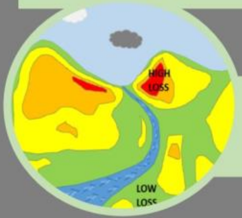
From Field to Stream: *Holistic approach to tracing sediment origins at a catchment scale*

Sediment fingerprinting provides dominant land use source of sediment/OC within catchment streams

However, it is likely there are many different areas of that land use within a catchment



SOC loss modelling can identify areas of a catchment at high risk of SOC loss

Accelerated **soil erosion** due to changes in climate and human activity results in **loss of soil organic carbon (SOC)** from land to the waterways

Quantification of **terrestrial to aquatic SOC fluxes** and their drivers, is crucial for their integration within the wider **carbon cycle** and **climate change mitigation**

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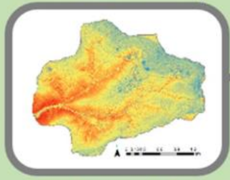
The James Hutton Institute

STARS Soils Training And Research Studentships

SEPA Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

Soil OC content (%)

Index of Connectivity

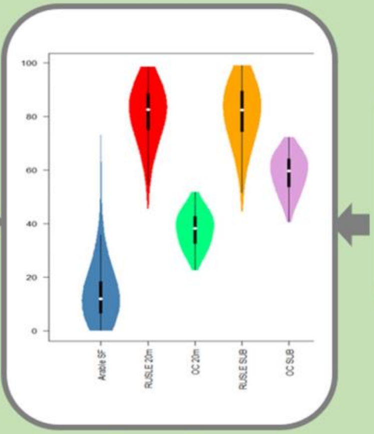


RUSLE erosion model

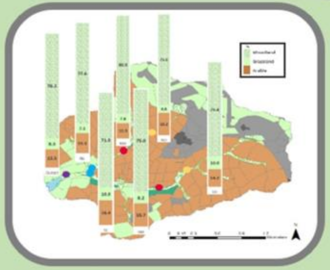
Soil OC loss

Per Sub-catchment land-use

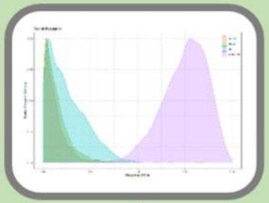
Per 20m stream buffer land-use



Land use specific source soil proportions



Bayesian-based unmixing model (MixSIAR)

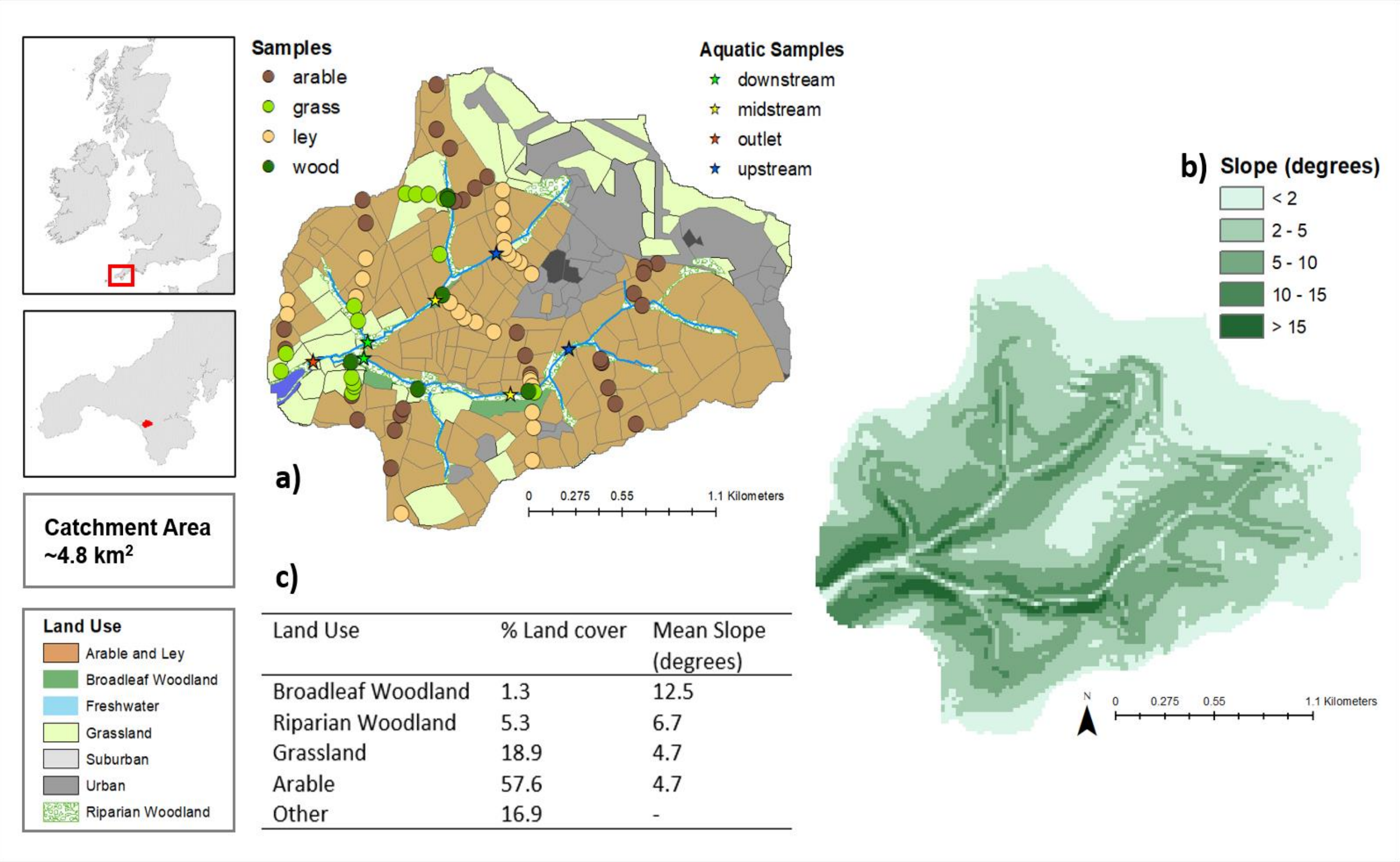


N-alkane biomarkers

Sediment Fingerprinting (SF)

Study Catchment 4.8km² @ Carminowe Creek, Cornwall, UK

Study Site – Carminowe Creek and Loe Pool, Cornwall, UK



Land Use	% Land cover	Mean Slope (degrees)
Broadleaf Woodland	1.3	12.5
Riparian Woodland	5.3	6.7
Grassland	18.9	4.7
Arable	57.6	4.7
Other	16.9	-

Data collected for a 2017 sediment fingerprinting study tracing the origins of OC in a Loe Pool lake core (Glendell et al., 2017)

75 terrestrial soil samples

7 streambed sediment samples

%OC, *n*-alkane concentrations

Glendell, M., Jones, R., Dungait, J.A.J., Meusburger, K., Schwendel, A.C., Barclay, R., Barker, S., Haley, S., Quine, T.A., Meersmans, J., 2018. Tracing of particulate organic C sources across the terrestrial-aquatic continuum, a case study at the catchment scale (Carminowe Creek, southwest England). Sci. Total Environ. 616, 1077–1088. https://doi.org/10.1016/j.scitotenv.2017.10.211

Sediment Fingerprinting – streambed sediment

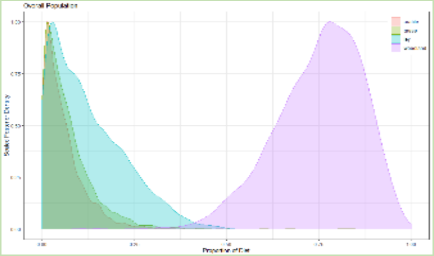
Physical and biogeochemical characteristics (soil type, topography, climate, land use) can be used to characterise each source using a "fingerprint"

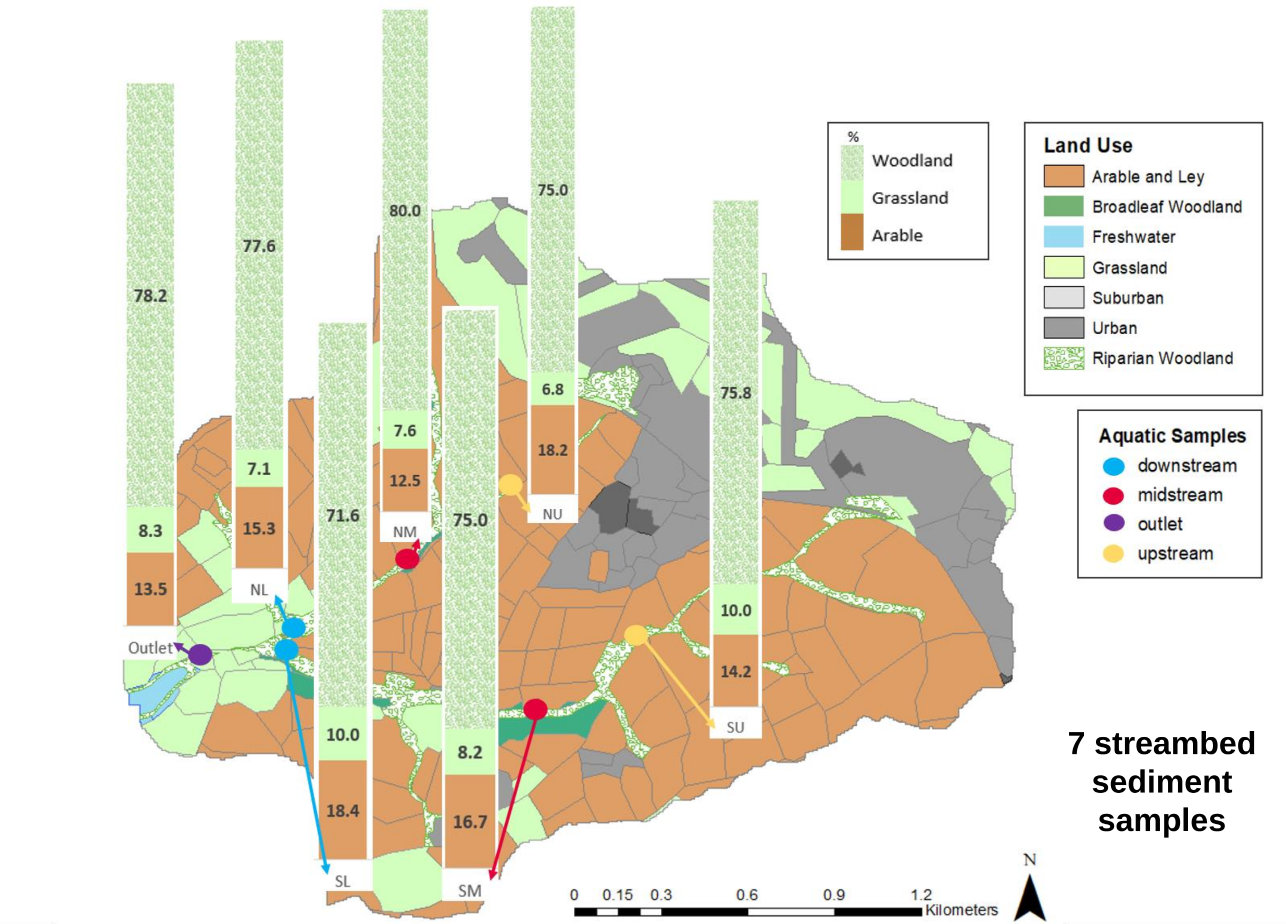
By assuming fingerprint properties behave conservatively statistical models can identify sediment sources and amount of sediment contributed by each source.

Primary source of soil OC is from plant tissue and plant to soil transfer consists of various organic compounds

Using OC biomarkers such as *n*-alkanes we can distinguish sediment sources originating from different land uses

Bayesian based unmixing model (MixSIAR) (Stock and Semmens, 2016)





7 streambed sediment samples

Stock, B.C., Semmens, B.X., 2016. MixSIAR GUI User Manual. Version 3.1. https://doi.org/10.5281/zenodo.1209993

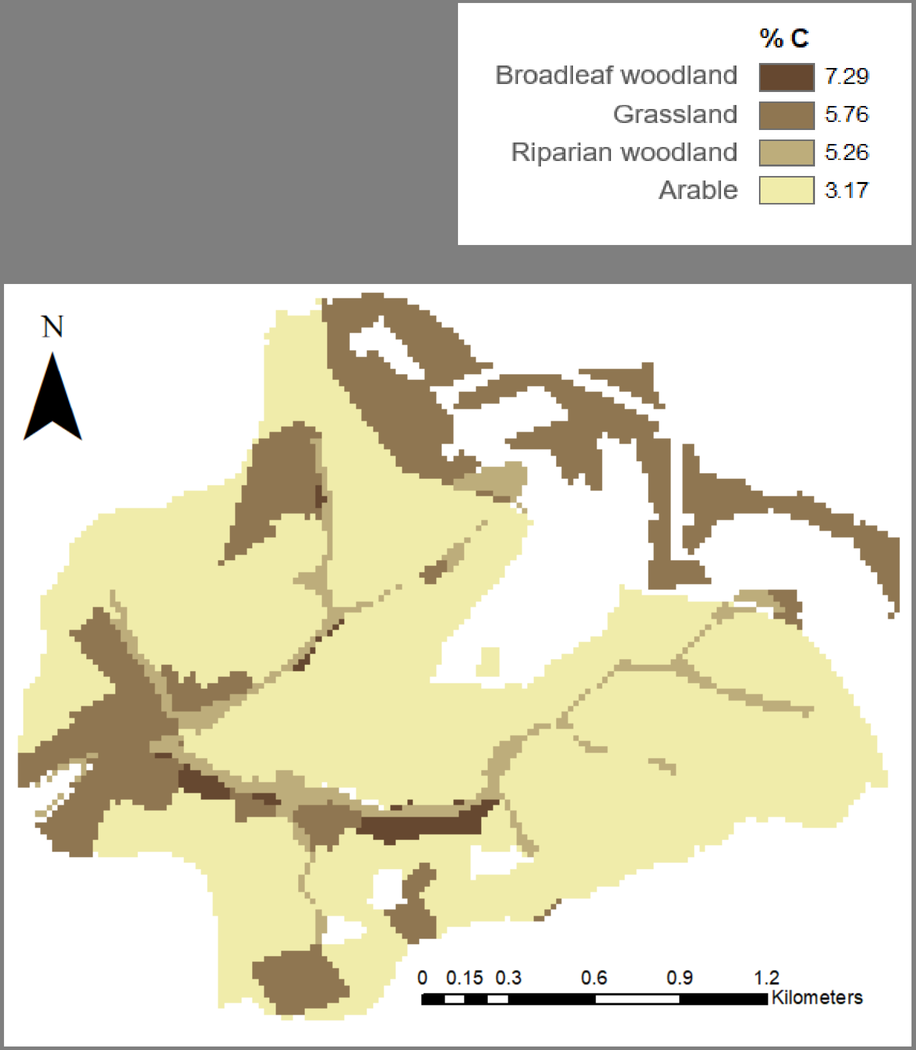
Soil OC loss modelling – SOC mapping

Linear regression model

7 land-use and topographic environmental predictors considered: land use, slope, curvature, flow length, accumulated flow, topographic wetness index and aspect.

Best model selected using smallest Akaike Information Criterion (AIC) and highest adjusted R^2.
→ Single predictor: land use

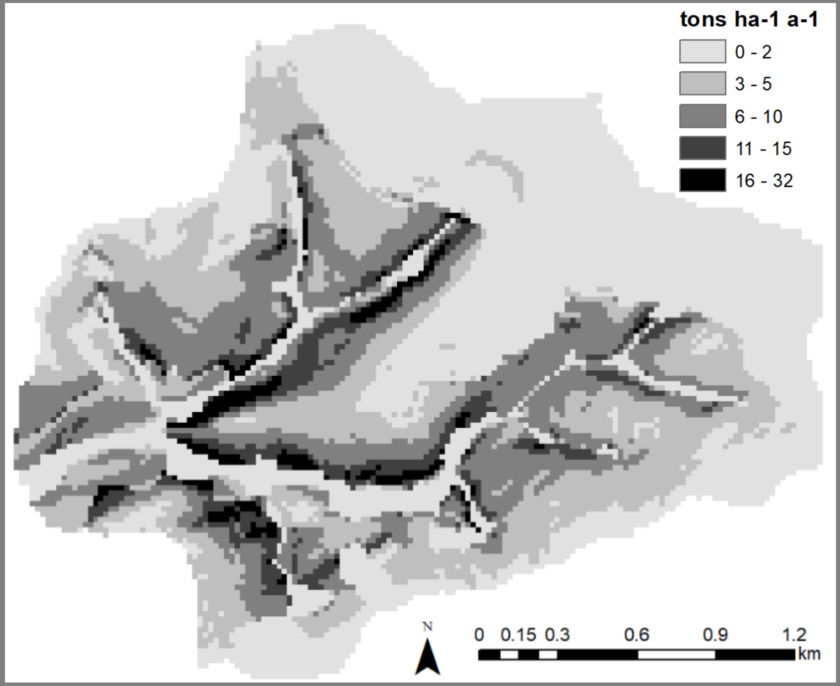
A leave-one-out cross-validation
→ root mean square error (RMSE) and R^2



Soil OC loss modelling – RUSLE

The Revised Universal Soil Loss Equation (**RUSLE**) has been used extensively in many different parts of the world to calculate long-term average annual soil loss

RUSLE uses topography, soil type, climate, land use and management characteristics of a catchment to calculate the rill and interrill erosion across the area



$$SL = R.K.S.L.C.P$$

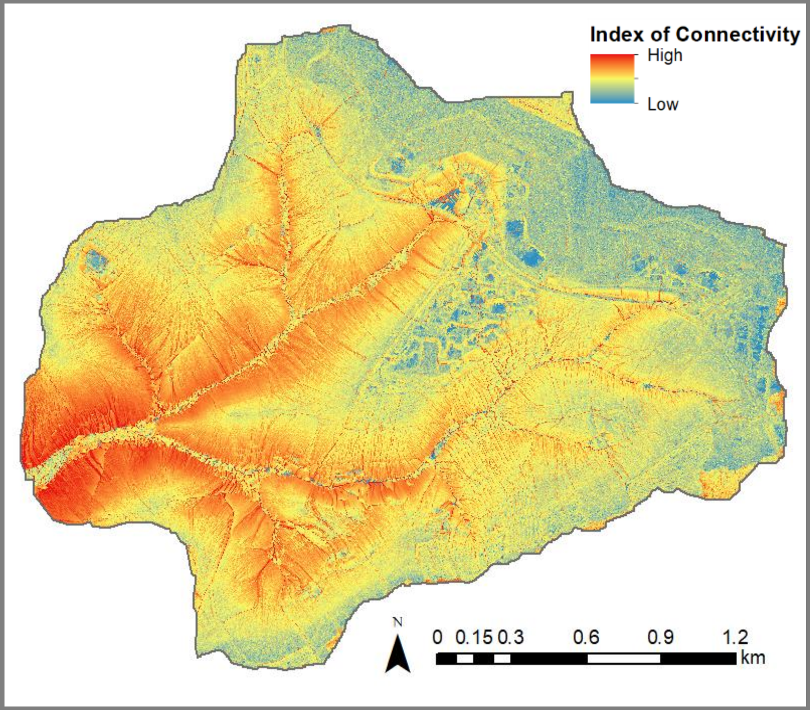
where **SL** is the mean soil loss (tons ha^{-1} yr^{-1}),
R is the rainfall intensity factor (MJ mm ha^{-1} h^{-1} yr^{-1}),
K is the soil erodibility factor (tons ha h ha^{-1} MJ^{-1} mm^{-1})
S and **L** are the slope and slope-length factors,
C and **P** are the dimensionless cover-management factor and conservation support practice factor

RUSLE spatial erosion maps can provide estimates of the relative contribution of each land use to erosion within a catchment

Soil OC loss modelling – Index of Connectivity

RUSLE provides no simulation of source to stream connectivity or sediment routing
→ predicts gross erosion not net erosion

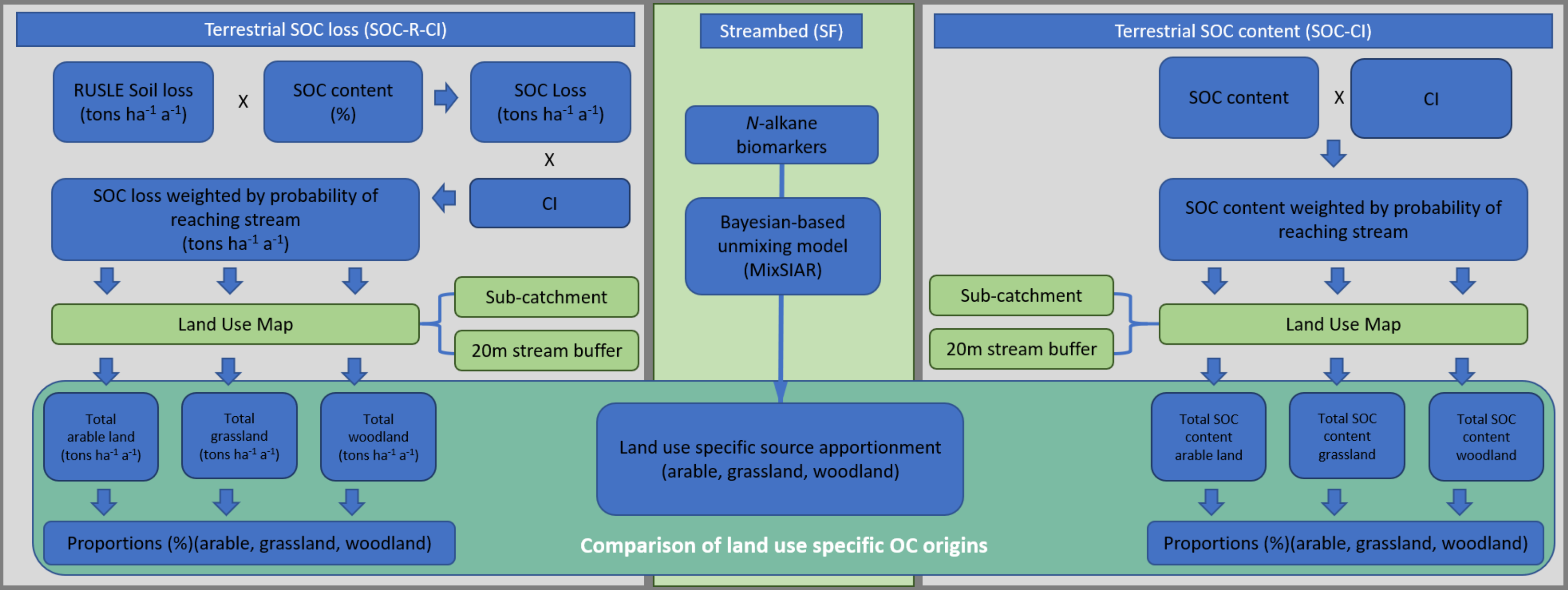
Combined RUSLE with probability of connectivity in order to better predict terrestrial to aquatic fluxes.



Using the Index of connectivity (CI) approach of Borselli et al. (2008), sources identified using methods such as RUSLE can be connected, through slopes, to landscape "sinks" providing an estimate of potential connection between areas of upslope erosion and streams

Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. Catena 75, 268–277. https://doi.org/10.1016/j.catena.2008.07.006

Approach Overview



Terrestrial SOC loss (SOC-R-CI)

RUSLE Soil loss (tons ha^{-1} a^{-1}) X SOC content (%) → SOC Loss (tons ha^{-1} a^{-1})

X

CI

SOC loss weighted by probability of reaching stream (tons ha^{-1} a^{-1})

Land Use Map

Sub-catchment

20m stream buffer

Total arable land (tons ha^{-1} a^{-1})

Total grassland (tons ha^{-1} a^{-1})

Total woodland (tons ha^{-1} a^{-1})

Proportions (%)(arable, grassland, woodland)

Streambed (SF)

N-alkane biomarkers

Bayesian-based unmixing model (MixSIAR)

Land use specific source apportionment (arable, grassland, woodland)

Comparison of land use specific OC origins

Terrestrial SOC content (SOC-CI)

SOC content X CI

SOC content weighted by probability of reaching stream

Sub-catchment

20m stream buffer

Land Use Map

Total SOC content arable land

Total SOC content grassland

Total SOC content woodland

Proportions (%)(arable, grassland, woodland)

- Sub-catchments contributing to the 7 streambed sediment positions delineated
- To evaluate if closer match to SF could be obtained by considering only land in close proximity to the stream channel (rather than whole sub-catchment), SOC-CI and SOC-R-CI were also calculated for a 20m stream buffer at each of the 7 streambed positions

Uncertainty Analysis

Cover-management C-factor within RUSLE model can be set to account for differences in erosion potential between land use types

→ range of values found for RUSLE C factor in literature can lead to a difference in RUSLE output of between one to two orders of magnitude

This study primarily concerned with comparison of RUSLE SOC loss between land uses

→ evaluate magnitude of errors due to uncertainty associated with the RUSLE C-factor as well as that introduced by the modelling of SOC content (%SOC)

Monte Carlo

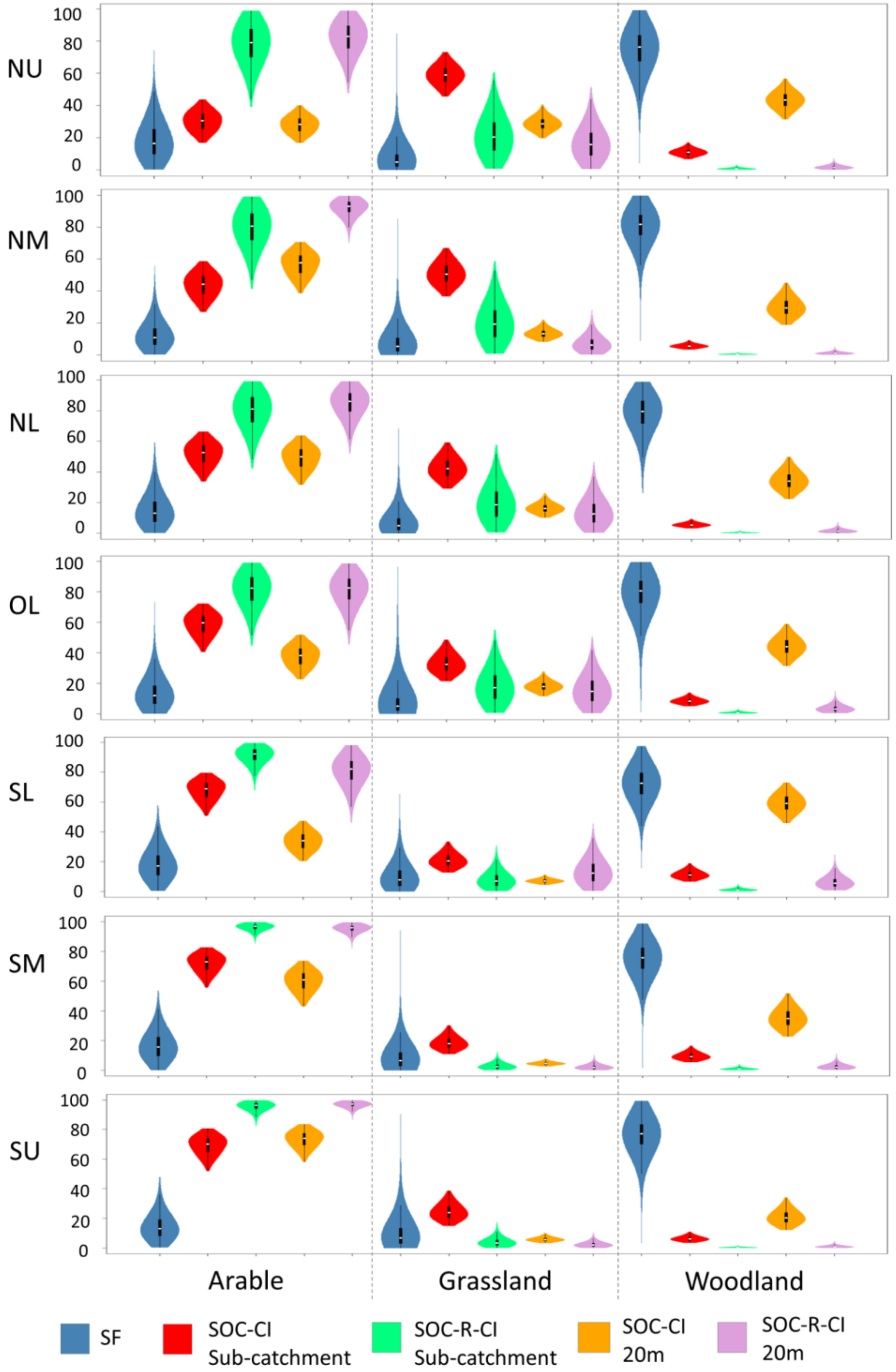
- 3,000 iterations
- *RUSLE C factor*: randomly sampled from a uniform distribution defined for each land use by maximum and minimum values found in the literature
- *%SOC content*: randomly sampled from a uniform distribution defined by +/-1 RMSE from the leave-one-out cross-validation of the %SOC map

Comparison of land use specific proportions of SOC delivered to Carminowe Creek streams

Violin plots represent probability density, the median (white dot) and interquartile range of the data distribution

SF → woodland dominated

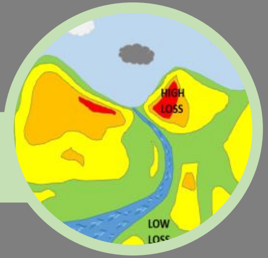
RUSLE SOC loss → arable dominated



Terrestrial to aquatic fluxes – Connectivity and Processes

We know the dominant land use of the OC in our stream

We know the dominant land use for catchment erosion



Why do they do not match?

Catchment connectivity

Discrepancy between the primary sources and the SOC delivered to the waterways can be due to factors affecting catchment connectivity, such as preferential runoff pathways (e.g. road, tracks, gateways) and buffer zones (e.g. permanent riparian vegetation)

Difference in Processes

RUSLE models sheet interrill and small rill erosion only. It does not consider other geomorphological processes (e.g. gully, bank and channel erosion, bank overflow, leaf and wood fall) which may make a significant contribution to streambed OC

Terrestrial to aquatic fluxes – Conclusions

Even considering the uncertainty in the SOC loss modelling there is a disconnect between soil OC loss estimates using RUSLE (arable dominated) and SF (woodland dominated)

Although providing estimates regarding potential SOC loss from the areas of catchment prone to water erosion, the catchment-wide rill and inter-rill erosion processes represented in RUSLE did not provide a realistic estimate of OC input to the streams

Two-fold influence of extensive riparian woodland which i) likely disconnected much eroded sediment from upslope arable and grassland fields, reducing their presence in streambed sediment and, ii) provided delivery of woodland derived OM to streams

Highlights the importance of considering catchment connectivity and intermediate sediment storage (buffers) in the estimation of terrestrial to aquatic transfer of SOC

Further Work

This study was focussed on streambed sediments only and in future studies it will be important to assess if the comparison between SOC erosion modelling and SF would be closer if SF of both streambed and suspended sediment was considered