Table S1

Presentation of the tested and selected values and associated criteria for the band height and forest cover threshold metrics, which are used to estimate forest-line elevation.

Metric	Tested values	Selected value	Criteria
Band height	25 m; 50 m; 100 m	100 m	Minimum height for minimum noise level
Forest cover threshold	0%; 2.5%; 5%	5%	Minimum threshold to prevent retaining too many small wooded tracts below the forest line

Table S2

Presentation of the dominant tree species classes used in our study, based on the tree species composition at the forest line and the closed forest line, and their original corresponding categories in the *BD Forêt® v2* (BDF2), with counts in brackets.

Dominant tree species class	BDF2 corresponding categories for closed forest	BDF2 corresponding categories for forest
Conifers	-	Conifers (15)
Mountain pine	Mountain pine (50) Conifers (1)*	Mountain pine (11) Conifers (38)
Fir	Fir (21)	Fir (7) Conifers (10)
Mixed	Mixed (18)	Mixed (7)
Deciduous	Deciduous (8)	Deciduous (13)
Beech	Beech (16)	Beech (5) Deciduous (8)

*The municipality with undifferentiated conifers at the closed forest line was grouped with municipalities where mountain pine formed the closed forest line, as mountain pine also formed closed forest line for the neighbouring municipalities, to avoid classes with small sample size (and subsequent statistical fitting problems).

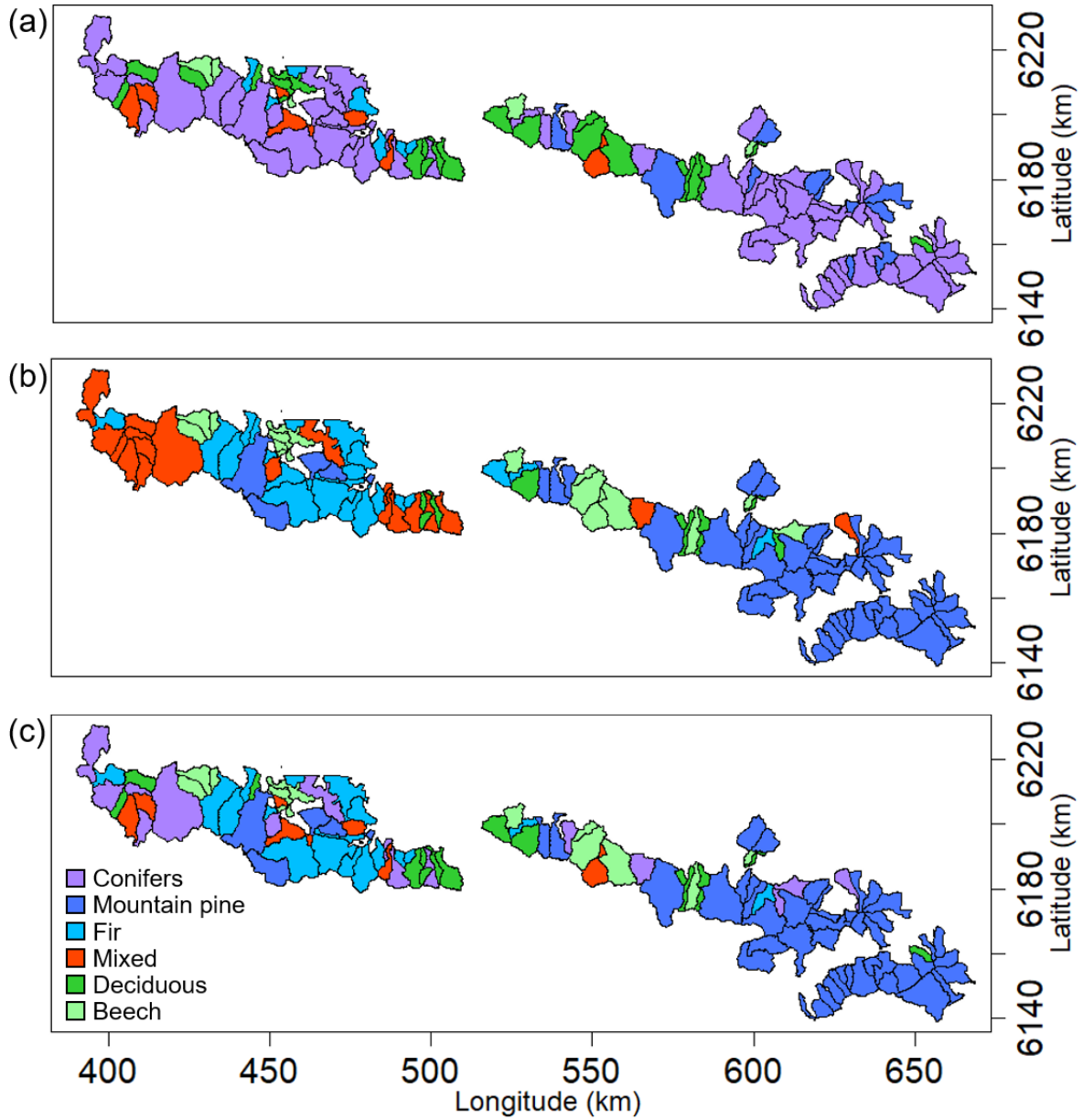
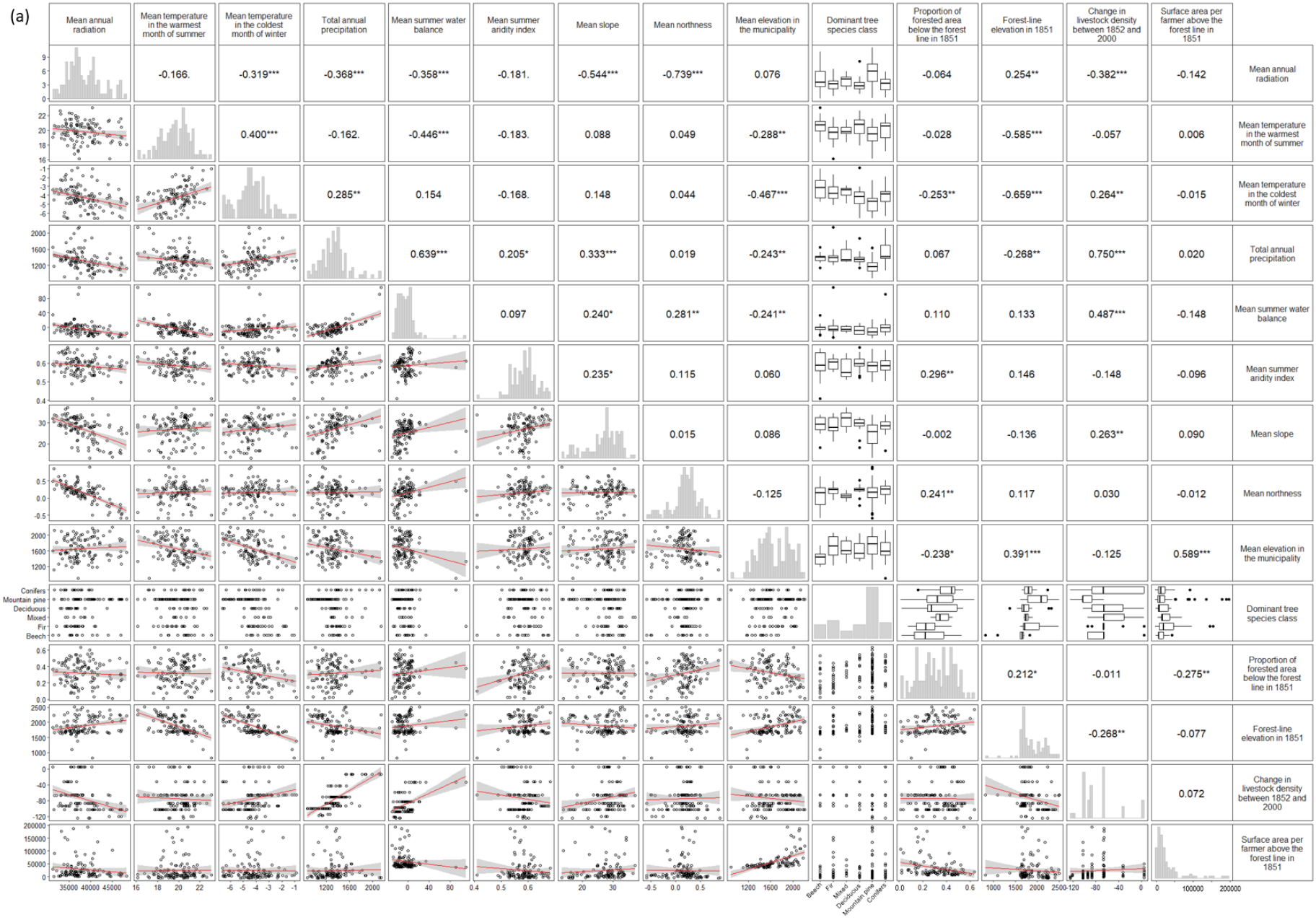


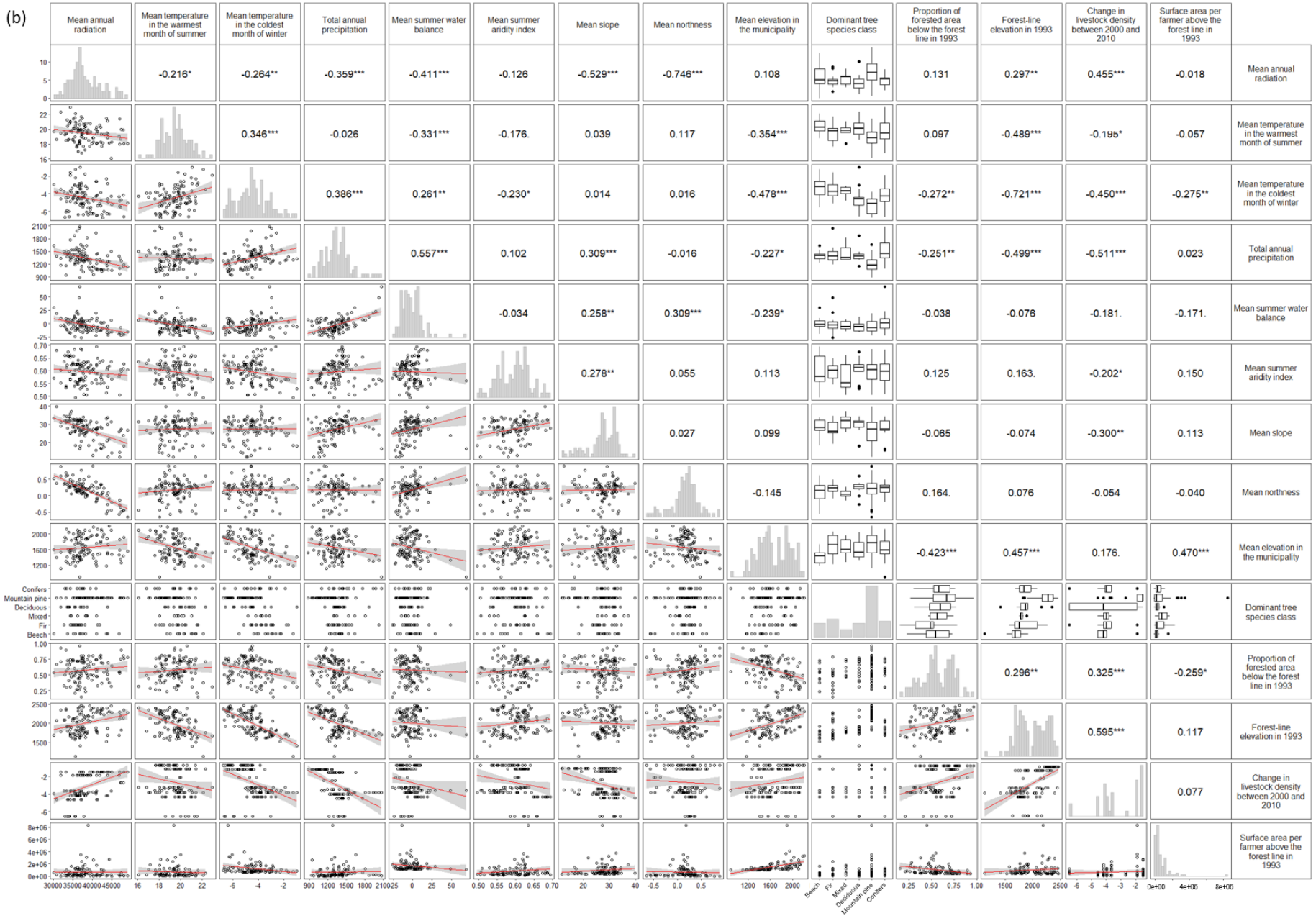
Figure S3

BD Forêt® v2 (IGN) dominant tree species category at the forest line (a), dominant tree species class at the closed forest line (b) and deduced dominant tree species class at the forest line (c) for each municipality in the study area. The only municipality where closed forest dominant tree species was "Conifers" was grouped with the category "Mountain pine" (see Table S2). Map (c) was derived from maps (a) and (b). See M&M and Table S2 for details.

(a)


Mean annual radiation
Mean temperature in the warmest month of summer
Mean temperature in the coldest month of winter
Total annual precipitation
Mean summer water balance
Mean summer aridity index
Mean slope
Mean northness
Mean elevation in the municipality
Dominant tree species class
Proportion of forested area below the forest line in 1851
Forest-line elevation in 1851
Change in livestock density between 1852 and 2000
Surface area per farmer above the forest line in 1851
-0.166.
-0.319***
-0.368***
-0.358***
-0.181.
-0.544***
-0.739***
0.076
-0.064
0.254**
-0.382***
-0.142
0.400***
-0.162.
-0.446***
-0.183.
0.088
0.049
-0.288**
-0.028
-0.585***
-0.057
0.006
0.285**
0.154
-0.168.
0.148
0.044
-0.467***
-0.253**
-0.659***
0.264**
-0.015
0.639***
0.205*
0.333***
0.019
-0.243**
0.067
-0.268**
0.750***
0.020
0.097
0.240*
0.281**
-0.241**
0.110
0.133
0.487***
-0.148
0.235*
0.115
0.060
0.296**
0.146
-0.148
-0.096
0.015
0.086
-0.002
-0.136
0.263**
0.090
-0.125
0.241**
0.117
0.030
-0.012
-0.238*
0.391***
-0.125
0.589***
Conifers
Mountain pine
Deciduous
Mixed
Fir
Beech
0.212*
-0.011
-0.275**
-0.268**
-0.077
0.072

(b)


Mean annual radiation
Mean temperature in the warmest month of summer
Mean temperature in the coldest month of winter
Total annual precipitation
Mean summer water balance
Mean summer aridity index
Mean slope
Mean northness
Mean elevation in the municipality
Dominant tree species class
Proportion of forested area below the forest line in 1993
Forest-line elevation in 1993
Change in livestock density between 2000 and 2010
Surface area per farmer above the forest line in 1993
-0.216* -0.264** -0.359*** -0.411*** -0.126 -0.529*** -0.746*** 0.108 0.131 0.297** 0.455*** -0.018
0.346*** -0.026 -0.331*** -0.176. 0.039 0.117 -0.354*** 0.097 -0.489*** -0.195* -0.057
0.386*** 0.261** -0.230* 0.014 0.016 -0.478*** -0.272** -0.721*** -0.450*** -0.275**
0.557*** 0.102 0.309*** -0.016 -0.227* -0.251** -0.499*** -0.511*** 0.023
-0.034 0.258** 0.309*** -0.239* -0.038 -0.076 -0.181. -0.171.
0.278** 0.055 0.113 0.125 0.163. -0.202* 0.150
0.027 0.099 -0.065 -0.074 -0.300** 0.113
-0.145 0.164. 0.076 -0.054 -0.040
-0.423*** 0.457*** 0.176. 0.470***
0.296** 0.325*** -0.259*
0.595*** 0.117
0.077
Conifers
Mountain pine
Deciduous
Mixed
Fir
Beech

(c)

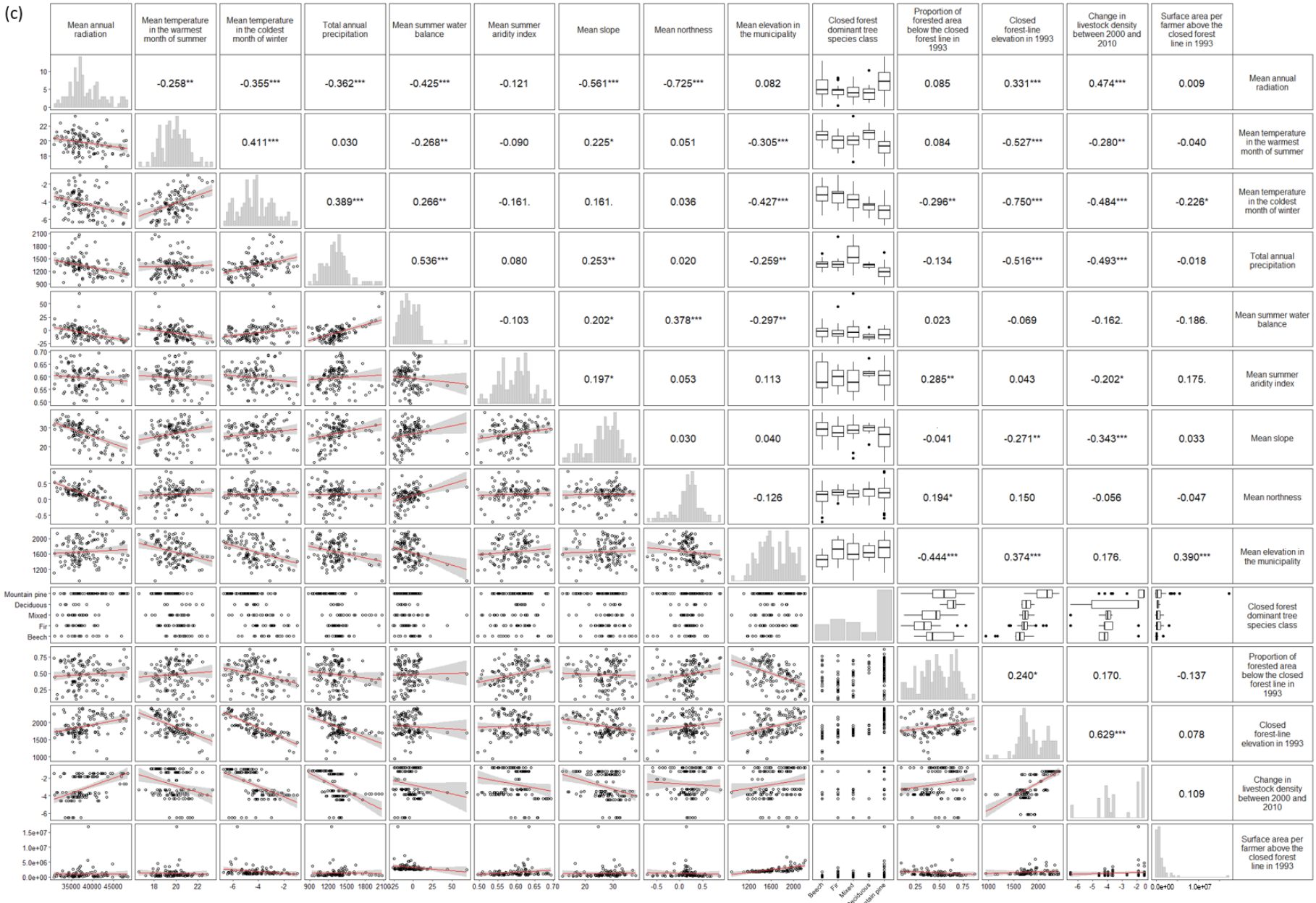

Mean annual radiation
Mean temperature in the warmest month of summer
Mean temperature in the coldest month of winter
Total annual precipitation
Mean summer water balance
Mean summer aridity index
Mean slope
Mean northness
Mean elevation in the municipality
Closed forest dominant tree species class
Proportion of forested area below the closed forest line in 1993
Closed forest-line elevation in 1993
Change in livestock density between 2000 and 2010
Surface area per farmer above the closed forest line in 1993
-0.258** -0.355*** -0.362*** -0.425*** -0.121 -0.561*** -0.725*** 0.082 0.085 0.331*** 0.474*** 0.009
0.411*** 0.030 -0.268** -0.090 0.225* 0.051 -0.305*** 0.084 -0.527*** -0.280** -0.040
0.389*** 0.266** -0.161. 0.161. 0.036 -0.427*** -0.296** -0.750*** -0.484*** -0.226*
0.536*** 0.080 0.253** 0.020 -0.259** -0.134 -0.516*** -0.493*** -0.018
-0.103 0.202* 0.378*** -0.297** 0.023 -0.069 -0.162. -0.186.
0.197* 0.053 0.113 0.285** 0.043 -0.202* 0.175.
0.030 0.040 -0.041 -0.271** -0.343*** 0.033
-0.126 0.194* 0.150 -0.056 -0.047
-0.444*** 0.374*** 0.176. 0.390***
0.240* 0.170. -0.137
0.629*** 0.078
0.109
Mean annual radiation
Mean temperature in the warmest month of summer
Mean temperature in the coldest month of winter
Total annual precipitation
Mean summer water balance
Mean summer aridity index
Mean slope
Mean northness
Mean elevation in the municipality
Closed forest dominant tree species class
Proportion of forested area below the closed forest line in 1993
Closed forest-line elevation in 1993
Change in livestock density between 2000 and 2010
Surface area per farmer above the closed forest line in 1993
Mountain pine
Deciduous
Mixed
Fir
Beech

Figure S4

Correlations between potential drivers for the two time periods: 1851-1993 (a) and 1993-2010 (b) and related to the closed forest line (c). The upper panel shows Pearson's correlation coefficients for continuous *vs.* continuous and boxplots for continuous *vs.* discrete variables. The diagonal indicates the histogram of the distribution of the variable. The lower panel shows points with regression for continuous *vs.* continuous and continuous *vs.* discrete variables. Mean annual radiation, mean temperature in the warmest month of summer, mean temperature in the coldest month of winter, total annual precipitation, mean summer water balance, mean summer aridity index, mean slope and mean northness were calculated in the 300 m above the forest line in 1851 (a), the forest-line in 1993 (b), and the closed forest line in 1993 (c).

The mean annual radiation was negatively correlated with the mean slope in the 300 m above the forest line and the closed forest line, and to a greater extent with the mean northness in the 300 m above the forest line and closed forest line. The mean temperature in the warmest month of summer and the mean temperature in the coldest month of winter in the 300 m above the forest line and the closed forest line were negatively correlated with the forest-line and closed forest-line elevations. Total annual precipitation was positively correlated with mean summer water balance in the 300 m above the forest line and closed forest line. Dominant tree species class varied with forest-line elevation for the two periods: forest-line elevation was maximal for mountain pine, then conifers were second, deciduous stands third, followed by mixed stands and fir, and forest-line elevation was minimal for beech ($r = 0.53$ and $r = 0.78$ respectively between 1851 and 1993 and between 1993 and 2010). In addition, dominant tree species class also varied from western to eastern Pyrenees: beech, fir and mixed stands were more frequent in the western part while the mountain pine stands were more frequent in the eastern part of the Pyrenees, deciduous stands were more frequent in the centre, and conifers stands were distributed across the whole range (Figure S3c). Closed forest dominant tree species class followed the same trend: closed forest-line elevation was maximal for mountain pine and minimal for beech, with fir, mixed and deciduous stands in between ($r = 0.77$). In addition, closed forest dominant tree species class also varied from western to eastern Pyrenees: fir and mixed stands were more frequent in the western part while the mountain pine stands were more frequent in the eastern part of the Pyrenees, beech and deciduous stands were more frequent in the centre (Figure S3b). Forest-line and closed forest-line elevations in 1993 were positively correlated with livestock density change between 2000 and 2010. Surface area per farmer above the forest line was positively correlated with the mean elevation in the municipality, and the correlation was higher

in 1851. Forest-line and closed forest-line elevations were negatively correlated with total annual precipitation in the 300 m above the forest line and closed forest line in 1993. Total annual precipitation in the 300 m above the forest line in 1851 was highly and positively correlated with change in livestock density between 1852 and 2010, while total annual precipitation in the 300 m above the forest line and closed forest line in 1993 were negatively correlated with change in livestock density between 2000 and 2010.

Table S5

Forest-line and closed forest-line elevation estimates for each of the 114 municipalities in 1851, 1993 and 2010. The municipalities belonging to the Catalan Pyrenees and used in the calculations of mean forest-line shift velocity for this area are in brown.

			Forest-line elevation (m a.s.l.)			Closed forest-line elevation (m a.s.l.)	
Municipality	**Arrondissement**	**Department**	**1851**	**1993**	**2010**	**1993**	**2010**
Artigues	Foix	Ariège	2101	2294	2272	2262	2265
Ascou	Foix	Ariège	1804	2043	2059	1916	1959
Aston	Foix	Ariège	1652	2193	2244	1908	2140
Auzat	Foix	Ariège	1651	1857	1901	1814	1864
Axiat	Foix	Ariège	1692	1681	1681	1680	1675
Ax-les-Thermes	Foix	Ariège	2198	2259	2270	2095	2251
Gestiès	Foix	Ariège	1540	1899	1937	1677	1865
Goulier	Foix	Ariège	1645	1778	1783	1729	1780
Lercoul	Foix	Ariège	1648	1743	1940	1665	1689
Lordat	Foix	Ariège	1676	1871	1679	1665	1679
Luzenac	Foix	Ariège	1744	2116	2138	1951	2045
Mérens-les-Vals	Foix	Ariège	2041	2344	2372	2173	2333
Mijanès	Foix	Ariège	2024	2320	2326	2308	2307
Montferrier	Foix	Ariège	1692	2056	2049	1845	2005
Montségur	Foix	Ariège	1683	2118	2137	2118	2137
Orgeix	Foix	Ariège	1875	2083	2019	1920	1981
Orlu	Foix	Ariège	1896	2179	2258	1931	2181
Perles-et-Castelet	Foix	Ariège	1688	2149	2177	1949	2177
Savignac-les-Ormeaux	Foix	Ariège	1704	2088	2286	1922	2100
Siguer	Foix	Ariège	1673	1926	1979	1853	1916
Antras	Saint-Girons	Ariège	1699	1750	1765	1730	1735
Aulus-les-Bains	Saint-Girons	Ariège	1734	1744	1788	1692	1728
Bethmale	Saint-Girons	Ariège	1652	1853	1839	1734	1839
Bonac-Irazein	Saint-Girons	Ariège	1617	2065	1944	1716	1846
Couflens	Saint-Girons	Ariège	1714	1840	1915	1779	1863
Les Bordes-sur-Lez	Saint-Girons	Ariège	1837	2131	2045	1814	1939
Saint-Lary	Saint-Girons	Ariège	1686	1794	1763	1642	1762
Seix	Saint-Girons	Ariège	1636	1779	1829	1719	1744
Sentein	Saint-Girons	Ariège	1674	1915	1902	1790	1864
Sentenac-d'Oust	Saint-Girons	Ariège	1650	1807	1736	1651	1684
Ustou	Saint-Girons	Ariège	1707	1731	1767	1707	1733
Counozouls	Limoux	Aude	2124	2171	2267	2100	2185
Escouloubre	Limoux	Aude	2235	1880	2233	1844	1975
Le Bousquet	Limoux	Aude	1891	2176	2231	2176	2180
Bagnères-de-Luchon	Saint-Gaudens	Haute-Garonne	1891	1923	2056	1799	1944
Castillon-de-Larboust	Saint-Gaudens	Haute-Garonne	2003	2080	2066	1918	1981
Cazeaux-de-Larboust	Saint-Gaudens	Haute-Garonne	1805	1827	1964	1808	1862
Gouaux-de-Larboust	Saint-Gaudens	Haute-Garonne	1644	1640	1640	1640	1640

			Forest-line elevation (m a.s.l.)			Closed forest-line elevation (m a.s.l.)	
Municipality	**Arrondissement**	**Department**	**1851**	**1993**	**2010**	**1993**	**2010**
Melles	Saint-Gaudens	Haute-Garonne	1701	1861	1914	1776	1793
Oô	Saint-Gaudens	Haute-Garonne	2323	2163	2144	1854	2031
Saint-Aventin	Saint-Gaudens	Haute-Garonne	1731	1916	2066	1916	1886
Arbéost	Argelès	Hautes-Pyrénées	1099	1133	1278	1131	1241
Arcizans-Avant	Argelès	Hautes-Pyrénées	1377	1413	1555	1413	1400
Arras-en-Lavedan	Argelès	Hautes-Pyrénées	1685	1675	1682	1675	1682
Arrens-Marsous	Argelès	Hautes-Pyrénées	2053	2032	2136	1792	1841
Barèges	Argelès	Hautes-Pyrénées	1729	2165	2297	1970	2024
Beaucens	Argelès	Hautes-Pyrénées	1684	1635	1716	1570	1651
Cauterets	Argelès	Hautes-Pyrénées	2503	2395	2361	1949	2126
Chèze	Argelès	Hautes-Pyrénées	1742	1785	1870	1533	1771
Estaing	Argelès	Hautes-Pyrénées	1670	2062	2058	1710	1832
Gavarnie	Argelès	Hautes-Pyrénées	1778	1900	1935	1855	1867
Gazost	Argelès	Hautes-Pyrénées	1697	1612	1626	1439	1626
Gèdre	Argelès	Hautes-Pyrénées	1854	1823	1895	1754	1815
Grust	Argelès	Hautes-Pyrénées	1711	1712	1753	1712	1753
Luz-Saint-Sauveur	Argelès	Hautes-Pyrénées	1706	1770	1852	1685	1823
Saligos	Argelès	Hautes-Pyrénées	818	1527	1501	1179	1461
Sazos	Argelès	Hautes-Pyrénées	1884	2029	2107	1747	1969
Viey	Argelès	Hautes-Pyrénées	1662	1689	1700	948	1698
Villelongue	Argelès	Hautes-Pyrénées	1607	1625	1852	1623	1674
Adervielle-Pouchergues	Bagnères	Hautes-Pyrénées	1846	1698	1866	1636	1731
Ancizan	Bagnères	Hautes-Pyrénées	1609	1578	1602	1578	1602
Aragnouet	Bagnères	Hautes-Pyrénées	2215	2236	2290	1946	2073
Aulon	Bagnères	Hautes-Pyrénées	1702	1771	1775	1718	1757
Azet	Bagnères	Hautes-Pyrénées	1877	2079	2068	1727	1980
Bagnères-de-Bigorre	Bagnères	Hautes-Pyrénées	1739	1817	2236	1715	1800
Campan	Bagnères	Hautes-Pyrénées	1716	1623	1636	1615	1624
Génos	Bagnères	Hautes-Pyrénées	1906	1889	2091	1652	2025
Germ	Bagnères	Hautes-Pyrénées	1650	1684	1728	1684	1726
Loudenvielle	Bagnères	Hautes-Pyrénées	1667	1912	2022	1656	1991
Saint-Lary-Soulan	Bagnères	Hautes-Pyrénées	2494	2276	2334	2153	2219
Tramezaïgues	Bagnères	Hautes-Pyrénées	2034	2131	2248	1922	2061
Vielle-Aure	Bagnères	Hautes-Pyrénées	2405	2449	2437	2125	2134
Accous	Oloron	Pyrénées-Atlantiques	1714	1716	1753	1676	1717
Arette	Oloron	Pyrénées-Atlantiques	1808	1696	1857	1696	1676
Béost	Oloron	Pyrénées-Atlantiques	1611	1600	1626	1577	1624
Borce	Oloron	Pyrénées-Atlantiques	1801	1758	1783	1757	1782
Cette-Eygun	Oloron	Pyrénées-Atlantiques	1668	1830	1870	1722	1754
Eaux-Bonnes	Oloron	Pyrénées-Atlantiques	1833	1685	1714	1554	1702
Etsaut	Oloron	Pyrénées-Atlantiques	1777	1791	1802	1777	1798
Laruns	Oloron	Pyrénées-Atlantiques	1872	1845	1906	1792	1825

			Forest-line elevation (m a.s.l.)			Closed forest-line elevation (m a.s.l.)	
Municipality	**Arrondissement**	**Department**	**1851**	**1993**	**2010**	**1993**	**2010**
Lées-Athas	Oloron	Pyrénées-Atlantiques	2244	1758	2025	1713	1715
Lescun	Oloron	Pyrénées-Atlantiques	1682	1683	1708	1616	1696
Urdos	Oloron	Pyrénées-Atlantiques	1734	1772	1821	1772	1787
Corsavy	Céret	Pyrénées-Orientales	1635	2200	2239	2048	2219
Le Tech	Céret	Pyrénées-Orientales	1750	1826	1986	1826	1911
Prats-de-Mollo-la-Preste	Céret	Pyrénées-Orientales	1729	2139	2238	2044	2146
Angoustrine-Villeneuve-des-Escaldes	Prades	Pyrénées-Orientales	2026	2303	2339	2150	2304
Casteil	Prades	Pyrénées-Orientales	2341	2348	2439	2220	2342
Err	Prades	Pyrénées-Orientales	2204	2312	2382	2266	2338
Estoher	Prades	Pyrénées-Orientales	2230	2348	2342	2244	2285
Eyne	Prades	Pyrénées-Orientales	2205	2397	2486	2393	2395
Fontpédrouse	Prades	Pyrénées-Orientales	2368	2453	2742	2361	2405
Fontrabiouse	Prades	Pyrénées-Orientales	2115	2395	2362	2117	2146
Formiguères	Prades	Pyrénées-Orientales	2030	2375	2373	2234	2349
Les Angles	Prades	Pyrénées-Orientales	2244	2340	2347	2305	2307
Llo	Prades	Pyrénées-Orientales	2257	2390	2403	2328	2379
Mantet	Prades	Pyrénées-Orientales	2176	2337	2339	2293	2314
Mosset	Prades	Pyrénées-Orientales	2158	2261	2272	2213	2269
Nohèdes	Prades	Pyrénées-Orientales	2220	2270	2242	2220	2241
Nyer	Prades	Pyrénées-Orientales	2204	2462	2453	2392	2450
Olette	Prades	Pyrénées-Orientales	2256	2279	2287	2262	2268
Palau-de-Cerdagne	Prades	Pyrénées-Orientales	2038	2118	2123	2120	2117
Planès	Prades	Pyrénées-Orientales	2425	2427	2423	2414	2420
Porta	Prades	Pyrénées-Orientales	1999	2397	2401	2317	2368
Porté-Puymorens	Prades	Pyrénées-Orientales	1844	2369	2409	2256	2381
Py	Prades	Pyrénées-Orientales	2232	2248	2267	2212	2244
Réal	Prades	Pyrénées-Orientales	2120	2259	2249	2223	2249
Saint-Pierre-dels-Forcats	Prades	Pyrénées-Orientales	2251	2367	2505	2367	2412
Sansa	Prades	Pyrénées-Orientales	2232	2289	2347	2202	2311
Taurinya	Prades	Pyrénées-Orientales	2136	2350	2356	2301	2344
Thuès-Entre-Valls	Prades	Pyrénées-Orientales	2412	2427	2565	2395	2409
Valcebollère	Prades	Pyrénées-Orientales	2179	2223	2278	2178	2229
Valmanya	Prades	Pyrénées-Orientales	2031	2205	2224	2074	2201
Vernet-les-Bains	Prades	Pyrénées-Orientales	2266	2349	2437	2218	2212

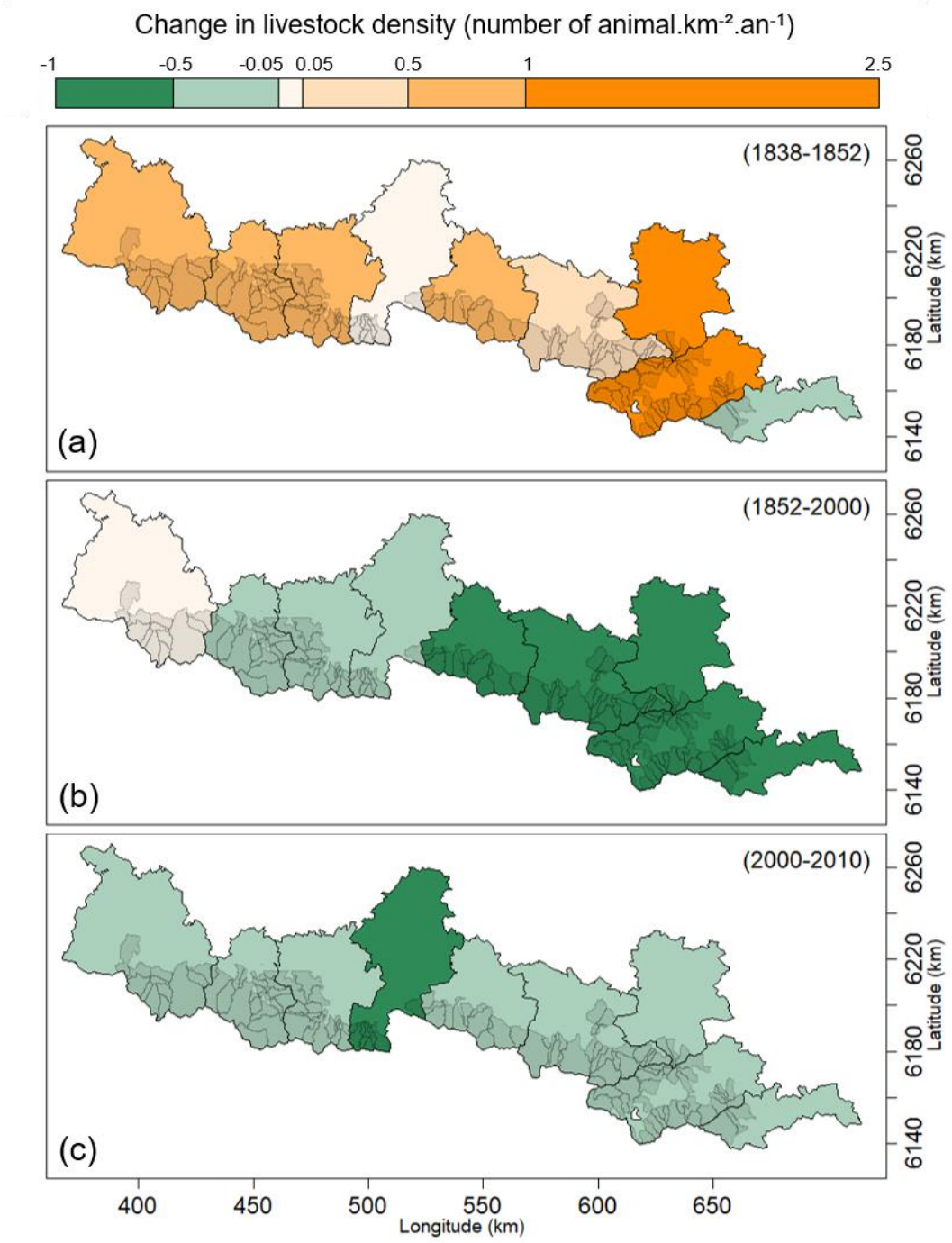


Figure S6

Change in livestock density (number of animals.km^{-2}.an^{-1}) in the 9 arrondissements of the study area for three periods: 1838-1852 (a), 1852-2000 (b) and 2000-2010 (c). The 114 municipalities that belong to these 9 arrondissements are also shown in transparency.

Table S7

Mean forest-line and closed forest-line shift velocities for the total of municipalities, the western municipalities (division at 520 km of longitude), the eastern municipalities and the municipalities belonging to the Catalan Pyrenees (see Table S5). The corresponding calculation is presented in the last column.

Shift period	Total	West	East	Catalan Pyrenees	Calculation
Forest 1851-1993	0.87	0.22	1.33	1.45	Mean forest-line shift velocity between 1851 and 1993
Forest 1993-2010	3.55	5.56	2.09	2.82	Mean forest-line shift velocity between 1993 and 2010
Forest 1901-2018	1.44	1.36	1.49	1.74	(mean forest-line shift velocity between 1851 and 1993 * (1993-1901) + mean forest-line shift velocity between 1993 and 2010 * (2018-1993)) / (2018-1901)
Forest 1953-2015	1.82	2.12	1.60	1.94	(mean forest-line shift velocity between 1851 and 1993 * (1993-1953) + mean forest-line shift velocity between 1993 and 2010 * (2015-1993)) / (2015-1953)
Forest 1956-2006	1.56	1.61	1.53	1.81	(mean forest-line shift velocity between 1851 and 1993 * (1993-1956) + mean forest-line shift velocity between 1993 and 2010 * (2006-1993)) / (2006-1956)
Closed forest 1851-1993	0.07	-0.71	0.63	0.77	Mean closed forest-line shift velocity between 1851 and 1993
Closed forest 1993-2010	5.58	8.28	3.62	4.18	Mean closed forest-line shift velocity between 1993 and 2010
Closed forest 1953-2015	2.03	2.48	1.69	1.98	(mean closed forest-line shift velocity between 1851 and 1993 * (1993-1953) + mean closed forest-line shift velocity between 1993 and 2010 * (2015-1993)) / (2015-1953)