Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

Appendix S1. Description of the selected insect species for biological control of ragweed

Ophraella slobodkini Futuyma (Coleoptera: Chrysomelidae) is recorded as a monophagous leaf beetle on *A. artemisiifolia* in field conditions, but it can also be reared on the closely related *Iva frutescens* L. in the laboratory (Futuyma, 1991). The geographic distribution of *O. slobodkini* is very restricted, known only from inland Florida.

Ophraella communa LeSage (Coleoptera: Chrysomelidae), an oligophagous leaf beetle with *A. artemisiifolia* as its preferred host plant, originates from North America, from southern Canada to Mexico, but no records exist from peninsular Florida (LeSage, 1986; Futuyma & McCafferty, 1990; Palmer & Goeden, 1991; Zhou *et al.*, 2011a). It was accidently introduced to a number of countries in eastern Asia (Shiyake & Moriya, 2005). It is currently used as the most efficient and successful biological control agent against *A. artemisiifolia* in China (Zhou *et al.*, 2011b) and also cause large damage to *A. artemisiifolia* in Japan (Fukano & Doi, 2013). Müller-Schärer *et al.* (2014) reported a first record of *O. communa* in Europe (Southern Switzerland and Northern Italy) in 2013 as an accidental introduction. Under favourable environmental conditions, *O. communa* has 4-7 generations per year, which allows it to build up high local densities during the second half of the *A. artemisiifolia* growing season. This beetle can cause complete defoliation and death of *A. artemisiifolia* under both experimental and field conditions (Palmer & Goeden, 1991; Zhou *et al.*, 2014), and where it occurs in Northern Italy, it has significantly reduced pollen concentrations in the air since 2013 (Bonini *et al.*, 2015; Bonini *et al.*, in press).

Zygogramma suturalis Fabricius (Coleoptera: Chrysomelidae) is an oligophagous leaf beetle native to North America. Its adults and larvae are able to feed and complete their development only on *A. artemisiifolia* and the closely related *A. psilostachya* D.C. (Reznik & Kovalev, 1989; Reznik, 1993). It was introduced into the former USSR from USA and Canada in 1978, released in 1981-1982, then successfully acclimated and was able to suppress and even locally exterminate *A. artemisiifolia* and certainly became the most well-known insect used to control *A. artemisiifolia* in Russia (Kovalev, 1989). Since 1982, numerous releases were made in the south of European Russia and the Ukraine (Kovalev & Medvedev, 1983), but high efficiency was never recorded. In Croatia, *Z. suturalis* was introduced in the 1980's, has become well established but so far densities of beetles in the field are low and had no significant impact on *A. artemisiifolia* (Igrc *et al.*, 1995; Winston *et al.*, 2014). It was also introduced in China as biological control agent and released in 1993 but did not become established (Ma *et al.*, 2008).

Zygogramma disrupta Rogers (Coleoptera: Chrysomelidae) is closely related to *Z. suturalis* and considered to be more fecund and better adapted to hot and dry climate. It was repeatedly released in the 1980's in former USSR but never became established (Kovalev & Medvedev, 1983).

Epiblema strenuana Walker (Lepidoptera: Tortricidae), a stem mining and gall-inducing moth endemic to North America, is a common miner of the lateral branches of mature *Ambrosia* and characteristically produces fusiform galls in the larval stage (Stegmaier Jr, 1971), with 3–4 generations per year under favourable conditions (Ma *et al.*, 2008). It was introduced from Mexico to Australia in 1982 against *Parthenium hysterophorus* L. and became established and has spread widely also on *A. artemisiifolia* since (McFadyen, 1992). The moth was introduced from Australia to China in 1990; it was released in 1993 for managing *A. artemisiifolia* and successfully established in southern China (Wan *et al.*, 1995). In southern China, *O. communa* and *E. strenuana* coexist in many areas invaded by *A.*

artemisiifolia and are recommended to be used together to control *A. artemisiifolia* in China (Zhou *et al.*, 2014).

Tarachidia (syn.: Ponometia) candefacta Hübner (Lepidoptera: Noctuidae), is a small noctuid moth native to North America that feeds on various species in the Asteraceae, including asters (*Aster* spp.) and ragweed (*Ambrosia* spp.) (Gilstrap & Goeden, 1974). Chronologically, it was the first intentional introduction of a natural enemy as the biological control agent of an invasive alien weed into Europe, in Krasnodar territory of the former USSR in 1969 (Kovalev & Runeva, 1970), but so far has been considered ineffective (Reznik, 2009). It was only recorded regularly and expanded slowly after 1990, with increasing population densities in Krasnodar territory and Rostov province of Russia in 2005 (Poltavsky & Artokhin, 2006; Reznik, 2009). It was also introduced into China between 1987-1989 but never established in the field (Wan *et al.*, 2005).

References

Bonini, M., Šikoparija, B., Prentović, M., Cislaghi, G., Colombo, P., Testoni, C., Grewling, L., Lommen, S., Müller-Schärer, H. & Smith, M. (2015) Is the recent decrease in airborne *Ambrosia* pollen in the Milan area due to the accidental introduction of the ragweed leaf beetle *Ophraella communa*? *Aerobiologia*, **31**, 499-513.

Bonini, M., Šikoparija, B., Prentović, M., Cislaghi, G., Colombo, P., Testoni, C., Grewling, Ł., Lommen, S., Müller-Schärer, H. & Smith, M. (in press) Brief communication: A follow-up study examining airborne *Ambrosia* pollen in the Milan area in 2014 in relation to the accidental introduction of the ragweed leaf beetle *Ophraella communa*. *Aerobiologia*,

Fukano, Y. & Doi, H. (2013) Population abundance and host use pattern of *Ophraella communa* (Coleoptera: Chrysomelidae) in its native and introduced range. *Biocontrol Science and Technology*, **23**, 595-601.

Futuyma, D.J. (1991) A new species of *Ophraella Wilcox* (Coleoptera: Chrysomelidae) from the Southeastern United States. *Journal of the New York Entomological Society*, **99**, 643-653.

Futuyma, D.J. & McCafferty, S.S. (1990) Phylogeny and the evolution of host plant associations in the leaf beetle genus *Ophraella* (Coleoptera, Chrysomelidae). *Evolution*, 1885-1913.

Gilstrap, F.E. & Goeden, R.D. (1974) Biology of *Tarachidia candefacta*, a Nearctic noctuid introduced into the USSR for ragweed control. *Annals of the Entomological Society of America*, **67**, 265-270.

Igrc, J., DeLoach, C.J. & Zlof, V. (1995) Release and establishment of *Zygogramma suturalis* F (Coleoptera: Chrysomelidae) in Croatia for control of common ragweed (*Ambrosia artemisiifolia* L.). *Biological control*, **5**, 203-208.

Kovalev, O. (1989) Spread out of adventive plants of *Ambrosiaceae tribe* in Eurasia and methods of biological control of *Ambrosia* L. (Asteraceae). *Proc Zool Inst (Leningrad)* 7-23.

Kovalev, O.V. & Runeva, T.D. (1970) *Tarachidia candefacta* Hübn. (Lepidoptera, Noctuidae), an efficient phytophagous insect in biological control of weeds of the genus *Ambrosia*. *Entomologicheskoe Obozrenie*, **49**, 23-36.

Kovalev, O.V. & Medvedev, L.N. (1983) Theoretical foundations of introduction of *Ambrosia* leaf beetles of the genus *Zygogramma* Chewr. (Coleoptera: Chrysomelidae) to the USSR for biological control of *Ambrosia* weeds. *Entomologicheskoe Obozrenie*, **62**, 17-32.

LeSage, L. (1986) A taxonomic monograph of the Nearctic galerucine genus *Ophraella Wilcox* (Coleoptera: Chrysomelidae). *Memoirs of the Entomological Society of Canada*, **118**, 3-75.

Ma, J., Guo, J., Wan, F., Hu, X., Wan, F., Li, B. & Guo, J. (2008) Biological Control of *Ambrosia artemisiifolia* and *A. trifida*. *Biological invasions: Biological control theory and practice*, pp. 157-185. Science Press, Beijin, China.

McFadyen, R.C. (1992) Biological control against *parthenium* weed in Australia. *Crop protection*, **11**, 400-407.

Müller-Schärer, H., Lommen, S.T.E., Rossinelli, M., Bonini, M., Boriani, M., Bosio, G. & Schaffner, U. (2014) *Ophraella communa*, the ragweed leaf beetle, has successfully landed in Europe: fortunate coincidence or threat? *Weed Research*, **54**, 109-119.

Palmer, W. & Goeden, R. (1991) The host range of *Ophraella communa L*esage (Coleoptera: Chrysomelidae). *The Coleopterists' Bulletin*, 115-120.

Poltavsky, A. & Artokhin, K. (2006) *Tarachidia candefacta* (Lepidoptera: Noctuidae) in the south of European Russia. *Phegea*, **34**, 41-44.

Reznik, S.Y. (1993) Influence of target plant density on herbivorous insect oviposition choice: *Ambrosia artemisiifolia* L.(Asteraceae) and *Zygogramma suturalis* F.(Coleoptera: Chrysomelidae). *Biocontrol Science and Technology*, **3**, 105-113.

Reznik, S.Y. (2009) Common ragweed (*Ambrosia artemisiifolia* L.) in Russia: spread, distribution, abundance, harmfulness and control measures. In: *Ambrosia: The first international ragweed review*, pp. 88-97. AFEDA, Saint-Priest, France.

Reznik, S.Y. & Kovalev, O. (1989) Feeding behavior of adults of the ragweed leaf beetle *Zygogramma suturalis* (Coleoptera, Chrysomelidae). *Trudy Zool. Inst. Akad. Nauk SSSR*, **189**, 56-61.

Shiyake, S. & Moriya, S. (2005) Expansion of *Ophraella communa* LeSage in east Asia. *Kontyu to Shizen*, **40**, 11-13.

Stegmaier Jr, C.E. (1971) Lepidoptera, Diptera, and Hymenoptera associated with *Ambrosia artemisiifolia* (Compositae) in Florida. *Florida Entomologist*, 259-272.

Wan, F., Liu, W., Ma, J. & Guo, J. (2005) *Ambrosia artemisiifolia* and *A. trifida*. *Biology and management of invasive alien species in agriculture and forestry* (ed. by F. Wan, X. Zheng and J. Guo), pp. 662-688. Science Press, Beijing, China.

Wan, F.H., Wang, R. & Ding, J. (1995) Biological control of *Ambrosia artemisiifolia* with introduced insect agents, *Zygogramma suturalis* and *Epiblema strenuana*. *Eighth International Symposium on Biological Control of Weeds*, pp. 193-200. Canterbury, New Zealand.

Winston, R., Schwarzländer, M., Hinz, H., Day, M., Cock, M. & Julien, M. (2014) Biological control of weeds: A world catalogue of aents and their target Weeds, 5th edn. USDA

Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, USA. In. FHTET-2014-04
Zhou, Z.-S., Guo, J.-Y., Michaud, J.P., Li, M. & Wan, F.-H. (2011a) Variation in cold hardiness among geographic populations of the ragweed beetle, *Ophraella communa* LeSage (Coleoptera: Chrysomelidae), a biological control agent of *Ambrosia artemisiifolia* L.(Asterales: Asteraceae), in China. *Biological invasions*, **13**, 659-667.
Zhou, Z.-S., Guo, J.-Y., Zheng, X.-W., Luo, M., Chen, H.-S. & Wan, F.-H. (2011b) Reevaluation of biosecurity of *Ophraella communa* against sunflower (*Helianthus annuus*). *Biocontrol Science and Technology*, **21**, 1147-1160.
Zhou, Z.-S., Chen, H.-S., Zheng, X.-W., Guo, J.-Y., Guo, W., Li, M., Luo, M. & Wan, F.-H. (2014) Control of the invasive weed *Ambrosia artemisiifolia* with *Ophraella communa* and *Epiblema strenuana*. *Biocontrol Science and Technology*, **24**, 950-964.

Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

Appendix S2. Additional sources for *A. artemisiifolia* and the six insect species

Geo-referenced occurrence records of the seven species were downloaded from online resources the Global Biodiversity Information Facility online database (GBIF; http://www.gbif.org), the Southwest Environmental Information Network (SEINet; http://swbiodiversity.org), the Barcode of Life Data Systems (BOLD; http://www.boldsystems.org/) and the Berkeley Ecoinformatics Engine (Ecoengine; https://ecoengine.berkeley.edu/). For additional *A. artemisiifolia* data were obtained from the Jepson Herbarium (University of California, Berkeley), the Marion Ownbey Herbarium (Washington State University), the USF Herbarium (University of South Florida), the C. V. Starr Virtual Herbarium (New York Botanical Garden), J. F. Bell Museum of Natural History Herbarium (University of Minnesota) and the National Herbarium in Tbilisi, Georgia. Additional occurrences of the six biological control insect agents were obtained from the Essig Museum of Entomology (University of California, Berkeley), the Bohart Museum of Entomology (University of California, Davis), the Bugguide (Iowa State University), the Mississippi Entomological Museum (Mississippi State University), the TAMU Insect Collection (TAMUIC, Texas A&M University), the C. A. Triplehorn Insect Collection (Ohio State University), the E. H. Strickland Entomological Museum (University of Alberta), the Property and Environment Research Center (PERC, Montana), the Illinois Natural History Survey (INHS; Prairie Research Institute), Florida State Collection of Arthropods (Florida Department of Agriculture and Consumer Services) and McGuire Center collection (MGCL).

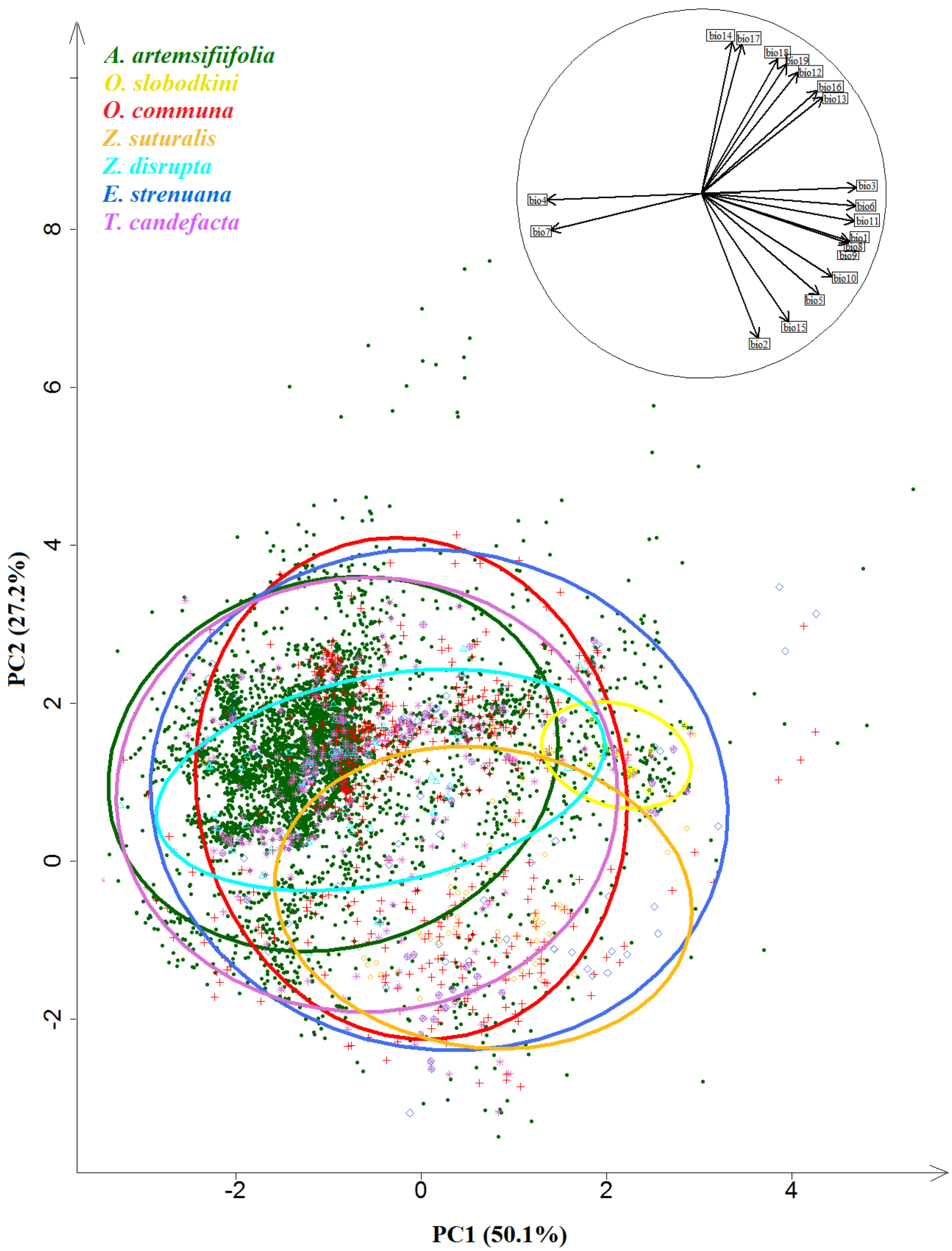
Besides data engine and museum/institute collections, we also obtained occurrences data from publications and field surveys. Publications were found through google scholar, using the Latin names (without author) of the insects as the exact searching phrase. Additional 190 occurrences of *O. communa* were collected from 55 publications out of 524 google scholar results by using "Ophraella communa" as the exact searching phrase; 227 occurrences were obtained from field survey collected by the consortium of the EU-COST Action on "Sustainable management of Ambrosia artemisiifolia in Europe" (SMARTER) in 2013-2014; and 381 occurrences in the USA were obtained from Douglas J. Futuyma (Stony Brook University, NY); and 45 in China through personal contact with Dr. Zhongshi Zhou (Chinese Academy Agricultural Sciences). Additional 11 occurrences of *O. slobodkini* were collected from 9 publications of google scholar by using "Ophraella slobodkini" as the exact searching phrase; and 10 additional occurrences were collected from field survey in Florida in May-June 2014. Additional two occurrences of *Z. disrupta* were collected from field sample collections in Florida in May-June 2014; and six occurrences from 13 publications of google scholar by using "Zygogramma disrupta" as the exact searching phrase. Additional 50 occurrences of *Z. suturalis* were collected from 49 publications out of 248 google scholar results by using "Zygogramma suturalis" as the exact search phrase. Additional 21 occurrences of *E. strenuana* were collected from 17 publications out of 434 google scholar results by using "Epiblema strenuana" as the exactl searching phrase. Additional 99 occurrences of *T. candefacta* were collected from 77 publications out of 152 google scholar results by using "Tarachidia candefacta" OR "Ponometia candefacta"; personal collection data from Dr. James E. Hayden and Mr. Louis A. Somma (Florida Department of Agriculture and Consumer Services, Division of Plant Industry, FDACS-DPI, USA), Dr. Oleg V. Kovalev (Zoological Institute Russian Academy of Sciences), Dr. Alexander Poltavsky (Southern Federal University, Russia), and Dr. Dejan V. Stojanović (Institute of Lowland Forestry and Environment Protection, Serbia) yielded 326 occurrences.

Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

Appendix S3. Principal Component Analysis of all species

In order to assess whether the selected six biological control candidates are suitable to control *A. artemisiifolia*, we organized the dataset into a single correlation matrix of 19 bioclimatic variables (Table S1 in Supporting Information, GDD could not be used in this analysis as we used different values for the plant invader and six insect species, cf. above) × seven species (the plant and the six insect species), on which we calibrated a Principal Component Analysis (PCA) to visualize characteristics in few dimensions. The 19 bioclimatic variables were extracted from worldwide occurrences of each species. The principal components (PCs) describe the bioclimatic variation in the study area among our occurrences. Then the scores along the PCs for occurrences of each species were used to understand the factors underlying differences among species' distributions. We use ellipses as a graphical summary of the cloud of points corresponding to the scores of each species, defined by the gravity center of the cloud with the 90% confidence interval of scores delimited (Fig. S1). The first two PCs accounted for 77.3% of the total variances, with the most important axis (50.1%) representing primarily bioclimatic variables (Fig. S1). Temperature variables, especially seasonality and isothermality, varied mainly along the first axis, and precipitation variables varied mainly along the second axis. Overall, the PCA shows a large overlap in climatic space between *A. artemisiifolia* and the six insect species, suggesting the six insect species are suitable candidates.



Appendix S3: Fig. S1. Principal component analysis (PCA) of *Ambrosia artemisiifolia* (dark green, bullet), and its potential biocontrol agent herbivores *Ophraella slobodkini* (yellow, square plus), *O. communa* (red, plus), *Zygogramma suturalis* (cyan, triangle), *Z. disrupta* (goldenrod, circle), *Epiblema strenuana* (blue, diamond) and *Tarachidia candefacta* (orchid, star) for 19 climatic factors (variables list in Table S1 in Supporting Information). The inlayed correlation circle (r = 3) shows the climatic variables used and their correlation with the PCA axes. Axes inertia are given in brackets. For details on ellipses see Methods.

Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

Appendix S4: Table S1. List of all 19 predictors available in WORLDCLIM bioclimatic data set (http://www.worldclim.org/bioclim), and GDD.

WORLDCLIM Variable	Description
BIO1	Annual mean temperature
BIO2	Mean diurnal range
BIO3	Isothermality
BIO4	Temperature seasonality
BIO5	Max temperature of warmest month
BIO6	Min temperature of coldest month
BIO7	Temperature annual range
BIO8	Mean temperature of wettest quarter
BIO9	Mean temperature of driest quarter
BIO10	Mean temperature of warmest quarter
BIO11	Mean temperature of coldest quarter
BIO12	Annual precipitation
BIO13	Precipitation of wettest month
BIO14	Precipitation of driest month
BIO15	Precipitation seasonality
BIO16	Precipitation of wettest quarter
BIO17	Precipitation of driest quarter
BIO18	Precipitation of warmest quarter
BIO19	Precipitation of coldest quarter
GDD	Growing degree days (based on monthly average temperatures using Thom's formula)

Appendix S4: Table S2. Importance of the climatic variables for *Ambrosia artemisiifolia* and its six potential biological control insect agents (*Ophraella slobodkini*, *O. communa*, *Zygogramma suturalis, Z. disrupta*, *Epiblema strenuana* and *Tarachidia candefacta*) under current climate condition and under four future climate scenarios: HD-26 (HadGEM2-AO, rcp26); HD-85 (HadGEM2-AO, rcp85); IP-26 (IPSL-CM5A-LR, rcp26); IP-85 (IPSL-CM5A-LR, rcp85). 19 bioclimatic variables can be found in Table S1 in Supporting Information.

Calibration	modelling	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	gdd
A. artemisiifolia	GLM	1	0.017	0	0.751	0.624	0.834	0.316	0.008	0.078	0.546	0.53	0.152	0.294	0.073	0.007	0.066	0.115	0	0.023	0.598
	GBM	0.002	0.001	0.056	0.025	0	0	0.001	0	0.007	0.003	0.002	0	0.001	0.118	0.003	0.001	0.022	0.001	0	0.112
	RF	0.01	0.008	0.116	0.021	0.003	0.005	0.003	0.006	0.046	0.004	0.008	0.007	0.004	0.022	0.031	0.003	0.02	0.008	0.006	0.024
	MAXENT	0	0.044	0.029	0.102	0.053	0.017	0.08	0.029	0.066	0.03	0.027	0.05	0.048	0.079	0.01	0.007	0.011	0.009	0.042	0.069
O. communa	GLM	0	0	0	0	0	0.203	0.628	0.035	0.087	0	0.81	0	0	0.192	0.159	0.326	0.882	0	0	0.398
	GBM	0.007	0.022	0.009	0.009	0.027	0.001	0.059	0.001	0.027	0.003	0.002	0.001	0.022	0.002	0.002	0.005	0.036	0.001	0.032	0.003
	RF	0.003	0.014	0.012	0.025	0.011	0.003	0.029	0.003	0.01	0.006	0.003	0.005	0.009	0.009	0.007	0.008	0.015	0.003	0.01	0.004
	MAXENT	0.002	0.054	0.068	0.118	0.203	0.082	0.061	0.016	0.193	0.069	0.04	0.016	0.372	0.034	0.024	0.192	0.125	0.144	0.118	0.125
O. slobodkini	GLM	0.59	0	0	0.281	0	0	0	0	0	0	0	0	0	0.359	0	0	0	0.667	0	0
	GBM	0.027	0.026	0.018	0.053	0.083	0.018	0.018	0.071	0.046	0	0	0.01	0	0.074	0	0	0.028	0.055	0.111	0
	RF	0.009	0.027	0.046	0.042	0.055	0.083	0.037	0.036	0.028	0.062	0.055	0.054	0.055	0.055	0.014	0.044	0.027	0.092	0.037	0.081
	MAXENT	0.056	0.203	0	0	0	0	0.1	0.109	0	0.11	0	0	0	0.128	0	0	0.239	0.788	0.111	0.009
Z. disrupta	GLM	0.535	0	0.463	0.878	0	0	0	0	0	1	0	0	0	0	0	0	0	0.338	0	0
	GBM	0.001	0.006	0.012	0.003	0.101	0.001	0	0.001	0.001	0.032	0	0.004	0.085	0	0	0.002	0	0	0	0
	RF	0.002	0.005	0.001	0.001	0.003	0	0	0.001	0	0.009	0	0.001	0.011	0	0	0.002	0	0	0	0.002
	MAXENT	0.023	0	0.047	0.281	0.035	0.023	0	0.046	0.021	0.616	0	0.041	0.228	0	0.082	0.054	0	0	0.099	0.009
Z. suturalis	GLM	0	0	0	0.358	0	0.517	0	0	0	0	0	0	0	0.883	0	0	0	0	0	0
	GBM	0.003	0.001	0.001	0.021	0.007	0	0	0.003	0.001	0.003	0.002	0.036	0	0.264	0.01	0.001	0.01	0.01	0.003	0.001
	RF	0.001	0.001	0.002	0.005	0.002	0.001	0.001	0.003	0.001	0.003	0.001	0.016	0.002	0.045	0.004	0.002	0.013	0.007	0.001	0.003
	MAXENT	0	0	0	0.075	0	0.026	0.077	0	0	0	0	0.258	0	0.449	0.034	0.026	0.328	0.026	0.163	0
E. strenuana	GLM	0	0	0	0	0.209	0	0	0	0	0	0	0	0.708	0	0.089	0.53	0.71	0.276	0	0
	GBM	0.005	0.001	0.003	0.018	0.018	0.001	0	0.003	0.005	0.026	0.001	0.003	0.013	0.001	0.004	0.005	0.002	0.009	0.252	0
	RF	0.002	0.001	0.004	0.01	0.004	0.002	0.001	0.001	0.003	0.01	0.002	0.002	0.007	0.002	0.003	0.004	0.004	0.007	0.055	0.003
	MAXENT	0.69	0.288	0.005	0	0.067	0.008	0.011	0.01	0.407	0.345	0.007	0.005	0.013	0.142	0.549	0.068	0.001	0.582	0.012	0.01
T. candefacta	GLM	0.761	0	0	0.849	0.93	0.229	0.819	0	0.087	1	0.333	0.649	0.632	0	0.107	0.786	0.632	0	0.069	0
	GBM	0.001	0.004	0.111	0.004	0.036	0.003	0.008	0.003	0.003	0.145	0.001	0.006	0.002	0.002	0.014	0.002	0.001	0.001	0.01	0
	RF	0.003	0.006	0.03	0.009	0.025	0.002	0.006	0.005	0.003	0.059	0.004	0.003	0.003	0.003	0.01	0.003	0.003	0.003	0.005	0.009
	MAXENT	0	0.045	0.26	0.189	0.119	0.005	0.117	0.166	0.11	0.542	0	0.214	0.009	0.111	0.031	0.018	0.002	0.129	0.146	0.007

Calibration (HD-26)	modelling	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	gdd
A. artemisiifolia	GLM	1	0.191	0.563	0.829	0.94	0.774	0.936	0.007	0.027	0.317	0.261	0.247	0.018	0.091	0	0.238	0	0	0.009	0.832
	GBM	0.003	0.006	0.063	0.023	0	0.002	0.002	0	0.001	0.001	0.006	0.001	0.001	0.033	0.025	0.003	0.095	0	0	0.142
	RF	0.015	0.008	0.028	0.059	0.003	0.006	0.006	0.005	0.004	0.008	0.023	0.02	0.003	0.046	0.036	0.007	0.028	0.004	0.008	0.025
	MAXENT	0.003	0.027	0.041	0.24	0.026	0.021	0.134	0.003	0.027	0.038	0.087	0.088	0.016	0.052	0.016	0.074	0.034	0.059	0.042	0.144
O. communa	GLM	0	0.144	0.112	0	0.053	0.112	0	0.081	0	0	0	0.643	0.097	0.19	0.324	0.642	0.961	0.171	0	0
	GBM	0.003	0.03	0.024	0.01	0.012	0.001	0.048	0.002	0.001	0.008	0.006	0.002	0.048	0	0.001	0.003	0.116	0.002	0.015	0.003
	RF	0.002	0.019	0.013	0.006	0.005	0.003	0.011	0.003	0.002	0.006	0.004	0.003	0.008	0.004	0.005	0.004	0.021	0.002	0.007	0.004
	MAXENT	0	0.022	0.005	0.078	0.045	0.047	0.046	0.005	0.082	0.003	0.01	0.192	0.294	0.183	0.024	0.018	0.162	0.063	0.049	0.051
O. slobodkini	GLM	1	0	0.359	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.252	0	0.585
	GBM	0.375	0	0	0	0	0	0	0.041	0	0.022	0	0	0	0.4	0	0	0.006	0	0	0
	RF	0.001	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0.039	0	0	0.001
	MAXENT	0	0.1	0	0.049	0	0	0	0.152	0.012	0.265	0	0	0.137	0.326	0	0	0.028	0.132	0	0
Z. disrupta	GLM	0	0	0	0	0.307	0	0	0.186	0.171	1	0	0.274	0.243	0	0	0	0	0.15	0	0
	GBM	0.001	0.003	0.001	0	0	0	0	0.001	0	0.679	0	0.079	0.002	0.001	0	0	0	0	0.003	0
	RF	0.002	0.002	0.003	0.001	0	0	0.001	0.002	0	0.01	0	0.003	0.001	0.003	0	0.002	0	0.001	0.001	0.002
	MAXENT	0	0.096	0	0	0.265	0	0	0.076	0.296	0.725	0.049	0.114	0	0.029	0.106	0.077	0	0	0.217	0
Z. suturalis	GLM	0	0	0	0	0	0.227	0	0	0	0.418	0	0	0	0.084	0.082	0	0	0.496	0	0
	GBM	0.001	0.004	0	0	0.028	0	0.001	0.005	0	0.053	0	0.01	0	0.001	0.009	0	0.002	0.053	0.001	0
	RF	0.002	0.002	0	0.001	0.009	0	0.001	0.006	0	0.013	0.001	0.006	0.001	0.001	0.002	0.001	0.002	0.008	0.001	0.002
	MAXENT	0	0.162	0.047	0.051	0.102	0.11	0.047	0.356	0.231	0.319	0.057	0.073	0	0.126	0.095	0	0	0.297	0.232	0.06
E. strenuana	GLM	0	0.19	0	0	0.33	0.157	0	0.437	0	0.698	0	0	0	0	0	0	0	0	0	0
	GBM	0.009	0.016	0.005	0.015	0.014	0.001	0.001	0.028	0.005	0.044	0	0.004	0.001	0.002	0.023	0.01	0.004	0.014	0.081	0.001
	RF	0.003	0.005	0.004	0.008	0.005	0.001	0.002	0.021	0.006	0.006	0.001	0.002	0.003	0.005	0.011	0.009	0.006	0.004	0.018	0.003
	MAXENT	0	0.009	0	0.026	0	0	0	0	0	0.025	0	0	0.025	0	0	0	0	0.969	0.004	0
T. candefacta	GLM	0	0	0	0.533	0	0.388	0	0	0	0.859	0	0	0.258	0	0	0.51	0.125	0	0.258	0.511
	GBM	0.003	0.003	0.015	0.006	0.111	0.001	0.001	0.004	0.001	0.017	0.001	0.002	0.003	0.002	0.002	0.003	0.027	0.004	0.022	0.005
	RF	0.006	0.004	0.005	0.006	0.015	0.001	0.003	0.003	0.001	0.017	0.003	0.003	0.003	0.003	0.003	0.004	0.009	0.003	0.008	0.009
	MAXENT	0.006	0.015	0.083	0.064	0.266	0.055	0.134	0.059	0.105	0.118	0.062	0.065	0.073	0.146	0.07	0.058	0.438	0.134	0.141	0.208

Calibration (HD-85)	modelling	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	gdd
A. artemisiifolia	GLM	1	0.027	0.305	0.817	0	0.667	0.114	0.003	0.016	0	0.514	0	0	0.018	0	0	0.122	0.021	0	0.816
	GBM	0.001	0	0.043	0.02	0.003	0.001	0	0	0	0.001	0.012	0	0	0	0.006	0.002	0.206	0.004	0.006	0.12
	RF	0.015	0.005	0.073	0.028	0.003	0.008	0.004	0.003	0.004	0.006	0.02	0.009	0.003	0.008	0.042	0.006	0.036	0.04	0.01	0.029
	MAXENT	0.008	0.017	0.01	0.199	0.062	0.06	0.041	0.006	0.03	0.053	0.098	0.016	0.034	0.016	0.04	0.05	0.067	0.063	0.029	0.096
O. communa	GLM	0	0	0.267	0.979	0.084	0.144	0.74	0	0	0.61	0.871	0	0.106	0.23	0.174	0.532	0.992	0	0	0
	GBM	0.004	0.021	0.041	0.014	0.003	0.002	0.008	0.012	0.001	0.022	0.003	0.001	0.013	0.001	0.001	0.002	0.196	0	0.013	0.003
	RF	0.003	0.014	0.021	0.006	0.004	0.003	0.006	0.011	0.003	0.009	0.006	0.004	0.007	0.006	0.003	0.006	0.044	0.003	0.006	0.007
	MAXENT	0.019	0.078	0.164	0.163	0.1	0.062	0.071	0.202	0.074	0.075	0.109	0.009	0.105	0.047	0.087	0.046	0.171	0.068	0.089	0.056
O. slobodkini	GLM	0	0	0.155	0	0	0	0	0	0	0.498	0	0	0	0	0	0	0	0.496	0	0
	GBM	0.089	0	0	0	0	0	0	0.014	0	0.043	0	0	0	0	0	0	0	0.206	0	0
	RF	0.001	0	0	0	0	0	0	0.001	0	0.079	0	0	0	0	0	0	0	0.087	0	0.002
	MAXENT	0	0	0	0	0	0	0	0.416	0	0	0	0	0	0	0	0	0.025	0.449	0.092	0
Z. disrupta	GLM	0	0.087	0	0	0	0	0	0	0	0.735	0	0.542	0	0	0	0	0	0	0	0
	GBM	0	0.002	0.005	0	0	0	0	0	0.001	0.625	0	0.153	0	0	0.001	0.001	0	0	0.002	0
	RF	0.005	0.031	0.037	0.003	0.007	0.002	0.014	0.014	0.007	0.01	0.003	0.012	0.043	0.013	0.016	0.014	0.008	0.024	0.005	0.005
	MAXENT	0	0.005	0	0	0	0	0	0.058	0.024	0.837	0.153	0.098	0	0	0.019	0	0.015	0.068	0.179	0
Z. suturalis	GLM	0	0.097	0	0	0	0	0.305	0.217	0	0.63	0	0.191	0.214	0.158	0.333	0.968	0	0.179	0	0
	GBM	0.002	0.011	0.001	0.008	0.01	0.001	0.025	0.001	0.004	0.39	0.003	0.019	0	0.028	0.003	0.002	0.005	0.008	0.012	0.001
	RF	0.001	0.002	0	0.002	0.004	0.001	0.007	0	0.001	0.03	0.001	0.003	0	0.011	0.002	0.002	0.004	0.001	0.015	0.001
	MAXENT	0.079	0.152	0.047	0.082	0	0.029	0.547	0.017	0	0.291	0.042	0.091	0	0.078	0	0.17	0.173	0.022	0.249	0.091
E. strenuana	GLM	0	0.144	0	0	0	0.363	0	0.185	0	0	0	0	0	0	0	0.371	0	0	0	0.328
	GBM	0.032	0.039	0.003	0.005	0.01	0.003	0.005	0.003	0.009	0.029	0.002	0.003	0.003	0.006	0.001	0.013	0.003	0.008	0.104	0.004
	RF	0.01	0.026	0.003	0.003	0.006	0.002	0.004	0.003	0.003	0.009	0.003	0.001	0.003	0.005	0.002	0.004	0.006	0.005	0.029	0.01
	MAXENT	0.149	0.24	0.045	0.253	0.073	0.083	0.112	0.069	0.147	0.142	0.116	0.267	0.069	0.108	0.006	0.325	0.102	0.146	0.44	0.366
T. candefacta	GLM	0	0	0	0.419	0	0.112	0	0.039	0.072	0.794	0	0.151	0	0.179	0.123	0	0.638	0	0	0.672
	GBM	0.006	0.002	0.001	0.022	0.003	0.002	0.001	0.002	0.007	0.146	0.006	0.004	0.002	0.001	0.002	0.002	0.004	0.01	0.019	0.005
	RF	0.007	0.001	0.001	0.008	0.006	0.003	0.002	0.002	0.004	0.042	0.004	0.003	0.002	0.005	0.002	0.003	0.005	0.008	0.008	0.011
	MAXENT	0.002	0.023	0.039	0.236	0.177	0.176	0.013	0.103	0.153	0.197	0.282	0.055	0.121	0.088	0.124	0.19	0.183	0.087	0.079	0.164

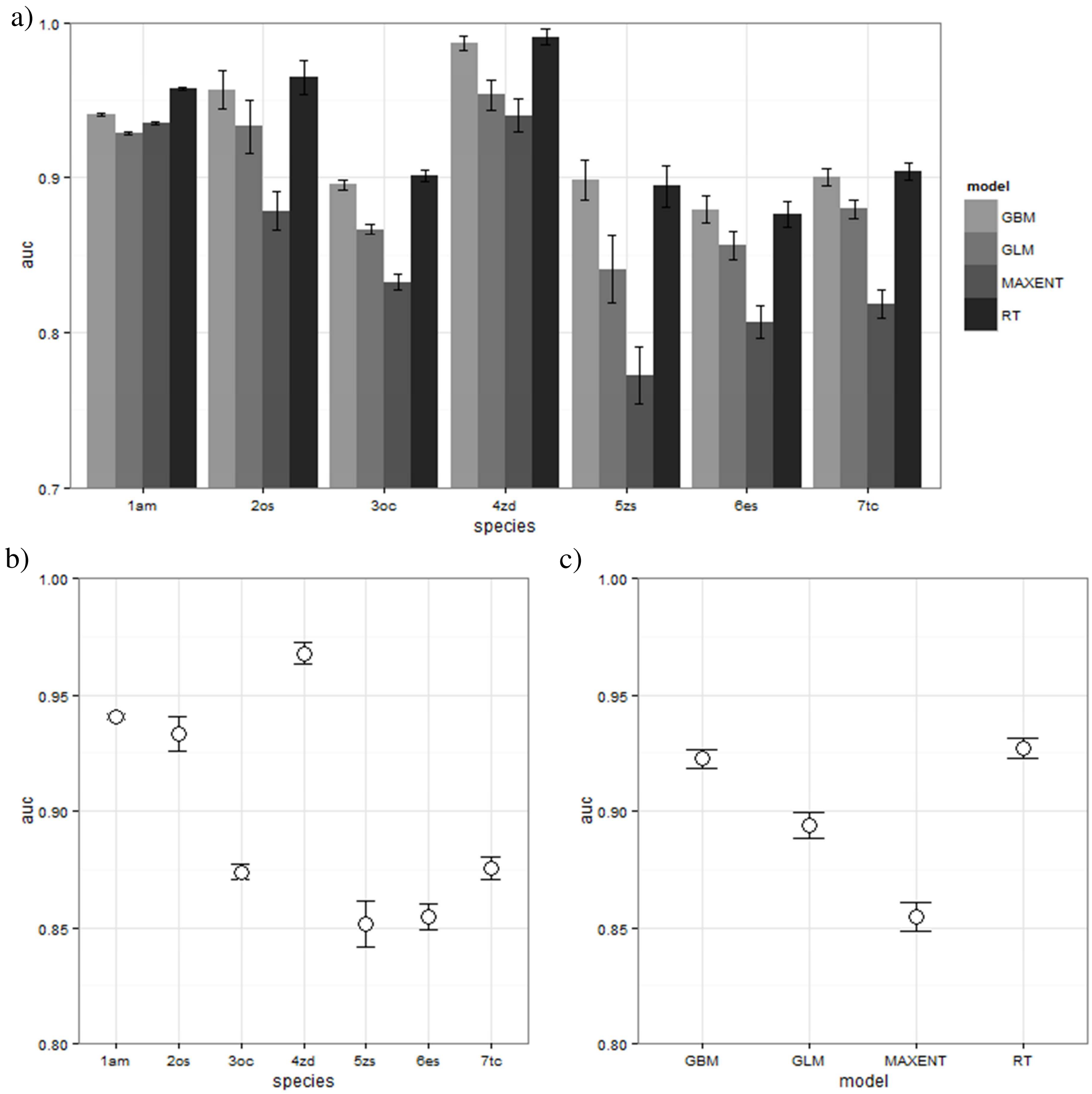
Calibration (IP-26)	modelling	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	gdd
A. artemisiifolia	GLM	1	0	0.118	0.581	0.922	0.725	0.813	0.004	0.039	0	0.272	0.075	0.19	0.087	0.017	0	0.113	0.017	0.058	0.779
	GBM	0.001	0.004	0.049	0.035	0.001	0.003	0.002	0	0.002	0.004	0.001	0.001	0.002	0.082	0.003	0.001	0.029	0.001	0	0.132
	RF	0.011	0.009	0.098	0.048	0.003	0.006	0.003	0.004	0.01	0.006	0.007	0.015	0.004	0.032	0.025	0.003	0.02	0.016	0.006	0.029
	MAXENT	0	0.025	0.017	0.08	0.051	0.033	0.019	0.005	0.044	0.055	0.031	0.011	0.044	0.075	0.029	0.015	0.019	0.029	0.097	0.054
O. communa	GLM	0	0.138	0	0	0.138	0.038	0	0.086	0.209	0.448	0	0	0.243	0.594	0.179	0.328	0	0.121	0.229	0
	GBM	0.005	0.04	0.002	0.003	0.017	0.003	0.058	0.001	0.05	0.003	0.003	0.002	0.038	0.003	0.003	0.003	0.012	0.003	0.007	0.023
	RF	0.006	0.014	0.006	0.005	0.009	0.005	0.023	0.003	0.023	0.004	0.003	0.004	0.007	0.005	0.005	0.005	0.009	0.003	0.004	0.009
	MAXENT	0.002	0.021	0	0.124	0.222	0.176	0.064	0.153	0.24	0.157	0.069	0.058	0.22	0.223	0.116	0	0.047	0.106	0.058	0.179
O. slobodkini	GLM	0	0	0	0	0.991	0	0	0	0	0	0	0	0	0	0	0	0	0.166	0	0
	GBM	0.182	0.063	0.009	0	0.036	0.154	0	0.138	0.027	0.014	0.036	0.027	0.045	0.073	0.009	0.018	0	0.429	0.005	0
	RF	0.002	0	0.009	0	0.002	0.006	0	0.04	0	0.001	0.012	0.01	0	0	0	0.002	0	0.261	0	0.004
	MAXENT	0	0.052	0	0	0.065	0	0	0.117	0	0.056	0.066	0	0	0	0	0	0.066	0.778	0	0
Z. disrupta	GLM	0.921	0.811	0.849	0	0.298	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.33
	GBM	0	0.002	0.009	0.012	0.042	0	0	0.008	0	0.342	0	0.002	0	0	0	0.001	0	0	0.001	0
	RF	0.004	0.012	0.015	0.005	0.041	0.001	0.006	0.01	0.001	0.084	0.002	0.007	0	0	0.001	0.003	0.002	0.001	0.001	0.018
	MAXENT	0	0.073	0.028	0.039	0	0	0	0.171	0.03	0.683	0	0.048	0	0	0.05	0	0.175	0	0.367	0.082
Z. suturalis	GLM	0	0	0	0	0	0	0	0	0.185	0.512	0.427	0	0	0.159	0	0	0	0.2	0.446	0.578
	GBM	0.002	0.001	0	0.001	0.003	0.002	0.001	0.008	0.002	0.036	0	0.229	0	0.029	0.001	0.001	0.006	0.002	0	0
	RF	0.003	0.001	0	0.001	0.002	0	0	0.004	0.001	0.009	0	0.024	0	0.014	0.001	0.004	0.004	0.002	0.001	0.004
	MAXENT	0	0.234	0.086	0.031	0	0.06	0.056	0.342	0.034	0.383	0.06	0.458	0	0	0.109	0	0.111	0.194	0.406	0
E. strenuana	GLM	1	0	0.587	1	0.484	0.629	0	0	0	0.699	0	0	0.587	0.102	0.672	0.492	0.393	0	0.748	0.859
	GBM	0.004	0.001	0.001	0.064	0.014	0.003	0.001	0.003	0.007	0.042	0	0.003	0.009	0.002	0.01	0.007	0.001	0.021	0.186	0
	RF	0.002	0.001	0.002	0.02	0.006	0.001	0.002	0.001	0.007	0.012	0.002	0.002	0.007	0.003	0.004	0.006	0.002	0.007	0.045	0.003
	MAXENT	0	0	0	0.199	0.033	0.018	0.014	0	0.018	0.076	0.02	0.002	0.006	0.05	0.162	0.012	0.063	0.147	0.184	0
T. candefacta	GLM	0	0.313	0	0	0.356	0.203	0.694	0	0.124	1	0.849	0	0	0	0	0	0	0	0	0
	GBM	0	0.001	0.03	0.01	0.002	0.003	0.011	0.004	0.003	0.367	0.001	0.019	0.005	0.002	0.005	0.001	0.001	0.001	0.017	0.001
	RF	0.003	0.005	0.006	0.012	0.009	0.003	0.006	0.007	0.003	0.082	0.003	0.004	0.004	0.003	0.003	0.002	0.005	0.002	0.008	0.007
	MAXENT	0	0.049	0.167	0.293	0.136	0.137	0.098	0.12	0.016	0.308	0.195	0.263	0.276	0.115	0.079	0.021	0.048	0.094	0.083	0.104

Calibration (IP-85)	modelling	Bio1	Bio2	Bio3	Bio4	Bio5	Bio6	Bio7	Bio8	Bio9	Bio10	Bio11	Bio12	Bio13	Bio14	Bio15	Bio16	Bio17	Bio18	Bio19	gdd
A. artemisiifolia	GLM	1	0.267	0.535	0.835	0.13	0.599	0.41	0.003	0.062	0.436	0.639	0.061	0.078	0.16	0.008	0	0.169	0.01	0	0.765
	GBM	0.001	0.003	0.055	0.029	0.001	0	0.002	0	0.004	0.003	0.011	0	0.001	0.12	0.001	0.002	0.015	0	0.001	0.152
	RF	0.012	0.006	0.091	0.015	0.003	0.006	0.003	0.003	0.007	0.006	0.007	0.008	0.003	0.015	0.036	0.006	0.018	0.007	0.006	0.024
	MAXENT	0.001	0.04	0.061	0.133	0.024	0.085	0.07	0.016	0.052	0.013	0.042	0.043	0.08	0.13	0.015	0.108	0.035	0.025	0.035	0.132
O. communa	GLM	0	0	0.209	0.12	0	0.103	0	0	0.123	0.186	0.81	0.587	0.455	0.795	0	0.676	0.35	0.358	0.128	0.593
	GBM	0.006	0.006	0.03	0.006	0.011	0	0.083	0.002	0.011	0.001	0.003	0.003	0.008	0.002	0.009	0.008	0.032	0.004	0.013	0.011
	RF	0.005	0.007	0.01	0.009	0.007	0.002	0.018	0.002	0.005	0.003	0.004	0.004	0.005	0.005	0.007	0.006	0.01	0.004	0.005	0.007
	MAXENT	0.007	0.093	0.08	0.027	0.254	0.044	0.189	0.106	0.115	0.087	0.155	0.07	0.046	0.087	0.099	0.188	0.073	0.038	0.123	0.127
O. slobodkini	GLM	0	0	0.212	0	0	0	0	0.954	0	0	0	0	0.375	0	0	0	0	0	0	0
	GBM	0.173	0	0.008	0	0.114	0.17	0	0.05	0	0	0	0	0.053	0.006	0	0	0	0.009	0	0
	RF	0.001	0	0	0.002	0.004	0.011	0	0.005	0.001	0.001	0.002	0	0	0	0	0.001	0	0.001	0.001	0.001
	MAXENT	0.039	0	0.05	0.034	0	0.009	0	0.645	0	0	0.029	0	0	0	0.028	0	0	0.471	0	0.071
Z. disrupta	GLM	0	0	0.347	0.308	0	0	0	0	0	0.887	0	0	0	0	0	0	0.171	0	0	0
	GBM	0	0.002	0.004	0.002	0.084	0.005	0.001	0	0.003	0.296	0	0.001	0	0	0	0	0	0	0.001	0
	RF	0.001	0.013	0.012	0	0.005	0.001	0.002	0.001	0.001	0.039	0.001	0	0.001	0	0	0.001	0	0.002	0	0
	MAXENT	0	0.02	0	0	0.179	0	0	0.073	0	0.762	0.029	0.043	0.078	0.02	0	0	0.024	0	0.063	0
Z. suturalis	GLM	0	0	0	0	0	0.11	0	0.047	0	0.287	0	0.52	0	0	0	0	0	0	0.065	0
	GBM	0.001	0.001	0.001	0.004	0.007	0	0	0.032	0	0.045	0	0.052	0.001	0.001	0.002	0.01	0.001	0.008	0.008	0
	RF	0.002	0	0	0.003	0.003	0	0.001	0.01	0.001	0.013	0	0.009	0.002	0.001	0	0.007	0.003	0.005	0.002	0.003
	MAXENT	0.064	0.05	0.102	0.119	0	0.2	0.069	0.106	0.034	0.267	0.099	0.067	0	0.051	0.17	0.17	0.155	0.049	0.128	0.097
E. strenuana	GLM	0.999	0	0	0	0	0	0.109	0	0	0	0	0	0.634	0.125	0	0.283	0	0	0	0.934
	GBM	0.012	0.006	0.003	0.024	0.008	0.003	0.003	0.003	0.006	0.012	0.001	0.001	0.004	0.002	0.009	0.003	0	0.071	0.12	0.002
	RF	0.006	0.004	0.003	0.007	0.004	0.002	0.003	0.003	0.003	0.004	0.004	0.001	0.001	0.004	0.004	0.002	0.005	0.01	0.051	0.007
	MAXENT	0.018	0.227	0	0.212	0.16	0.175	0.184	0.007	0.055	0.094	0	0.009	0.06	0.073	0.123	0	0.006	0.216	0.327	0.181
T. candefacta	GLM	0	0.267	0	0	0.317	0.361	0	0.045	0.138	0.873	0	0.438	0	0	0	0.093	0	0	0.582	0
	GBM	0.006	0.006	0.006	0.022	0.002	0.001	0.011	0.003	0.007	0.083	0.002	0.003	0.008	0.004	0.009	0.003	0.001	0.001	0.011	0.003
	RF	0.007	0.002	0.004	0.011	0.008	0.003	0.006	0.002	0.004	0.025	0.004	0.003	0.004	0.006	0.005	0.003	0.003	0.003	0.006	0.006
	MAXENT	0.005	0.106	0.093	0.263	0.07	0.052	0.045	0.105	0.153	0.143	0.136	0.227	0.091	0.189	0.064	0.172	0.046	0.108	0.234	0.161

Appendix S4: Table S3. List of bioclimatic variables used in our model for *Ambrosia artemisiifolia* and its six potential biological control candidates (*Ophraella slobodkini*, *O. communa*, *Zygogramma suturalis, Z. disrupta*, *Epiblema strenuana* and *Tarachidia candefacta*) under current and four future climatic scenarios.

Species	Current climate variables	*Future climate variables			
		HD-26	HD-85	IP-26	IP-85
A. artemisiifolia	1,3,4,5,6,7,9,14,gdd	1,3,4,7,11,14,15,17,gdd	1,3,4,6,11,15,17,18,gdd	1,3,4,5,6,7,14,17,gdd	1,3,4,6,11,14,15,17,gdd
O. communa	5,7,9,11,13,16,17,19,gdd	2,3,5,12,13,15,16,17,19	2,3,4,7,8,10,11,13,17,gdd	2,5,7,9,10,13,14,16,gdd	3,5,7,11,12,14,16,17,gdd
O. slobodkini	6,17,gdd	8,18,gdd	8,18,gdd	5,11,18,gdd	6,18,gdd
Z. disrupta	1,2,3,4,5,10,13,16,18	2,5,8,9,10,12,13,14,19	2,3,8,10,11,12,13,18,19	1,2,3,5,9,10,17,19,gdd	2,3,4,5,8,10,13,17,19
Z. suturalis	4,6,7,12,14,15,17,18,19	5,8,9,10,12,13,15,17,18	2,5,8,10,11,12,14,15,16	1,6,7,8,12,14,16,17,gdd	4,6,8,10,12,16,17,18,19
E. strenuana	1,10,13,15,16,17,18,19,gdd	2,4,5,8,10,15,16,17,19	1,2,4,6,8,10,16,19,gdd	1,4,5,10,13,15,16,18,19	1,2,4,7,13,16,18,19,gdd
T. candefacta	3,4,5,7,10,12,15,16,19	4,5,6,10,13,16,17,19,gdd	4,6,9,10,11,17,18,19,gdd	2,3,4,5,7,10,11,12,13	2,4,5,6,9,10,12,14,19

The variable numbers represent the WORLDCLIM bioclimatic data and gdd (Table S1)
*The four future climate scenarios of downscaled IPPC5 (CMIP5) data at 5 minutes spatial resolution in 2050 (average for 2041-2060): HD-26 (HadGEM2-AO, rcp26); HD-85 (HadGEM2-AO, rcp85); IP-26 (IPSL-CM5A-LR, rcp26); IP-85 (IPSL-CM5A-LR, rcp85) (http://www.worldclim.org/cmip5_5m).



Appendix S4: Fig. S1. Differences in discrimination ability (AUC) across all levels (i.e. species and models); a) across both species and models, (b) across species, (c) across models. Data are presented as means ± standard error of the mean.

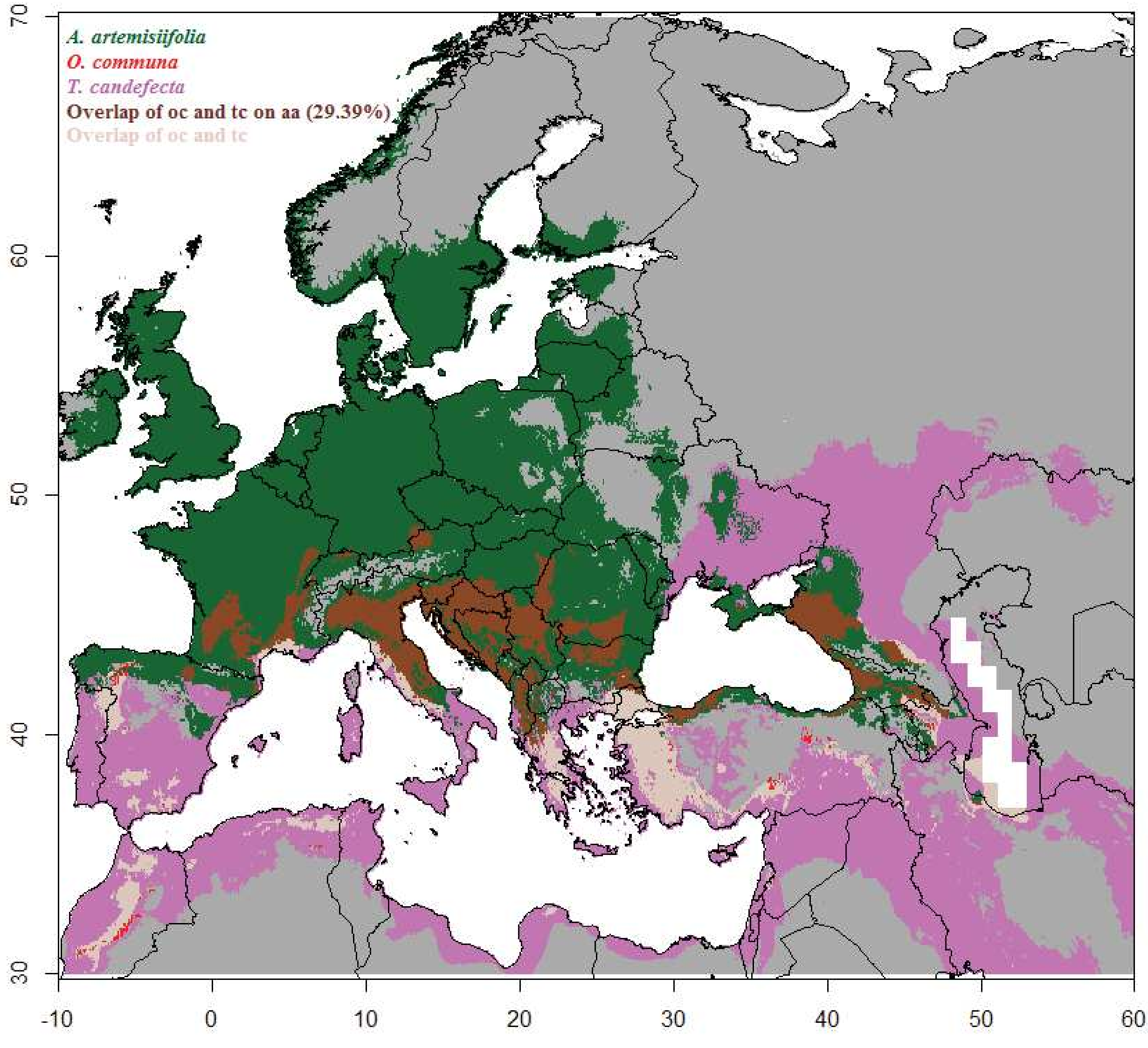
Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

Appendix S5: Table S1. List of overlap percentage of all combination of two and three biocontrol on the area of *A. artemisiifolia* in Europe under current climate condition.

Species Combination			Percentage Overlap
	O. communa	*Z. suturalis*	18.83%
	O. communa	*Z. disrupta*	18.08%
	O. communa	*E. strenuana*	21.62%
	O. communa	*T. candefacta*	29.39%
	Z. suturalis	*Z. disrupta*	5.54%
	Z. suturalis	*E. strenuana*	13.62%
	Z. suturalis	*T. candefacta*	25.72%
	Z. disrupta	*E. strenuana*	11.54%
	Z. disrupta	*T. candefacta*	25.46%
	E. strenuana	*T. candefacta*	28.14%
O. communa	*Z. suturalis*	*Z. disrupta*	18.84%
O. communa	*Z. suturalis*	*E. strenuana*	22.19%
O. communa	*Z. suturalis*	*T. candefacta*	29.56%
O. communa	*Z. disrupta*	*E. strenuana*	21.62%
O. communa	*Z. disrupta*	*T. candefacta*	29.39%
O. communa	*E. strenuana*	*T. candefacta*	31.19%
Z. suturalis	*Z. disrupta*	*E. strenuana*	13.65%
Z. suturalis	*Z. disrupta*	*T. candefacta*	25.72%
Z. suturalis	*E. strenuana*	*T. candefacta*	28.36%
Z. disrupta	*E. strenuana*	*T. candefacta*	28.14%

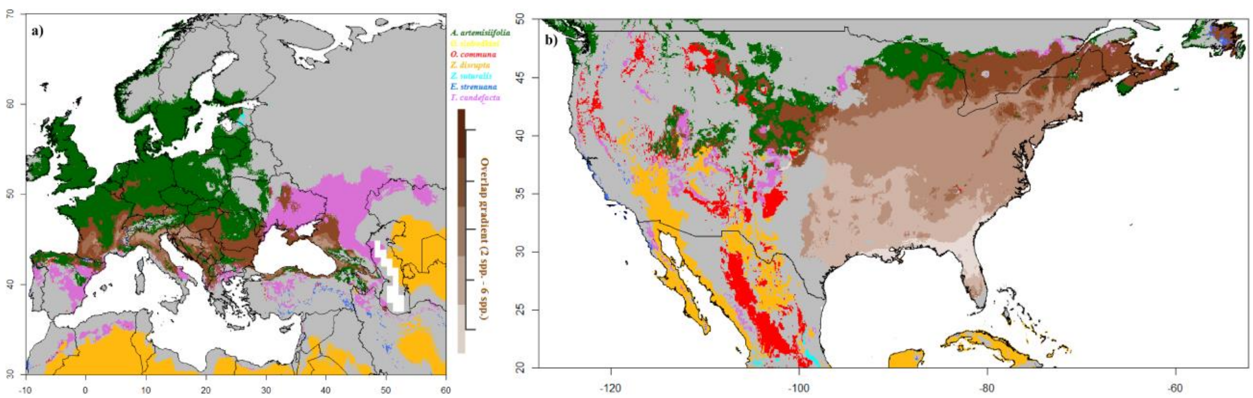
Appendix S5: Fig. S1. Geographical predictions of overlap of Ambrosia artemisiifolia and its potential biocontrol agent herbivores *Ophraella communa*, and *Tarachidia candefacta* that are predicted to cover the largest area as a combination under future climatic scenarios. The climatic suitability (dark green, red, and orchid) indicates the optimal threshold of the percentage of models predicting each species. Dark sienna indicates the "overlap" region of the invasive *A. artemisiifolia* and both *O. communa* and *T. candefacta*. Light sienna indicates the overlap area of *O. communa* and *T. candefacta*. Models calibrated in Europe only.



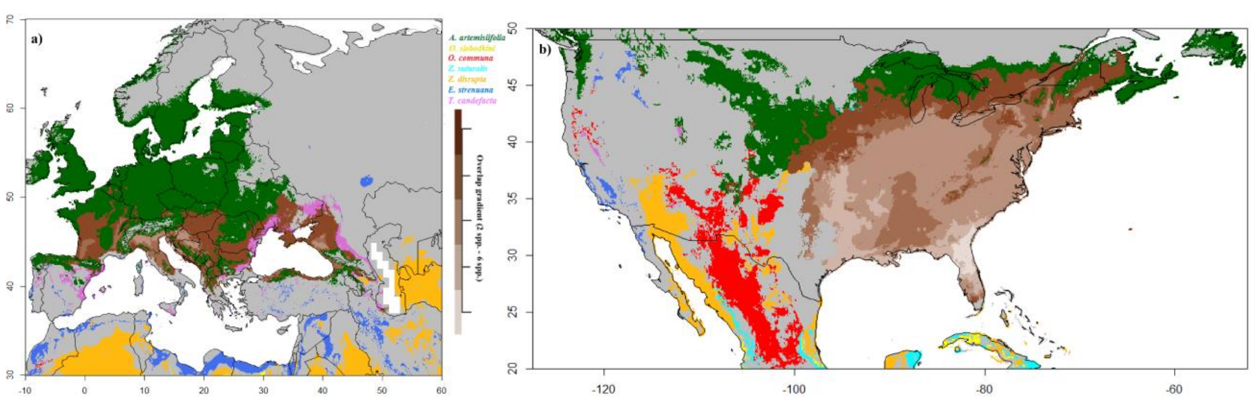
Climatic suitability ranking of biological control candidates: a biogeographic approach for ragweed management in Europe

Yan Sun, Olivier Brönnimann, George K. Roderick, Alexander Poltavsky, Suzanne T. E. Lommen and Heinz Müller-Schärer

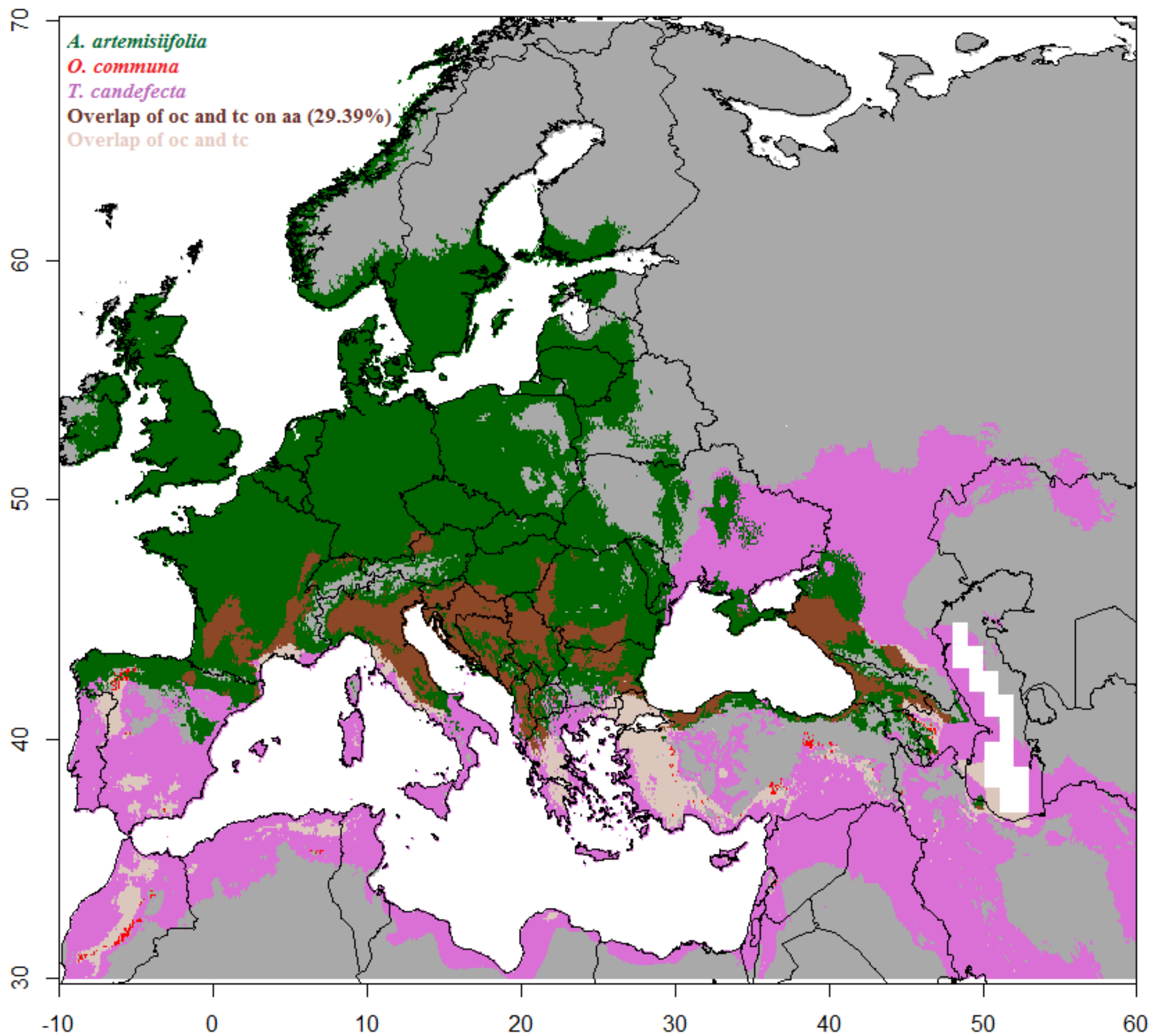
Appendix S6: Fig. S1. Geographical predictions of overlap of *Ambrosia artemisiifolia* and its potential biocontrol agent herbivores *Ophraella slobodkini*, *O. communa*, *Zygogramma suturalis*, *Z. disrupta*, *Epiblema strenuana* and *Tarachidia candefacta* under present climatic scenarios. The climatic suitability (dark green, yellow, red, cyan, goldenrod, blue and orchid) indicates the optimal threshold of the percentage of models predicting each species. The "overlap" region indicate where the invasive *A. artemisiifolia* and its potential biocontrol agents (dark to light sienna indicating one to six herbivore species). Models calibrated in Europe only (a) and models calibrated in North America only (b).



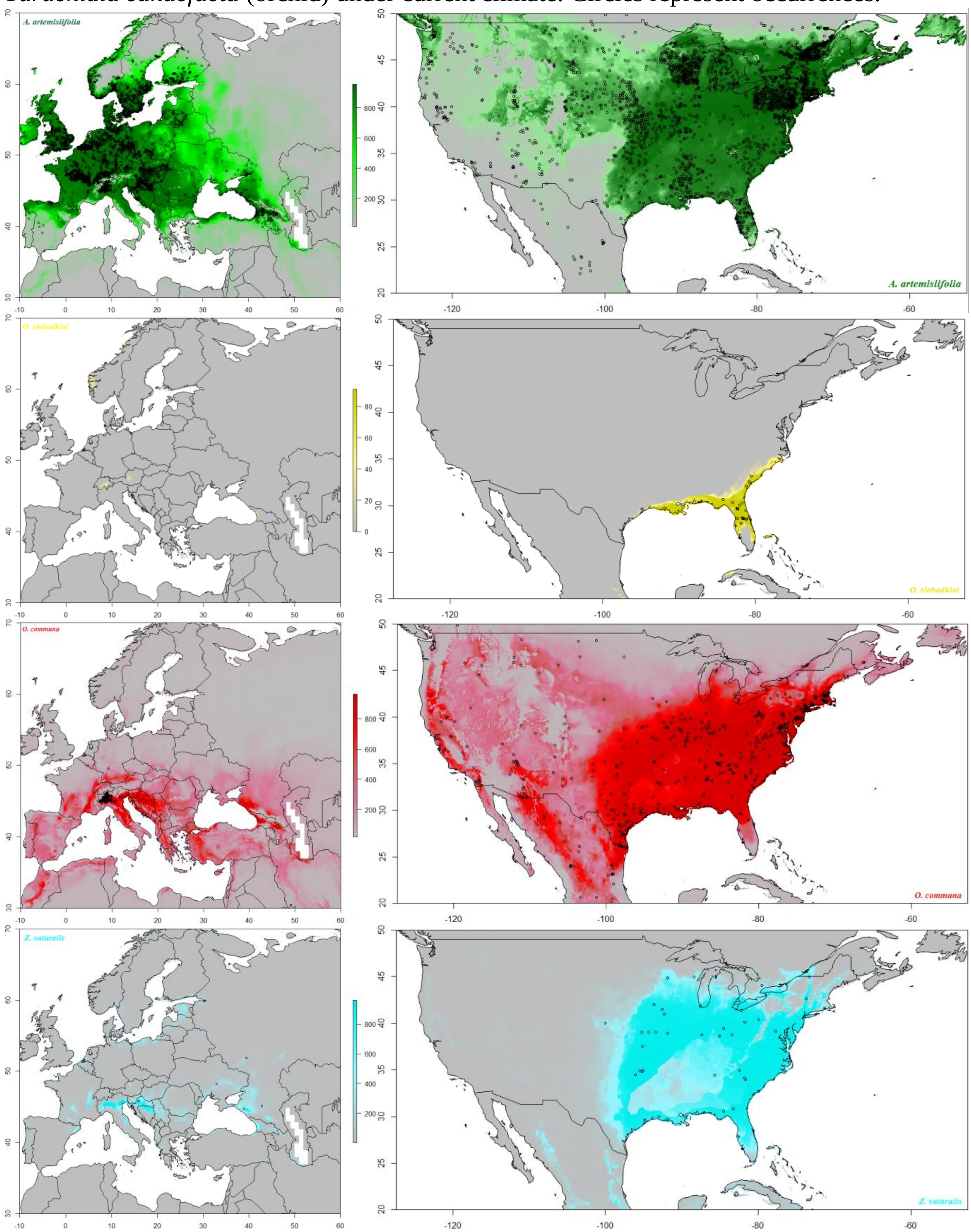
Appendix S6: Fig. S2. Geographical predictions of overlap of *Ambrosia artemisiifolia* and its potential biocontrol agent herbivores *Ophraella slobodkini*, *O. communa*, *Zygogramma suturalis*, *Z. disrupta*, *Epiblema strenuana* and *Tarachidia candefacta* under future climatic scenarios. The climatic suitability (dark green, yellow, red, cyan, goldenrod, blue and orchid) indicates the optimal threshold of the percentage of models predicting each species. The "overlap" region indicate where the invasive *A. artemisiifolia* and its potential biocontrol agents (dark to light sienna indicating one to six herbivore species). Models calibrated in Europe only (a) and models calibrated in North America only (b).

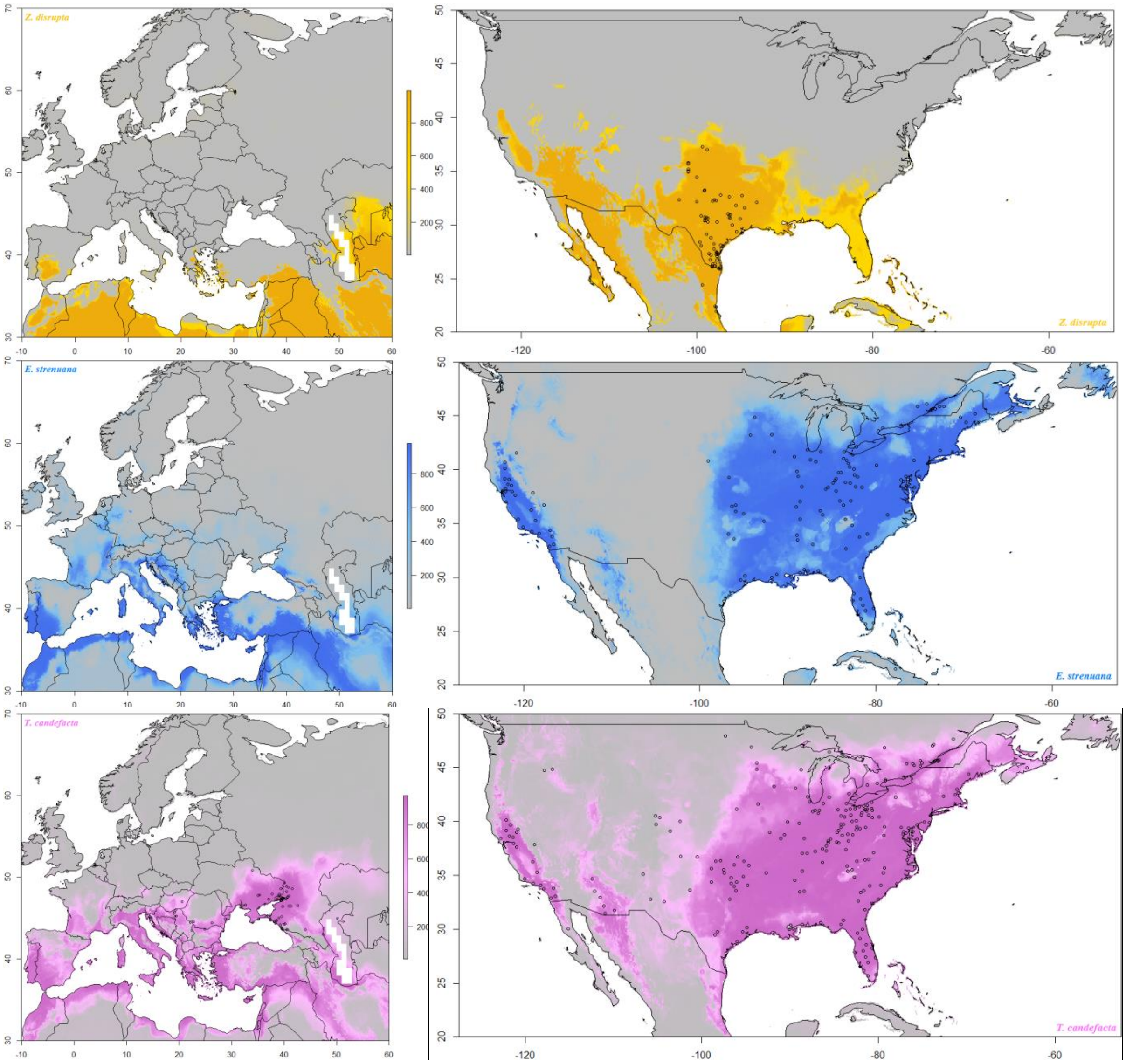


Appendix S6: Fig. S3. Geographical predictions of overlap of *Ambrosia artemisiifolia* and its potential biocontrol agent herbivores *Ophraella communa*, and *Tarachidia candefacta* that are predicted to cover the largest area as a combination under future climatic scenarios. The climatic suitability (dark green, red, and orchid) indicates the optimal threshold of the percentage of models predicting each species. Dark sienna indicates the "overlap" region of the invasive *A. artemisiifolia* and both *O. communa* and *T. candefacta*. Light sienna indicates the overlap area of *O. communa* and *T. candefacta.* Models calibrated in Europe only.

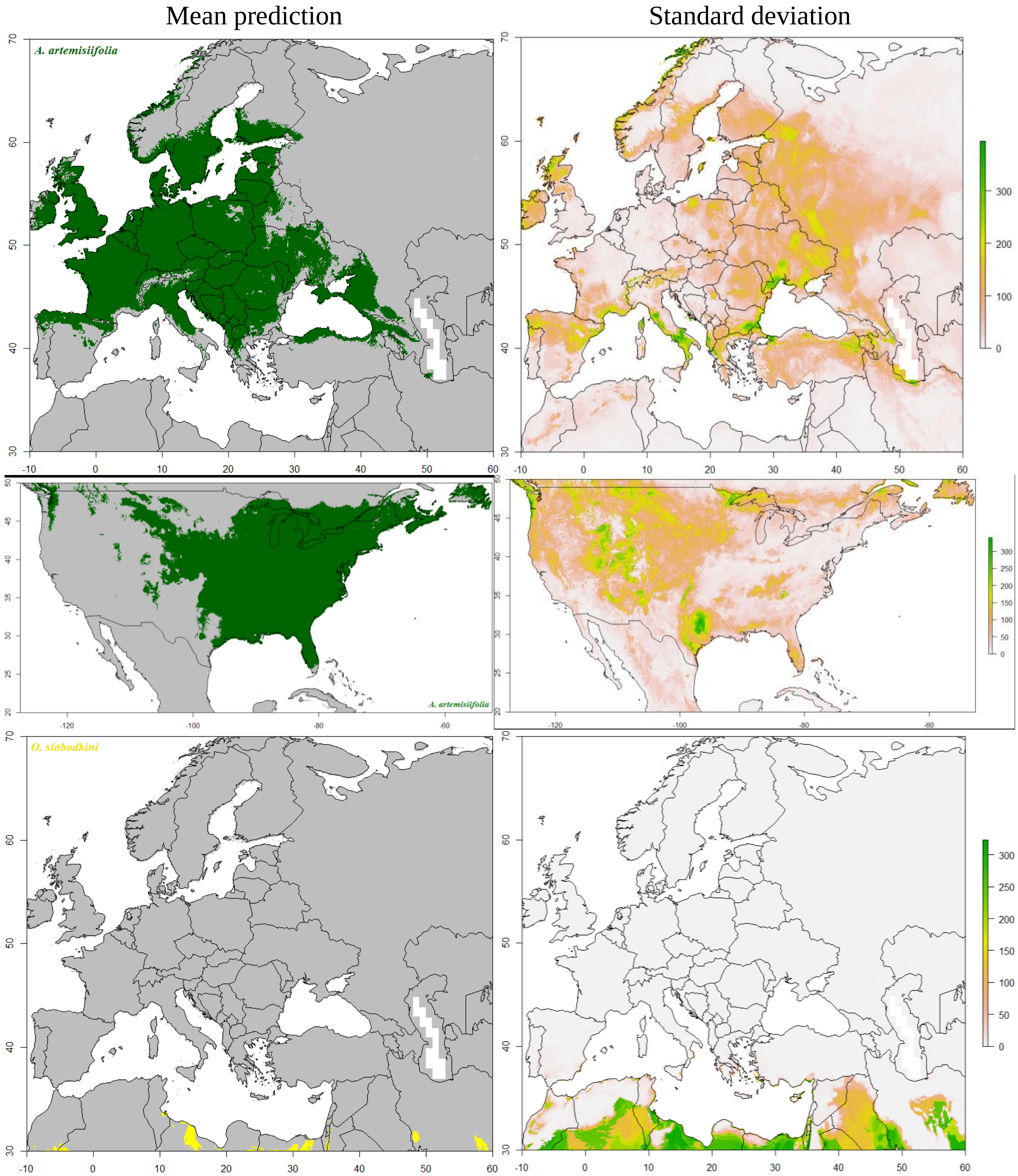


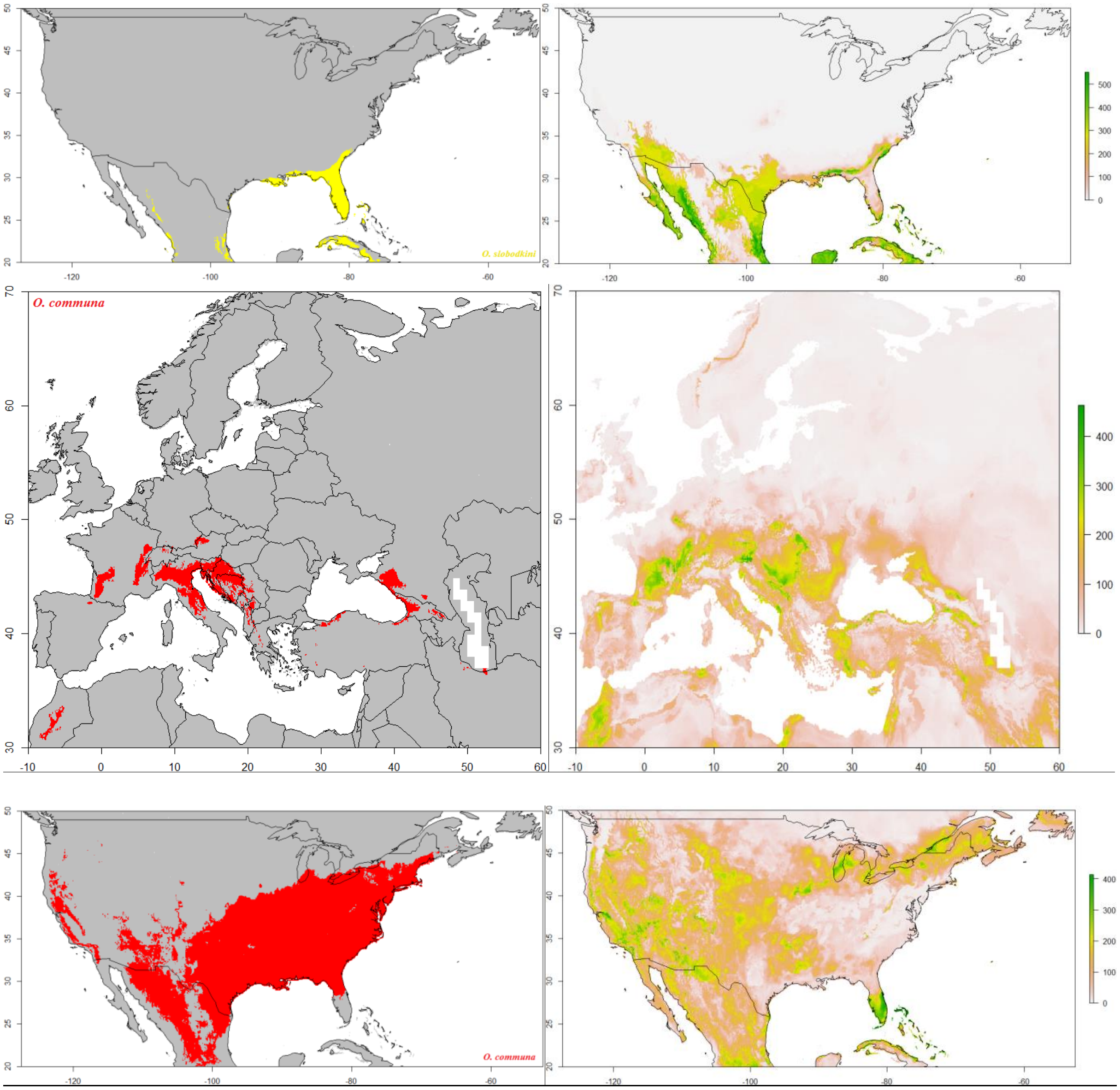
Appendix S6: Fig. S4. Geographical predictions of *Ambrosia artemisiifolia* (dark green) and its potential biocontrol agent herbivores *Ophraella slobodkini* (yellow), *O. communa* (red), *Zygogramma suturalis* (cyan), *Z. disrupta* (goldenrod), *Epiblema strenuana* (blue) and *Tarachidia candefacta* (orchid) under current climate. Circles represent occurrences.

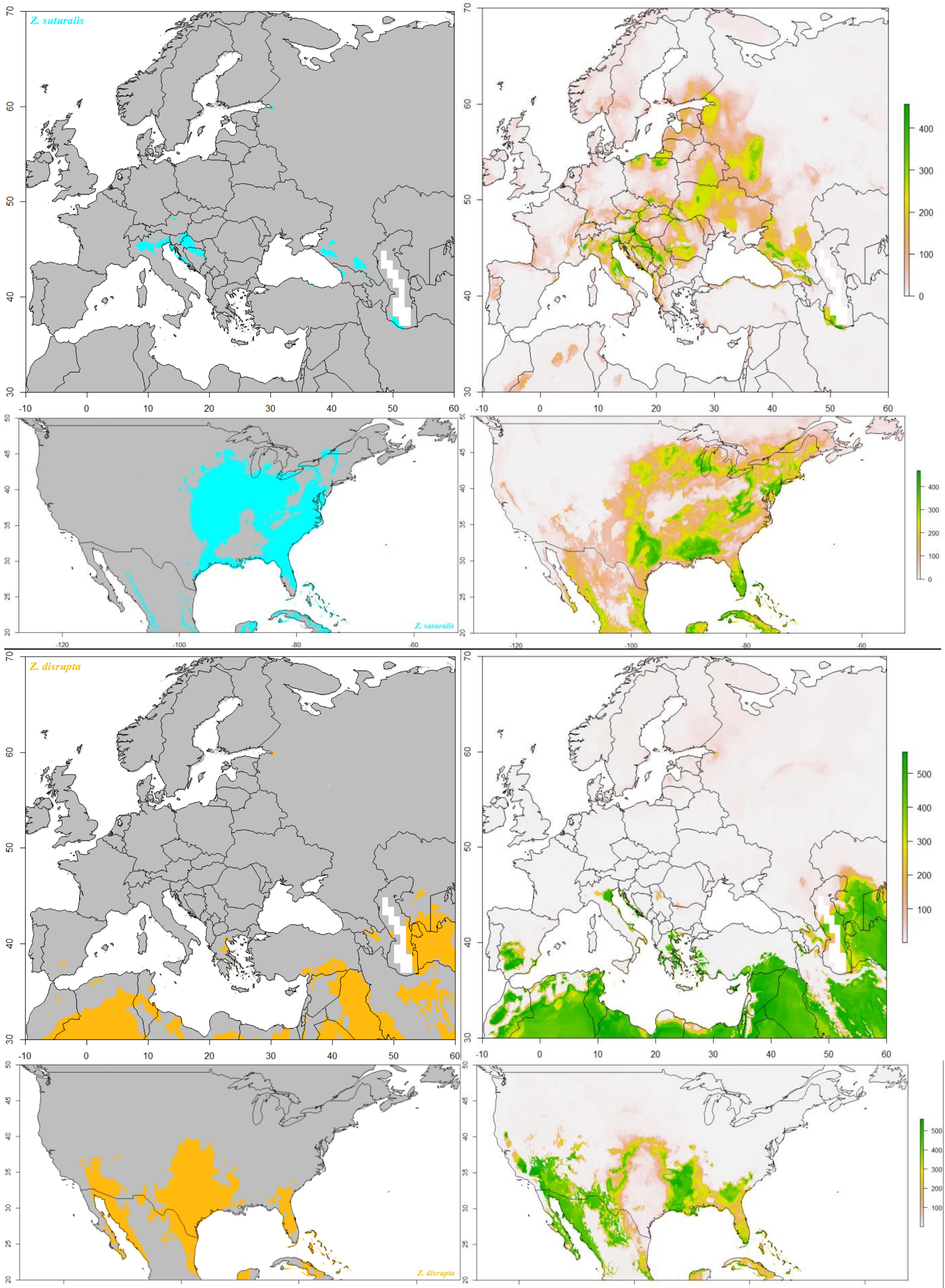


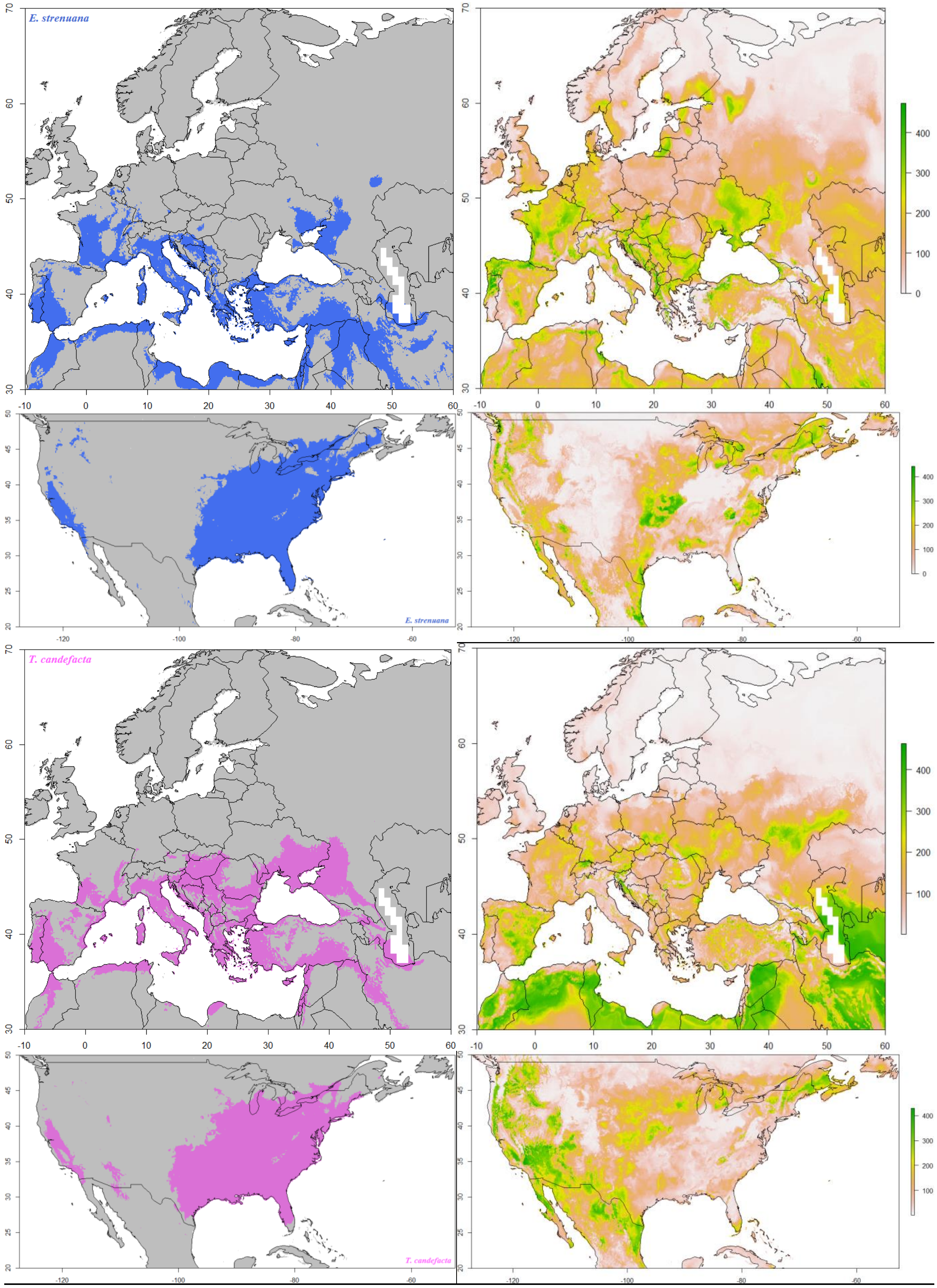

Z. disrupta
800
600
400
200
Z. disrupta
E. strenuana
800
600
400
200
E. strenuana
T. candefacta
800
600
400
200
T. candefacta
70
60
50
40
30
-10
0
10
20
30
40
50
60
50
45
40
35
30
25
20
-120
-100
-80
-60

Appendix S6: Fig. S5. Geographical predictions of *Ambrosia artemisiifolia* (dark green) and its potential biocontrol agent herbivores *Ophraella slobodkini* (yellow), *O. communa* (red), *Zygogramma suturalis* (cyan), *Z. disrupta* (goldenrod), *Epiblema strenuana* (blue) and *Tarachidia candefacta* (orchid) under four future climatic scenarios, left are the mean of four predictions, and right are the SD of the four predictions.




O. slobodkini
O. communa
O. communa


Z. suturalis
Z. suturalis
Z. disrupta
Z. disrupta


E. strenuana
T. candefacta