Mapping the functionality of soils in Scotland using a neural network-based digital soil mapping approach

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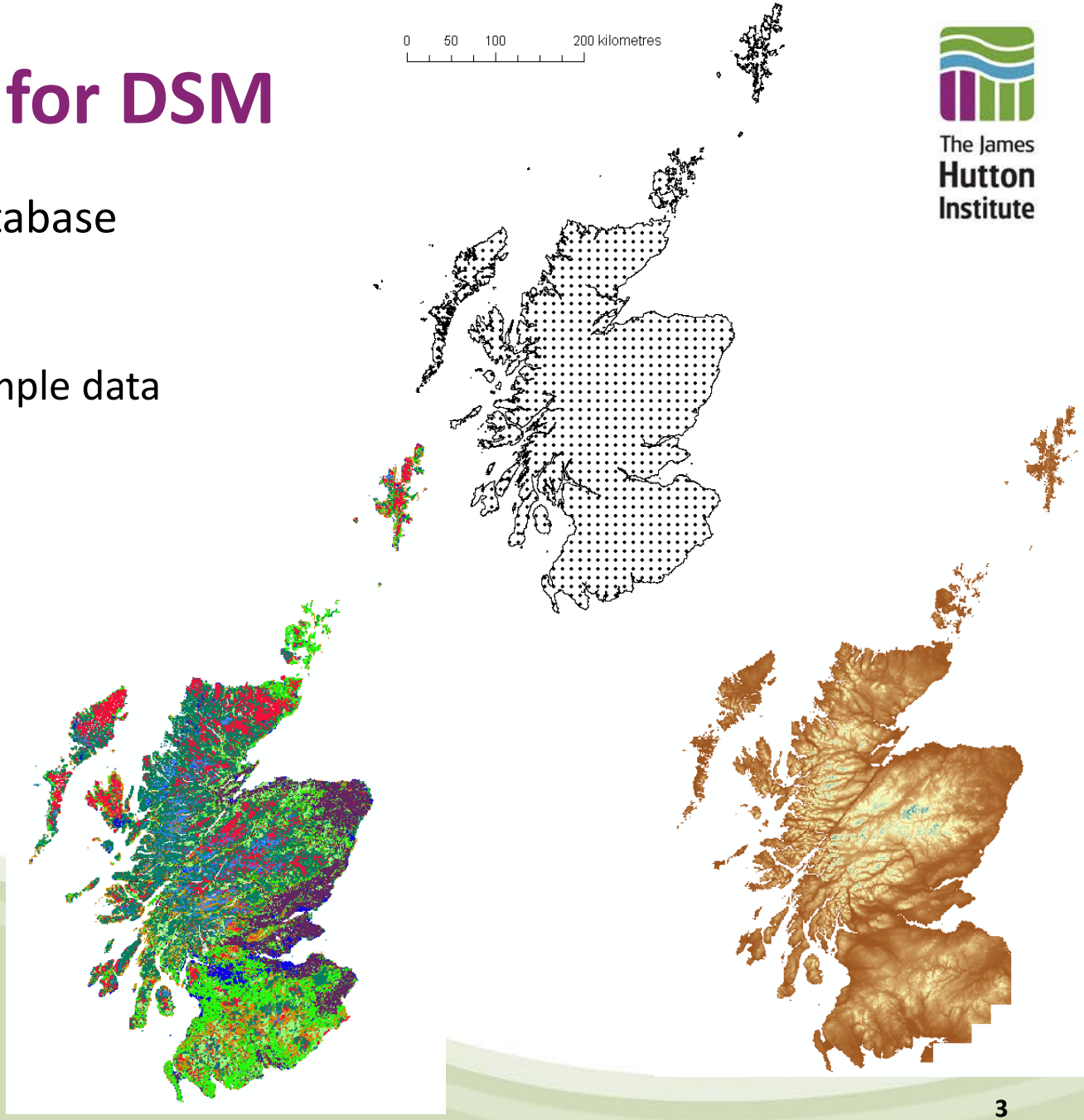
Outline

- Scottish Soils Database for parameter modelling
  - What is the Scottish Soils Database?
  - Additional data used (SCORPAN)
- Digital Soil Mapping using the trained model
  - Accuracy, resolution etc.
- Translation of mapped parameters to processes, functions and ecosystem services

Data used for DSM

- Scottish Soils Database
  - NSIS
  - Additional sample data
- Spatial datasets
  - Topography
  - Climate
  - Vegetation
  - Soil
  - Geology



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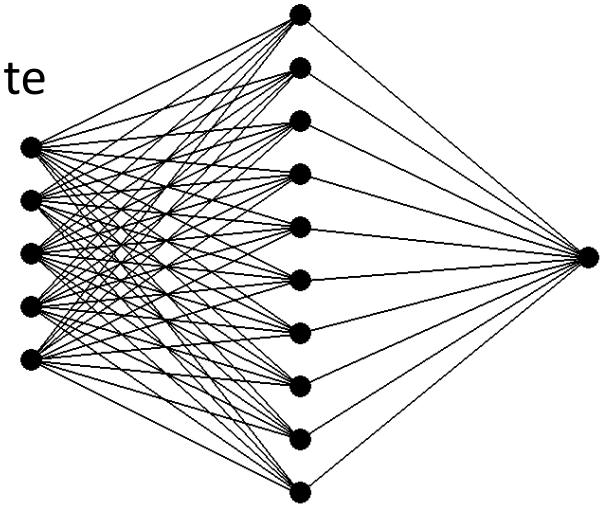
NN model

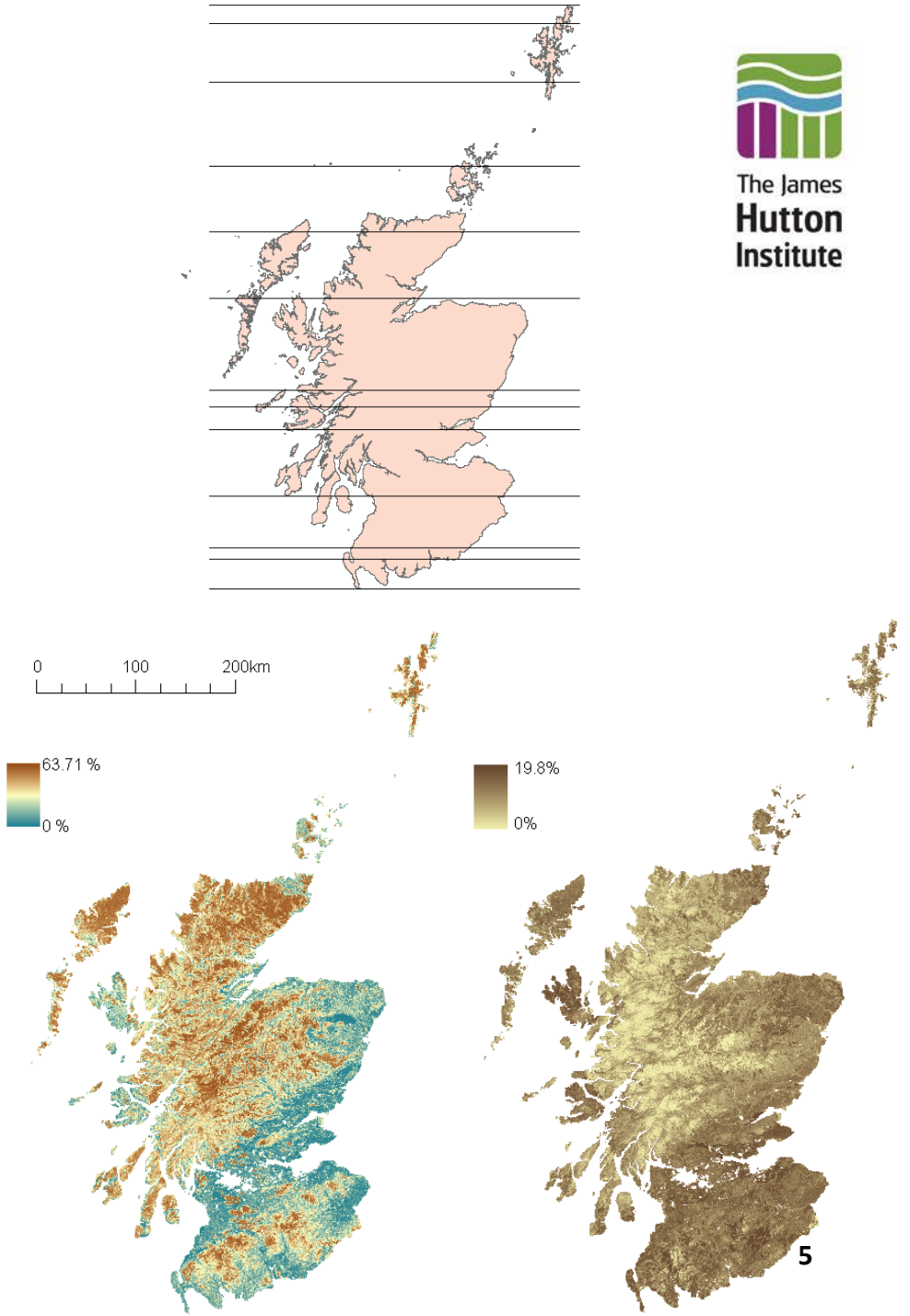
- Backpropagation neural network training
  - BPNN is slow to train, clunky and less accurate
  - It's easy to code and optimise, and runs fast
- 10-fold cross-validation
- Separate models for each parameter
  - Not every sample analysed for everything



- Accuracy evaluation (RSQ, RPIQ)
  - The good: rooting depth (0.924, 3.75); pH (0.839, 2.56); BD (0.744, 2.03); SOC (0.754, 2.08)
  - The bad: sand (0.620, 1.68); silt (0.667, 1.74); clay (0.627, 1.64)
  - The ugly: sum cations (0.491, 1.47); base saturation (0.522, 1.49)

DSM mapping

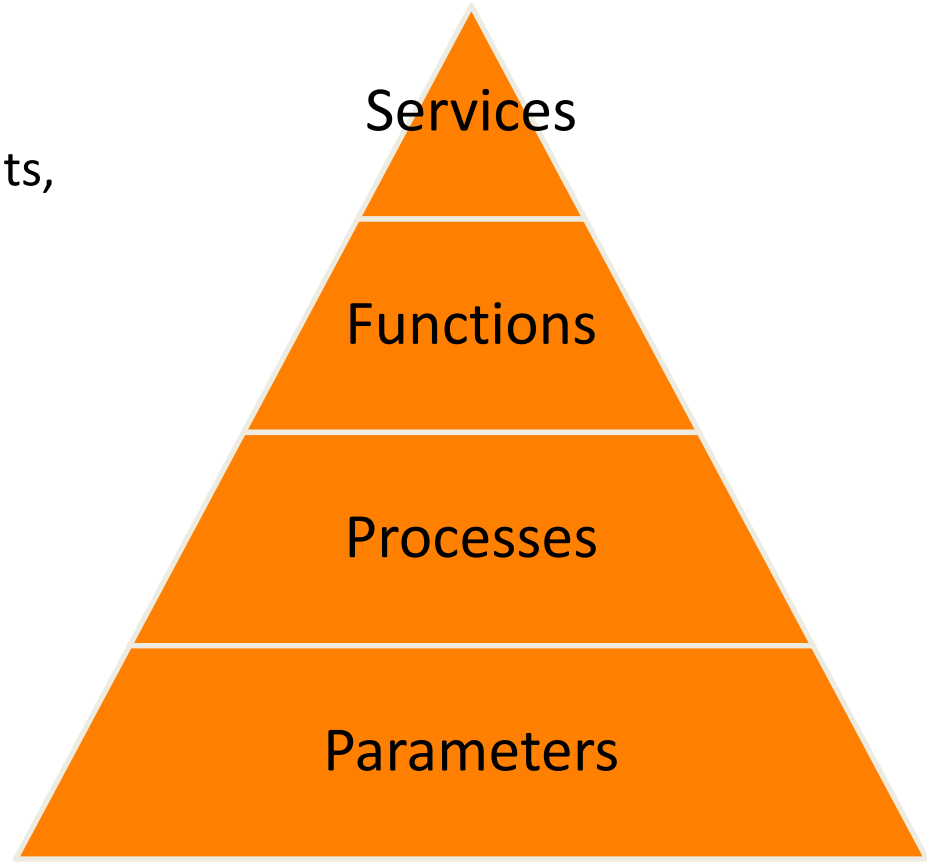
- Data preparation
  - Data ‘strips’ containing SCORPAN information
- 100m resolution mapping
  - Could be improved using 10m DTM
  - Land cover etc. 30-50 m scale
  - Time/processing limitations
- Mapping ongoing at multiple depth (5cm ranges)
  - 0, 5, 10 cm complete
  - Training data valid to 100 cm



%carbon (l), pH (r)

Parameters to services

- Pyramid of services (adapted from Haines-Young, Potschin et al.)
  - Not including higher levels (benefits, values)
- Separate pyramid for each service
  - Not every function is needed to describe all services
  - Not every parameter is needed to describe all processes
  - Etc.
  - Reduces complexity of the model
  - Allows existing information to be incorporated and used



Matrix multiplication concept

	Process A	Process B
Parameter A	i1	i2
Parameter B	i3	i4
Parameter C	i5	i6

X

	Function A	Function B	Function C	Function D
Process A	j1	j2	j3	j4
Process B	j5	j6	j7	j8

=

	Function A	Function B	Function C	Function D
Parameter A	i1j1 + i2j5	i1j2 + i2j6	i1j3 + i2j7	i1j4 + i2j8
Parameter B	i3j1 + i4j5	i3j2 + i4j6	i3j3 + i4j7	i3j4 + i4j8
Parameter C	i5j1 + i6j5	i5j2 + i6j6	i5j3 + i6j7	i5j4 + i6j8

- Uses straightforward matrix multiplication
- Simple accounting of relationships
- Could be improved by using correlations in measured systems
- Does not take into account synergies/interactions
- Assumes linear relationships

Parameters to processes

- Normalised to range [-1, 1]
- Selection of processes based on services of interest
- Plenty of scope for argument
  - About the values
  - About the allocation within each 'level'

	Heat capacity	Mineral weathering	Rooting	GHG prod.	Cation exch.	SOM turnover	SOM accum.	SOM amount	Hydraulic cond.	Water ret.	Leaching	Erosion
Rooting depth	0	0	0.5	0.5	0.5	0.5	0	0.5	0	0.5	0	0.5
BD	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Total cations	0	0	0	0	0.5	0	0	0	0	0	0.5	0
Base saturation	0	0	0	0	0.5	0.5	0	0	0	0	-0.5	0
Carbon	1	1	0	1	1	1	1	1	1	0.5	1	1
pH	0	-1	0	-1	0	1	-1	0	0	0	-1	0
Sand	0	-0.5	0.5	0	0	0.5	0	0	1	-0.5	0	0
Silt	0	0.5	0	0	0	0	0	0	0	0	0	0
Clay	0	0	-0.5	0	0	-0.5	0	0	-1	0.5	0	0
Air temp.	0	1	1	1	0.5	1	-1	0	0	0	0	0
Rainfall	1	0.5	0	-0.5	0	0	1	0	0	0	1	1
Slope	0	0	0	0	0	0	-1	0	0	-1	1	1

Processes to functions

	Water supply	Pest control	Nut. buff.	Nut. avail.	Maint. pollin.	Temp. Buff.	Inter & infil	Support biodiv.	N fix.	Nut. cycling	Peat accum.	Prim. prod.	Reg. of GHGs
Heat capacity	0	0	0	-0.5	0	1	0	0	0	-1	1	0	1
Miner. weath.	0	0	0.5	0.5	0	0	0	0	0	0.5	0	0	0
Rooting	0	0.5	0	1	0.5	0	0.5	0.5	1	0.5	-0.5	1	-0.5
GHG prod.	0	0	-0.5	-0.5	0	0	0	0	-1	0	-1	0	-1
Cation exch.	0	0	1	0.5	0	0	0	0	0.5	0	0	0.5	0
SOM turnover	0	1	-0.5	1	1	0	0	1	0.5	1	-1	0.5	-1
SOM accum.	0	0	0	0.5	0	0	0	0	0.5	-0.5	1	0	1
SOM amount	0	0.5	0.5	0.5	0.5	0.5	0.5	0	-0.5	1	0	0	0
Hydr. cond.	-0.5	0.5	0	0	0.5	0	1	0	0	0.5	0	0.5	-0.5
Water ret.	1	0	0.5	0.5	0	1	0	0	0	0	1	0.5	0.5
Leaching	0	0	-1	-1	0	0	0	-0.5	-1	0	0	0	0
Erosion	-0.5	0	-1	-1	-1	0	-1	-1	-1	0	-1	-1	-1

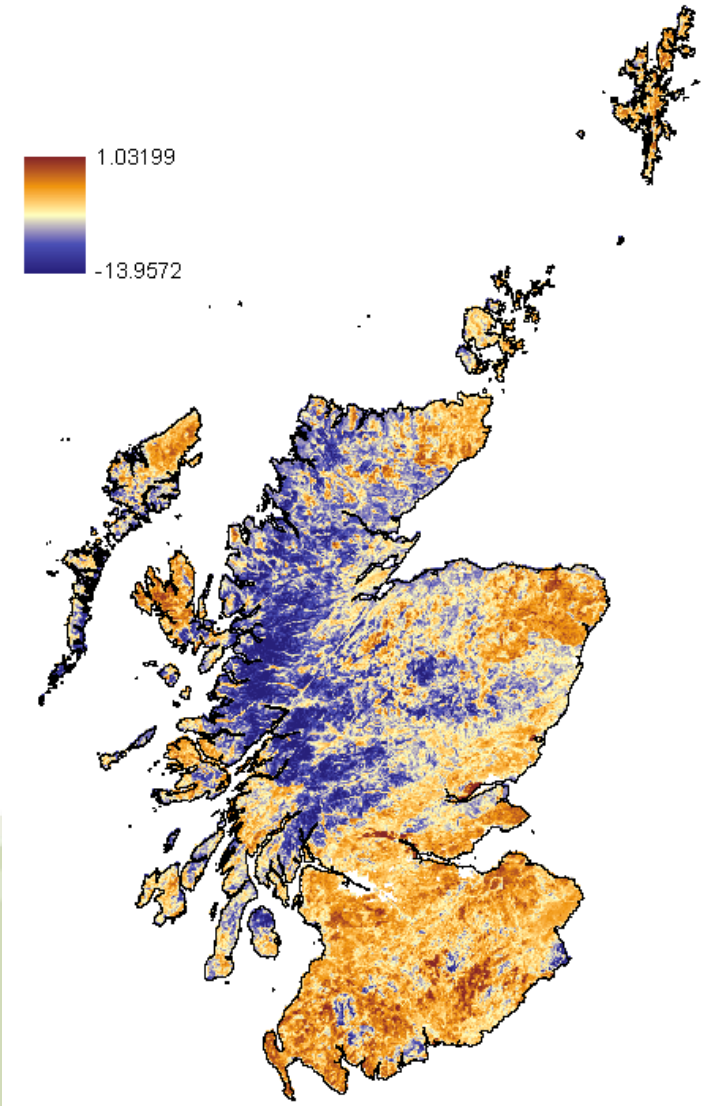
Functions to services

	Land capability for agriculture	Carbon sequestration	Drinking water provision
Water supply	1	1	1
Biocontrol/regulation of pests/diseases	0.5	0	1
Nutrient buffering	0.5	0	0
Nutrient availability	1	0	0
Capacity to maintain sufficient pollinators	1	0	0
Temperature buffering	0	0.5	0
Interception and infiltration	0.5	0	1
Support biodiversity	0.5	0	0
Nitrogen fixation	0.5	0	0
Nutrient cycling	0	-1	0
Peat accumulation	0	1	0
Primary production	0.5	1	0
Regulation of soil GHG emissions	0	1	0

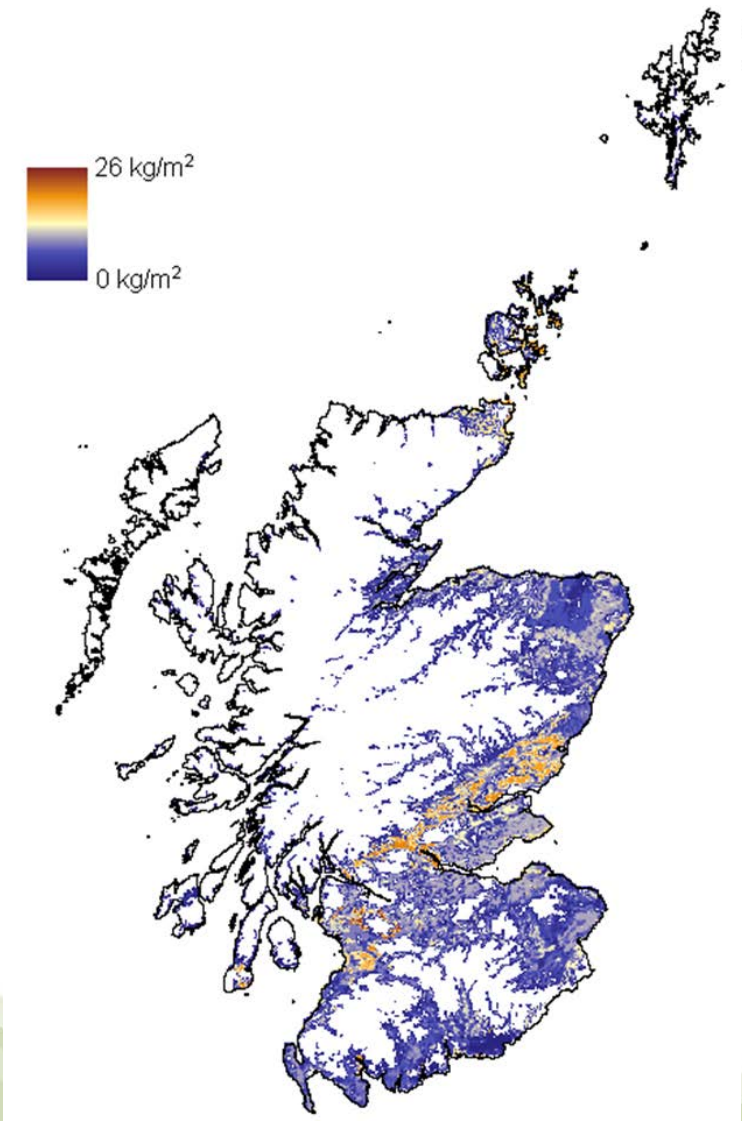
Parameters to services

	Land capability for agriculture	Carbon sequestration	Drinking water provision
Rooting depth	2.625	-2.625	1.25
BD	-2.5	0.375	-1.75
Total cations	-0.375	0.25	0
Base saturation	3.5	-1	0.5
Carbon	0.75	-2	2
pH	5.25	-2.5	1
Sand	2.875	-4	1.5
Silt	0.375	-0.25	0
Clay	-3.25	4.25	-1.5
Air temp.	6	-7.75	2
Rainfall	-6	3.25	-1.5
Slope	-10	-9.5	-2.5

Carbon storage potential

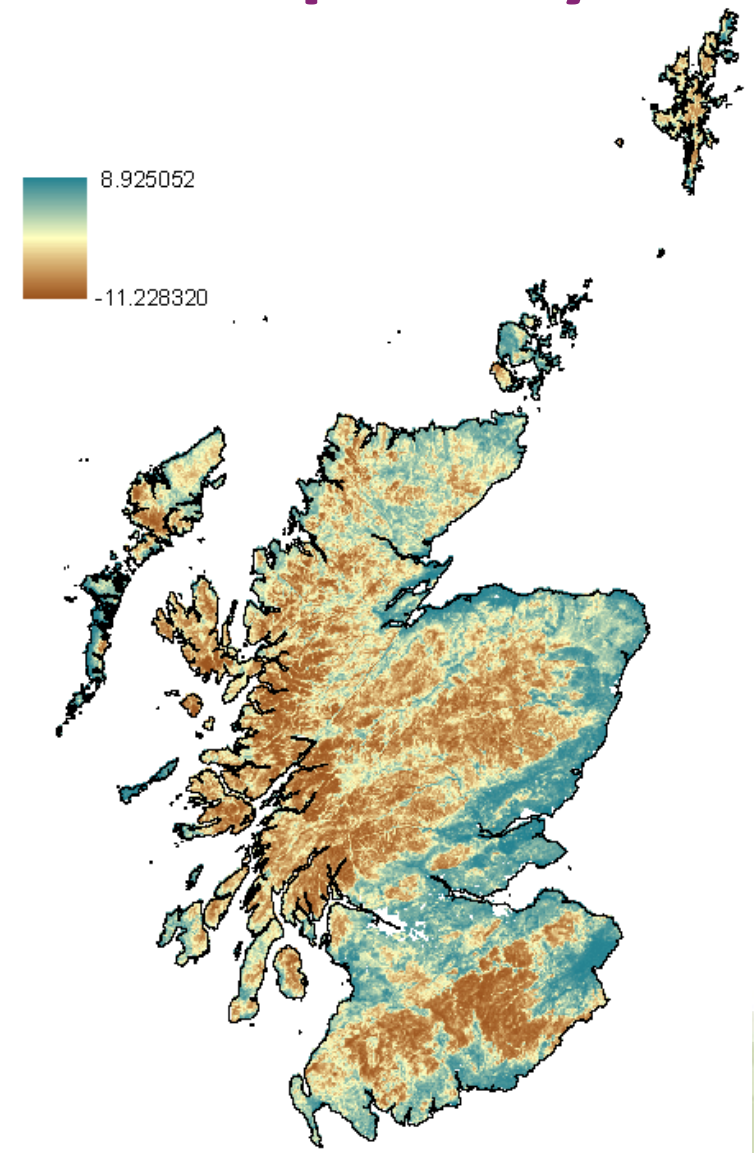


Matrix approach



Storage potential (Lilly et al.)

Land capability for agriculture



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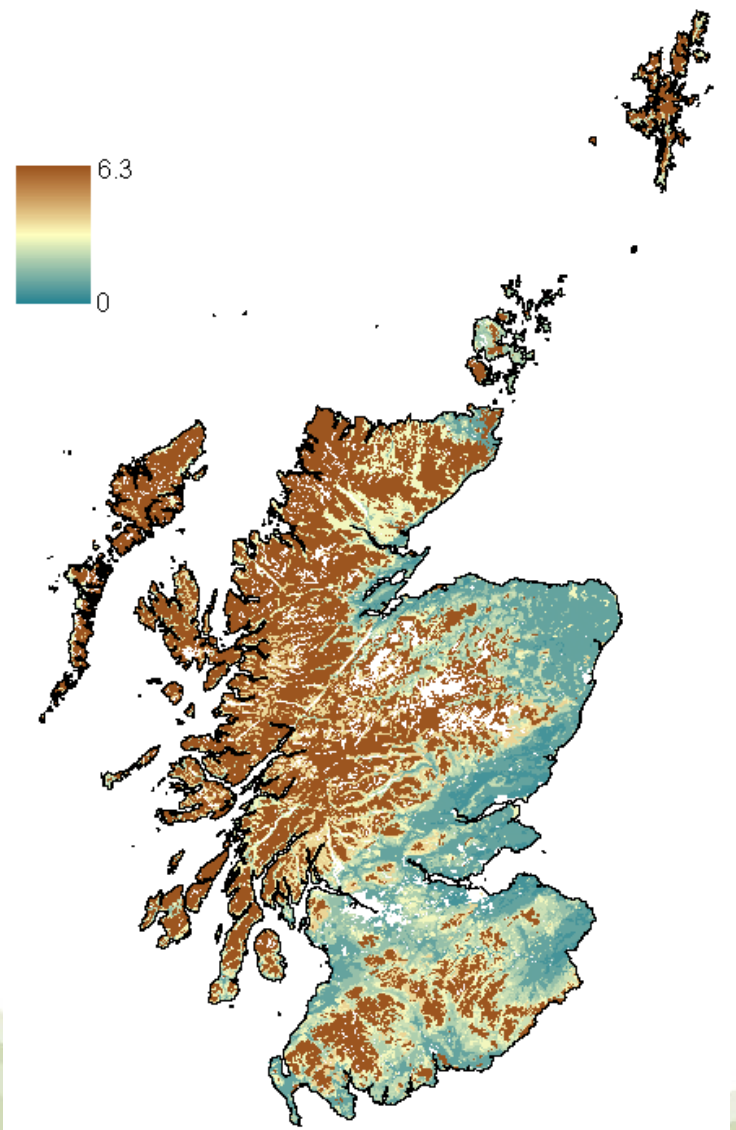
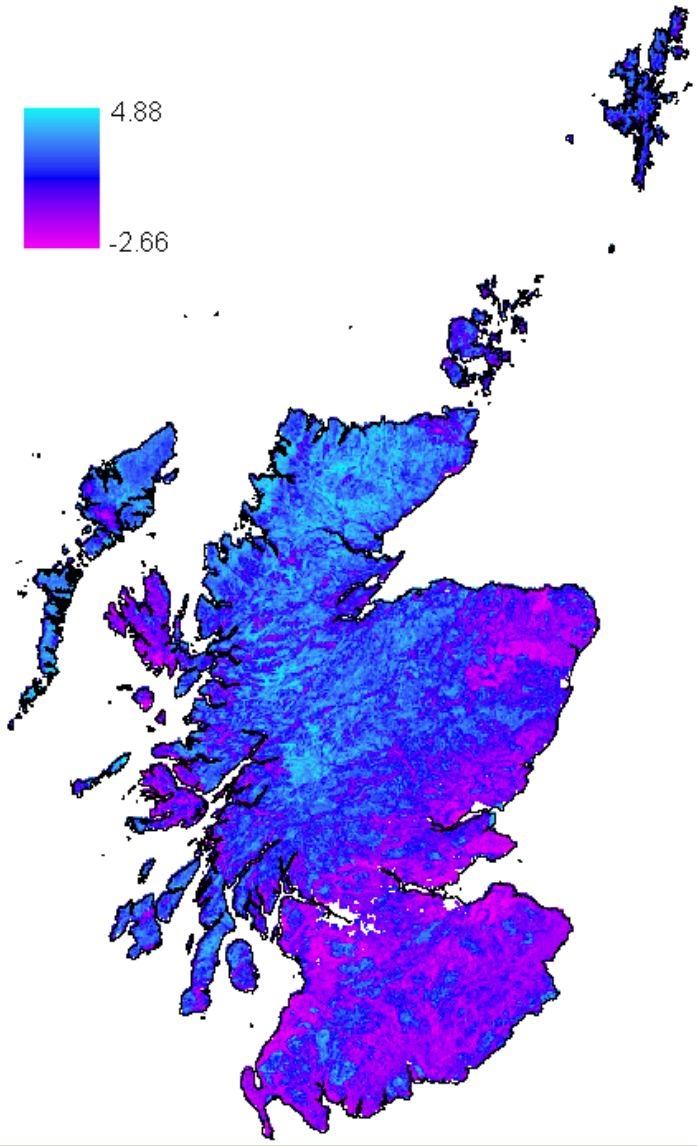
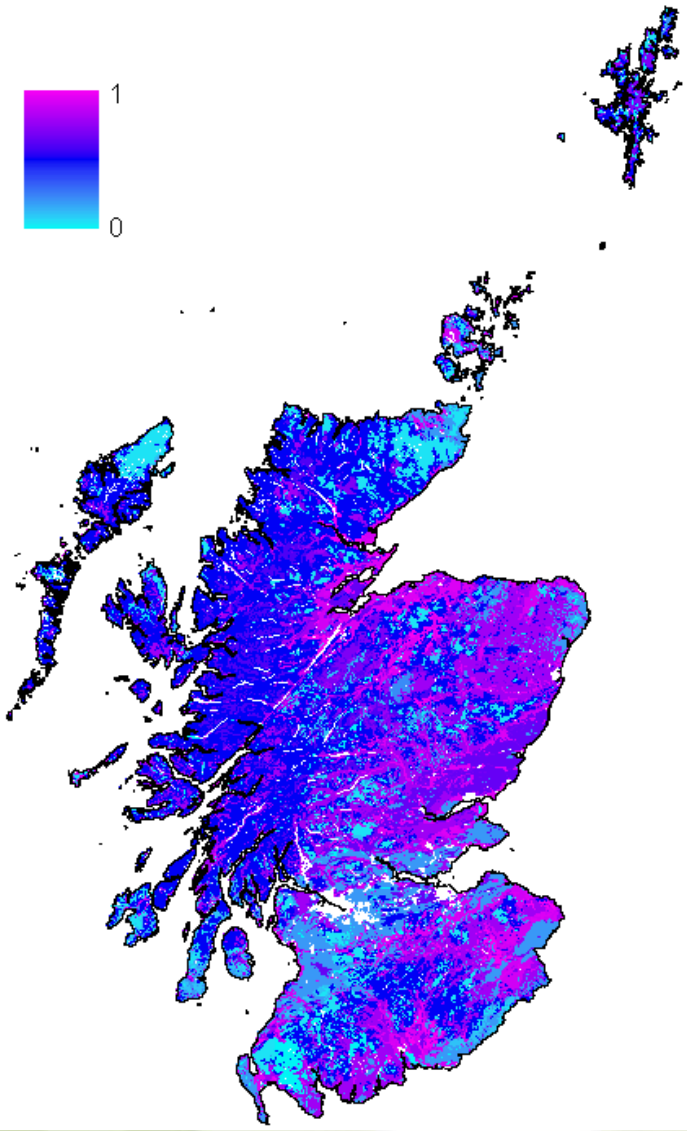


LCA (Brown & Towers)

Water supply





Matrix approach

Base flow index from HOST

Conclusions

- Appears applicable to full range of landscapes/land uses
- Provides different results to existing maps, need further examination to determine if/where it is simply wrong
- Good for rapid, high resolution function/service assessment, provided they are well defined!
- Flexible – can accommodate additional information
- What are the flaws?
  - Assumes linearity in relationships
  - Ignores synergies
  - Highly dependent upon valuation of relationships – needs good underpinning evaluations/statistics
- How can it be improved?
  - Need some way of expressing nonlinear relationships
  - Expansion to include additional environmental & soil parameters, processes, functions etc.