Appendix S1. FATE-HD base model

FATE-HD 'base model' description

FATE-HD has been validated for the different plant communities present in the Ecrins National Park (ENP) (Boulangeat, Georges & Thuiller 2014). Although large areas of the park are managed and used for different activities (around 68% of the total area), the park has a very diverse flora, with ca. 2000 plant species. Different types of vegetation are mostly maintained by current abiotic conditions or land-use activities and can thus be expected to shift under climate and land-use changes.

FATE-HD currently simulates 24 plant functional groups (PFGs; Table S1) and five different height strata (0-1.5m; 1.5-4m; 4-10m; 10-20m; taller than 20m). Each group represents species that are similar in terms of bioclimatic niche, competitive ability for light resources, demography and response to disturbances (see Boulangeat *et al.* 2012 for details and validation of the PFG classification used). Chamaephyte groups, C1-6, are only present in the first height stratum, except for C4 which reaches the second stratum; herbaceous groups, H1-10, are mostly hemicryptophytes and are only present in the first height stratum; and phanerophyte groups, P1-8, reach at least the third height stratum, with six reaching the fourth stratum and two reaching the fifth (Table S1). Population dynamics, dispersal and competition for light resources are all explicitly simulated for each PFG, both spatially and temporally.

Population dynamics partially depend on habitat suitability (HS). Habitat suitability is calculated for each PFG from a set of bioclimatic variables and includes a stochastic component in order to simulate yearly oscillations of habitat quality resulting from interannual climate variability. Maps of 'current' HS were produced using PFG presence/absence information across the French Alps (see Boulangeat, Georges & Thuiller 2014) that was related to seven environmental variables using the *R* package *biomod2* (Thuiller *et al.* 2009). These variables were slope, percentage of calcareous soil and five ‘BIOCLIM’ variables (isothermality, temperature seasonality, temperature annual range, mean temperature of coldest quarter and annual precipitation), averaged across years 1961-1990 to obtain ‘current’ climate values (i.e. ‘current’ HS). Predictions of PFG distributions using the chosen environmental variables were obtained from a set of different modelling approaches and combined into a single output using a weighted sum of predictions (Thuiller *et al.* 2009; Boulangeat, Georges & Thuiller 2014).

Dispersal of PFGs is modelled for both long and short distances, depending on the PFG in question. Competition for light resources is also modelled according to PFG type and stratum, as both differ in relation to their shade tolerance. The amount of shade is calculated per pixel in function of PFGs abundances per stratum. The more abundant a stratum is the more shade it casts on below strata, decreasing the amount of available light (see Boulangeat, Georges & Thuiller 2014 for more information on simulated population dynamics, competition and dispersal mechanisms).

Two types of disturbances were included in the model: grazing and mowing, with grazing having three levels of intensity, low (1), medium (2) and high (3). They were implemented in a spatially explicit manner, by assigning a binary variable reflecting the presence/absence of a particular disturbance to each pixel. Grazing affected PFGs by causing mortality, or resprouting (preventing mature plants from producing seeds) in proportions that varied according to PFGs’ palatability classes (Table S1) and age. Mowing removed all trees above 1.5m (in the second stratum or higher) by causing their death (see Boulangeat, Georges & Thuiller 2014 for more information on land-use disturbances).

Traits were used as basis for the parameterisation of PFG population dynamics, light competition and dispersal mechanisms, as well as responses to grazing and mowing. For instance, PFGs with higher palatability values suffered stronger effects from grazing. The full list of trait values are shown in Table S1 and we refer the reader to Boulangeat, Georges and Thuiller (2014) for a complete list of parameters used in the base model.

Land-use and gradual climate change scenarios

Gradual climate change (CC) was simulated according to IPCC previsions of the A1B scenario for years 2020, 2050 and 2080. Values of BIOCLIM variables were projected using the regional climate model (RCM) RCA3 (Samuelsson *et al.* 2011) fed by the global circulation model (GCM) CCSM3 (derived from the ENSEMBLES EU project outputs; NCAR community 2004). Outputs from the RCM were then downscaled to 100 x 100 m resolution using the change factor method (Diaz-Nieto & Wilby 2005) and used to calculate future HS maps. We then interpolated between current HS projections (referring to the 1961-1990 period) and time step 2020, and between time steps 2020, 2050 and 2080 to obtain a more gradual change at every 15 years for 90 years (for further details on construction of future HS maps see Boulangeat *et al.* 2014). Current HS projections were used during simulation years 0 to 14, before CC was implemented.

The chosen land-use change scenario, the abandonment of all grazing and mowing activities, represents a current trend of land-use change observed not only in the ENP (Esterni *et al.* 2006), but in other regions of the European Alps (Gehrig -

Fasel, Guisan & Zimmermann 2007), and is associated with the eventual interruption of European subsidies for agriculture (Boulangeat *et al.* 2014).

Table S1. Plant functional groups and their trait values. Life form classes are chamaephytes (C1-6), herbaceous (H1-10) and phanerophytes (P1-8). PFGs with larger values of ‘light’, ‘dispersal’ and ‘palatability’ are, respectively, light-loving, long-distance dispersers and preferred by grazers (thus more affected by grazing). ‘No. strata’ indicates the number of strata a PFG can occupy in the model. ‘SLA’ and ‘LDMC’ stand for average specific leaf area and average leaf dry matter content, respectively. SLA values for species of PFGs H10 and P8 were obtained from Kattge *et al.* (2011). Table partially adapted from Boulangeat *et al.* (2012) and (Boulangeat, Georges & Thuiller 2014).

PFG	No. Strata	Dispersal	Light	Height (cm)	Palatability	Longevity (years)	Maturity (years)	Seed mass (g)	SLA ($mm^2 mg^{-1}$)	LDMC ($mg g^{-1}$)	Leaf area (mm^2)
C1	1	6	7	27	3	27	5	23.91	19.21	262.74	12.95
C2	1	4	8	13	3	19	4	0.38	18.02	196.03	1.05
C3	1	1	8	7	0	45	6	0.51	14.39	221.21	0.66
C4	2	6	6	209	2	158	10	192.99	16.83	330.52	16.97
C5	1	6	6	76	0	39	8	75.01	8.28	390.18	0.94
C6	1	7	6	18	2	92	8	39.50	13.40	354.97	0.86
H1	1	3	8	17	3	11	4	0.86	17.22	260.65	5.00
H2	1	6	7	42	3	10	3	4.04	22.11	250.74	18.76
H3	1	7	7	50	3	9	3	2.37	24.43	238.24	79.05
H4	1	3	5	76	0	7	4	0.36	29.76	228.53	541.13
H5	1	3	7	40	3	7	4	1.94	20.71	243.02	31.34
H6	1	3	6	73	3	8	4	2.31	28.21	227.85	76.68
H7	1	5	6	19	0	7	4	0.40	19.25	195.45	97.07
H8	1	3	8	19	0	8	4	0.89	23.11	274.24	0.18
H9	1	7	8	19	3	9	4	0.38	21.09	417.58	1.40
H10	1	7	6	100	3	9	4	6.20	21.14	0.22	353.31
P1	3	6	6	1175	2	193	15	177.93	12.03	346.77	34.01

P2	3	5	6	750	2	177	15	0.13	17.17	350.81	14.43
P3	4	4	5	1667	2	351	18	86.41	15.30	265.26	65.52
P4	5	6	7	2500	0	600	15	6.82	10.06	279.75	0.20
P5	5	6	4	2500	2	450	25	114.06	11.86	309.25	20.28
P6	4	4	8	1650	2	160	20	6.10	19.24	282.18	12.36
P7	3	4	5	600	2	310	15	78.27	15.65	360.50	47.42
P8	3	4	7	800	2	100	15	0.17	14.62	0.36	8.26

References

Boulangeat, I., Georges, D., Dentant, C., Bonet, R., Van Es, J., Abdulhak, S., Zimmermann, N.E. & Thuiller, W. (2014) Anticipating the spatio-temporal response of plant diversity and vegetation structure to climate and land use change in a protected area. *Ecography,* **37,** 1230-1239.

Boulangeat, I., Georges, D. & Thuiller, W. (2014) FATE-HD: a spatially and temporally explicit integrated model for predicting vegetation structure and diversity at regional scale. *Global Change Biology,* **20,** 2368-2378.

Boulangeat, I., Philippe, P., Abdulhak, S., Douzet, R., Garraud, L., Lavergne, S., Lavorel, S., Van Es, J., Vittoz, P. & Thuiller, W. (2012) Improving plant functional groups for dynamic models of biodiversity: at the crossroads between functional and community ecology. *Global Change Biology,* **18,** 3464-3475.

Diaz-Nieto, J. & Wilby, R.L. (2005) A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. *Climatic Change,* **69,** 245-268.

Esterni, M., Rovera, G., Bonet, R., Salomez, P., Cortot, H. & Guilloux, J. (2006) DELPHINE - Découpage de l'Espace en Liaison avec les Potentialités Humaines et en Interrelation avec la Nature. Parc National des Ecrins.

Gehrig-Fasel, J., Guisan, A. & Zimmermann, N.E. (2007) Tree line shifts in the Swiss Alps: Climate change or land abandonment? *Journal of Vegetation Science,* **18,** 571-582.

Kattge, J., Díaz, S., Lavorel, S., Prentice, I.C., Leadley, P., Bönisch, G., Garnier, E., Westoby, M., Reich, P.B., Wright, I.J., Cornelissen, J.H.C., Violle, C., Harrison, S.P., Bodegom, P.M.v., Reichstein, M., Enquist, B.J., Soudzilovskaia, N.A., Ackerly, D.D., Anand, M., Atkin, O., Bahn, M., Baker, T.R., Baldocchi, D., Bekker, R., Blanco, C., Blonder, B., Bond, W.J., Bradstock, R., Bunker, D.E., Casanoves, F., Cavender-Bares, J., Chambers, J.Q., Chapin, F.S., Chave, J., Coomes, D., Cornwell, W.K., Craine, J.M., Dobrin, B.H., Duarte, L., Durka, W., Elser, J., Esser, G., Estiarte, M., Fagan, W.F., Fang, J., Fernández-Méndez, F., Fidelis, A., Finegan, B., Flores, O., Ford, H., Frank, D., Freschet, G.T., Fyllas, N.M., Gallagher, R.V., Green, W.A., Gutierrez, A.G., Hickler, T., Higgins, S., Hodgson, J.G., Jalili, A., Jansen, S., Joly, C., Kerkhoff, A.J., Kirkup, D., Kitajima, K., Kleyer, M., Klotz, S., Knops, J.M.H., Kramer, K., Kühn, I., Kurokawa, H., Laughlin, D., Lee, T.D., Leishman, M., Lens, F., Lenz, T., Lewis, S.L., Lloyd, J., Llusià, J., Louault, F., Ma, S., Mahecha, M.D., Manning, P., Massad, T., Medlyn, B., Messier, J., Moles, A.T., Müller, S.C., Nadrowski, K., Naeem, S., Niinemets, Ü., Nöllert, S., Nüske, A., Ogaya, R., Oleksyn, J., Onipchenko, V.G., Onoda, Y., Ordoñez, J., Overbeck, G., Ozinga, W.A., Patiño, S., Paula, S., Pausas, J.G., Peñuelas, J., Phillips, O.L., Pillar, V., Poorter, H., Poorter, L., Poschlod, P., Prinzing, A., Proulx, R., Rammig, A., Reinsch, S., Reu, B., Sack, L., Salgado-Negret, B., Sardans, J., Shiodera, S., Shipley, B., Siefert, A., Sosinski, E., Soussana, J.-F., Swaine, E., Swenson, N., Thompson, K., Thornton, P., Waldram, M., Weiher, E., White, M., White, S., Wright, S.J., Yguel, B., Zaehle, S., Zanne, A.E. & Wirth, C. (2011) TRY - a global database of plant traits. *Global Change Biology,* **17,** 2905-2935.

NCAR community (2004) Community Climate System Model, version 3.0.

Samuelsson, P., Jones, C.G., Willén, U., Ullerstig, A., Gollvik, S., Hansson, U., Jansson, C., Kjellström, E., Nikulin, G. & Wyser, K. (2011) The Rossby Centre

Regional Climate model RCA3: model description and performance. *Tellus A,* **63,** 4-23.

Thuiller, W., Lafourcade, B., Engler, R. & Araújo, M.B. (2009) BIOMOD–a platform for ensemble forecasting of species distributions. *Ecography,* **32,** 369-373.