Supporting Information for

Climate-driven reduction in biomass production of the Eurasian steppe coincides with nomadic migration during the first millennium CE

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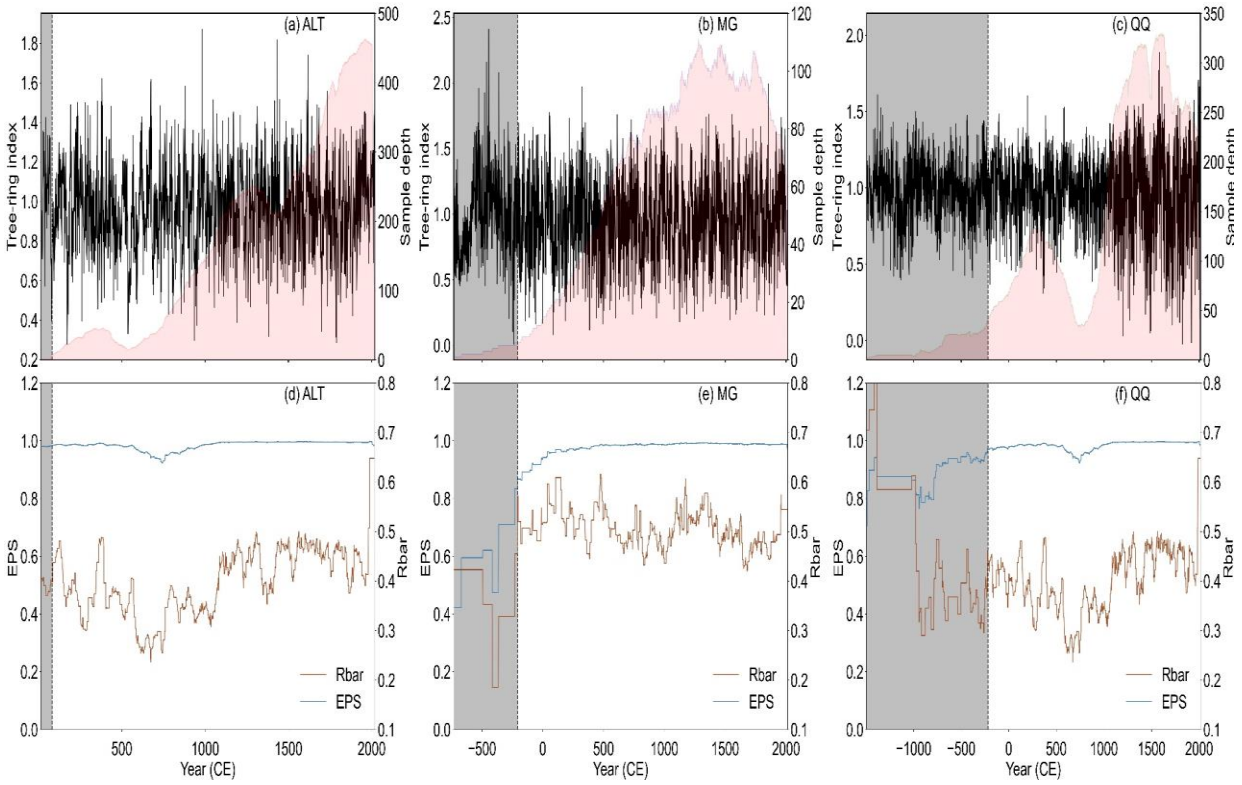

Fig. S1. (a-c) Plot of the composite chronologies (ALT, MG, QQ), and (d-f) its running expressed population signal (EPS) and the sample depth.

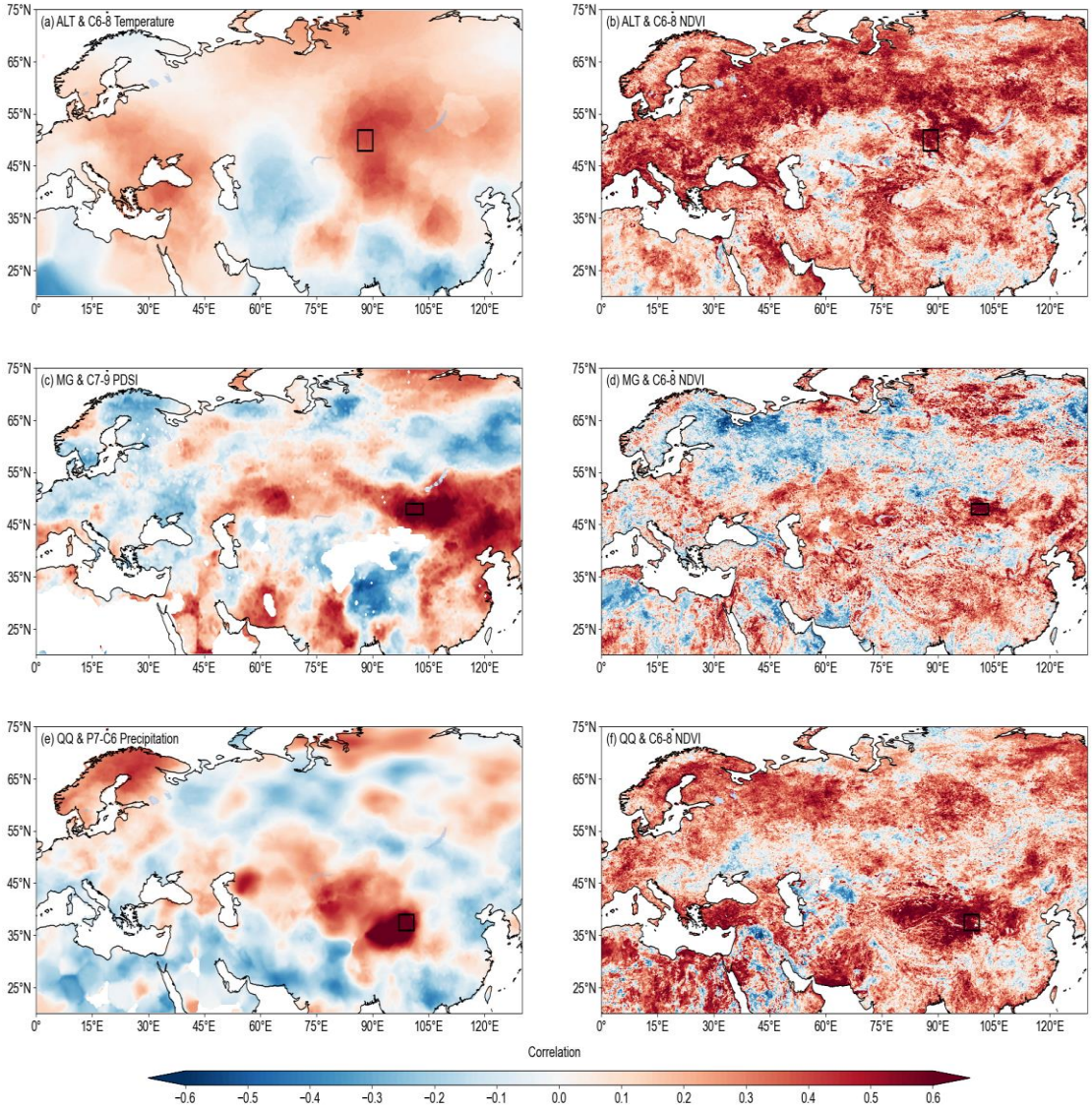

Fig. S2. (a-f) Spatial correlation patterns between the composite chronologies (ALT, MG, QQ) and climatic factors and June–August NDVI data over the common periods.

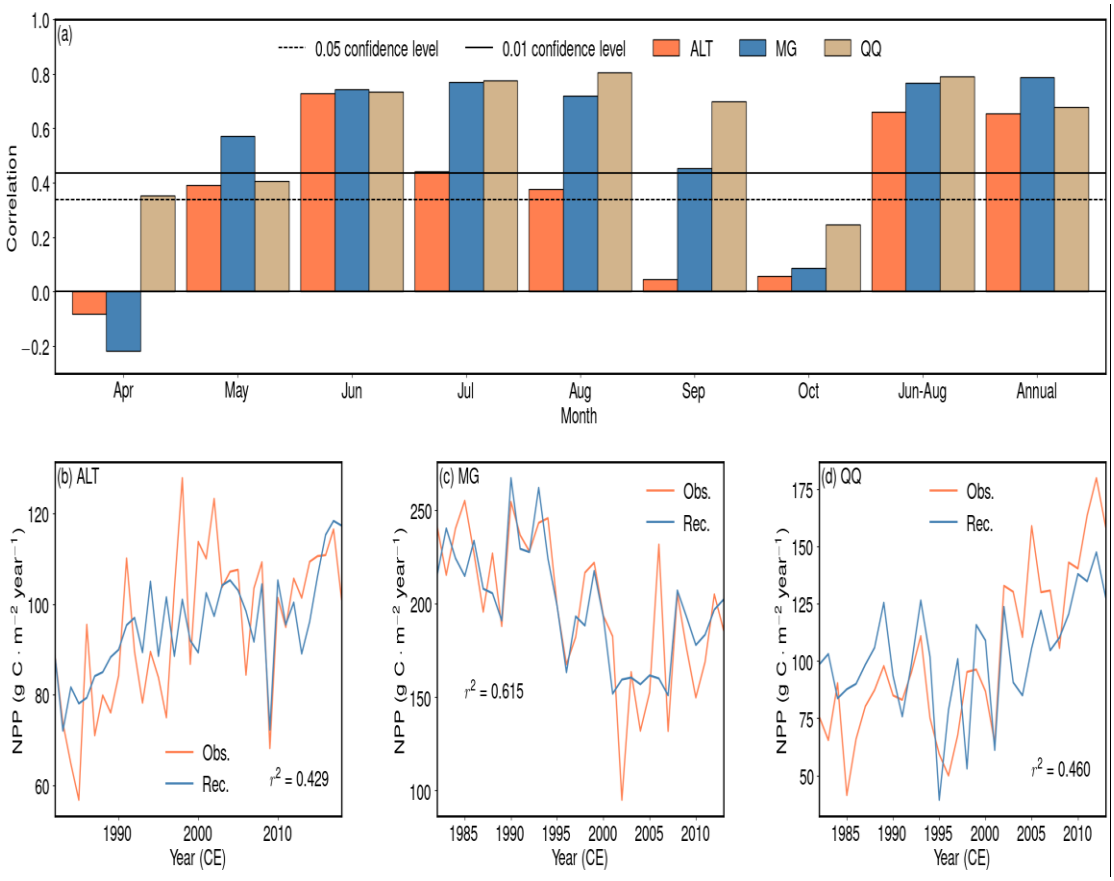

Fig. S3. (a) Correlations of the composite chronologies (ALT, MG, QQ) and monthly NPP. (b-d) Comparison of the reconstructed and observed NPP since 1982.

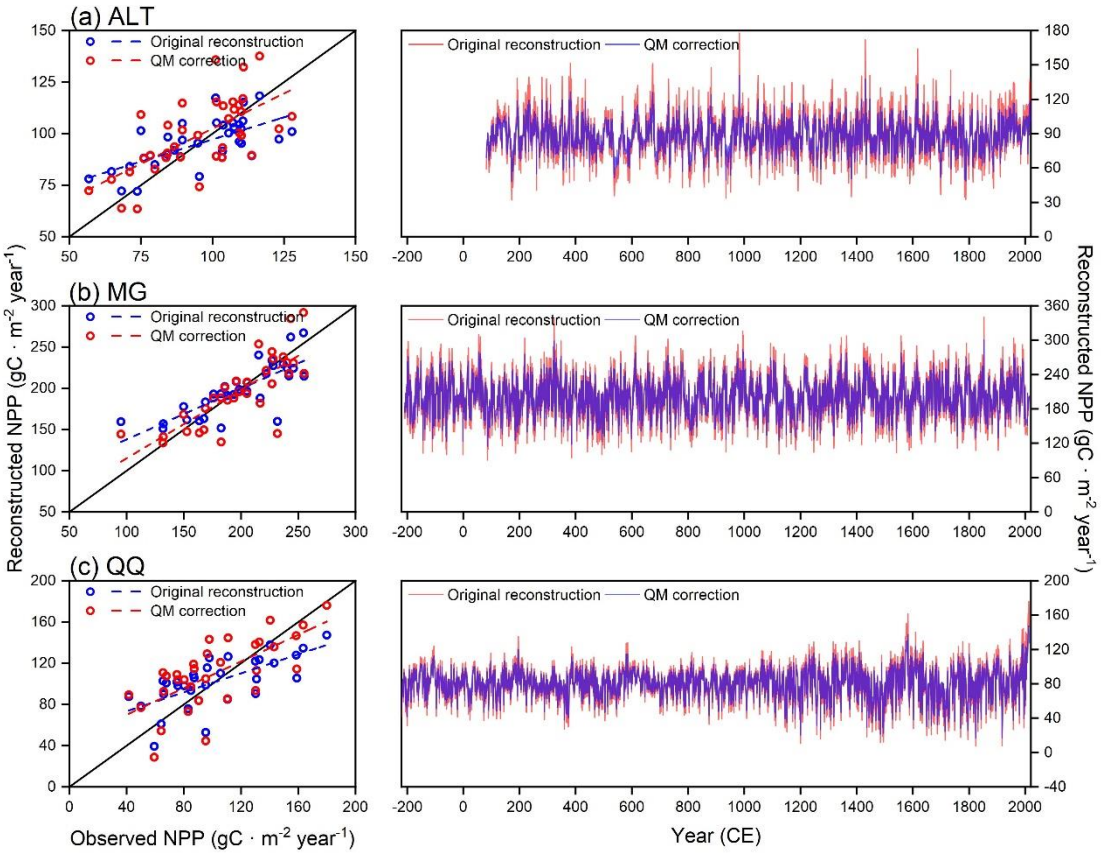

Fig. S4. (a) The 1:1 scatter plot (left) and the comparison of NPP reconstructions (right) before and after bias correction using the quantile mapping (QM) method. (b-c) are same as (a), but for MG and QQ, respectively.

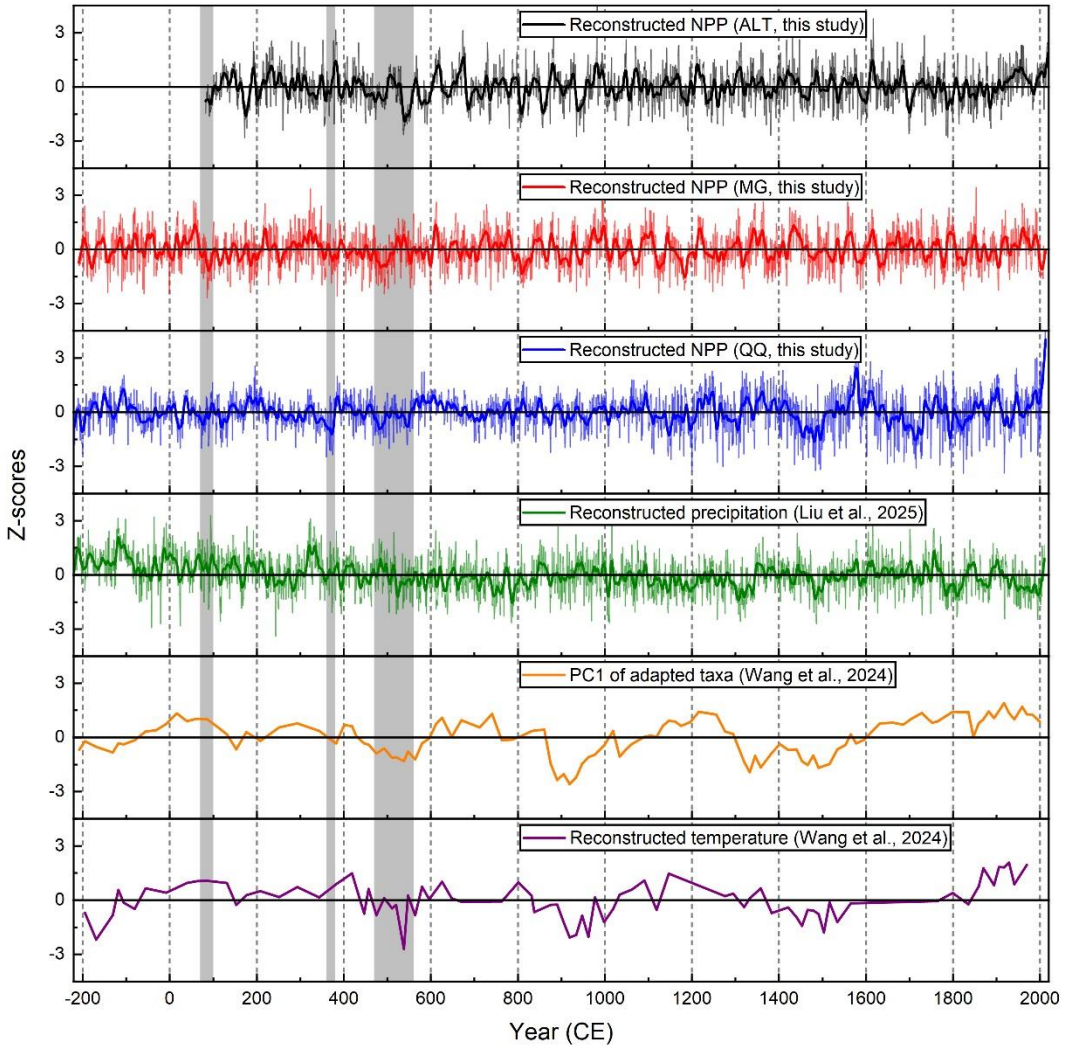

Fig. S5. NPP reconstructions based on tree-ring widths from this study, precipitation reconstruction based on tree-ring oxygen isotopes from Liu et al. (2025), PC1 from different chironomid taxa, and reconstructed temperature based on lake sediments from Wang et al. (2024). Three major migration periods (70s–100s, 360s–380s, and 470s–560s) are highlighted in grey shading.

Table S1. Sampling site information.

Region	Site	Latitude	Longitude	Altitude	Period	Species
Altai Mountains	mong016	48.6	88.37	/	1469–2004	*Larix sibirica*
	mong020	48.27	88.87	/	1537–2005	*Larix sibirica*
	mong024	48.5	88.5	/	1215–2004	*Larix sibirica*
	mong025	48.7	88.8	/	1565–2004	*Larix sibirica*
	russ246	47.5	87.5	/	-359–2011	*Larix sibirica*
	ZLS	46.72	90.95	2425	1563–2019	*Larix sibirica*
	DKL1	48.14	88.34	2332	1170–2019	*Larix sibirica*
	DKL2	48.14	88.36	2282	1221–2019	*Larix sibirica*
Mongolia	mong041	48.17	99.87	2060	-732–2014	*Pinus sibirica*
	mong042	46.68	101.77	2125	-416–2013	*Pinus sibirica*
Qilian Mountains	chin005	37	98.5	3800	840–1993	*Juniperus przewalskii*
	chin052	37.45	97.54	3920	404–2002	*Juniperus przewalskii*
	chin054	37.45	97.79	3700	711–2003	*Juniperus przewalskii*
	chin055	37.51	97.06	3780	1237–2002	*Juniperus przewalskii*
	chin061	37.03	98.63	3700	857–2003	*Juniperus przewalskii*
	chin069	36.95	98.55	/	-1495–808	*Juniperus przewalskii*
	chin070	38.57	99.33	/	56–2009	*Juniperus przewalskii*
	YQ	39.61	97.88	3100-3500	134–1140	*Juniperus przewalskii*
	CHN	37	98.74	3588	1708–2013	*Juniperus przewalskii*

Table S2. Leave-one-out cross-validation statistics for the NPP reconstructions.

	r	RE	PMT	Sign test
ALT (1982-2018)	0.610**	0.370**	6.204**	$26^{+}/11^{-}$*
MG (1982-2013)	0.784**	0.375**	4.475**	$27^{+}/5^{-}$**
QQ (1982-2013)	0.622**	0.381**	4.789**	$23^{+}/9^{-}$**

*, **: Significant at $p < 0.05$, $p < 0.01$.

Table S3. Comparisons with important historical events related to the migration of nomadic peoples in Inner Eurasia.

Event	NPP anomaly (%)	Consecutive 2+ years below a standard deviation (%)
Xiongnu occupied Qilian Mountain and forced the Yuezhi to migrate westward	190–170 BC: -12.2% (MG)	182–179 BC: -23.1% –-35.9% (MG)
Han Dynasty expelled the Xiongnu and occupied the Hexi Corridor	134–123 BC: -7.4% (QQ)	120–119 BC: -25.8%–-29.4% (MG)
Eastern Han defeated the Northern Xiongnu and forced them to migrate westward	69–101 CE: -9.8% (MG) 82–101 CE: -15.0% (ALT) 58–92 CE: -9.8% (QQ)	86–88 CE: -31.6%–-54.8% (MG) 91–92 CE: -20.6%–-35.1% (MG)
Xiongnu migrated southward deep into Han Empire territories	105–125 CE: -8.0% (MG) 129–142 CE: -9.2% (MG) 154–171 CE: -9.6% (MG) 180–211 CE: -8.8% (MG) 166–185 CE: -23.3% (ALT)	185–187 CE: -28.3%–-48.7% (MG) 171–174 CE: -30.8%–-63.7% (ALT) 176–178 CE: -36.1%–-51.3% (ALT)
Upheaval of the Five Barbarians	256–312 CE: -8.5% (QQ) 331–379 CE: -17.2% (QQ) 368–388 CE: -9.4% (MG)	366–367 CE: -45.2%–-55.7% (QQ) 369–370 CE: -36.2%–-57.0% (QQ) 372–376 CE: -33.4%–-62.8% (QQ) 356–358 CE: -21.6%–-34.1% (MG)
Nomadic peoples continue to migrate to northern China and Europe	403–420 CE: -5.5% (MG) 427–447 CE: -6.2% (MG) 455–468 CE: -6.8% (MG) 470–516 CE: -12.2% (MG)	484–486 CE: -21.3%–-38.5% (MG) 493–495 CE: -33.0%–-50.0% (MG) 500–502 CE: -24.7%–-44.4% (MG)
Replacement of the Rouran by the Türks, and Avars reach Black Sea	531–561 CE: -27.0% (ALT) 512–553 CE: -8.7% (QQ) 548–559 CE: -11.1% (MG)	551–553 CE: -27.5%–-43.8% (MG) 555–556 CE: -24.5%–-32.7% (MG)
Division of the Turkic Empire into the Western and the Eastern Empires	570–602 CE: -16.6% (ALT) 577–588 CE: -8.1% (MG)	580–581 CE: -24.1%–-25.2% (MG) 578–581 CE: -23.2%–-27.9% (ALT)
Fall of the Eastern Turkic and Xueyantuo Khanates	632–643 CE: -13.1% (MG) 626–647 CE: -9.6% (ALT)	627–628 CE: -25.0%–-33.5% (ALT)
Decline of the Uighur Khanate	787–834 CE: -14.1% (MG)	799–800 CE: -24.5%–-26.4% (MG) 807–810 CE: -32.6%–-38.4% (MG)
Chaotic period before Genghis Khan unified Mongolia	1158–1210 CE: -11.5% (MG) 1174–1194 CE: -15.8% (ALT) 1103–1135 CE: -6.6% (QQ) 1138–1184 CE : -13.0% (QQ) 1191–1211 CE: -18.6% (QQ)	1180–1186 CE: -27.4%–-45.8% (MG) 1189–1190 CE: -26.9%–-27.5% (MG) 1181–1183 CE: -30.3%–-64.6% (QQ) 1186–1187 CE: -24.2%–-34.8% (ALT) 1190–1191 CE: -51.7%–-54.9% (ALT)