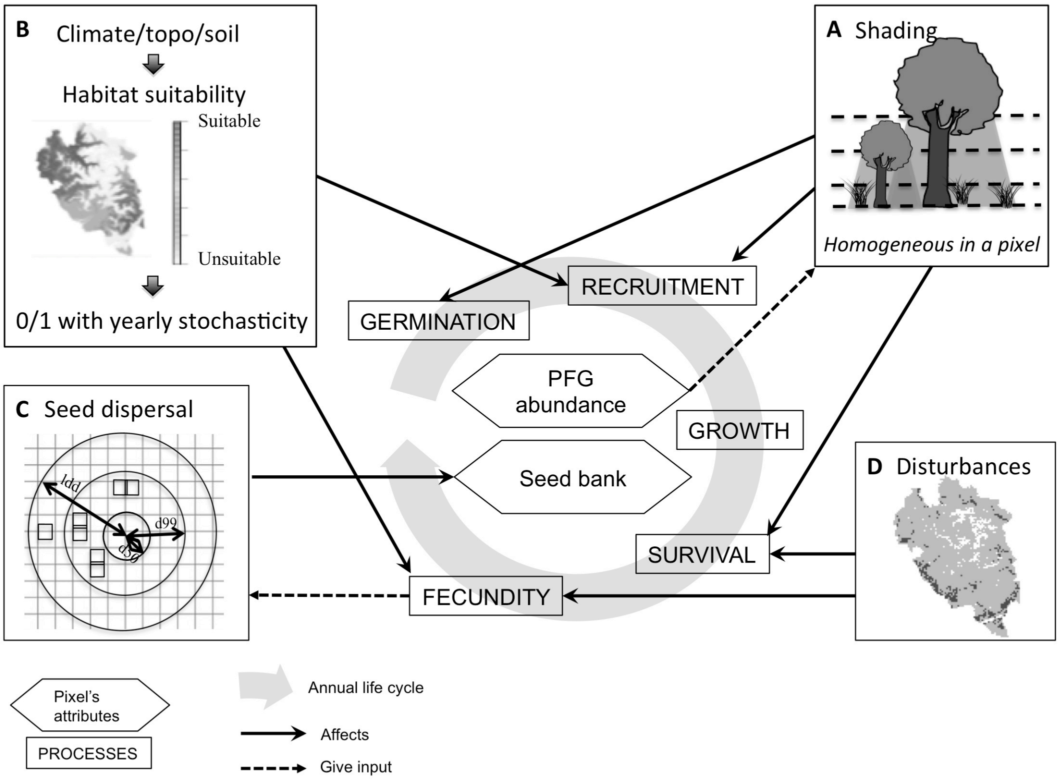
Anticipating the spatio-temporal response of plant diversity and vegetation structure to climate and land use change in a protected area, Boulangeat, I., Georges, D., Dentant, C., Bonet, R., Van Es, J., Abdulhak, S., Zimmermann, N.E., Thuiller, W.

Appendix A1: Model and parameters

The FATE-HD model with the same parameterization is presented and validated in Boulangeat *et al.* (in press).

a - THE MODEL



(A) In each pixel, PFG cohorts are located in height strata. The number of strata and the transition heights are free parameter that can be set according to the vegetation under investigation. The available light in each stratum is calculated according to the total abundance of the PFGs across all the upper strata and then converted to three classes (shade, half-shade, and full high) according to the respective abundance thresholds: 3,000; 7,000; 10,000. Shade tolerance is given as binary parameters for these three classes. Two other PFG specific parameters are used: (1) maximum abundance corresponds to the total shade that a PFG will produce for the lower strata, when its demography is a equilibrium (2) the relative shade of immature versus mature allows weighting the abundance of younger cohort (e.g. for trees) in the calculation of the available light.

(B) Each year, the habitat suitability maps with values ranging from 0 to 1 are converted to binary filters according to a threshold randomly drawn from a uniform law. The annual variability in environmental conditions thereby affects all PFGs in the same way, representing “good” and “bad” years for the vegetation.

(C) The seed dispersal model determines seed influx in each pixel, which depends on the distance from the sources. 50% of the seeds fall uniformly in the immediate neighborhood of adjacent cells. 49% of the seeds are distributed further, with the same concentration as in the immediate neighborhood but by pairs of pixels. This dispersal by packages simulates the spatial autocorrelation of dispersed seeds and avoids meaningless dilutions. Finally, 1% of the seeds fall into a random long distance pixel. See Boulangeat *et al.* (in press) for comparison with kernel functions.

(D) Each disturbance removes a percentage of each cohort abundance, or affect the seed bank, and may impede seed production. The sensitivity of different cohorts are given as parameters for defined age class, vegetation height, and PFG.

Germination: For each light class (shade, half-shade, full light), the germination rate of a PFG is given as a proportion of the germination under optimal conditions.

Recruitment: Recruitment occurs when the habitat filter is drawn as favorable and the light conditions are suitable to the PFG. The number of seedlings S produced in a favorable environment is determined so that PFG demography is stable (death=recruitment) when the PFG reaches its maximum abundance. It therefore depends on the number of years the PFG will produce seeds and the maximum abundance of the PFG:

$$S = G*A_{max} / (L-M),$$

where G is the number of germinants, A_{max} is the maximum abundance of mature PFG, L the longevity and M the maturity age.

Growth: A set of fixed parameters defines the ages at which each PFG reaches each stratum.

Survival: A PFG cohort dies when its reach its longevity, when it is disturbed, or when light conditions are no longer favorable.

Fecundity: Fecundity is considered as relative to an unknown maximum fecundity reached when mature PFG abundance equals to the maximum abundance parameter of the PFG. It is proportional to the abundance of mature PFG in a pixel. No seeds are produced when the habitat is not favorable.

b – THE PLANT FUNCTIONAL GROUPS

List of the 24 plant functional groups used in the simulations and the species which determined these groups. H1 to H10 represent herbaceous plants (mostly Hemicryptophyts). C1 to C6 represent Chamaephyts. P1 to P8 represent Phanerophyts. The interpretation was made *a posteriori* based on expert knowledge of determinant species and the PFG's average attributes.

PFG	Species list
H1 Alpine species (which do not tolerate shade, and have a short dispersal distance)	*Oxyria digyna, Polygonum viviparum, Ranunculus glacialis, Ranunculus kuepferi, Ranunculus montanus, Geum montanum, Geum reptans, Potentilla aurea, Potentilla erecta, Potentilla grandiflora, Saxifraga stellaris robusta, Linaria alpina alpina, Carex capillaris, Carex curvula, Carex foetida, Carex frigida, Carex nigra, Carex panicea, Carex rupestris, Eriophorum latifolium, Eriophorum polystachion, Eriophorum scheuchzeri, Kobresia myosuroides, Trichophorum cespitosum, Juncus alpinoarticulatus alpinoarticulatus, Juncus trifidus, Luzula alpinopilosa, Agrostis alpina, Agrostis rupestris, Alopecurus alpinus, Avenula versicolor versicolor, Festuca halleri halleri, Festuca quadriflora, Phleum alpinum, Poa alpina, Poa cenisia, Poa laxa, Doronicum grandiflorum, Trisetum distichophyllum, Athamanta cretensis, Hieracium glaciale, Leontodon montanus, Leontodon pyrenaicus helveticus, Taraxacum alpinum, Campanula cochleariifolia, Astragalus alpinus, Lotus alpinus, Trifolium alpinum, Trifolium pallescens, Achillea nana, Gentiana punctata, Arnica montana, Epilobium anagallidifolium, Plantago alpina.*
H2 Mountainous species which tolerate nitrophilous soils and have a long dispersal distance	*Rumex acetosa, Rumex pseudalpinus, Fragaria vesca, Galium aparine, Galium verum, Carex caryophyllea, Carex sempervirens, Agrostis capillaris, Agrostis stolonifera, Festuca nigrescens, Sesleria caerulea, Astrantia major, Leucanthemum vulgare, Carum carvi, Meum athamanticum, Chenopodium bonus-henricus, Lathyrus pratensis, Lotus corniculatus, Onobrychis montana, Trifolium montanum, Trifolium pratense, Geranium sylvaticum, Plantago media.*
H3 Mountainous to lowland species found in wet niches and which have a long dispersal distance	*Ranunculus acris, Trollius europaeus, Urtica dioica, Aegopodium podagraria, Anthoxanthum odoratum, Arrhenatherum elatius elatius, Dactylis glomerata, Deschampsia cespitosa, Festuca rubra, Crepis pyrenaica, Poa pratensis, Taraxacum officinale, Heracleum sphondylium, Pimpinella major, Trifolium repens, Vicia cracca, Plantago lanceolata.*
H4 Undergrowth and shadow species which do not tolerate full light	*Aconitum lycoctonum vulparia, Aruncus dioicus, Dryopteris dilatata, Dryopteris filix-mas, Athyrium filix-femina, Prenanthes purpurea.*

H5 Mountainous to subalpine species which have a short dispersal distance and tolerate dry soils	*Pulsatilla alpina, Ranunculus bulbosus, Anthericum liliago, Luzula sieberi, Achnatherum calamagrostis, Agrostis agrostiflora, Briza media, Bromus erectus, Deschampsia flexuosa, Festuca acuminata, Festuca flavescens, Festuca laevigata, Festuca marginata gallica, Koeleria vallesiana, Phleum alpinum rhaeticum, Stipa eriocaulis eriocaulis, Trisetum flavescens, Leontodon autumnalis, Leontodon hispidus, Tolpis staticifolia, Festuca melanopsis, Hugueninia tanacetifolia, Laserpitium halleri, Laserpitium siler, Silene flos-jovis, Hypericum maculatum, Salvia pratensis, Epilobium dodonaei fleischeri.*
H6 Tall plants typical of megaphorbiaies which can form undergrowth	*Ranunculus aduncus, Cacalia alliariae, Saxifraga rotundifolia, Valeriana officinalis, Carex flacca, Cicerbita alpina, Luzula nivea, Avenula pubescens, Brachypodium rupestre, Calamagrostis varia, Festuca altissima, Melica nutans, Milium effusum, Molinia caerulea arundinacea, Poa nemoralis, Hieracium murorum, Hieracium prenanthoides, Senecio ovatus ovatus, Chaerophyllum aureum, Chaerophyllum villarsii, Cardamine pentaphyllos, Laserpitium latifolium, Knautia dipsacifolia, Mercurialis perennis, Gentiana lutea, Epilobium angustifolium.*
H7 Plants species found in rocky habitats and undergrowth at all elevations	*Cacalia alpina, Cryptogramma crispa, Asplenium ramosum, Asplenium septentrionale septentrionale, Asplenium trichomanes quadrivalens, Equisetum arvense, Cystopteris fragilis, Gymnocarpium robertianum, Woodsia alpina, Hieracium pilosella, Homogyne alpina, Petasites albus, Tussilago farfara.*
H8 Subalpine to alpine species not usually grazed and which have a short dispersal distance	*Cacalia leucophylla, Cirsium spinosissimum, Omalotheca supina, Murbeckiella pinnatifida pinnatifida, Gentiana alpina.*
H9 Short subalpine to alpine species which have long dispersal distance	*Anthoxanthum odoratum nipponicum, Nardus stricta, Poa supina, Silene vulgaris prostrata.*
H10 Mountainous species which have a long dispersal distance and tolerate shade	*Heracleum sphondylium elegans.*
C1 Thermophilous chamaephytes which have a long dispersal distance	*Rumex acetosella, Cotoneaster integerrimus, Potentilla neumanniana, Rubus idaeus, Rubus saxatilis, Valeriana montana, Lonicera caerulea, Helianthemum grandiflorum, Helianthemum nummularium, Anthyllis montana, Hippocrepis comosa, Achillea millefolium, Stachys recta, Teucrium chamaedrys, Thymus pulegioides.*
C2 Alpine and subalpine chamaephytes species	*Rumex scutatus, Salix hastata, Saxifraga aizoides, Saxifraga oppositifolia, Helictotrichon sedenense sedenense, Leucanthemopsis alpina, Cerastium alpinum, Cerastium cerastoides, Cerastium latifolium, Cerastium pedunculatum, Cerastium uniflorum, Sempervivum arachnoideum, Vaccinium uliginosum microphyllum, Antennaria dioica, Thymus polytrichus, Artemisia umbelliformis eriantha, Artemisia umbelliformis umbelliformis.*

C3 Chamaephytes which have a short dispersal distance	*Androsace pubescens, Androsace vitaliana, Primula hirsuta, Primula latifolia, Dryas octopetala, Salix herbacea, Salix reticulata, Salix retusa, Saxifraga bryoides, Saxifraga exarata, Eritrichium nanum nanum, Noccaea rotundifolia, Pritzelago alpina alpina, Gypsophila repens, Sagina glabra, Sagina saginoides, Silene acaulis, Silene acaulis bryoides, Sedum album, Sedum alpestre, Sedum dasyphyllum, Empetrum nigrum hermaphroditum, Rhododendron ferrugineum, Globularia cordifolia.*
C4 Tall shrubs	*Amelanchier ovalis, Crataegus monogyna, Rosa pendulina, Salix laggeri, Juniperus communis, Alnus alnobetula, Lonicera xylosteum, Cornus sanguinea, Corylus avellana, Ribes petraeum.*
C5 Mountainous to subalpine heath found in dry climates	*Arctostaphylos uva-ursi crassifolius, Calluna vulgaris, Hippocrepis emerus.*
C6 Mountainous to subalpine heath found in wet climates	*Vaccinium myrtillus, Vaccinium vitis-idaea vitis-idaea.*
P1 Thermophilous pioneer trees (deciduous trees and pines)	*Prunus avium, Sorbus aria, Sorbus aucuparia, Sorbus mougeotii, Pinus cembra, Pinus sylvestris.*
P2 Small deciduous pioneer trees (e.g. colonising riversides)	*Populus tremula, Salix daphnoides.*
P3 Tall forest edge trees	*Tilia platyphyllos, Acer pseudoplatanus Fraxinus excelsior.*
P4 Tall pioneer	*Larix decidua.*
P5 Late succession trees found in wet climates	*Picea abies, Fagus sylvatica.*
P6 Intermediate succession trees found in dry climates	*Pinus uncinata, Betula pendula.*
P7 Small forest edge trees	*Acer opalus, Acer campestre campestre.*
P8 Small pioneer found in cold climates	*Betula alba.*

C – THE PARAMETERIZATION

Shade tolerance

We used five strata in our simulations (0-1.5m; 1.5-4m; 4-10m; 10-20m; above 20m). Maximum shade was set to 3,000 for PFGs which remain in the first stratum only, to 7,000 for PFG which can reach the second stratum, and to 10,000 for taller PFGs. The relative shade of immature plants has been set to 100% for herbaceous, 50% for small trees or shrubs (C4; P2; P7; P8) and 10% for other trees. Tolerance to different light levels was parameterized according to Flora Indicativa (Landolt *et al.* 2010).

	H1	**H10**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**
Maximum shade	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Relative shade of immature vs mature plants (%)	100	100	100	100	100	100	100	100	100	100
Tolerance of germinants to shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of germinants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of germinants to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tolerance of immature plants to shade	no	yes	no	no	yes	no	yes	yes	no	no
Tolerance of immature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of immature plants to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tolerance of mature plants to shade	no	yes	no	no	yes	no	yes	yes	no	no
Tolerance of matures to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of matures to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Maximum shade	3000	3000	3000	7000	3000	3000	10000	10000	10000	10000	10000	10000	10000	10000
Relative shade of immature vs mature plants (%)	100	100	100	50	100	100	10	50	10	10	10	10	50	50
Tol. of germinants to shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of germinants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of germinants to full light	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no	yes
Tol. of immature plants to shade	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no
Tol. of immature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of immature plants to full light	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tol. of mature plants to shade	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no
Tol. of mature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of mature plants to full light	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

Demographic parameters

Relative germination performance was chosen with the aim of decreasing germination performance in response to increasing shade for herbaceous plants (90%, 80%, 50%), and ensuring the germination performance of woody plants is unaffected by light conditions (90%, 90%, 90%), according to the results obtained by Milberg *et al.* (2000).

Trees and shrubs' ages at which they reach each stratum were determined using a growth rate equation involving maturity age, life span, relative shade of immature, and maximum plant canopy height. H (height) is expressed as a function of A (age) as:

$$H = H_{max}*(1\text{-exp}(-k*A))$$

where H_{max} is the canopy height and $k = -\frac{\log(1-H_{imm})}{\frac{1}{2}*A_{mat}}$ with H_{imm} as the relative size of immature versus mature plants and A_{mat} the maturity age.

PFG longevities and maturity ages were given by expert knowledge from the Ecrins National park and the literature (ANDROSACE database, Boulangeat *et al.* 2012).

	H1	H10	H2	H3	H4	H5	H6	H7	H8	H9
Maturity age (year)	4	4	3	3	4	4	4	4	4	4
Life span (year)	11	9	10	9	7	7	8	7	8	9

	C1	C2	C3	C4	C5	C6	P1	P2	P3	P4	P5	P6	P7	P8
Maturity age (year)	5	4	6	10	8	8	15	15	18	15	25	20	15	15
Life span (year)	27	19	45	158	39	92	193	177	351	600	450	160	310	100

Habitat suitability

The habitat suitability models were calibrated over the whole French Alps in order to increase the robustness of projections into the future climatic conditions (Barbet-Massin *et al*. 2012).

We used species observations from the database of the Conservatoire Botanique National

Alpin (CBNA), which includes all records of the Ecrins National Park and additional records in the entire region of the French Alps (Boulangeat *et al.* 2012). We used the 15,000 community plots of the database for which the exhaustive list of species was recorded to infer true absences. The observation of one representative species of a PFG determined its presence. A PFG true absence was considered where none of its determining species were observed in a community plot. We used seven environmental variables to model the large-scale abiotic constraints for each PFG: (1) the slope angle**,** taken from the French Digital Elevation Model with 50x50m resolution, made by the IGN-France (http://professionnels.ign.fr/bdalti) (2) the percentage of calcareous soil was calculated from the European Soil Database http://eusoils.jrc.ec.europa.eu/data.html with a 1km resolution. (see also Dullinger *et al.* 2012). (3) isothermality, (4) temperature seasonality, (5) temperature annual range, (6) mean temperature of coldest quarter, and (7) annual precipitation. These five bioclimatic variables are known to influence the physiology of species in the Alps (Körner 2004) and their pairwise correlations were low. Temperature and precipitation from the 1 km Worldclim climate grids available online were downscaled to a resolution of 100m, using a specific method that was developed for Mountainous areas (Dullinger *et al.* 2012).

Habitat suitability models were built using the *biomod2* package (Thuiller *et al.* 2009) in R (2011) and using five algorithms from different families: (1) Generalized Linear Model, (2) Boosted Regression Trees, (3) Generalized Additive Model, (4) Multivariate Adaptive Regression Splines and (5) Random Forest. We weighted the presence and absence of each PFT to give a prevalence of 0.5 in order to be able to compare the models whatever the PFG distribution (narrow, wide spread, etc.)._We used a ten-fold cross validation procedure with 70% of the data for calibration and 30% for evaluation with True Skill Statistics (TSS, Allouche *et al.* 2006). All models from different repetitions and algorithms were combined using an ensemble forecasting strategy: (1) All models gave binary projections using the threshold maximising the TSS in the evaluation procedures. (2) These projections were averaged, each one having its TSS score as weight. (4) The average projection were rescaled to fall between 0 and 1, which is the percentage of agreement between models.

Seed dispersal

Dispersal classes were given as the median of representative species values. We found most of our species in Vittoz *et al.* (2007). Missing data were given by local experts (J. Van Es, R. Douzet, P. Vittoz) following the same protocol as in Vittoz *et al.* (2007). The two first distance parameters are reported from Vittoz *et al.* (2007). Long distance parameter was set according to the dispersal class following Engler & Guisan (2009).

PFG	Dispersal class	Maximal distance for 50% of seeds (m)	Maximal distance for 99% of seeds (m)	Long distance dispersal (m)
C1	6	400	1500	10000
C2	4	40	150	5000
C3	1	0.1	1	1000
C4	6	400	1500	10000
C5	6	400	1500	10000
C6	7	500	5000	10000
H1	3	2	15	1000
H10	7	500	5000	10000
H2	6	400	1500	10000
H3	7	500	5000	10000
H4	3	2	15	1000
H5	3	2	15	1000
H6	3	2	15	1000
H7	5	100	500	5000
H8	3	2	15	1000
H9	7	500	5000	10000
P1	6	400	1500	10000
P2	5	100	500	5000
P3	4	2	15	1000
P4	6	400	1500	10000
P5	6	400	1500	10000
P6	4	40	150	5000
P7	4	40	150	5000
P8	4	40	150	5000

Disturbances

Responses to mowing and grazing were parameterized by the experts of the National Park.

Mowing parameters table. Mowing was assumed to include the removal of all trees in the field. Other PFG were partly killed or had their mature plants not producing seeds.

Herbaceous			**Chamaephytes**			**Phanerophytes**	
Juveniles were unaffected Senescents (longevity – 2) were all killed			One year old individuals were not affected All other juveniles were killed Senescents (longevity – 2) were all killed			Trees above 1.5m were all killed, assuming that mowing is associated with destruction of trees	
PFG	*Mature plants that did not produced seeds*	*Mature plants that were killed*	*PFG*	*Mature plants that did not produced seeds*	*Mature plants killed*	*PFG*	*Juveniles of one year that were killed*
H1	50%	40%	C1	50%	50%	P1	80%
H2	90%	0%	C2	50%	50%	P2	80%
H3	90%	0%	C3	-	100%	P3	100%
H4	-	100%	C4	-	100%	P4	100%
H5	90%	0%	C5	-	100%	P5	100%
H6	50%	40%	C6	-	100%	P6	100%
H7	50%	40%				P7	100%
H8	50%	40%				P8	100%
H9	90%	0%					
H10	90%	0%					

Grazing parameters for herbaceous and herbaceous chamaephytes. C3, C5, H4, H7 and H8 were unaffected. 3 different types of grazing were differentiated: G1= light grazing; G2= extensive grazing; G3= intensive grazing. The parameterisation was carried out with PNE experts and according to the palatability of the determinant species of each PFG (Jouglet *et al.*)

	C6		**C1, C2, H1, H2, H3, H5, H6, H9, H10**	
G1	*Juv.*	10% killed	*Juv.*	10% killed
	Mat.	10% no seeds	*Mat.*	50% no seeds
	Sen.	10% respr.	*Sen.*	10% respr.
G2	*Juv.*	10% killed	*Juv.*	50% killed
	Mat.	90% no seeds	*Mat.*	100% no seeds
	Sen.	50% respr.; 10% killed	*Sen.*	50% respr.; 10% killed
G3	*Juv.*	50% killed	*Juv.*	90% killed
	Mat.	100% no seeds	*Mat.*	90% no seeds; 10% killed
	Sen.	50% respr.; 10% killed	*Sen.*	50% respr.; 50% killed

Grazing parameters for phanerophytes and shrub chamaephytes. 3 different types of grazing were differentiated: G1= light grazing; G2= extensive grazing; G3= intensive grazing. Individuals above 1.5m were unaffected. Percentages represent the proportion of killed plants.

	Age classes	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**C4**
G1	*1 year old*	100%	100%	80%	100%	0%	-	40%	100%	100%
	<1.5m	-	-	-	-	-	-	-	-	-
G2	*1 year old*	100%	100%	80%	100%	-	-	40%	100%	100%
	<1.5m	-	-	-	50%	-	-	-	-	-
G3	*1 year old*	100%	100%	80%	100%	40%	100%	40%	100%	100%
	<1.5m	40%	40%	10%	80%	10%	40%	-	-	40%

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weighting the abundance of younger cohort (e.g. for trees) in the calculation of the available light.

(B) Each year, the habitat suitability maps with values ranging from 0 to 1 are converted to binary filters according to a threshold randomly drawn from a uniform law. The annual variability in environmental conditions thereby affects all PFGs in the same way, representing "good" and "bad" years for the vegetation.

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(D) Each disturbance removes a percentage of each cohort abundance, or affect the seed bank, and may impede seed production. The sensitivity of different cohorts are given as parameters for defined age class, vegetation height, and PFG.

Germination: For each light class (shade, half-shade, full light), the germination rate of a PFG is given as a proportion of the germination under optimal conditions.

Recruitment: Recruitment occurs when the habitat filter is drawn as favorable and the light conditions are suitable to the PFG. The number of seedlings S produced in a favorable environment is determined so that PFG demography is stable (death=recruitment) when the PFG reaches its maximum abundance. It therefore depends on the number of years the PFG will produce seeds and the maximum abundance of the PFG:

$$S = G*A_{max} / (L-M),$$

where G is the number of germinants, A_{max} is the maximum abundance of mature PFG, L the longevity and M the maturity age.

Growth: A set of fixed parameters defines the ages at which each PFG reaches each stratum.

Survival: A PFG cohort dies when its reach its longevity, when it is disturbed, or when light conditions are no longer favorable.

Fecundity: Fecundity is considered as relative to an unknown maximum fecundity reached when mature PFG abundance equals to the maximum abundance parameter of the PFG. It is proportional to the abundance of mature PFG in a pixel. No seeds are produced when the habitat is not favorable.

b – THE PLANT FUNCTIONAL GROUPS

List of the 24 plant functional groups used in the simulations and the species which determined these groups. H1 to H10 represent herbaceous plants (mostly Hemicryptophyts). C1 to C6 represent Chamaephyts. P1 to P8 represent Phanerophyts. The interpretation was made *a posteriori* based on expert knowledge of determinant species and the PFG's average attributes.

PFG	Species list
H1 Alpine species (which do not tolerate shade, and have a short dispersal distance)	*Oxyria digyna, Polygonum viviparum, Ranunculus glacialis, Ranunculus kuepferi, Ranunculus montanus, Geum montanum, Geum reptans, Potentilla aurea, Potentilla erecta, Potentilla grandiflora, Saxifraga stellaris robusta, Linaria alpina alpina, Carex capillaris, Carex curvula, Carex foetida, Carex frigida, Carex nigra, Carex panicea, Carex rupestris, Eriophorum latifolium, Eriophorum polystachion, Eriophorum scheuchzeri, Kobresia myosuroides, Trichophorum cespitosum, Juncus alpinoarticulatus alpinoarticulatus, Juncus trifidus, Luzula alpinopilosa, Agrostis alpina, Agrostis rupestris, Alopecurus alpinus, Avenula versicolor versicolor, Festuca halleri halleri, Festuca quadriflora, Phleum alpinum, Poa alpina, Poa cenisia, Poa laxa, Doronicum grandiflorum, Trisetum distichophyllum, Athamanta cretensis, Hieracium glaciale, Leontodon montanus, Leontodon pyrenaicus helveticus, Taraxacum alpinum, Campanula cochleariifolia, Astragalus alpinus, Lotus alpinus, Trifolium alpinum, Trifolium pallescens, Achillea nana, Gentiana punctata, Arnica montana, Epilobium anagallidifolium, Plantago alpina.*
H2 Mountainous species which tolerate nitrophilous soils and have a long dispersal distance	*Rumex acetosa, Rumex pseudalpinus, Fragaria vesca, Galium aparine, Galium verum, Carex caryophyllea, Carex sempervirens, Agrostis capillaris, Agrostis stolonifera, Festuca nigrescens, Sesleria caerulea, Astrantia major, Leucanthemum vulgare, Carum carvi, Meum athamanticum, Chenopodium bonus-henricus, Lathyrus pratensis, Lotus corniculatus, Onobrychis montana, Trifolium montanum, Trifolium pratense, Geranium sylvaticum, Plantago media.*
H3 Mountainous to lowland species found in wet niches and which have a long dispersal distance	*Ranunculus acris, Trollius europaeus, Urtica dioica, Aegopodium podagraria, Anthoxanthum odoratum, Arrhenatherum elatius elatius, Dactylis glomerata, Deschampsia cespitosa, Festuca rubra, Crepis pyrenaica, Poa pratensis, Taraxacum officinale, Heracleum sphondylium, Pimpinella major, Trifolium repens, Vicia cracca, Plantago lanceolata.*
H4 Undergrowth and shadow species which do not tolerate full light	*Aconitum lycoctonum vulparia, Aruncus dioicus, Dryopteris dilatata, Dryopteris filix-mas, Athyrium filix-femina, Prenanthes purpurea.*

H5 Mountainous to subalpine species which have a short dispersal distance and tolerate dry soils	*Pulsatilla alpina, Ranunculus bulbosus, Anthericum liliago, Luzula sieberi, Achnatherum calamagrostis, Agrostis agrostiflora, Briza media, Bromus erectus, Deschampsia flexuosa, Festuca acuminata, Festuca flavescens, Festuca laevigata, Festuca marginata gallica, Koeleria vallesiana, Phleum alpinum rhaeticum, Stipa eriocaulis eriocaulis, Trisetum flavescens, Leontodon autumnalis, Leontodon hispidus, Tolpis staticifolia, Festuca melanopsis, Hugueninia tanacetifolia, Laserpitium halleri, Laserpitium siler, Silene flos-jovis, Hypericum maculatum, Salvia pratensis, Epilobium dodonaei fleischeri.*
H6 Tall plants typical of megaphorbiaies which can form undergrowth	*Ranunculus aduncus, Cacalia alliariae, Saxifraga rotundifolia, Valeriana officinalis, Carex flacca, Cicerbita alpina, Luzula nivea, Avenula pubescens, Brachypodium rupestre, Calamagrostis varia, Festuca altissima, Melica nutans, Milium effusum, Molinia caerulea arundinacea, Poa nemoralis, Hieracium murorum, Hieracium prenanthoides, Senecio ovatus ovatus, Chaerophyllum aureum, Chaerophyllum villarsii, Cardamine pentaphyllos, Laserpitium latifolium, Knautia dipsacifolia, Mercurialis perennis, Gentiana lutea, Epilobium angustifolium.*
H7 Plants species found in rocky habitats and undergrowth at all elevations	*Cacalia alpina, Cryptogramma crispa, Asplenium ramosum, Asplenium septentrionale septentrionale, Asplenium trichomanes quadrivalens, Equisetum arvense, Cystopteris fragilis, Gymnocarpium robertianum, Woodsia alpina, Hieracium pilosella, Homogyne alpina, Petasites albus, Tussilago farfara.*
H8 Subalpine to alpine species not usually grazed and which have a short dispersal distance	*Cacalia leucophylla, Cirsium spinosissimum, Omalotheca supina, Murbeckiella pinnatifida pinnatifida, Gentiana alpina.*
H9 Short subalpine to alpine species which have long dispersal distance	*Anthoxanthum odoratum nipponicum, Nardus stricta, Poa supina, Silene vulgaris prostrata.*
H10 Mountainous species which have a long dispersal distance and tolerate shade	*Heracleum sphondylium elegans.*
C1 Thermophilous chamaephytes which have a long dispersal distance	*Rumex acetosella, Cotoneaster integerrimus, Potentilla neumanniana, Rubus idaeus, Rubus saxatilis, Valeriana montana, Lonicera caerulea, Helianthemum grandiflorum, Helianthemum nummularium, Anthyllis montana, Hippocrepis comosa, Achillea millefolium, Stachys recta, Teucrium chamaedrys, Thymus pulegioides.*
C2 Alpine and subalpine chamaephytes species	*Rumex scutatus, Salix hastata, Saxifraga aizoides, Saxifraga oppositifolia, Helictotrichon sedenense sedenense, Leucanthemopsis alpina, Cerastium alpinum, Cerastium cerastoides, Cerastium latifolium, Cerastium pedunculatum, Cerastium uniflorum, Sempervivum arachnoideum, Vaccinium uliginosum microphyllum, Antennaria dioica, Thymus polytrichus, Artemisia umbelliformis eriantha, Artemisia umbelliformis umbelliformis.*

C3 Chamaephytes which have a short dispersal distance	*Androsace pubescens, Androsace vitaliana, Primula hirsuta, Primula latifolia, Dryas octopetala, Salix herbacea, Salix reticulata, Salix retusa, Saxifraga bryoides, Saxifraga exarata, Eritrichium nanum nanum, Noccaea rotundifolia, Pritzelago alpina alpina, Gypsophila repens, Sagina glabra, Sagina saginoides, Silene acaulis, Silene acaulis bryoides, Sedum album, Sedum alpestre, Sedum dasyphyllum, Empetrum nigrum hermaphroditum, Rhododendron ferrugineum, Globularia cordifolia.*
C4 Tall shrubs	*Amelanchier ovalis, Crataegus monogyna, Rosa pendulina, Salix laggeri, Juniperus communis, Alnus alnobetula, Lonicera xylosteum, Cornus sanguinea, Corylus avellana, Ribes petraeum.*
C5 Mountainous to subalpine heath found in dry climates	*Arctostaphylos uva-ursi crassifolius, Calluna vulgaris, Hippocrepis emerus.*
C6 Mountainous to subalpine heath found in wet climates	*Vaccinium myrtillus, Vaccinium vitis-idaea vitis-idaea.*
P1 Thermophilous pioneer trees (deciduous trees and pines)	*Prunus avium, Sorbus aria, Sorbus aucuparia, Sorbus mougeotii, Pinus cembra, Pinus sylvestris.*
P2 Small deciduous pioneer trees (e.g. colonising riversides)	*Populus tremula, Salix daphnoides.*
P3 Tall forest edge trees	*Tilia platyphyllos, Acer pseudoplatanus Fraxinus excelsior.*
P4 Tall pioneer	*Larix decidua.*
P5 Late succession trees found in wet climates	*Picea abies, Fagus sylvatica.*
P6 Intermediate succession trees found in dry climates	*Pinus uncinata, Betula pendula.*
P7 Small forest edge trees	*Acer opalus, Acer campestre campestre.*
P8 Small pioneer found in cold climates	*Betula alba.*

C – THE PARAMETERIZATION

Shade tolerance

We used five strata in our simulations (0-1.5m; 1.5-4m; 4-10m; 10-20m; above 20m). Maximum shade was set to 3,000 for PFGs which remain in the first stratum only, to 7,000 for PFG which can reach the second stratum, and to 10,000 for taller PFGs. The relative shade of immature plants has been set to 100% for herbaceous, 50% for small trees or shrubs (C4; P2; P7; P8) and 10% for other trees. Tolerance to different light levels was parameterized according to Flora Indicativa (Landolt *et al.* 2010).

	H1	**H10**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**
Maximum shade	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Relative shade of immature vs mature plants (%)	100	100	100	100	100	100	100	100	100	100
Tolerance of germinants to shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of germinants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of germinants to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tolerance of immature plants to shade	no	yes	no	no	yes	no	yes	yes	no	no
Tolerance of immature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of immature plants to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tolerance of mature plants to shade	no	yes	no	no	yes	no	yes	yes	no	no
Tolerance of matures to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tolerance of matures to full light	yes	yes	yes	yes	no	yes	yes	yes	yes	yes

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Maximum shade	3000	3000	3000	7000	3000	3000	10000	10000	10000	10000	10000	10000	10000	10000
Relative shade of immature vs mature plants (%)	100	100	100	50	100	100	10	50	10	10	10	10	50	50
Tol. of germinants to shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of germinants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of germinants to full light	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no	yes
Tol. of immature plants to shade	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no
Tol. of immature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of immature plants to full light	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	yes	yes	yes	yes
Tol. of mature plants to shade	no	no	no	yes	yes	yes	yes	yes	yes	no	yes	no	yes	no
Tol. of mature plants to half-shade	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Tol. of mature plants to full light	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes

Demographic parameters

Relative germination performance was chosen with the aim of decreasing germination performance in response to increasing shade for herbaceous plants (90%, 80%, 50%), and ensuring the germination performance of woody plants is unaffected by light conditions (90%, 90%, 90%), according to the results obtained by Milberg *et al.* (2000).

Trees and shrubs' ages at which they reach each stratum were determined using a growth rate equation involving maturity age, life span, relative shade of immature, and maximum plant canopy height. H (height) is expressed as a function of A (age) as:

$$H = H_{max} * (1 - \exp(-k * A))$$

where H_{max} is the canopy height and $k = -\frac{\log(1 - H_{imm})}{\frac{1}{2} * A_{mat}}$ with H_{imm} as the relative size of immature versus mature plants and A_{mat} the maturity age.

PFG longevities and maturity ages were given by expert knowledge from the Ecrins National park and the literature (ANDROSACE database, Boulangeat *et al.* 2012).

	H1	**H10**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**	**H9**
Maturity age (year)	4	4	3	3	4	4	4	4	4	4
Life span (year)	11	9	10	9	7	7	8	7	8	9

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Maturity age (year)	5	4	6	10	8	8	15	15	18	15	25	20	15	15
Life span (year)	27	19	45	158	39	92	193	177	351	600	450	160	310	100

Habitat suitability

The habitat suitability models were calibrated over the whole French Alps in order to increase the robustness of projections into the future climatic conditions (Barbet-Massin *et al*. 2012).

We used species observations from the database of the Conservatoire Botanique National

Alpin (CBNA), which includes all records of the Ecrins National Park and additional records in the entire region of the French Alps (Boulangeat *et al.* 2012). We used the 15,000 community plots of the database for which the exhaustive list of species was recorded to infer true absences. The observation of one representative species of a PFG determined its presence. A PFG true absence was considered where none of its determining species were observed in a community plot. We used seven environmental variables to model the large-scale abiotic constraints for each PFG: (1) the slope angle**,** taken from the French Digital Elevation Model with 50x50m resolution, made by the IGN-France (http://professionnels.ign.fr/bdalti) (2) the percentage of calcareous soil was calculated from the European Soil Database http://eusoils.jrc.ec.europa.eu/data.html with a 1km resolution. (see also Dullinger *et al.* 2012). (3) isothermality, (4) temperature seasonality, (5) temperature annual range, (6) mean temperature of coldest quarter, and (7) annual precipitation. These five bioclimatic variables are known to influence the physiology of species in the Alps (Körner 2004) and their pairwise correlations were low. Temperature and precipitation from the 1 km Worldclim climate grids available online were downscaled to a resolution of 100m, using a specific method that was developed for Mountainous areas (Dullinger *et al.* 2012).

Habitat suitability models were built using the *biomod2* package (Thuiller *et al.* 2009) in R (2011) and using five algorithms from different families: (1) Generalized Linear Model, (2) Boosted Regression Trees, (3) Generalized Additive Model, (4) Multivariate Adaptive Regression Splines and (5) Random Forest. We weighted the presence and absence of each PFT to give a prevalence of 0.5 in order to be able to compare the models whatever the PFG distribution (narrow, wide spread, etc.)._We used a ten-fold cross validation procedure with 70% of the data for calibration and 30% for evaluation with True Skill Statistics (TSS, Allouche *et al.* 2006). All models from different repetitions and algorithms were combined using an ensemble forecasting strategy: (1) All models gave binary projections using the threshold maximising the TSS in the evaluation procedures. (2) These projections were averaged, each one having its TSS score as weight. (4) The average projection were rescaled to fall between 0 and 1, which is the percentage of agreement between models.

Seed dispersal

Dispersal classes were given as the median of representative species values. We found most of our species in Vittoz *et al.* (2007). Missing data were given by local experts (J. Van Es, R. Douzet, P. Vittoz) following the same protocol as in Vittoz *et al.* (2007). The two first distance parameters are reported from Vittoz *et al.* (2007). Long distance parameter was set according to the dispersal class following Engler & Guisan (2009).

PFG	Dispersal class	Maximal distance for 50% of seeds (m)	Maximal distance for 99% of seeds (m)	Long distance dispersal (m)
C1	6	400	1500	10000
C2	4	40	150	5000
C3	1	0.1	1	1000
C4	6	400	1500	10000
C5	6	400	1500	10000
C6	7	500	5000	10000
H1	3	2	15	1000
H10	7	500	5000	10000
H2	6	400	1500	10000
H3	7	500	5000	10000
H4	3	2	15	1000
H5	3	2	15	1000
H6	3	2	15	1000
H7	5	100	500	5000
H8	3	2	15	1000
H9	7	500	5000	10000
P1	6	400	1500	10000
P2	5	100	500	5000
P3	4	2	15	1000
P4	6	400	1500	10000
P5	6	400	1500	10000
P6	4	40	150	5000
P7	4	40	150	5000
P8	4	40	150	5000

Disturbances

Responses to mowing and grazing were parameterized by the experts of the National Park.

Mowing parameters table. Mowing was assumed to include the removal of all trees in the field. Other PFG were partly killed or had their mature plants not producing seeds.

Herbaceous			**Chamaephytes**			**Phanerophytes**	
Juveniles were unaffected Senescents (longevity – 2) were all killed			One year old individuals were not affected All other juveniles were killed Senescents (longevity – 2) were all killed			Trees above 1.5m were all killed, assuming that mowing is associated with destruction of trees	
PFG	*Mature plants that did not produced seeds*	*Mature plants that were killed*	*PFG*	*Mature plants that did not produced seeds*	*Mature plants killed*	*PFG*	*Juveniles of one year that were killed*
H1	50%	40%	C1	50%	50%	P1	80%
H2	90%	0%	C2	50%	50%	P2	80%
H3	90%	0%	C3	-	100%	P3	100%
H4	-	100%	C4	-	100%	P4	100%
H5	90%	0%	C5	-	100%	P5	100%
H6	50%	40%	C6	-	100%	P6	100%
H7	50%	40%				P7	100%
H8	50%	40%				P8	100%
H9	90%	0%					
H10	90%	0%					

Grazing parameters for herbaceous and herbaceous chamaephytes. C3, C5, H4, H7 and H8 were unaffected. 3 different types of grazing were differentiated: G1= light grazing; G2= extensive grazing; G3= intensive grazing. The parameterisation was carried out with PNE experts and according to the palatability of the determinant species of each PFG (Jouglet *et al.*)

	C6		**C1, C2, H1, H2, H3, H5, H6, H9, H10**	
G1	*Juv.*	10% killed	*Juv.*	10% killed
	Mat.	10% no seeds	*Mat.*	50% no seeds
	Sen.	10% respr.	*Sen.*	10% respr.
G2	*Juv.*	10% killed	*Juv.*	50% killed
	Mat.	90% no seeds	*Mat.*	100% no seeds
	Sen.	50% respr.; 10% killed	*Sen.*	50% respr.; 10% killed
G3	*Juv.*	50% killed	*Juv.*	90% killed
	Mat.	100% no seeds	*Mat.*	90% no seeds; 10% killed
	Sen.	50% respr.; 10% killed	*Sen.*	50% respr.; 50% killed

Grazing parameters for phanerophytes and shrub chamaephytes. 3 different types of grazing were differentiated: G1= light grazing; G2= extensive grazing; G3= intensive grazing. Individuals above 1.5m were unaffected. Percentages represent the proportion of killed plants.

	Age classes	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**C4**
G1	*1 year old*	100%	100%	80%	100%	0%	-	40%	100%	100%
	<1.5m	-	-	-	-	-	-	-	-	-
G2	*1 year old*	100%	100%	80%	100%	-	-	40%	100%	100%
	<1.5m	-	-	-	50%	-	-	-	-	-
G3	*1 year old*	100%	100%	80%	100%	40%	100%	40%	100%	100%
	<1.5m	40%	40%	10%	80%	10%	40%	-	-	40%

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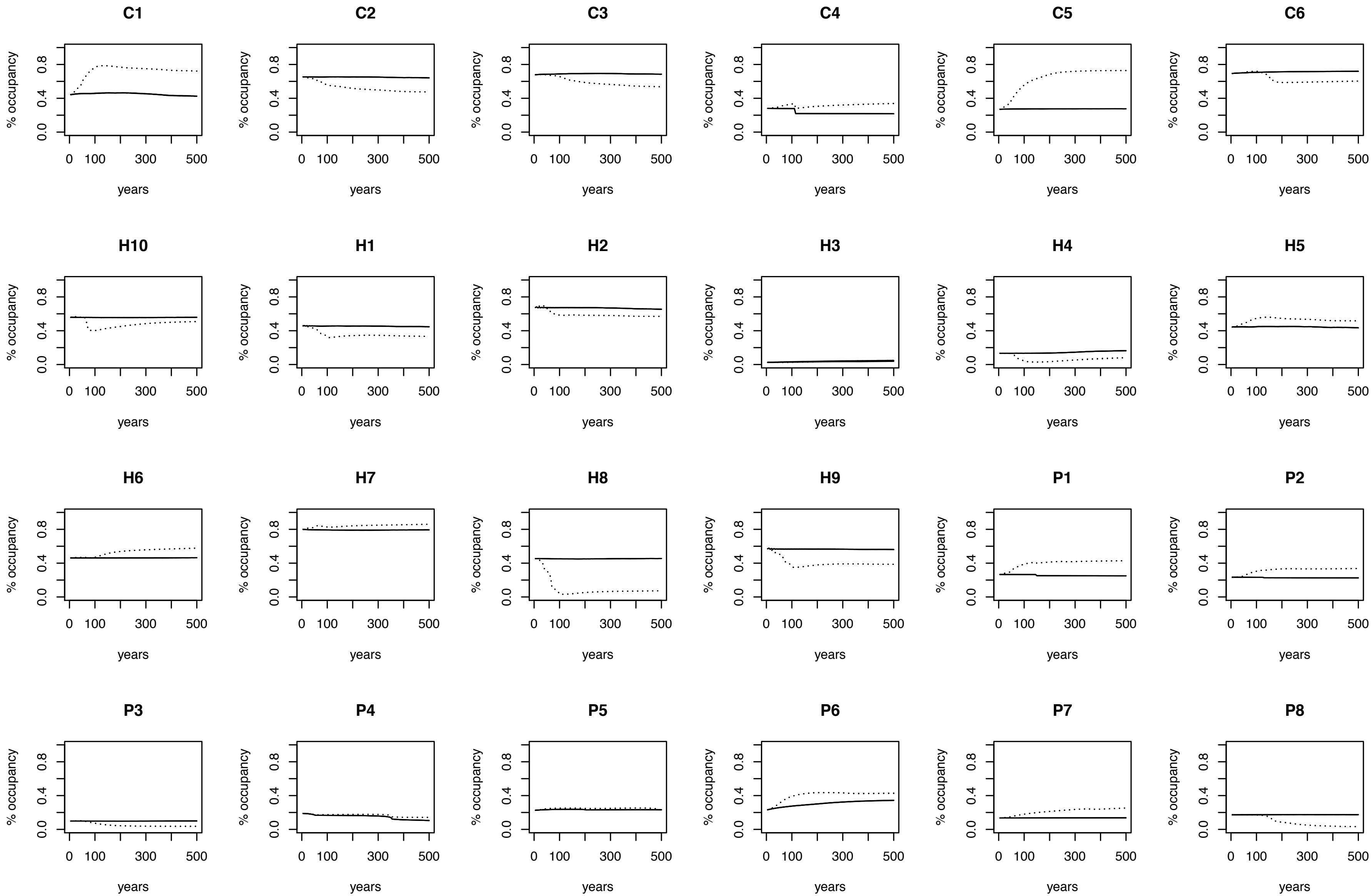
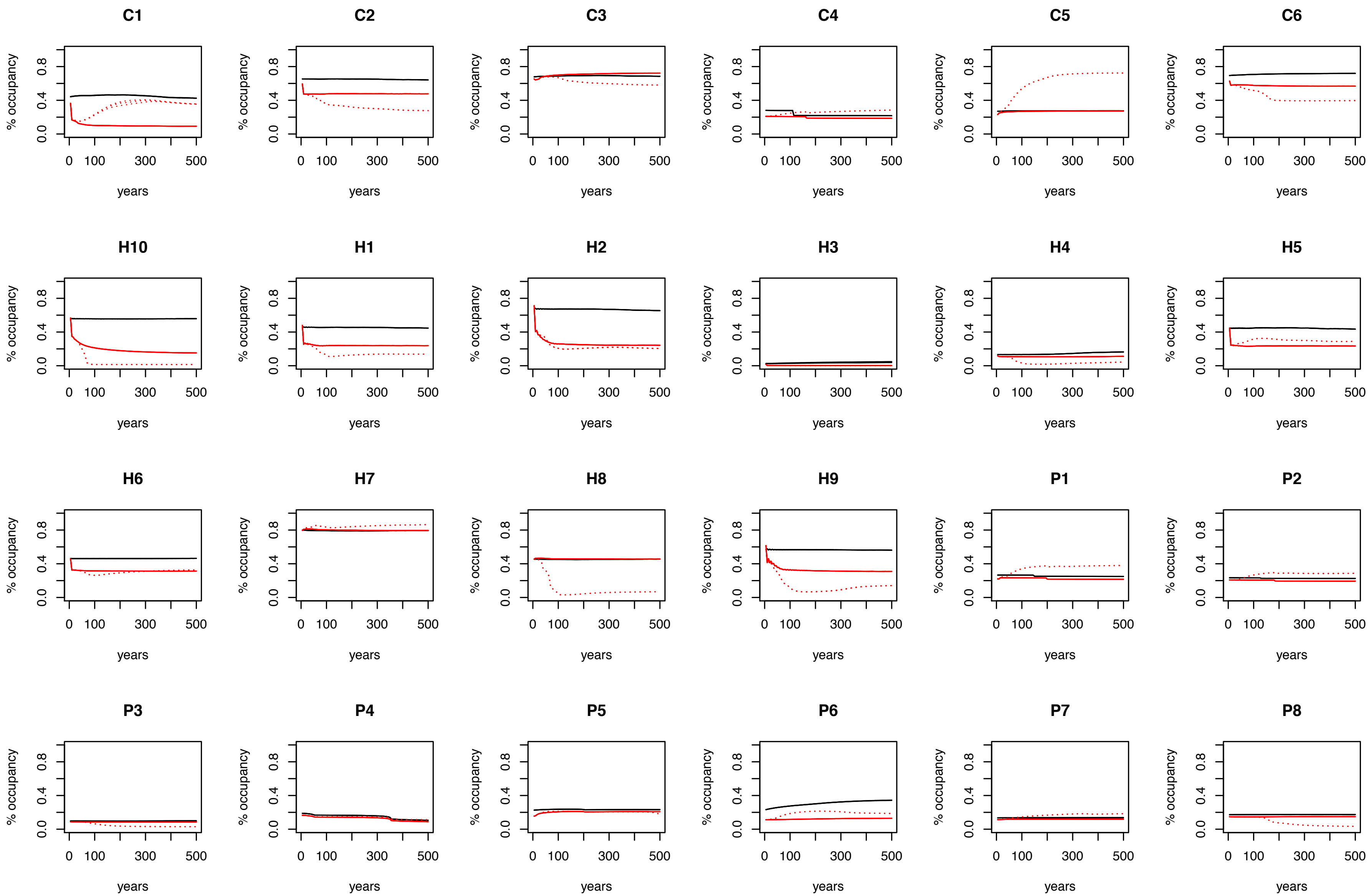
Appendix A2: Evolution of PFG range sizes and the average elevation of their distribution

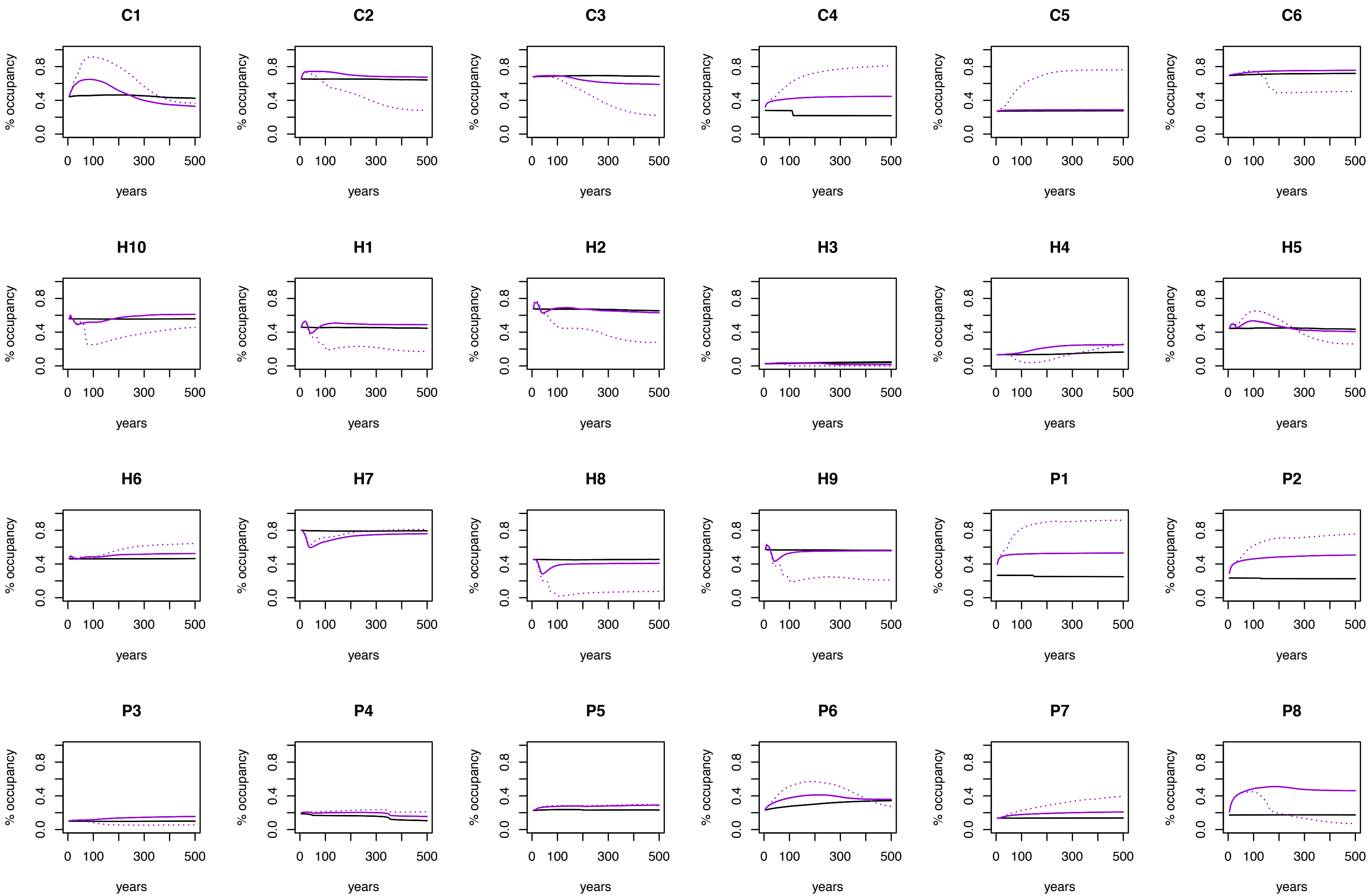
Fig. A2a. Evolution of PFG range sizes. All six repetitions are superimposed in the graphs. The solid lines correspond to scenarios without climate change and the dotted lines to scenarios accounting for climate change. **(a)** Same management as current. **(b)** Land use intensification management. **(c)** Land use abandonment scenario.


C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
% occupancy
years
0.0
0.4
0.8
0
100
300
500

(a)


C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
% occupancy
0.0 0.4 0.8
years
0 100 300 500

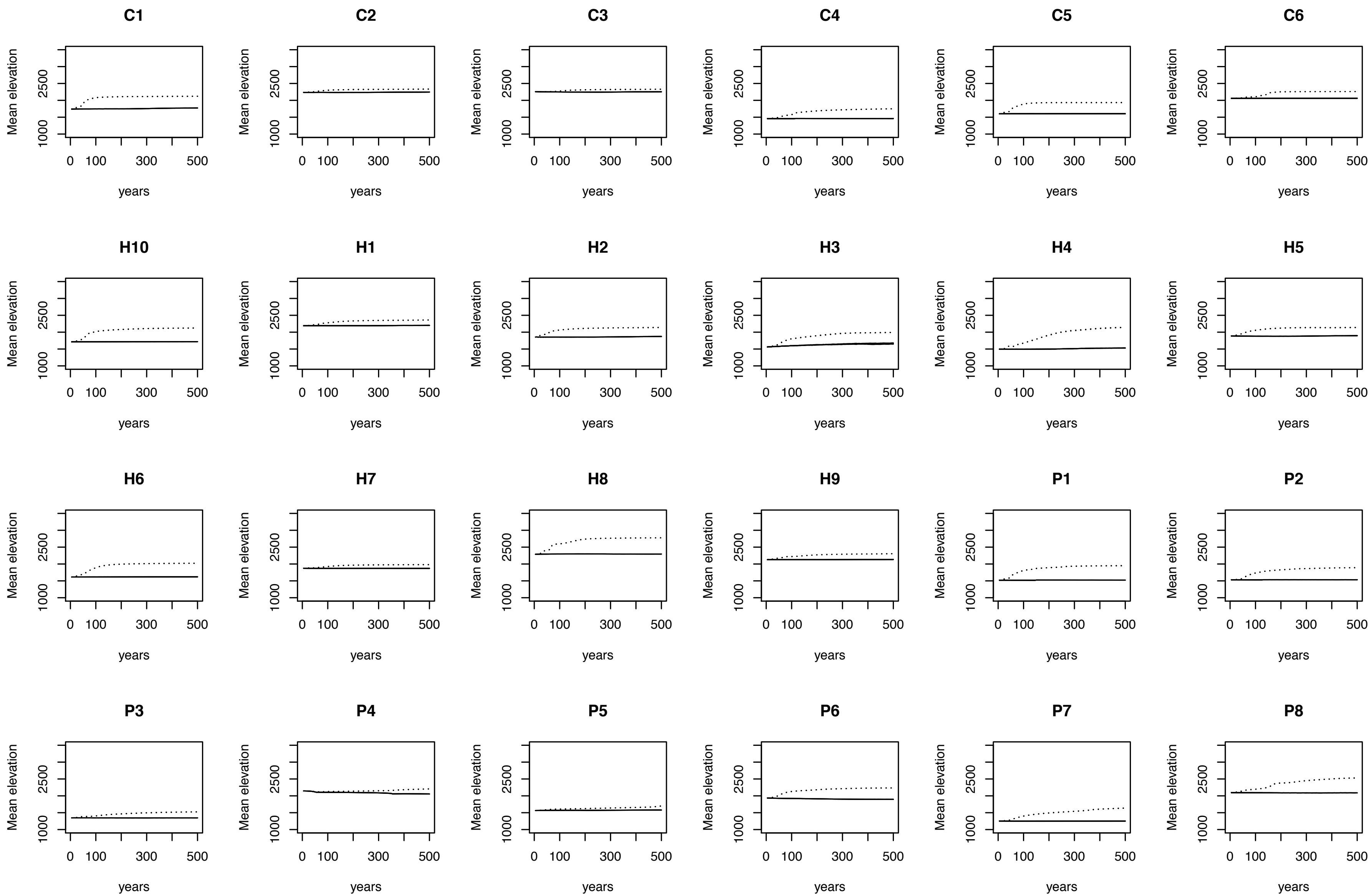
(b)



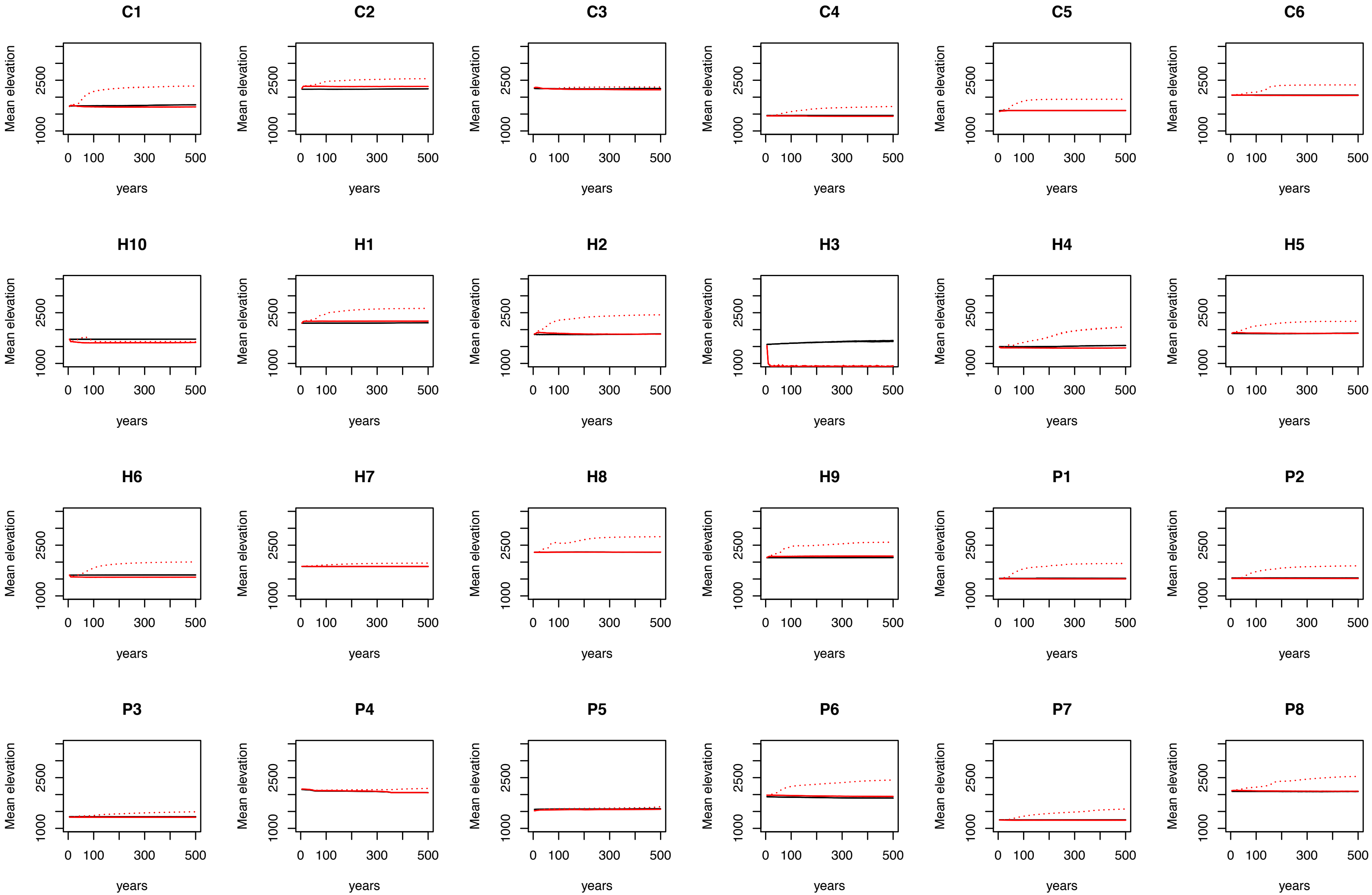
C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
% occupancy
years
0.0
0.4
0.8
0
100
300
500

(c)

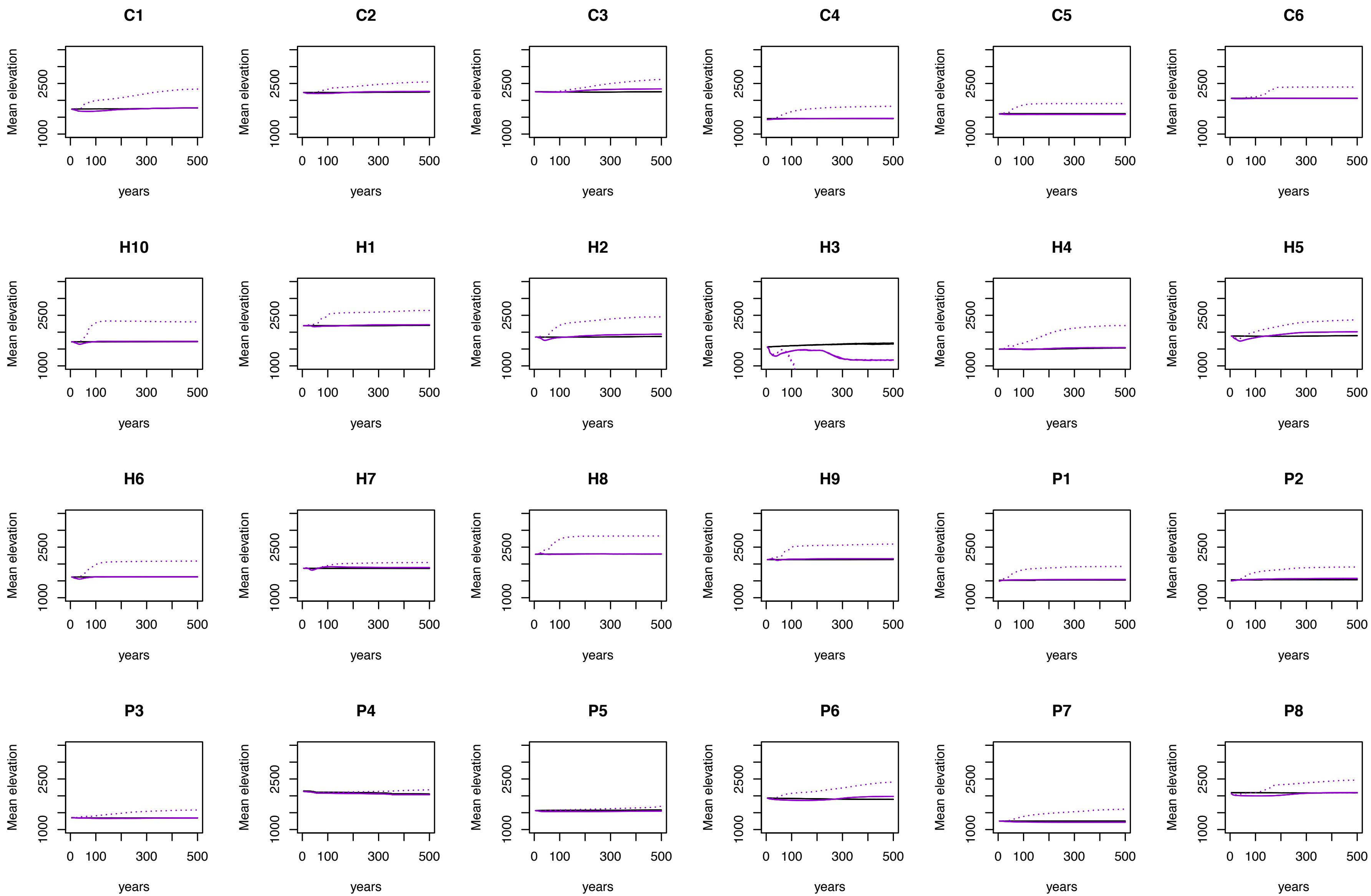
Fig. A2b. Evolution of the average elevations of PFG distributions. All six repetitions are superimposed in the graphs. The solid lines correspond to scenarios without climate change and the dotted lines to scenarios accounting for climate change. **(a)** Same management as current. **(b)** Land use intensification management. **(c)** Land use abandonment scenario.


C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
Mean elevation
1000
2500
0
100
300
500
years

(a)


C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
Mean elevation
years
1000
2500
0
100
300
500

(b)


C1
C2
C3
C4
C5
C6
H10
H1
H2
H3
H4
H5
H6
H7
H8
H9
P1
P2
P3
P4
P5
P6
P7
P8
Mean elevation
1000
2500
years
0
100
300
500

(c)

Anticipating the spatio-temporal response of plant diversity and vegetation structure to climate and land use change in a protected area, Boulangeat, I., Georges, D., Dentant, C., Bonet, R., Van Es, J., Abdulhak, S., Zimmermann, N.E., Thuiller, W.

Appendix A3: Better understanding the time-lag before observing the effect of climate change on vegetation

Climate change effects on the vegetation are not immediate. In order to better understand which parameters are the most important in the "migration limitation", we repeated the simulation with a regular seeding (addition of seeds of all PFGs everywhere in the landscape every five years).

Fig. A3a Evolution of the tree cover through time and effect of the dispersal limitation. For three chosen scenarios varying land use and accounting for climate change, we report the evolution of tree cover though time (black line) and compare it to simulations including a addition of seeds of all PFGs everywhere in the landscape every 5 years (red line).

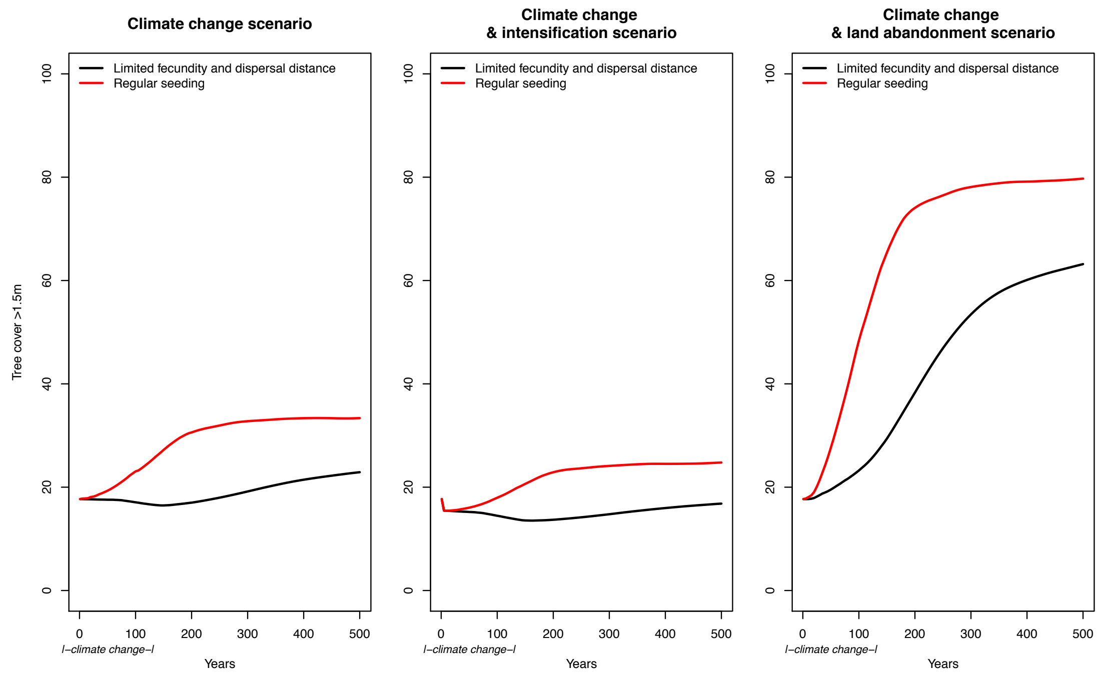


Fig. A3b Forest colonisation in the Fressinière valley under two contrasted management scenarios. The percentage of tree cover varies from 0 (yellow) to 100% (dark green). Pastures are shown at year zero in white. The red circle shows a high elevation zone that trees couldn't reach under the land use intensification scenario, as a consequence of the grazed pastures constituting a dispersal barrier.