,5%

		Blind Interpretation				Plausibility Analysis			
		Prod TC	95% CI	User TC	95% CI	Prod TC	95% CI	User TC	95% CI
PL	TCD>30%	82,8%	1,9%	88,3%	1,6%	86,9%	1,7%	89,3%	1,5%
	TCD>1%	91,8%	1,3%	88,9%	1,5%	91,9%	1,3%	89,4%	1,5%
	TCD>10%	92,7%	1,3%	93,4%	1,2%	92,7%	1,3%	94,0%	1,2%
PT	TCD>30%	90,0%	1,5%	93,3%	1,2%	91,0%	1,4%	95,0%	1,1%
	TCD>1%	85,8%	2,8%	95,0%	2,2%	85,9%	2,8%	95,7%	2,1%
	TCD>10%	76,8%	4,1%	92,2%	2,7%	77,5%	4,1%	93,0%	2,6%
RO	TCD>30%	75,0%	4,4%	80,0%	4,1%	84,8%	3,5%	89,3%	3,1%
	TCD>1%	82,6%	2,2%	96,0%	1,1%	82,6%	2,2%	96,0%	1,1%
	TCD>10%	85,1%	2,1%	97,6%	0,8%	85,4%	2,1%	98,0%	0,8%
SE	TCD>30%	87,4%	1,9%	97,7%	0,8%	91,3%	1,6%	98,6%	0,6%
	TCD>1%	95,3%	0,6%	97,1%	0,8%	95,5%	0,6%	97,1%	0,8%
	TCD>10%	90,3%	1,4%	97,3%	0,8%	91,0%	1,3%	97,3%	0,8%
TR	TCD>30%	86,8%	1,7%	95,6%	1,0%	91,1%	1,4%	96,5%	0,9%
	TCD>1%	90,9%	1,0%	84,6%	1,0%	91,0%	1,0%	85,8%	1,0%
	TCD>10%	83,8%	1,2%	86,1%	1,0%	84,4%	1,2%	87,3%	0,9%
	TCD>30%	84,2%	1,1%	78,6%	1,1%	88,6%	0,9%	83,0%	1,0%

4.2. Forest Type (FTY)

Thematic classification accuracy results for FTY are shown in Table 14 below. Accuracy figures were calculated following the procedure described in 0 taking the weight of Table 7 into account.

At pan-European level, it is noticeable that all forest user and producer accuracy values are lower than the minimum accuracy threshold of 85% for the blind interpretation and most of them are lower than these requirements for the plausibility analysis (except the producer accuracy for the Broadleaved class and the user accuracy for the Coniferous class).

At biogeographical regions level, the Anatolian, Arctic, Atlantic, Black Sea, Mediterranean and Steppic regions show very low results under the requirements for both analyses. The best results are obtained for Continental and Pannonic regions for which most of the accuracies are greater than the minimum accuracy thresholds of 85% for the plausibility analysis. At country level, Republic Czech and Slovakia, Leetonia, Lithuania and Latvia, Spain, France, Iceland, Italia, Norway, Portugal and Turkey show as expected the lowest results since these countries are associated to the biogeographical regions with the lower accuracies. The better results are obtained for Greece, Hungary and Romania with accuracy figure greater than the minimum requirements of 85%.

As previously for the First and Second Specific Contracts⁵, the lower results are obtained for the mixed forest class at pan-European level and disaggregated levels with both user and producer accuracies that don't meet the target requirements for nearly all of them (blind and plausibility analysis). The analysis shows very high amount of omission and commission errors for the mixed forest class. The coniferous forest class shows the better results with a greater balance between the user and the producer accuracies that meet the minimum accuracy requirement (85%) and the target accuracy (90%) for most of them in a plausibility approach (very few omission or commissions errors). The broadleaved forest class shows intermediate results with better producer accuracies mostly greater than the target requirements than user accuracies lower than the minimum thresholds.

⁵ See <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

Table 14: FTY product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km² and per thematic classes: Non-Forest (NF), Broadleaved (B), Coniferous (C) and mixed (M). Values in green indicate accuracies greater than the 85% threshold, n corresponds to the number of observations

	Blind Interpretation												Plausibility Analysis													
	Overall	Prod B	CI 95%	Prod C	CI 95%	Prod M	CI 95%	User B	CI 95%	User C	CI 95%	User M	CI 95%	Overall	Prod B	CI 95%	Prod C	CI 95%	Prod M	CI 95%	User B	CI 95%	User C	CI 95%	User M	CI 95%
EEA39	87.1%	81.2%	0,5%	78,9%	0,5%	53,7%	0,6%	69,7%	0,5%	84,2%	0,4%	62,0%	0,6%	89.7%	85,8%	0,4%	82,6%	0,4%	65,1%	0,6%	75,1%	0,5%	88,4%	0,4%	71,9%	0,5%
Alpine	84.7%	82,7%	1,4%	81,0%	1,5%	54,0%	1,9%	69,2%	1,7%	82,6%	1,4%	61,5%	1,8%	87,2%	85,5%	1,3%	83,7%	1,4%	65,6%	1,8%	73,9%	1,6%	87,0%	1,3%	70,5%	1,7%
Anatolian	94.3%	72,5%	1,2%	75,0%	1,2%	100,0%	0,0%	46,0%	1,3%	71,4%	1,2%	11,1%	0,8%	94,9%	79,5%	1,1%	75,0%	1,2%	100,0%	0,0%	49,2%	1,3%	71,4%	1,2%	22,2%	1,1%
Arctic	99.7%	8,3%	0,0%	62,5%	0,1%	0,0%	0,0%	25,0%	0,1%	26,3%	0,1%	0,0%	0,0%	99,8%	32,0%	0,1%	70,0%	0,1%	64,1%	1,3%	100,0%	0,0%	36,8%	0,1%		
Atlantic	90,6%	73,7%	1,3%	69,6%	1,3%	51,7%	1,3%	75,4%	1,2%	70,8%	1,2%	54,1%	1,3%	92,3%	78,7%	1,2%	74,8%	1,2%	37,0%	4,7%	80,1%	1,1%	76,1%	1,1%	64,1%	1,3%
Black Sea	79,3%	84,9%	3,5%	84,6%	3,5%	28,6%	4,4%	65,3%	4,6%	71,7%	4,4%	53,3%	4,9%	81,6%	86,5%	3,3%	90,0%	2,9%	70,3%	1,7%	67,4%	4,6%	78,3%	4,0%	37,0%	4,7%
Boreal	82,3%	84,8%	1,3%	81,9%	1,4%	61,2%	1,8%	57,7%	1,8%	88,3%	1,2%	74,7%	1,6%	86,1%	89,5%	1,1%	84,9%	1,3%	56,8%	1,2%	63,5%	1,8%	92,8%	0,9%	70,3%	1,7%
Continental	89,6%	85,9%	0,8%	80,2%	1,0%	48,2%	1,2%	76,9%	1,0%	89,2%	0,8%	66,5%	1,1%	91,6%	88,9%	0,8%	83,5%	0,9%			81,5%	0,9%	90,5%	0,7%	56,8%	1,2%
Macaronesia	96,0%	100,0%	0,0%	100,0%	0,0%			75,0%	10,7%	100,0%	0,0%			100,0%	100,0%	0,0%	100,0%	0,0%			100,0%	0,0%				
Mediterranean	82,4%	76,2%	1,2%	72,0%	1,2%	40,8%	1,4%	66,0%	1,3%	78,9%	1,1%	31,1%	1,3%	86,7%	83,9%	1,0%	78,2%	1,1%	80,0%	2,2%	73,5%	1,2%	84,5%	1,0%	70,0%	1,3%
Pannonian	96,5%	89,5%	1,7%	66,7%	2,6%	75,0%	2,4%	89,5%	1,7%	100,0%	0,0%	60,0%	2,7%	97,1%	91,2%	1,6%	66,7%	2,6%			91,2%	1,6%	100,0%	0,0%	80,0%	2,2%
Steppic	97,9%	80,0%	2,7%					80,0%	2,7%	0,0%	0,0%			97,9%	80,0%	2,7%			0,0%	0,0%	80,0%	2,7%	0,0%	0,0%		
AL+ME+MK+RS+XK	86,0%	79,1%	3,1%	84,6%	2,7%	62,5%	3,6%	85,2%	2,7%	78,6%	3,1%	55,6%	3,7%	86,9%	81,2%	2,9%	84,6%	2,7%	62,5%	3,6%	85,2%	2,7%	78,6%	3,1%	55,6%	3,7%
AT + CH + LI	87,9%	77,4%	3,4%	92,9%	2,1%	66,7%	3,9%	61,5%	4,0%	90,3%	2,4%	68,8%	3,8%	90,1%	83,9%	3,0%	93,1%	2,1%	75,0%	3,6%	66,7%	3,9%	93,1%	2,1%	75,0%	3,6%
BA + HR + SI	87,7%	92,0%	2,6%	83,3%	3,5%	61,5%	4,6%	85,1%	3,4%	76,9%	4,0%	64,0%	4,6%	89,8%	92,9%	2,4%	87,5%	3,1%	71,4%	4,3%	86,8%	3,2%	80,8%	3,8%	80,0%	3,8%
BE + LU + NL + DK	93,4%	84,4%	2,9%	75,0%	3,2%	27,3%	3,3%	81,8%	2,9%	60,0%	3,6%	60,0%	3,6%	95,1%	93,1%	2,1%	88,9%	2,3%	33,3%	3,5%	81,8%	2,9%	80,0%	3,0%	80,0%	3,0%
BG	92,2%	91,7%	2,4%	95,2%	1,9%	46,2%	4,4%	87,5%	2,9%	90,9%	2,6%	100,0%	0,0%	94,7%	94,1%	2,1%	95,5%	1,9%	66,7%	4,2%	90,9%	2,6%	95,5%	1,9%	100,0%	0,0%
CZ + SK	87,0%	96,1%	1,6%	64,7%	4,1%	34,8%	4,0%	72,1%	3,8%	91,7%	2,3%	33,3%	4,0%	87,9%	91,2%	2,4%	69,4%	4,0%	50,0%	4,2%	76,5%	3,6%	94,4%	1,9%	45,8%	4,2%
DE	91,3%	80,3%	1,9%	85,8%	1,6%	60,0%	2,3%	75,4%	2,0%	90,1%	1,4%	79,2%	1,9%	93,2%	83,7%	1,7%	86,8%	1,6%	69,4%	2,2%	83,1%	1,8%	92,6%	1,2%	81,1%	1,8%
EE + LT + LV	87,7%	85,9%	2,6%	73,2%	3,3%	67,5%	3,5%	80,2%	2,9%	88,1%	2,4%	60,0%	3,6%	88,4%	89,0%	2,3%	72,6%	3,3%	69,2%	3,4%	80,2%	2,9%	89,8%	2,2%	60,0%	3,6%
EL	83,9%	77,3%	3,4%	69,2%	3,7%	33,3%	3,8%	78,1%	3,3%	62,1%	3,9%	22,2%	3,4%	89,5%	83,8%	3,0%	77,4%	3,4%	100,0%	0,0%	86,5%	2,8%	82,8%	3,1%	55,6%	4,0%
ES	83,4%	70,6%	1,9%	65,8%	2,0%	54,8%	2,1%	70,3%	1,9%	78,7%	1,7%	34,3%	1,9%	88,7%	82,1%	1,6%	73,9%	1,8%	83,0%	1,5%	78,7%	1,7%	82,7%	1,5%	58,2%	2,0%
FI	77,6%	78,8%	2,4%	80,3%	2,4%	53,2%	3,0%	51,0%	3,0%	86,8%	2,1%	73,0%	2,7%	82,7%	83,8%	2,1%	83,4%	2,3%	63,0%	2,9%	60,8%	3,0%	91,5%	1,7%	75,9%	2,6%
FR	88,7%	87,1%	1,3%	71,6%	1,7%	40,4%	1,9%	74,9%	1,6%	73,8%	1,7%	57,1%	1,9%	90,1%	88,7%	1,2%	73,9%	1,7%	47,7%	1,9%	77,7%	1,6%	78,5%	1,6%	66,7%	1,8%
HU	95,4%	87,5%	2,6%	100,0%	0,0%	75,0%	3,4%	85,4%	2,7%	100,0%	0,0%	75,0%	3,4%	96,6%	92,3%	2,1%	100,0%	0,0%	80,0%	3,1%	87,8%	2,5%	100,0%	0,0%	100,0%	0,0%
IE + UK	95,6%	64,3%	1,9%	78,0%	1,5%	92,9%	0,9%	75,0%	1,6%	100,0%	0,0%	59,1%	1,8%	95,9%	65,1%	1,9%	80,0%	1,4%	93,3%	0,9%	77,8%	1,5%	100,0%	0,0%	63,6%	1,7%
IS	99,7%	8,3%	0,0%	62,5%	0,1%	0,0%	0,0%	25,0%	0,1%	26,3%	0,1%	0,0%	0,0%	99,8%	32,0%	0,1%	70,0%	0,1%			100,0%	0,0%	36,8%	0,1%	0,0%	0,0%
IT	81,8%	84,9%	2,0%	72,2%	2,5%	22,5%	2,3%	61,8%	2,7%	70,3%	2,6%	39,1%	2,7%	86,7%	91,3%	1,6%	81,6%	2,2%	47,1%	2,8%	70,5%	2,5%	83,8%	2,1%	69,6%	2,6%
NO	79,8%	57,1%	2,7%	61,8%	2,5%	43,2%	2,4%	48,7%	2,4%	61,2%	2,4%	56,9%	2,4%	86,4%	69,7%	2,4%	73,6%	2,2%	66,2%	2,3%	66,1%	2,3%	77,9%	2,0		

However, most of the confusion is between the forest classes. This is illustrated in Table 15 which shows the thematic accuracy results with the three forest classes regrouped in one unique forest class. At European level, accuracies are greater than 90%. This is slightly surprising considering that the TCD layer exhibits a higher user accuracy compared to producer accuracy. At biogeographical region and country or group of country level, a similar trend is observed with a few exceptions that there is a general tendency to over classify forest resulting in a relatively greater level of commission errors.

Table 15: FTY product thematic accuracy results overall, per bio-geographical region and per country or group of countries greater than 90,000km² and per thematic classes: Non-Forest (NF) and regrouped Forest (F) classes. Values in green indicate accuracies greater than the 85% threshold, n corresponds to the number of observations

	n PSU	Blind Interpretation				Plausibility Analysis			
		Prod F	CI 95%	User F	CI 95%	Prod F	CI 95%	User F	CI 95%
Europe (Part)	15,051	90,4%	0,3%	88,7%	0,4%	92,0%	0,3%	90,2%	0,3%
Alpine	1,670	92,4%	1,0%	87,8%	1,2%	92,9%	0,9%	89,1%	1,2%
Anatolian	1,059	80,3%	1,1%	52,7%	1,3%	85,2%	0,9%	55,9%	1,3%
Arctic	336	54,5%	0,1%	60,0%	0,1%	68,6%	0,1%	80,0%	0,1%
Atlantic	2,221	85,5%	1,0%	87,7%	0,9%	87,0%	1,0%	89,6%	0,8%
Black Sea	309	92,1%	2,6%	82,7%	3,7%	92,2%	2,6%	83,3%	3,6%
Boreal	2,328	93,0%	0,9%	95,6%	0,7%	94,5%	0,8%	96,2%	0,7%
Continental	3,582	92,0%	0,7%	93,4%	0,6%	93,1%	0,6%	94,9%	0,5%
Macaronesia	25	100,0%	0,0%	83,3%	9,2%	100,0%	0,0%	100,0%	0,0%
Mediterranean	3,053	86,1%	0,9%	79,3%	1,1%	89,2%	0,8%	82,1%	1,0%
Pannonian	373	92,2%	1,5%	92,2%	1,5%	92,3%	1,5%	93,8%	1,3%
Steppic	95	100,0%	0,0%	83,3%	2,5%	100,0%	0,0%	83,3%	2,5%
AL+ME+MK+RS+XK	406	83,3%	2,8%	87,9%	2,5%	85,3%	2,7%	87,9%	2,5%
AT + CH + LI	322	94,8%	1,8%	88,8%	2,6%	95,6%	1,7%	90,2%	2,4%
BA + HR + SI	324	95,7%	1,9%	90,1%	2,8%	95,8%	1,9%	91,9%	2,6%
BE + LU + NL + DK	288	86,3%	2,7%	91,7%	2,0%	90,0%	2,4%	93,8%	1,8%
BG	282	92,4%	2,3%	94,0%	2,1%	94,8%	1,9%	94,8%	2,0%
CZ + SK	323	96,8%	1,4%	94,5%	1,9%	93,8%	2,0%	93,8%	2,1%
DE	939	91,5%	1,3%	96,1%	0,9%	92,8%	1,2%	97,7%	0,7%
EE + LT + LV	449	93,9%	1,8%	94,4%	1,7%	94,8%	1,6%	94,4%	1,7%
EL	342	87,6%	2,7%	84,3%	2,9%	89,6%	2,5%	90,3%	2,4%
ES	1,305	82,9%	1,5%	82,7%	1,5%	88,8%	1,3%	85,7%	1,4%
FI	872	89,0%	1,9%	95,5%	1,3%	91,3%	1,7%	96,4%	1,1%
FR	1,402	92,4%	1,0%	88,9%	1,2%	92,7%	1,0%	90,5%	1,1%
HU	237	91,3%	2,2%	89,4%	2,4%	93,5%	1,9%	91,5%	2,2%
IE + UK	804	82,5%	1,5%	88,9%	1,1%	82,7%	1,5%	90,0%	1,1%
IS	325	54,5%	0,1%	60,0%	0,1%	68,6%	0,1%	80,0%	0,1%
IT	773	92,7%	1,4%	77,1%	2,3%	94,4%	1,3%	80,6%	2,2%
NO	853	85,8%	1,7%	87,2%	1,6%	88,3%	1,6%	90,7%	1,4%
PL	810	95,0%	1,1%	90,8%	1,4%	95,1%	1,1%	93,0%	1,3%
PT	233	76,9%	4,2%	80,5%	4,0%	82,0%	3,8%	83,9%	3,7%
RO	600	92,8%	1,5%	97,0%	0,9%	93,8%	1,4%	97,5%	0,9%
SE	1,166	96,3%	0,9%	93,5%	1,2%	96,7%	0,9%	93,9%	1,2%
TR	1,996	87,6%	1,0%	75,4%	1,2%	88,5%	0,9%	76,2%	1,2%

As previously for the First and Second Specific Contracts, the main cause of the confusion appears to be related to the presence of the mixed forest class which was not present in the 20m layer as shown in Figure 13. For example, the producer and user accuracies for the broadleaved and the coniferous would be respectively 83.9%/87.2% and 81.7%/89.0% if the mixed forest class would not be considered. The accuracies would be very close to the target accuracies, and even exceed the requirement in certain cases; demonstrating that the presence of the mixed forest class leads to confusion. Therefore, in areas where forest is mixed but with a dominance of say coniferous in the 20m data and homogeneously distributed across the sample unit, the

resulting 100m pixel will still be coniferous whereas if the distribution is heterogeneous, the same proportion of mixed forest in the sample unit could result in the pixel classified as mixed. The mixed class is typically associated with transition areas between broadleaved and coniferous forest and it is well known that transition areas exhibits lower accuracies than in homogeneous areas

A study is conducted in parallel in the frame of the Third specific contract to analyse this process and assess the accuracy of the 20m FTY layer over areas classified as mixed and non-mixed forest in the 100m layer. The interpretation is conducted based on the SSUs and the aggregation is performed following the same rules than that of the map production. The results of the study show a substantial improvement with the accuracies of area covered with Mixed forest. Nevertheless, the accuracy of the Mixed forest class is still relatively low whilst broadleaf and coniferous exhibits good producer and user accuracies. In fact, the mixed class is typically associated with transition areas between broadleaved and coniferous forest and it is proved now that transition areas exhibit lower accuracies than in homogeneous areas.

It is also worth noting that the user and producer accuracy of the broadleaf and coniferous type are very close or exceeding the target accuracy when only considering the confusion between forest types.

(a)	Non-forest	Broadleaved	Coniferous	Mixed forest	Total	Overall User accuracy	User accuracy between Forest types
Non-forest	9176	310	126	68	9679		
Broadleaved	425	1828	101	268	2622	69,7%	83,2%
Coniferous	93	39	1536	157	1825	84,2%	88,7%
Mixed forest	91	74	185	572	923	62,0%	68,8%
Total	9785	2252	1947	1065	15049		
Overall Producer accuracy		81,2%	78,9%	53,7%		Overall Accuracy	81,4%
Producer accuracy between Forest types		94,1%	84,3%	57,4%			
(b)	Non-forest	Broadleaved	Coniferous	Mixed forest	Total	Overall User accuracy	User accuracy between Forest types
Non-forest	9259	252	112	56	9679		
Broadleaved	363	1969	88	202	2622	75,1%	87,1%
Coniferous	87	28	1613	97	1826	88,4%	92,8%
Mixed forest	75	45	139	663	923	71,9%	78,3%
Total	9784	2295	1952	1019	15050		
Overall Producer accuracy		85,8%	82,6%	65,1%		Overall Accuracy	89,7%
Producer accuracy between Forest types		96,4%	87,7%	68,9%			

Figure 13: Error matrices at pan-European level for the HRL FTY product for (a) blind interpretation and (b) plausibility analysis.

4.3. Tree Cover Density Change (TCDC)

TCDC values were regrouped according to the thresholds as detailed in section 1.2.3 to perform a thematic accuracy assessment:

- -100 to -30 values corresponding to decreased tree cover density
- 0: unchanged areas
- 30 to 100 values corresponding to increased tree cover density

TCDC values were also regrouped to produce a binary map changed/unchanged area with increased and decreased values aggregated to one class.

The results at European level are shown in Table 16 and Table 17. Accuracy figures were calculated following the procedure described in 0 taking the weight of Table 9 into account. At European level, for the plausibility analysis, the accuracy only meets the target accuracy (90%) for both user and producer accuracies of the unchanged area class and for the producer accuracy for both Increased and Decreased classes suggesting a low amount of omission errors regarding the change tree cover density. Nevertheless, the results show very low user accuracies for the changed classes (respectively 15.0% and 38.1% for the Increased and Decreased classes for the plausibility analysis) suggesting a very high amount of commission errors (and possibly explaining the few omission errors). The results with the aggregated change classes tend to highlight the same tendency with a very high amount of commission errors.

At country and biogeographical region level, the results are similar with the requirement only met for the producer accuracies for the change classes. All the countries or biogeographical regions show a very high amount of commission errors for both increased and decreased classes (and the aggregated change class).

The main reason explaining the very high amount of commission errors is related to the HRL TCD 2012 status layer. Indeed, as highlighted by the bulk interpretation/plausibility team, the 2012 TCD value is often wrongly estimated whereas the 2015 value is typically very close to the validation interpretation as proved in the section 4.1. This leads to the commission errors with false increased/decreased change detected.

Table 16: TCDC product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km² and per thematic classes: Unchanged areas (UC), Increase (I) and Decrease (D) tree cover density. Values in green indicate accuracies greater than the 85% threshold.

	Blind Interpretation												Plausibility Analysis													
	Prod UC	CI 95%	Prod I	CI 95%	Prod D	CI 95%	User UC	CI 95%	User I	CI 95%	User D	CI 95%	Prod UC	CI 95%	Prod I	CI 95%	Prod D	CI 95%	User UC	CI 95%	User I	CI 95%	User D	CI 95%		
EEA39	94,3%	0,2%	47,5%	0,7%	70,6%	0,5%	99,7%	0,1%	3,5%	0,4%	20,6%	0,44%	95,2%	0,2%	94,3%	0,3%	91,3%	0,3%	99,9%	0,0%	15,0%	0,4%	38,1%	0,41%		
Alpine	91,9%	0,4%	67,7%	1,7%	74,9%	1,1%	99,8%	0,1%	4,1%	1,2%	14,3%	1,1%	92,5%	0,4%	100,0%	0,0%	83,7%	1,0%	99,9%	0,1%	6,7%	1,2%	25,1%	1,0%		
Anatolian	98,3%	0,2%					100,0%	0,0%	0,0%	0,8%	0,0%	2,0%	98,4%	0,2%					100,0%	0,0%	0,0%	0,8%	0,0%	2,0%		
Arctic	96,5%	0,0%					100,0%	0,0%	0,0%	0,0%	0,0%	0,0%	96,6%	0,0%					100,0%	0,0%	0,0%	0,0%	0,0%	0,0%		
Atlantic	94,2%	0,3%	43,6%	1,7%	51,1%	1,1%	99,6%	0,1%	3,6%	0,9%	10,7%	1,1%	95,2%	0,3%	100,0%	0,0%	81,9%	0,7%	99,9%	0,1%	15,2%	0,8%	33,8%	1,0%		
Black Sea	93,0%	1,2%			18,4%	2,5%	99,7%	0,4%	0,0%	3,3%	2,3%	3,2%	94,0%	1,1%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	13,7%	3,3%	9,2%	3,2%		
Boreal	93,2%	0,5%	36,9%	1,9%	75,1%	1,4%	99,2%	0,3%	5,2%	1,6%	32,1%	1,3%	95,0%	0,4%	91,2%	0,9%	96,2%	0,6%	99,8%	0,1%	22,1%	1,5%	62,5%	1,0%		
Continental	94,8%	0,2%	58,5%	1,3%	82,8%	0,9%	99,8%	0,1%	4,1%	0,8%	29,7%	0,8%	95,7%	0,2%	92,7%	0,7%	92,5%	0,6%	99,9%	0,1%	21,2%	0,7%	42,7%	0,7%		
Macaronesia	84,5%	0,7%			0,0%	0,0%	96,5%	2,5%	0,0%	0,0%	0,0%	0,0%	85,5%	0,7%			100,0%	0,0%	100,0%	0,0%	0,0%	0,0%	33,3%	0,7%		
Mediterranean	94,5%	0,3%	10,1%	0,5%	57,1%	0,9%	99,6%	0,1%	0,4%	0,9%	13,8%	0,8%	95,2%	0,3%	89,6%	0,5%	92,0%	0,5%	99,9%	0,1%	6,9%	0,9%	30,2%	0,8%		
Pannonian	93,6%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	10,1%	1,5%	54,1%	2,1%	94,9%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	33,0%	1,2%	54,1%	2,1%		
Steppic	96,0%	0,7%			100,0%	0,0%	100,0%	0,0%	0,0%	2,6%	100,0%	0,0%	97,4%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	36,4%	2,3%	100,0%	0,0%		
AL+ME+MK+RS+XK	91,9%	0,5%			100,0%	0,0%	100,0%	0,0%	0,0%	1,6%	24,8%	1,1%	92,2%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	1,9%	1,6%	30,8%	0,8%		
AT + CH + LI	88,2%	0,7%	100,0%	0,0%	54,3%	5,6%	99,4%	0,8%	11,1%	1,3%	22,4%	0,9%	88,6%	0,7%	100,0%	0,0%	62,3%	5,3%	99,4%	0,8%	13,3%	1,3%	31,0%	0,9%		
BA + HR + SI	86,1%	1,0%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	2,0%	1,9%	23,8%	1,9%	87,1%	0,9%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	6,0%	1,9%	46,0%	1,5%		
BE + LU+ NL + DK	92,7%	0,3%	100,0%	0,0%	64,3%	5,5%	99,3%	0,9%	4,6%	0,9%	44,5%	0,8%	94,0%	0,3%	100,0%	0,0%	85,4%	1,0%	99,7%	0,2%	20,0%	0,9%	60,3%	0,6%		
BG	92,8%	0,9%			100,0%	0,0%	100,0%	0,0%	0,0%	2,6%	19,5%	0,2%	94,3%	0,8%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	22,7%	2,5%	34,1%	0,2%		
CZ + SK	92,1%	0,4%			100,0%	0,0%	100,0%	0,0%	0,0%	1,3%	36,2%	0,9%	93,3%	0,4%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	17,5%	1,3%	44,7%	0,9%		
DE	96,5%	0,6%	58,0%	1,2%	64,3%	0,2%	99,9%	0,1%	6,3%	2,3%	12,6%	2,1%	97,0%	0,6%	77,9%	1,0%	82,5%	0,1%	99,9%	0,1%	16,2%	2,3%	32,9%	2,1%		
EE + LT + LV	93,3%	0,7%	0,0%	0,0%	100,0%	0,0%	99,7%	0,5%	0,0%	1,9%	18,4%	1,9%	95,4%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	23,5%	1,8%	52,9%	0,9%		
EL	93,1%	0,4%			18,4%	0,7%	99,8%	0,1%	0,0%	1,1%	2,1%	0,6%	93,8%	0,4%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	4,3%	1,1%	21,7%	0,6%		
ES	95,7%	0,5%	0,0%	2,1%	70,2%	1,7%	99,7%	0,2%	0,0%	1,8%	6,1%	1,8%	96,1%	0,5%	100,0%	0,0%	87,9%	1,2%	99,9%	0,1%	5,6%	1,8%	19,1%	1,8%		
FI	94,4%	1,3%	33,1%	3,0%	68,6%	1,2%	98,6%	0,4%	11,0%	4,4%	33,7%	3,6%	96,1%	1,2%	88,8%	0,8%	90,2%	0,8%	99,6%	0,2%	37,7%	4,0%	53,1%	3,6%		
FR	95,1%	0,5%	58,3%	1,6%	22,3%	1,6%	99,7%	0,2%	2,5%	1,6%	6,3%	2,1%	96,0%	0,5%	100,0%	0,0%	57,3%	1,6%	99,8%	0,1%	23,2%	1,6%	22,6%	2,0%		
HU	91,7%	0,6%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	11,0%	1,4%	53,2%	1,7%	93,5%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	35,8%	1,3%	53,2%	1,7%		
IE + UK	96,3%	0,5%	100,0%	0,0%	76,3%	2,8%	99,9%	0,2%	8,2%	1,5%	26,7%	3,0%	96,7%	0,5%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	12,3%	1,5%	47,1%	2,6%		
IS	96,4%	0,1%					100,0%	0,0%	0,0%	0,1%	0,0%	0,0%	96,4%	0,1%					100,0%	0,0%	0,0%	0,1%	0,0%	0,0%		
IT	94,1%	1,0%	18,9%	2,1%	16,7%	2,0%	99,6%	0,3%	1,3%	2,7%	1,3%	3,1%	95,0%	0,9%	100,0%	0,0%	100,0%	0,0%	100,0%	0,0%	12,3%	2,6%	18,5%	3,1%		
NO	93,8%	0,9%			78,2%	0,1%	100,0%	0,0%	99,8%	0,1%	8,1%	2,6%	13,4%	3,3%	94,5%	0,8%	100,0%	0,0%	86,2%	0,1%	100,0%	0,0%	4,9%	2,6%	23,4%	3,1%
PL	96,7%	0,7%	57,2%	1,2%	100,0%	0,0%	99,8%	0,1%	8,1%	2,6%	47,5%	2,2%	97,3%	0,5%	81,9%	1,0%	100,0%	0,0%	99,8%	0,1%	27,4%	2,4%	59,0%	1,9%		
PT	89,9%	0,3%	12,3%	0,5%	58,5%	0,8%	97,6%	0,3%	4,0%	0,7%	19,9%	0,8%	93,5%	0,3%	82,8%	0,6%	100,0%	0,0%	99,7%	0,1%	34,0%	0,5%	51,9%	0,6%		
RO	96,2%	0,5%	12,1%	3,2%	69,8%	2,0%	99,4%	0,3%	2,2%	2,2%	36,0%	0,2%	96,8%	0,4%	1											

Table 17: TCDC product thematic accuracy results per bio-geographical region and per country or group of countries greater than 90,000km² and per thematic classes: Unchanged areas (UC), Changed areas (C). Values in green indicate accuracies greater than the 85% threshold.

	Blind Interpretation						Plausibility Analysis									
	Prod UC	CI 95%	Prod C	CI 95%	User UC	CI 95%	User C	CI 95%	Prod UC	CI 95%	Prod C	CI 95%	User UC	CI 95%	User C	CI 95%
Europe (Part)	94,3%	0,2%	64,4%	0,6%	99,7%	0,1%	9,2%	0,5%	95,2%	0,2%	93,4%	0,3%	99,9%	0,0%	22,6%	0,4%
Alpine	91,9%	0,4%	77,9%	1,4%	99,8%	0,1%	7,3%	1,2%	92,5%	0,4%	95,1%	0,6%	99,9%	0,1%	12,0%	1,2%
Anatolian	98,3%	0,2%			100,0%	0,0%	0,0%	1,5%	98,4%	0,2%			100,0%	0,0%	0,0%	1,5%
Arctic	96,5%	0,0%			100,0%	0,0%	0,0%	0,0%	96,6%	0,0%			100,0%	0,0%	0,0%	0,0%
Atlantic	94,2%	0,3%	55,4%	1,4%	99,6%	0,1%	7,1%	1,0%	95,2%	0,3%	91,7%	0,6%	99,9%	0,1%	22,6%	0,9%
Black Sea	93,0%	1,2%	18,4%	2,5%	99,7%	0,4%	0,9%	3,3%	94,0%	1,1%	100,0%	0,0%	100,0%	0,0%	11,8%	3,3%
Boreal	93,2%	0,5%	59,8%	1,7%	99,2%	0,3%	14,1%	1,5%	95,0%	0,4%	94,1%	0,8%	99,8%	0,1%	35,7%	1,4%
Continental	94,8%	0,2%	76,4%	1,0%	99,8%	0,1%	11,8%	0,8%	95,7%	0,2%	92,6%	0,6%	99,9%	0,1%	27,5%	0,7%
Macaronesia	84,5%	0,7%	0,0%	0,0%	96,5%	2,5%	0,0%	0,8%	85,5%	0,7%	100,0%	0,0%	100,0%	0,0%	4,5%	0,8%
Mediterranean	94,5%	0,3%	46,3%	0,9%	99,6%	0,1%	5,5%	0,9%	95,2%	0,3%	91,3%	0,5%	99,9%	0,1%	15,8%	0,9%
Pannonic	93,6%	0,5%	100,0%	0,0%	100,0%	0,0%	21,6%	1,7%	94,9%	0,5%	100,0%	0,0%	100,0%	0,0%	38,5%	1,5%
Steppic	96,0%	0,7%	100,0%	0,0%	100,0%	0,0%	9,4%	2,6%	97,4%	0,5%	100,0%	0,0%	100,0%	0,0%	42,4%	2,2%
AL+ME+MK+RS+XK	91,9%	0,5%	100,0%	0,0%	100,0%	0,0%	11,2%	1,5%	92,2%	0,5%	100,0%	0,0%	100,0%	0,0%	14,9%	1,4%
AT + CH + LI	88,2%	0,7%	76,7%	4,4%	99,4%	0,8%	13,5%	1,4%	88,6%	0,7%	80,6%	4,0%	99,4%	0,8%	17,2%	1,4%
BA + HR + SI	86,1%	1,0%	100,0%	0,0%	100,0%	0,0%	6,2%	2,0%	87,1%	0,9%	100,0%	0,0%	100,0%	0,0%	13,7%	1,9%
BE + LU+ NL + DK	92,7%	0,3%	69,1%	5,2%	99,3%	0,9%	16,5%	0,9%	94,0%	0,3%	91,2%	0,8%	99,7%	0,2%	32,0%	0,8%
BG	92,8%	0,9%	100,0%	0,0%	100,0%	0,0%	2,2%	2,6%	94,3%	0,8%	100,0%	0,0%	100,0%	0,0%	24,0%	2,4%
CZ + SK	92,1%	0,4%	100,0%	0,0%	100,0%	0,0%	11,8%	1,3%	93,3%	0,4%	100,0%	0,0%	100,0%	0,0%	26,3%	1,3%
DE	96,5%	0,6%	69,9%	1,1%	99,9%	0,1%	8,7%	2,3%	97,0%	0,6%	84,5%	0,9%	99,9%	0,1%	20,4%	2,3%
EE + LT + LV	93,3%	0,7%	66,7%	4,4%	99,7%	0,5%	7,2%	2,0%	95,4%	0,5%	100,0%	0,0%	100,0%	0,0%	35,2%	1,7%
EL	93,1%	0,4%	18,4%	0,7%	99,8%	0,1%	0,7%	1,1%	93,8%	0,4%	100,0%	0,0%	100,0%	0,0%	10,0%	1,1%
ES	95,7%	0,5%	40,9%	2,2%	99,7%	0,2%	3,7%	1,9%	96,1%	0,5%	89,7%	1,1%	99,9%	0,1%	13,8%	1,9%
FI	94,4%	1,3%	52,7%	2,3%	98,6%	0,4%	21,3%	4,2%	96,1%	1,2%	89,5%	0,8%	99,6%	0,2%	44,7%	3,8%
FR	95,1%	0,5%	46,4%	1,6%	99,7%	0,2%	4,6%	1,8%	96,0%	0,5%	85,1%	1,1%	99,8%	0,1%	23,1%	1,7%
HU	91,7%	0,6%	100,0%	0,0%	100,0%	0,0%	22,9%	1,6%	93,5%	0,5%	100,0%	0,0%	100,0%	0,0%	40,7%	1,5%
IE + UK	96,3%	0,5%	83,9%	2,4%	99,9%	0,2%	14,4%	2,3%	96,7%	0,5%	100,0%	0,0%	100,0%	0,0%	23,8%	2,1%
IS	96,4%	0,1%			100,0%	0,0%	0,0%	0,5%	96,4%	0,1%			100,0%	0,0%	0,0%	0,5%
IT	94,1%	1,0%	18,2%	2,0%	99,6%	0,3%	1,3%	2,8%	95,0%	0,9%	100,0%	0,0%	100,0%	0,0%	14,0%	2,8%
NO	93,8%	0,9%	100,0%	0,0%	100,0%	0,0%	3,8%	2,9%	94,5%	0,8%	100,0%	0,0%	100,0%	0,0%	10,1%	2,8%
PL	96,7%	0,7%	85,0%	0,9%	99,8%	0,1%	22,0%	2,5%	97,3%	0,5%	90,8%	0,7%	99,8%	0,1%	38,6%	2,2%
PT	89,9%	0,3%	43,7%	0,8%	97,6%	0,3%	14,6%	0,9%	93,5%	0,3%	95,1%	0,4%	99,7%	0,1%	46,0%	0,6%
RO	96,2%	0,5%	52,6%	2,8%	99,4%	0,3%	13,6%	1,9%	96,8%	0,4%	100,0%	0,0%	100,0%	0,0%	25,7%	1,9%
SE	92,5%	1,1%	65,5%	2,5%	99,5%	0,3%	9,9%	3,2%	94,2%	1,1%	96,0%	1,3%	99,9%	0,2%	27,3%	3,1%
TR	96,5%	0,3%	22,0%	1,4%	99,8%	0,1%	1,5%	1,1%	96,7%	0,3%	77,7%	0,7%	99,9%	0,0%	4,8%	1,1%

5. Conclusions and recommendations

5.1. TCD

The HRL TCD product was assessed based on a scatterplot as well as applying a threshold to determine its thematic accuracy:

- Based on scatterplots, it appears that map density values slightly underestimate actual TCD values at very low tree cover density (0-20%) and very high density (>90%) although for the latter, this could also be due to the sampling approach for the collection of reference data that may overestimate actual TCD when classified at 100%.

Moreover, all regression coefficients show very good results with values greater than 0.5 and closed to 0.8/0.9. It seems that there is a strong relationship between validation and map data; the reference and map information are meant to represent the same information. The lowest values are related to regions or countries with very low tree cover or complex landscapes (e.g. Arctic bio-geographical region with Iceland, Mediterranean or Anatolian bio-geographical regions with Portugal, Spain, Greece, Turkey, Italy and the Balkan countries) with a R^2 close to 0.5-0.75.

Regression slopes are consistently close to 1 with very few variabilities but smaller than 1 which is mainly a result of commission errors (TCD detected in non-tree covered areas) and a slight underestimation of TCD values at very high tree cover density (>90%).

The intercept parameter shows good values close to 0 with some of them slightly over 1 which is a result of the commission errors (positive intercept) or omission errors (negative intercept) for the associated bio-geographical region or countries. While optimal value should be close to 0 with a slope close to 1, some results present an intercept around/above 3. The greatest values are related to the Black Sea, Alpine and Mediterranean bio-geographical regions well-known to be especially prone to omission and commissions errors due to a very complex landscape (Macchia, garrigue, alpine shrubs) that are confused with forests.

- Regarding the accuracy assessment, results show that the HRL TCD product meets the thematic classification accuracy requirements based on a 10 and 30% threshold of TCD values. Indeed, at European level, for both blind and plausibility interpretation, the accuracy meets the minimum accuracy requirement (85%) for both user and producer accuracies and the target accuracy (90%) is also for all the user accuracies and the producer accuracy with a 30% threshold for the plausibility analysis.

Nevertheless, there is variability from country to country or based on biogeographical regions. Best results are obtained in countries or biogeographical regions with high tree cover (e.g. Continental and Boreal regions and the associated countries: e.g. Austria, Switzerland and Liechtenstein, Germany, Finland, Norway,) and the worst results in countries or biogeographical regions with low tree cover (e.g. Artic, Anatolian, Mediterranean, Pannonic and the associated countries: e.g. Iceland, Italy, Turkey, Greece, Portugal). The results are surprisingly low for the Atlantic regions where the producer accuracy suggests a high amount of omission errors. At country level, United-Kingdom and Ireland, Belgium, Luxembourg, Netherlands and Denmark show consequently unexpected very high amount of omission errors.

The main findings and recommendations for the HRL TCD product can be summarised as follows:

- TCD layer meets the minimum accuracy at pan-European level for omission errors and exceeds the target accuracy for commission errors.
- The quality of the Tree Cover mask (threshold > 1%) is also very good with a producer accuracy close to 90% and a user accuracy exceeding 90% for both the blind and plausibility approaches.

3. Results provided at lot, bio-geographical regions and country/group of country level, should provide a sound basis for further improving the product.
4. Based on the recommendations from the previous Specific Contract, the stratification procedure was simplified and leaded to most effective results for both commission and omission errors.

5.2. FTY

At pan-European level, the analysis of the HRL FTY product shows that the forest user and producer accuracies values are lower than the minimum accuracy threshold of 85% for the blind interpretation and most of them are lower than these requirements for the plausibility analysis (except the producer accuracy for the Broadleaved class and the user accuracy for the Coniferous class). At countries and biogeographical regions level, the trend is similar to TCD with lowest results for Artic or Mediterranean regions and associated countries (Iceland, Spain, Italia, Portugal, Turkey) and best results for regions with high tree cover (e.g. Continental) for which most of the accuracies are greater than the minimum accuracy thresholds of 85% for the plausibility analysis. The better results are obtained for Greece, Hungary and Romania with accuracy figure greater than the minimum requirements of 85%.

As previously reported for the first and second Specific Contracts⁶, most of the confusion are between the forest classes and the lower results are obtained for the mixed forest class at pan-European level and disaggregated levels with both user and producer accuracies that don't meet the target requirements for nearly all of them (blind and plausibility analysis). The coniferous forest class shows the better results with a greater balance between the user and the producer accuracies that meet the minimum accuracy requirement (85%) and the target accuracy (90%) for most of them in a plausibility approach (very few omission or commissions errors). The broadleaved forest class shows intermediate results with better producer accuracies mostly greater than the target requirements than user accuracies lower than the minimum thresholds.

The mixed class is typically associated with transition areas between broadleaved and coniferous forest and it is well known that transition areas exhibits lower accuracies than in homogeneous areas. A study is conducted in parallel in the frame of the Third specific contract to analyse this process and assess the accuracy of the 20m FTY layer over areas classified as mixed and non-mixed forest in the 100m layer. In any case, the mixed forest class as it is defined does seem to pose problem from a user perspective because it does not necessarily correspond to actual mixed forest but is a result of the aggregation process. In other word, what could be considered as a homogeneous forest patch containing a mix of broadleaf and coniferous forest will either be classified as broadleaf or coniferous forest in the 20m product depending on which forest type is dominant, resulting in either coniferous or broadleaf in the 100m product. However, two separate stands of pure broadleaf and coniferous forests contained within a 100m pixel will result in a mixed forest which seems to be illogical. Therefore, we would suggest that the mixed class should be dropped or more in line with the reality, but this would probably mean introducing a mixed class for the 20m product. Alternatively, the mixed class could be renamed as "Transition areas" which would better correspond to reality.

The main findings and recommendations for the HRL FTY product can be summarised as follows:

1. The FTY layer mainly meets the minimum accuracy requirement for broadleaf and coniferous forest types with respect to omission errors
2. The FTY layer meets the minimum accuracy requirement for coniferous type
3. Most of the confusion are between the forest classes and the least accurate results are obtained for the mixed forest class
4. The definition of the mixed forest type for the 100m layer purely based on aggregation rules poses a problem and it is suggested to abandon this class or focus the validation on the full resolution FTY product (at 10m spatial resolution for the incoming HRL FTY 2018).
5. Results provided at bio-geographical regions and country/group of country level, should provide a sound basis for further improving the product.

⁶ See <https://land.copernicus.eu/user-corner/technical-library/hrl-forest-2012-validation-report-1>

5.3. TCDC

The results at European level for the **HRL TCDC** show that the accuracy only meets the target accuracy (90%) for both user and producer accuracies of the unchanged area class and for the producer accuracy for both Increased and Decreased classes (few omission errors regarding the change tree cover density).

Nevertheless, the results show unsatisfying very low user accuracies for the changed classes (respectively 15.0% and 38.1% for the Increased and Decreased classes for the plausibility analysis) suggesting a very high amount of commission errors (and possibly explaining the few omission errors).

At country and biogeographical region level, the results are similar with the requirement only met for the producer accuracies for the change classes. All the countries or biogeographical regions show a very high amount of commission errors for both increased and decreased classes (and the aggregated change class).

The main findings and recommendations for the HRL TCDC product can be summarised as follows:

1. The TCDC layer only meets the minimum accuracy requirement for increased and decreased changes with respect to omission errors.
2. The TCDC shows very high amount of commission errors which lead to unreliable changes.
3. The next exercise for the production of the Forest layer should include the reprocessing of the change layers to ensure more temporally and spatially consistent changes.
4. Results provided at bio-geographical regions and country/group of country level, should provide a sound basis for further improving the product.
5. The efficiency of the stratification was also demonstrated for the TCDC product resulting in narrow confidence intervals.
6. A recommendation for the future TCDC product would be to include information on the time frame of the change.

Annex 1. Tree Cover Density (TCD) Scatterplot for bio-geographical regions

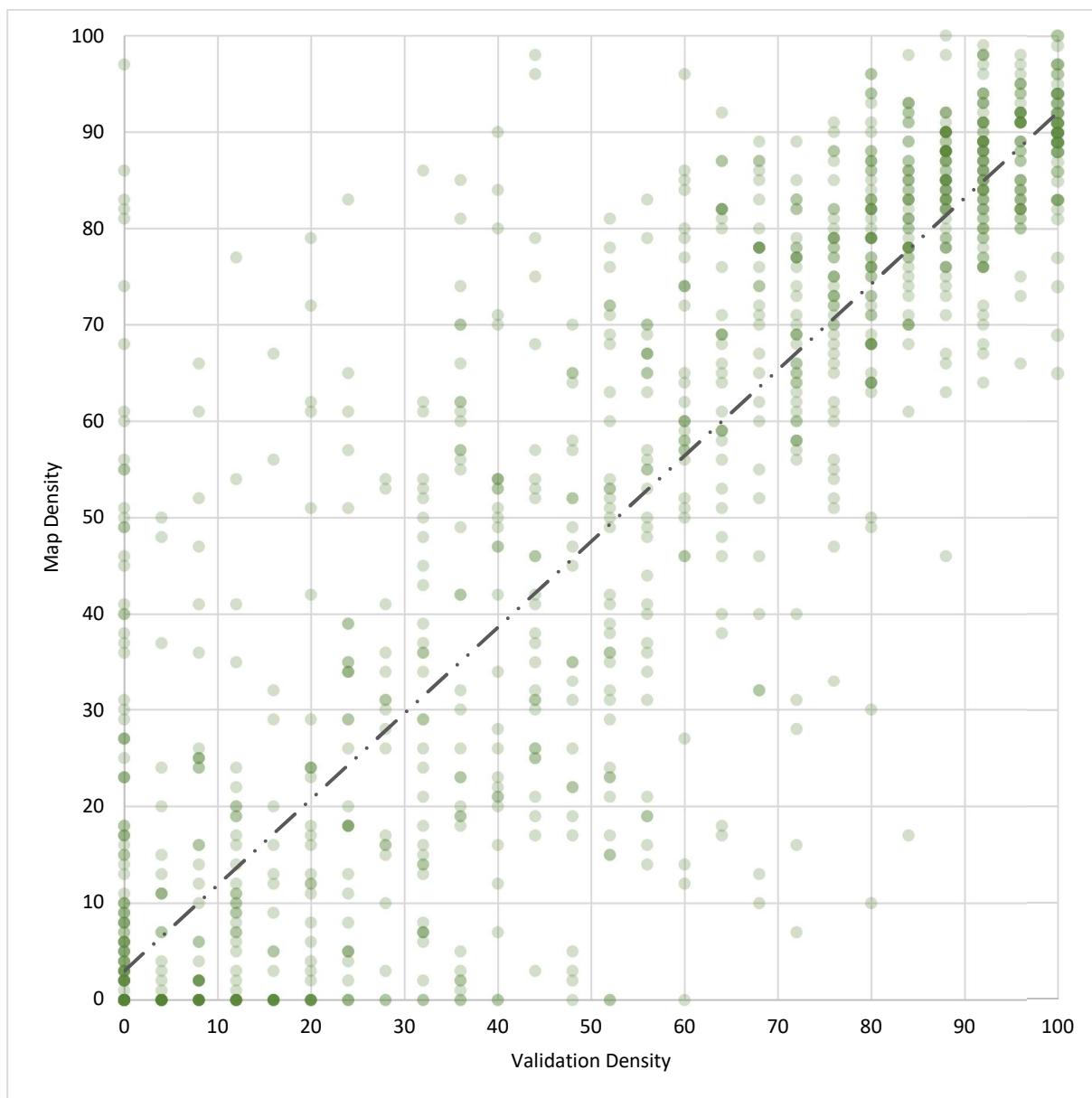


Figure 14: Scatterplot of all sample units for the Anatolian bio-geographical region HRL TCD, n=1,059, R²=0.62,
Map_Density = 0.9071*Validation_Density+1.3609

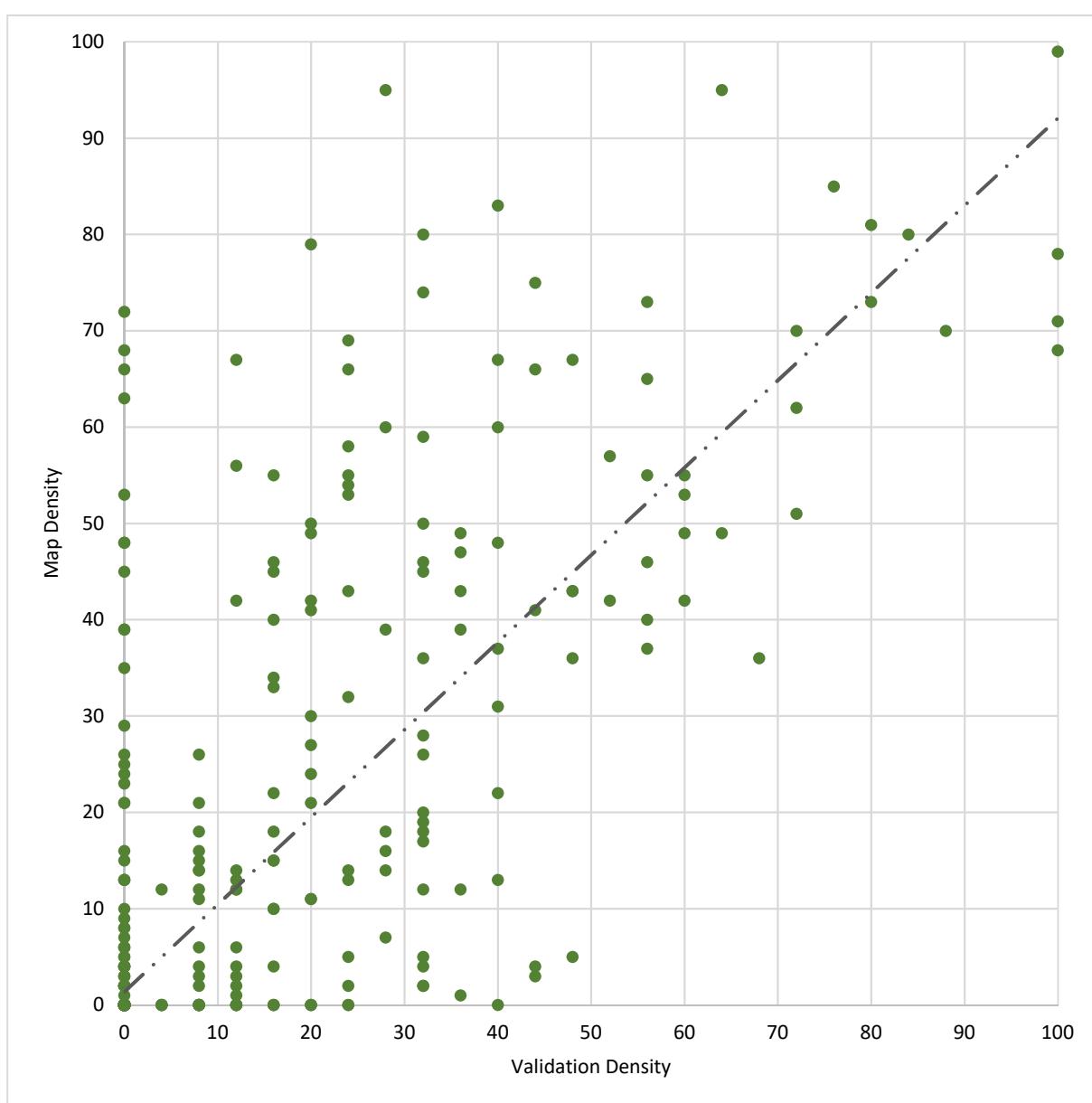


Figure 15: Scatterplot of all sample units for the Anatolian bio-geographical region HRL TCD, n=1,059, R²=0.62,
Map_Density = 0.9071*Validation_Density+1.3609

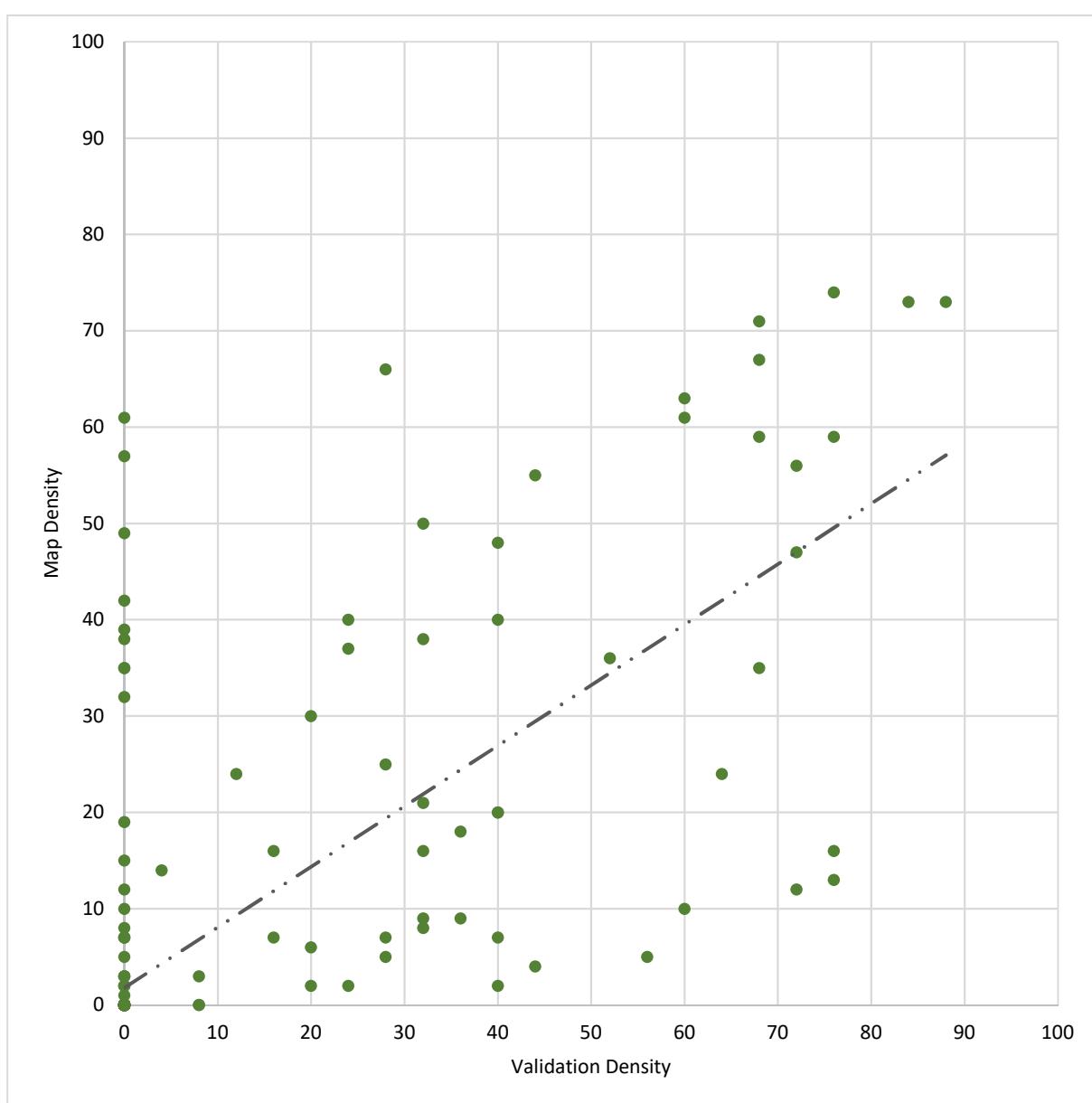


Figure 16: Scatterplot of all sample units for the Arctic bio-geographical region HRL TCD, n=336, R²=0.53, Map_Density = 0.6284*Validation_Density+1.7842

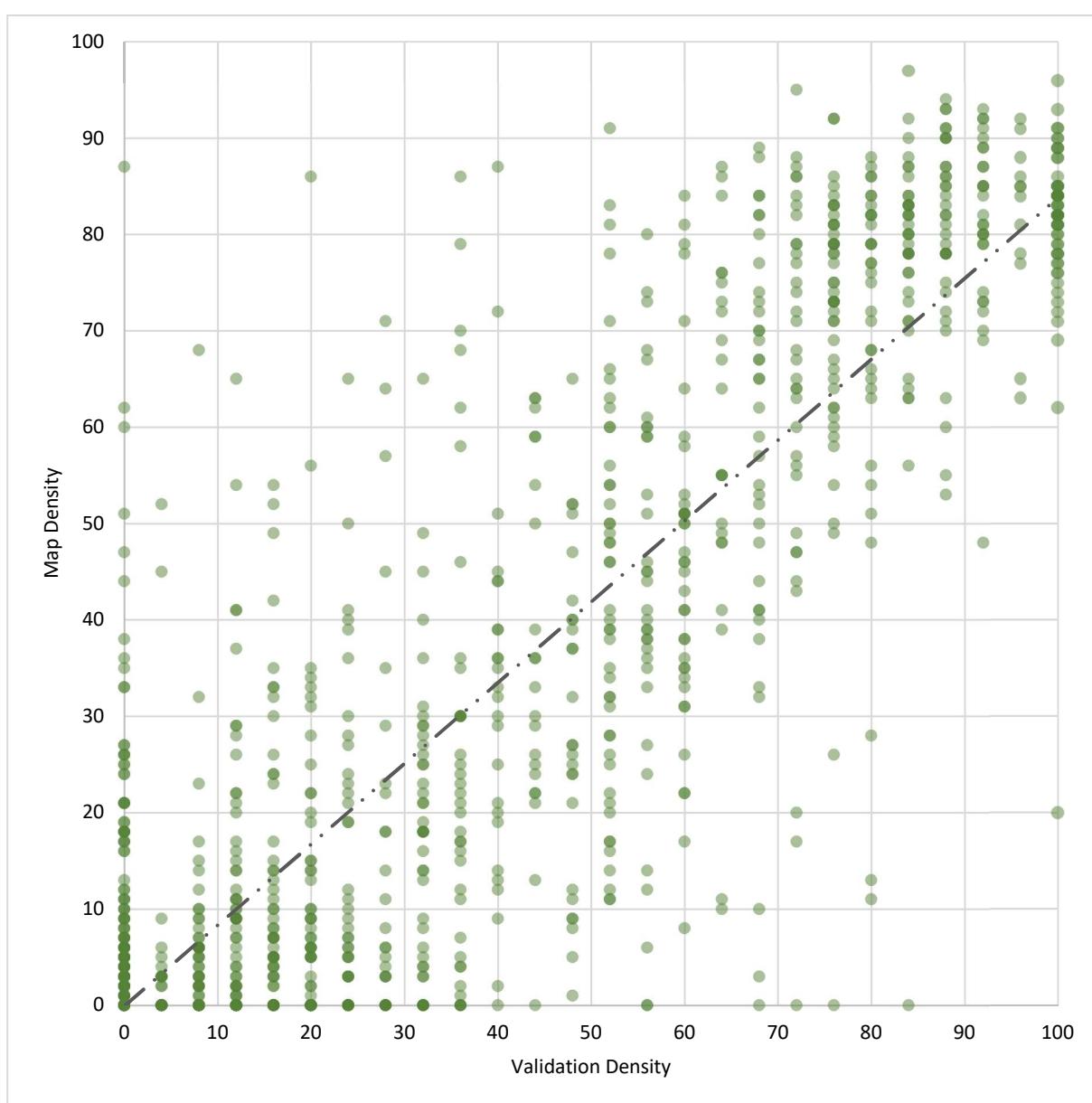


Figure 17: Scatterplot of all sample units for the Atlantic bio-geographical region HRL TCD, n=2,221, R²=0.82, Map_Density = 0.8392*Validation_Density-0.1051

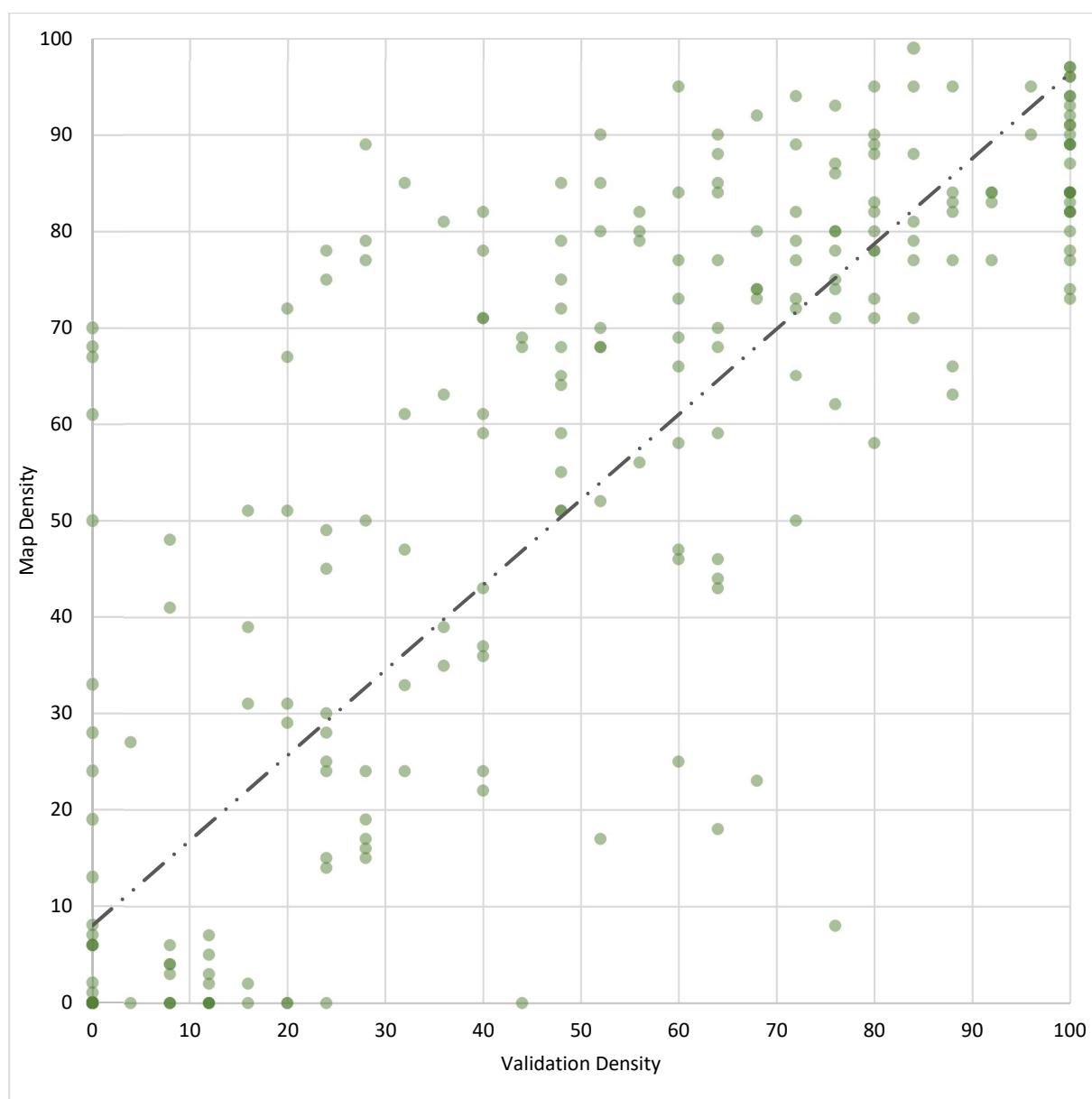


Figure 18: Scatterplot of all sample units for the Black Sea bio-geographical region HRL TCD, n=336, R²=0.76, Map_Density = 0.8844*Validation_Density+7.9968

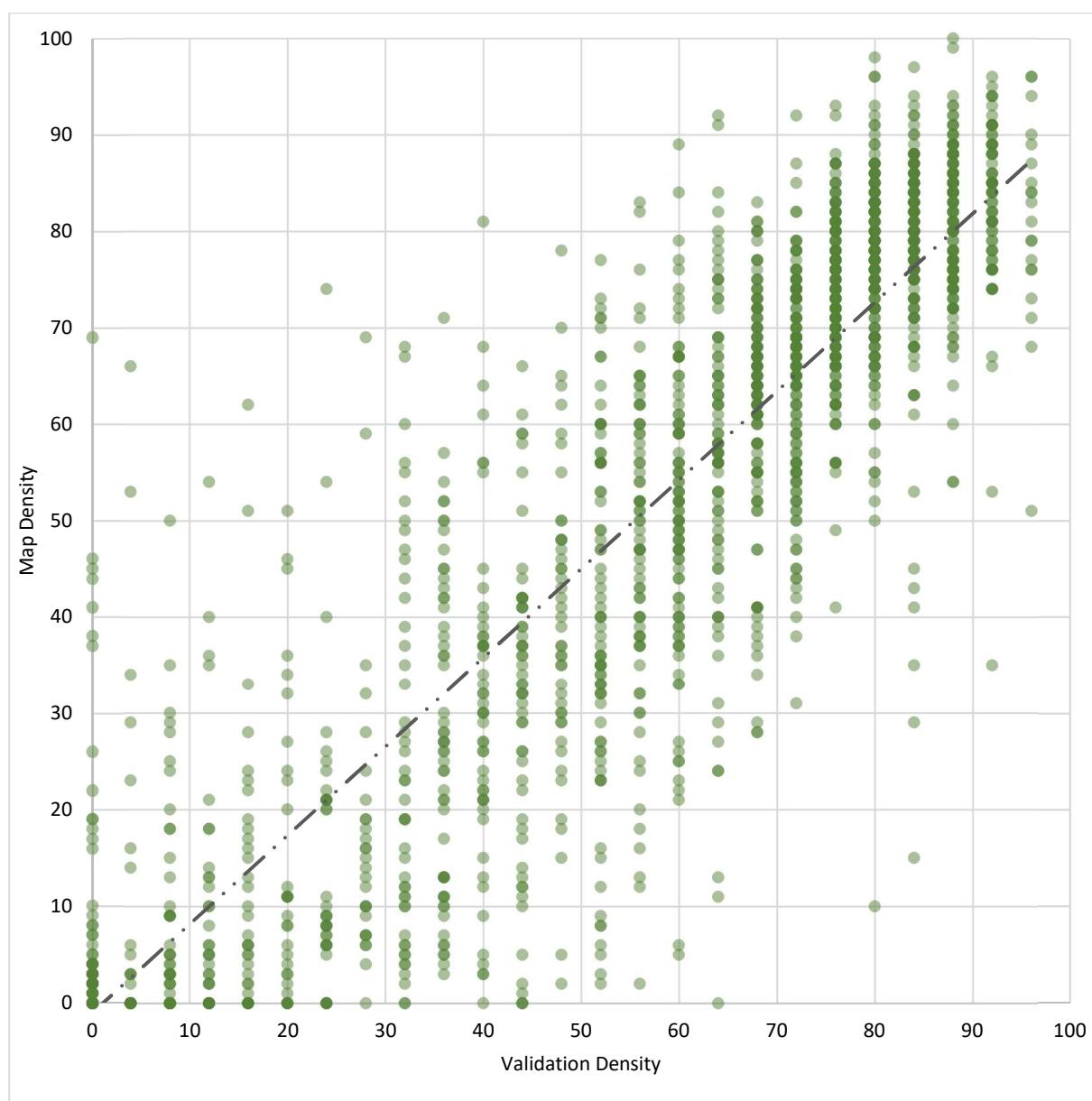


Figure 19: Scatterplot of all sample units for the Boreal bio-geographical region HRL TCD, n=2,328, R²=0.86, Map_Density = 0.9207*Validation_Density-1.0176

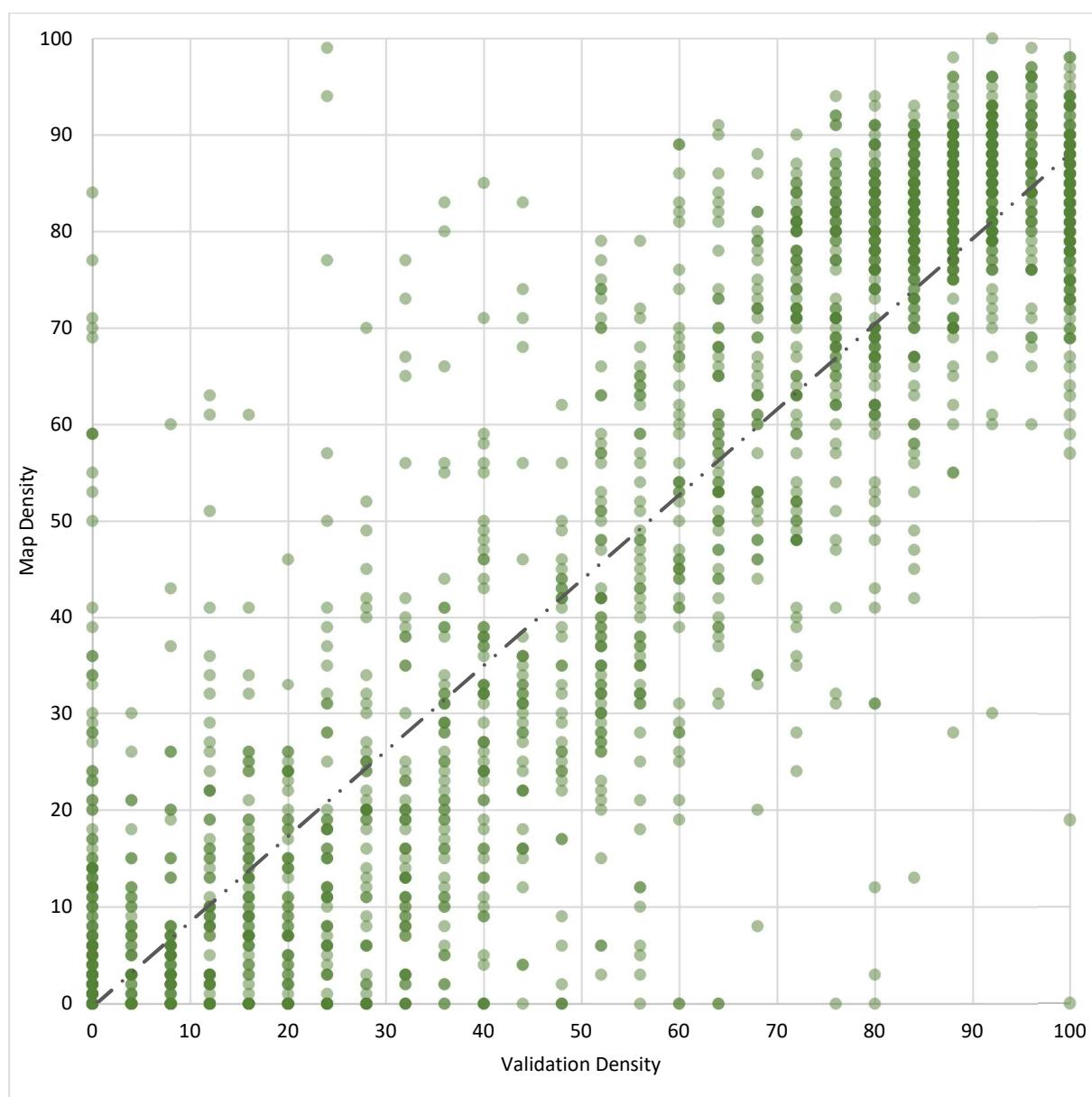


Figure 20: Scatterplot of all sample units for the Continental bio-geographical region HRL TCD, n=3,582, R²=0.89,
Map_Density = 0.8851*Validation_Density-0.4069

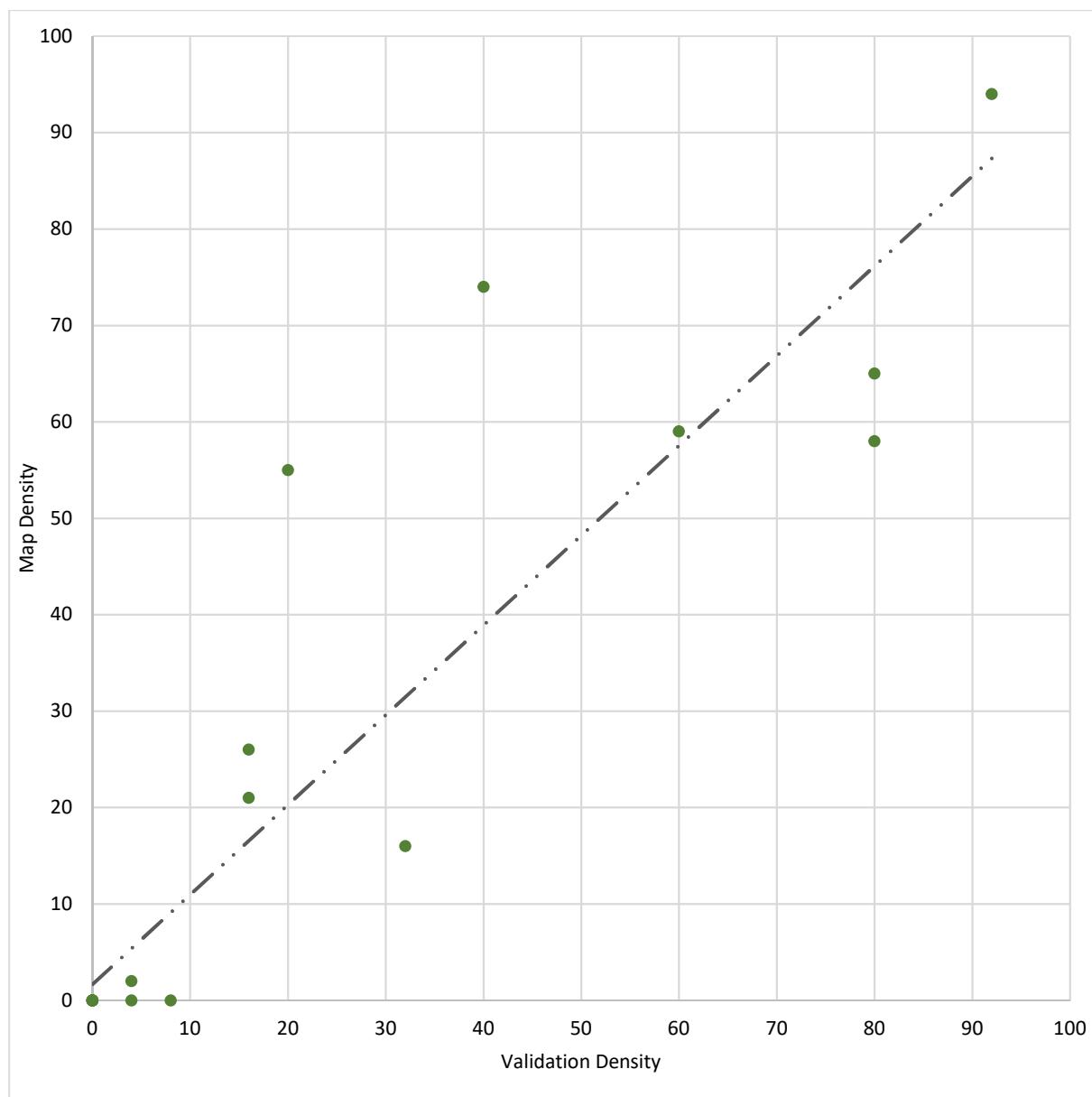


Figure 21: Scatterplot of all sample units for the Macaronesia bio-geographical region HRL TCD, n=25, R²=0.83,
Map_Density = 0.9311*Validation_Density+1.6672

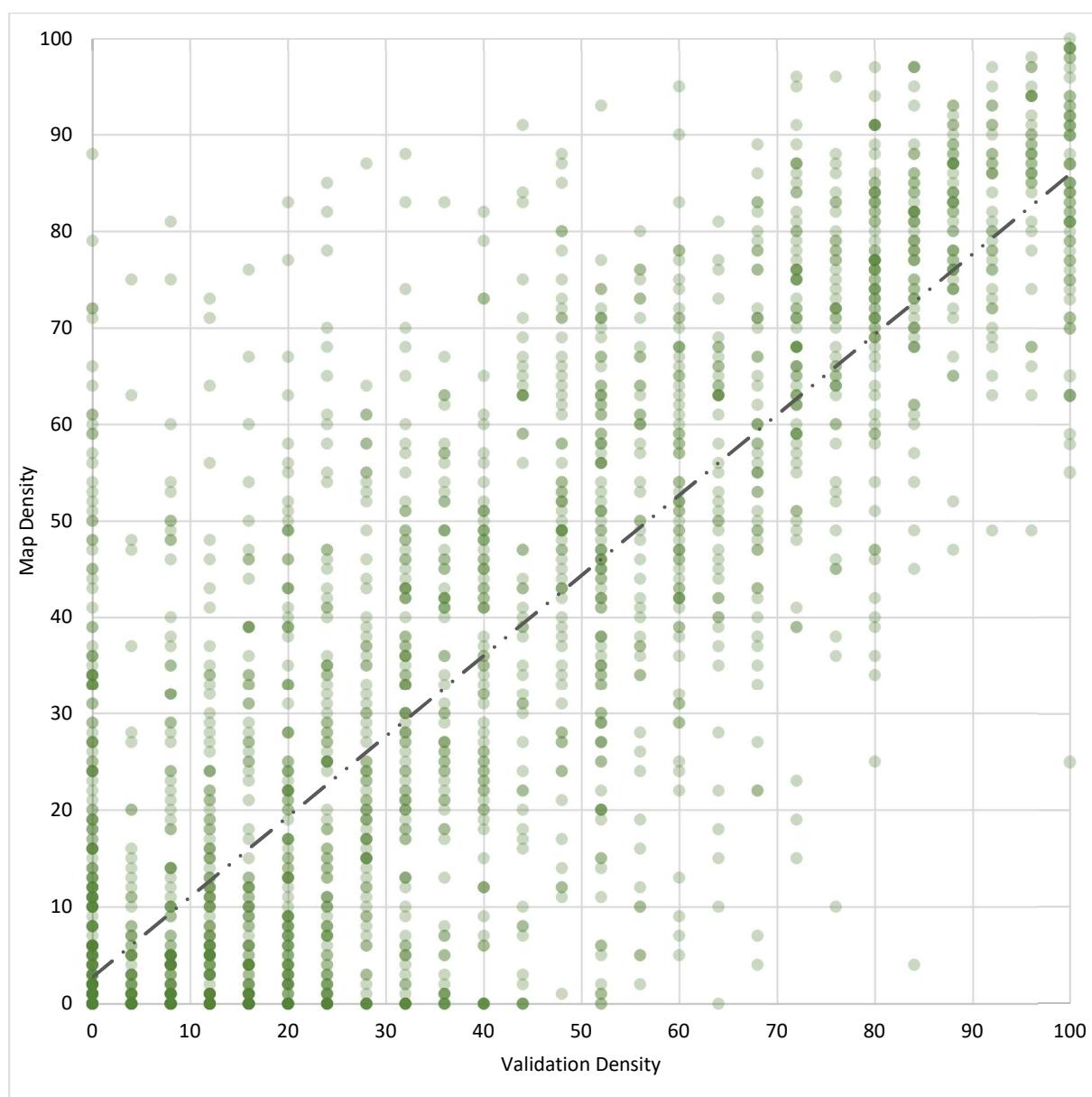
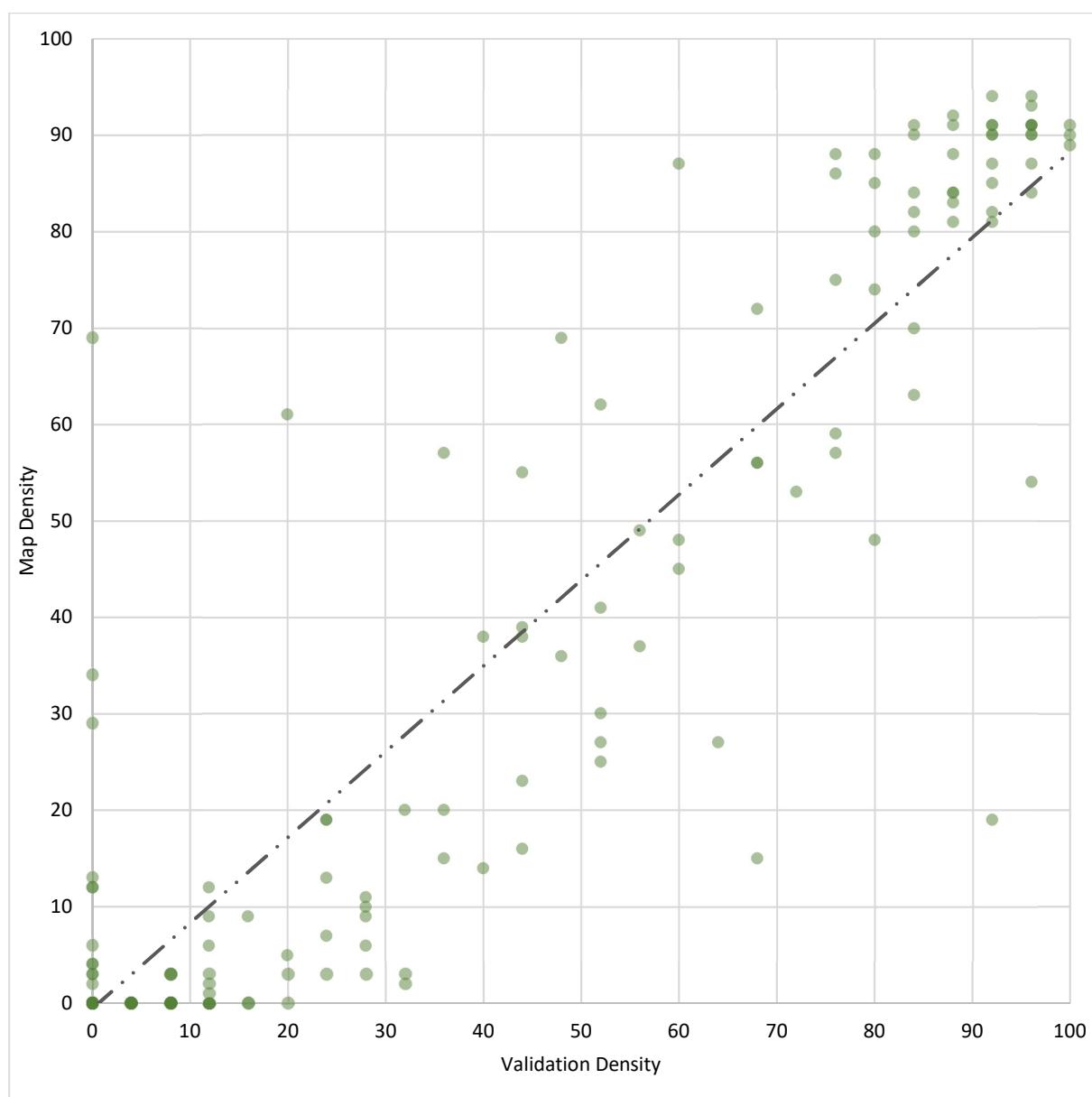


Figure 22: Scatterplot of all sample units for the Mediterranean bio-geographical region HRL TCD, n=3,053, R²=0.73,
Map_Density = 0.833*Validation_Density+2.689



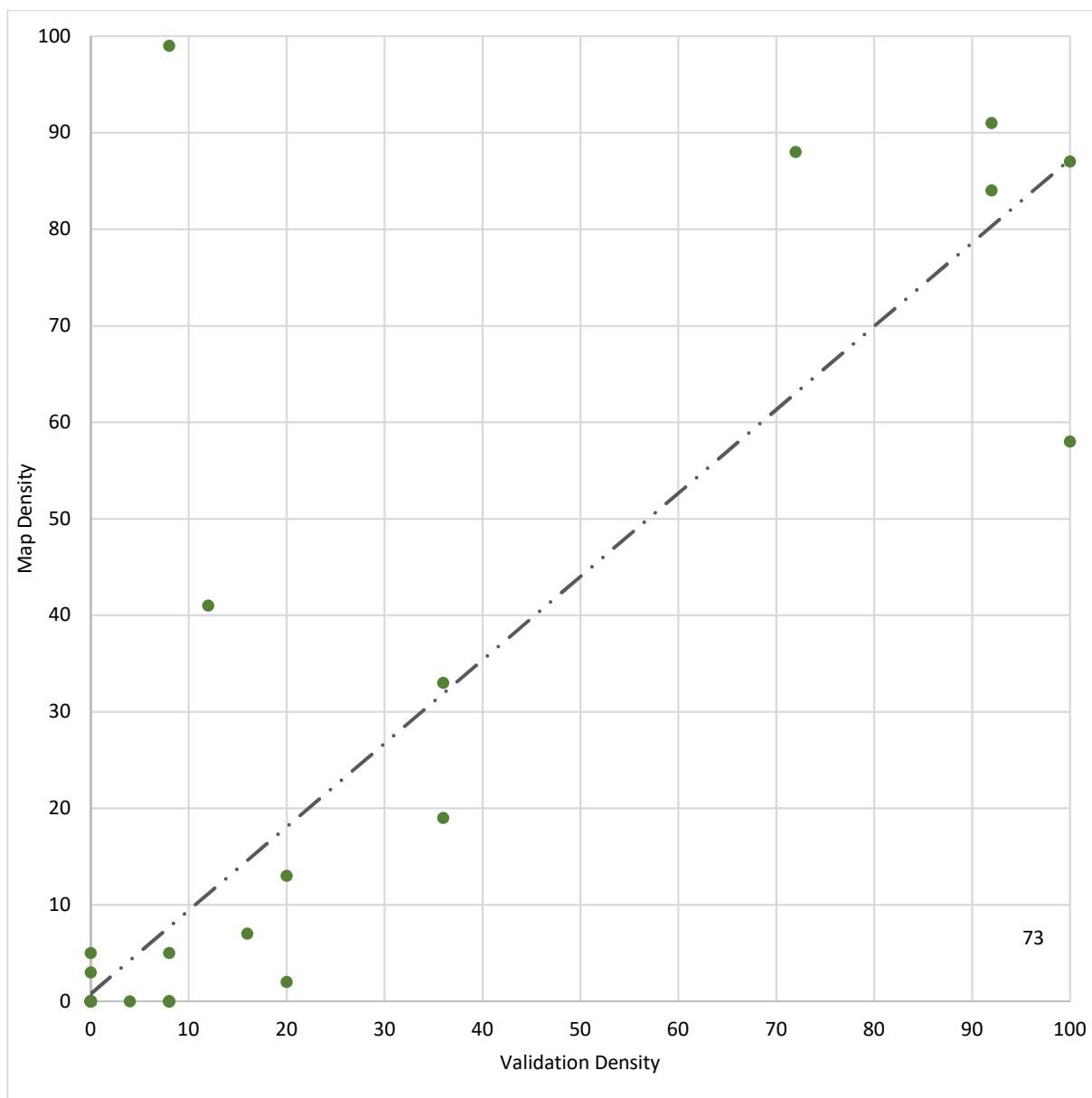


Figure 24: Scatterplot of all sample units for the Steppic bio-geographical region HRL TCD, n=95, $R^2=0.73$, $\text{Map_Density} = 0.8646 * \text{Validation_Density} + 0.7868$

Annex 2. Tree Cover Density (TCD) Scatterplot for countries and group of countries greater than 90,000km²

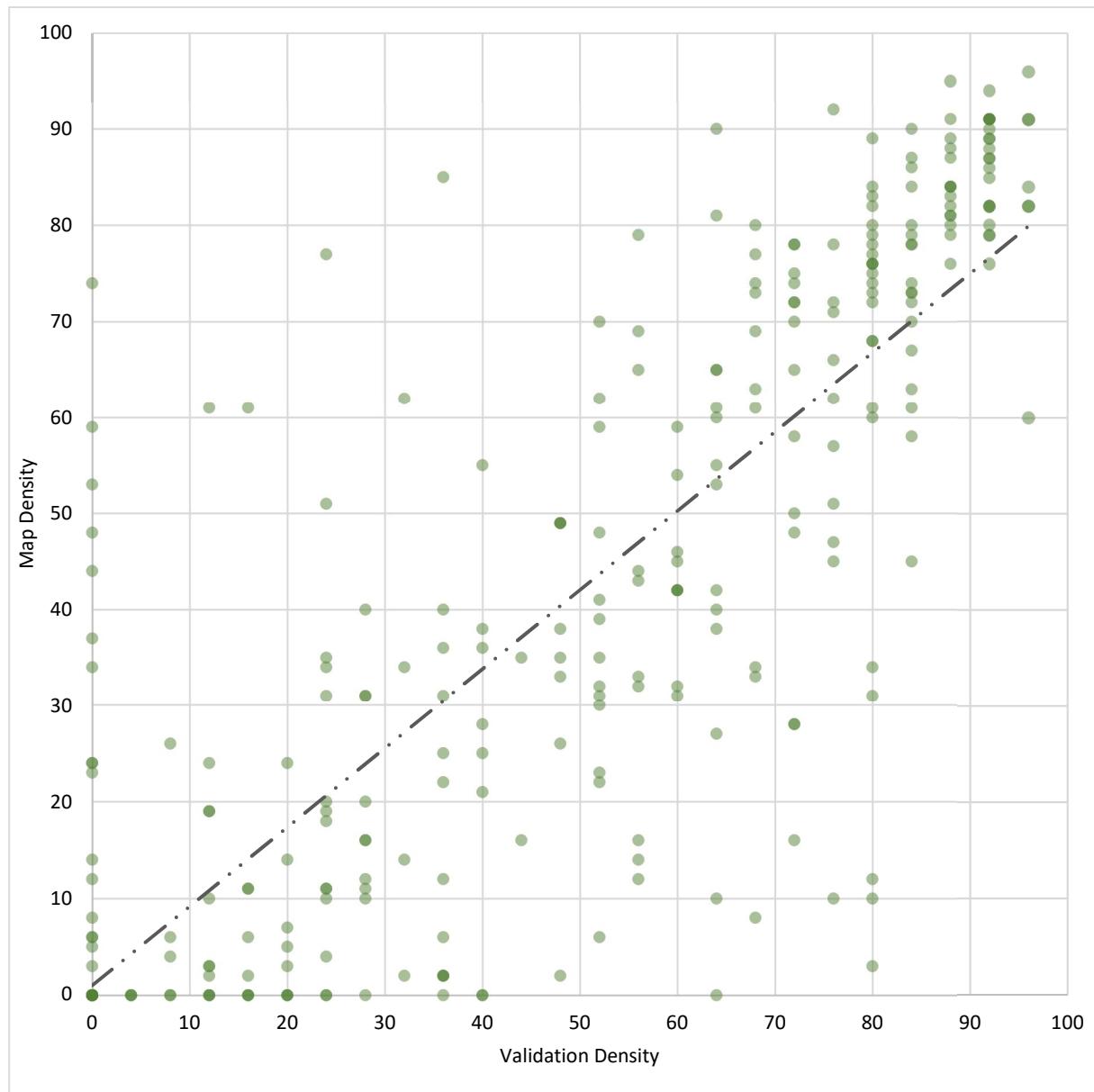


Figure 25: Scatterplot of all sample units for AL+ME+MK+RS+KK HRL TCD, n=406, R²=0.76, Map_Density = 0.8227*Validation_Density+0.9424

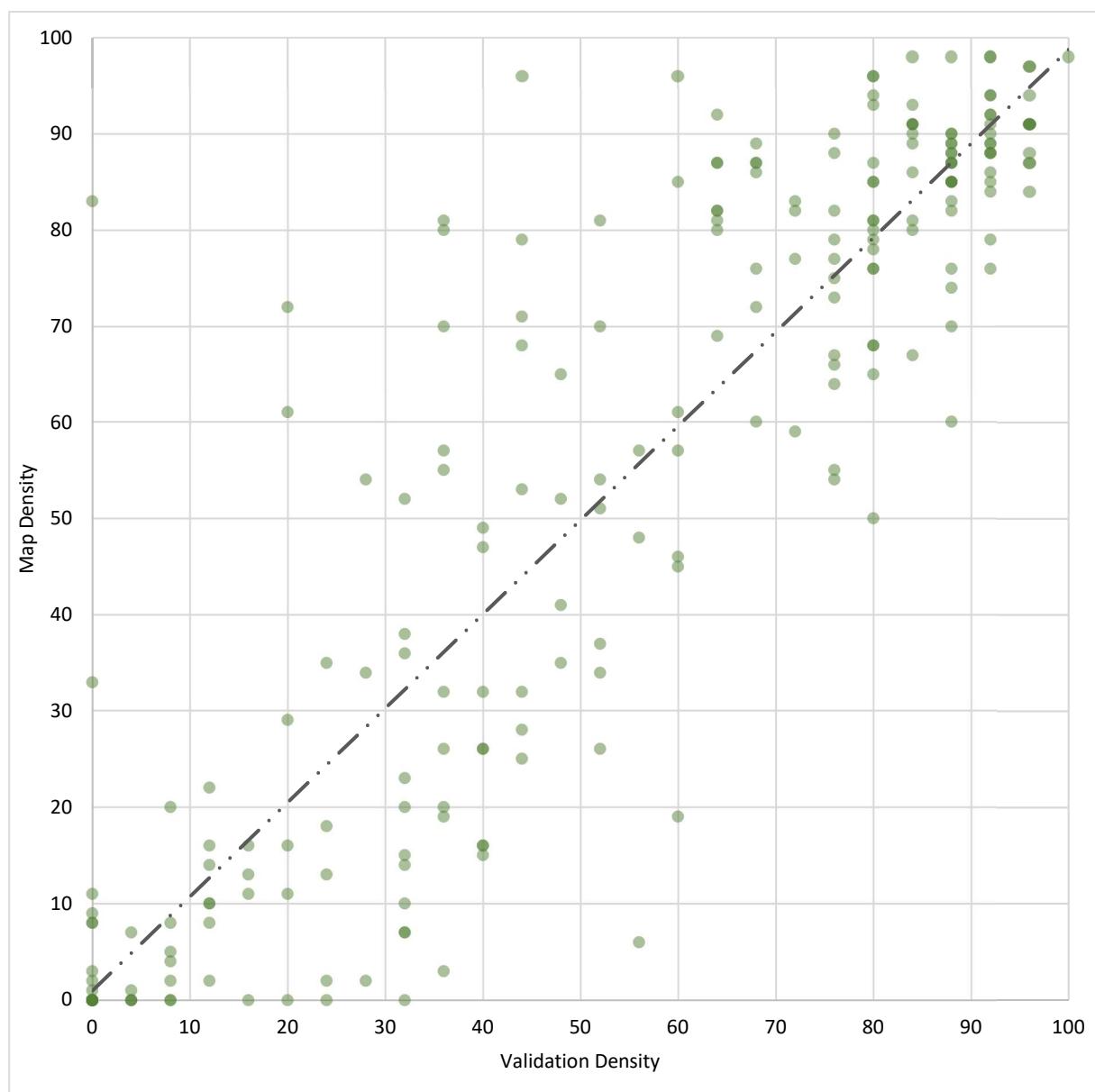


Figure 26: Scatterplot of all sample units for AT+CH+LI HRL TCD, n=322, R²=0.87, Map_Density = 0.978*Validation_Density+0.9642

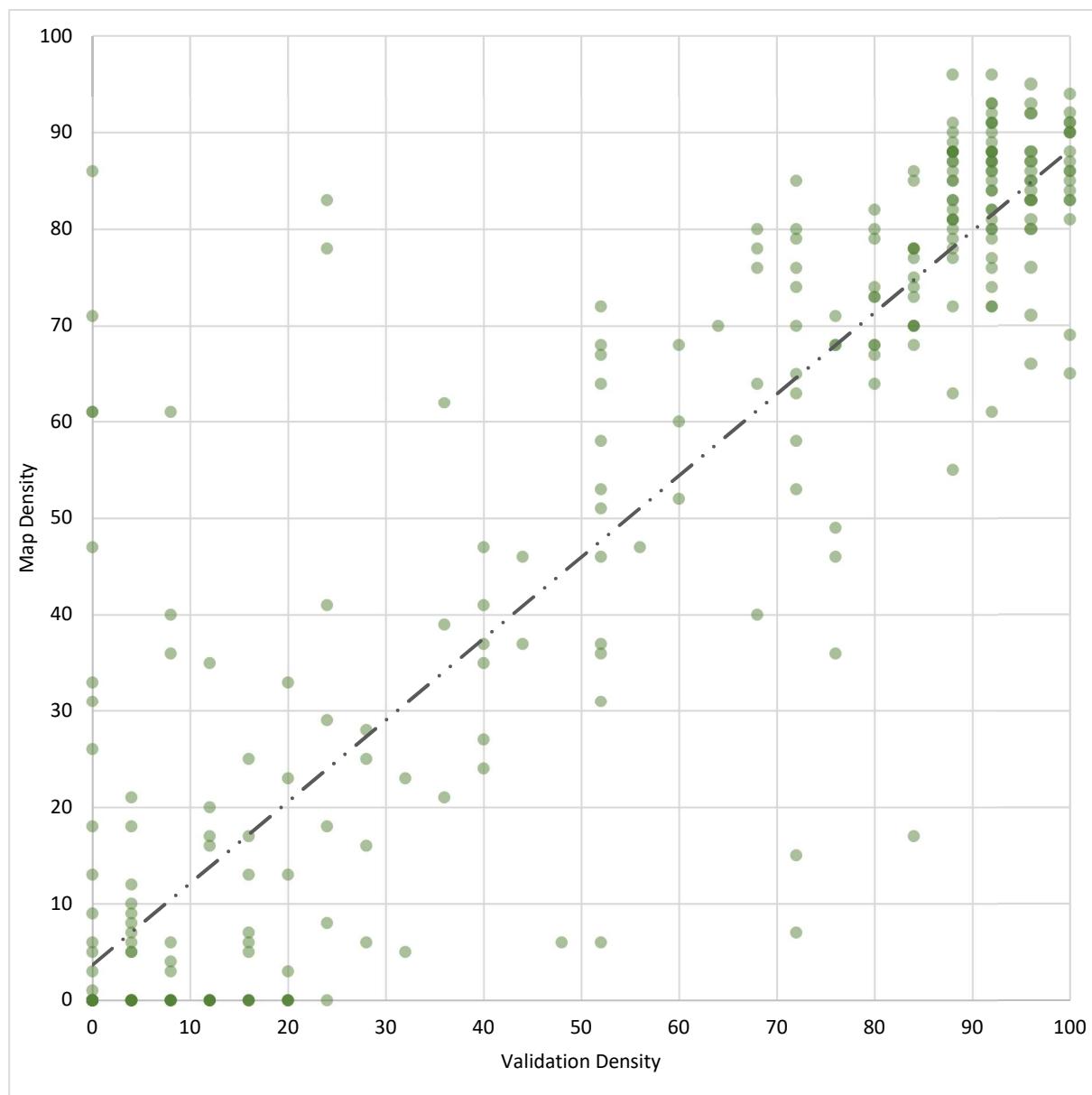


Figure 27: Scatterplot of all sample units for BA + HR + SI HRL TCD, n=324, $R^2=0.84$, $\text{Map_Density} = 0.8457 * \text{Validation_Density} + 3.6551$

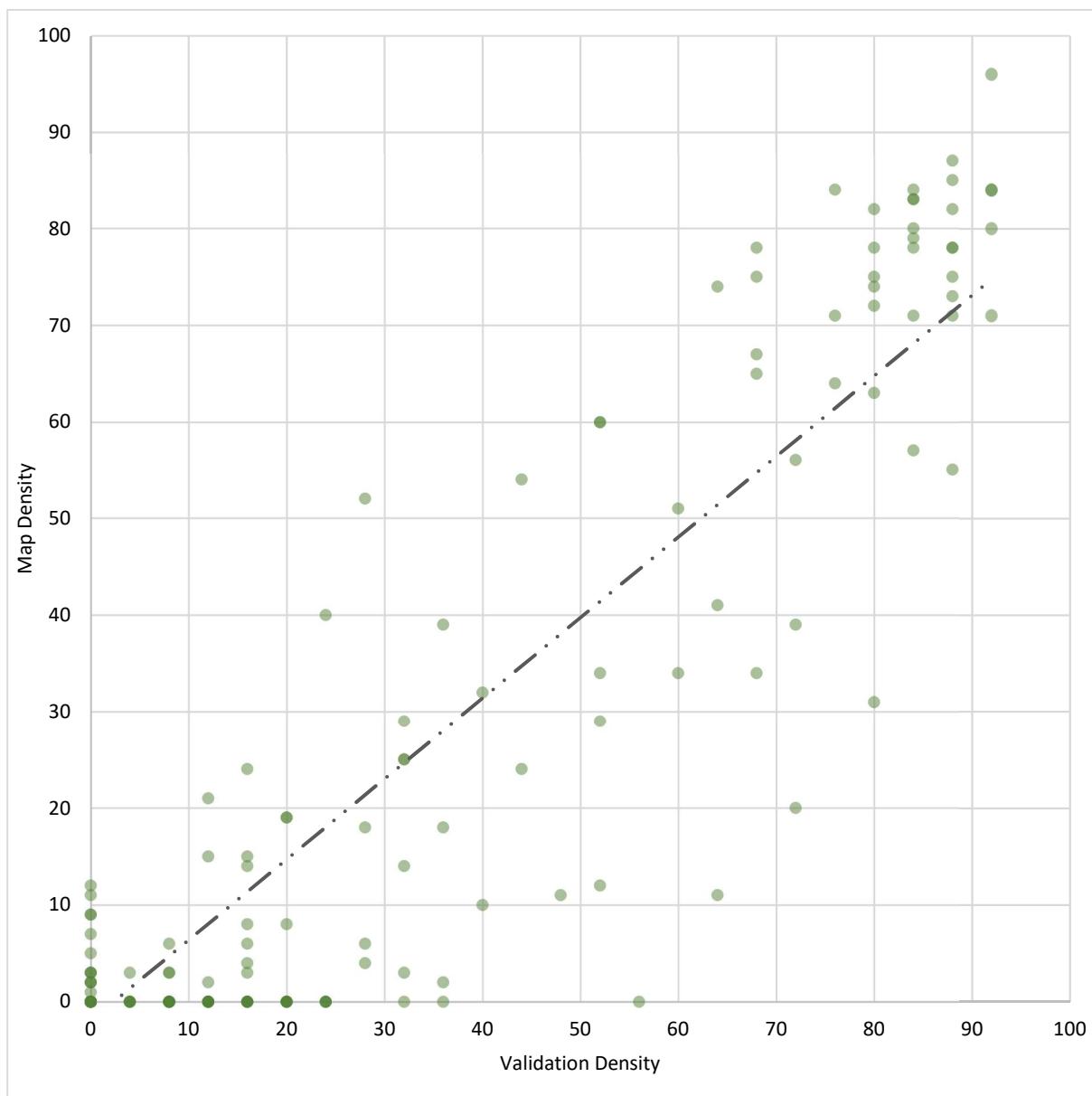


Figure 28: Scatterplot of all sample units for BE + LU+ NL + DK HRL TCD, n=288, R²=0.86, Map_Density = 0.8344*Validation_Density-1.9662

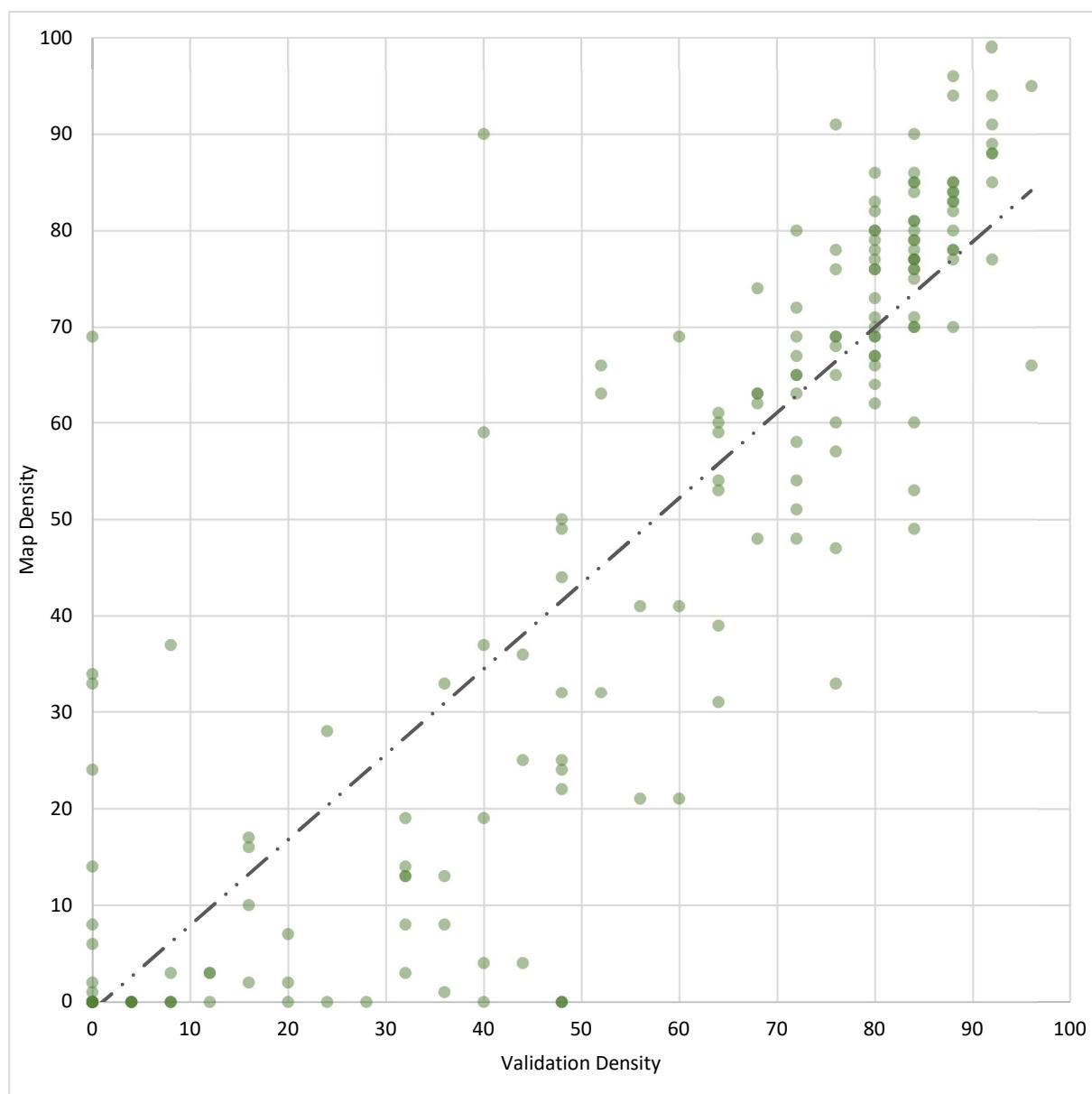
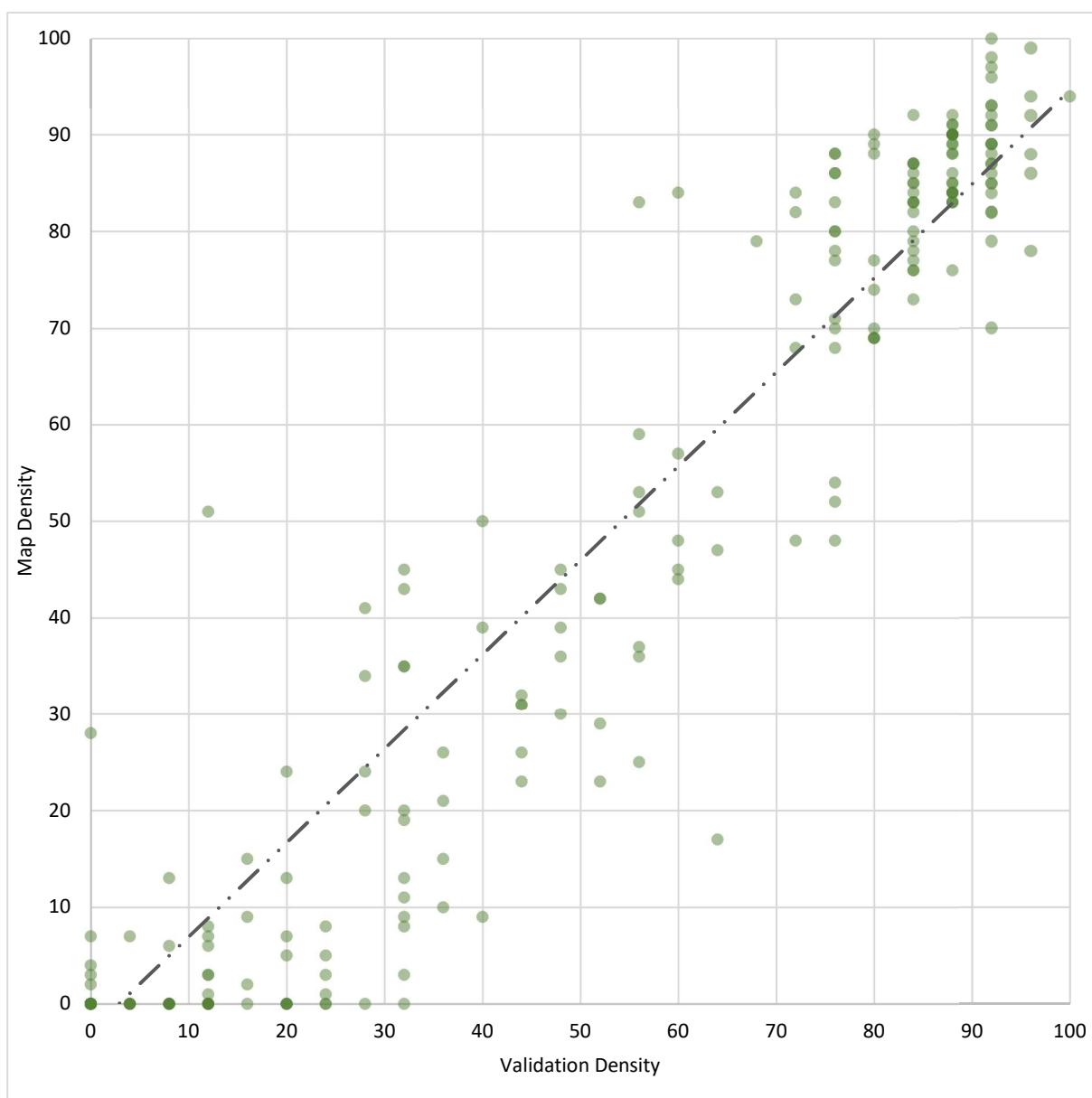


Figure 29: Scatterplot of all sample units for BG HRL TCD, n=282, R²=0.88, Map_Density = 0.8859*Validation_Density - 0.9186



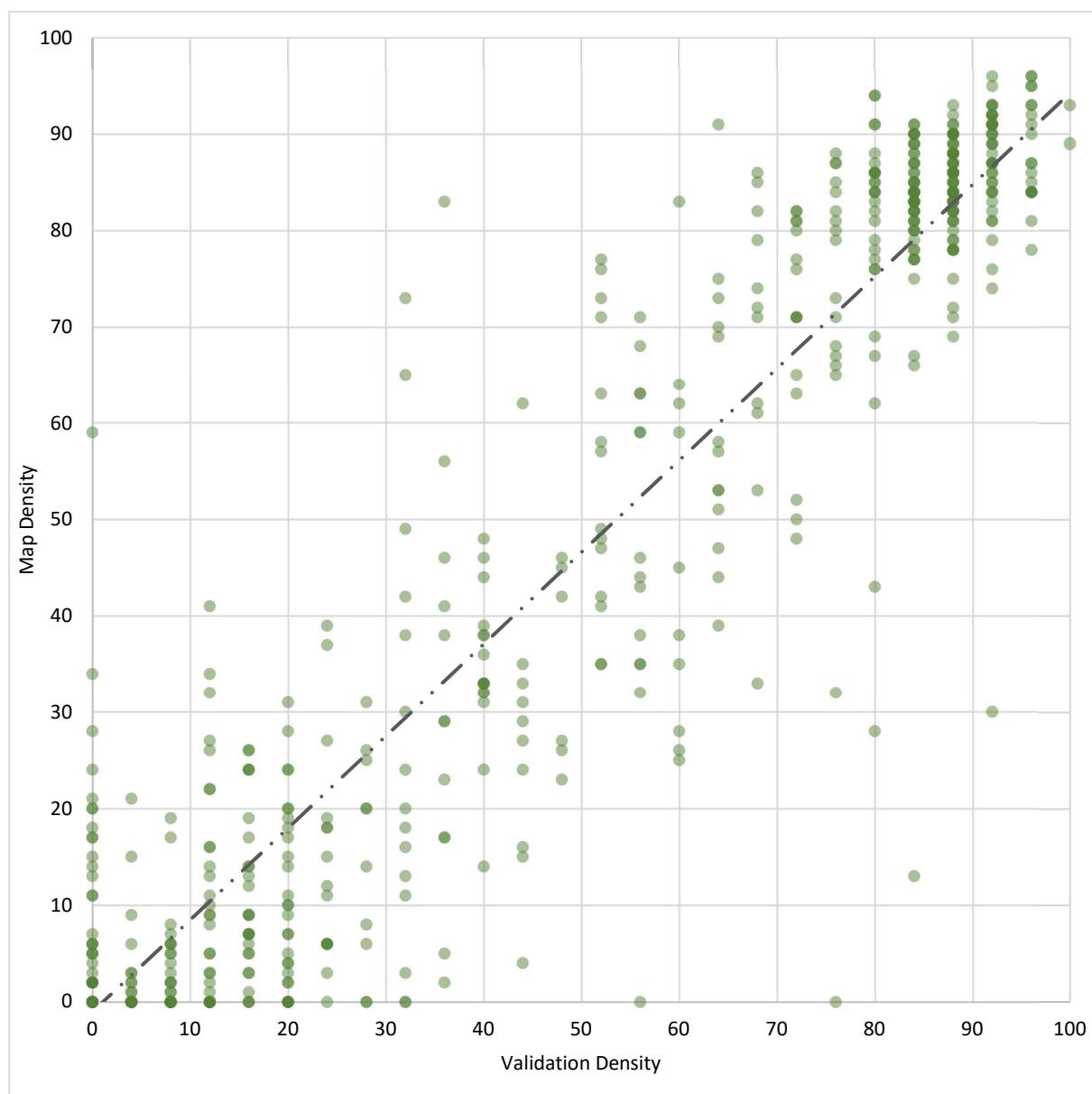


Figure 31: Scatterplot of all sample units for DE HRL TCD, n=939, $R^2=0.92$, $\text{Map_Density} = 0.9531 * \text{Validation_Density} - 1.035$

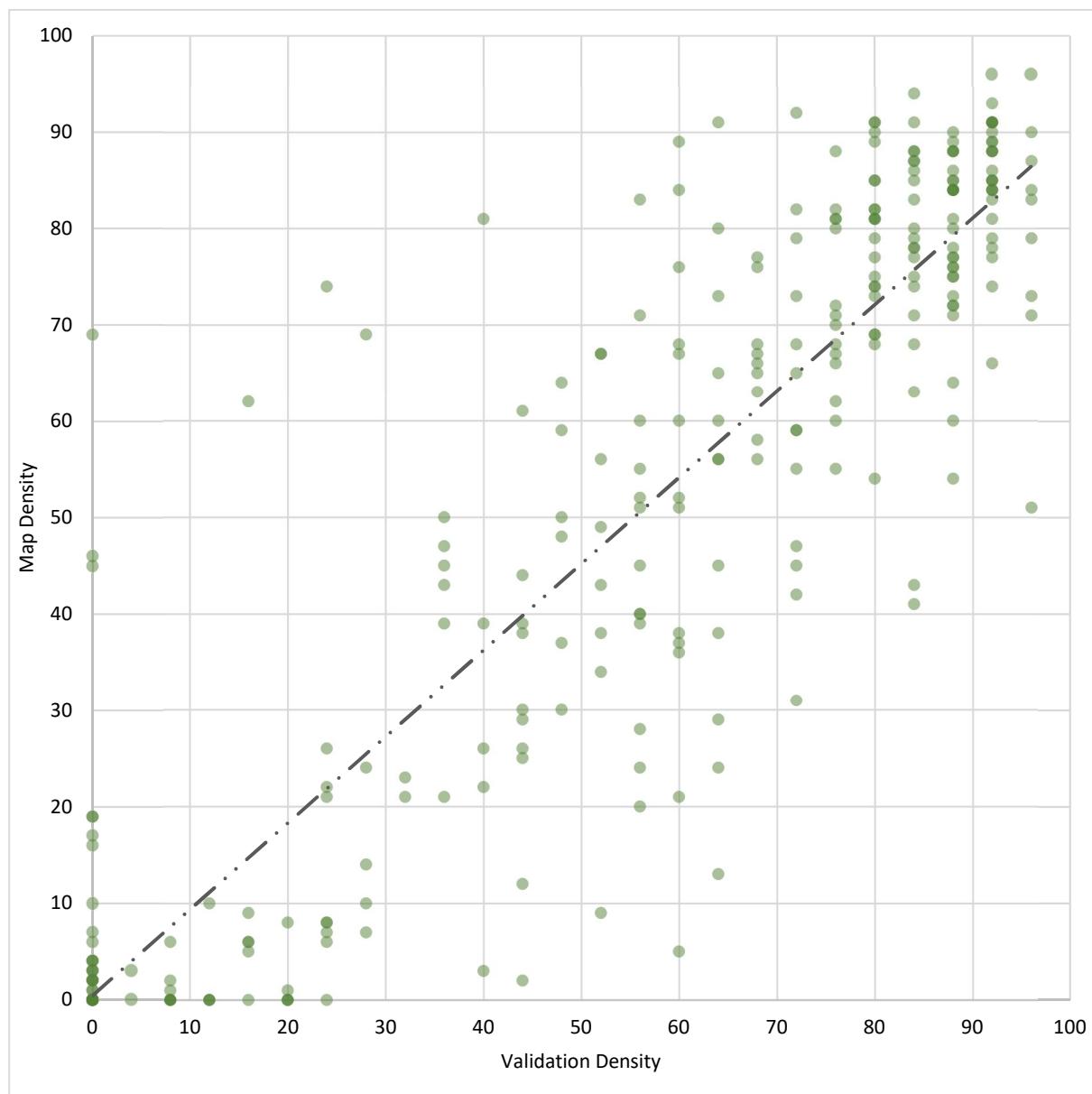


Figure 32: Scatterplot of all sample units for EE + LT + LV HRL TCD, n=449, $R^2=0.88$, Map_Density = $0.8958 * \text{Validation_Density} + 0.4239$

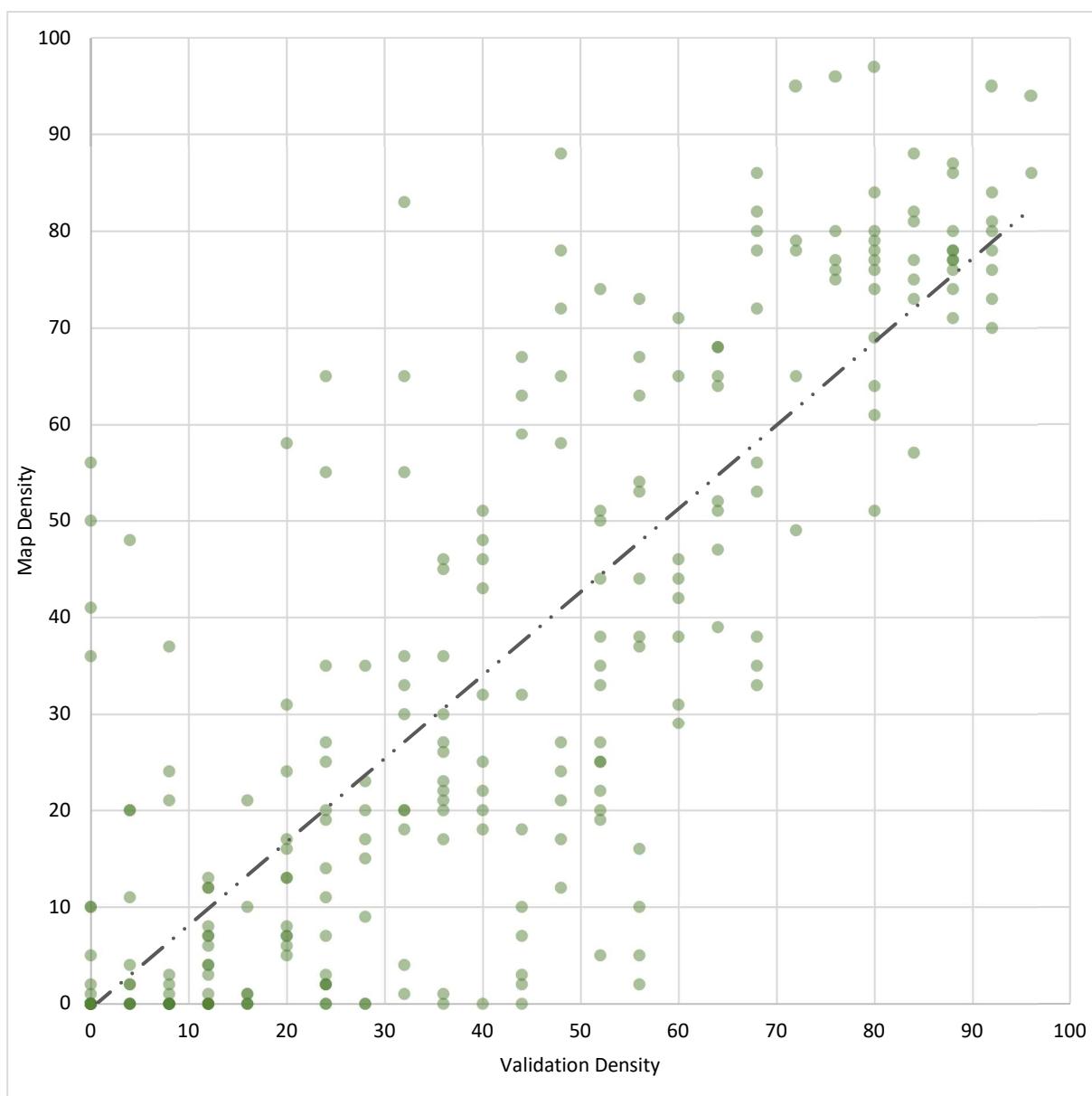


Figure 33: Scatterplot of all sample units for EL HRL TCD, n=342, $R^2=0.74$, $\text{Map_Density} = 0.8626 * \text{Validation_Density} - 0.5168$

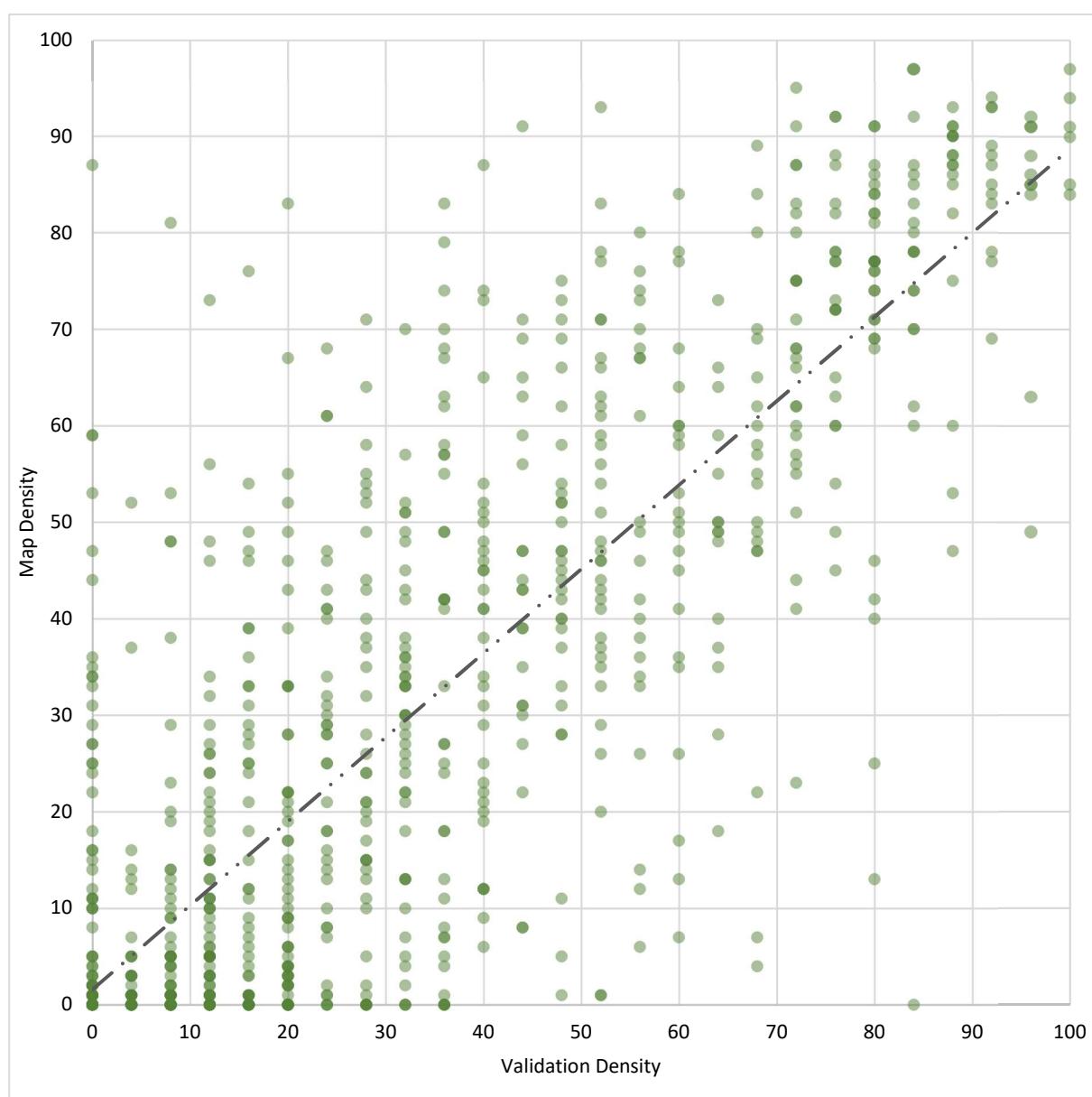


Figure 34: Scatterplot of all sample units for ES HRL TCD, n= 1305, $R^2 = 0,73$, $Map_Density = 0,8719 * Validation_Density + 1.5603$

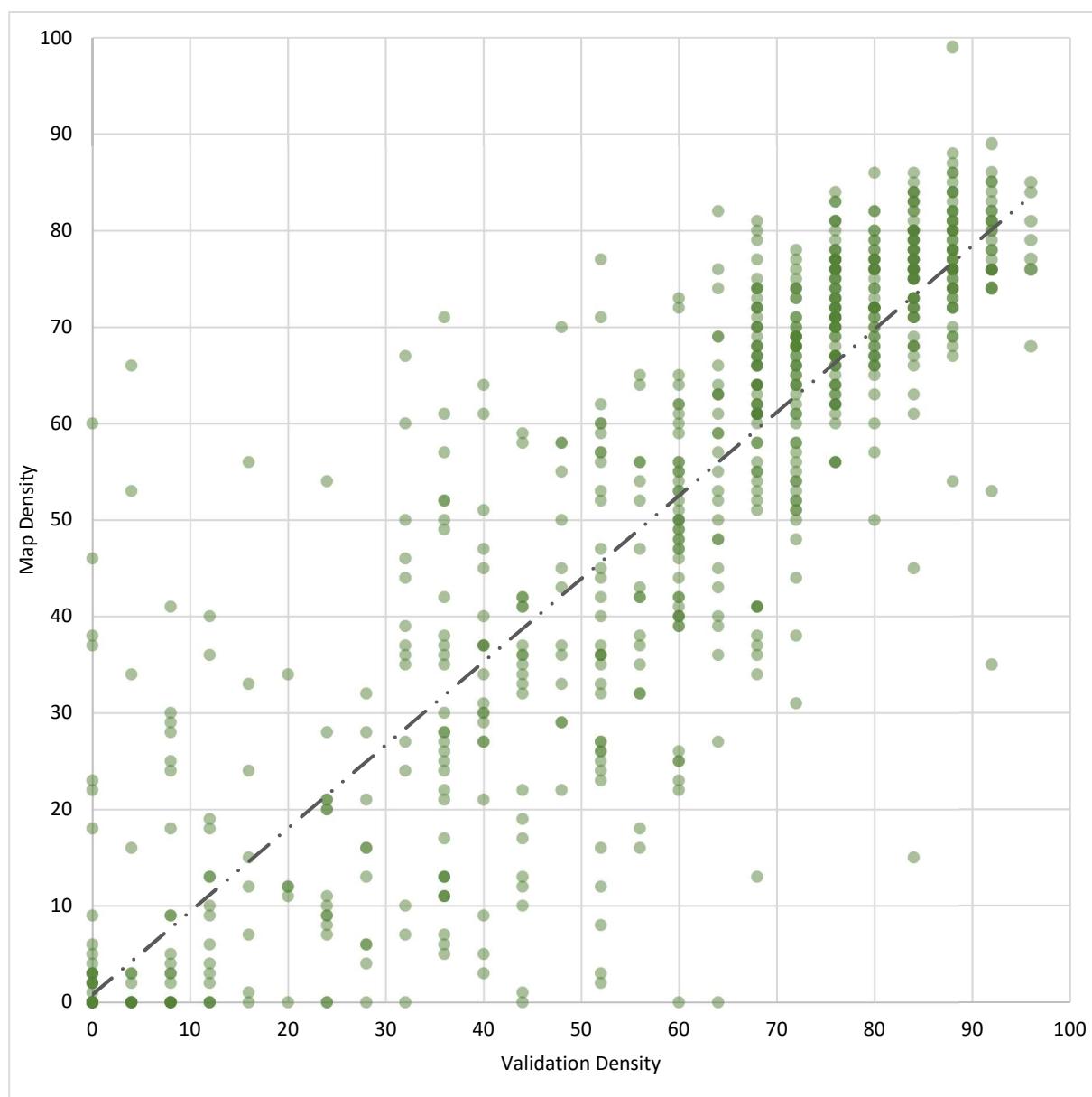


Figure 35: Scatterplot of all sample units for FI HRL TCD, n=872, R²=0.84, Map_Density = 0.8626*Validation_Density+0.7699

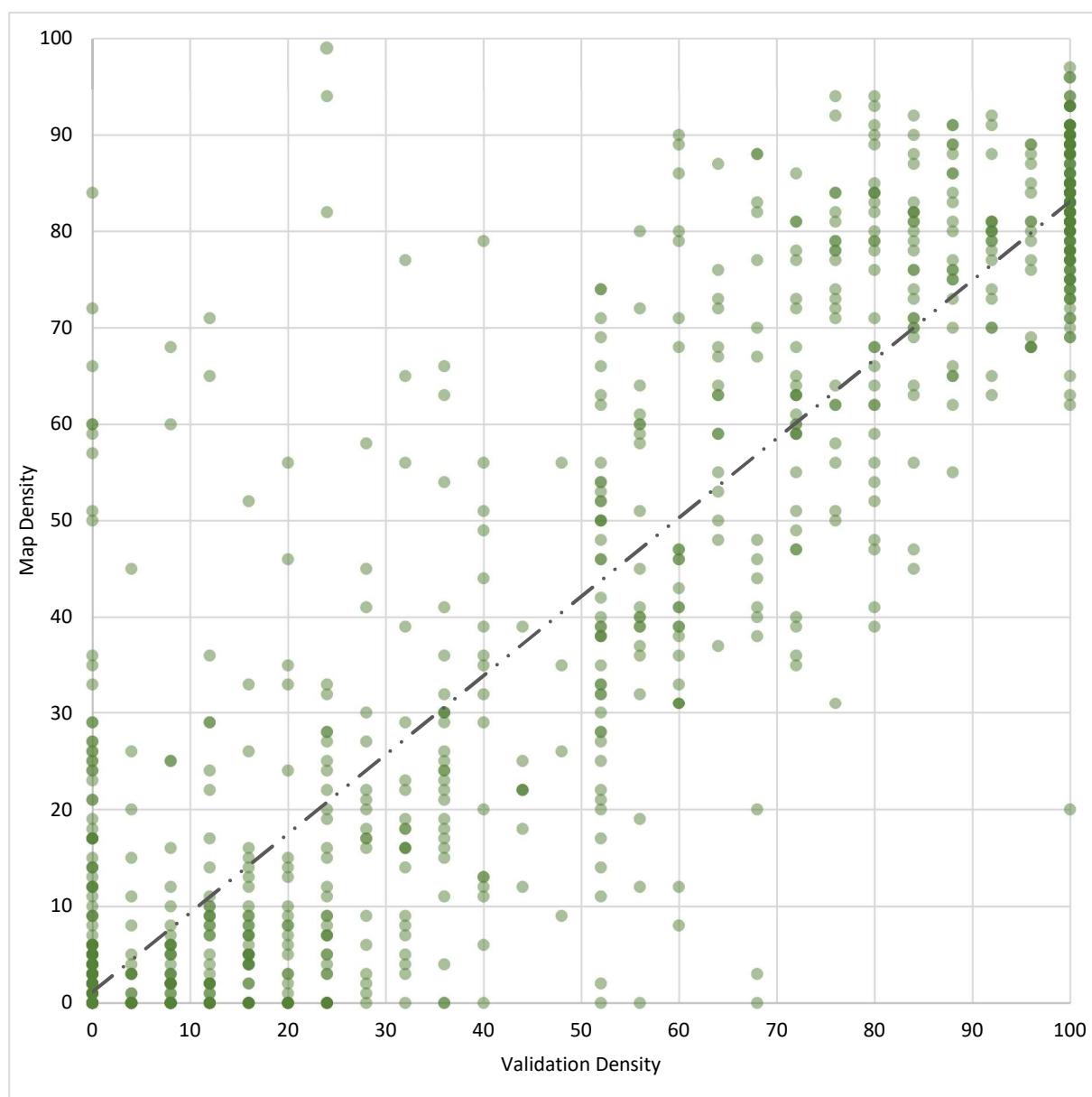
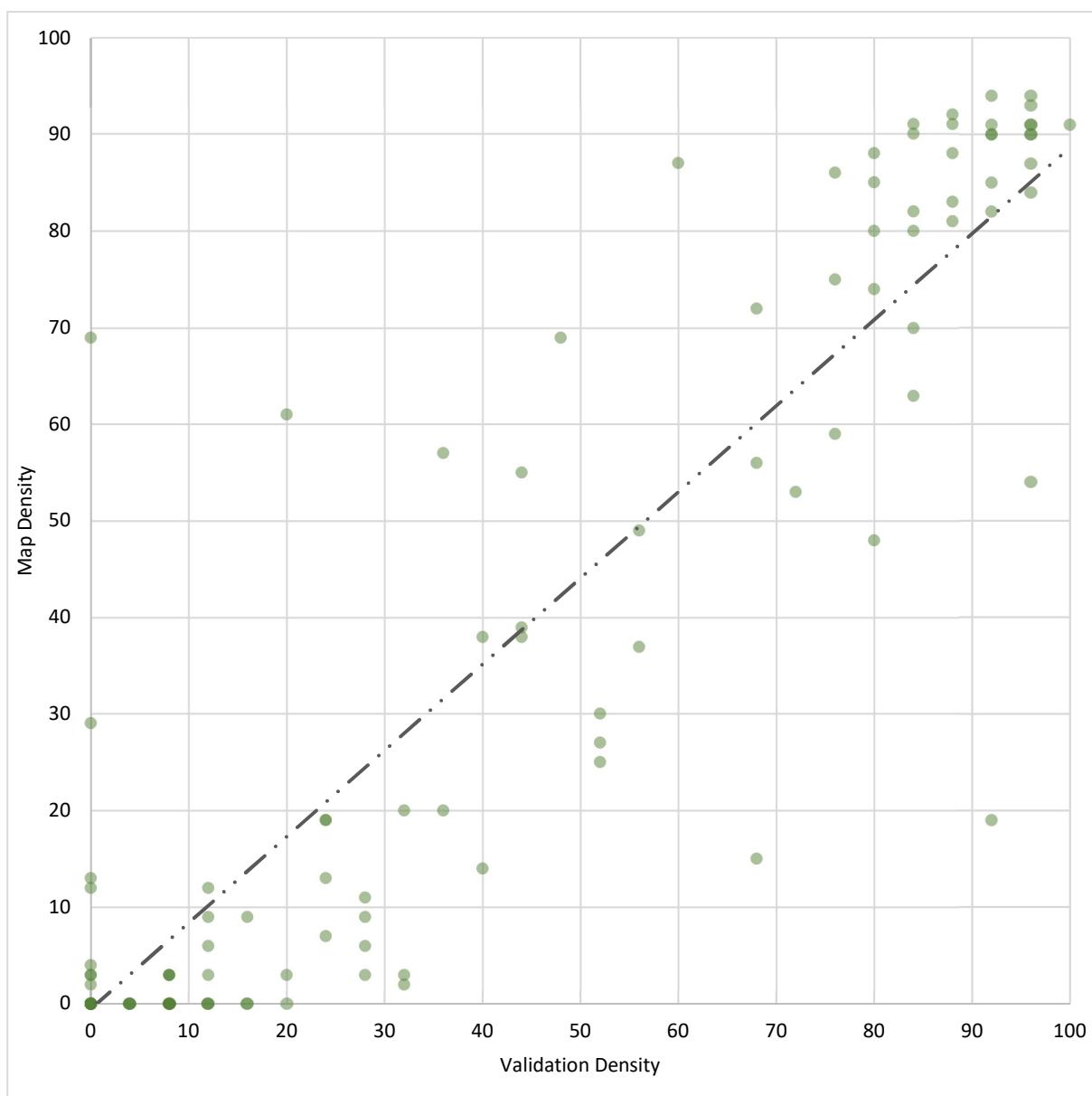


Figure 36: Scatterplot of all sample units for FR HRL TCD, n=1402, $R^2=0.85$, $\text{Map_Density} = 0.8197 * \text{Validation_Density} + 1.1329$



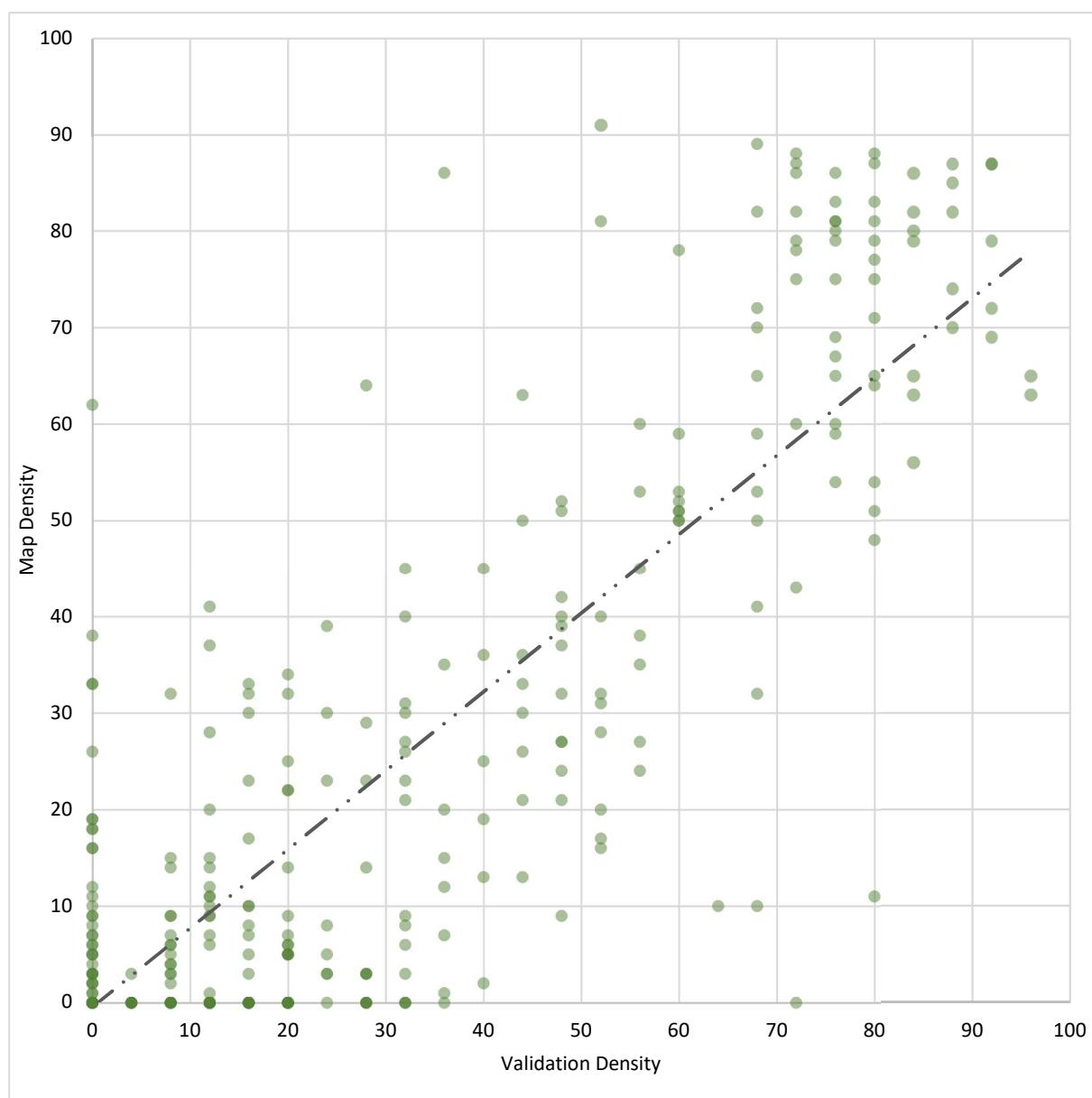
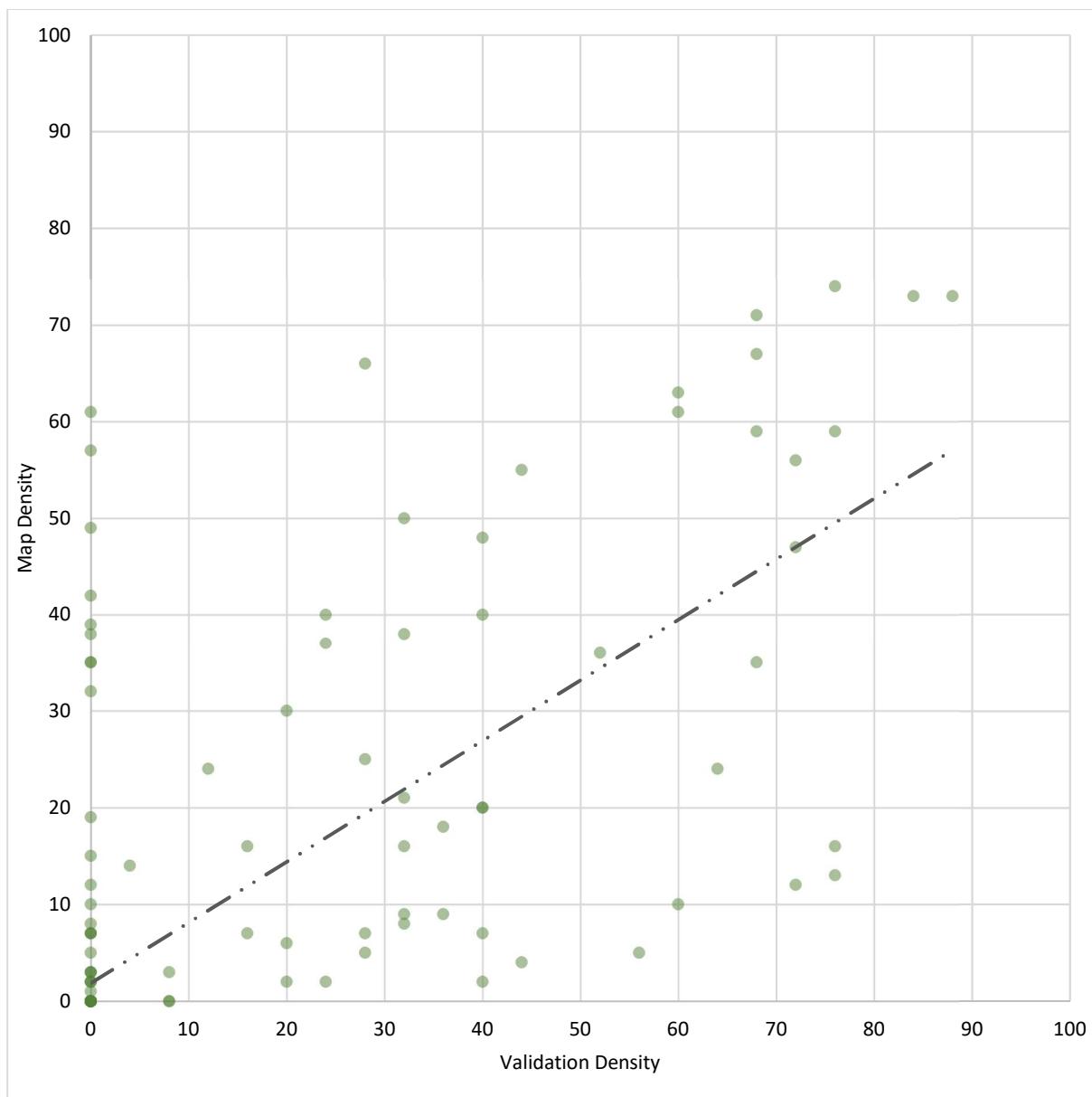


Figure 38: Scatterplot of all sample units for IE + UK HRL TCD, n=804, R²=0.79, Map_Density = 0.8175*Validation_Density - 0.5079



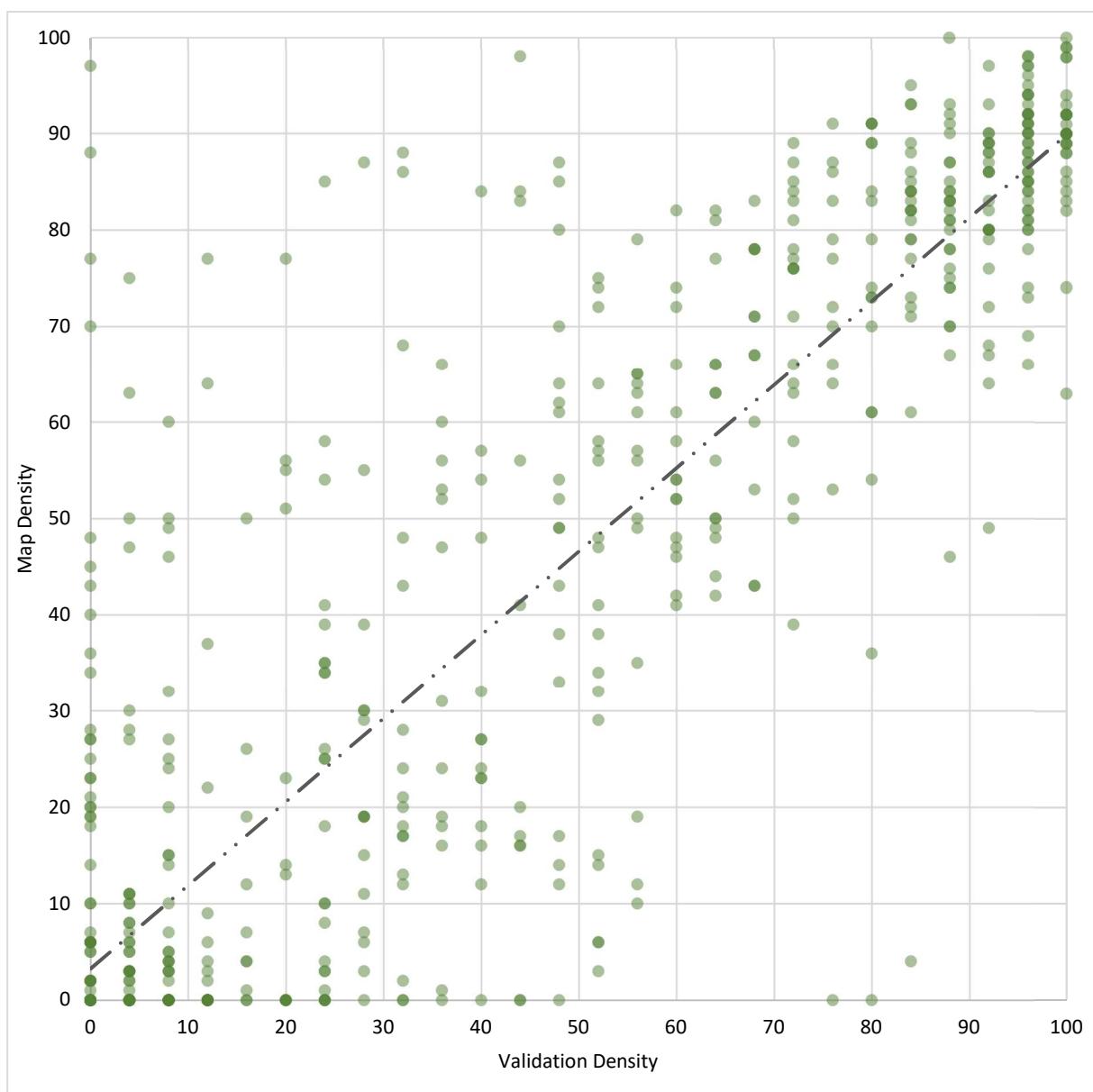


Figure 40: Scatterplot of all sample units for IT HRL TCD, n=773, $R^2=0.78$, $\text{Map_Density} = 0.8668 * \text{Validation_Density} + 3.2402$

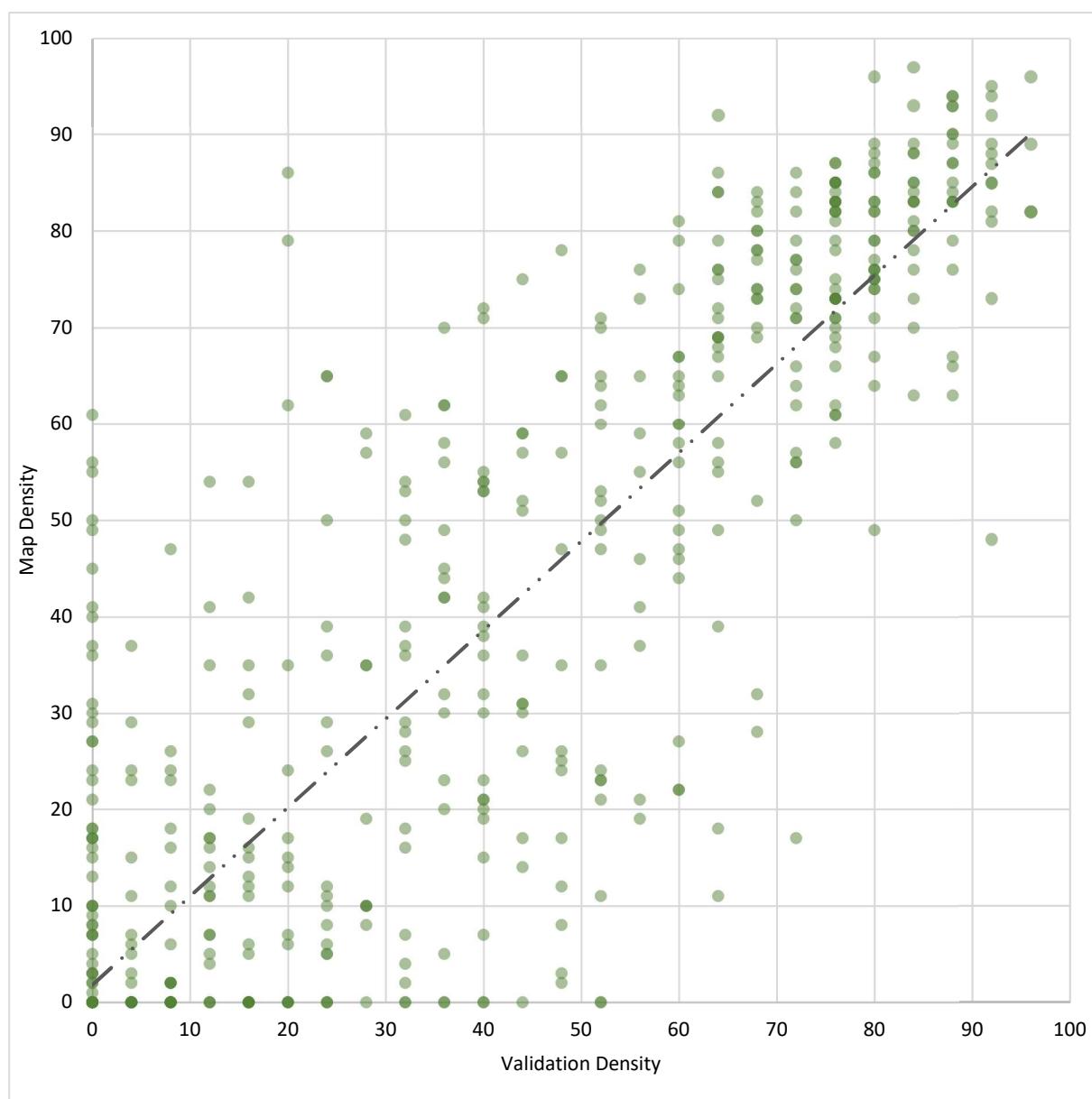


Figure 41: Scatterplot of all sample units for NO HRL TCD, n=853, $R^2=0.82$, Map_Density = $0.9204 * \text{Validation_Density} + 1.7893$

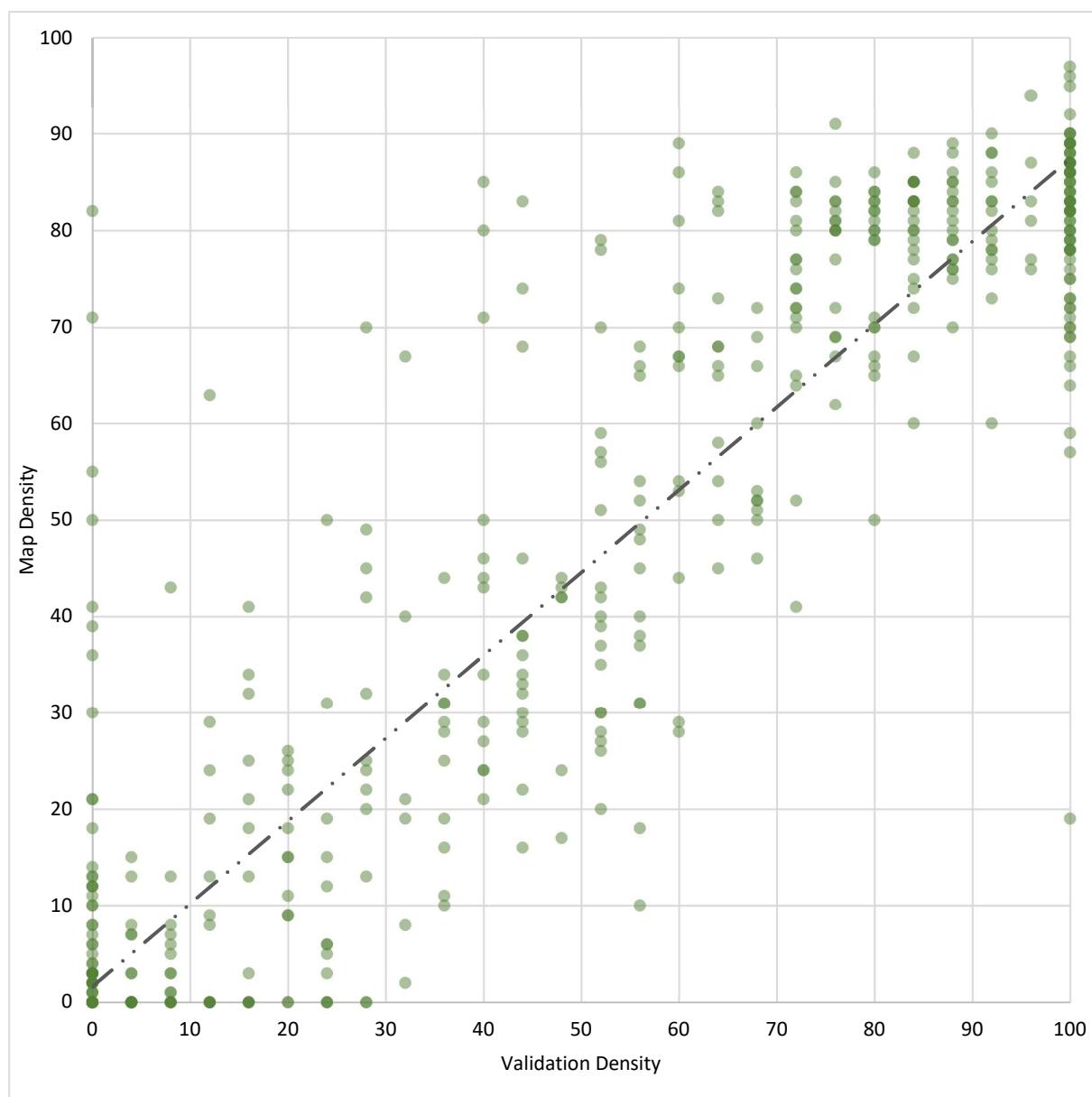


Figure 42: Scatterplot of all sample units for PL HRL TCD, n=810, R²=0.89, Map_Density = 0.8585*Validation_Density+1.6097

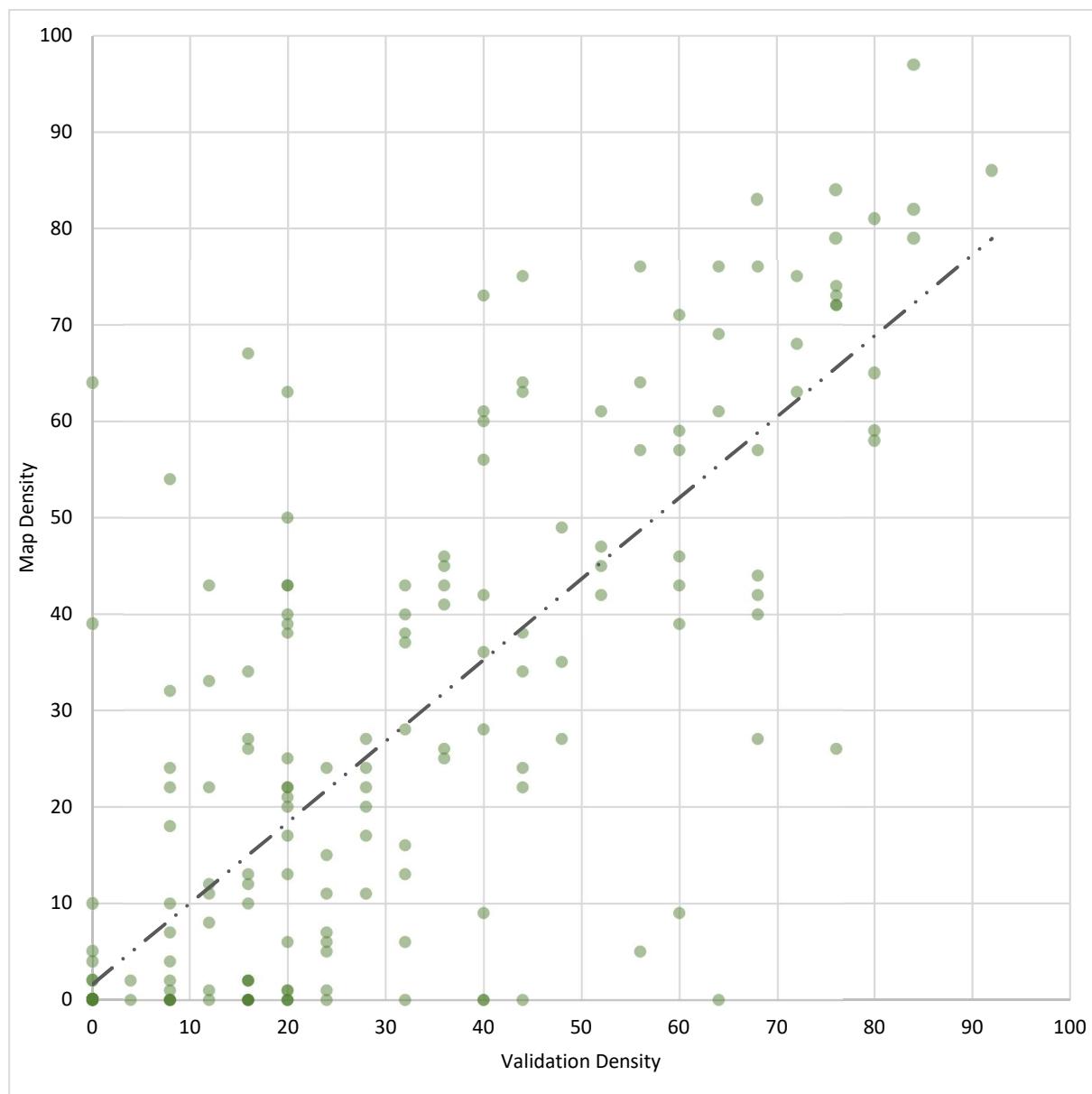


Figure 43: Scatterplot of all sample units for PT HRL TCD, n=233, $R^2=0.66$, $\text{Map_Density} = 0.8406 * \text{Validation_Density} + 1.6119$

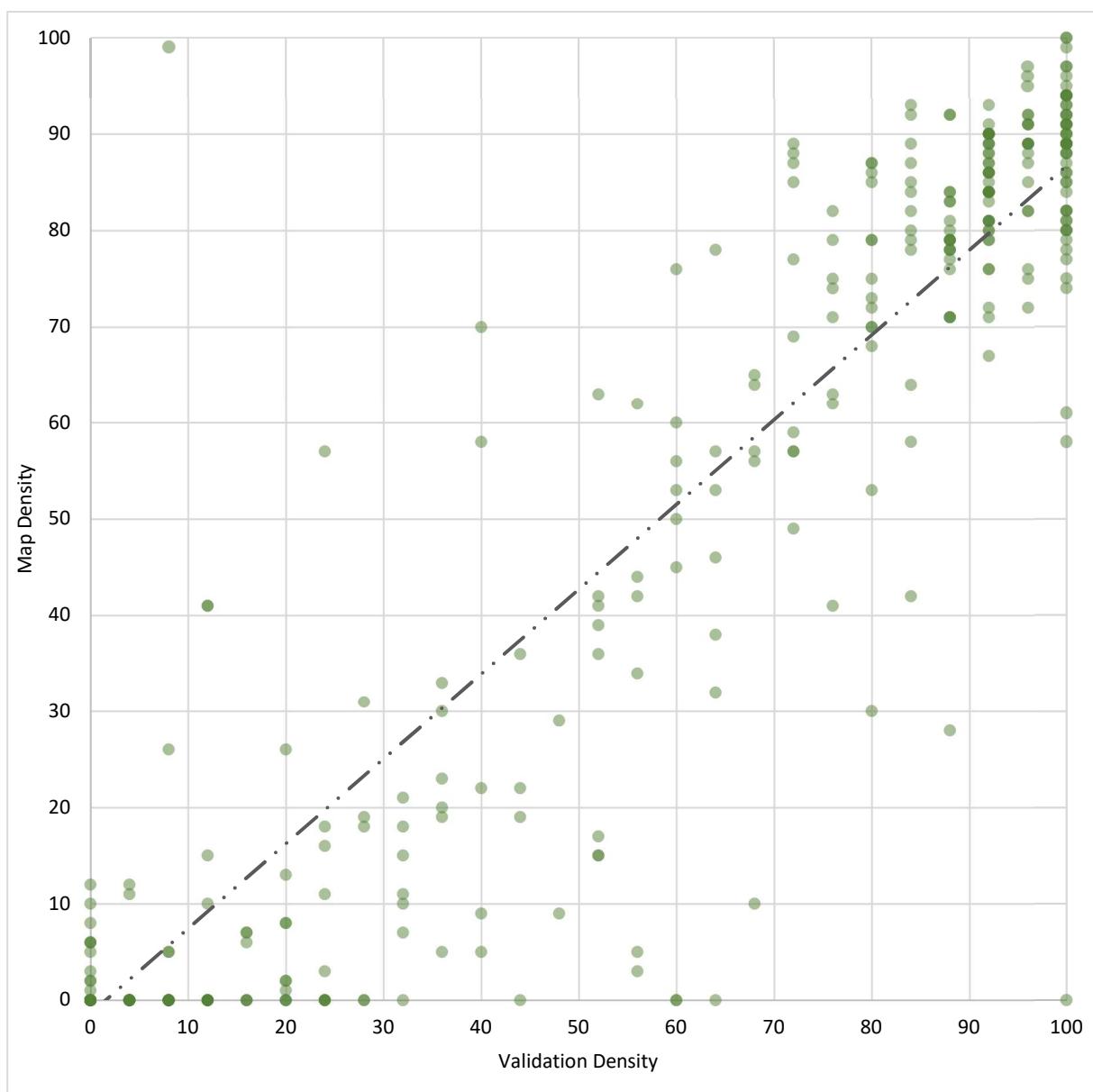


Figure 44: Scatterplot of all sample units for RO HRL TCD, n=600, $R^2=0.9077$, $\text{Map_Density} = 0.8809 * \text{Validation_Density} - 1.3879$

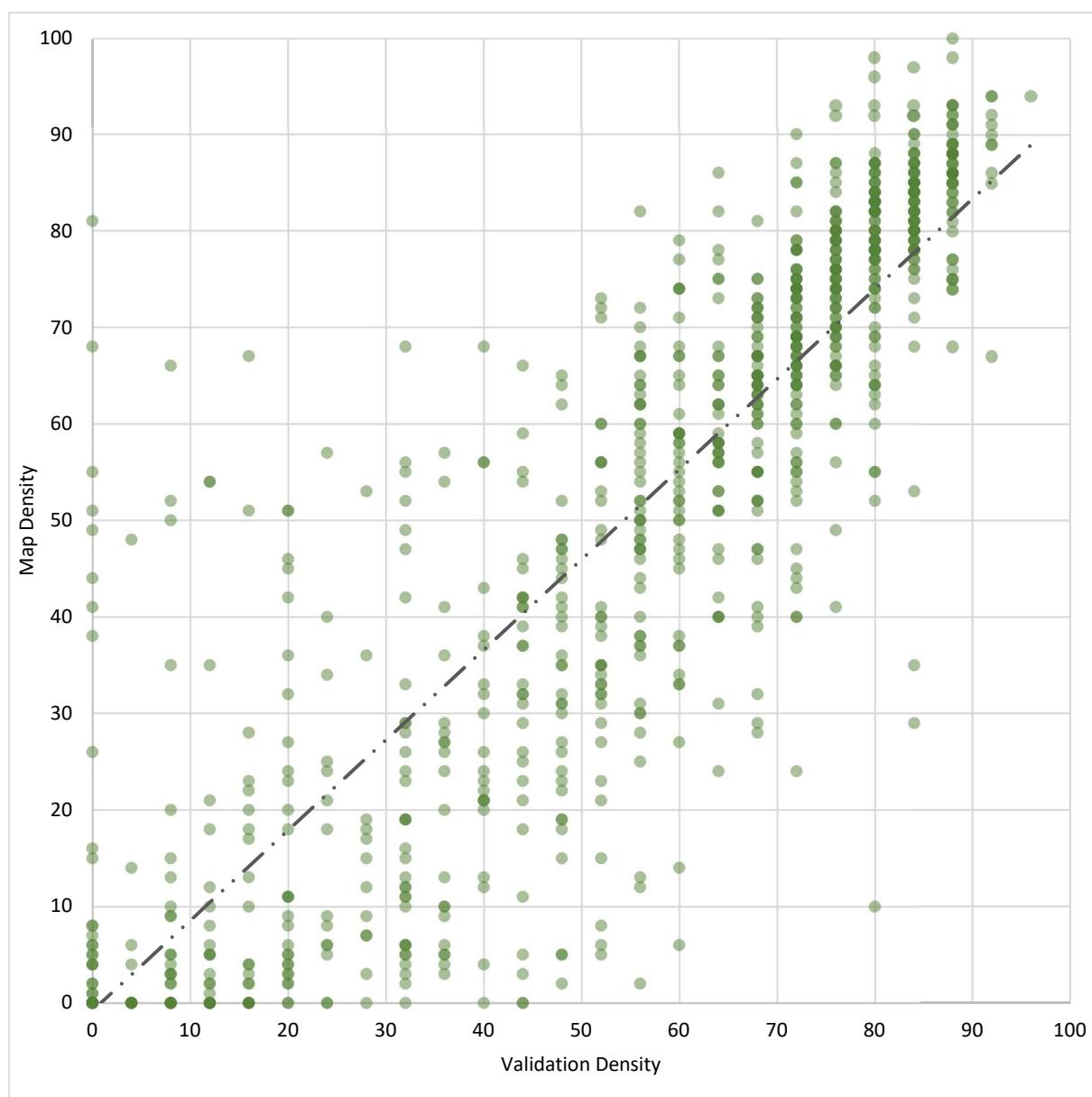


Figure 45: Scatterplot of all sample units for SE HRL TCD, n=1166, $R^2=0.84$, $\text{Map_Density} = 0.9352 * \text{Validation_Density} - 0.8252$

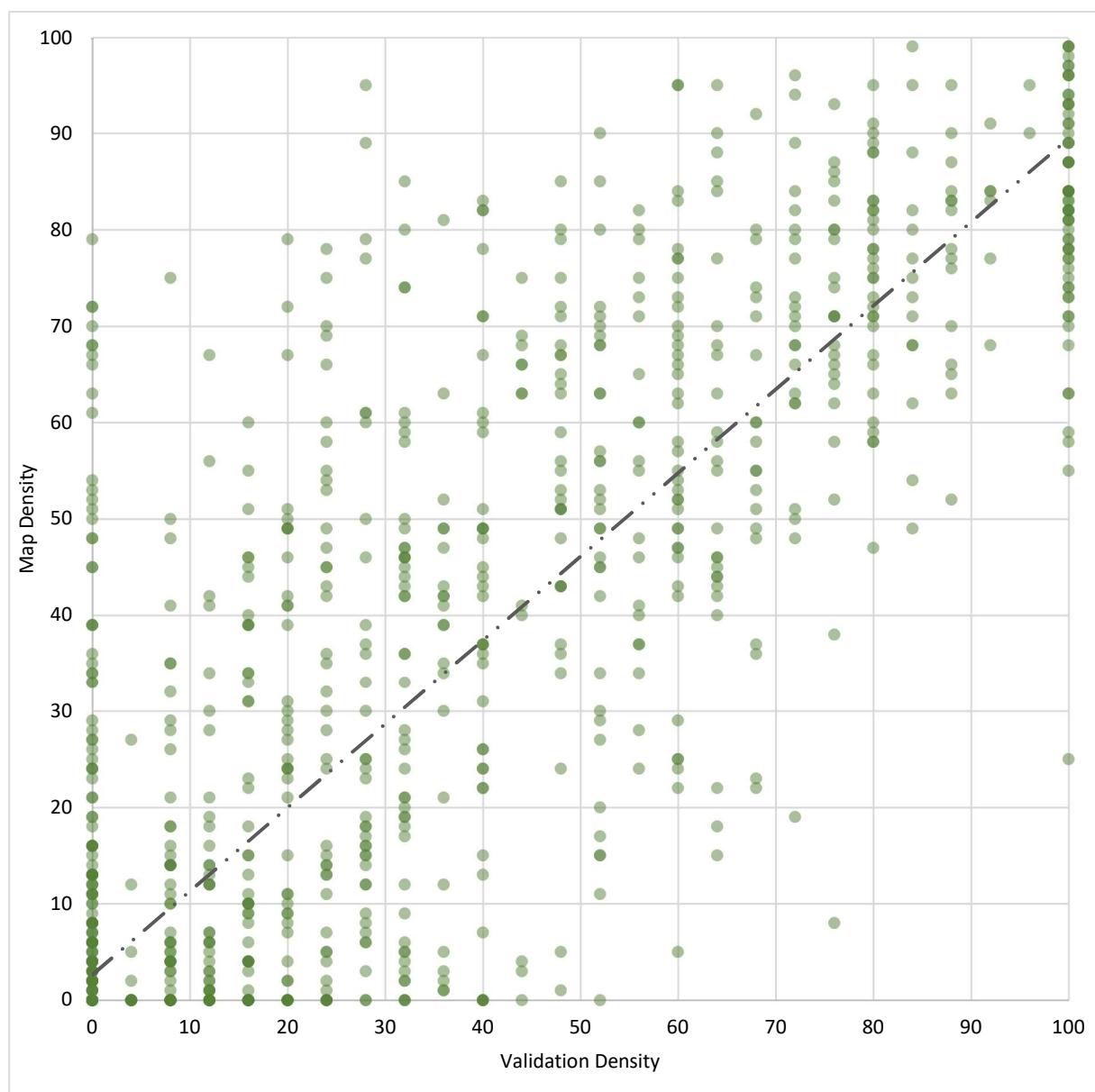


Figure 46: Scatterplot of all sample units for TR HRL TCD, n=1996, $R^2=0.76$, $\text{Map_Density} = 0.8691 * \text{Validation_Density} + 2.6184$