A step towards unveiling the sediment provenance in a small urban catchment — Setun river case study

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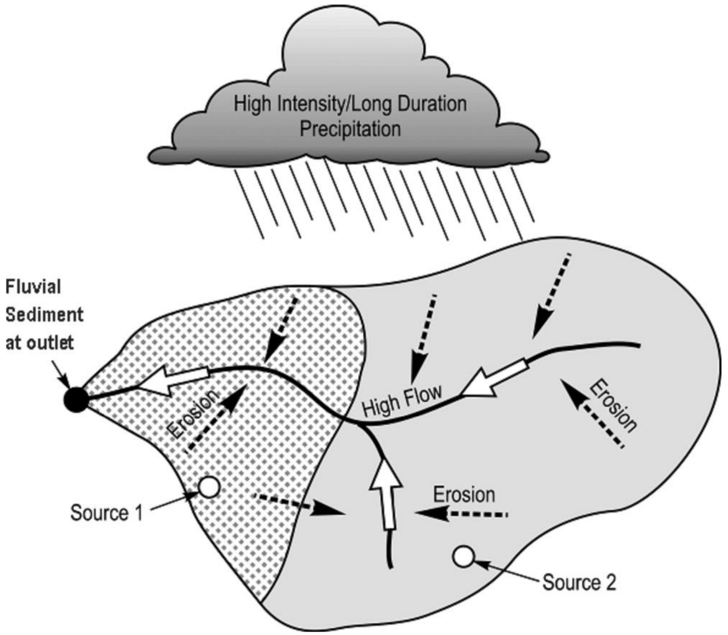
Fingerprinting — a tool to quantify the provenance of sediments/contaminants

International Journal of Sediment Research
Volume 28, Issue 4, December 2013, Pages 560-578

Sediment fingerprinting in fluvial systems: review of tracers, sediment sources and mixing models

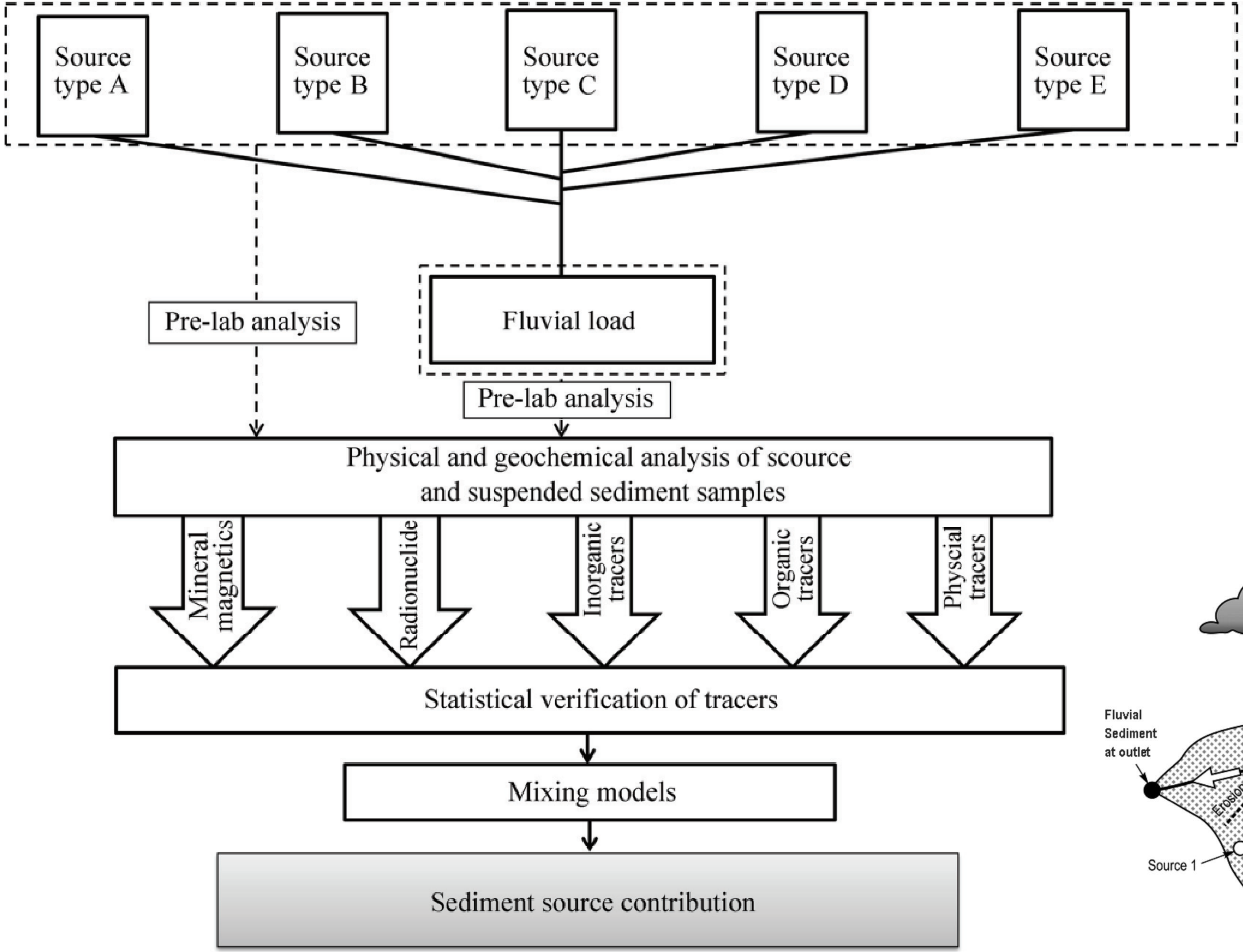
Arman HADDADCHI [a], Darren S. RYDER [b], Olivier EVRARD [c], Jon OLLEY [d]

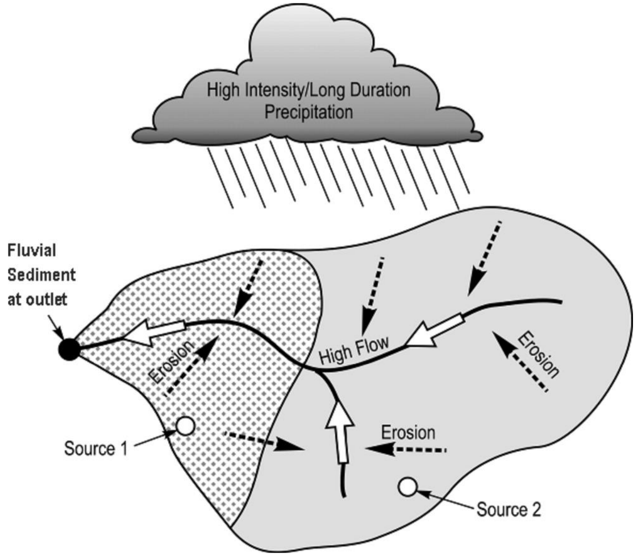
Suspended sediments in fluvial systems originate from a myriad of diffuse and point sources, with the relative contribution from each source varying over time and space. The process of sediment fingerprinting focuses on developing methods that enable discrete sediment sources to be identified from a composite sample of suspended material.



Fingerprinting concept

Fingerprinting concept





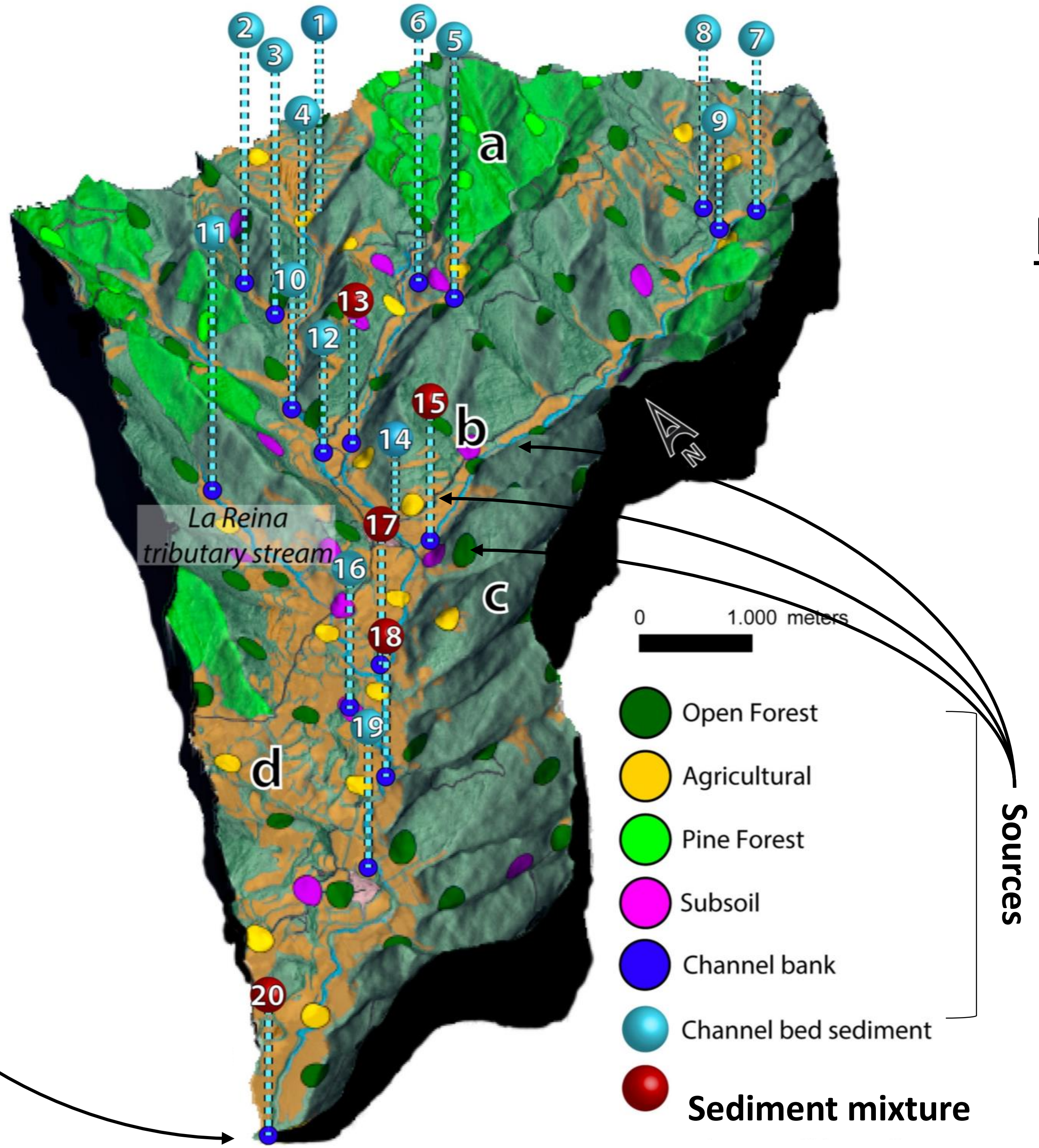
Haddadchi et al., 2013

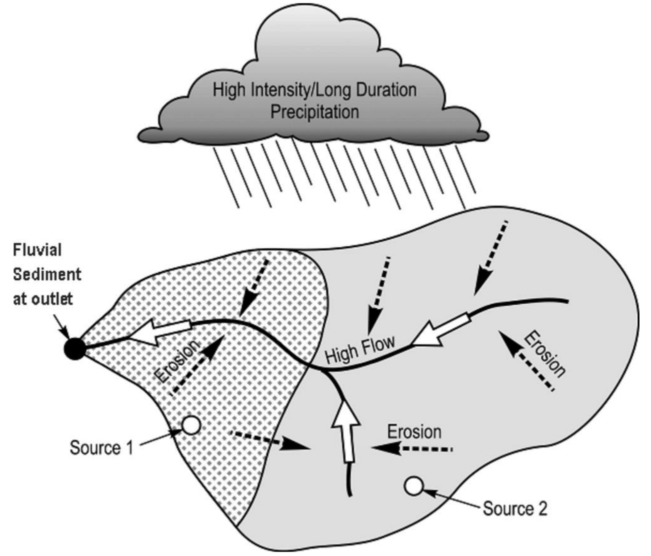
Fingerprinting concept

What is the contribution of different sources to the sediment mixture (i.e. target)?

Fingerprinting assesses the relative contribution of the selected sediment sources for sediment mixture

Sediment mixture (Target)

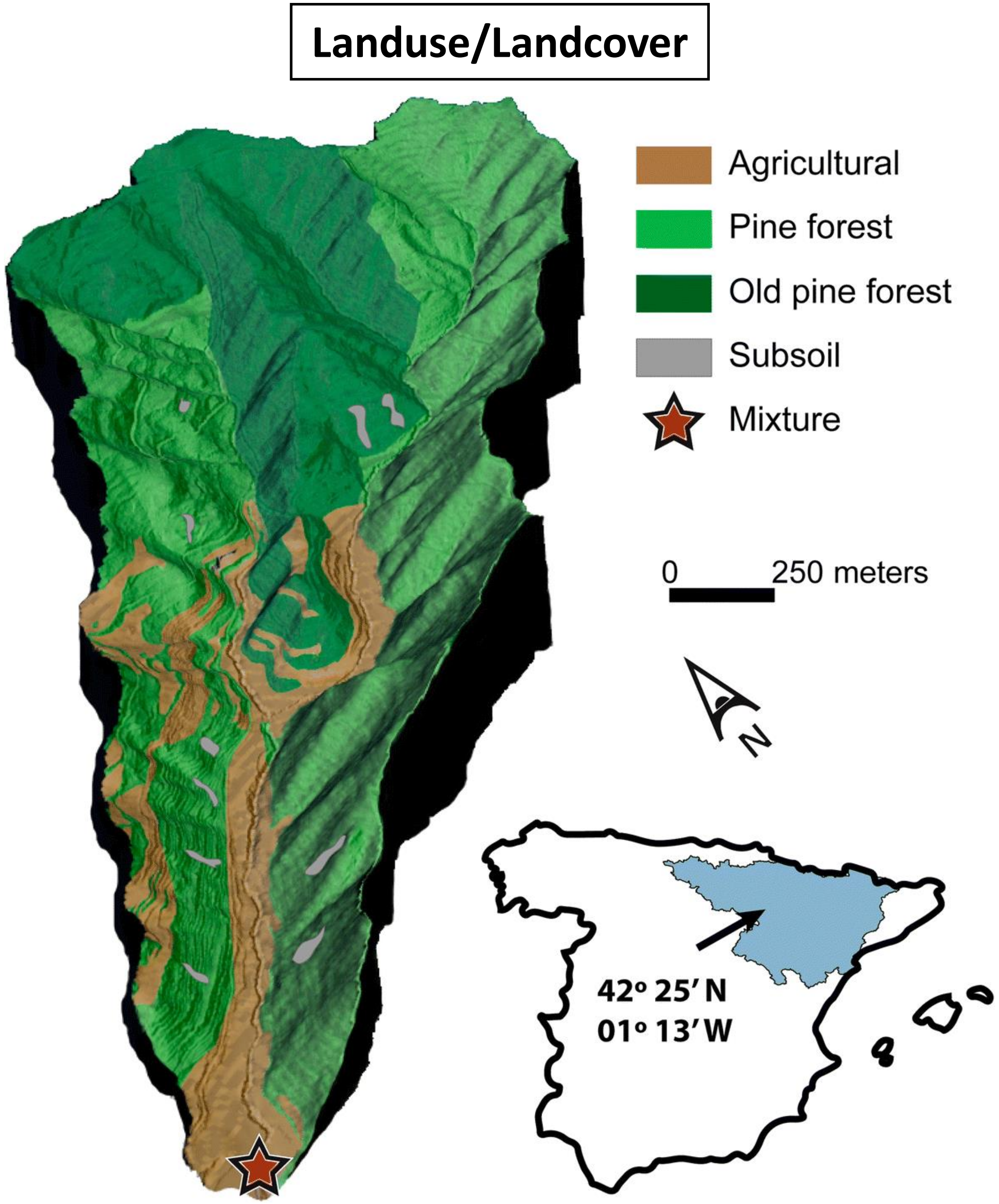


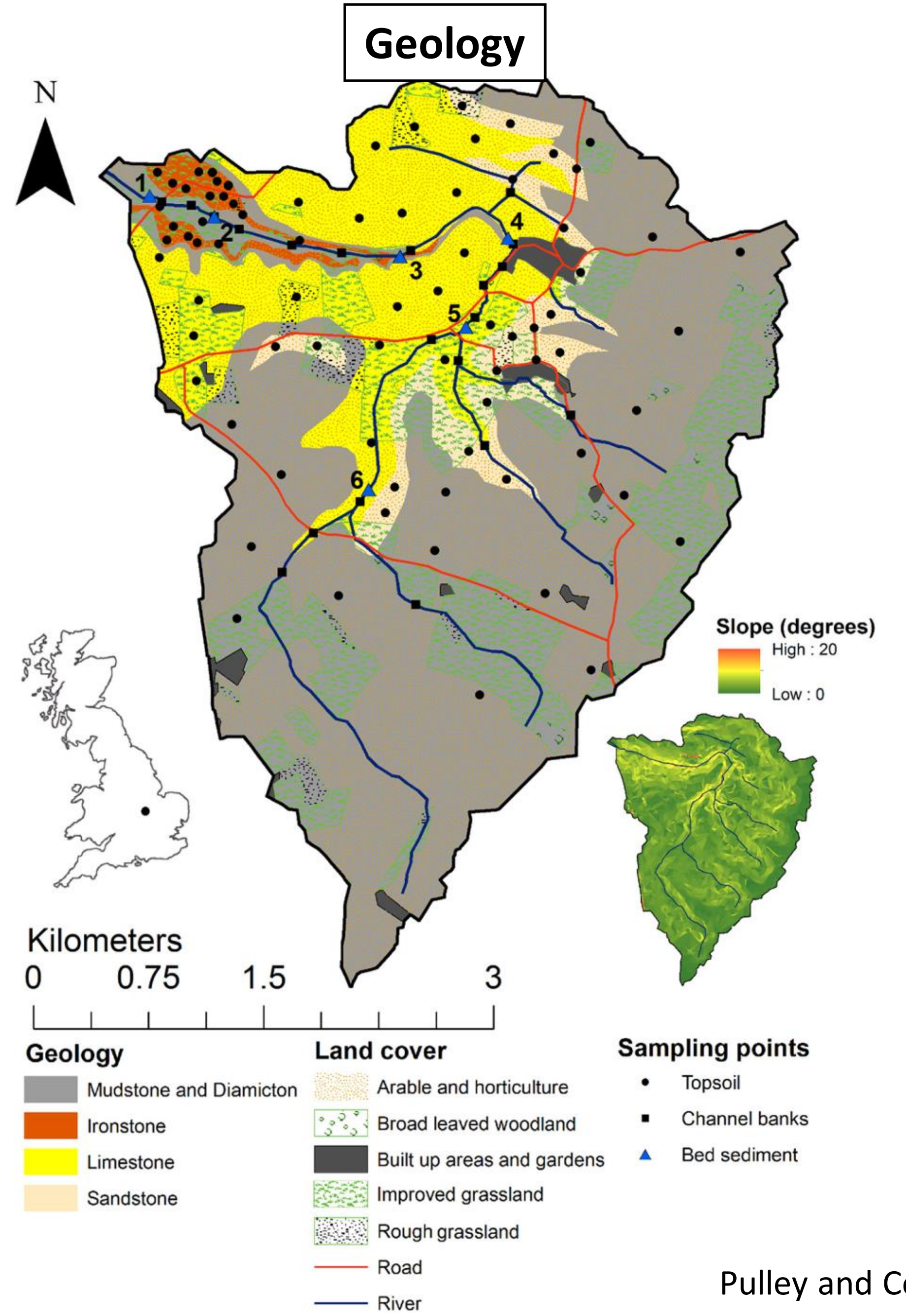


Lizaga et al., 2019

What can be sediment source?

Source selection



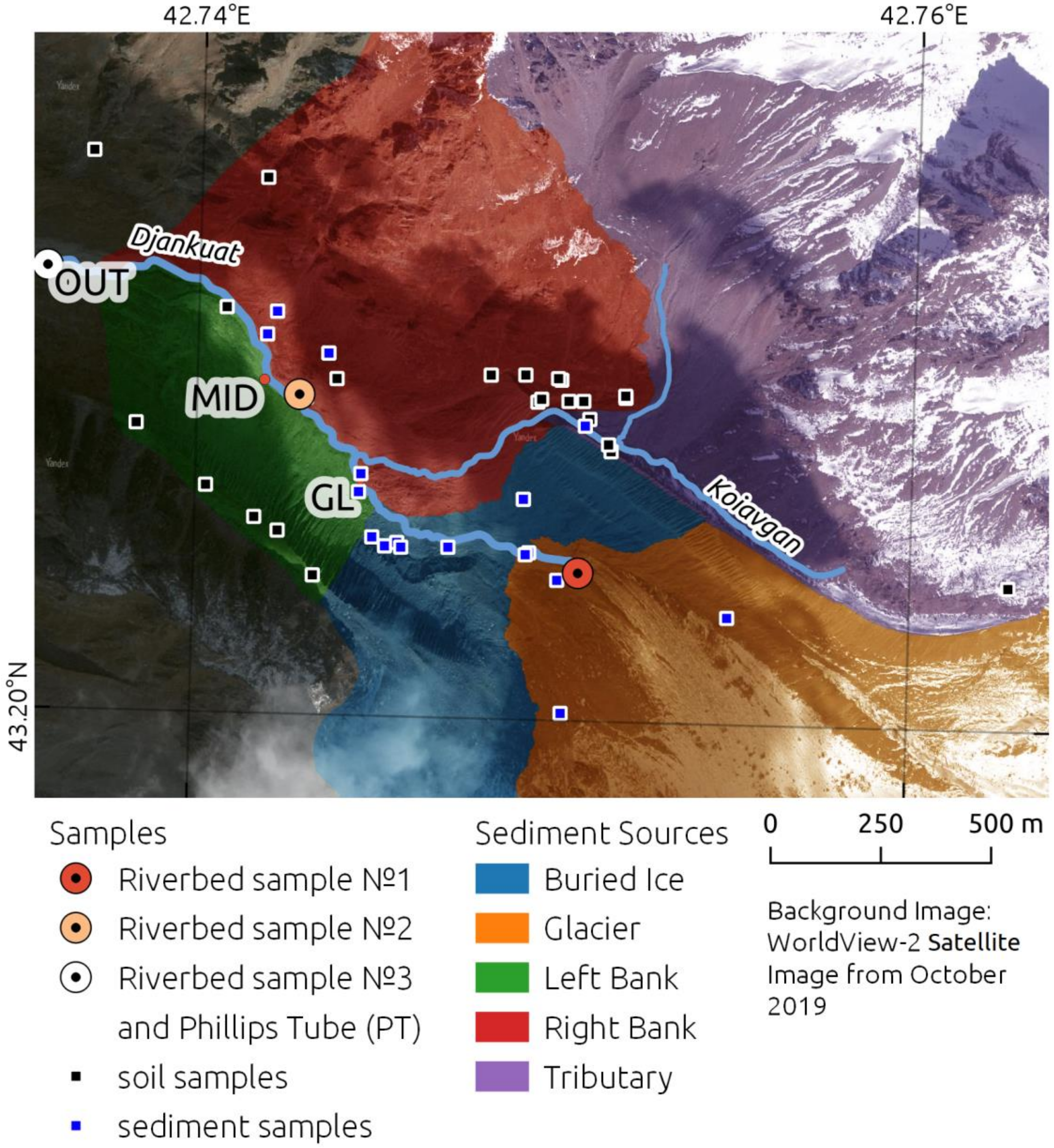


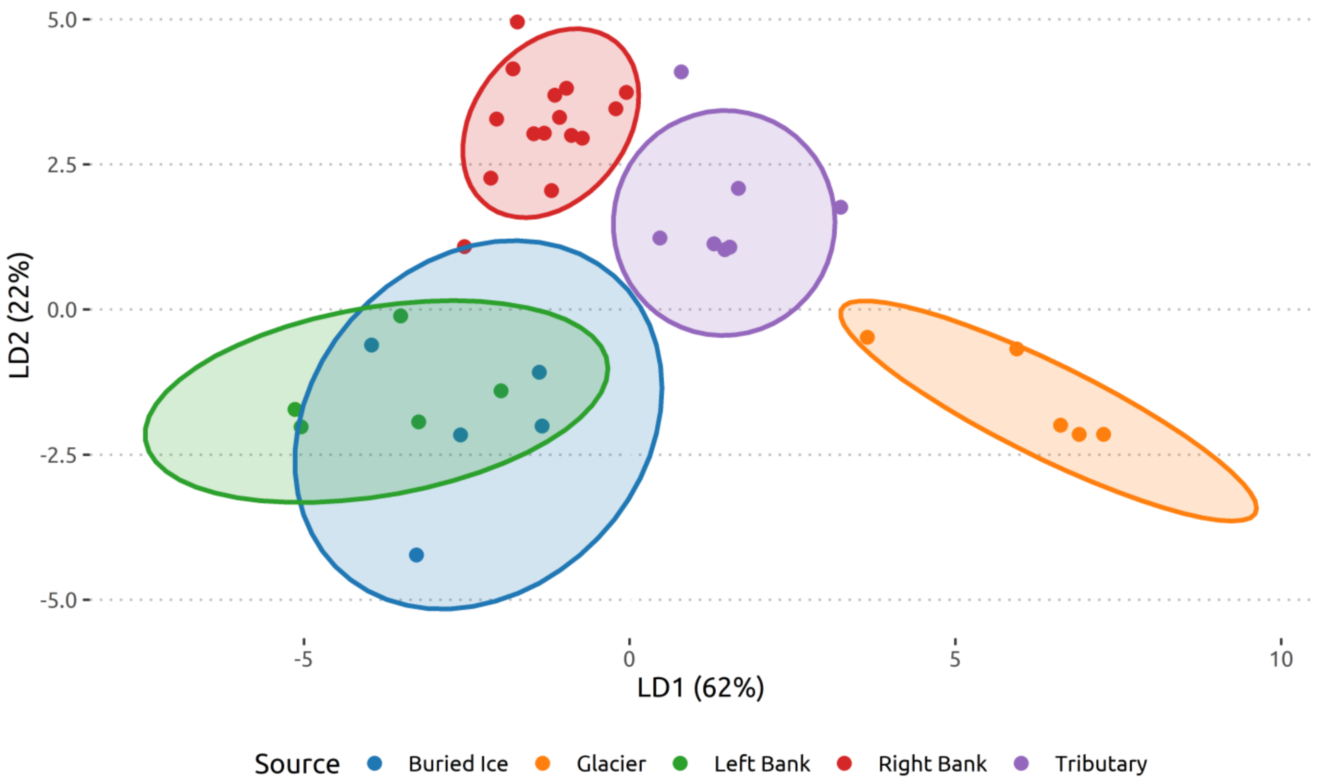
Lizaga et al., 2020

Pulley and Collins, 2018

Source selection

«Geomorphology»

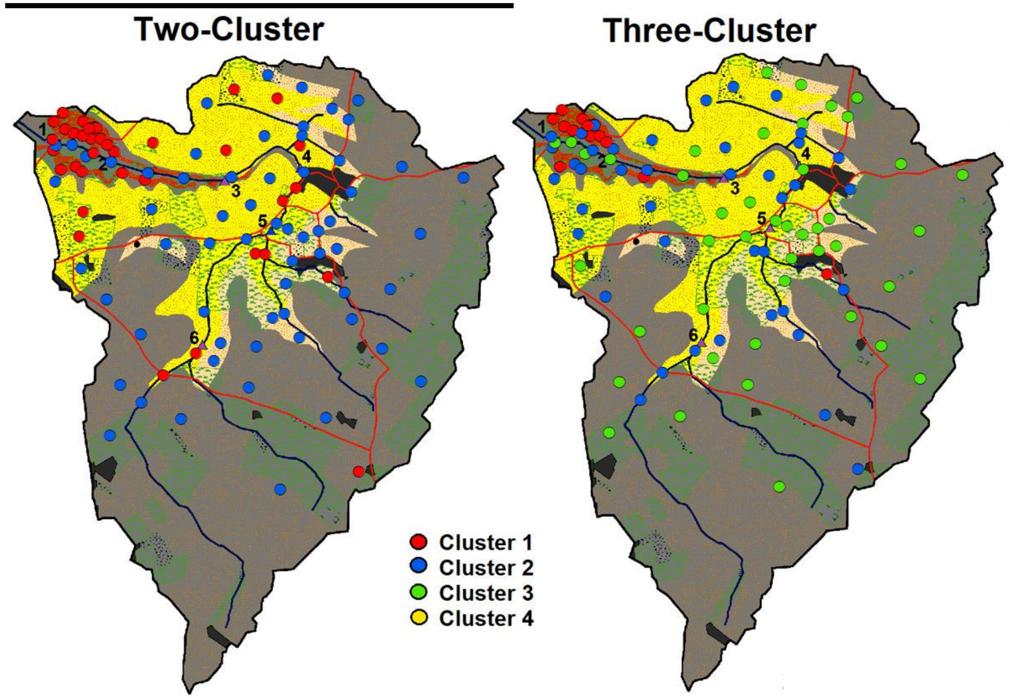


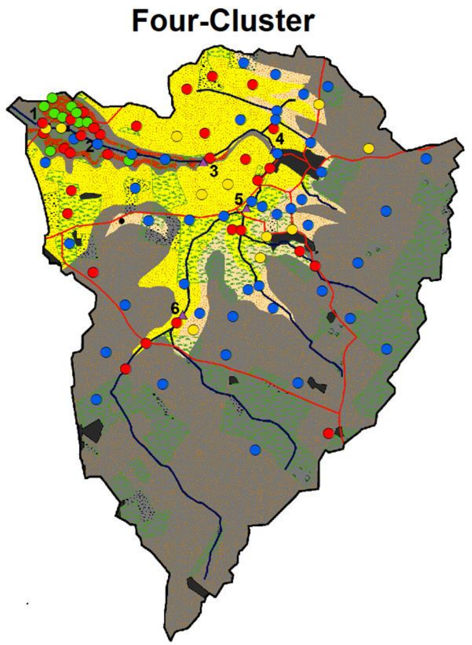


5 sources were selected based on geomorphology map, sediment connectivity, landform classification

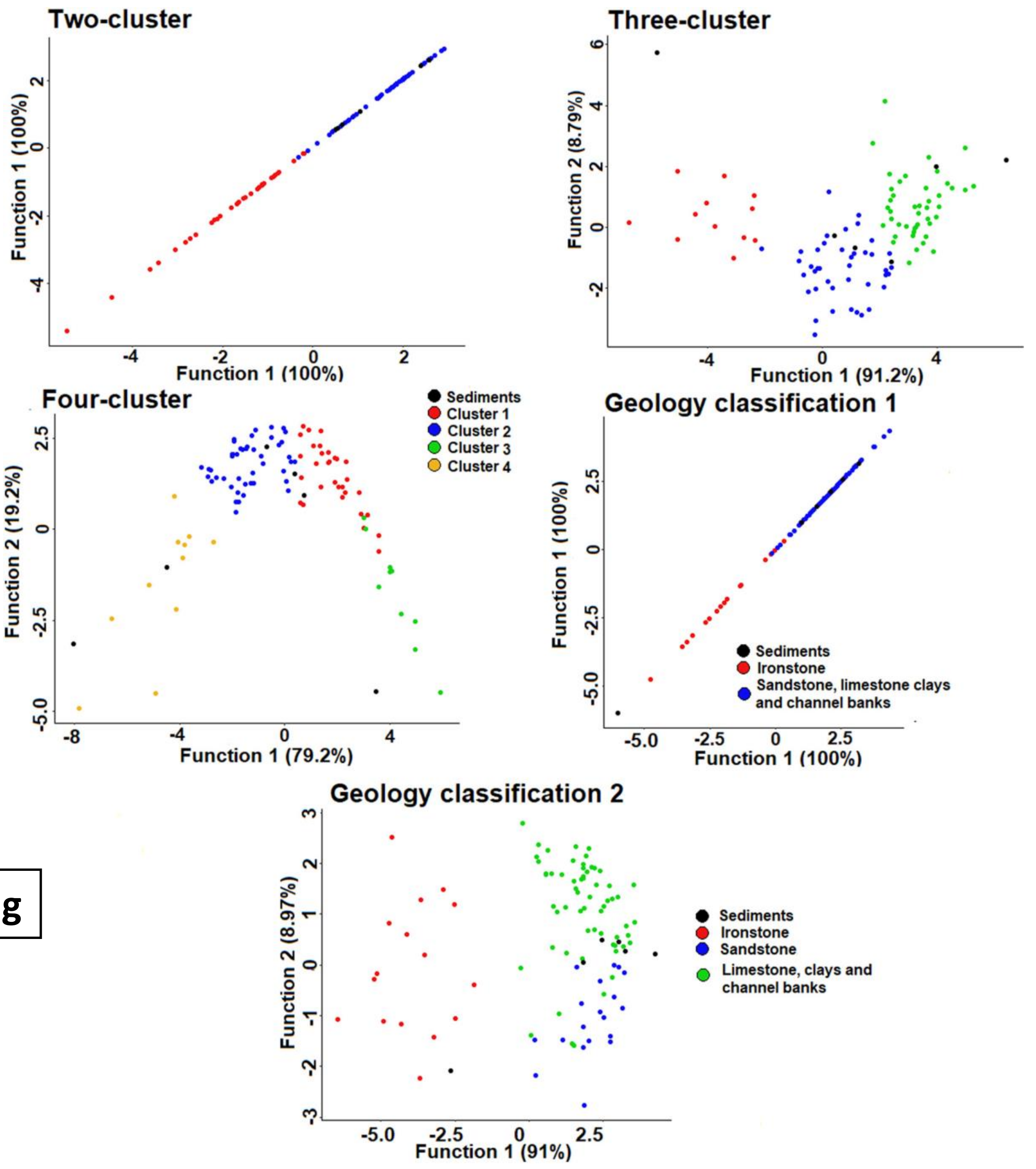
Tsyplenkov et al., 2021

Source selection





K-mean/C-mean clustering



Pulley and Collins, 2018

What about tracers?

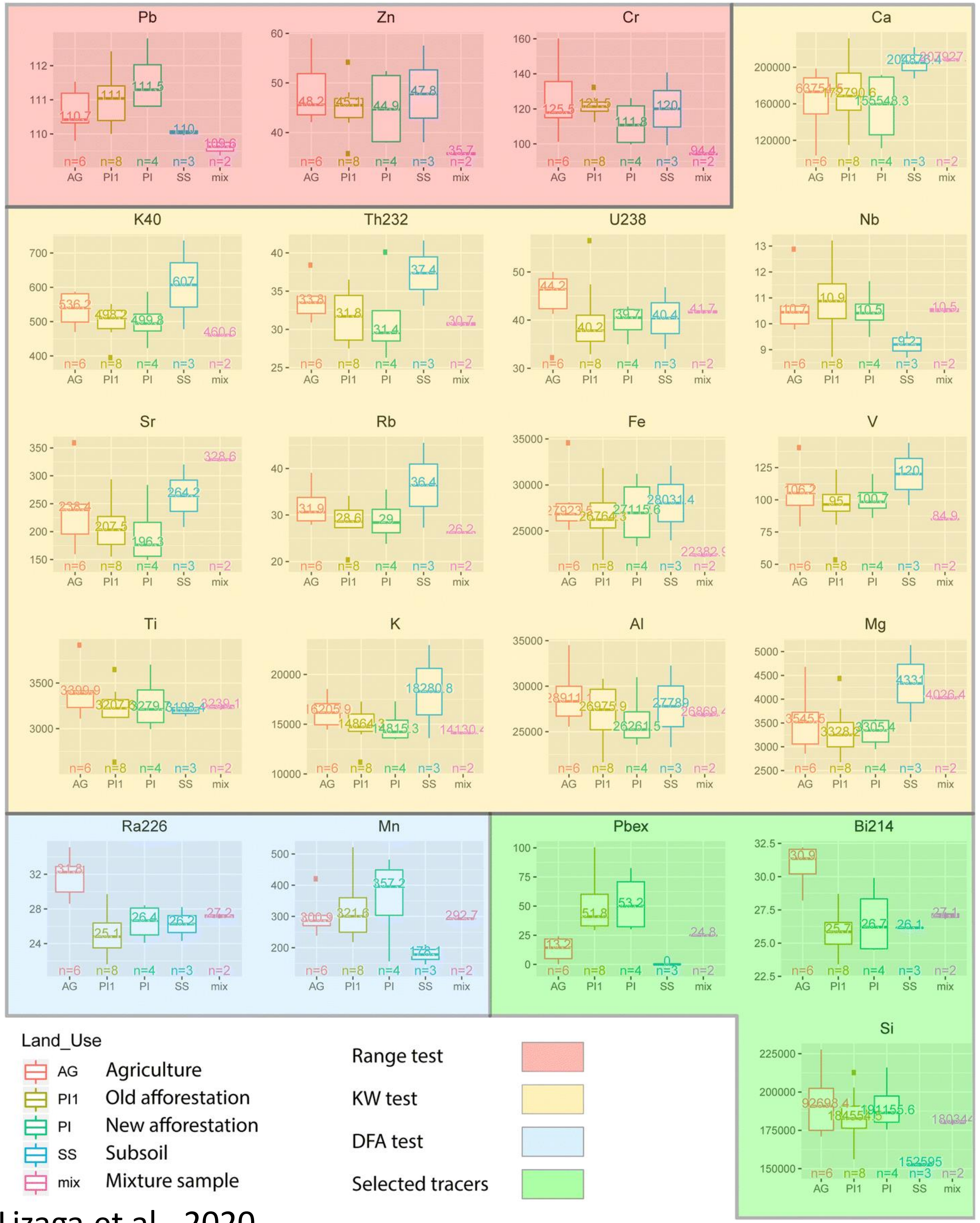
Tracer selection

Table 2 The range of tracing techniques, their applicability and success in discriminating among sources from twenty published sediment fingerprinting studies

Study	Physical tracers	Organic	Inorganic	Radionuclide	Magnetic tracers	Best tracers	Description of location and sediment sources	Most contributed area (percent of contribution)
(Walling et al., 1993)		C, N		^{137}Cs, ^{210}Pb	χ ARM, SIRM, IRM		Jackmoor Brook Basin (UK) six sources: two groups of pastures, three groups of cultivated areas, channel banks	Cultivated areas (57.5%), Pasture surfaces (23.6%), Channel banks (18.9%).
							River Dart Basin four sources: pasture, two groups of cultivated fields, channel banks	Pasture surfaces (48.2%), Cultivated areas (30.8%), Channel bank (21%),
(Walling et al., (1995)		C, N		^{137}Cs, $^{210}Pb_{ex}$, ^{226}Ra	χ, ARM, SIRM, IRM		River Culm Basin (UK) seven source types: Cretacepus/Eocene pasture, Cretacepus/Eocene cultivated, Triassic pasture, Triassic cultivated, Permian pasture, Permian cultivated, and channel banks	Triassic cultivated (29.5 %), Permian cultivated (19.7), Channel banks (12%)
(Slattery et al., 1995)					χ_{lf}, χ_{hf} SIRM, IRM		North Oxfordshire watershed (UK) three sources: Cultivated areas, channel banks, combined surficial soil/channel bank areas	Cultivated areas (38%), Channel banks (34%), combined surficial soil/channel bank areas (28%)
Collins 1997		C, N, P_{tot}	Fe_{pyr}, Fe_{dit}, Al_{pyr}, Al_{dit}, Mn_{pyr}, Fe_{tot}, Al_{tot}, Mn_{tot}, Fe_{oxa}, Mn_{oxa}, Al_{oxa}, Cu, Zn, Pb, Cr, Co, Ni, Na, Mg, Ca, K,	^{137}Cs		Ca, Co, Na, Fe_{dit}, Mn_{oxa}, Ni	The Exe Basin (UK) four sources: woodland, pasture areas, cultivated areas, channel banks	The Exe basin: Pasture areas (71.7%), Cultivated areas (20.4%), Channel banks (5.3%), Woodland (2.6%).
						Fe_{oxa}, Ca, C	The Severn Basin (UK) four sources: woodland, pasture areas, cultivated areas, channel banks	The Severn basin: Pasture areas (65.3%), Cultivated areas (25.4%), Channel banks (7.5%), Woodland (1.8%).
Collins 1997	Absolute particle size	C, N, P_{tot}	Fe_{pyr}, Fe_{dit}, Mn_{pyr}, Mn_{dit}, Al_{pyr}, Al_{dit}, Fe_{tot}, Mn_{tot}, Al_{tot}, Fe_{oxa}, Mn_{oxa}, Al_{oxa}, Cu, Zn, Pb, Cr, Co, Ni, Na, Mg, Ca, K	^{137}Cs, ^{210}pb		Ni, Co, K, P_{tot}, N	The Dart Basin (UK) four sources: woodland, pasture areas, cultivated areas, channel banks	Pasture areas (78%), Cultivated areas (14%), woodland (4.5%), channel banks (3.5%)
						N, Cu, ^{137}Cs	The Plynlimon Basin (Uk) three sources: forest areas, pasture areas, channel banks	Pasture areas (66%), Forest areas (25%), Channel banks (9%)
Wallbrink, Murray et al. 1998				^{137}Cs, $^{210}Pb_{ex}$		^{137}Cs, $^{210}Pb_{ex}$	Murrumbidgee River (Australia) uncultivated areas, cultivated areas, channel banks	Uncultivated areas (78%), Cultivated areas (22%)
(Walling et al., 1999)		C, N, P, P_{tot}	Al, Ca, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sr, Zn, total P	^{137}Cs, $^{210}Pb_{ex}$, ^{226}Ra	χ, SIRM	N, Total P, Sr, Ni, Zn ^{226}Ra, ^{137}Cs, $^{210}Pb_{ex}$, Fe, Al	Swale River (UK) four sources: woodland, uncultivated areas, cultivated areas, channel banks	Uncultivated areas (42%), Cultivated areas (30%), Channel banks (28%)
							Ure River four sources: woodland, uncultivated areas, cultivated areas, channel banks	Uncultivated areas (45%), Channel banks (37%), Cultivated areas (17%)
							Nidd River four sources: woodland, uncultivated areas, cultivated areas, channel banks	Uncultivated areas (75%), Channel banks (15%)
							Ouse River four sources: woodland, uncultivated areas, cultivated areas, channel banks	Cultivated areas (38%), Channel banks (37%), Uncultivated areas (24.6%)
							Wharfe River four sources: woodland, uncultivated areas, cultivated areas, channel banks	Uncultivated areas (69.5%), Channel banks (22.5%)

Haddadchi et al., 2013

How should I select tracers?



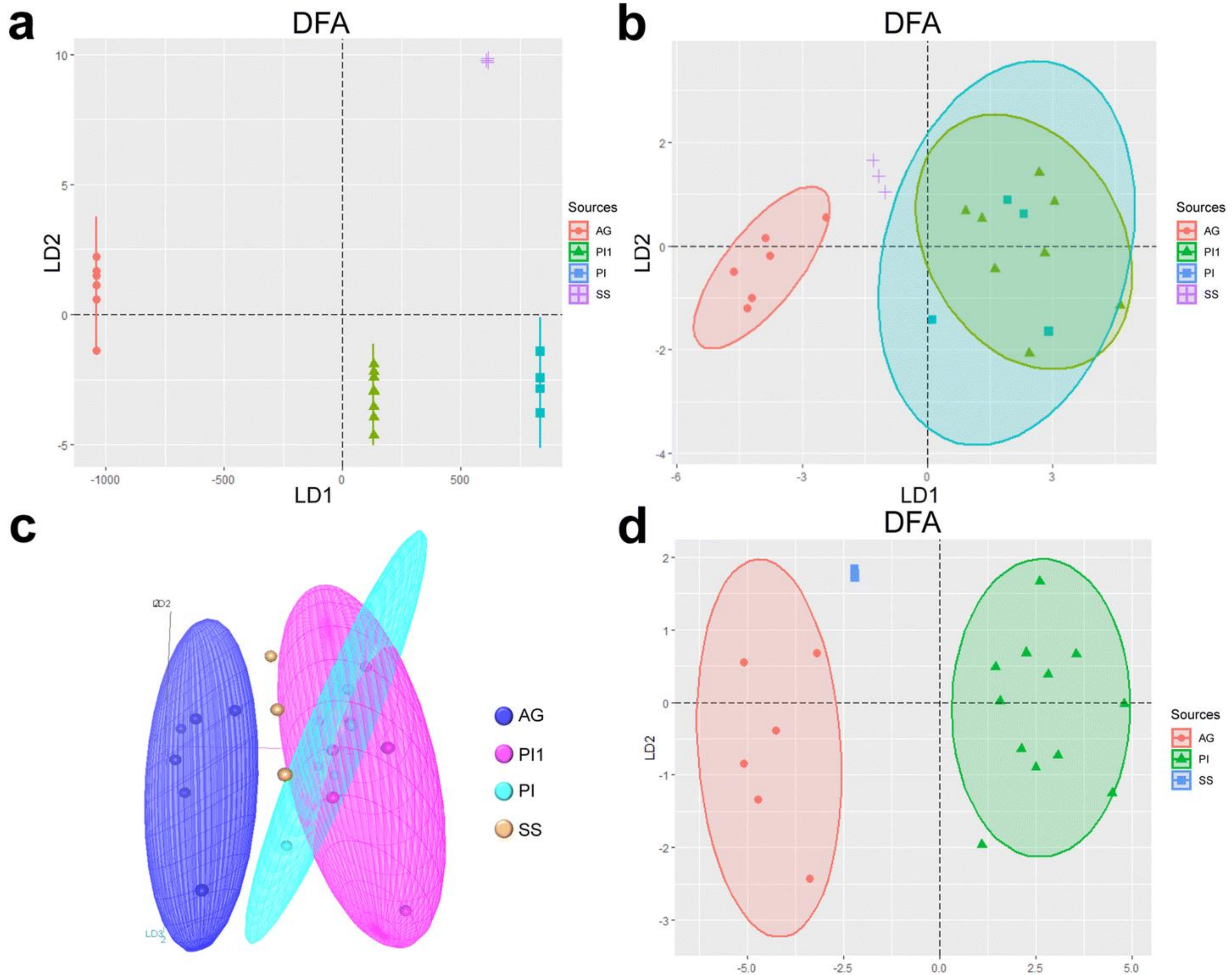
Lizaga et al., 2020

Main aim of tracer selection is to further minimise the likelihood of non-conservative tracers being used in the un-mixing model

General approach:

1. **Range test**
   it is determined if the concentrations of each tracer within the target sediment samples fall within the medians +/− one median absolute deviation (MAD) and the minimum – maximum range of the source groups
2. **Kruskal-Wallis rank sum test**
   This step excludes from the original data frame the properties which do not show significant differences between sources.
3. **Discriminant function analysis test**
   a stepwise forward variable selection using the Wilk's Lambda criterion.

Why do we need tracer selection?



Lizaga et al., 2020

LDA plot of the data example of a small catchment for the different land covers: agricultural (AG), old pine forest (PI); recent pine forest (PI) and subsoil (SS). **a) Before running the statistical test, the dataset shows collinearity.** b & c) 2D and 3D LDA display of the dataset after running the statistical selection. d) LDA display after merging both pines sources PI and PI1

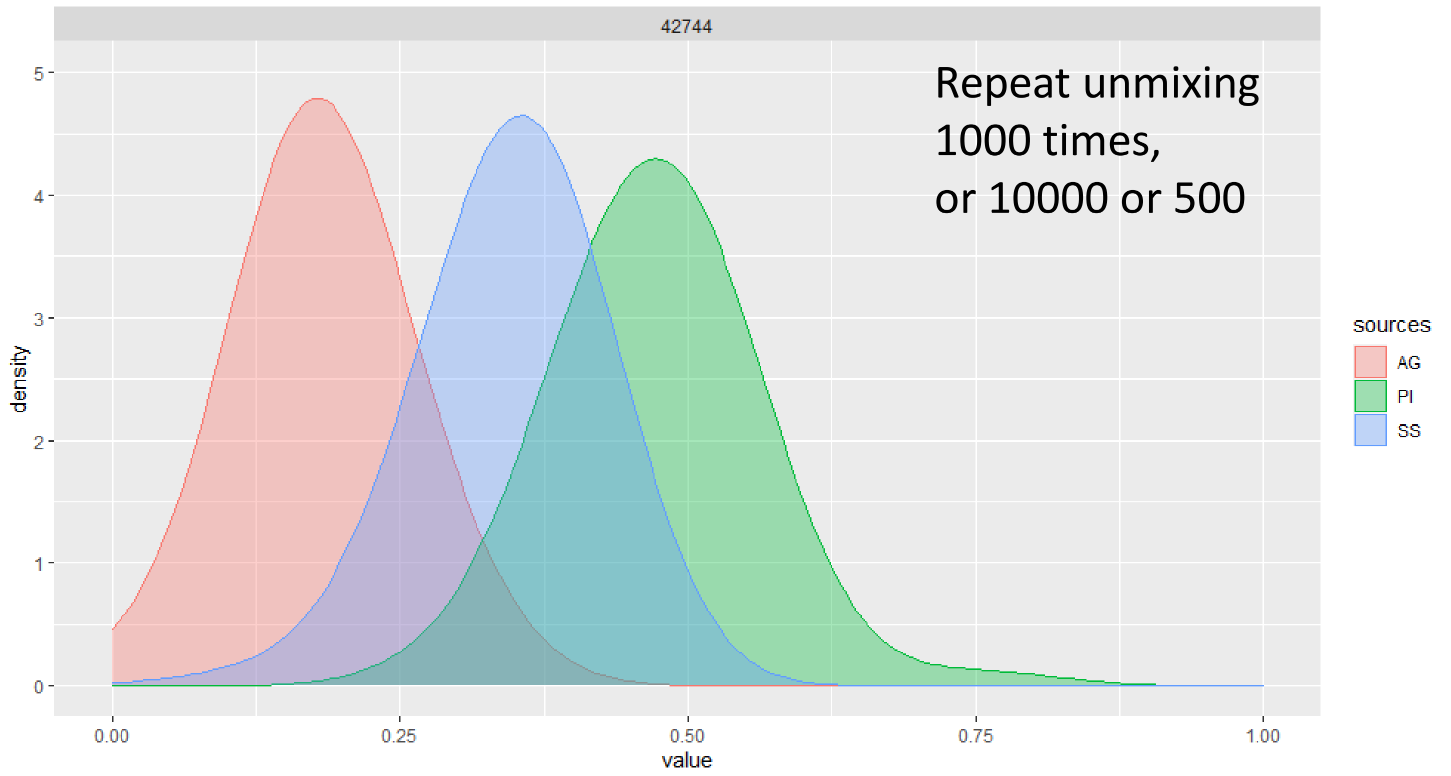
LDA — linear discriminant analysis, a way to reduce data dimensions. Here from 22 dimension to 2

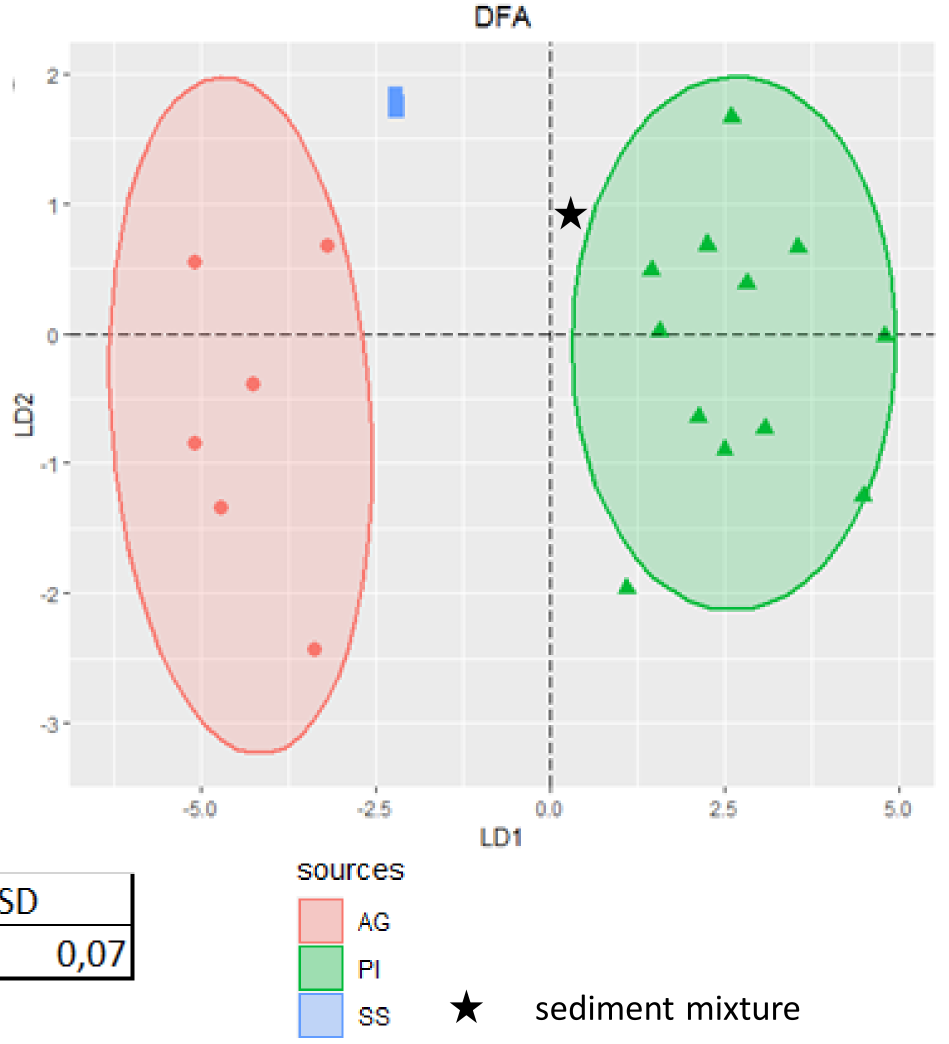
Unmixing process

Unmixing

Unmixing assesses the relative contribution of the selected sediment sources for each mixture in the dataset.

Variability analysis is assessed following classical frequentist inference utilising a Monte-Carlo method (Helton 1994). A succession of deterministic calculations is executed, each with different input values sampled from their respective distributions, to obtain probability distributions of the targeted outcomes.





id	GOF,mean	GOF,SD	AG,mean	AG,SD	PI,mean	PI,SD	SS,mean	SS,SD
42744	0,94	0,04	0,18	0,06	0,47	0,08	0,35	0,07

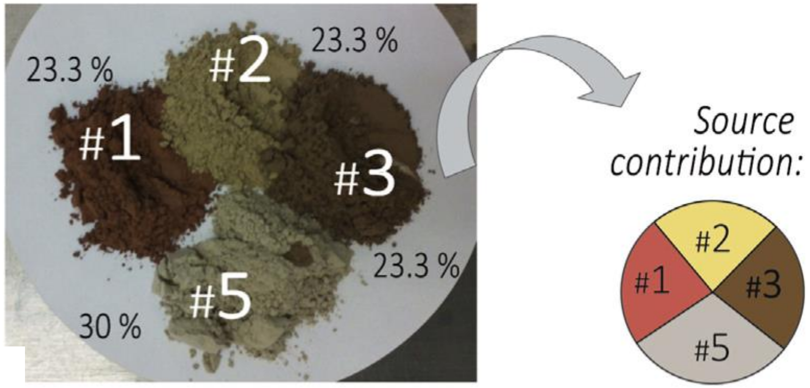
Lab Experiment

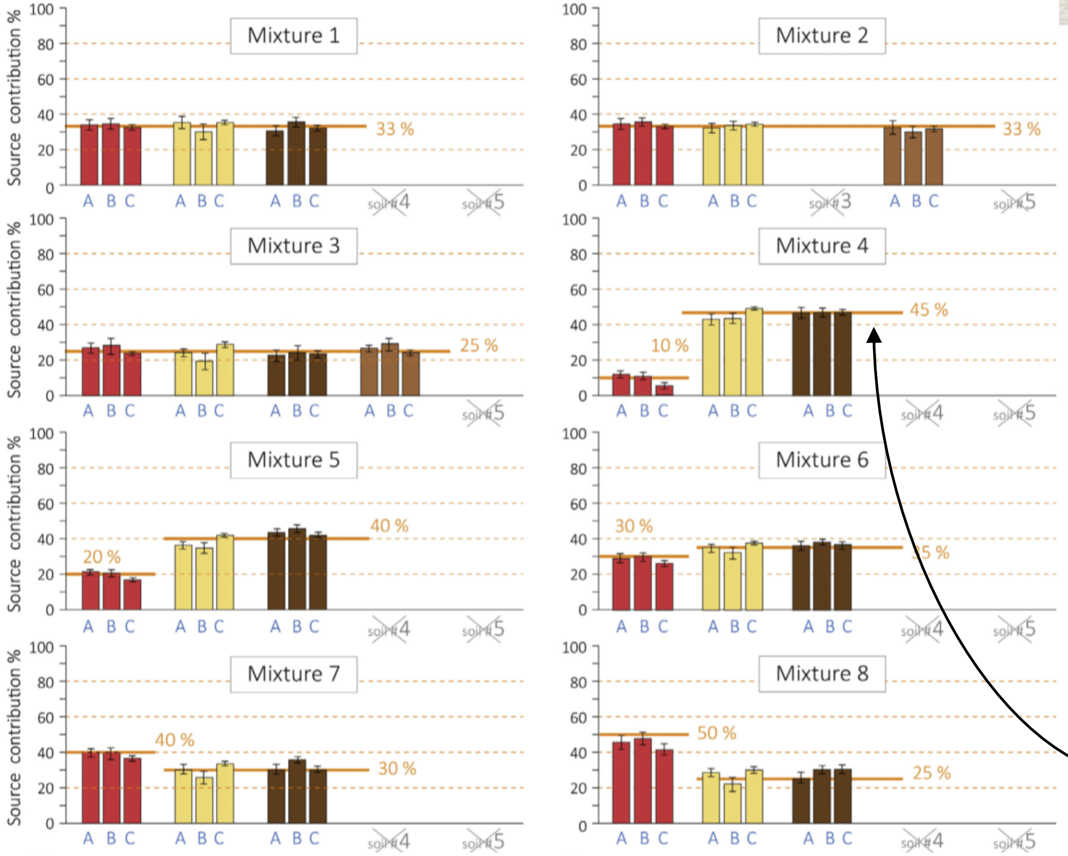
Does it work?

Artificial Sources

Artificial Mixture

Example Mix 10



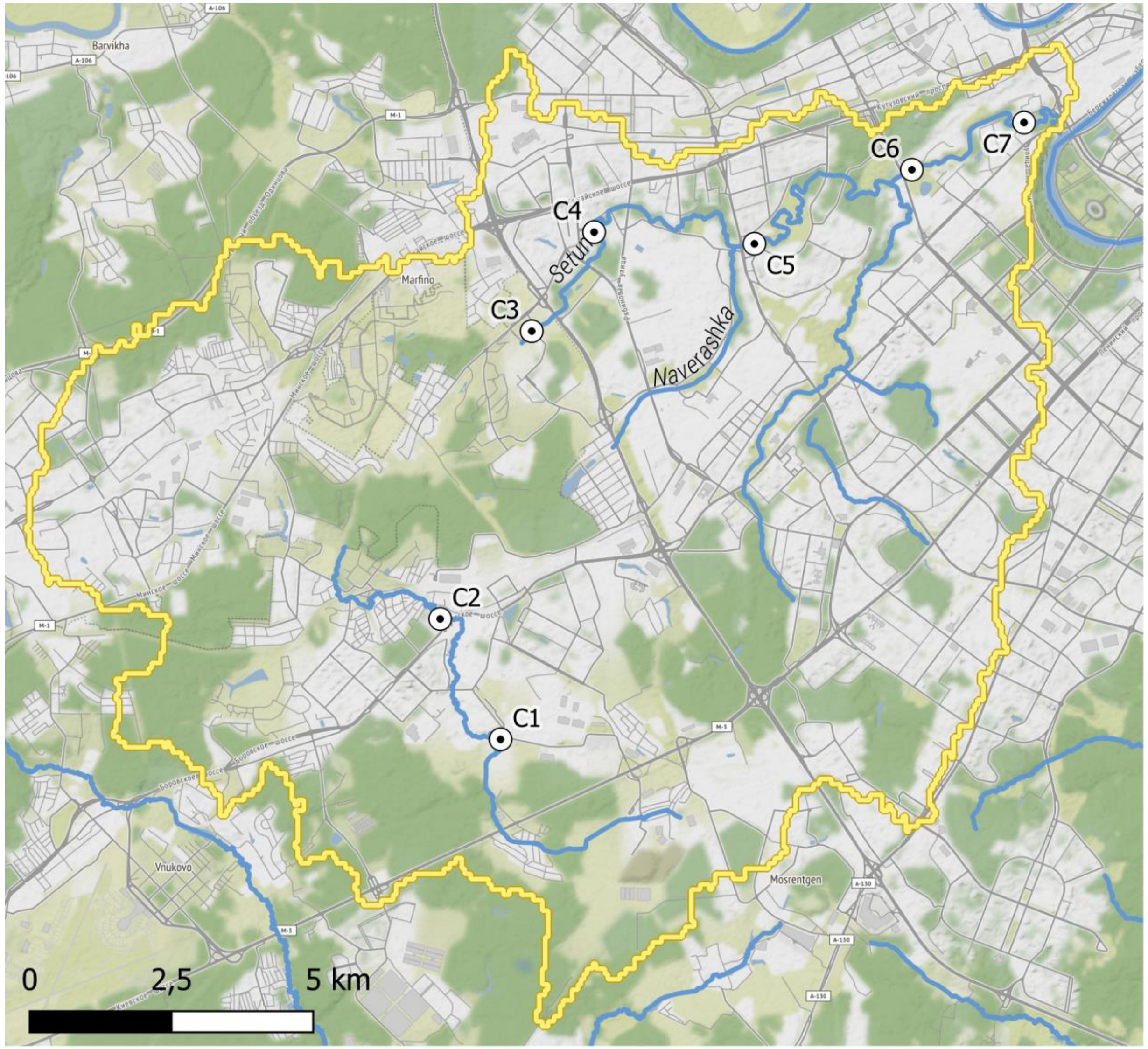


Gaspar et al. (2019) performed a laboratory experiment to test the sensitivity of the FingerPRO model, using as experimental sediments 14 artificial mixtures composed of different proportions and numbers of sources selected from five soils as experimental sources. Twelve artificial mixtures were created by mixing a known proportion of source soils sieved to < 63 µm in different proportions obtaining experimental sediments with three or four sources. This research aims to test the sensitivity of the model by comparing the estimated source contributions for three sets of selected tracers.

Estimated source contributions for the 12 artificial mixtures using tracer sets A, B and C. Solid line in orange represents the real proportion of each source.

Gaspar et al., 2019

What can we do?



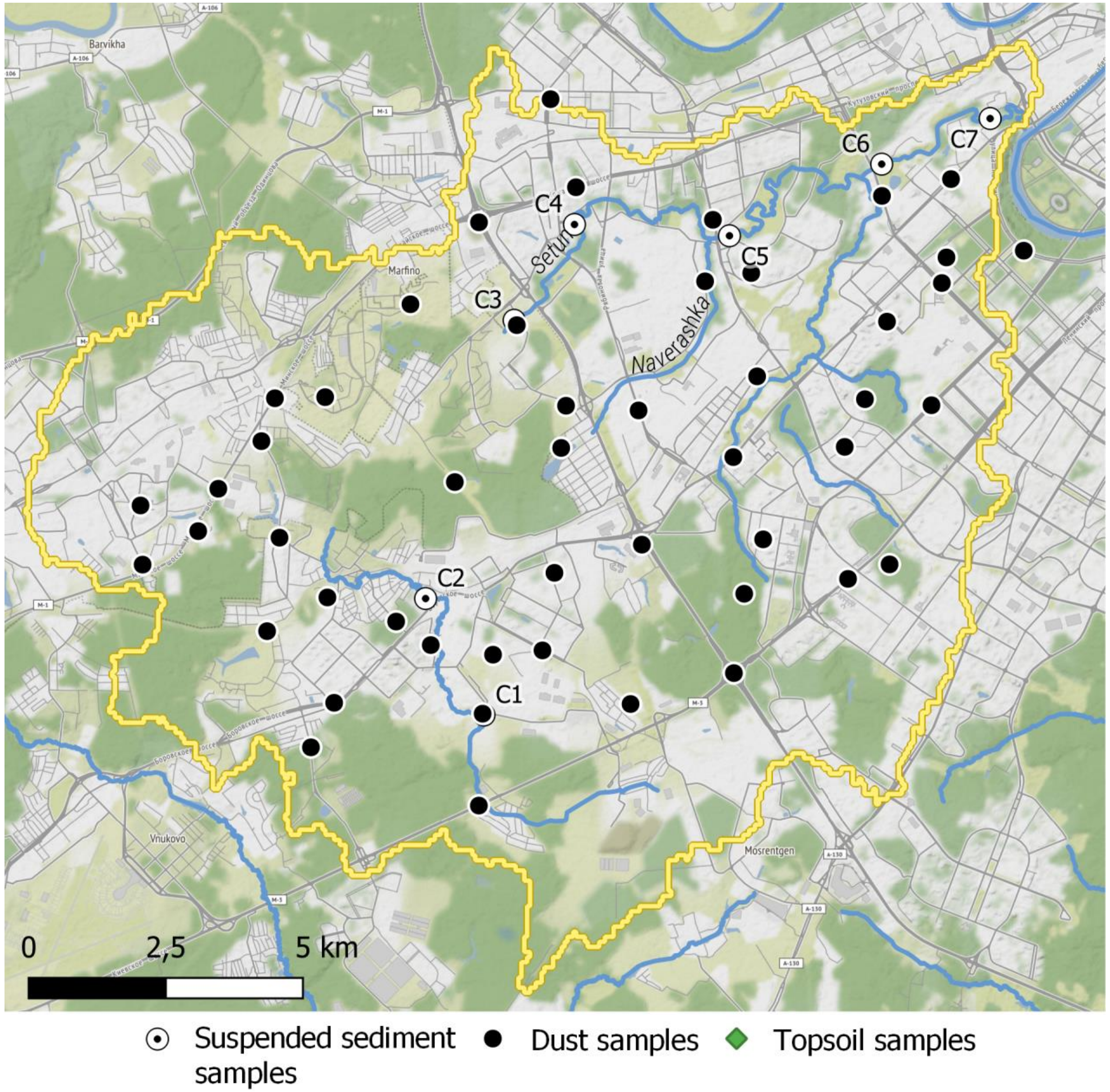
⊙ Suspended sediment samples ● Dust samples ◆ Topsoil samples

Tracing sediment sources

- > 150 source samples
  - 94 soil samples
  - 104 road dust samples
  - > 4 stream bank sediment samples
- 7 suspended sediment sampling points (mixture samples)
  - Equipped with Phillips tube integral sampler
  - 3-month sample rotation

- Unmixing sediments samples with **SIFT**: SedIment Fingerprinting Tool (Pulley & Collins, 2018)

ROTHAMSTED RESEARCH



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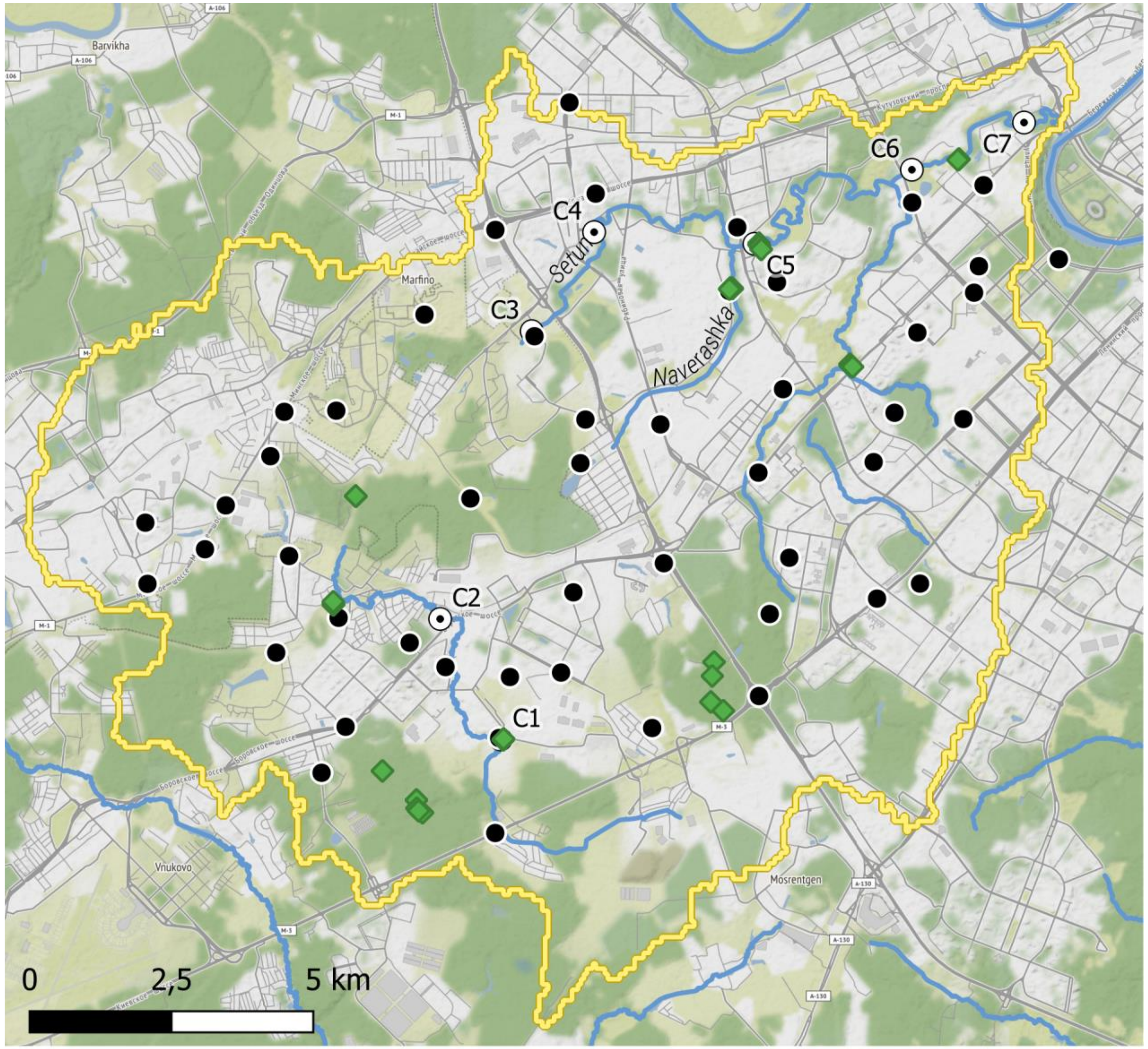

Suspended sediment samples · Dust samples · Topsoil samples

Tracing sediment sources

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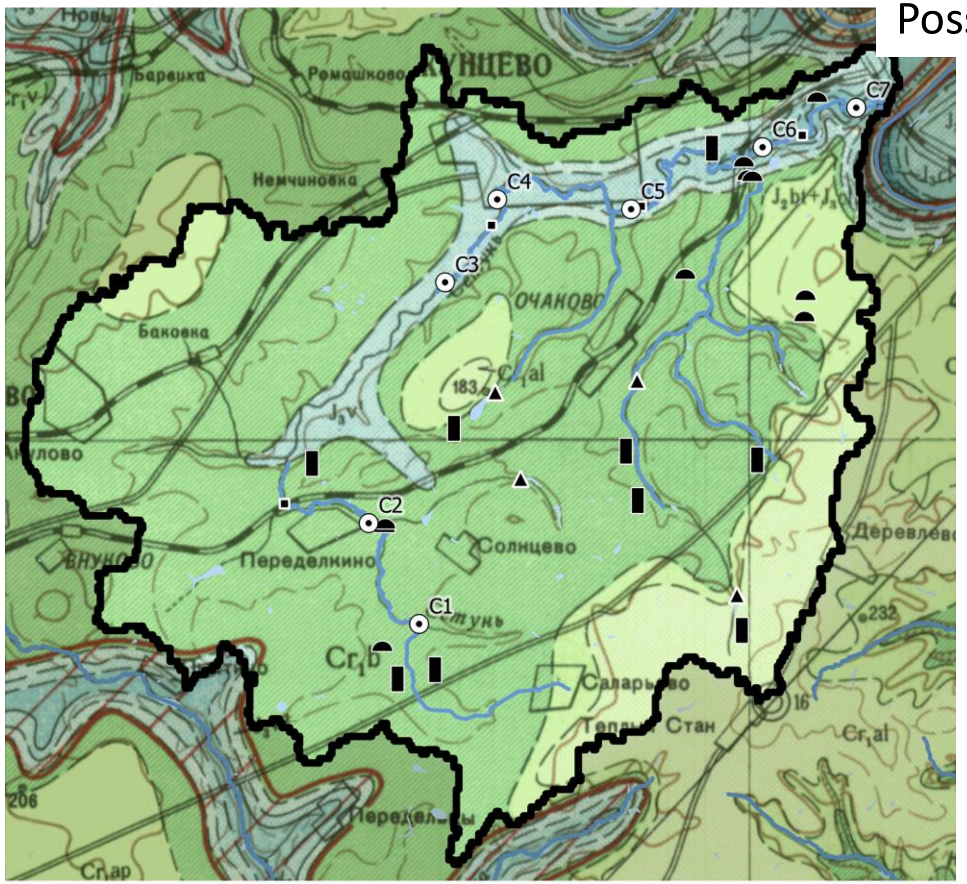
ROTHAMSTED RESEARCH

Additional sampling is needed

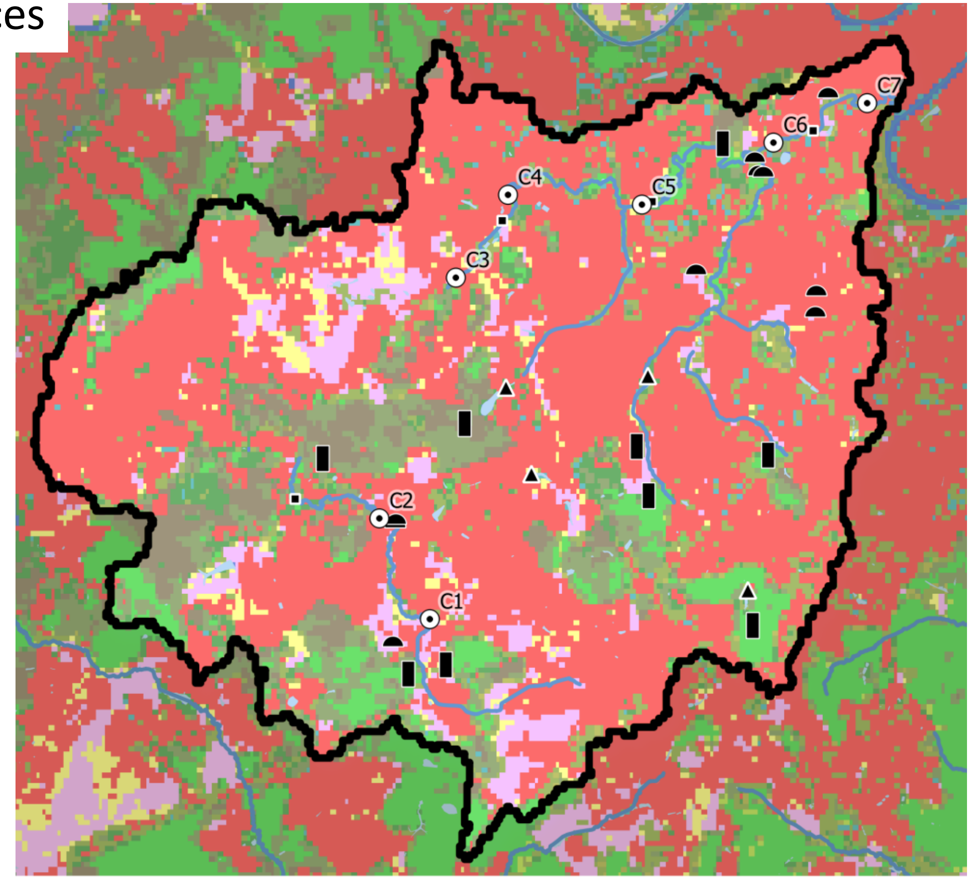
Possible sources



Samples
- Construction
- Pond sediments
- Stream banks samples
- Topsoil samples
- Suspended sediment samples

Geology
- Cr_1b — Sandy clay and sandstones with phosphorite
- Cr_1al — Quartz-Glauconite sands
- J_3v_1 — Sandy clays and clays with Glauconite
- J_3ox — Clays

0 2,5 5 km



Samples
- Construction
- Pond sediments
- Stream banks samples
- Topsoil samples
- Suspended sediment samples

Landuse
- Herbaceous vegetation
- Managed vegetation
- Built up
- Closed forest, evergreen, broad leaf
- Closed forest, deciduous broad leaf

0 2,5 5 km

Thank you for attention

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