

Supplementary Materials for:

Dropped in the Ocean – $^{87}\text{Sr}/^{86}\text{Sr}$ as a provenance tool for ice-rafted Arctic driftwood

Georgia M. Hole¹, Danielle Sinclair² & Marc Macias-Fauria¹

¹Biogeosciences Research Group, School of Geography and the Environment, University of Oxford, Oxford, OX1 3QY, UK.

²Department of Zoology, 11a Mansfield Rd, Oxford OX1 3SZ, UK.

Corresponding author: Georgia M. Hole (georgia.hole@ouce.ox.ac.uk)

Contents of this file

- S1. Text S1 – Further methodology details including Table S1
- S2. Dataset ds01 and ds02 (uploaded separately)
- S3. Figures S3.1 to S3.6
- S4. Figures S4.1 to S4.2
- S5. Bibliography

S1. Further Methodology details

S1.1 Sampling

Methods for the extraction, isolation and purification of strontium from driftwood through cleaning, microwave digestion, extraction chromatography and MC-ICP-MS (Multicollector-Inductively Coupled Plasma Mass Spectrometer) were developed in the clean-suite labs in the Earth Sciences Department, University of Oxford. Initially, method testing for strontium concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ ratio analysis was conducted on 7 test samples of driftwood. Following the above method of manual column chemistry and testing, a subset of 20 Arctic driftwood samples collected from northern Svalbard then underwent the developed methodology.

S1.2 Extraction Chromatography

Initial manual extraction chromatography on these test samples used Teflon elution columns and Triskem Sr resin. The stationary phase of Triskem Sr resin consists of a dicyclohexano 18-crown-6 derivative dissolved in octanol. The resin is selective of Sr over Ca which can be a major constituent in many samples. Pb is also strongly retained on the Sr Resin, allowing for a facile elution of Sr from the resin using dilute HNO₃, leaving Pb retained. The eluted Sr was collected in Savillex[®] PFA vials and dried down on hotplates at 90°C. In addition to samples, a blank was prepared using the same digestion procedure, but without sample intake.

Following the above method of manual column chemistry and testing on test samples, a subset of the Arctic driftwood samples collected from northern Svalbard were analysed after utilising and refining these developed protocols. Sr extraction was undertaken via automated chromatographic purification using the prepFAST-MC[™] system (Elemental Scientific (ESI), Omaha, NE, USA), on an ESI Sr/Ca-1000 column (ESI part no. CF-MC-SrCa-1000) including supplied Sr-Ca ion exchange resin. including supplied Sr-Ca ion exchange resin. The methodology used was adapted from Romaniello et al. (2015), with a longer wash of 4ml between each sample. The ⁸⁷Sr/⁸⁶Sr analyses were performed on the Nu Plasma Multi-Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS).

S1.3 Sr concentration Analysis

Following Sr extraction and purification, samples then underwent concentration and elemental analysis on the Thermo Element 2 Inductively Coupled Plasma Mass Spectrometer (ICP-MS), with concentrations of Sr (Table S1) consistent with values expected in wood material, and sufficient for further ⁸⁷Sr/⁸⁶Sr analysis.

Table S1. Sr concentrations for driftwood test samples. DL = Detectable Level.

sample	Concentration (ppm)	
	Sr86	Sr88
Microwave blank	below DL	below DL
JM1a1	7.731	7.805
JM1a2	6.553	6.502
JM1b1	11.903	11.717
JM1b2	9.651	9.419
NK01b	10.512	10.373
NK02a	6.029	5.979
NK02b	3.493	3.486
NK03a	4.684	4.665
NK03b	7.825	7.767
NK04a	4.439	4.301
NK04b	9.263	8.970
NK05a	7.852	7.768
NK05b	7.689	7.618
NK06a	3.118	3.050
NK06b	8.332	8.155

S1.4 Labware and Reagents

All labware underwent washing with analytical grade HCl and environmental grade HNO₃ to prevent contamination. Samples and Sr elutes were processed in Savillex® Teflon vials, with digestions, chromatography and cleaning undertaken in a Class 100 laminar flow exhaust hood. All acids used in this study were purified by sub-boiling distillation in-house from concentrated reagent grade acids. All acids and reagents used were stored within Parafilm-sealed Teflon or PTFE containers that had undergone cleaning. Ultra-pure water (≥ 18.2 M Ω cm) for cleaning and processing samples was prepared via a purification sequence with a Milli-Q® system (Millipore, USA).

S2. Datasets

Dataset ds01.xlsx contains the dataset produced and analysed in this study. Existing provenance data by tree-ring-width (TRW) cross-dating with reference chronologies from the circum-Arctic boreal forest zone Hole et al. (2021) are compared to the $^{87}\text{Sr}/^{86}\text{Sr}$ signature measured (in this study), to investigate possible alignment between driftwood $^{87}\text{Sr}/^{86}\text{Sr}$ signatures and available bioavailable/river values for the determined provenance regions.

S2.2 Dataset ds02.xlsx contains correlation analysis between queried averaged $^{87}\text{Sr}/^{86}\text{Sr}$ values from modelled global bioavailable isoscape by Bataille et al. (2020) for buffer zones of 5km, 20km, 100km, 200km, and 500km radius around driftwood sample match points provided by TRW crossdating in Hole et al. (2021).

S3. Additional Sample crossdating plots

Description: Maps showing sample crossdate match locations determined by TRW crossdating by Hole et al. (2021), with this study's measured $^{87}\text{Sr}/^{86}\text{Sr}$ value ranges displayed in black, with existing river $^{87}\text{Sr}/^{86}\text{Sr}$ data (in blue), plant $^{87}\text{Sr}/^{86}\text{Sr}$ data (in green), soil $^{87}\text{Sr}/^{86}\text{Sr}$ data (in brown), compiled by Bataille (2020).

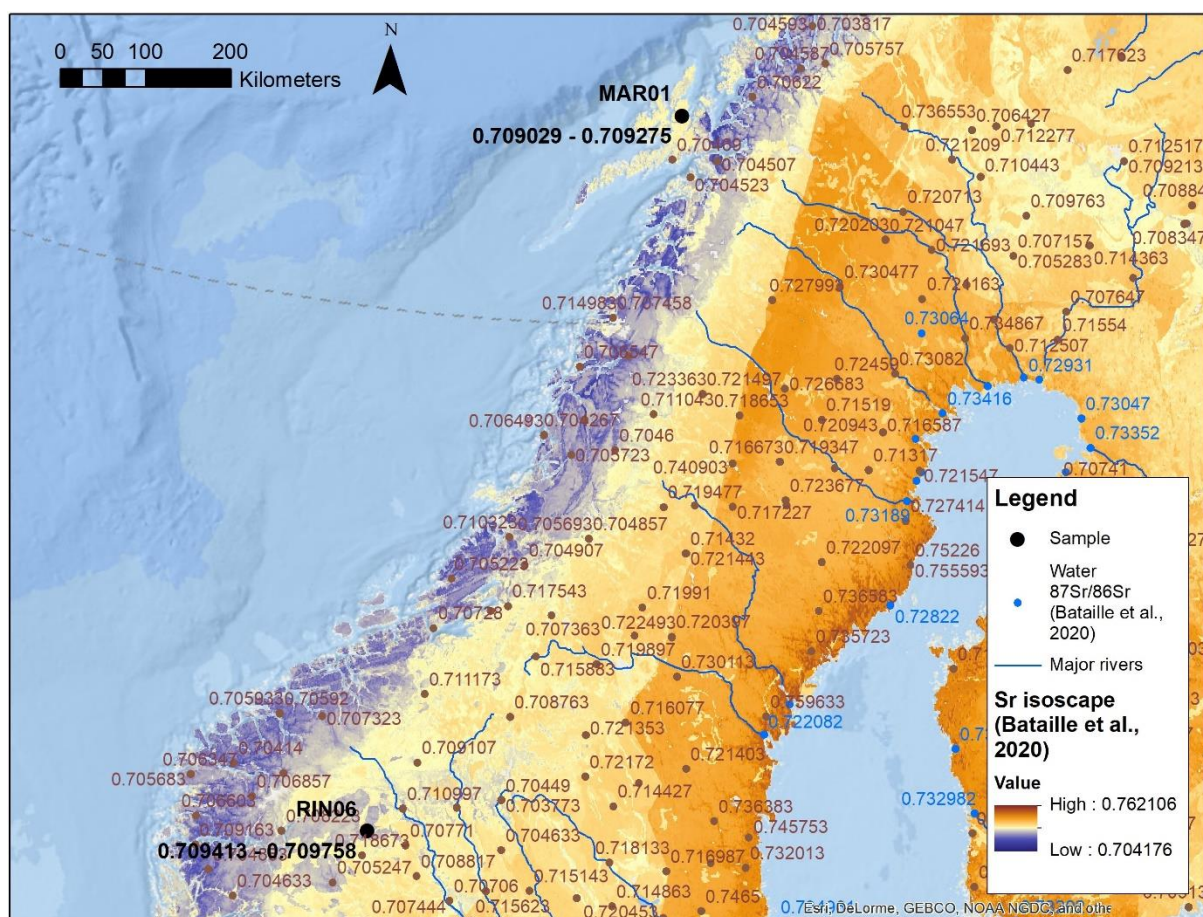


Figure S3.1. Samples **MAR01** and **RIN06** crossdate match locations determined by TRW crossdating by Hole et al. (2021), with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, compiled river $^{87}\text{Sr}/^{86}\text{Sr}$ data (blue) and soil $^{87}\text{Sr}/^{86}\text{Sr}$ data (brown) by Bataille (2020). There is no proximal river $^{87}\text{Sr}/^{86}\text{Sr}$ data available for assessing the measured $^{87}\text{Sr}/^{86}\text{Sr}$ values for this provenanced region. The available river $^{87}\text{Sr}/^{86}\text{Sr}$ surrounding the Eastern Norway coastline have higher $^{87}\text{Sr}/^{86}\text{Sr}$ values, while proximal soil $^{87}\text{Sr}/^{86}\text{Sr}$ have values that span the range of the measured sample $^{87}\text{Sr}/^{86}\text{Sr}$ values. High heterogeneity is seen in values and may also reflect different integration of Sr sources to those for riparian trees.

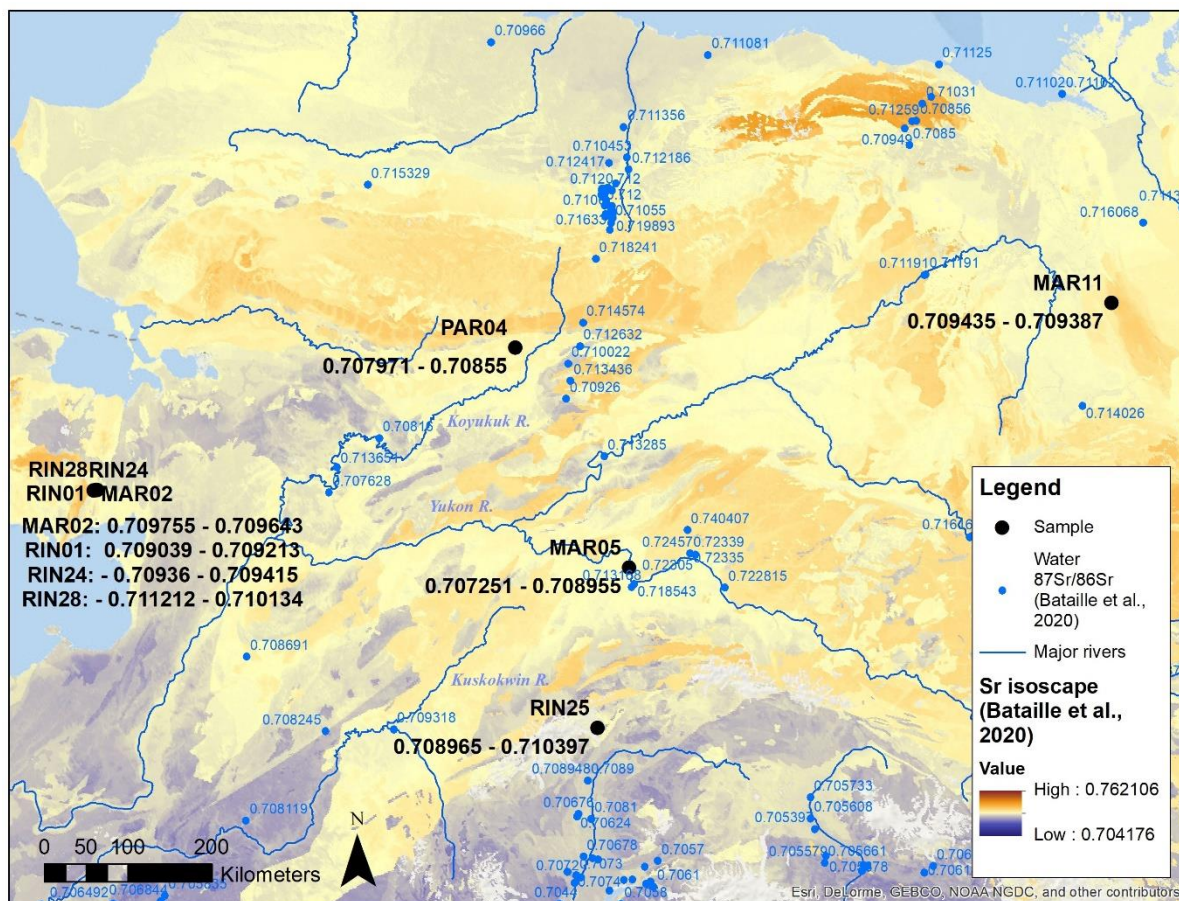


Figure S3.2. Sample MAR05 crossdate match locations in Alaska & Canada, determined by TRW crossdating by Hole et al. (2021), with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, compiled river $^{87}\text{Sr}/^{86}\text{Sr}$ data (blue) and soil $^{87}\text{Sr}/^{86}\text{Sr}$ data (brown) by Bataille (2020).

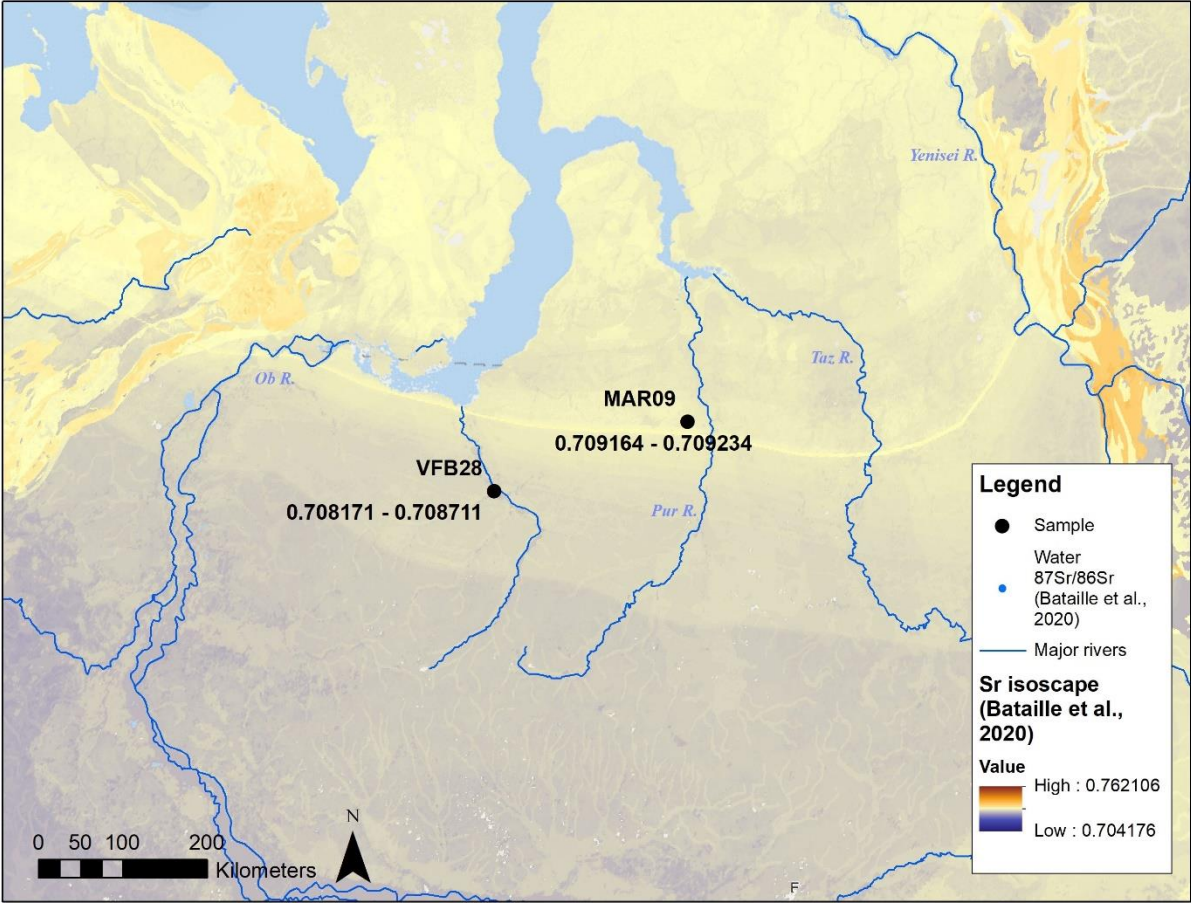
MAR02, RIN01, RIN24, RIN28: crossdate match locations in western Alaska, west of the Yukon and Koyukuk rivers, with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, and compiled river $^{87}\text{Sr}/^{86}\text{Sr}$ data by Bataille (2020) in blue. The closest river $^{87}\text{Sr}/^{86}\text{Sr}$ values show a range 0.707628-0.713651, which covers the sample measured range of all samples.

MAR05: crossdate match location in central Alaska along the Tanana river. A surrounding diverse range of $^{87}\text{Sr}/^{86}\text{Sr}$, with the surrounding range of 0.705201-0.715232 with multiple areas within each $^{87}\text{Sr}/^{86}\text{Sr}$ range. Examining river $^{87}\text{Sr}/^{86}\text{Sr}$ proximal to MAR05 from the Tanana river, as collated by Bataille et al. (2020), river values show a higher range of 0.713168-0.740407, out of the value obtained with sample MAR05. ~200km south-west, river values reach more agreement with MAR05, in the range 0.708245-0.709318.

MAR11: crossdate match location in northern Canada west of the Mackenzie river. The most proximal values show higher ranges or 0.71138-0.716068, although the lack of values close to the sample provenance region complicates interpretation.

PAR04: crossdate match location proximal to Koyukuk river. River values show a higher range of 0.70926-0.714574, out of the value obtained with sample PAR04. Downstream, ~200km south-west, river values reach more agreement with PAR04, in the range 0.70768-0.70816. Discussed further in main text.

RIN25: crossdate match location in southern Alaska, south of the Kuskokwim and Tanana rivers. The most proximal reference river $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.708948-0.7089 are close to the lower range of the sample.



125 **Figure S3.3.** Sample MAR09 and VFB28 crossdate match locations in northern Russia east of the Ob river,
126 determined by TRW crossdating by Hole et al. (2021). No available river $^{87}\text{Sr}/^{86}\text{Sr}$ in the region makes direct
127 comparisons difficult, while the global isoscape of bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ by Bataille (2020) shows values of
128 ~ 0.709 for the region, fitting with the samples.

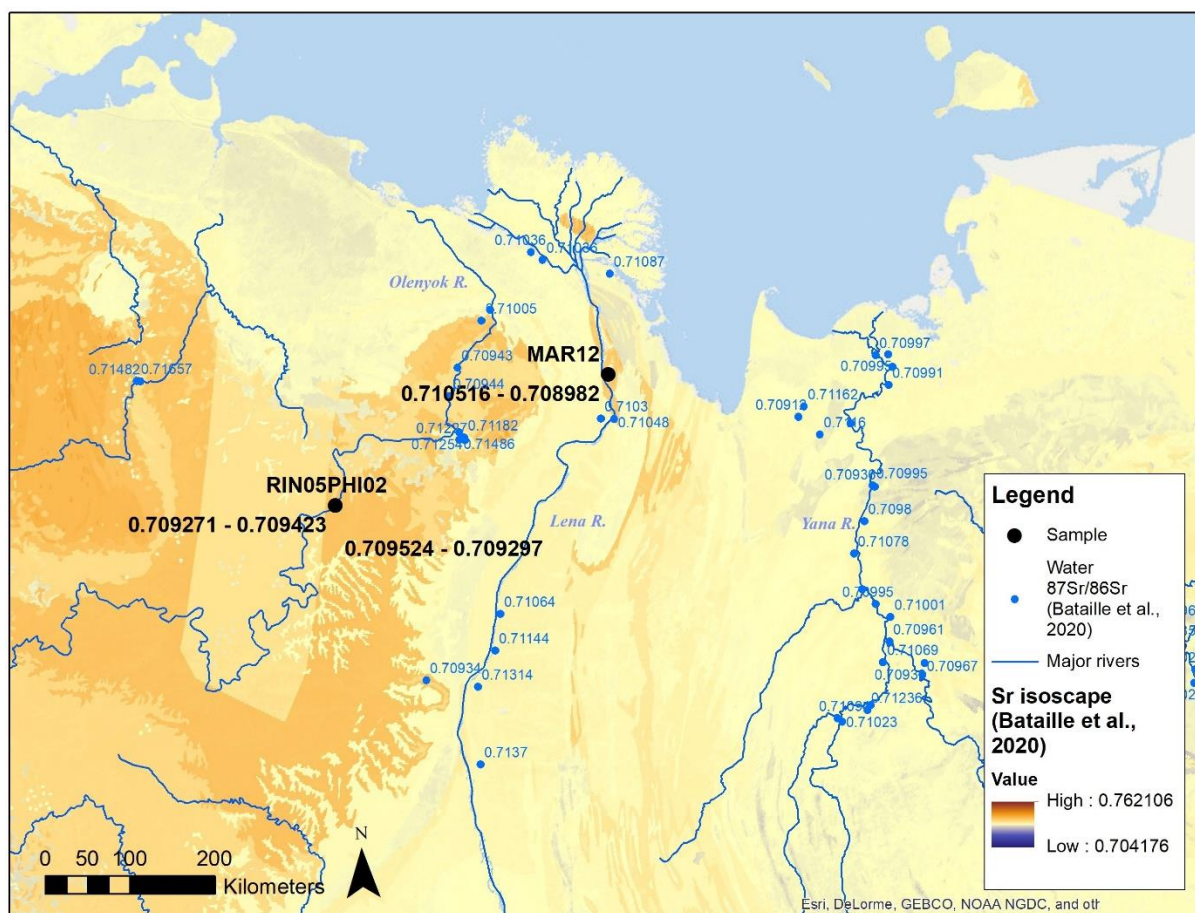
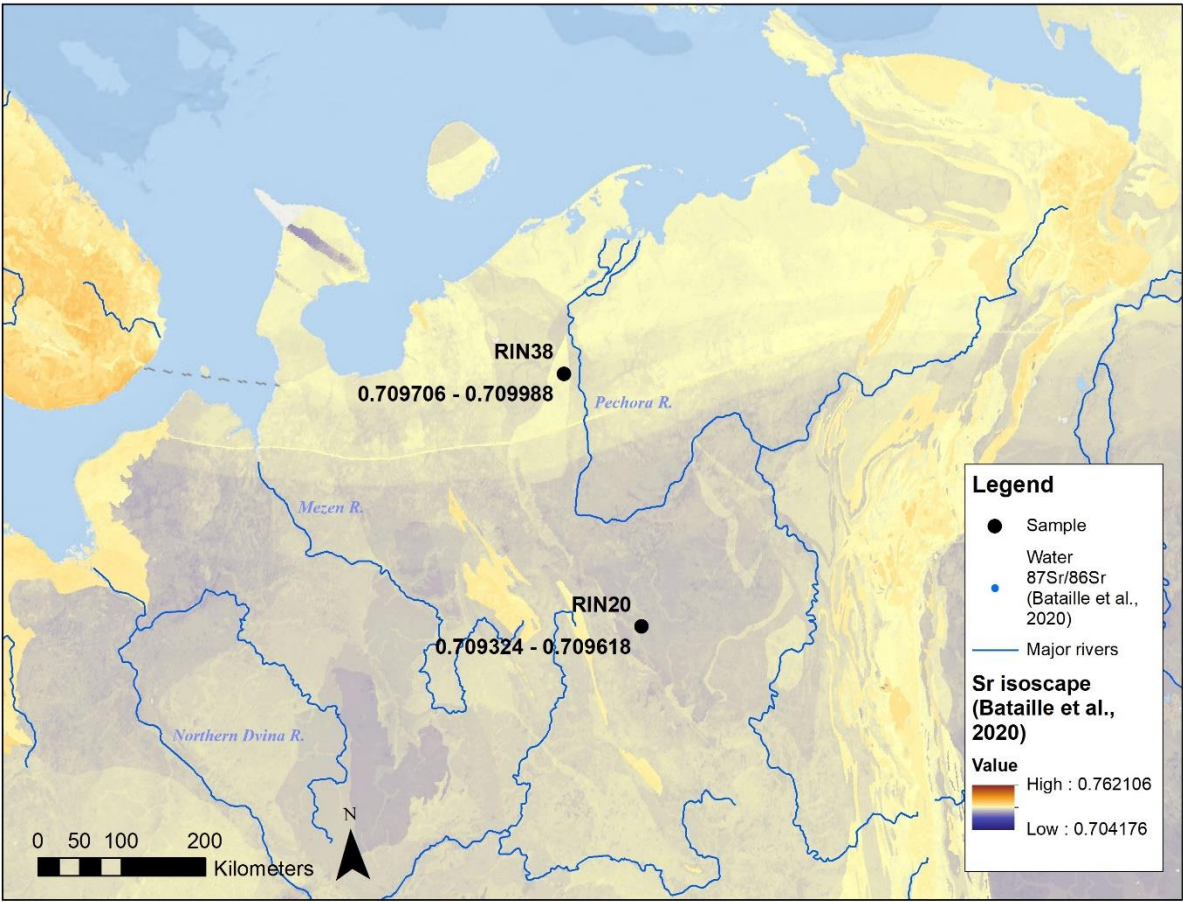


Figure S3.4. Sample crossdate match locations in eastern Siberia, determined by TRW crossdating by Hole et al. (2021), with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, with compiled river $^{87}\text{Sr}/^{86}\text{Sr}$ data by Bataille (2020) in blue.

MAR12: match location along the Lena river. The value range fits with the proximal river $^{87}\text{Sr}/^{86}\text{Sr}$ value range of 0.7103-0.7048.

PHI02: crossdate match location of eastern Siberia along the Olenyok river. There is a lack of measured river $^{87}\text{Sr}/^{86}\text{Sr}$ along the closest section of the Olenyok, although downstream the range 0.70943-0.71486 does overlap with the sample $^{87}\text{Sr}/^{86}\text{Sr}$ range, with river $^{87}\text{Sr}/^{86}\text{Sr}$ ~200km south-east near the Lena also showing aligning value of 0.70934.

RIN05: crossdate match location in eastern Siberia west of the Lena river. Similarly to sample PHI02, there is a lack of measured river $^{87}\text{Sr}/^{86}\text{Sr}$ along the closest section, with downstream the range 0.70943-0.71486 close to the upper end of the sample $^{87}\text{Sr}/^{86}\text{Sr}$ range, and river $^{87}\text{Sr}/^{86}\text{Sr}$ ~200km south-east near the Lena also showing aligning value of 0.70934.



145

146 **Figure S3.5.** Sample crossdate match location in western Russia, determined by TRW crossdating by Hole et al.
147 (2021), with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, and no available reference river $^{87}\text{Sr}/^{86}\text{Sr}$ data for
148 comparison.

149 **RIN20 & RIN38:** match locations west of the Pechora river,. The global bioavailable $^{87}\text{Sr}/^{86}\text{Sr}$ isoscape by
150 Bataille (2020) shows the region with $^{87}\text{Sr}/^{86}\text{Sr}$ values ~ 0.709 , fitting with the sample values.

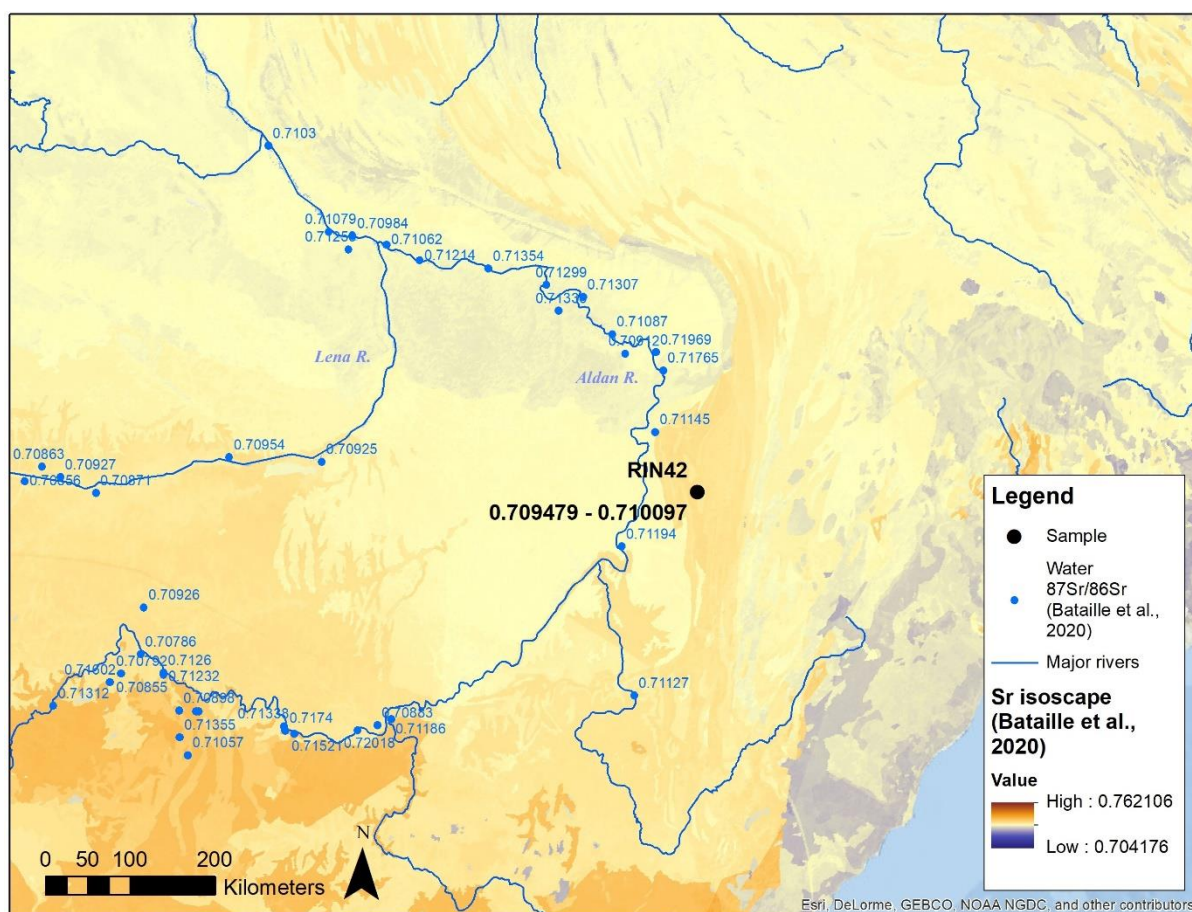
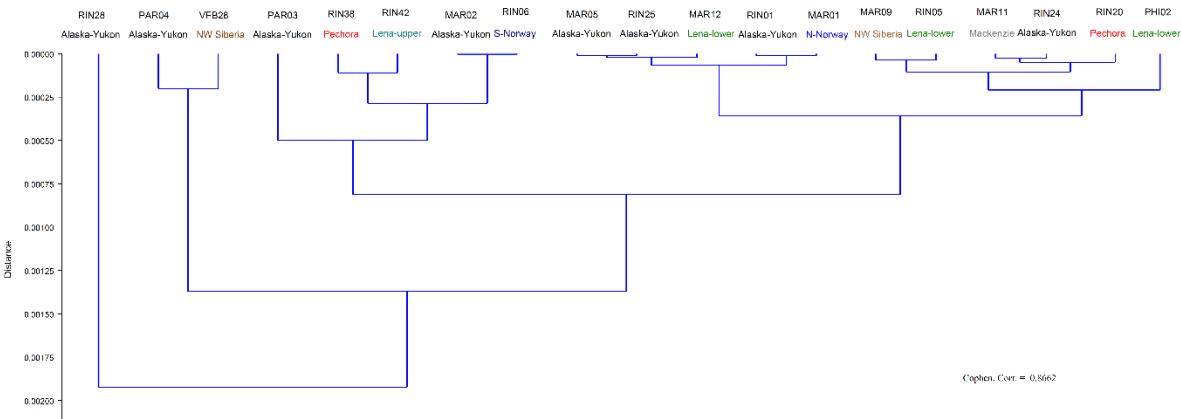


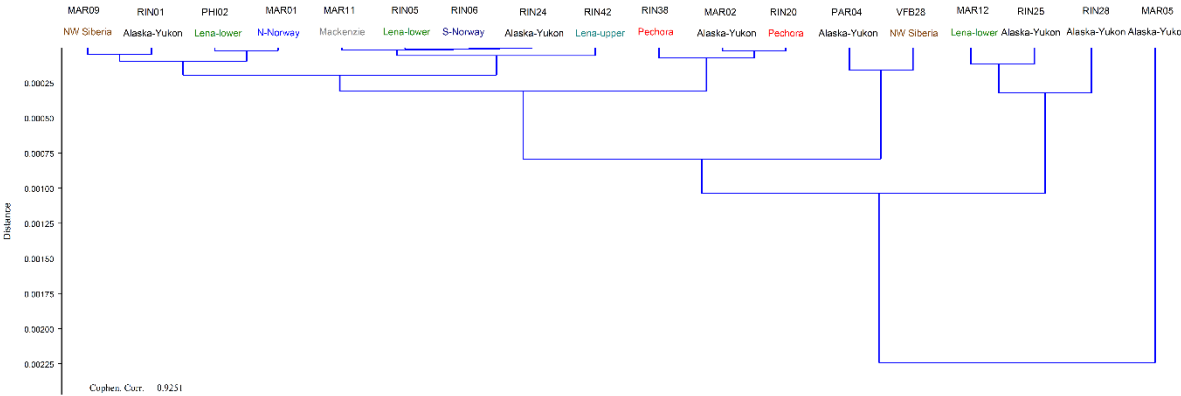
Figure S3.6. Sample RIN42 crossdate match location of eastern Siberia, east of the Aldan river, determined by TRW crossdating by Hole et al. (2021), with measured $^{87}\text{Sr}/^{86}\text{Sr}$ value range displayed in black, with compiled river $^{87}\text{Sr}/^{86}\text{Sr}$ data by Bataille (2020) in blue. The nearest river $^{87}\text{Sr}/^{86}\text{Sr}$ values of 0.70912-0.71765 cover the sample $^{87}\text{Sr}/^{86}\text{Sr}$ range.

S4. UPGMA analysis plots

Description: Unweighted pair-group average (UPGMA) cluster analysis was employed to create groups of similar valued data by minimising the joined averaged Euclidean distances between all members in any two groups. A separate cluster analysis was undertaken for inner, outer, and averaged $^{87}\text{Sr}/^{86}\text{Sr}$ readings (average plot Figure 5 within main text). Consistency between clusters (intra-sample consistency) and between the cluster and their TRW-inferred provenances were analysed. Cluster analysis was performed using Past 4.04 (Hammer et al., 2001).



167 **Figure S4.1.** Unweighted pair-group average (UPGMA) cluster analysis on inner $^{87}\text{Sr}/^{86}\text{Sr}$ readings for
168 19 driftwood samples. Cluster analysis was performed using PAST 4.04 (Hammer et al., 2001).



171 **Figure S4.2.** Unweighted pair-group average (UPGMA) cluster analysis on outer $^{87}\text{Sr}/^{86}\text{Sr}$ readings for
172 19 driftwood samples. Cluster analysis was performed using PAST 4.04 (Hammer et al., 2001).

175 **S5. Bibliography**

176 Bataille, C. P., Crowley, B. E., Wooller, M. J., & Bowen, G. J. (2020). Advances in global
177 bioavailable strontium isoscapes. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 555,
178 109849. [https://doi.org/https://doi.org/10.1016/j.palaeo.2020.109849](https://doi.org/10.1016/j.palaeo.2020.109849)

179 Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological statistics software
180 package for education and data analysis. *Palaeontologia Electronica*, 4(1), 9.

181 Hole, G. M., Rawson, T., Farnsworth, W. R., Schomacker, A., Ingolfsson, O., & Macias-Fauria, M.
182 (2021). A driftwood-based record of Arctic sea ice during the last 500 years from northern
183 Svalbard reveals sea ice dynamics in the Arctic Ocean and Arctic peripheral seas [Preprint].

184 *Journal of Geophysical Research: Oceans.*
185 <https://doi.org/https://doi.org/10.1002/essoar.10507454.1>
186 Romaniello, S. J., Field, M. P., Smith, H. B., Gordon, G. W., Kim, M. H., & Anbar, A. D. (2015).
187 Fully automated chromatographic purification of Sr and Ca for isotopic analysis. *Journal of*
188 *Analytical Atomic Spectrometry*, 30(9), 1906–1912. <https://doi.org/10.1039/c5ja00205b>
189