EPA STRIVE Programme 2007-2013

Multiple Classifier System

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ISIS Final Technical Report 12

Prepared for the Environmental Protection Agency
by
Teagasc and Cranfield University

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DISCLAIMER

The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA STRIVE PROGRAMME 2007-2013

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Executive Summary

The Irish Soil Information System (ISIS) project was established in 2008, following a comprehensive inventory of Irish soil data compiled by Daly and Fealy (2007) which highlighted that soil data coverage of Ireland was incomplete in both detail and extent. The ISIS project is funded under the Environmental Protection Agency STRIVE Research Programme 2007-2013 and co-funded by Teagasc. It was led by Teagasc with the participation of researchers from Cranfield University (UK) and University College Dublin. The overall objective of the ISIS project was to conduct a programme of structured research into the national distribution of soil types and construct a soil map, at 1:250,000 scale, which will identify and describe the soils according to a harmonised national legend. This map is now available in digital format and forms the basis of a new soil information system for Ireland (http://isis.teagasc.ie).

The ISIS project has utilised existing data and maps from the previous National Soil Survey (NSS) conducted by An Foras Talúntais (forerunner organisation to Teagasc). The NSS produced: mapping at 1:126,720 scale for 44% of the country; a General Soil Map of Ireland and a National Peatland map, both at 1:575,000 scale and other miscellaneous large scale mapping of experimental farms. In addition, more recent map products have been included such as the Indicative Soil and Subsoil mapping (Fealy and Green, 2009) with national coverage using GIS and remote sensing techniques.

Comparison of soil information at European scale has led to the requirement for the harmonisation and coordination of soil data across Europe, and, in light of the demands for soil protection on a regional basis within member states there is a growing need to support policy with a harmonised soil information system. The European Soil Bureau Network (ESBN) Technical Working Group dealing with Soil Monitoring and Harmonisation recommended a soil map of Europe at a scale of 1:250,000 as an economically feasible intermediate scale that can identify specific problems at regional scale (Montanarella and Jones, 1999).

The ISIS project adopted a combined methodology of utilising novel predicted mapping techniques in tandem with traditional soil survey applications. This unique combination at a national scale has resulted in the development of a new national soil map for Ireland. Building upon the detailed work carried out by the An Foras Talúntais (AFT) survey (known as *Terra Cognita*), the ISIS project generated soil-landscape models at a generalised scale of 1:250,000 for the counties of Carlow, Clare, Kildare, Laois, Leitrim, Limerick, Meath, Offaly, Tipperary South, Waterford, Westmeath, Wexford, West Cork, West Mayo and West Donegal. These soil-landscape models (also referred to as soilscapes) were used as the baseline data for statistical models (random forests, Bayesian belief networks and neural networks) to predict soil map units in counties where there was no map available (referred to as *Terra Incognita*). To validate the methodology, this work was supported by a 2.5 year field survey, in which 11,000 locations were evaluated for soil type, using an auger bore survey approach. These data were used to check the predicted soil mapping units (associations) for counties: Cavan, Dublin, East Cork, East Donegal, East Mayo, Galway, Kerry, Kilkenny, Louth, Monaghan, Roscommon, Sligo, Tipperary South and Wicklow, where a detailed soil

survey map was not available. Where new soil information was generated, due to previously unknown combinations of soil-landscape units, profile pits were selected at representative locations across the country. These 225 pits were described and sampled in detail and were used to generate a new soil classification system for the country. The final product is a unique combination of new and traditional methodologies and soils data from both the AFT and the ISIS project. The final, soil association map of Ireland consists of 58 associations (excluding areas of alluvium, peat, urban, rock or marsh) that are made up from 213 soil series. Associated representative profile information is available in the online soil information system.

A key component of the ISIS project has been the development of a soil and land information system and associated public web site. This system has been designed to hold the complete set of information deriving both from the ISIS field programme and modelling activity, as well as the previously existing legacy soils information available for Ireland. Drawing on this information system, the web site is designed to hold and disseminate this information online both in cartographic and tabular form to stakeholders. Prior to this development, there has been no harmonised computerised system in place to hold and manipulate national Irish soils data. The information system therefore addresses the pressing need and requirement for a publicly-accessible, integrated IT framework based upon contemporary informatics standards to serve the many and varied stakeholders having an interest in soils information in Ireland.

Technical Note on Soil Classification

Two Irish soil classification systems were developed during the ISIS project. An **Interim Soil Classification** was developed in the early stages of the project to enable the harmonisation and generalisation of the county soil maps published by An Foras Talúntais (AFT) and the rationalisation of the original AFT soil series. The **Interim Soil Classification** was used during the development of Work Packages (WP): WP1 and WP2, to produce the training data for the predictive mapping and for most of the field programme in WP3. In 2013/4, **the Interim Soil Classification** was modified following a World Reference Base style hierarchical approach that recognises Great Soil Groups and defines sub-groups by supplementary diagnostic horizons. The **Final Soil Classification** System was developed to provide a more user-friendly classification system that adopts the approach of a hierarchical key for recognition of Great Soil Groups and diagnostic horizons to define the sub-groups.

The **Final Soil Classification** System was subsequently implemented during the description of representative soil profiles, final map production and is included in the updated soil profile handbook, and national soil series list. This modified system is the **Final Soil Classification** system for Ireland that appears in the map and associated information system on the ISIS website.

This Final Technical Report was developed using the **Interim Soil Classification**, and describes a significant contribution to the production of the final New Soil Map of Ireland. Table B below details the differences between the **Interim** and the **Final Soil Classification** Systems.

The **Final Soil Classification** System for Ireland has 3 hierarchical levels:

1. Great Soil Groups:

The classification criteria for the Great Soil Groups (GSG) were based on recognisable features used by An Foras Talúntais (National Soil Survey of Ireland) to classify the soils of Ireland at Great Soil Group level. Table A provides an overview of the key criteria for recognizing the Great Soil Groups. The sequence follows World Reference Base (WRB) principles.

2. Soil Sub-groups:

The Irish Soil Classification of soil sub-groups (SSG) is based on the recognition of diagnostic horizons, properties and materials which, where possible, should be observed and measured in the field. The selection of diagnostic characteristics takes into account their relationship with soil forming processes. Diagnostic features are selected that are significant to soil management. Subgroups are named with a maximum of two diagnostic features that represent the most important processes occurring in the soil profile. Table B provides a look-up table between the interim and the modified classification systems, listing the Great Soil Groups and Sub-groups.

3. Soil Series

The classification of series is based on the same principles as the interim classification system. Within a sub-group a series is further defined by the nature of the soil texture and parent material.

4. Soil Associations

For mapping purposes, the soil series are combined to form soil associations that are identified by the most frequently occurring soil series and combinations of ancillary series. Each association is named after the key (lead) soil series, which is the most extensive soil in the association, e.g. Kilrush series is the dominant component in the Kilrush Association. To facilitate mapping, each soil association based on the Interim Classification is assigned an alphanumeric code that comprises the soil subgroup code (numeric) concatenated with a single alphabetic character, e.g. 711b for Kilrush Association. In the Final Soil Classification, the Kilrush Association is assigned the code 0700b in accordance with Tables A and B. With respect to classification terminology, the reports (3, 4, 5, 11 & 12) describing the predictive mapping programme refer only to soil association codes that relate to the Interim Soil Classification. However, the ISIS Soil Information System contains a translation table that links the interim soil association codes to the codes that relate to the Final Soil Classification. Thus the results of the predictive mapping can be linked to the final version of the New Soil Map of Ireland.

Table A: Sequencing of the Great Soil Groups (GSG) in the Final Irish Soil Classification

Criteria	GSG code	Great Soil Group (GSG)
Soils with thick organic layers	**1**	**OMBROTROPHIC PEAT**
	2	**MINEROTROPHIC PEAT**
Shallow or extremely gravelly soils	**3**	**RENDZINAS**
	4	**LITHOSOLS**
Soils influenced by water	**5**	**ALLUVIAL SOILS**
	6	**GROUNDWATER GLEYS**
	7	**SURFACE-WATER GLEYS**
Soils affected by Fe/Al chemistry increase	**8**	**PODZOLS**
	9	**BROWN PODZOLICS**
Soils with clay enriched subsoil	**10**	**LUVISOLS**
Relatively young or soils with limited profile development	**11**	**BROWN EARTHS**

For more details of the finalised Irish Soil Classification System please refer to the following documents:

ISIS Final Technical Report 10: Simo et al. (2014). The Irish Field Handbook for Soil Profile Descriptions. Available from http://erc.epa.ie.safer/reports

ISIS Final Technical Report 13: Simo et al. (2014). The Irish Soil Information System Map and Legend. Available from http://erc.epa.ie.safer/reports

ISIS Final Technical Report 9: Creamer et al. (2014). The Irish Soil Information System National Soil Series - Description and Classification of Representative Profiles. Available from http://erc.epa.ie.safer/reports

Table B Linkage between the Interim and Final Irish Soil Classifications for Soil Subgroups

Interim SSG_code	Interim Soil Subgroup (SSG)	SSG code	Soil Subgroup (SSG)
911	Raw Ombrotrophic Peat Soils	110	Natural Ombrotrophic Peat Soils
912	Earthy Ombrotrophic Peat Soils	170	Drained Ombrotrophic Peat Soils
913	Cut-over Ombrotrophic Peat Soils	180	Cut-over Ombrotrophic Peat Soils
914	Industrial Ombrotrophic Peat Soils	190	Industrial Ombrotrophic Peat Soils
921	Raw Minerotrophic Peat Soils	210	Natural Minerotrophic Peat Soils
922	Earthy Minerotrophic Peat Soils	270	Drained Minerotrophic Peat Soils
		280	Cut-over Minerotrophic Peat Soils
211	Typical Rendzinas	300	Typical Rendzinas
215	Histic Rendzinas	310	Histic Rendzinas
213	Humic Rendzinas	360	Humic Rendzinas
214	Stagnic Rendzinas		
212	Gleyic Rendzinas		
111	Typical Lithosols	400	Typical Lithosols
113	Histic Lithosols	410	Histic Lithosols
112	Humic Lithosols	460	Humic Lithosols
821	Typical Alluvial Gleys	500	Typical Alluvial Gley Soils
		510	Histic Alluvial Gley Soils
823	Typical Calcareous Alluvial Gleys	550	Typical Calcareous Alluvial Gley Soils
		551	Histic Calcareous Alluvial Gley Soils
824	Humic Calcareous Alluvial Gleys	556	Humic Calcareous Alluvial Gley Soils
822	Humic Alluvial Gleys	560	Humic Alluvial Gley Soils
811	Typical Brown Alluvial Soils	570	Typical Alluvial Soils
812	Gleyic Brown Alluvial Soils	572	Gleyic Alluvial Soils
813	Humic Brown Alluvial Soils	576	Humic Alluvial Soils
721	Typical Groundwater Gleys	600	Typical Groundwater Gleys
		610	Histic Groundwater Gleys
723	Calcareous Groundwater Gleys	650	Calcareous Groundwater Gleys
		651	Histic Calcareous Groundwater Gleys
724	Humic Calcareous Groundwater Gleys	656	Humic Calcareous Groundwater Gleys
722	Humic Groundwater Gleys	660	Humic Groundwater Gleys
		690	Anthropic Groundwater Gleys
711	Typical Surface-water Gleys	700	Typical Surface-water Gleys
712	Humic Surface-water Gleys	760	Humic Surface-water Gleys
		790	Anthropic Surface-water Gleys
611	Ferric Podzols	800	Typical Podzols
621	Typical Gley Podzols	820	Gleyic Podzols
622	Stagno-Gley Podzols	830	Stagnic Podzols
632	Iron-pan Stagno Podzols	843	Stagnic Iron-pan Podzols
612	HumoFerric Podzols	860	Humic Podzols
		890	Anthropic Podzols
631	Ferric Stagno Podzols		
511	Typical Brown Podzolics	900	Typical Brown Podzolics
512	Gleyic Brown Podzolics	920	Gleyic Brown Podzolics
514	Stagnic Brown Podzolics	930	Stagnic Brown Podzolics
		936	Humi-Stagnic Brown Podzolics
513	Humic Brown Podzolics	960	Humic Brown Podzolics
		990	Anthropic Brown Podzolics
411	Typical Luvisols	1000	Typical Luvisols
412	Gleyic Luvisols	1020	Gleyic Luvisols
		1026	Humi-Gleyic Luvisols
414	Stagnic Luvisols	1030	Stagnic Luvisols
		1036	Humi-Stagnic Luvisols
413	Humic Luvisols	1060	Humic Luvisols
1020	Technosols	1090	Anthropic Luvisols
311	Typical Brown Earths	1100	Typical Brown Earths
312	Gleyic Brown Earths	1120	Gleyic Brown Earths
		1126	Humi-Gleyic Brown Earths
314	Stagnic Brown Earths	1130	Stagnic Brown Earths
315	Humi-stagnic Brown Earths	1136	Humi-Stagnic Brown Earths
321	Typical Calcareous Brown Earths	1150	Typical Calcareous Brown Earths
322	Gleyic Calcareous Brown Earths	1152	Gleyic Calcareous Brown Earths
323	Stagnic Calcareous Brown Earths	1153	Stagnic Calcareous Brown Earths
		1156	Humic Calcareous Brown Earths
		1159	Anthropic Calcareous Brown Earths
313	Humic Brown Earths	1160	Humic Brown Earths
		1190	Anthropic Brown Earths
		1196	Humi-Anthropic Brown Earths

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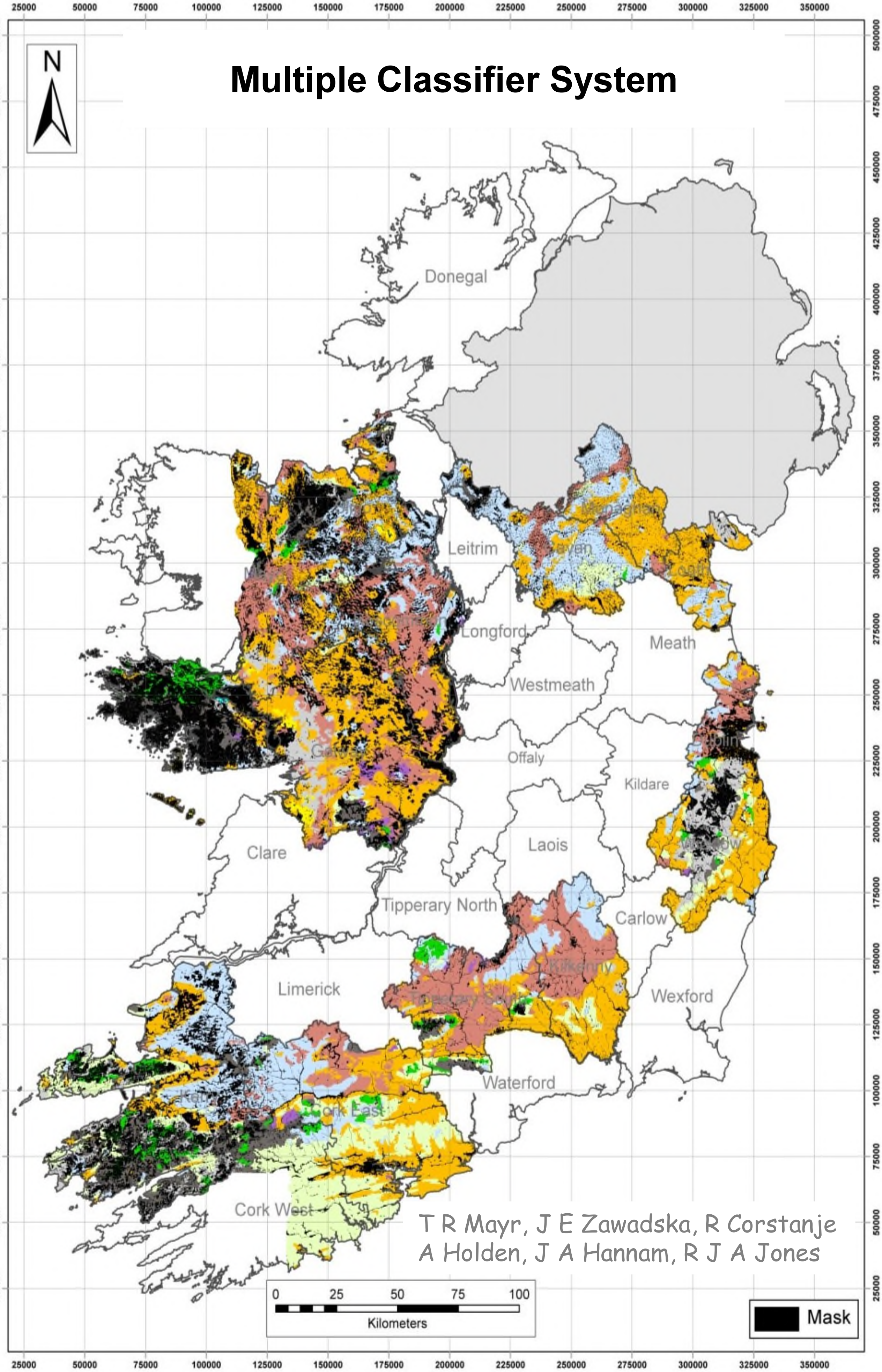
Multiple Classifier System



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IRISH SOIL INFORMATION SYSTEM (ISIS)

Multiple Classifier System

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ISIS_WP2_D4.3_FusionMap

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1. Introduction

An alternative to using a single, highly optimised classifier for a classification problem is to combine the outputs of multiple classifiers into a so-called multiple classification system (MCS). In the literature, MCSs have been important research topic and have been given many different names, including classier fusion, mixture of experts, voting pool of classifiers and classifier ensembles. MCSs are a form of decision-level data fusion. Classifiers may make independent errors, in which case the use of an MCS will improve the final classification. [Smith, 2002]

The underlying assumption of using MCS is that each classifier participating in the MCS has a merit that deserves exploitation. This is the case if the different classifiers are building using different subsets of features, different subsets of the data set, and/or different classifier models. It should be noted that, if the classes separate well in the feature space, all classifiers should return the same result and applying MCS is not likely to be of any benefit. [Smith, 2002]

In Xu *et al*. (1992), MCS are categorised into three types depending on the level of information being exploited. Type 1 regards classifier combination strategies based on the abstract level (class labels), Type 2 corresponds to the rank level and uses the class labels plus a priority ranking assigned to each class by each individual classifier, finally, Type 3 exploits the measurements of each classifier and provides for each classifier some measure of support for the classifiers decision. [Smith, 2002]

2. Methodology

The fusion model is based on the national accuracy assessment (Mayr *et al*., 2013) of the 5 predictive soil association maps developed in Phase 1 and 2 **(Table 1**). This process represents a Type 3 assessment according to Xu *et al*. (1992) and resulted in a single predictive map representing the respective soil associations with the highest accuracy score

2.1 Tools

Data Fusion is a complex process which requires the use of a range of tools and thus it was automated in a form of a model built within the Model Builder environment of ArcGIS 10.1. The key tool for the process is the ‘Highest position’ tool which identifies maps with the highest value of an attribute. In case of Data Fusion this is the highest accuracy score in a given location of the five predictive maps. The output of this tool indicates the source predictive maps attributed with the highest accuracy score at a given raster grid cell. Once the origin of the highest accuracy score is known, the soil associations which obtained that score can be extracted from respective predictive maps and combined into a single mapping output. The process also allows for mapping areas for which accuracy scores were supported by less than a given number of observations. If this option is used, the resulting map contains a new category called ‘Excluded’.

2.2 Application

The process is based on the predictive maps generalised to 1:250,000 scale without the post-processing mask applied. For the accuracy scores, however, the post-processing mask was incorporated to remove all masked areas form the evaluation. Individual accuracy levels for the 5 input maps are detailed in Table 2.

The automated process requires maps in a vector format such as a shapefile as inputs. However, the 'Highest position' tool uses data in raster format and should the vector input maps be used in a form as they were originally produced with polygon borders smoothed out, the output map would contain many artefacts in the form of small sliver polygons. In order to overcome this problem, the input vector maps were first converted into a raster format of 20 m grid size, followed by conversion back to the shapefile format. This created a "rasterised" shape of polygon borders which prevented the occurrence of aforementioned artefacts. A smoothing algorithm was subsequently applied as a part of map generalisation process, resulting in a natural look of the polygon borders. The conversion of input maps to raster and then back to polygon did not have a significant impact on the map contents given that the predictive maps had been created as raster maps in the first place.

2.3 Post-processing

Post-processing was undertaken in three steps:

- Raw data fusion output was generalised to 250,000 scale using the PPmodel;
- All small polygones (<30,000 m^2) were removed from the mask;
- Merging the fusion map with the mask.

This revised processed kept the precious detail of the mask, especially within the drumlin and alluvial areas.

3. Results

Results from the revised approach are detailed as follows:

- Predicted Soil Associations (Figure 1)
- Associated accuracy map (Figure 2)
- Hot-spot analysis (Figure 3)
- Associated number of auger bores (Figure 4)
- Associated source maps (Figure 5)

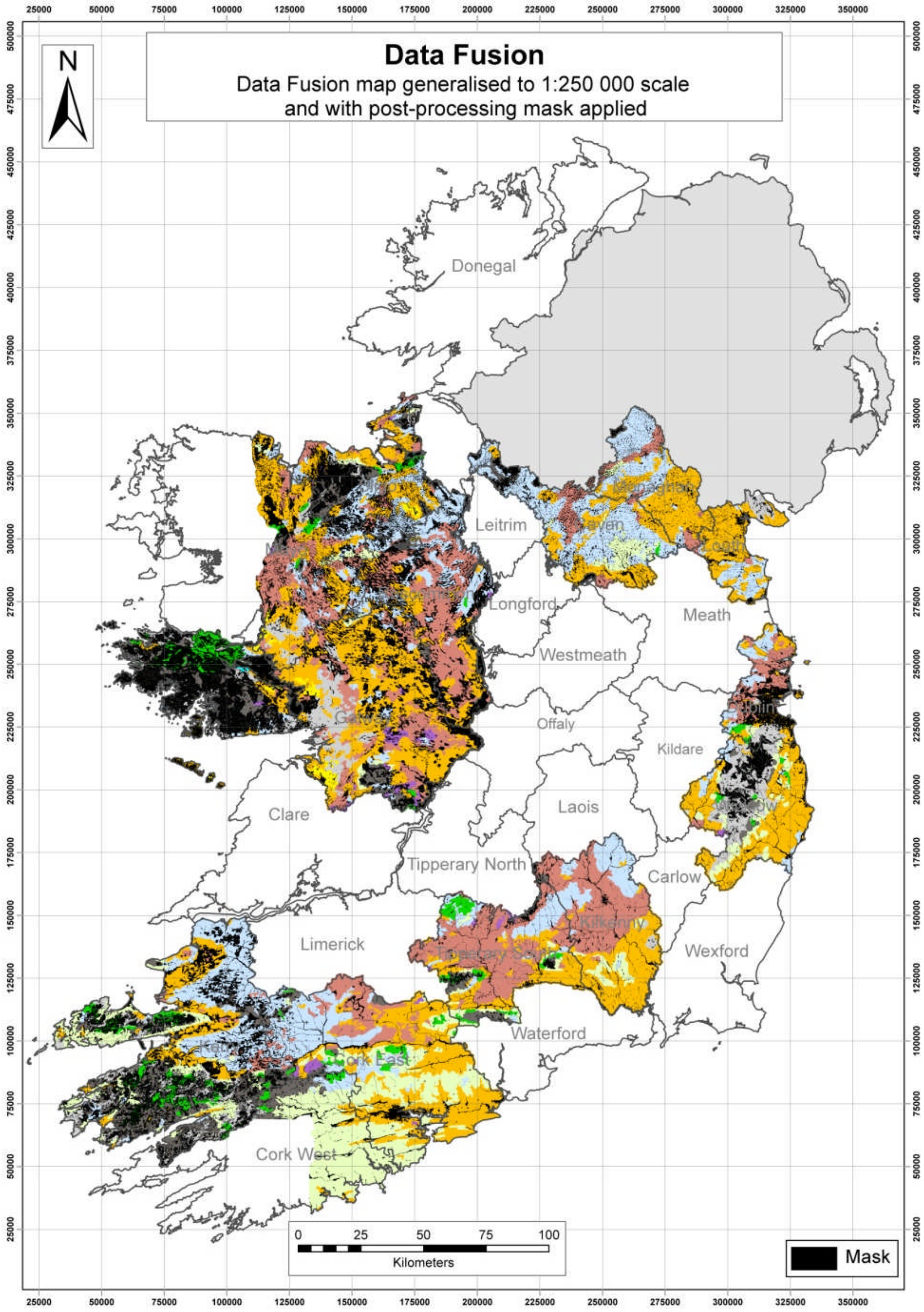

Figure 1: Fusion Model – predicted soil associations

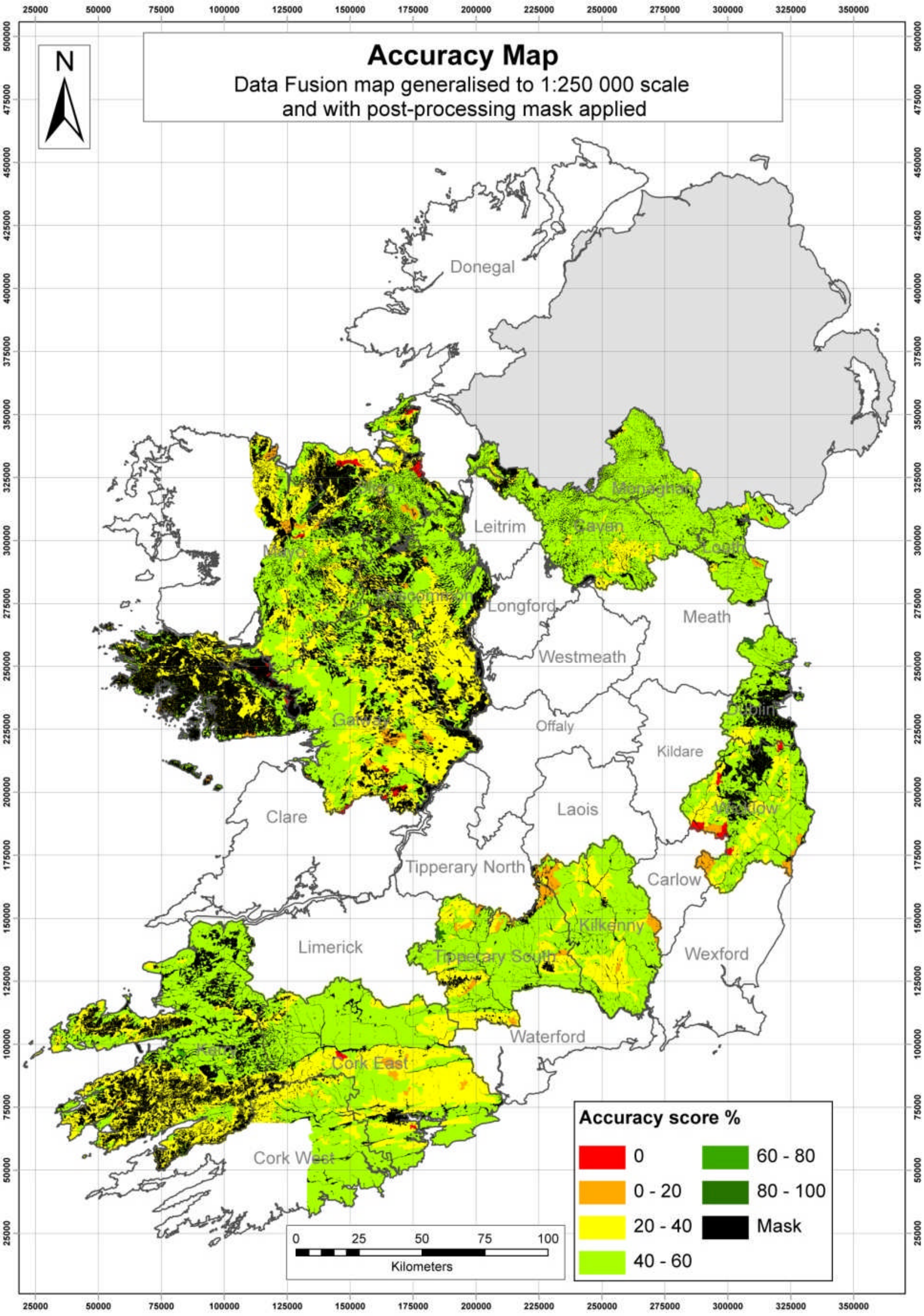

Figure 2: Fusion Model – accuracy assessment

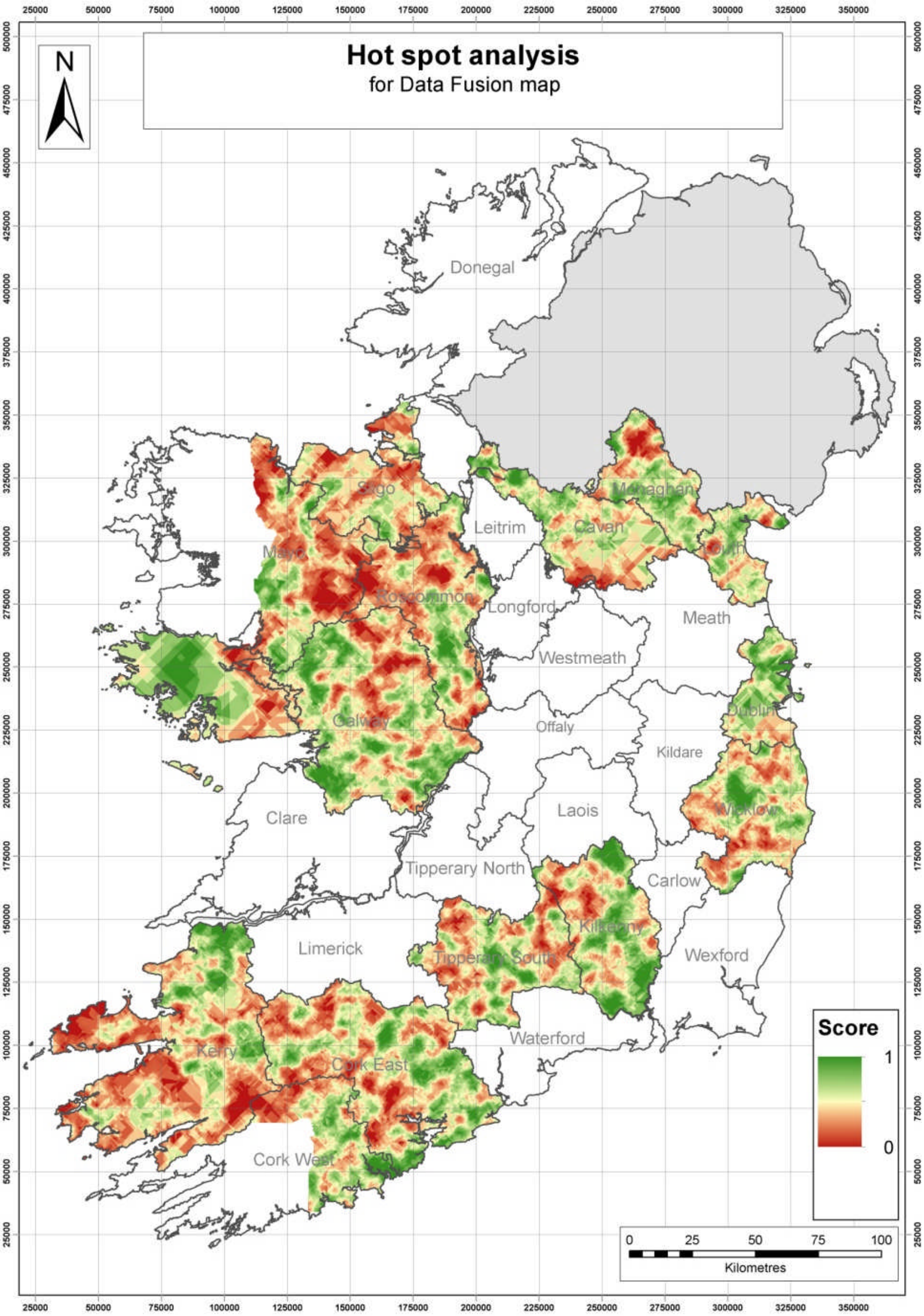

Figure 3: Fusion Model - hot-spot analysis (200m resolution)

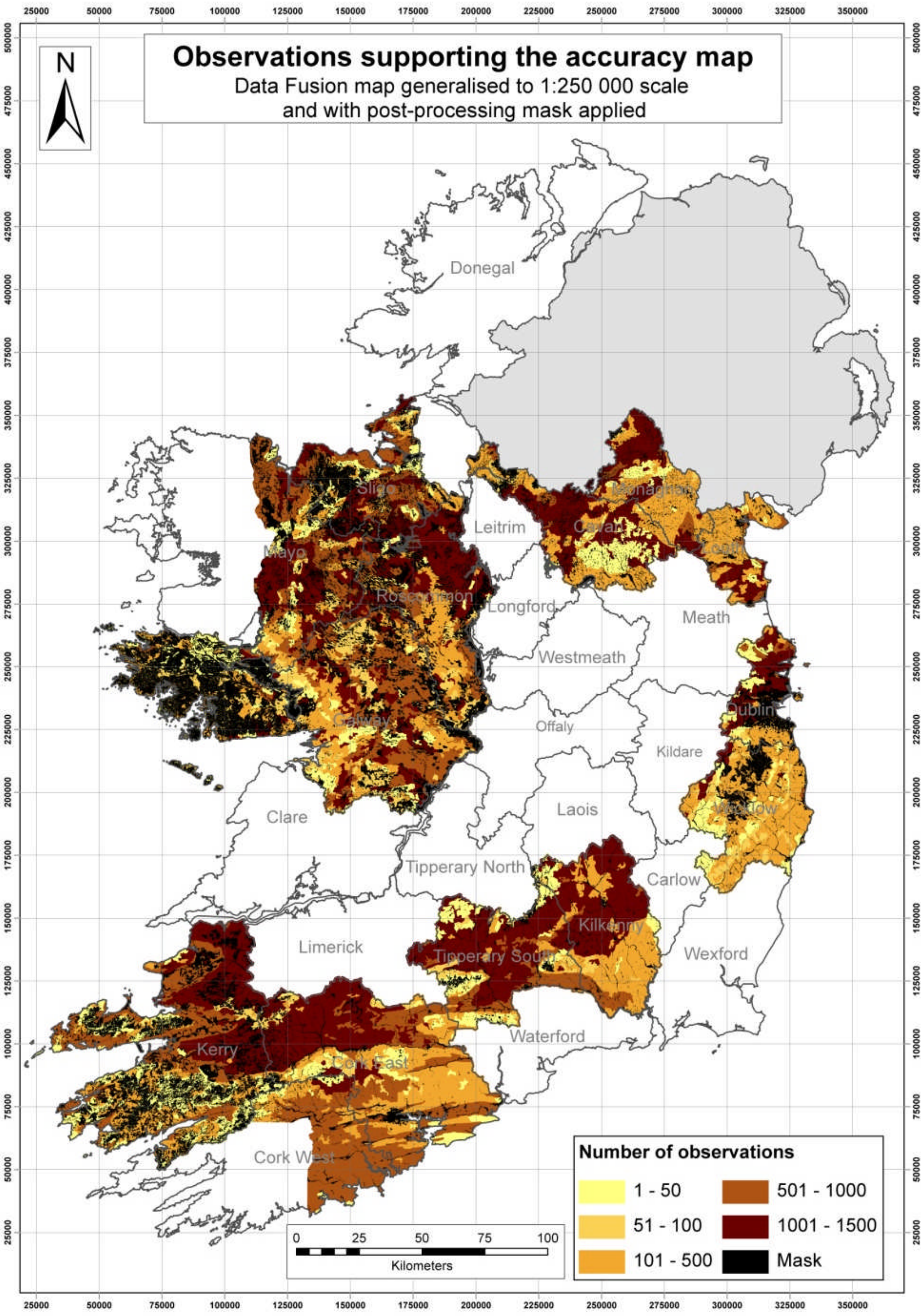

Figure 4: Fusion Model – number of observations

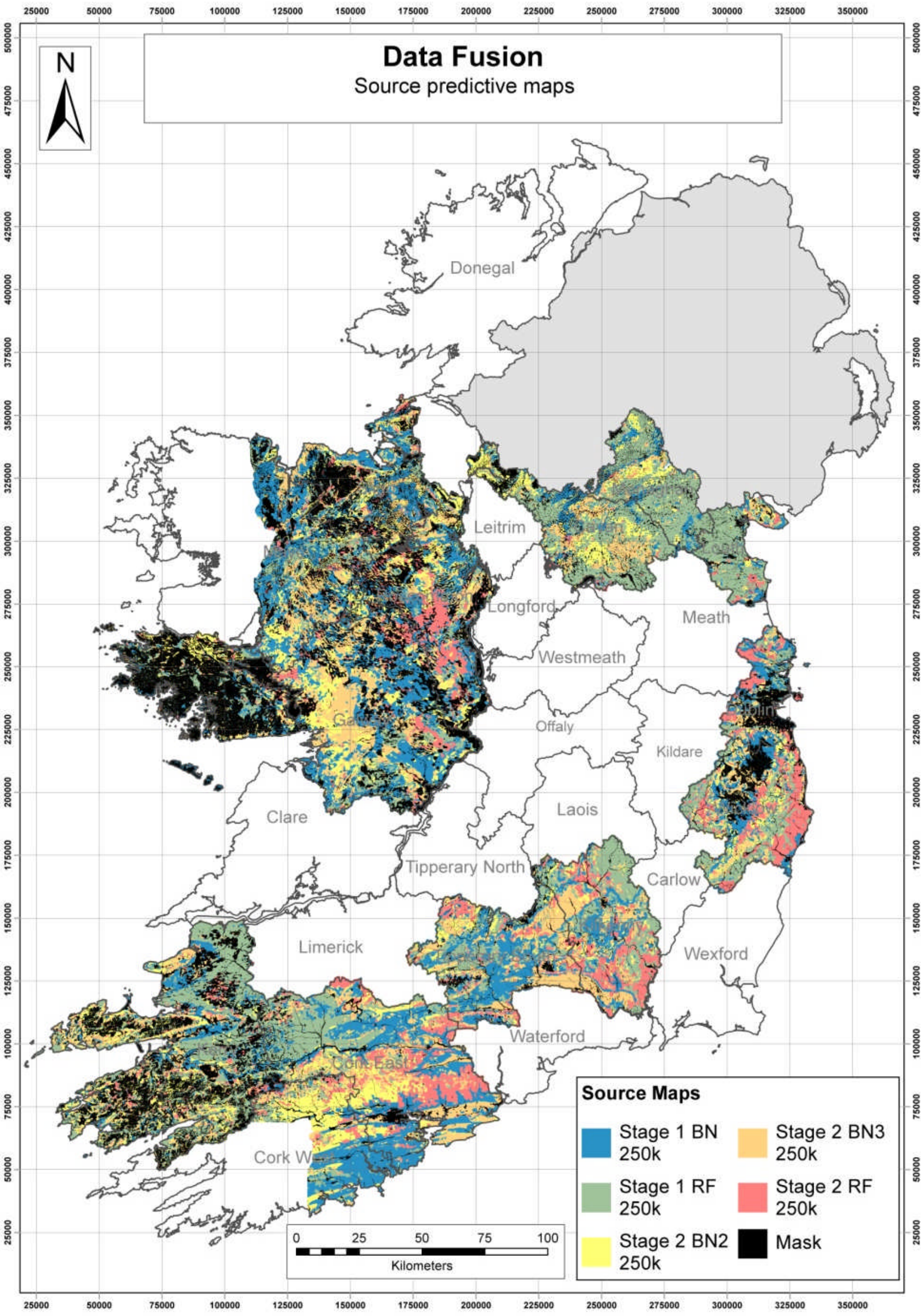

Figure 5: Fusion Model – models used in final prediction

4. Validation

The fusion map was validated using the same approach as outlined in Mayr *et al* (2013). Using all available auger bores an overall accuracy level of 42% (n=7684) was achieved. Detailed results for individual soil associations can be found in Table 2 and for individual counties in Table 3. It is important, however, to consider both the accuracy values as well as the number of auger bores available for a particular association, as both 0% or 100% accuracy levels can easily be achieved with very low number of auger bores.

5. Conclusions

Using data fusion has to combine the 5 individual predictive maps has shown to be beneficial. Overall accuracy has improved from 36% for RF in Stage 1 to 42%. The exercise has indicated that the largest benefits arise using a range of inference engines. In addition, the use of different approaches for extrapolating soilscapes has also proven to be useful.

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Table 1: Summary of predicted mapping outputs

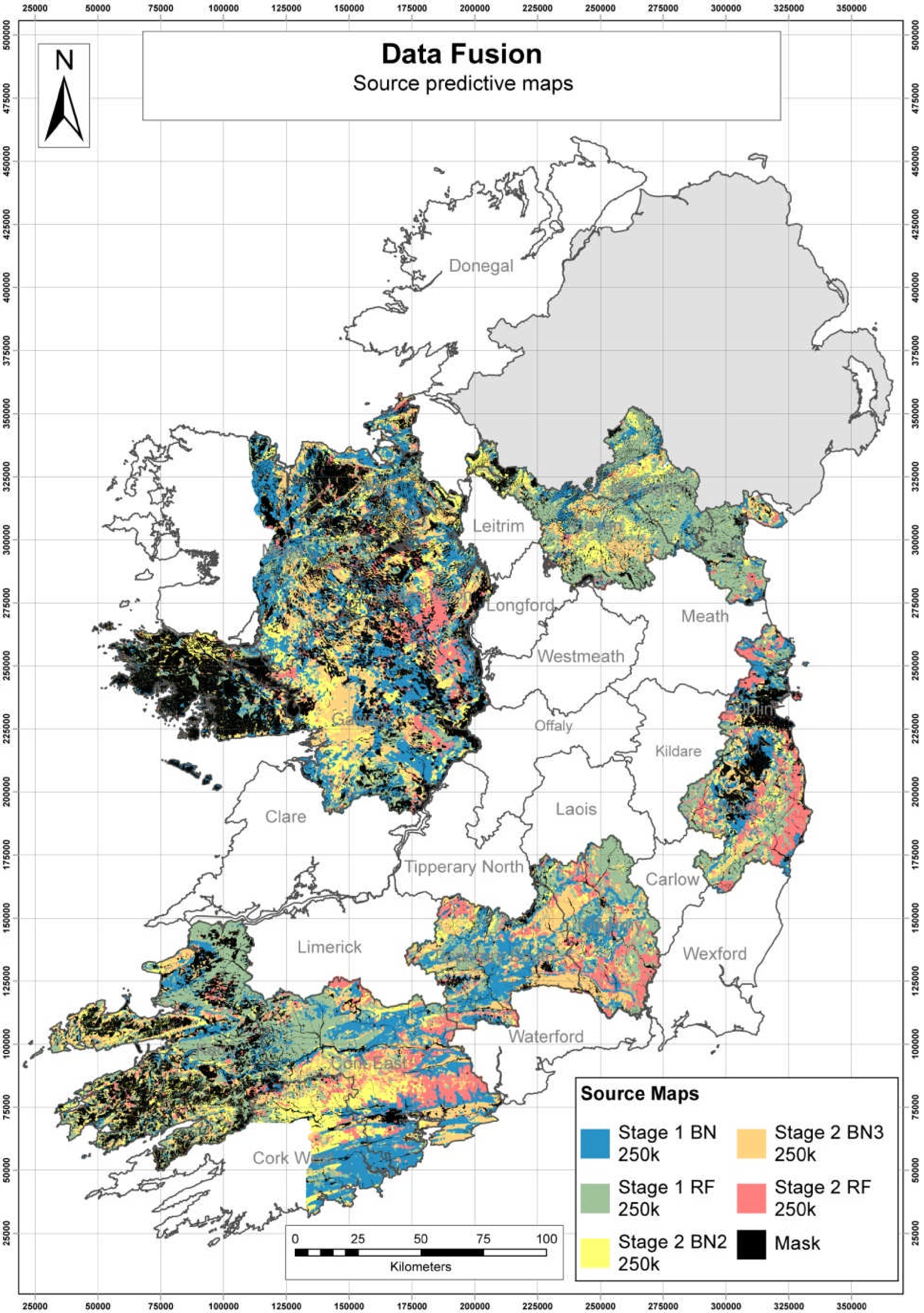
Output map	Soilscape extrapolation	Inference engine for SMU and NSA	Scale
ph1_RF_250k_v2_mask	Feature space	Random Forests (using all co-variates)	output generalised to 1:250,000, mask
ph1_BN_250k_v2_mask	Feature space	BBN (using all co-variates)	output generalised to 1:250,000, mask
ph2_BN2_1_250k_v2_mask	Bayesian Belief Network	BBN (using all co-variates except climate)	output generalised to 1:250,000, mask
ph2_BN3_1_250k_v2_mask	Bayesian Belief Network	BBN (using optimisation routine to select co-variates)	output generalised to 1:250,000, mask
ph2_RF_250k_v2_mask	Bayesian Belief Network	Random Forests (using all co-variates)	output generalised to 1:250,000, mask

Table 2: Soil Association level results

Association	Accuracy	Obs
112a	47.50	120
113a	49.18	183
113b	38.89	36
211b	54.84	31
213b	16.67	6
311a	52.46	406
311b	0.00	1
311c	31.72	227
311d	33.33	3
311e	45.76	271
311f	35.00	80
311h	20.00	20
311i	50.00	28
311l	32.26	31
311m	25.00	4
311n	49.46	744
311q	36.95	544
321a	42.86	84
321b	38.71	31
321c	42.86	63
411a	37.20	293
411c	11.76	17
411e	50.00	2
411f	100.00	2
411g	50.00	8
411h	0.00	5
411x	46.36	1236
414b	28.33	60
511a	0.00	2
511b	0.00	11
511e	40.83	725
511f	0.00	1
512a	37.50	8
513b	33.33	12
513c	33.33	51
513e	32.89	228
612a	33.33	24
632b	39.58	48
632f	36.36	44
711a	20.00	5
711b	41.24	1278
711c	51.82	110
711d	41.94	31
711e	66.67	6
711f	17.39	23
712a	16.67	6
712b	100.00	2
712c	11.11	9
712d	44.44	36
712e	0.00	6
712f	36.84	19
712g	15.38	13
722b	30.00	40
722c	0.00	3
722e	0.00	1
722f	0.00	2
723a	11.11	18
822g	25.00	4
911a	16.67	18
911b	39.18	97
911c	39.47	38
911d	26.22	164
913b	85.71	7
914a	31.48	54
922a	0.00	4

Table 3: County level results (accuracy and number of observations)

County	Accuracy	Obs.
Cavan	44.90	363
Cork	44.27	1667
Dublin	52.33	172
East Mayo	29.95	661
Galway	47.30	890
Kerry	36.57	823
Kilkenny	49.49	489
Louth	47.81	251
Monaghan	45.87	351
Roscommon	36.42	648
Sligo	36.05	258
Tipperary	38.73	599
Wicklow	40.34	528


Data Fusion
Source predictive maps
N
Donegal
Leitrim
Longford
Meath
Westmeath
Offaly
Kildare
Laois
Clare
Tipperary North
Carlow
Limerick
Wexford
Waterford
Cork East
Cork West
Source Maps
Stage 1 BN 250k
Stage 1 RF 250k
Stage 2 BN2 250k
Stage 2 BN3 250k
Stage 2 RF 250k
Mask
0
25
50
75
100
Kilometers
25000
50000
75000
100000
125000
150000
175000
200000
225000
250000
275000
300000
325000
350000
375000
400000
425000
450000
475000
500000