Appendix S2. Parameterising and simulating drought effects

Drought effects on vegetation dynamics in the Ecrins National Park (ENP) were simulated mechanistically, rather than physiologically. Drought was simulated in two phases that consisted first in the 1) identification of drought effects and then 2) on modelling drought responses. Both phases depended on PFGs' past drought exposure, which was reconstructed from historical climate data.

Identifying drought effects followed the same approach as the implemented habitat suitability (HS). Drought intensity (*Din*) maps were fed into the model to compare *Din* pixel values against parameters reflecting the PFGs' adaptations and tolerance to drought (past drought exposure). PFG responses also depended on their adaptation and tolerance to drought. In this appendix we detail how PFG past drought exposure was calculated, how PFG drought-related responses were parameterised and, lastly, how *Din* maps were produced to simulate drought events.

PFGs past drought exposure

Parameters for detecting and applying drought effects were based on PFGs' past drought exposure, built from PFG occurrence information and climate data across most of the French Alps.

Occurrence data for each PFG were obtained from the Conservatoire Botanique National Alpin (CBNA) vegetation-plot database, covering the majority of the French Alps (Boulangeat *et al.* 2012; CBNA 2015). Only data from exhaustive *relevés* (identification of all plant species within a plot) from 1980 to present were used. A PFG was considered present in a plot if at least one of its representative species was recorded (Table S2), resulting in the selection of 101 122 plots.

PFG past drought exposure was based on historical values of the moisture index (*MI*), an indicator of climatic drought that has been used in previous studies relating forest mortality and drought (Bigler *et al.* 2006; Gustafson & Sturtevant 2013). We calculated *MI* values across the whole French Alps using climate data obtained from the meteorological model Aurelhy (Benichou & Le Breton 1987), spanning years 1961 to 1990 and interpolated at a 100 m resolution. Monthly *MI* values (in mm) were calculated as:

$$MI_i = \sum_{j=1}^{n} P_j - PET_i \times n + 0.5$$

with P_j being daily precipitation, PET_i being the average daily potential evapotranspiration of month i – calculated following Turc's (1961) formula – and n the number of days in month i. Values were then subset by plot and crossed with PFG occurrence data to obtain a distribution of historical *MI* values for each PFG ($MI_{1961-1990}$). We also built distributions of drought intensity (*Din*) values for each PFG, by extracting the lowest value of *MI* in a year for each plot ($Din_{1961-1990}$).

Parameterisation of drought-related mortality and resprouting

Severe drought effects (immediate or post-drought) triggered drought-related mortality, with the possibility of resprouting, which depended on the soil moisture preference class of a given PFG. Soil moisture preference classes were built from the PFGs $MI_{1961-1990}$ distributions, assuming that they reflect their moisture preferences and, or, adaptations to drought. For each PFG, we calculated $\bar{x} - 2.5$ x SD of $MI_{1961-1990}$ (with $\bar{x}$ and SD being the mean and standard deviation, respectively) and scaled the results into four classes from zero (very low moisture preference) to four (very high moisture preference). These classes were then adjusted according to

expert-based knowledge of the soil moisture preferences of the species present in the PFGs, resulting into four final classes ranging from zero to three (Table S2).

Table S2. Description of the simulated plant functional groups (PFG) and their representative species. PFG occurrences were based on presence/absence data of their representative species across the French Alps. The PFG description reflects the main characteristics of the species it encompasses. Table partially adapted from Boulangeat, Georges and Thuiller (2014).

PFG	Species	PFG description
C1	*Achillea millefolium, Anthyllis montana, Cotoneaster integerrimus, Helianthemum grandiflorum, Helianthemum nummularium, Hippocrepis comosa, Lonicera caerulea, Origanum vulgare, Potentilla neumanniana, Rubus idaeus, Rubus saxatilis, Rumex acetosella, Stachys recta, Teucrium chamaedrys, Thymus pulegioides, Valeriana montana*	Thermophilous chamaephytes with long dispersal distance
C2	*Antennaria dioica, Artemisia umbelliformis umbelliformis, Cerastium alpinum, Cerastium cerastoides, Cerastium latifolium, Cerastium pedunculatum, Cerastium uniflorum, Helictotrichon sedenense sedenense, Leucanthemopsis alpina, Rumex scutatus, Salix glaucosericea, Salix hastata, Saxifraga aizoides, Saxifraga oppositifolia, Sempervivum arachnoideum, Thymus polytrichus, Vaccinium uliginosum microphyllum*	Alpine and subalpine chamaephyte species
C3	*Androsace pubescens, Androsace vitaliana, Dryas octopetala, Empetrum nigrum hermaphroditum, Eritrichium nanum nanum, Globularia cordifolia, Gypsophila repens, Juniperus sibirica, Noccaea rotundifolia, Polygala chamaebuxus, Primula hirsuta, Primula pedemontana pedemontana, Pritzelago alpina alpina, Rhododendron ferrugineum, Sagina glabra, Sagina saginoides, Salix herbacea, Salix reticulata, Salix retusa, Saxifraga bryoides, Saxifraga exarata, Sedum album, Sedum alpestre, Sedum dasyphyllum, Silene acaulis, Silene acaulis bryoides*	Chamaephytes with short dispersal distance
C4	*Alnus alnobetula, Amelanchier ovalis, Cornus sanguinea, Corylus avellana, Crataegus monogyna, Juniperus communis, Lonicera xylosteum, Ribes petraeum, Rosa pendulina, Salix laggeri, Salix purpurea*	Tall shrubs
C5	*Arctostaphylos uva-ursi crassifolius, Calluna vulgaris, Hippocrepis emerus*	Mountainous to subalpine heath found in dry climates
C6	*Vaccinium myrtillus, Vaccinium vitis-idaea vitis-idaea*	Mountainous to subalpine heath found in wet climates
H1	*Achillea nana, Agrostis alpina, Agrostis rupestris, Alchemilla pentaphyllea, Alopecurus alpinus, Astragalus alpinus, Athamanta cretensis, Avenula versicolor versicolor, Campanula cochleariifolia, Carex capillaris, Carex curvula, Carex echinata, Carex foetida, Carex frigida, Carex nigra,*	Alpine species, which do not tolerate shade and have short dispersal distance

	Carex panicea, Carex rupestris, Doronicum grandiflorum, Epilobium anagallidifolium, Eriophorum latifolium, Eriophorum polystachion, Eriophorum scheuchzeri, Festuca halleri halleri, Festuca quadriflora, Gentiana punctata, Geum montanum, Geum reptans, Hieracium glaciale, Juncus trifidus, Kobresia myosuroides, Leontodon montanus, Leontodon pyrenaicus helveticus, Linaria alpina alpina, Lotus alpinus, Luzula alpinopilosa, Oxyria digyna, Phleum alpinum, Plantago alpina, Poa alpina, Poa cenisia, Poa laxa, Polygonum viviparum, Potentilla aurea, Potentilla erecta, Potentilla grandiflora, Ranunculus glacialis, Ranunculus kuepferi, Ranunculus montanus, Saxifraga stellaris robusta, Taraxacum alpinum, Trichophorum cespitosum, Trifolium alpinum, Trifolium pallescens, Trifolium saxatile, Trifolium thalii, Trisetum distichophyllum	
H2	*Agrostis capillaris, Agrostis stolonifera, Alchemilla vulgaris, Carex caryophyllea, Carex sempervirens, Carum carvi, Chenopodium bonus-henricus, Festuca nigrescens, Fragaria vesca, Galium aparine, Galium odoratum, Galium verum, Geranium sylvaticum, Lathyrus pratensis, Leucanthemum vulgare, Lotus corniculatus, Meum athamanticum, Onobrychis montana, Rumex acetosa, Rumex pseudalpinus, Sesleria caerulea, Trifolium montanum, Trifolium pratense*	Mountainous species, which tolerate nitrophilous soils and have long dispersal distance
H3	*Aegopodium podagraria, Anthoxanthum odoratum, Arrhenatherum elatius elatius, Crepis pyrenaica, Dactylis glomerata, Deschampsia cespitosa, Festuca rubra, Heracleum sphondylium, Pimpinella major, Plantago lanceolata, Poa pratensis, Ranunculus acris, Rumex arifolius, Taraxacum officinale, Trifolium repens, Trollius europaeus, Vicia cracca*	Mountainous to lowland species found in wet niches and with long dispersal distance
H4	*Aconitum lycoctonum vulparia, Aruncus dioicus, Prenanthes purpurea*	Undergrowth and shadow species that do not tolerate full light
H5	*Achnatherum calamagrostis, Agrostis agrostiflora, Anthericum liliago, Aster bellidiastrum, Briza media, Deschampsia flexuosa, Epilobium dodonaei fleischeri, Festuca acuminata, Festuca flavescens, Festuca laevigata, Festuca marginata gallica, Festuca melanopsis, Festuca paniculata paniculata, Helictotrichon parlatorei, Hugueninia tanacetifolia, Hypericum maculatum, Laserpitium halleri, Laserpitium siler, Leontodon autumnalis, Leontodon hispidus, Luzula sieberi, Phleum alpinum rhaeticum, Pulsatilla alpina, Ranunculus bulbosus, Salvia pratensis, Silene flos-jovis, Stipa eriocaulis eriocaulis, Tolpis staticifolia, Trisetum flavescens*	Mountainous to subalpine species with short dispersal distance and tolerant to dry soils
H6	*Arabis alpina, Avenula pubescens, Brachypodium rupestre, Cacalia alliariae, Calamagrostis varia, Cardamine pentaphyllos, Carex flacca, Chaerophyllum aureum, Chaerophyllum villarsii, Cicerbita alpina, Epilobium angustifolium, Festuca altissima, Gentiana lutea, Hieracium*	Tall plants typical of *megaphorbiaies* that can form undergrowth

	murorum, Hieracium prenanthoides, Knautia dipsacifolia, Laserpitium latifolium, Luzula nivea, Melica nutans, Mercurialis perennis, Milium effusum, Molinia caerulea arundinacea, Oxalis acetosella, Poa nemoralis, Ranunculus aduncus, Saxifraga rotundifolia, Serratula tinctoria, Valeriana officinalis, Viola biflora	
H7	*Cacalia alpina, Hieracium pilosella, Homogyne alpina, Petasites albus, Tussilago farfara*	Plants species found in rocky habitats and undergrowth at all elevations
H8	*Cacalia leucophylla, Cirsium spinosissimum, Gentiana alpina, Murbeckiella pinnatifida pinnatifida, Omalotheca supina, Veratrum lobelianum*	Subalpine to alpine species not usually grazed, which have a short dispersal distance
H9	*Anthoxanthum odoratum nipponicum, Nardus stricta, Poa supina, Silene vulgaris prostrata*	Short subalpine to alpine species with long dispersal distance
H10	*Heracleum sphondylium elegans*	Mountainous species with long dispersal distance and shade tolerant
P1	*Pinus cembra, Pinus sylvestris, Prunus avium, Sorbus aria, Sorbus aucuparia, Sorbus mougeotii*	Thermophilous pioneer trees (deciduous trees and pines)
P2	*Populus tremula, Salix daphnoides*	Small deciduous pioneer trees (e.g. colonising riversides)
P3	*Abies alba, Acer pseudoplatanus, Fraxinus excelsior, Tilia platyphyllos*	Tall forest edge trees
P4	*Larix decidua*	Tall pioneer (larch)
P5	*Fagus sylvatica, Picea abies*	Late succession trees found in wet climates
P6	*Betula pendula, Pinus uncinata*	Intermediate succession trees found in dry climates
P7	*Acer campestre campestre, Acer opalus*	Small forest edge trees
P8	*Betula pubescens*	Small pioneer found in cold climates

Table S3. Drought-related parameters used in FATE-HD. Drought detection thresholds are based on plant functional groups' (PFG) $Din_{1961\text{-}1990}$ distributions and were calculated as $\overline{x} - 1.5 \times SD$ and $\overline{x} - 2.0 \times SD$ for moderate and severe droughts, respectively ($\overline{x}$ and SD standing for mean and standard deviation of $Din_{1961\text{-}1990}$, respectively). 'Drought sensitivity' determines the number of drought years that a PFG must experience before a severe drought produces severe effects (i.e. drought-related mortality). The 'cumulative drought response' determines the number of drought years needed before any type of drought produces severe effects. 'Recovery' is the number of years subtracted to the accumulated drought events during non-drought years and 'moist. pref.' (moisture preference) is the PFG soil moisture preference class. Drought mortality and resprouting proportions (for immediate or post-drought effects) depend on the PFG type, soil moisture class and age, being larger when the soil moisture preference is higher (but not necessarily different for all classes). Post-drought mortality is always lower than immediate drought mortality, and herbaceous and chamaephyte PFGs (except for C4) do not suffer post-drought mortality. As for resprouting proportions, herbaceous PFGs always resprout after severe drought events, but only phanerophytes and shrub chamaephyte (C4) PFGs are able to resprout during drought. Empty cells denote proportions of 0.

	Drought detection thresholds (in mm)		**Cumulative effect thresholds (no. drought events)**				**Drought mortality (immediate)**				**Resprouting (immediate)**				**Drought mortality (post-drought)**				**Resprouting (post-drought)**			
PFG	**Moderate**	**Severe**	**Drought sensitivity**	**Cumulative drought response**	**Recovery (years)**	**Moist. pref.**	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4	Age 1	Age 2	Age 3	Age 4
C1	-1679	-1891	2	3	2	0	0.1													1.0	1.0	1.0
C2	-1416	-1621	2	3	2	2	0.2			0.1										1.0	1.0	1.0
C3	-1515	-1737	2	3	2	2	0.2			0.1										1.0	1.0	1.0
C4	-1724	-1927	3	5	1	1	0.1			0.1			0.4	0.4						0.1	0.4	0.4

C5	-1674	-1885	2	3	2	0	0.1											1.0	1.0	1.0
C6	-1360	-1563	2	3	2	2	0.2			0.1								1.0	1.0	1.0
H1	-1431	-1637	1	2	2	2	0.2			0.1								1.0	1.0	1.0
H2	-1626	-1836	1	2	2	2	0.2			0.1								1.0	1.0	1.0
H3	-1681	-1885	1	2	2	2	0.2			0.1								1.0	1.0	1.0
H4	-1487	-1695	1	2	2	2	0.2			0.1								1.0	1.0	1.0
H5	-1676	-1888	1	2	2	1	0.2			0.1								1.0	1.0	1.0
H6	-1630	-1842	1	2	2	2	0.1			0.1								1.0	1.0	1.0
H7	-1620	-1847	1	2	2	2	0.2			0.1								1.0	1.0	1.0
H8	-1264	-1464	1	2	2	3	0.2			0.1								1.0	1.0	1.0
H9	-1387	-1586	1	2	2	3	0.4	0.1	0.1	0.2								1.0	1.0	1.0
H10	-1458	-1664	1	2	2	2	0.4	0.1	0.1	0.2								1.0	1.0	1.0
P1	-1673	-1883	3	5	1	0	0.1					0.4	0.4					0.1	0.4	0.4
P2	-1630	-1810	3	5	1	2	0.2			0.1	0.1	0.5	0.5	0.1				0.4	0.4	0.4
P3	-1637	-1838	3	5	1	2	0.2			0.1	0.1	0.5	0.5	0.1				0.4	0.4	0.4
P4	-1451	-1632	3	5	1	3	0.4	0.1	0.1	0.2	0.4	0.8	0.8	0.2	0.1	0.1	0.1	0.4	0.5	0.5
P5	-1525	-1734	3	5	1	1	0.1			0.1		0.4	0.4					0.1	0.4	0.4
P6	-1562	-1775	3	5	1	1	0.1			0.1		0.4	0.4					0.1	0.4	0.4
P7	-1683	-1862	3	5	1	0	0.1					0.4	0.4					0.1	0.4	0.4
P8	-1550	-1769	3	5	1	2	0.2			0.1	0.1	0.5	0.5	0.1				0.4	0.4	0.4

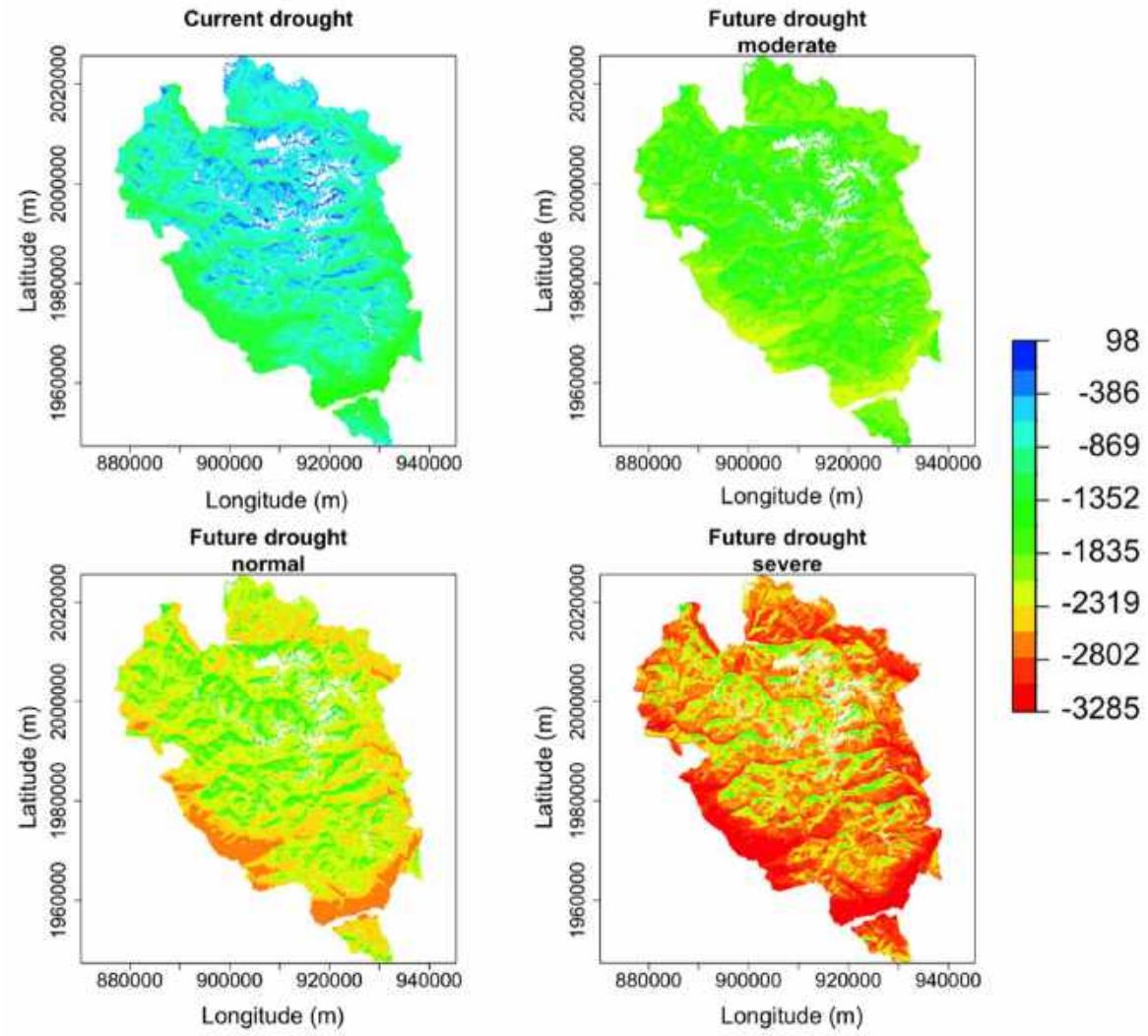

Figure S1. Current and future drought intensity (*Din*) maps. Drought events were simulated using *Din* (minimum yearly moisture index) maps that were fed into FATE-HD on a yearly basis. Current *Din* values were calculated as the average *Din* per pixel across years 1961-1990. Future 'normal' *Din* values were calculated from climate predictions for 2080 (following the A1B scenario; see Appendix S1 for further details), which were increased by 20% to calculate future 'moderate' *Din* values, or decreased by the same amount to calculate future 'severe' *Din* values (note that lower *Din* values cause more severe droughts).

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