Appendix S1: Portrait of Central European tree species under current and projected future climates

The following is a portrait type presentation of the results from species distribution modeling and a discussion of some management options. Four of the presented species have been fitted from Swiss data only (marked with the label [CH] after the spp. name). This is due to the fact that the Alps-wide models did not give sufficiently good models, mostly due to a lack of important variables. Some species have been lumped together as genera-level maps, due to the fact that not all forest inventories in Central Europe distinguish to the species level during field work. The following species are presented in this appendix:

Species List:

Abies alba

Description of model and ensemble projections

The current distribution model of *Abies alba* is predicted to cover most of the Northern Pre-Alps, the Jura mountains, and those areas of the Swiss Plateau that are not located too low. It is also predicted to occur at mid- to high altitudes South of the Alps. In addition, the species is modeled in some inner-alpine valleys, notably the region between Disentis and Chur. The modeled distribution does not capture some of the lower altitudes on the Swiss Plateau and all locations in the dry inner-alpine Valais, where the species was measured in the LFI. The species naturally inhabits primarily the subalpine and upper montane regions. The fact that some (the warmest) parts of the Plateau and Valais are not modeled to be suitable reflects the fact that the model does not find sufficient evidence for *Abies* being present in these regions consistently according to the model data from across the Alps (MANFRED project).

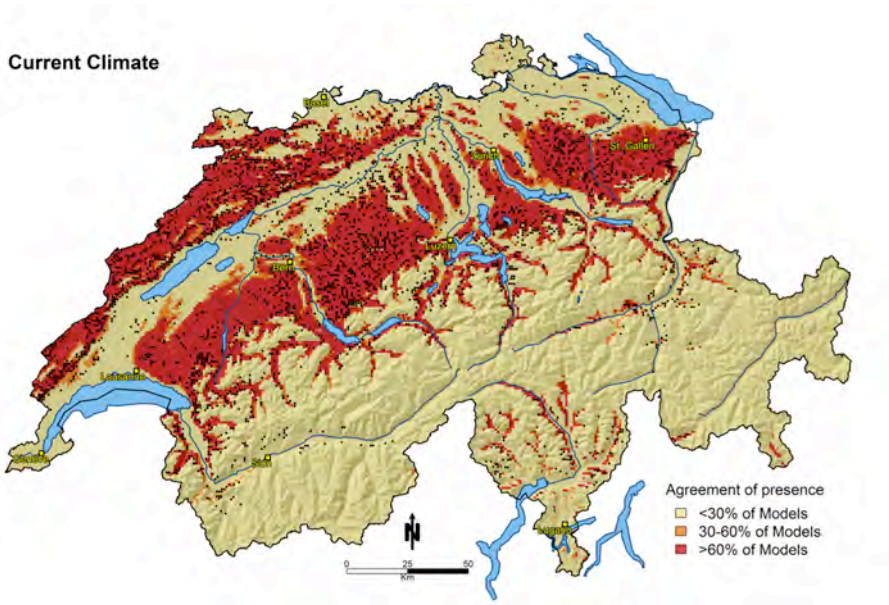


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid disappearance of *Abies* on the plateau and a retreat to Jura and higher Pre-Alps, and Insubrian mountains, meaning that these abandoned regions represent soon climate conditions, under which no presence of *Abies* is currently being observed given the many absence observations there. It is currently unclear as to how long Abies might still grow well on the Plateau despite finding unsuitable habitats soon. Growth analyses suggest that Abies can tolerate warmer climates, and even somewhat drier climates. This uncertainty cannot be resolved from SDM models, and likely by no other modelling approach.

Synthesis and Conclusions

The modelled distribution of *Abies alba* tends to underestimate the wide ecological amplitude of the species, although it fits the core of its current distribution well. As a tendency, the warm end of the species distribution is underrepresented, which means that it doesn't consistently occur under such conditions, but sometimes.

There is growing evidence (Maiorano *et al.* 2013; Tinner *et al.* 2013) that the species has a much wider ecological amplitude, spanning a temperature amplitude that ranges from Mediterranean climates to treeline conditions, given that a minimum annual rainfall of ca. 700-800mm are met. Given these numbers, *Abies alba* could serve well as an alternative to *Picea abies* as a future timber tree on the Plateau under A1B scenario conditions. Uncertain is currently the full reason for the lack of covering this large gradient, especially at the warm end. Reasons likely include the long history of human interventions in European forests, and the fact, that *Abies* has a very slow response to disturbance. It therefore might be a more natural component under even Submediterranean and Mediterranean conditions, but only, if disturbance rates and intensity remain low.

Range change statistics

	CH	Europe
Current range size [km²]	10'749	44'880
Future (2080) range size	3'952	16'673
Range Change 2080/2000 [%]	36.8%	37.1%
Overlap 2000/2080 [km²]	1'128	14'354
Overlap/current range [%]	10.5%	31.9%

The predicted overlap between current and future range is low (10%) in Switzerland but at least higher at the European scale (32%), meaning that within Europe, there remain significant areas, where the species is not threatened in the future due to sufficient range overlap. In addition, the view that *Abies alba* is more tolerant to heating and even a moderately drying climate means that the species might serve as an important future timber tree on the Plateau. Unclear is, however, how an increasing rate of climatic (e.g. drought) events and other disturbances (e.g. pests) might affect the future coping of *Abies* with the ongoing climate change.

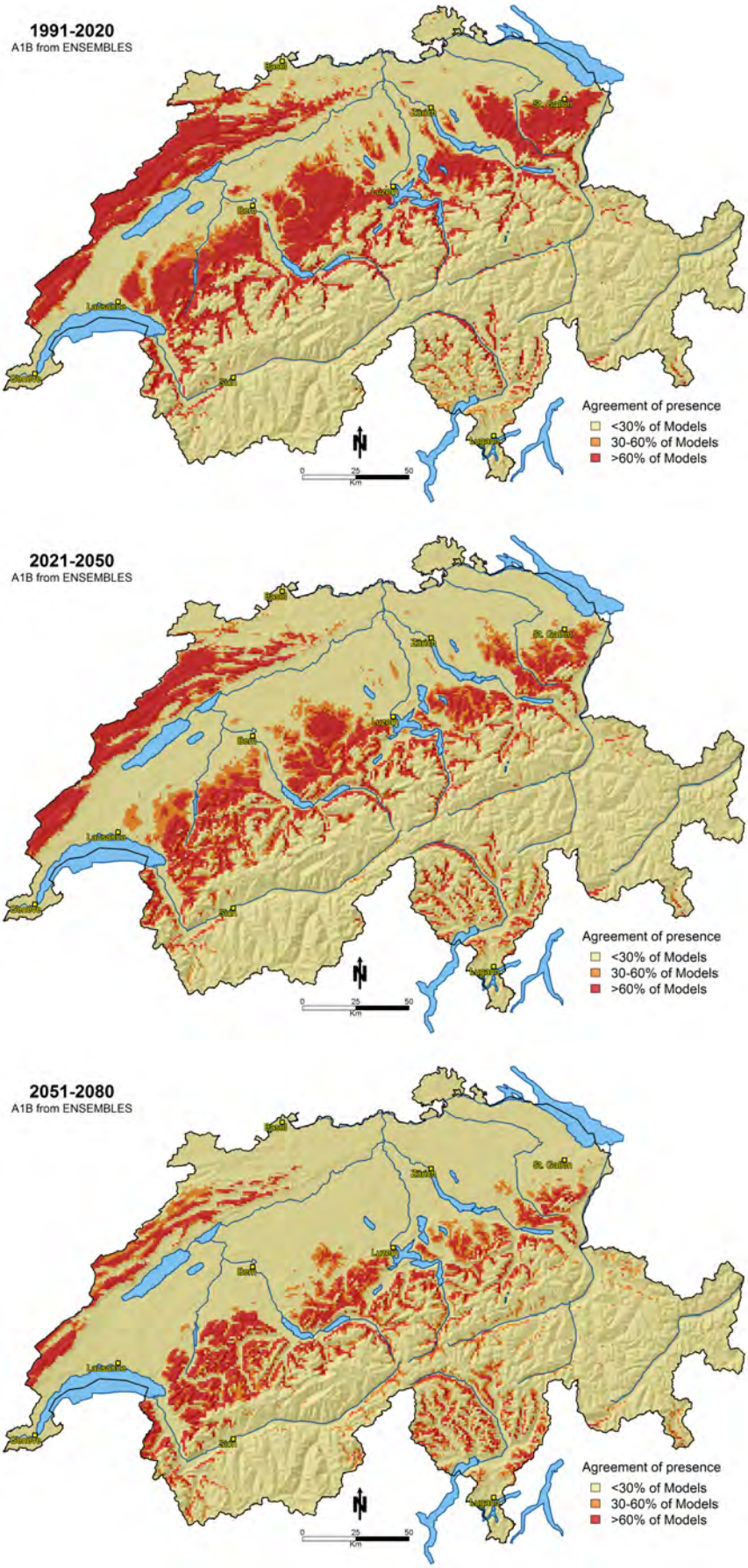


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

It remains therefore uncertain to promote *Abies* to a high degree; yet, it should remain on the agenda of future forest planning north of the Alps, even at low altitudes. The growth analyses (Appendix S2) do not contradict this statement, and predict a comparably good growth even under dry and warm conditions as long as average monthly summer precipitation doesn't fall below 75mm (totaling ca. 400mm in summer, or 700-800mm annually).

References

Maiorano L, Cheddadi R, Zimmermann NE, *et al.* (2013) Building the niche through time: using 13,000 years of data to predict the effects of climate change on three tree species in Europe. *Global Ecology and Biogeography* **22**, 302-317.

Tinner W, Colombaroli D, Heiri O, *et al.* (2013) The past ecology of Abies alba provides new perspectives on future responses of silver fir forests to global warming. *Ecological Monographs* **83**, 419-439.

Acer spp

Description of model and ensemble projections

The current distribution of *Acer spp.* (incl. *A. pseudoplatanus*, *A. platanoides* and *A. campestre*) predicted to cover most of the Swiss Plateau, the lower altitudes of the Jura Mountains, and the Northern Pre-Alps. In addition, the species also grows at higher altitudes in the inner alpine valleys and in the Ticino. This species group naturally inhabits primarily the lower montane and subalpine region, and regenerates partly well in beach forests on the Plateau (mostly *A. pseudoplatanus*). The distribution model predicts most of the area very well, except some of the high altitude locations in the Western Jura and Pre-Alps regions.

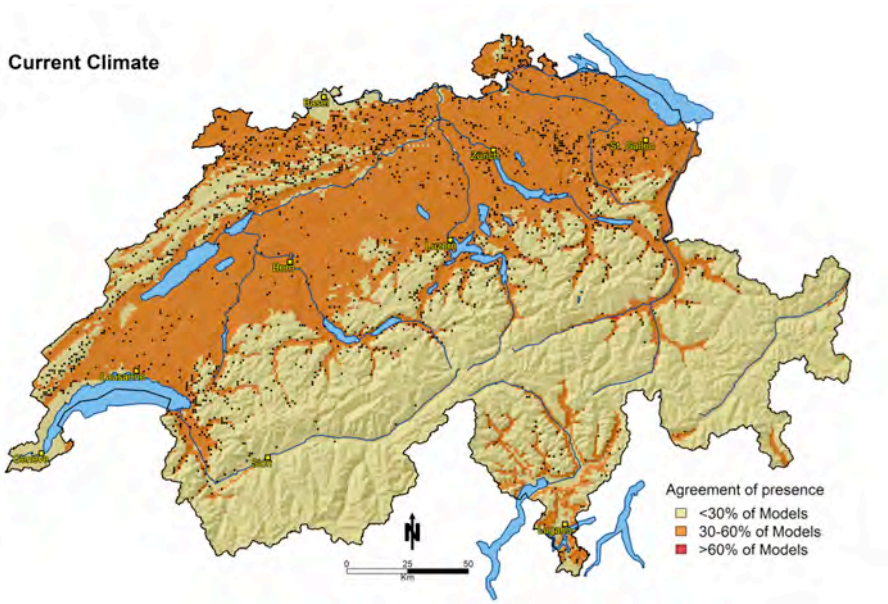


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict that these *Acer* species slowly disappears from the Plateau, meaning that these regions will harbor climate conditions, under which no presence of these species is currently being observed. The species "escapes" to higher altitudes throughout the Alps, and remains to be widely distributed in the Jura mountains and in the Ticino. The current distribution is modelled generally well, but with the typical "uncertainty" originating from the fact that the species group does not always occur where climate conditions are suitable.

Synthesis and Conclusions

The current distribution of this *Acer* species group is modelled comparably well, but some higher altitude areas in Western Switzerland and in the Pre-Alps are under-predicted, meaning that the 22% overlap between current and future range is likely too pessimistic, and a larger overlap actually exists. The species group reveals comparably high temperature amplitudes. By 2050 some areas on the Plateau become unsuitable for the group, but might still well be suitable for *A. campestre*, which has the highest tolerance to high temperatures and drier climates. Overall, the range of the species is predicted to become smaller (70% of the current range size).

Range change statistics

	CH	Europe
Current range size [km²]	17'960	–
Future (2080) range size	12'546	–
Range Change 2080/2000 [%]	69.8%	–
Overlap 2000/2080 [km²]	3'980	–
Overlap/current range [%]	22.1%	–

Two of the three species (*A. pseudoplatanus*, *A. platanoides*) have very similar requirements as *Fagus sylvatica*, and seem to have similar tolerances as well regarding future climate conditions. Regarding soil requirements, the two species are likely more demanding than *Fagus sylvatica* (Walthert *et al.* 2013), and will not accompany *Fagus* under all possible soil conditions. They require a higher base saturation and will not grow well on very acidic soils. Also, the species has a very slow migration capacity according to Meier et al. (2012), and may therefore have general difficulties to track climate change if large areas have to be overcome to find suitable habitats. It therefore may spread less well than predicted in the Ticino and in some inner Alpine valleys under changing climate conditions.

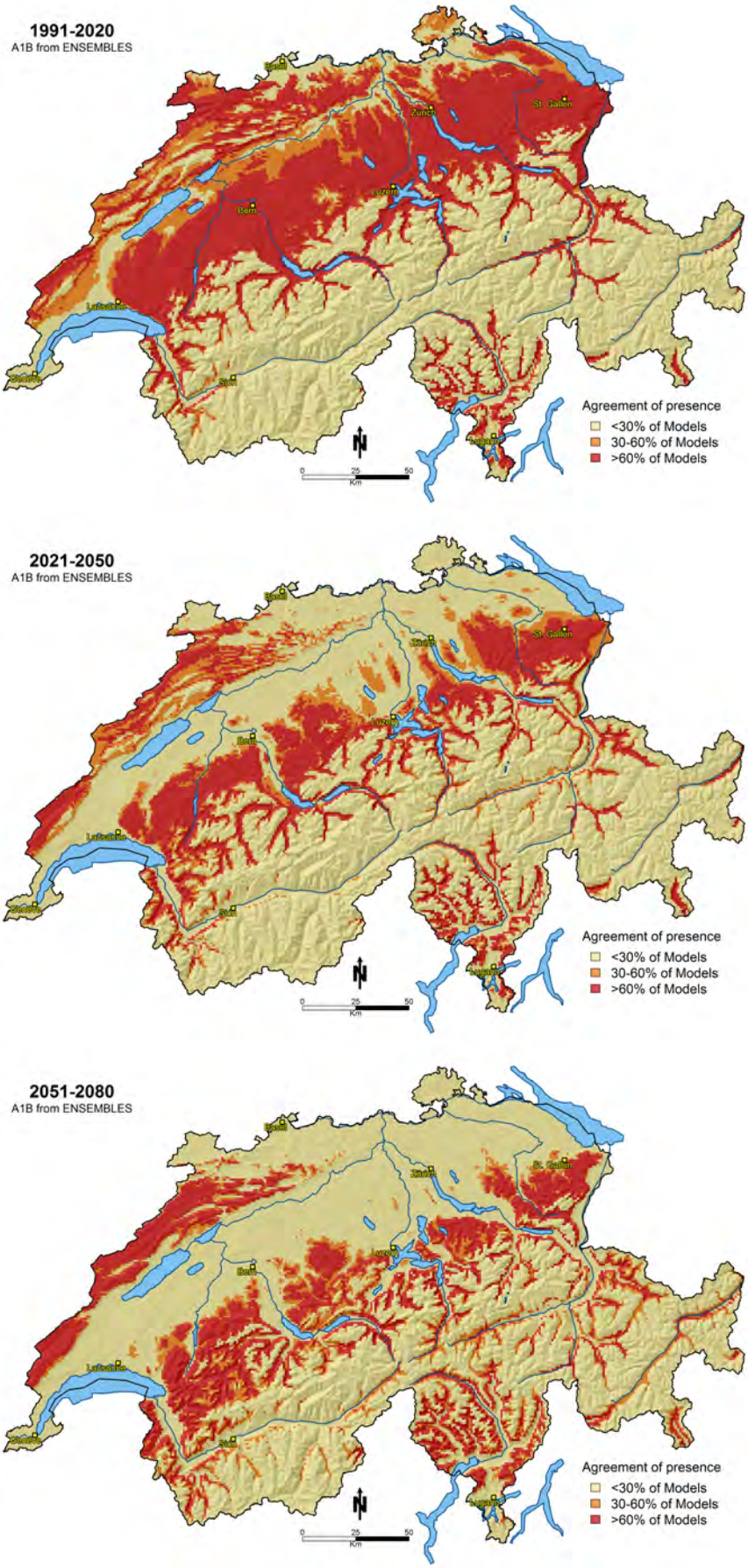


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Walthert L, Pannatier EG, Meier ES (2013) Shortage of nutrients and excess of toxic elements in soils limit the distribution of soil-sensitive tree species in temperate forests. *Forest Ecology and Management* **297**, 94-107.

Acer campestre

Description of model and ensemble projections

The current distribution of *Acer campestre* is represented well in the model, despite the fact that the species is rather sparsely distributed over the range it covers in Switzerland. It occurs infrequently in forests of the Swiss Plateau, the lower and mid altitudes of the Jura range and the Northern Pre-Alps, but also in the interior Alpine valleys and in the Ticino. As a comparably light-demanding species with a small maximum size, it is mostly found on forest edges, on ridges, or on very steep and dry slopes.

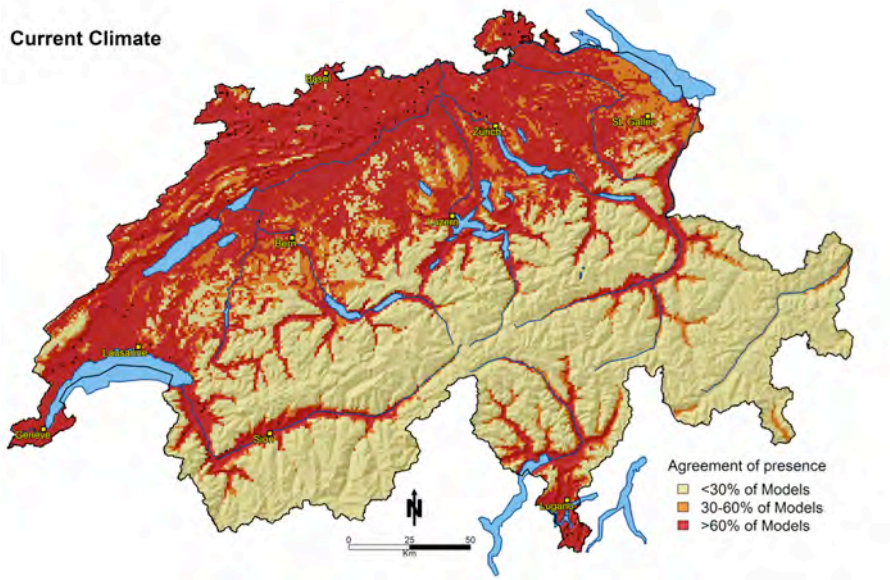


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario, almost all combinations of statistical and regional climate models predict a rapid spread of *A. campestre* throughout all low to mid altitudes in Switzerland, meaning that these regions represent soon climate conditions, which are favorable for *A. campestre.* The species is predicted to profit considerably from the warmer and slightly drier summer climates projected under this scenario.

Synthesis and Conclusions

The model fits the distribution of *Acer campestre* well, and can be considered a credible model to project the future habitat suitability of this species. The ensemble models project a 100% overlap between the current and the future range in Switzerland and still a very high overlap (78%) throughout Europe. This is a very high overlap, associated with a strong increase of the range in Switzerland (+58%), while in Europe the range size is largely maintained (-3%).

Range change statistics

	CH	Europe
Current range size [km²]	16’773	123’525
Future (2080) range size	26’596	120’410
Range Change 2080/2000 [%]	158.5%	96.7%
Overlap 2000/2080 [km²]	16’773	97’276
Overlap/current range [%]	100.0%	78.1%

As a non-supported timber, it will not profit from management support, and may only be used as energy wood source, if at all. However, from its ecological characteristics, the species should not have problems to adapt to future climate conditions. It is very shade tolerant as a juvenile, and thus is not among the first to appear in a stand during succession. However, after initial fast growth it rather stops soon growing further, does not become too tall, and is soon outcompeted by late successional, seral species such as beech (*Fagus sylvatica*) or oaks (*Q. robur*), etc. The species plays an important role as ornamental tree, and is widely planted in gardens or hedges. It will continue to play this role well, and will often be seen in hedges, at forest edges and only marginally in denser forests. In oak forests of a warmer world, it may have some importance in the future.

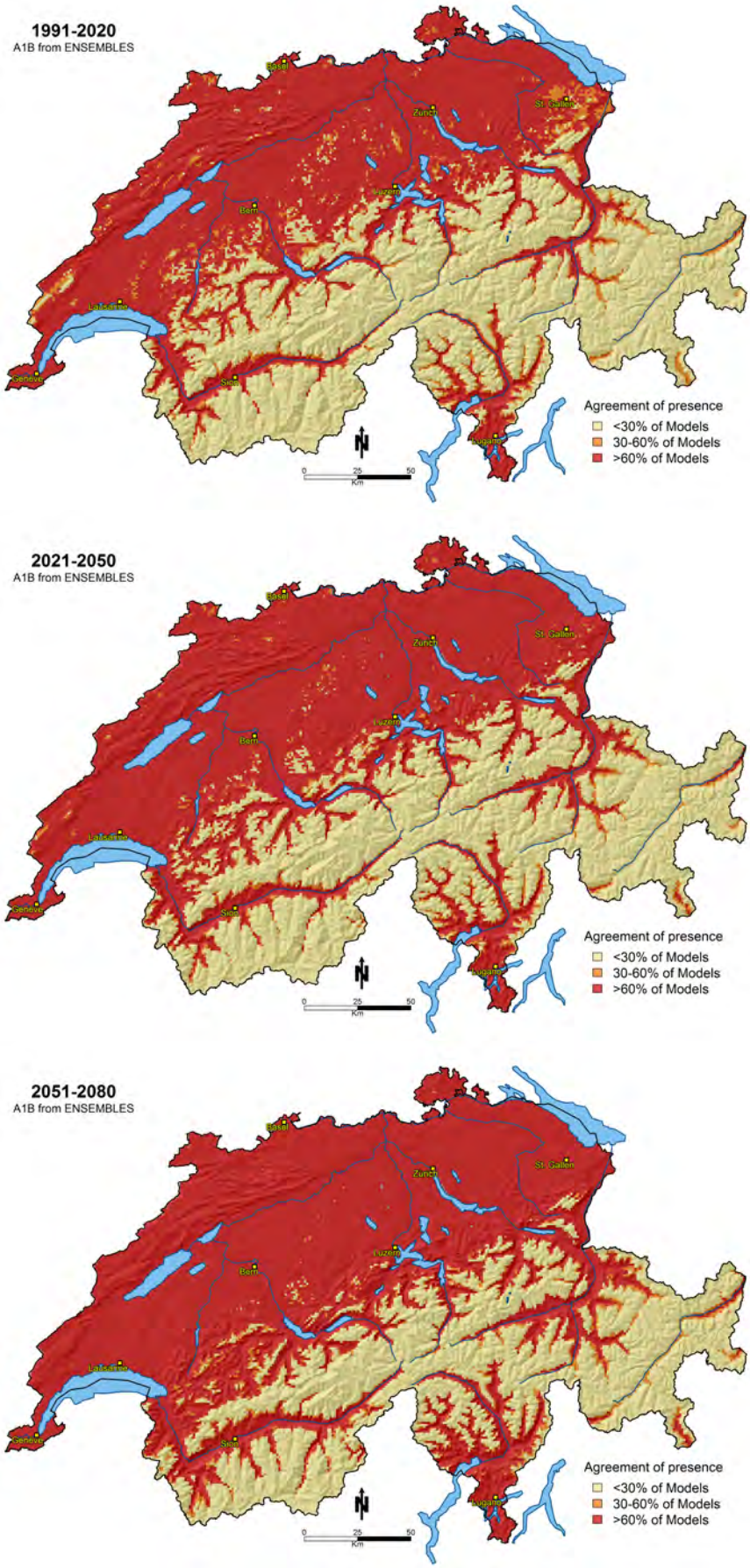


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Acer pseudoplatanus

Description of model and ensemble projections

The current distribution of *Acer pseudoplatanus* is predicted to cover most of the Swiss Plateau, the Jura Mountains, and the Northern Pre-Alps. In addition, the species also grows at higher altitudes in the inner alpine valleys and in the Ticino. The species naturally inhabits primarily the montane and subalpine region, and is planted widely on the Plateau. The distribution model does not well predict some of the high altitude locations in the Western Jura and Pre-Alps regions.

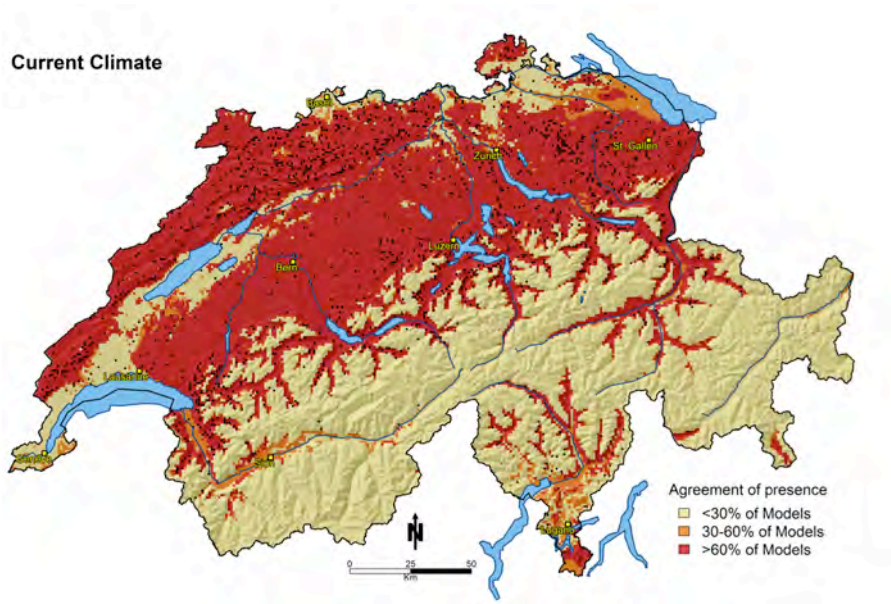


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict that *Acer pseudoplatanus* slowly disappears from the Plateau, meaning that these regions will represent climate conditions, under which no presence of *Acer* is currently being observed. The species "escapes" to higher altitudes throughout the Alps, and remains to be widely distributed in the Jura mountains.

Synthesis and Conclusions

The current distribution of *Acer pseudoplatanus* is modelled comparably well, but some higher altitude areas in Western Switzerland and in the Pre-Alps are under-predicted. Yet, the scenario predicting 45% overlap between current and future range is likely realistic, and a larger overlap may not exist in practice. At the European scale the overlap is quite high (>60%), which indicates that the species is not likely to face significant problems from migration limitation under a changing climate. The species reveals comparably high temperature amplitudes, and only by 2050 some areas on the Plateau become unsuitable. Due to a possibly slow immigration or expansion of other species (*Quercus* spp., possibly *Abies*), *Acer pseudoplatanus* might well be suitable past 2050 as a valuable tree in forests of the Plateau. Both, at the Swiss and at the European scale, the species is expected to lose 30-40% of its current range size.

Range change statistics

	CH	Europe
Current range size [km²]	18'777	76'067
Future (2080) range size	13'129	47'924
Range Change 2080/2000 [%]	69.9%	63.0%
Overlap 2000/2080 [km²]	8'384	46'417
Overlap/current range [%]	44.6%	61.1%

The species has very similar requirements as *Fagus sylvatica*, and seems to have similar tolerances as well regarding future climate conditions. Regarding soil conditions, the species is likely more demanding than *Fagus sylvatica*, and will not accompany *Fagus* under all possible soil conditions. It requires a higher base saturation and will not grow well on very acidic soils (Walthert *et al.* 2013). Also, the species has a very slow migration capacity according to Meier et al. (2012), and may therefore have general difficulties to track climate change if large areas have to be overcome to find suitable habitats. It therefore may spread less well than predicted in the Ticino and in some inner Alpine valleys under changing climate conditions.

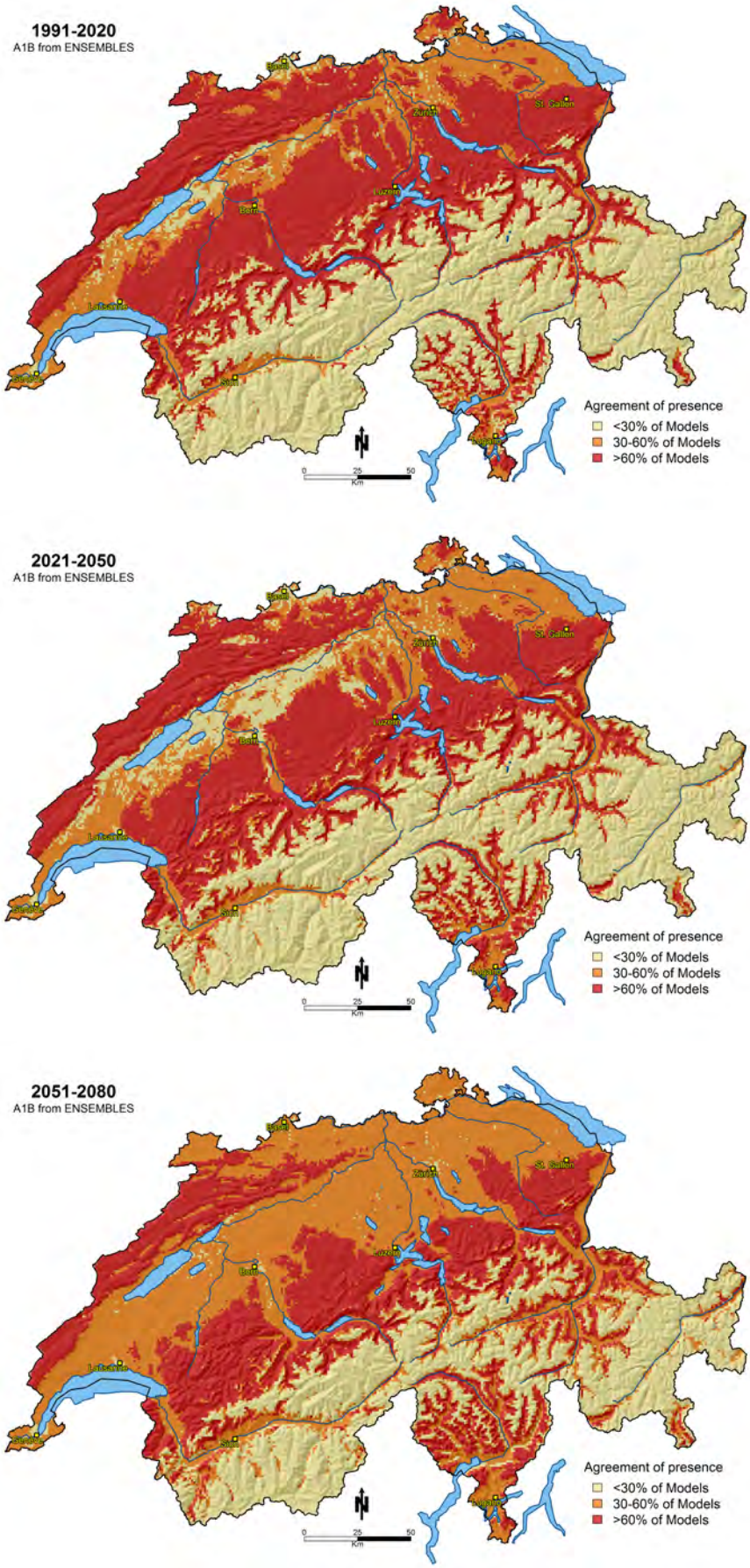


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Walthert L, Pannatier EG, Meier ES (2013) Shortage of nutrients and excess of toxic elements in soils limit the distribution of soil-sensitive tree species in temperate forests. *Forest Ecology and Management* **297**, 94-107.

Alnus glutinosa

Description of model and ensemble projections

The current distribution of *Alnus glutinosa* is modelled to cover most of the lowlands of the Swiss Plateau, the Northern and Interior Alps, as well as of the Ticino. The species naturally inhabits low altitude, moist forests throughout Europe and Western Asia. Some of the coldest observations in the Northwestern Pre-Alps and the Central Jura are not captured by the model ensemble, and likely represent conditions for which the models do not find sufficient evidence for *A. glutinosa* being present.

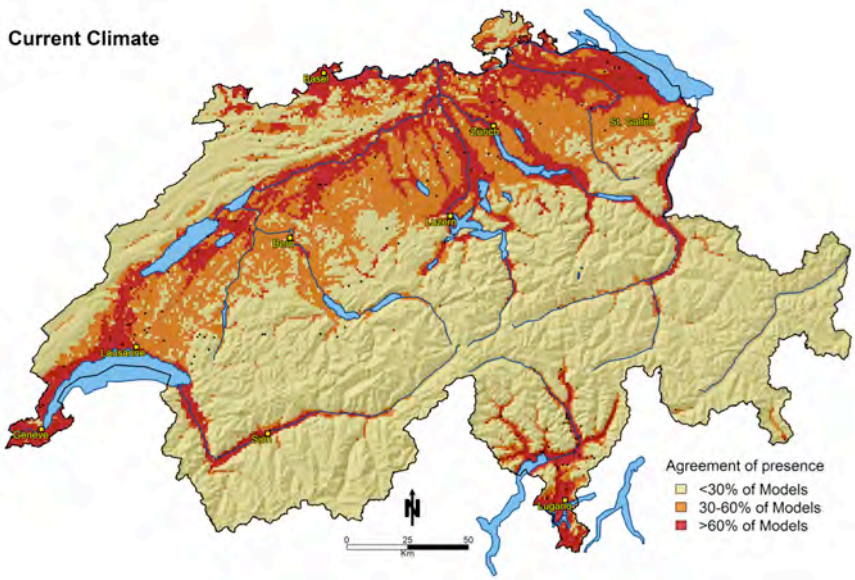


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a complete colonization of all lower altitudes in Switzerland by *A. glutinosa*, meaning that these regions represent soon climate conditions, under which no presence of *Picea* is currently being observed. The species doesn't seem to colonize much higher altitudes in the near future, and remains in the relatively flat areas of lower altitudes.

Synthesis and Conclusions

The model fits the distribution of *Alnus glutinosa* generally well, and can be considered a credible model to project the future habitat suitability of *A. glutinosa*. The ensemble models project a 100% overlap between the current and the future range in Switzerland and still a considerable overlap (71%) in Europe. In addition, the species projected to gain considerable range size in Switzerland (+174%)m but will likely lose ~20% of its current European range size. However, the species is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and in Europe. As a less preferred timber, it will not get assisted migration. Yet, the species likely doesn't depend on this help, as it has sufficient overlap in many regions of Europe.

Range change statistics

	CH	Europe
Current range size [km²]	6'686	172'507
Future (2080) range size	18'345	142'534
Range Change 2080/2000 [%]	274%	82.6%
Overlap 2000/2080 [km²]	6'686	121'992
Overlap/current range [%]	100%	70.7%

In addition, the species easily colonizes initial soils, as it has a symbiosis with the bacterium *Frankia alni*. This is a nitrogen-fixating bacterium, that allows *A. glutinosa* to grow on initial soils and it helps to improve soil fertility through this process. It depends on moist soils, tough, and cannot grow on moderately or considerably dry slopes. It therefore is often found along lakes and rivers, since it tolerates better than many other species high water tables and is a dominant species in alluvial forests. Yet, it also grows in other moist forests, though mostly not as dominant species. It grows best if the pH of the soil is ranging between 5.5 and 7.2, meaning that it prefers soils that are not too acidic, but rather high in pH. It usually appears early in successions, due to its capacity to grow on initial soils and due to its low shade tolerance.

The species is susceptible to *Phytophthora alni*, a recently evolved disease that has affected parts of Europe already. The timber is primarily used for fiber production in some regions (paper), and could also be used for energy wood production. It can help stabilize river banks, and can assist in flood control. It is also sometimes mixed into stands of other trees such as Walnut (*Juglans regia*), Douglas fir (*Pseudotsuga mensziesii*) or poplar (*Populus tremula*) to increase soil fertility through nitrogen fixing.

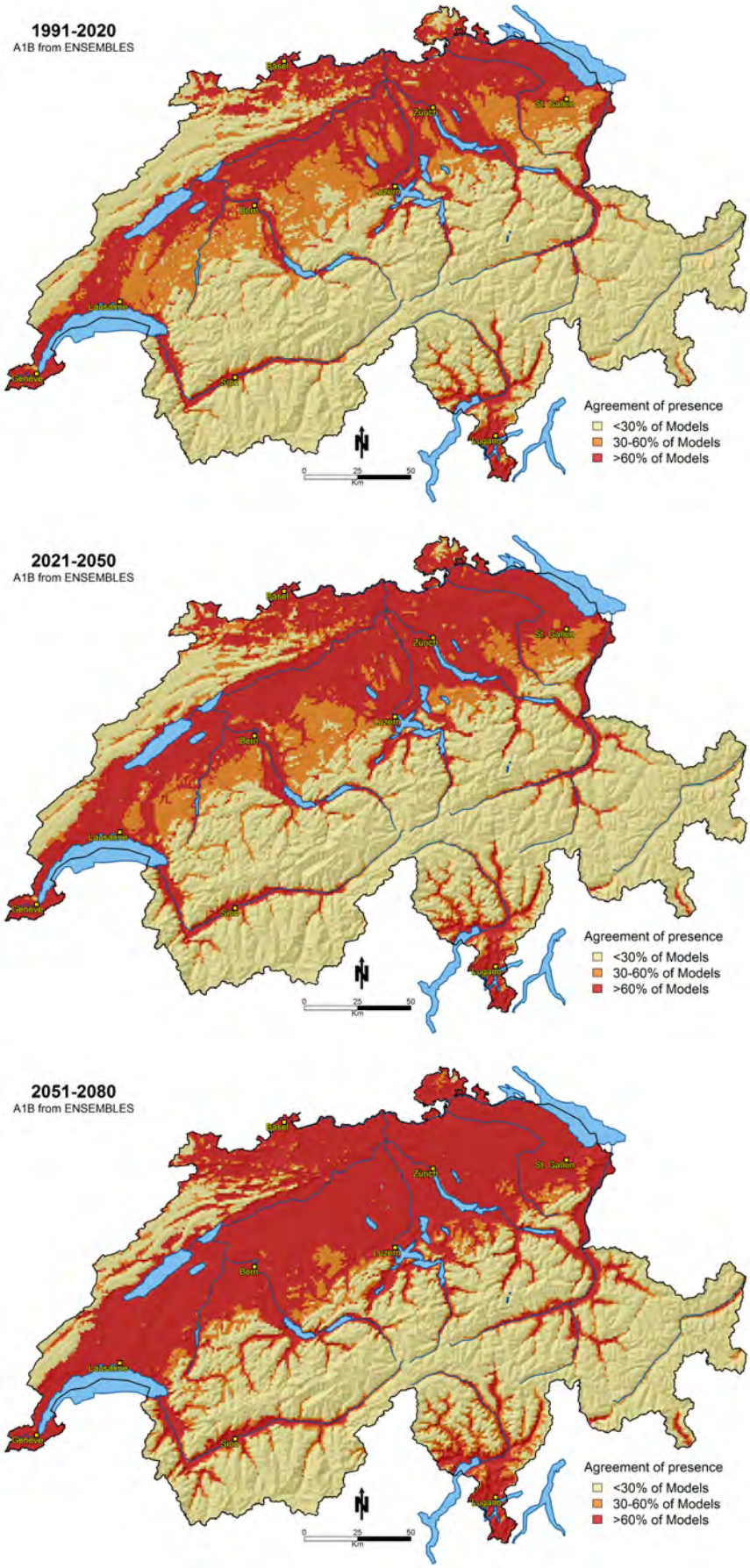


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Alnus incana

Description of model and ensemble projections

The current distribution of *Alnus incana* is modelled to cover most of the montane to upper montane belt of Switzerland irrespective of climate zone. Rather, the species primarily grows in valley bottoms in close distance to rivers and waters, primarily. This generates a quite patchy distribution, now and into the future. In general the current distribution of the species is very well captured. Due to its spotty and unsteady appearance in climate conditions that are generally well suited, the statistical models show some uncertainty at low altitude on the Plateau and in the Northeastern Jura Mountains, as to whether the species has a sound potential to grow in these regions. Yet, this is not so much a question of true uncertainty. Rather it reflects the fact that the species is unsteady under these climate conditions, and does not appear always when the climate is favorable.

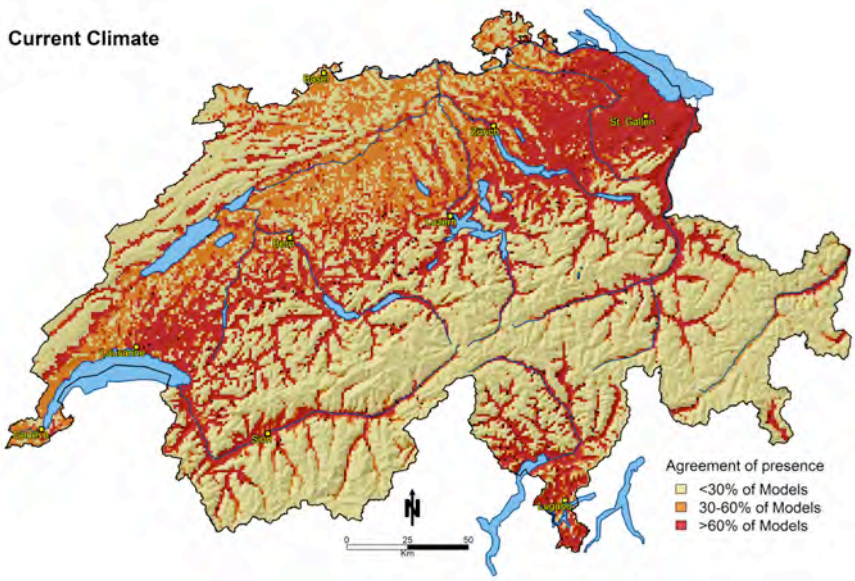


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict an upward shift of *A. incana* in all these regions, representing soon climate conditions, under which *A. incana* is likely to grow well. The Swiss Plateau is not considered a highly suitable habitat in the future. The species best growth in close distance to running (and partly standing) waters, and is not a strong competitor for light.

Synthesis and Conclusions

The model fits the distribution of *Alnus incana* well, and can be considered a credible model to project the future habitat suitability of the species. The ensemble models project a 90% overlap between the current and the future range in Switzerland, yet a much smaller overlap (10%) in Europe. This can be considered a sufficient overlap to thrive into the future without threat of extinction. Yet, at the European scale, the overlap is quite low, and may cause problems for the species to cope with future climates.

Range change statistics

	CH	Europe
Current range size [km²]	11'742	55'602
Future (2080) range size	15'368	25'710
Range Change 2080/2000 [%]	130.8%	46.2%
Overlap 2000/2080 [km²]	10'536	5'747
Overlap/current range [%]	89.7%	10.3%

The species is projected to increase its range in Switzerland quite considerable (+31%) while in Europe, it is projected to lose see a shrinking range by the end of the century (-54%). Yet, the species is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and in Europe. As an non-preferred timber, it will not profit from assisted migration to higher and more Northern altitudes, but it might also not depend on it, due to large spatial range overlaps between currently and future suitable habitats. As a pioneer and early successional species, it is also likely to rapidly colonize new suitable areas in the future.

Alnus incana is a light-demanding, fast growing tree species that grows well on initial soils. It grows in many places on the northern hemisphere, primarily in cool temperate regions. Through nitrogen fixation, it can help improve soil fertility. It primarily grows in alluvial regions, along mountain brooks and streams. Several subspecies have been described for different northern hemisphere regions. Several species of *Lepidoptera* with its caterpillars feed on *A. incana* as food source

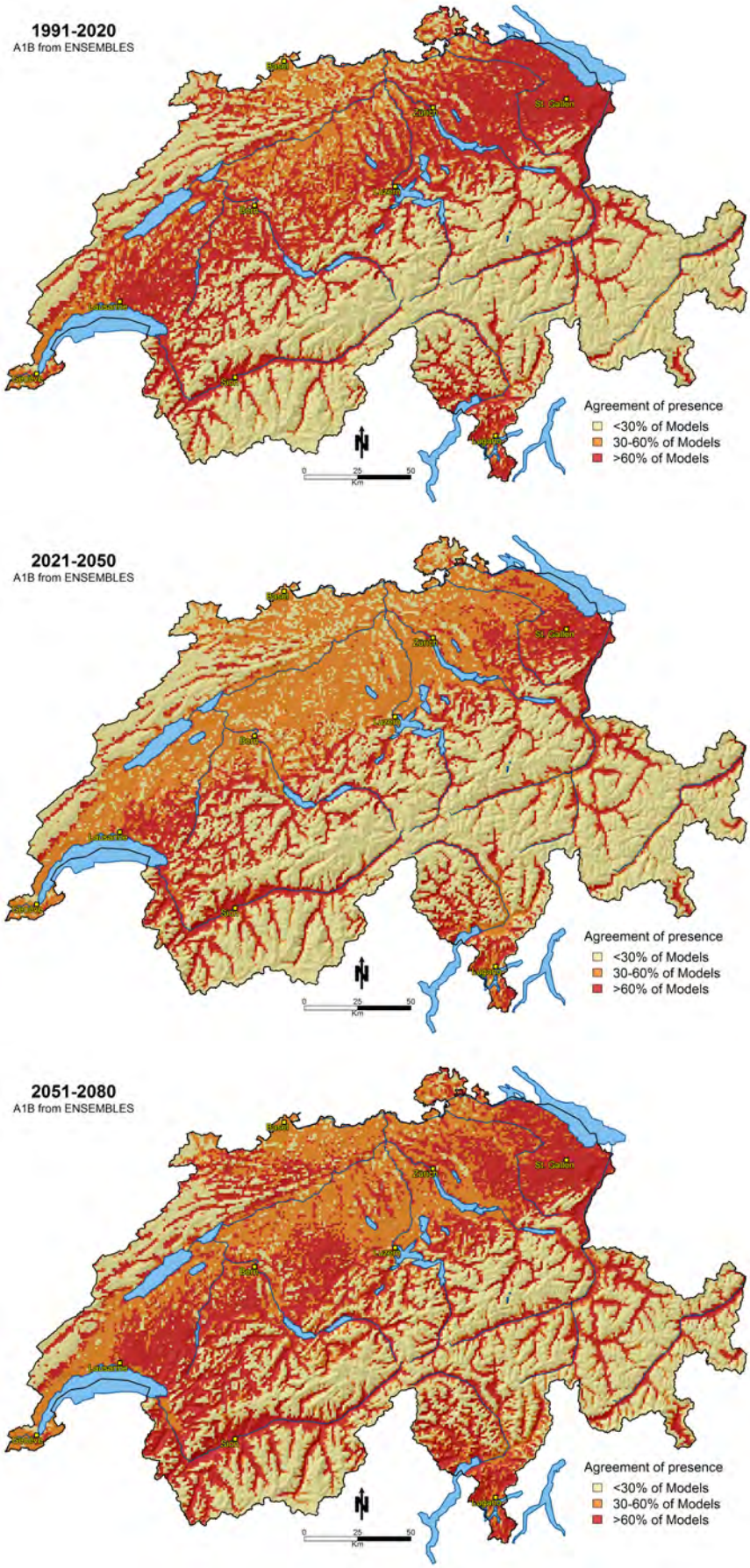


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Betula pendula

Description of model and ensemble projections

The current distribution of *Betula pendula* is simulated to cover primarily the low to mid altitudes of the warm and spring/summer-dry regions of Switzerland. The species occurs abundantly in the Ticino, in the Valais and scattered throughout other parts of Switzerland. The species is considered early-successional, meaning that it cannot compete against late successional, stand dominating broadleaf and needleleaf species. It grows fast, and disappears usually rapidly once stands are getting denser. Only in dry regions (Valais, Ticino) it can sustain longer in forest stands.

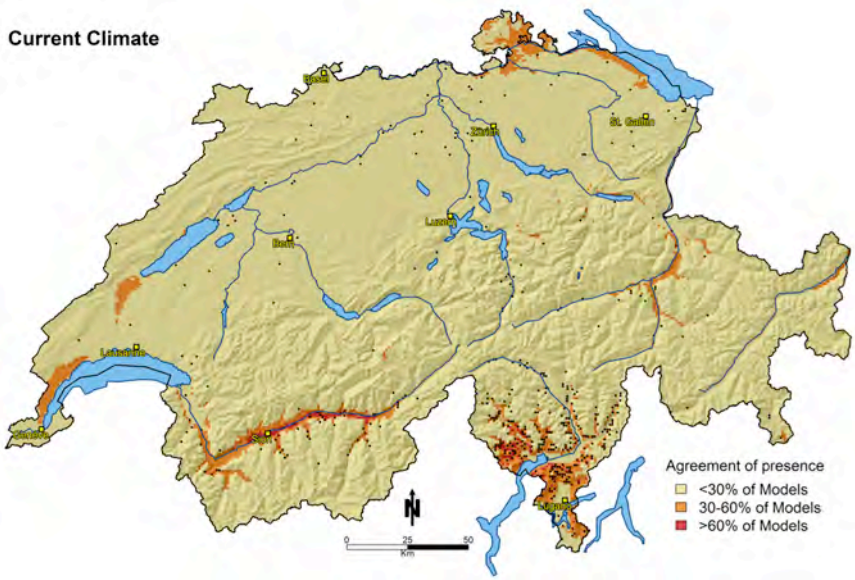


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

The model does not depict well the rare occurrences on the Plateau an in the Northern Pre-Alps. This is due to the fact that there is no sufficient evidence that the species consistently grows under these conditions. In fact, SDMs cannot cope well with species that are infrequently present under such conditions.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a spread of *Betula* to higher altitudes, an extension onto the Plateau and in the lower Engadin, meaning that these regions represent soon climate conditions, under which presence of *Betula* is currently being observed. The species remains strongly distributed in the Valais.

Synthesis and Conclusions

The model fits the distribution of *Betula pendula* comparably well, and can be considered a credible model to project the future habitat suitability of *Betula*. The ensemble models project a 46% overlap between the current and the future range in Switzerland and a similar overlap (44%) in Europe. In Switzerland (+163.8%) and Europe (-43.3%), considerable differences in range expansion/contraction are projected. In Switzerland, considerable uncertainties remain from the ensemble projections, since many areas of current and future range are only projected by a fraction of the climate & statistical model combinations (orange tone in maps of Figures 1 and 2). Yet, this is often the case when modelling early success species.

Range change statistics

	CH	Europe
Current range size [km²]	2'223	146'209
Future (2080) range size	5'864	82'845
Range Change 2080/2000 [%]	263.8%	56.7%
Overlap 2000/2080 [km²]	1'034	64'232
Overlap/current range [%]	46.3%	43.9%

However, the species will lose ca. 50% of its range, mostly in low altitudes. Yet, we do not consider this a real threat, since the species is very mobile, and will still find sufficient suitable habitat, both in Switzerland and in Europe. According to the modelling study by Meier *et al.* (2012), the species can almost completely track climate change due to its rapid seed dispersal, fast growth rate, and fast migration rate. According to this study, the species can even maintain its fast migration rate in the highly fragmented landscape of Central Europe.

Silver birch is strongly light demanding and does not grow well under competition. It grows best on more acidic soils that are rather dry. Due to its low shade tolerance, there is sufficient light on forest floors for a rich flora. In addition, it is a preferred food for insects. In Germany, ca. 500 species of insects have been reported on birch (*B. pendula* and *B. pendula*), mostly beetles and leptidopterans (Brändle & Brandl 2001), with 133 species of insects feeding almost exclusively on birch. The fact that it grows best on acidic soils explain the tight concentration of its preferred habitat in the interior and southern valleys.

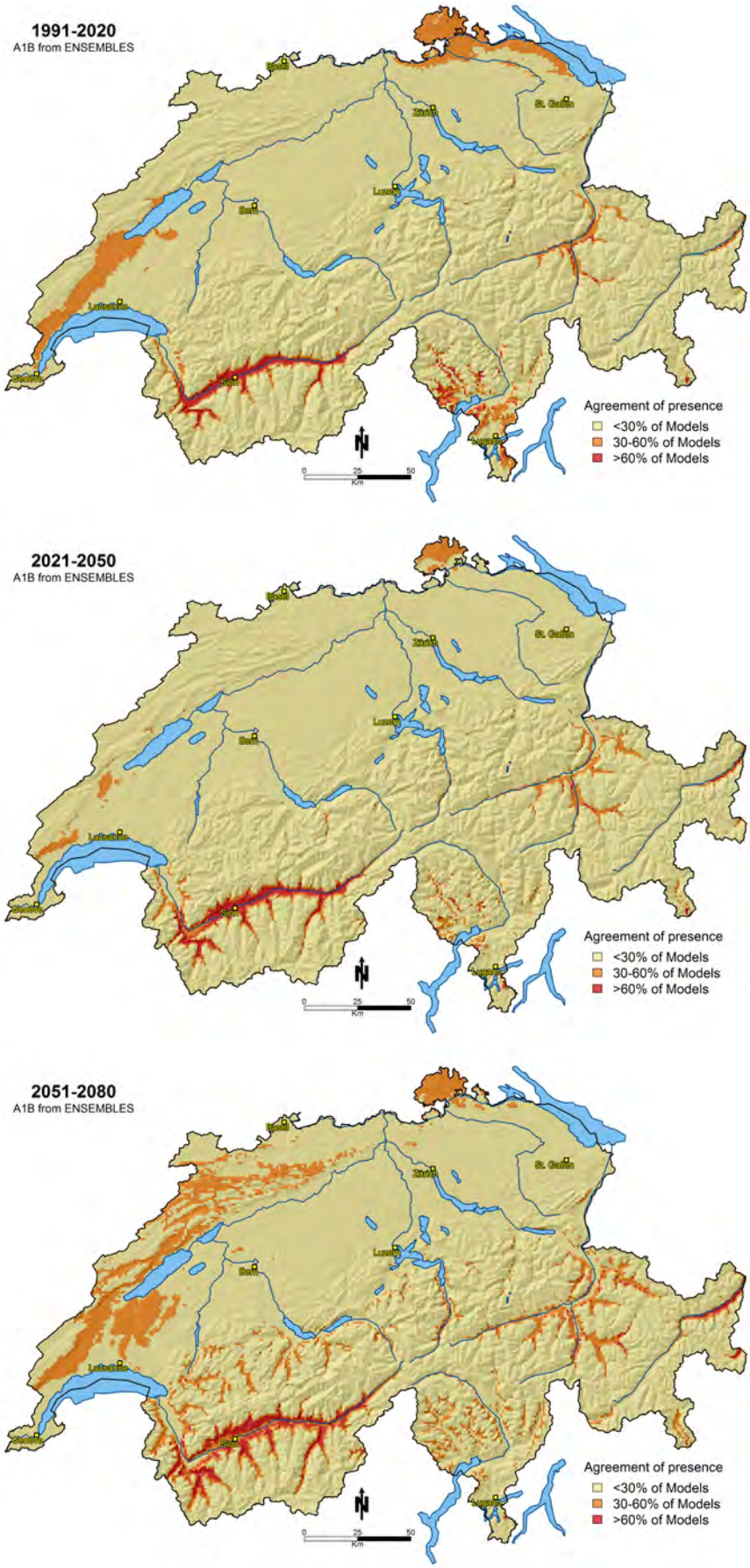


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Brändle M, Brandl R (2001) Species richness of insects and mites on trees: expanding Southwood. *Journal of Animal Ecology* **70**, 491–504.

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Carpinus betulus

Description of model and ensemble projections

The current distribution of *Carpinus betulus* is modelled to cover most of the warm regions of Switzerland (Valais, Chur basin, Canton of Geneva, low altitude regions in Basel and in the Canton of Schafhausen). Not well modeled is the Ticino, and some scattered regions in the Jura and Swiss Plateau of Northern Switzerland. The species naturally inhabits primarily the colline and montane belt, and is often favored by forest management where forests are cut frequently (coppice management). The fact that some parts of the Plateau region are not modeled to be suitable reflects the fact that the model does not find sufficient evidence for *Carpinus* being present in these situations consistently.

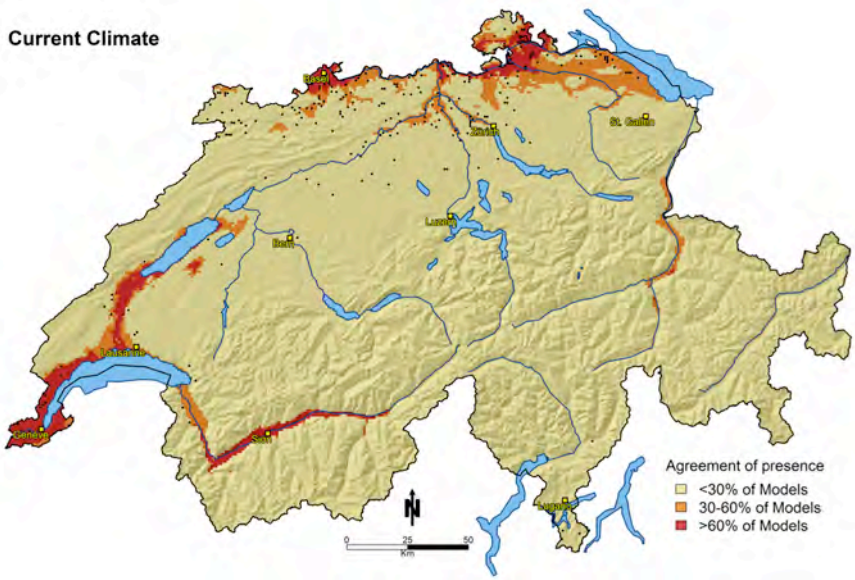


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *Carpinus* onto the Plateau and the interior valleys (Valais, Engadin, Chur basin), meaning that these regions represent soon climate conditions, under which presence of *Carpinus* is currently being observed. The species can be considered a "winner" of climate change.

Synthesis and Conclusions

The model fits the distribution of *Carpinus betulus* comparably well, and can be considered a credible model to project the future habitat suitability of *Carpinus*. The only exception is the lack of projecting suitable habitats in the Ticino, both under current and future climates. The ensemble models project a 17% overlap between the current and the future range in Switzerland and a somewhat higher overlap (35%) in Europe. This is not a very high overlap, but the species is likely moderately mobile and may thus cope quite well under climate change, since it grows relatively fast, produces flowers and fruits at relatively young age, and regenerates well after cutting or damage.

Range change statistics

	CH	Europe
Current range size [km²]	1'433	112'413
Future (2080) range size	7'712	50'565
Range Change 2080/2000 [%]	538.2%	44.9%
Overlap 2000/2080 [km²]	244	39'412
Overlap/current range [%]	17.0%	35.1%

In Europe, the species is projected to lose much of its range (>50%), while it is projected to expand its range by a factor of 5 in Switzerland. Again, this is likely not a severe problem due to its moderately high mobility. The lack of projecting suitable habitats in the Ticino must have its origin in the broad range of habitats the species can be found, and the inconsistent presence in specific climates due to variable management over the whole Alps. The species would naturally cover a much smaller range without human management interventions. This also cautions a bit the massive spread on the Plateau. This spread might be reasonable, if either the climate becomes really dry, or if coppice management practice is frequently applied. Otherwise, the projected suitability shift might be considered too optimistic under future conditions.

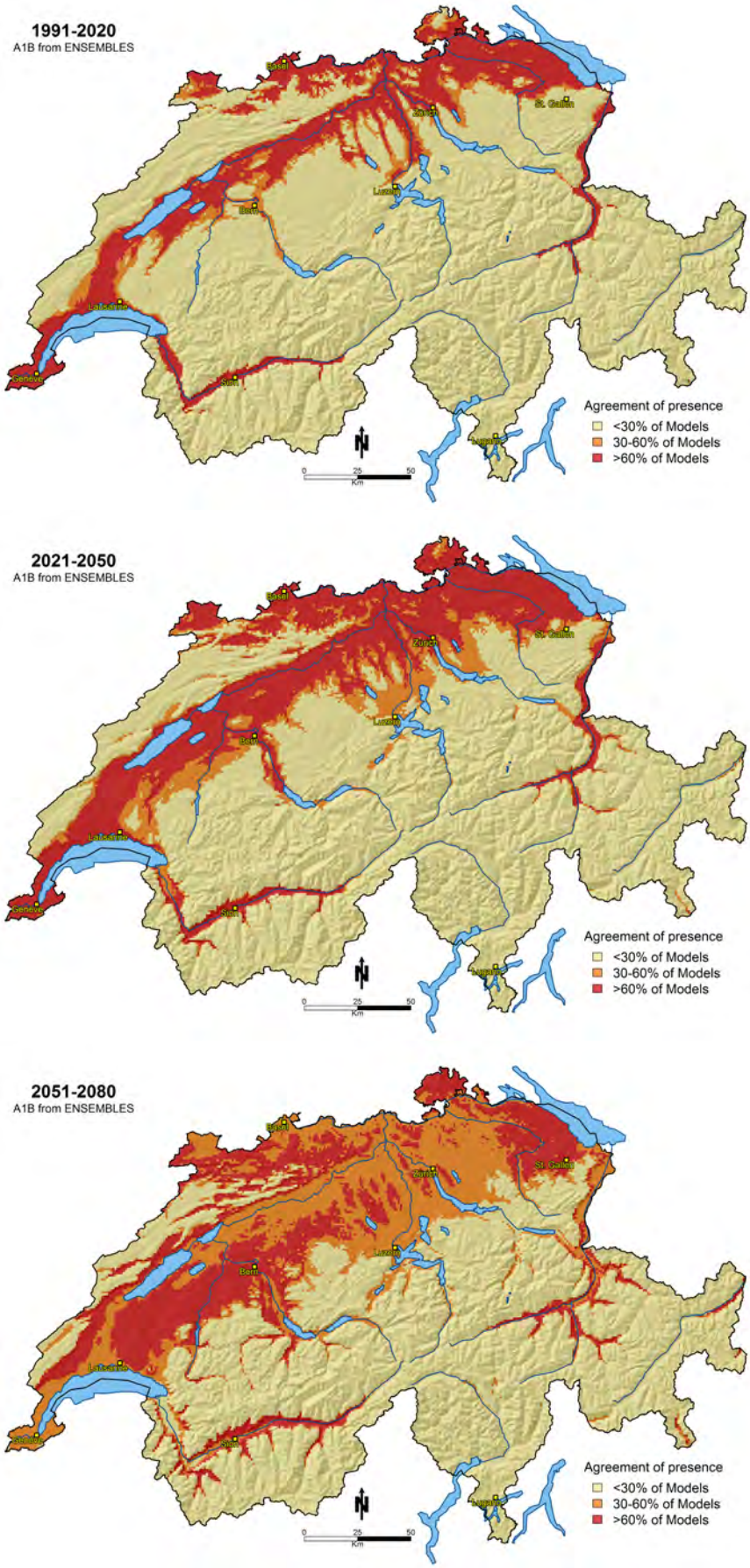


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Castanea sativa

Description of model and ensemble projections

The current distribution of *Castanea sativa* is modelled to cover the low altitudes of the Ticino and some warm regions North of the Alps (lower Valais, Reuss Valley and regions surrounding Lake Zurich and Walensee, Geneva). The species has been naturalized after being introduced by Romans and the traditional chestnut plantation forests nowadays form part of the natural heritage of the Ticino. The model reflects the observed distribution of the species very well, specifically south of the Alps. Obviously, some areas North of the Alps have similar climates. Observations from the Valais indicate that the species grows well, once planted.

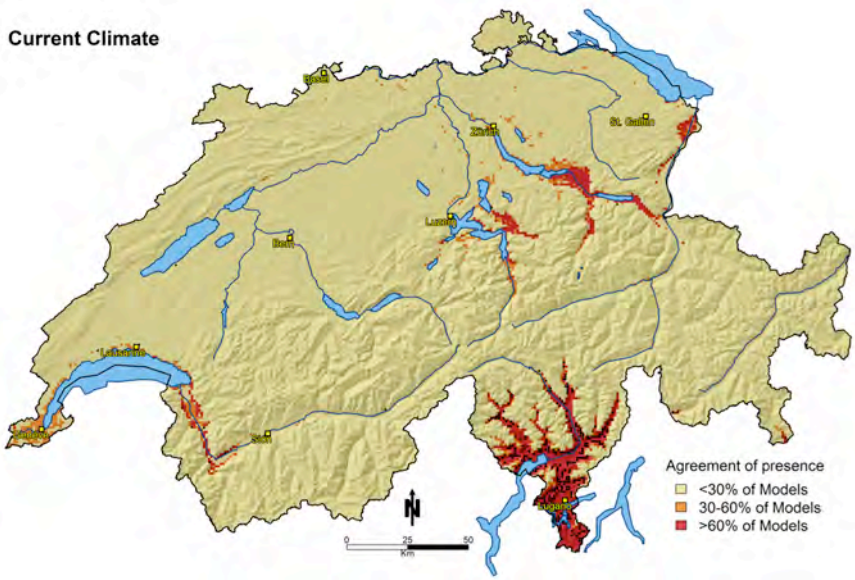


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models suggest a rapid spread of *Castanea* on the Plateau, starting from the regions that already have suitable climates today. It means that these regions soon will have climate conditions, under which *Castanea* is currently being observed to grow well. The Ticino is projected to remain suitable also at low altitudes.

Synthesis and Conclusions

The model fits the distribution of *Castanea sativa* well, and can be considered a credible model to project the future habitat suitability of the species. The ensemble models project a 100% overlap between the current and the future range in Switzerland. No model was available for Europe, since the ICP Forest Level I data set does not have sufficient distribution points for the species. The simulated spread is high, and primarily expands into regions, where the species is already planted successfully as an ornamental tree.

Range change statistics

	CH	Europe
Current range size [km²]	1'470	–
Future (2080) range size	15'585	–
Range Change 2080/2000 [%]	>999%	–
Overlap 2000/2080 [km²]	1'468	–
Overlap/current range [%]	99.8%	–

However, *Castanea* is not likely to expand the range that rapidly onto the Plateau on its own. It also is hampered by pests, and may thus not thrive well under warmer climates. As a late successional, slowly migrating species *Castanea* has difficulties to migrate the large distances required to track climate change and to migrate across the Alps (Meier *et al.* 2012). It therefore likely does not play a major role in Swiss Plateau forests in the future.

In the Ticino, the species is projected to still find suitable habitats at lowest elevations. It will depend on the tolerance and resistance to pests whether the species can still grow sufficiently well under these conditions in the future. Otherwise, oak species will re-colonize these regions, which *Castanea* occupies today.

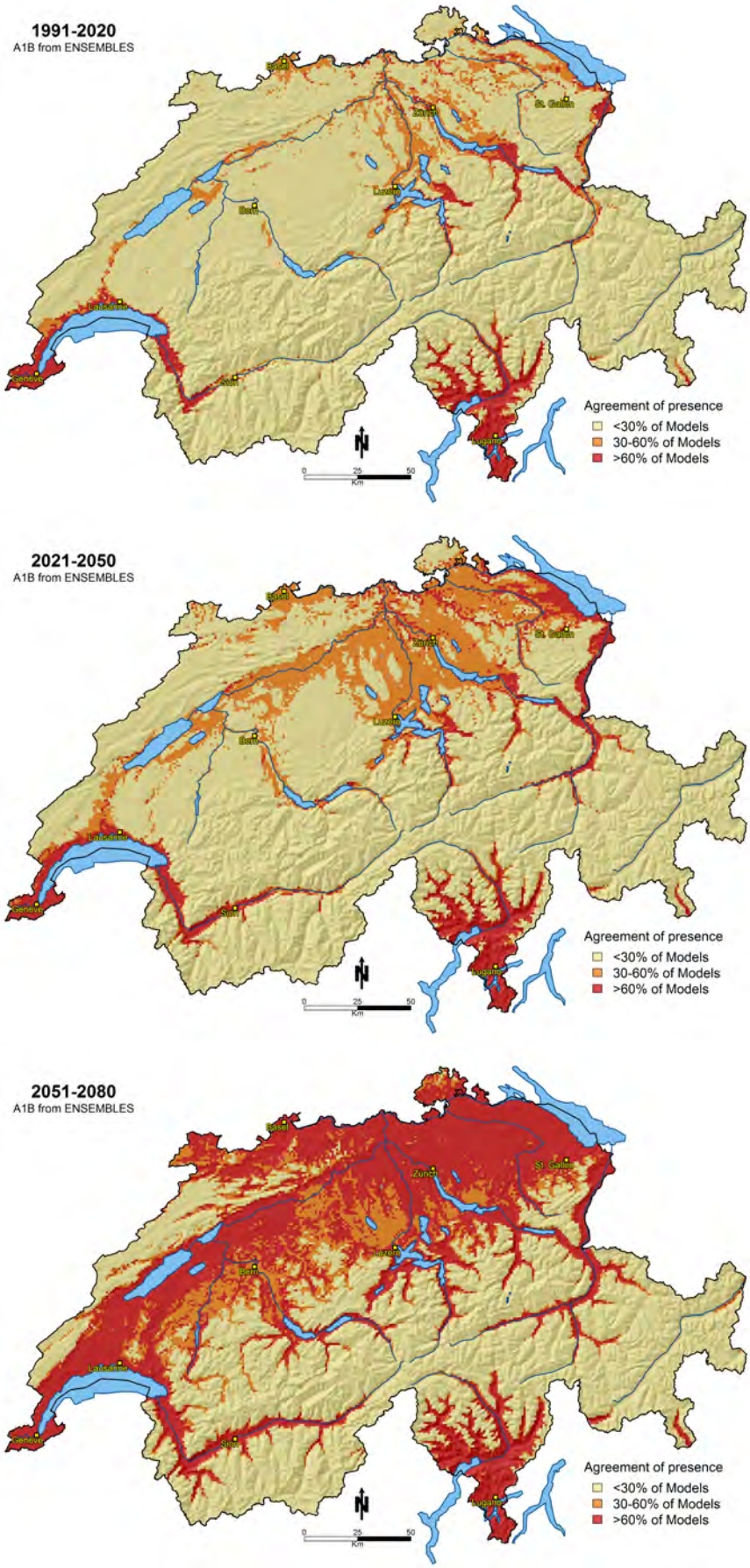


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Corylus avellana (tree form)

Description of model and ensemble projections

The current distribution of the tree form of *Corylus avellana* is modelled to cover primarily the lower altitudes of the Ticino, while north of the Alps we primarily expect the shrub form that does not reach the forest canopy. The model does not have a high degree of certainty, but captures the general distribution given by LFI observations.

Under expected climate change using the A1B scenario, combinations of statistical and regional climate models predict a spread of *C. avellana* within the Ticino to higher altitudes, and also a spread of the tree (canopy) form of the species to the north of the Alps. Yet, it does not spread really well across the whole plateau and rather remains simulated with uncertainty between central Northern Switzerland and the Reuss valley. None of the simulations really reaches high levels of certainty.

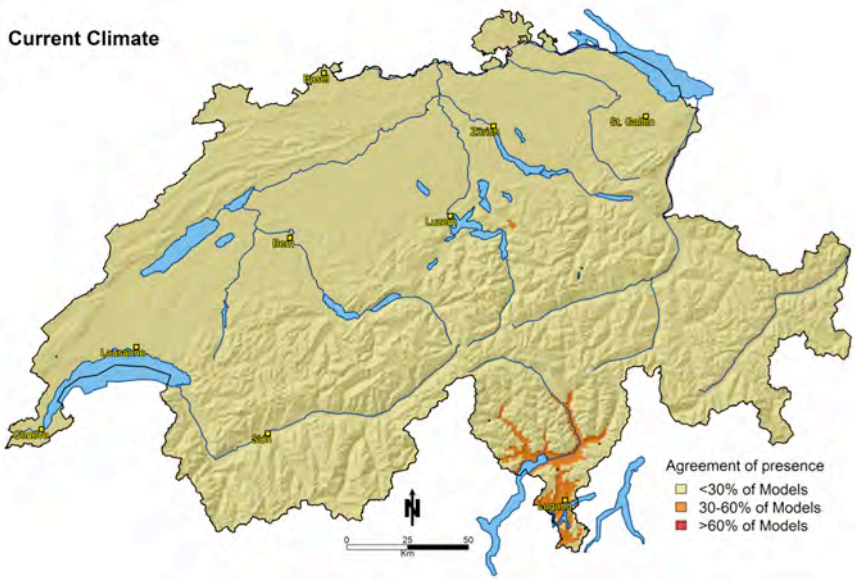


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Synthesis and Conclusions

The rather uncertain model fits the distribution of the canopy form of *C. avellana* in the Ticino comparably well, and can be considered a somewhat useful model to project the future habitat suitability of *C. avellana*. Yet, no sufficiently high certainty is reached to have high trust in the projections. The ensemble models project a 100% overlap between the current and the future range in Switzerland. No similar statistics is available for Europe. Also, the tree form of *C. avellana* is projected to increase its range considerably (more than 10-fold), and is expected to also occur north of the Alps. This reflects likely conditions of *Q. pubescens* or *Q. petraea* forests, where *C. avellana* can reach canopy height in a warmer and drier climate.

Range change statistics

	CH	Europe
Current range size [km²]	619	–
Future (2080) range size	8572	–
Range Change 2080/2000 [%]	>999%	–
Overlap 2000/2080 [km²]	619	–
Overlap/current range [%]	100%	–

Yet, all simulations are only available with very high uncertainty. Also, the species has no economic value, yet has high importance for many small rodents as a food source. The species will have no problem adjusting to climate change. It is quite insensitive to browsing and coppicing, and regenerates quickly after disturbance. It was one of the fastest migrating and earliest spreading species after the retreat of the glaciers during the early Holocene spread of larger woody plants in Europe (Huntley & Birks 1983; Lang 1994). Due to the high model uncertainties and the low economic or conservation value, we do not further discuss this species.

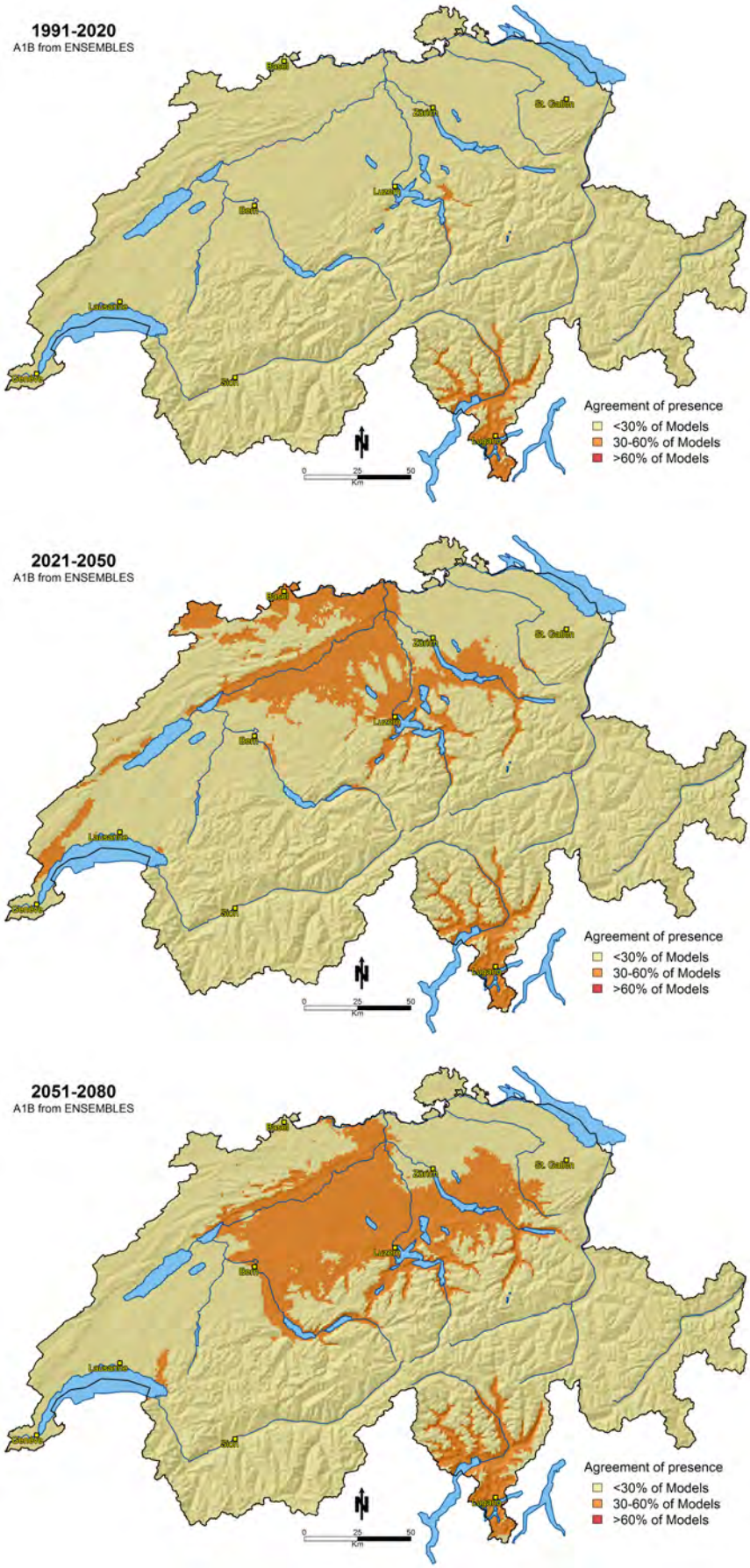


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Huntley B, Birks HJB (1983) *An atlas of Past and Present Pollen Maps for Europe: 0 - 13000 years ago* Cambridge University Press, Cambridge, UK.

Lang G (1994) *Quartäre Vegetationsgeschichte Europas: Methoden und Ergebnisse* Fischer, Jena [etc.].

Fagus sylvatica

Description of model and ensemble projections

The current distribution of *Fagus sylvatica* is modelled to cover most of the Swiss Plateau, the Jura Mountains, and the Northern Pre-Alps. In addition, the species also grows at mid elevations in the Ticino and touches some of the inner Alpine valleys, as long as they are not too dry. The species has never migrated into the Poschiavo valley despite suitable climate. The species naturally inhabits primarily the lower and upper montane region and dominates the forests on the Plateau.

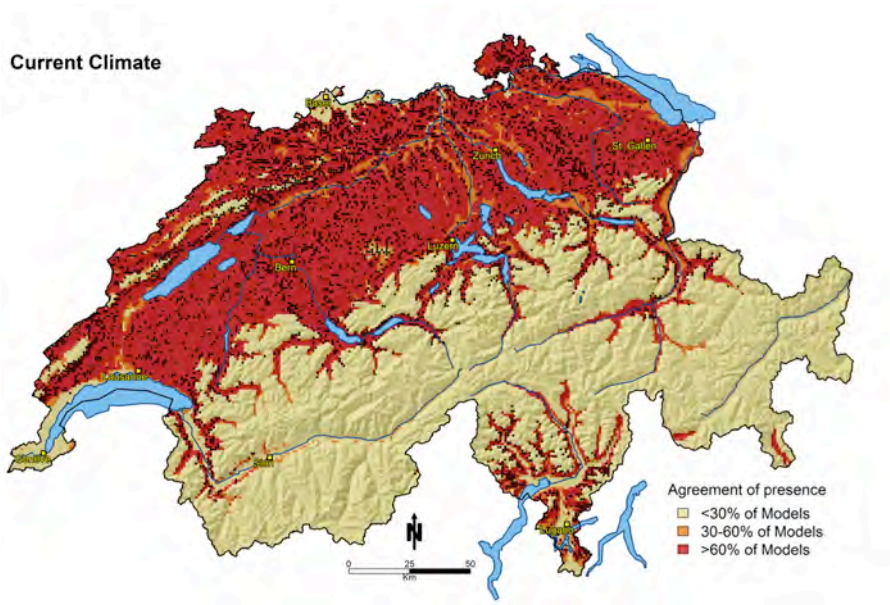


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a successive disappearance of *F. sylvatica* on the Plateau, meaning that these regions represent soon climate conditions, under which no presence of *Fagus* is currently being observed. The species "escapes" to higher altitudes. Yet, see the growth analyses (Appendix S2) for alternative views on the future of *Fagus* on the Swiss Plateau until 2100.

Synthesis and Conclusions

The model fits the distribution of *Fagus sylvatica* well, and can be considered a credible model to project the future habitat suitability of *Fagus*. The ensemble models project a 19% overlap between the current and the future range in Switzerland and even higher overlaps (58%) in Europe. This is a much higher overlap than previously modeled (Zimmermann *et al.* 2006). The difference mostly originates from using less extreme climate scenarios in this report. Here we used the A1B scenario, a moderate scenario from the fourth IPCC assessment report (IPCC 2007). The previous simulations were based on the 3rd assessment report (IPCC 2001), where the A1FI scenario was much more extreme compared to the current A1B.

Range change statistics

	CH	Europe
Current range size [km²]	17'678	95'695
Future (2080) range size	8'992	61'013
Range Change 2080/2000 [%]	50.8%	63.7%
Overlap 2000/2080 [km²]	3'383	55'139
Overlap/current range [%]	19.1%	57.6%

However, the species will lose much of its range and the future range is much smaller than the current one (51% and 63% for Switzerland and Europe, respectively). However, the species is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and in Europe. As a preferred timber, it might profit from assisted migration to higher altitudes, where necessary. There may be provenances (originating from the South of the Alps) that might be characterized by higher drought tolerance than the northern Alpine provenances, and these might be suitable alternatives to improve the drought adaptation of the species north of the Alps.

The disappearance on the Swiss Plateau means, that the future climate is warmer (and partly also drier) than any observed current distribution of *Fagus*. On the other hand it might take 100s if not 1000s of years, until the species is outcompeted by immigrating competitors, such as oak species. Until 2050, and despite projections of habitat loss on the Plateau, the climate will probably not bee extreme enough to drive *Fagus* to extinction. The growth analyses (S2) indicate that under a warming climate, *Fagus* thrives well, as long as summer precipitation is not declining.

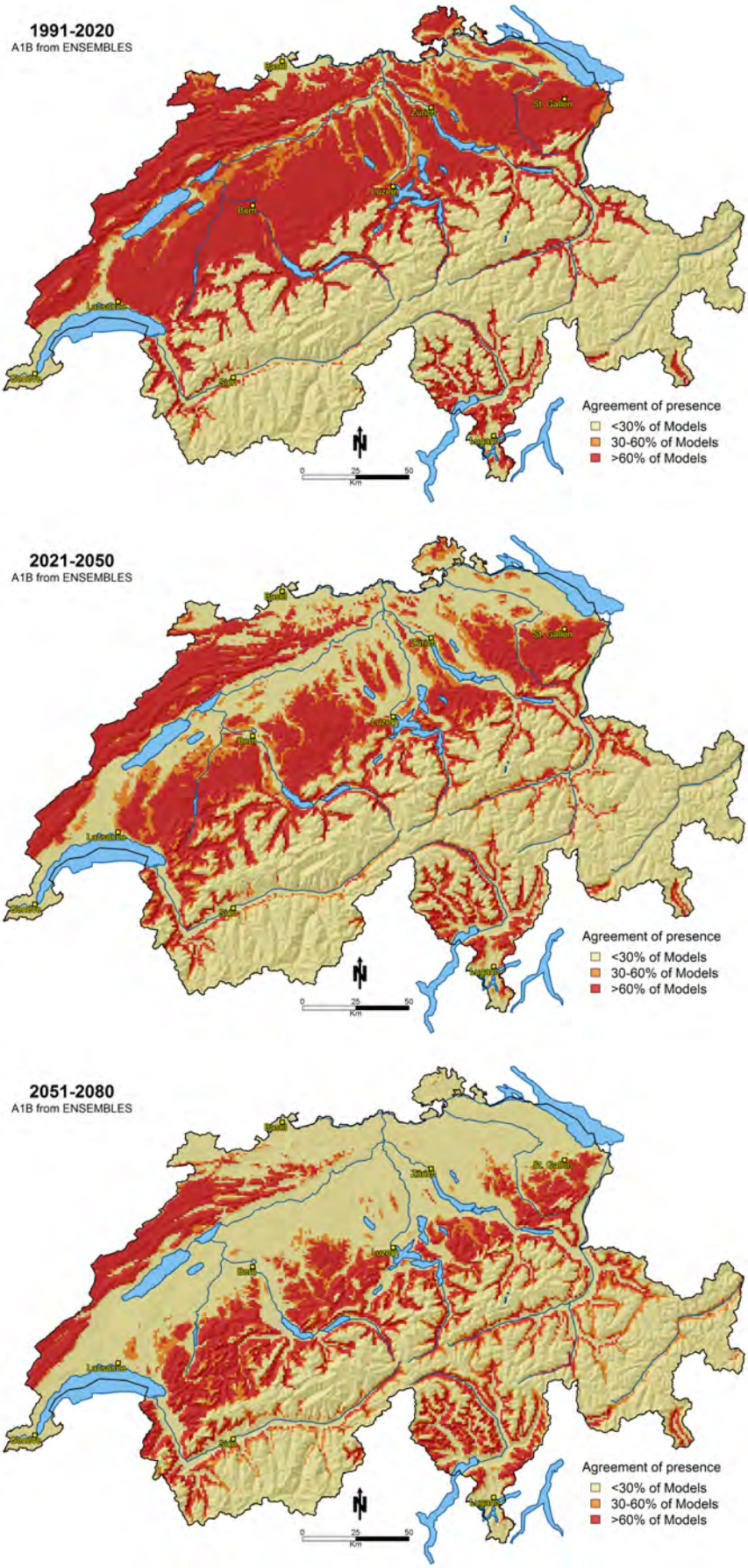


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

IPCC (2001) *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Zimmermann NE, Bolliger J, Gehrig-Fasel J, *et al.* (2006) Wo wachsen die Bäume in 100 Jahren? In: *Wald und Klimawandel* (ed. Wohlgemuth T), pp. 63-71. WSL, Birmensdorf, Schweiz.

Fraxinus spp

Description of model and ensemble projections

The current distribution of the genus *Fraxinus* is simulated to cover most of the Swiss Plateau, the lower altitudes of the Jura range, the Northern Pre-Alps, the interior valleys, as well as the Ticino. Some of the higher altitudes of the Jura range, the Valais and the Northern Pre-Alps are not modelled well for the genus. Obviously, there is not sufficient support in the model that these locations consistently harbor *Fraxinus* under these climate conditions. Also, all other regions where *Fraxinus* is projected to occur are prone to uncertainty, which is a common modelling problem for early successional species that do not persist long in forests during succession.

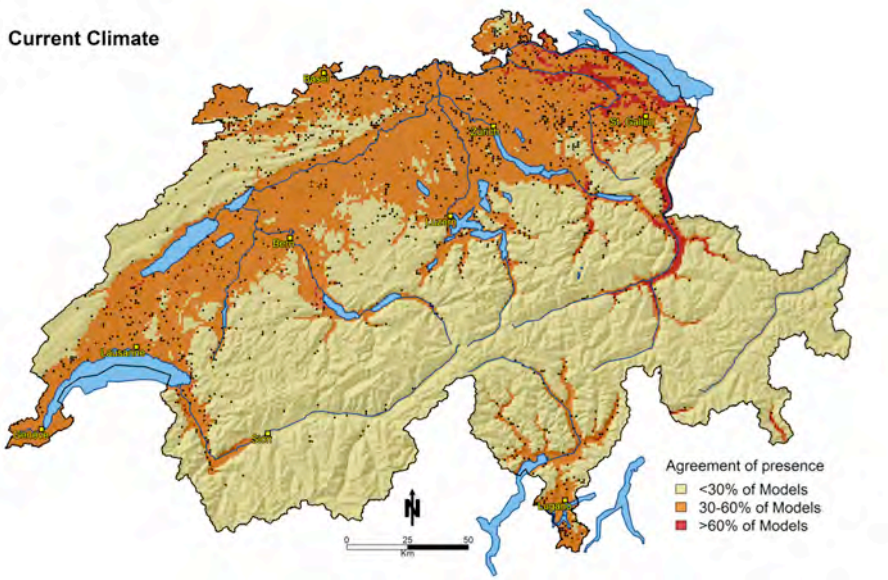


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a consistent spread of the genus *Fraxinus* everywhere to higher locations, meaning that these regions represent soon climate conditions, under which we currently observe presence of *Fraxinus* species. Only the region of Geneva is projected to harbor no suitable habitat conditions for the genus by the end of the Century. This is a bit surprising, since the genus contains a warm-adapted species (*F. ornus*).

Synthesis and Conclusions

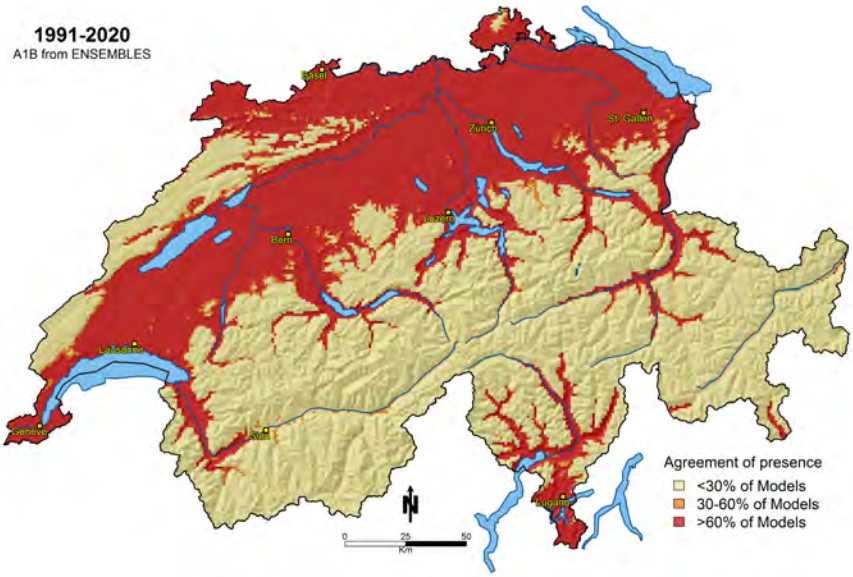
The model fits the distribution of the genus *Fraxinus* moderately well, and can be considered a fairly credible model to project the future habitat suitability of the *Fraxinus* genus. The ensemble models project a 91% overlap between the current and the future range in Switzerland, which can be considered very high. In addition, the genus will gain >50% in range size throughout Switzerland. This means that the genus is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and likely also in Europe. As an early successional, rapid growing and migrating species that is capable of growing on a wide range of soils and under a broad range of climate conditions, it will not require assisted migration and likely can track climate change quite considerably (Meier *et al.* 2012).

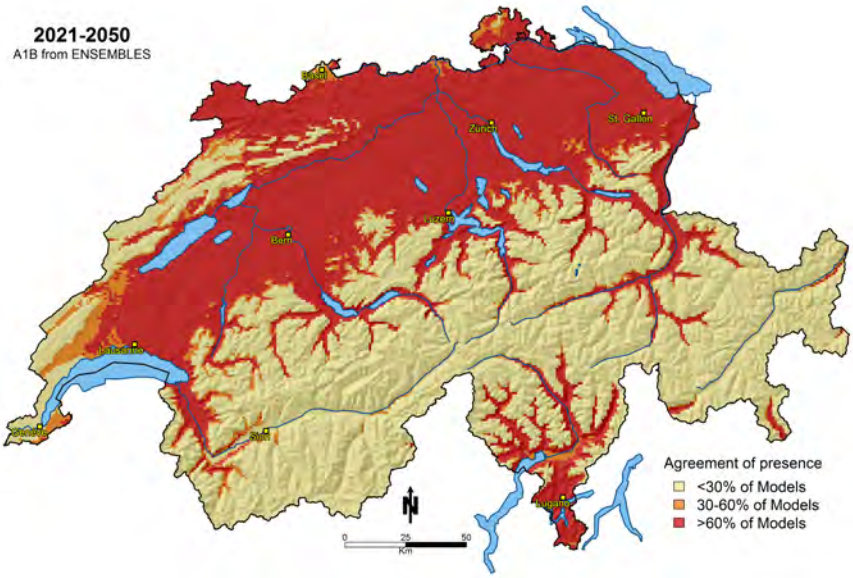
Range change statistics

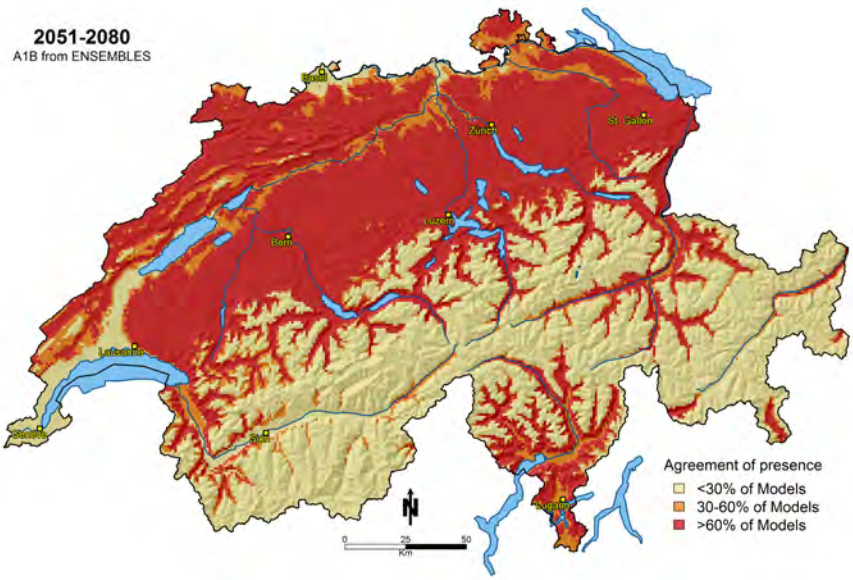
	CH	Europe
Current range size [km²]	15'249	–
Future (2080) range size	23'900	–
Range Change 2080/2000 [%]	156.8%	–
Overlap 2000/2080 [km²]	13'895	–
Overlap/current range [%]	91.2%	–

The genus (especially *F. excelsior*) is threatened by some pests, notably by the fungus *Hymenoscyphus pseudoalbidus* that is causing significant ash diebacks in Northern and Central Europe. The wood of some ash species is used for many different purposes due to its hard but elastic characteristics and its great finishing quality. Uses encompass bows, tool handles, electric guitar bodies, baseball bats, etc.

The genus is modelled with quite some uncertainty. This has likely two reasons: (i) it is common that early successional tree species do not exert a high probability of occurrence in most statistical models due to their ruderal nature. They simply do not steadily occur where conditions are suitable, and are therefore more difficult to model; (ii) the genus *Fraxinus* spans a very wide range of climate and soil conditions, partly due to the differing preferences of the two species *F. ornus* and *F. excelsior*. Yet, even on the common ash (*F. excelsior*) already encompasses a wide range of conditions, preferring moist or even wet, and deep soils to grow best on the one hand, but still growing in some regions on very shallow, highly insolated and dry slopes. It is therefore not easy to project exactly the locations and conditions where the genus with its differing species is most likely to occur. The overall model quality is therefore not very high.







References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Fraxinus excelsior

Description of model and ensemble projections

The current distribution of *Fraxinus excelsior* is modelled to cover most of the Swiss Plateau, the lower Jura Mountains, the Northern Pre-Alps, lower altitudes in dry Interior valleys, as well as the Ticino. Few of the highest altitude distribution points in the Jura are not well modelled, and the model ensemble is uncertain regarding the quite abundant observations in the Valais, where *F. excelsior* grows under quite different conditions, namely on dry and sunny slopes with shallow soils.

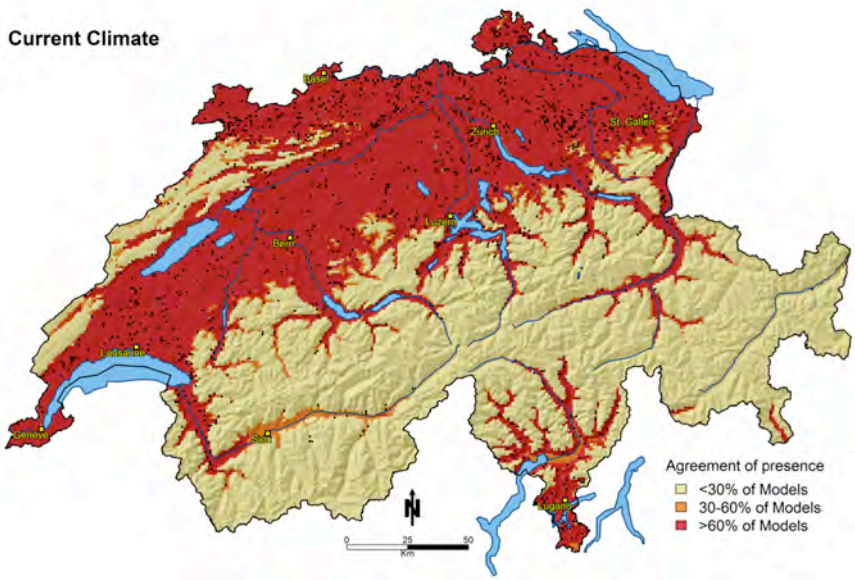


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario from ENSEMBLES, most combinations of statistical and regional climate models predict a clear spread of *F. excelsior* to higher altitudes almost everywhere in Switzerland, and the lowest altitudes are almost entirely kept suitable. Only in the lowest and warmest regions of the Swiss Plateau, the Valais and the Ticino, the model ensemble predicts a considerable uncertainty as to whether *F. excelsior* will still find suitable habitats. All other regions will soon harbor climate conditions, under which *F. excelsior* finds suitable habitats comparable to its currently observed distribution. Simply, the species "escapes" to higher altitudes.

Synthesis and Conclusions

The model fits the distribution of *Fraxinus excelsior* very well, and can be considered a credible model to project the future habitat suitability of *F. excelsior*. The ensemble models project a 58% overlap between the current and the future range in Switzerland and somewhat lower overlaps (35%) across Europe.

Range change statistics

	CH	Europe
Current range size [km²]	18'197	–
Future (2080) range size	17'849	–
Range Change 2080/2000 [%]	98.0%	–
Overlap 2000/2080 [km²]	10'603	–
Overlap/current range [%]	58.2%	–

With regards to range change, the species will only shrink its range size by 2% in Switzerland. This means that the species is not particularly threatened, and will still find sufficient suitable habitat in Switzerland. As one of the preferred timbers, it might profit from assisted migration to higher altitudes. In addition, the species has fast migration rates mostly due to its life history characteristics as an early successional, fast growing species. These have been reported to have fast migration rates that allow a species to almost track climate change (Meier *et al.* 2012). The species naturally inhabits primarily moist, mineral-rich and deep soils, requires a rather moist climate and enough light due to its low shade tolerance. It does not grow well under late spring frost climates. However, in some regions it also grows on very sunny and dry sites on shallow soils, representing completely different site conditions. Therefore, the species seems to encompass a very broad environmental niche spanning from very wet, waterlogged soils to very dry and shallow soils. Only on mesic and nutrient rich to moderately dry soils the species is outcompeted by late successional, seral species. Yet, the species can still be found in early successional stages, and therefore is modelled to occur almost everywhere below critical frost temperatures.

The fact that *F. excelsior* seems to have two poles along a moisture gradient had lead some ecologists to propose that these might represent two clades of the same broader species, a "water ash" and a "calcareous ash", where the latter represents those populations on well-drained, shallow and dry soils. Yet, genetic analyses have not been able to confirm any sub-specific typification. Therefore, it likely just represents a manifestation of a very broad environmental range. The species can still "survive" well in beech dominated forest landscapes because it tolerates quite high shade levels as juvenile. Only in the adult stage it is very shade intolerant.

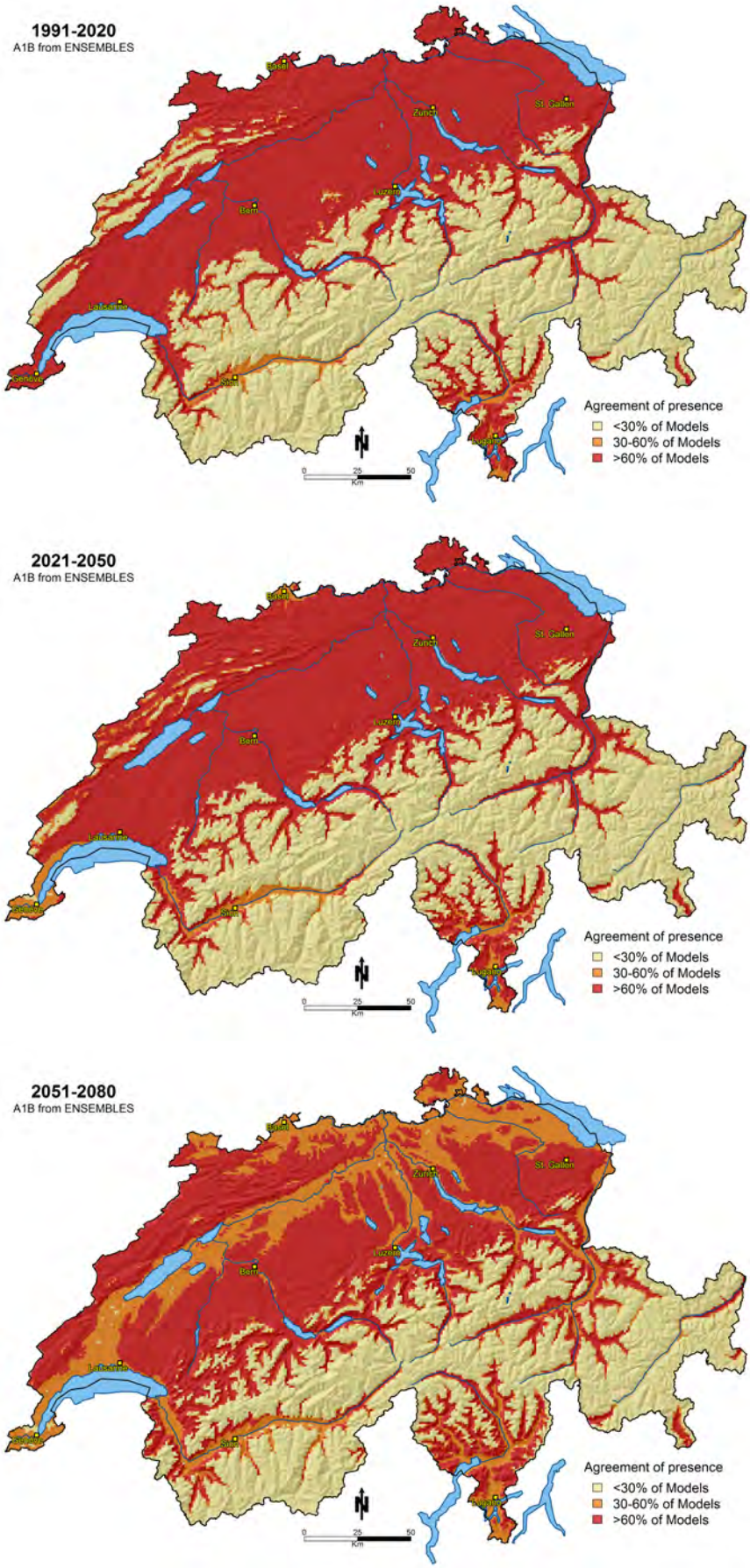


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Fraxinus ornus

Description of model and ensemble projections

The current distribution of *Fraxinus ornus* is modelled to cover simply the Southern part of the Ticino, the only region where the species is abundantly observed. Although the model is fitted from all data points across the Alps, the model ensemble sets the distribution limit approximately correctly, despite not matching all of the few individual observation points in the Ticino. Only some more Northern and isolated locations in the Central Ticino are not well captured by the model ensemble.

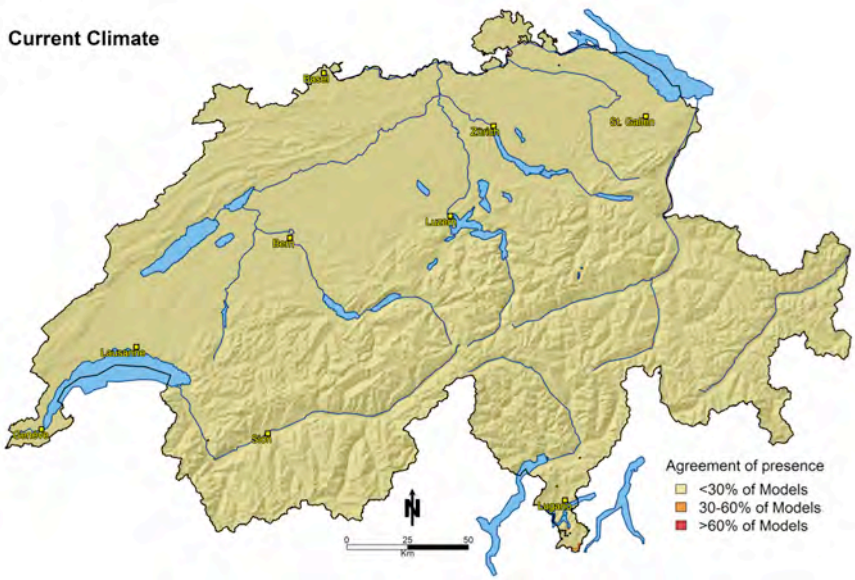


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a consistent spread of *Fraxinus ornus* into more Northern regions of the Ticino, soon also into the lower portion of the Valais, and finally onto the warmest parts of the Swiss Plateau and the Jura range. Specifically, the species is also projected to colonize the Geneva region, and the Chur basin, as well as the Poschiavo valley. Uncertain, but still notable habitats are finally modelled for the Reuss valley South of the Lake of Lucerne and the lowest parts of the Glarus region.

Synthesis and Conclusions

The model fits the more general distribution of *Fraxinus ornus* across the Alps (not shown) well, and can be considered a credible model to project the future habitat suitability of *F. ornus*. The ensemble models project only an 18% overlap between the current and the future range in Switzerland and a considerable overlap (78%) in Europe. Differing trends in Switzerland and Europe are also modelled regarding change in suitable habitat range between current and projected future climates. While in Switzerland the range is projected to expand more than three times the current size, the European range of suitable habitats is projected to increase only marginally (+23%).

Range change statistics

	CH	Europe
Current range size [km²]	218	46'739
Future (2080) range size	680	57'305
Range Change 2080/2000 [%]	312%	122.6%
Overlap 2000/2080 [km²]	39	36'204
Overlap/current range [%]	17.9%	77.5%

The model does not predict the few observations of *F. ornus* in the Ticino very accurately. This is not surprising for a model that is fitted across all sites of the European Alps. Yet, it still captures the range edge of the species approximately correctly. The species has its center of distribution in the Eastern Mediterranean region, and has been widely planted for ornamental reasons throughout the Mediterranean and Sub-Mediterranean regions. In Germany it is considered an established neophyte, which spreads often into vineyards.

The species can be considered a "winner" of projected climate change. It will likely spread in warmer regions of Switzerland together with Oaks (*Quercus pubescens*, *Q. petraea*, *Q. cerris*), hop hornbeam (*Ostrya carpinifolia*) and European hornbeam (*Carpinus betulus*). It prefers well-drained, dry and warm conditions. It also grows well on ruderal sites. The species will not have difficulties to grow well and adapt under changing climate conditions, since it grows moderately fast to maturity and re-seeds well.

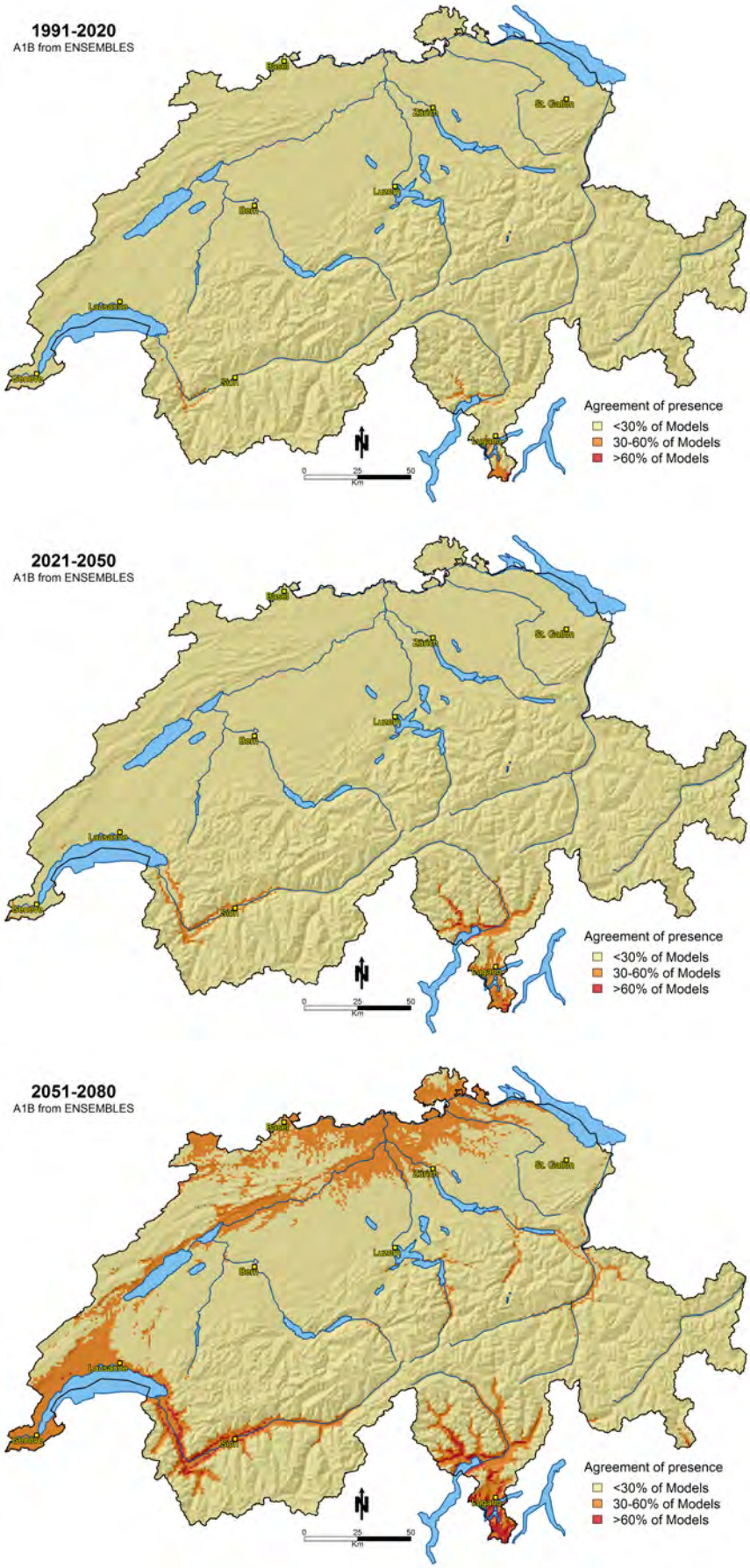


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Larix decidua

Description of model and ensemble projections

The current distribution of *Larix decidua* is simulated to colonize most of subalpine forests in the Interior and Sourthern Alps. In addition, the species also is modelled to find suitable habitats In some few parts North of the Alps such as in the Gastern Valley or in the Southern-most parts of the Lauterbrunnen valley (Stechelberg) and in the subalpine forests in the Rhine valley, nostly around Chur. Some parts like the Reuss uppermost valley and the Posterior Rhine valley are simulated to be suitable, despite having no (or not much) observations of the species being distributed there. On the other hand, the Anterior Rhine valley and some neighbouring valleys harbor significant portions of the species' distribution North of the Alps, and are well modelled. Underestimated are also some parts North of the Alps in Western Switzerland. All low elevation plantings on the Swiss Plateau and Jura Mountains are not modelled to be suitable habitats from the set of occurrences and absences used for this model.

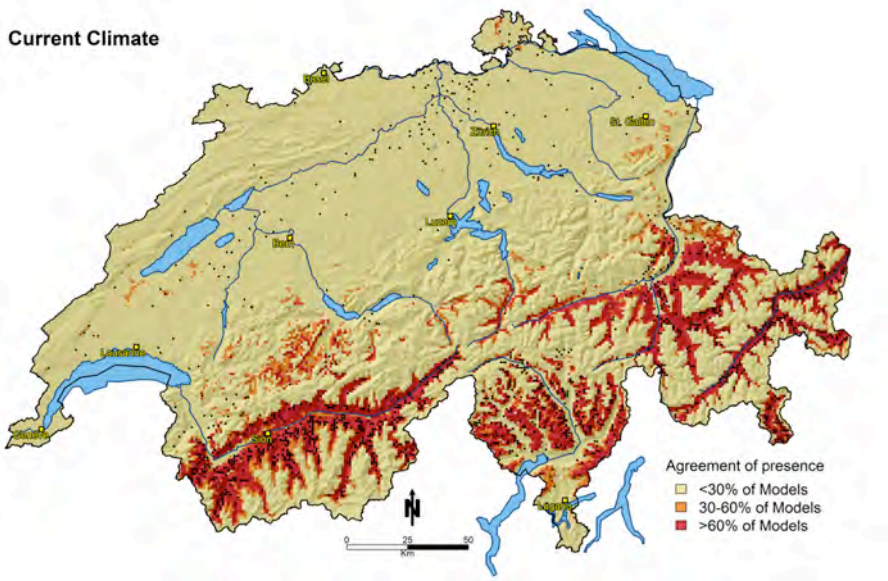


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a clear shift to higher altitudes of *L. decidua*, which leads to a stronger connection of the currently somewhat disconnected distribution range. This means that these regions represent soon climate conditions, under which presence of *L. decidua* is currently being observed. The species is expected to colonize all future subalpine zones, but still is expected to largely be absent in subalpine forests North of the Alps, with the exception of the Gotthard regions and - to a less certain degree – mountains in the Southern Simmen, Diemtig and Kander valley, where a moderate spread is projected.

Synthesis and Conclusions

The model projects the distribution of *Larix decidua* comparably well, and can be considered a credible model to project the future habitat suitability of *Larix*. The ensemble models project a 60% overlap between the current and the future range in Switzerland and a lower overlap (38%) in Europe. While in Switzerland (+45%) the species can be expected to expand its range of suitable habitats, it is projected to lose significant suitable habitat area (-61%) compared to its current range. Usually, species growing in high mountain environments tend to lose considerable range with increasing temperatures (Engler *et al.* 2011). However, *Larix decidua* is likely profiting from the projected decrease in summer precipitations throughout the Alps and Southern/Central Europe by expanding into regions that were too wet before. By this, *Larix* is expected to find more suitable habitats in by the end of the Century compared to today in the Alps, but not in the rest of Europe.

Range change statistics

	CH	Europe
Current range size [km²]	5'596	57'482
Future (2080) range size	8'137	22'394
Range Change 2080/2000 [%]	145.4%	38.9%
Overlap 2000/2080 [km²]	3'386	21'758
Overlap/current range [%]	60.5%	37.8%

Larix decidua inhabits sub-continental forests in the upper subalpine belt throughout the Alps, and best grows on step slopes on a range of different soil types. *Larix* is very light demanding, and the currently large distribution and local dominance may partly be a result of management (Alpine pasturing) effects. More shade tolerant species would have likely outcompeted *Larix* locally, if these hadn't been removed by man in order to increase the pasturing potential of the subalpine belt. Under a slowly decreasing (sub-) alpine pasturing regime, *Larix* might decrease somewhat it's abundance and range.

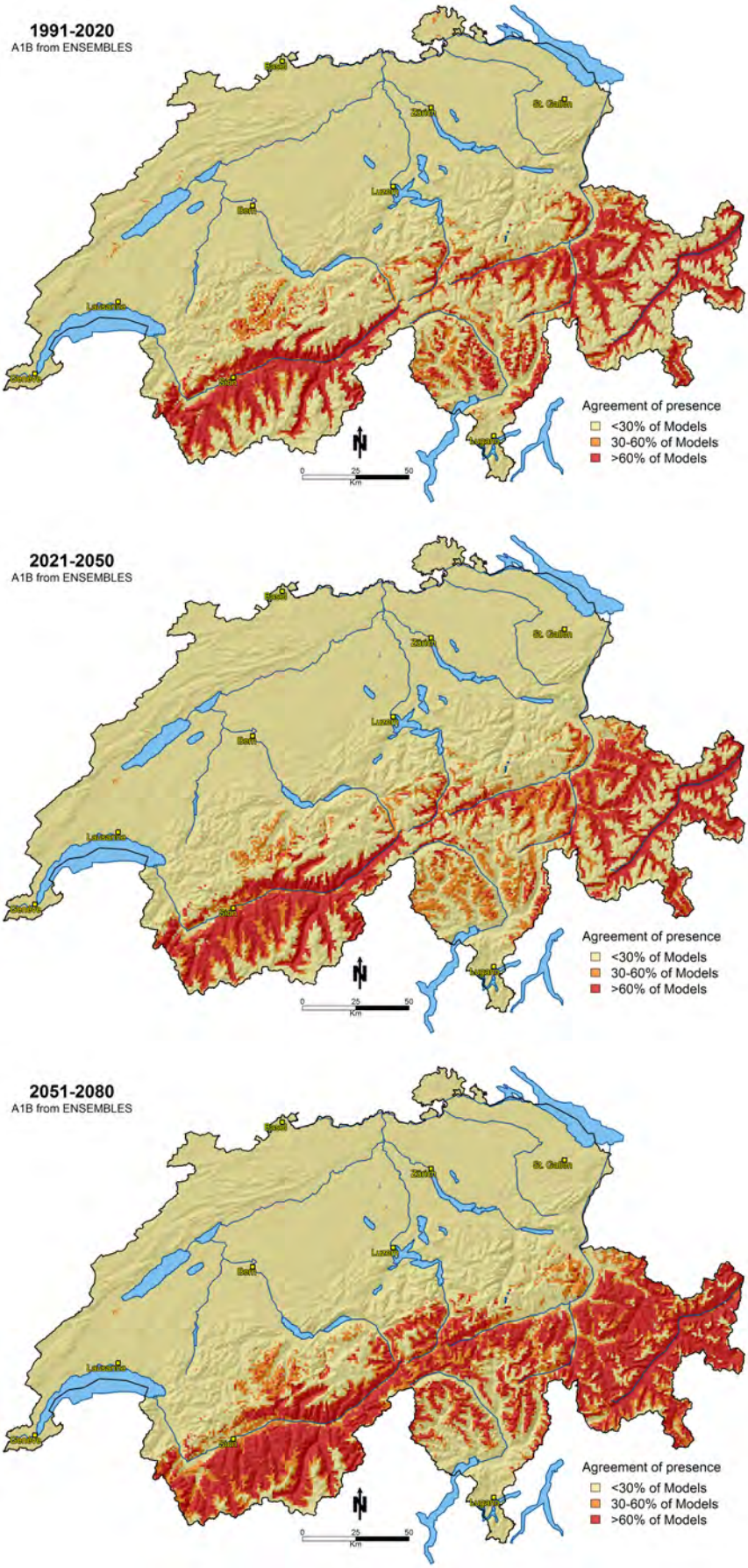


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

In addition, Larix is +/- regularly (7-10 yrs) attacked by the larch totrix (*Zeiraphera griseana*), a moth that has its distribution range throughout the boreal regions of Eurasia. Other pests are also reported. These might in addition limit the capacity of the species to adapt rapidly to new habitats under climate change. On the other hand, the species is considered early successional, grows fast (and is therefore also planted widely at low altitudes), and reaches maturation rapidly. It also grows sufficiently well on mineral soils, though it prefers more loamy soils to grow best. As a consequence of these life history characteristics, the species' migration capacity should be well adapted to climate and land use change (Meier *et al.* 2012).

References

Engler R, Randin CF, Thuiller W, *et al.* (2011) 21st century climate change threatens mountain flora unequally across Europe. *Global Change Biology* **17**, 2330-2341.

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Ostrya carpinifolia

Description of model and ensemble projections

The current distribution of *Ostrya carpinifolia* is modelled to cover primarily the low altitude regions of the Ticino. The model captures the general distribution of the species well, despite missing some specific pixels where the species obviously is present. The species naturally inhabits the colline region South of the Alps, and is profiting there primarily from coppice forest management.

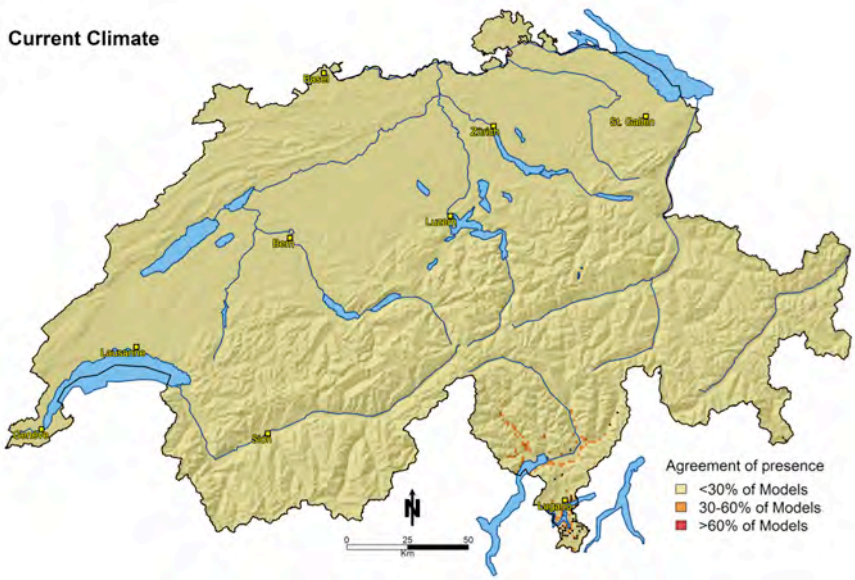


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *Ostrya* within the Ticino into more Northern valleys and to higher altitudes. This means that these regions represent soon climate conditions, under which presence of *Ostrya* is currently being observed. Some "Foen" (=chinook) regions (Upper Reuss valley) and otherwise specifically favored regions in the lower Valais seem to become suitable as well.

Synthesis and Conclusions

The model fits the distribution of *Ostrya carpinifolia* comparably well, and can be considered a credible model to project the future habitat suitability of *Ostrya*. The ensemble models project a 98% overlap between the current and the future range in Switzerland and still a high overlaps (73%) in Europe. This is a very high overlap between current and projected future distribution and suggests that this species is not much at risk in the future.

Range change statistics

	CH	Europe
Current range size [km²]	112	22'062
Future (2080) range size	742	22'155
Range Change 2080/2000 [%]	662%	100.4%
Overlap 2000/2080 [km²]	110	16'044
Overlap/current range [%]	98.2%	72.7%

Moreover, the species likely increases its distribution range considerable in Switzerland +562%, while in Europe it likely can maintain the current range size. This means that the species is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and in Europe under future climate conditions. However, it might depend largely on coppice forest practice, and may not easily be able to migrate into the beech or spruce forests the currently colonize the higher altitudes that will become suitable habitats for this species. This is a general problem for light demanding species such as *Ostrya,* which currently profit considerably from traditional forest management practice. Only if the climate becomes significantly drier, it might be able to migrate to those regions on its own.

The fact that the model does not depict well the spatial details of the current distribution of *Ostrya* in the Ticino likely originates from the pan-Alpine data basis, which is not necessarily the best source to predict exactly the Ticino distribution at it's cold, Northern distribution range limit in Southern Switzerland. Still, we consider the general pattern of the distribution range to be well covered by the model, and therefore we believe that the projections are credible for this species.

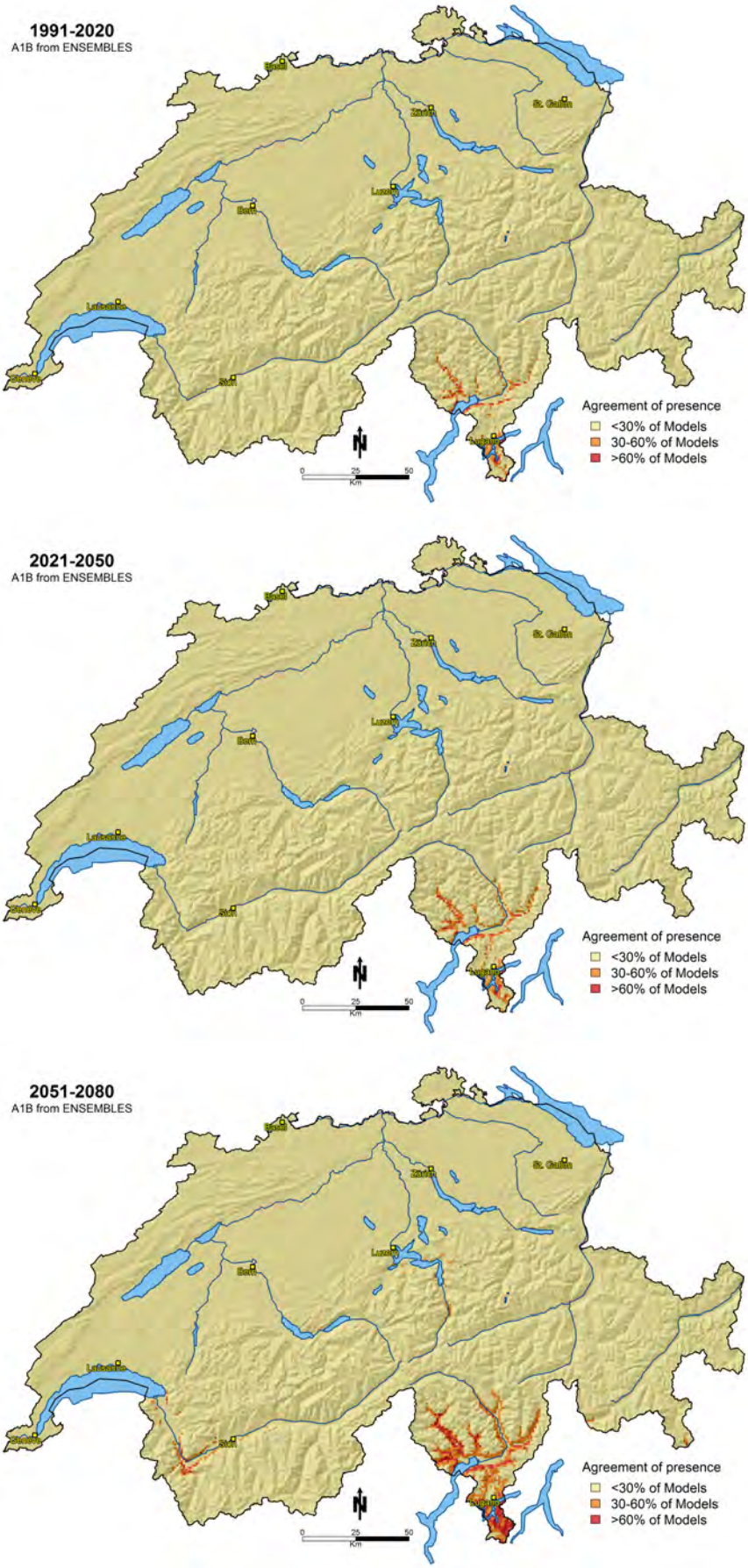


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Picea abies

Description of model and ensemble projections

The current distribution of *Picea abies* is modelled to cover most of the Swiss Plateau and the Northern Pre-Alps. In addition, the species also grows at higher altitudes in the inner Alpine valleys and in the Northern part of the Ticino. The species naturally inhabits primarily the subalpine region, and is planted widely on the Plateau. The fact that some (the warmest) parts of the Plateau region are not modeled to be suitable reflects the fact that the model does not find sufficient evidence for *Picea* being present in these situations consistently.

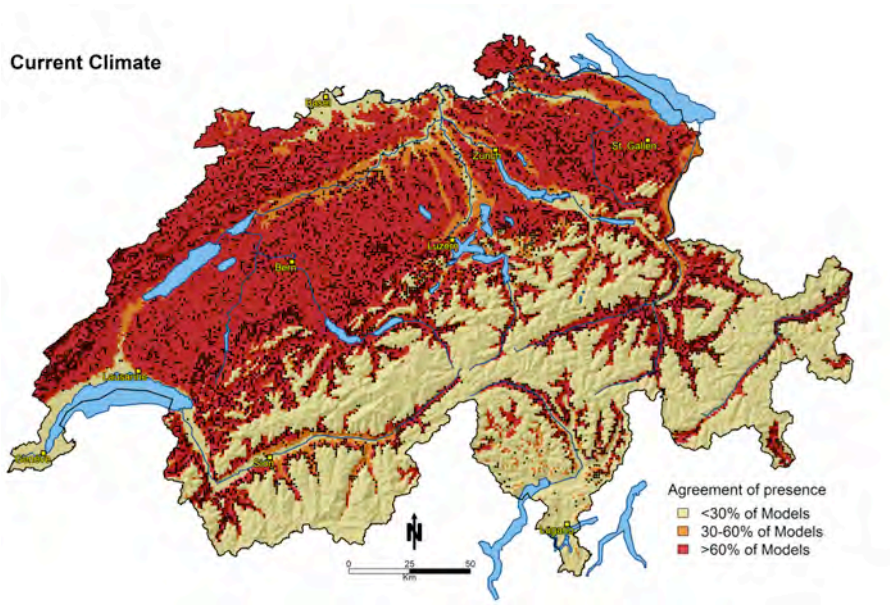


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid disappearance of *Picea* on the Plateau, meaning that these regions represent soon climate conditions, under which no presence of *Picea* is currently being observed. The species "escapes" to higher altitudes.

Synthesis and Conclusions

The model fits the distribution of *Picea abies* well, and can be considered a credible model to project the future habitat suitability of *Picea*. The ensemble models project a 31% overlap between the current and the future range in Switzerland and a similarly high overlap (41%) in Europe. This is a much higher overlap than previously modeled (Zimmermann *et al.* 2006). The difference mostly originates from using less extreme climate scenarios in this report. Here we used the A1B scenario, which is a moderate warming scenario from the fourth IPCC assessment report (IPCC 2007). The previous simulations were based on the 3rd assessment report (IPCC 2001), where the A1FI scenario was much more extreme compared to the current A1B.

Range change statistics

	CH	Europe
Current range size [km²]	21'072	159'325
Future (2080) range size	13'636	74'752
Range Change 2080/2000 [%]	64.7%	46.9%
Overlap 2000/2080 [km²]	6'533	65'444
Overlap/current range [%]	31.0%	41.0%

However, the species will lose ca. 50% of its range and the future range is much smaller than the current one (64% and 47% for Switzerland and Europe, respectively). Overall, the species is not particularly threatened, and will still find sufficient suitable habitat, both in Switzerland and in Europe. As a preferred timber, it will get assisted migration to higher altitudes, where necessary. There may be provenances (originating from the South of the Alps) that might be characterized by higher drought tolerance than the northern Alpine provenances, and these might be suitable alternatives to improve the drought adaptation of the species north of the Alps.

The disappearance on the Swiss Plateau means, that the future climate is warmer (and partly also drier) than any observed current distribution of *Picea*. On the other hand it might take 100s if not 1000s of years, until the species is outcompeted by immigrating competitor species, such as oaks or beech. Until 2050, and despite projections of habitat loss on the Plateau, the climate will probably not be extreme enough to drive *Picea* to extinction. The growth analyses (S2) indicate that under a warming climate, *Picea* might thrive well, as long as summer precipitation is not declining.

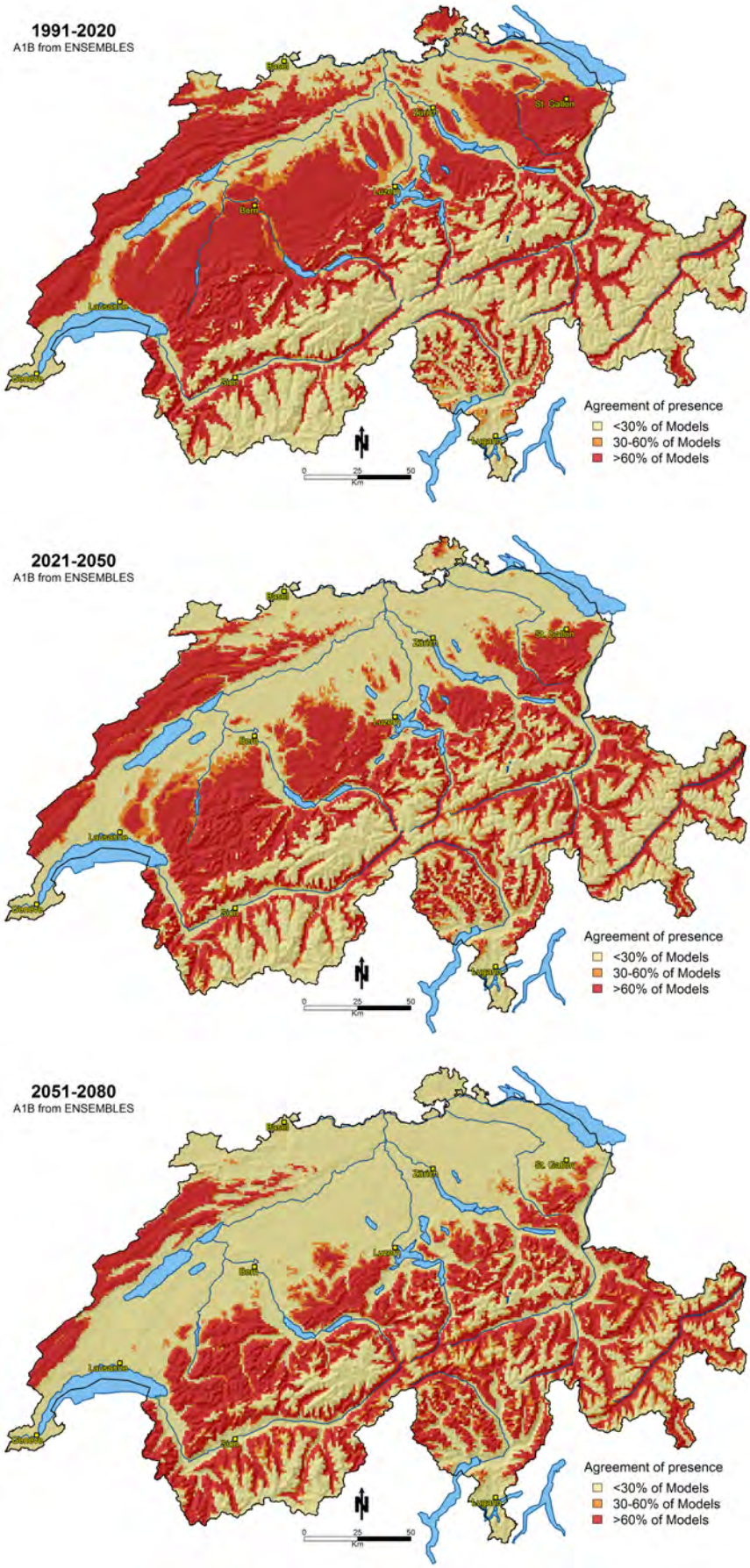


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

IPCC (2001) *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Zimmermann NE, Bolliger J, Gehrig-Fasel J, *et al.* (2006) Wo wachsen die Bäume in 100 Jahren? In: *Wald und Klimawandel* (ed. Wohlgemuth T), pp. 63-71. WSL, Birmensdorf, Schweiz.

Pinus cembra

Description of model and ensemble projections

The current distribution of *Pinus cembra* is modelled to cover most of the upper subalpine forests in the dry, Interior Alps, and partly also in the Northern Pre-Alps. However, in these regions, the species is less clearly predicted, and many projections are associated with comparably high uncertainty. Compared to the observed distribution, the species is probably over-predicted quite strongly in the Western Pre-Alps, and in the Anterior Rhine Valley, although, in both regions there are pockets of *P. cembra* distributions.

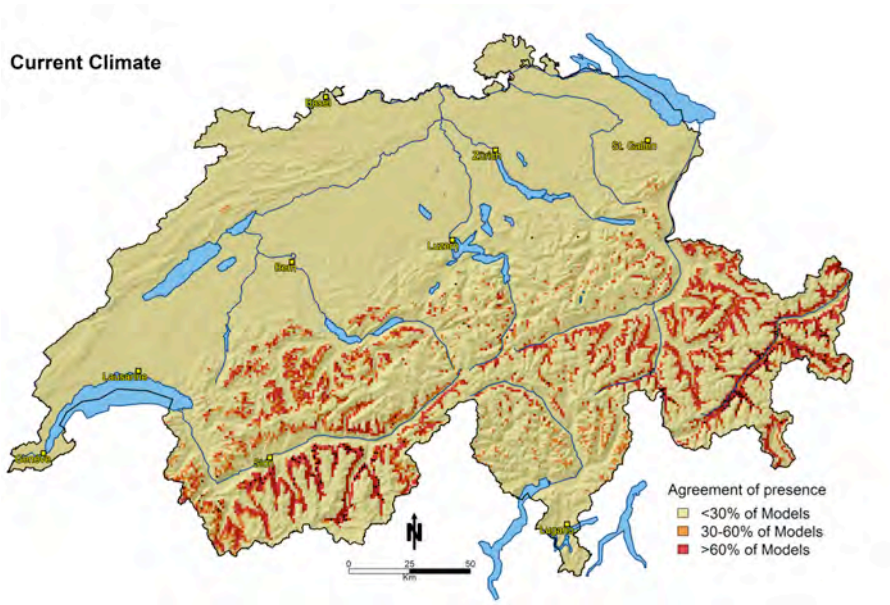


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid disappearance of *P. cembra* at the altitudes it currently colonizes, meaning that these regions represent soon climate conditions, under which no presence of *P. cembra* is currently being observed. The species "escapes" to higher altitudes. In addition, it primarily retreats to higher altitudes in the two centers of dry climates (Valais and Engadin), while in all other regions, the ensemble projections are very uncertain.

Synthesis and Conclusions

The model fits the distribution of *Pinus cembra* quite well, and can be considered credible, yet with overestimations in some regions North of the Alps. The ensemble models project only a 1% overlap between the current and the future range in Switzerland, which is one of the smallest of all species modelled in PorTree. Also, the overall range is projected to shrink to 30% of the currently modelled range size. This means that the species is projected to lose significant portions of its range, and that there is a very small overlap only between current and future suitable habitat range. This originates primarily from the fact that the thermal niche of the species is very narrow, and because there is not much land area above the current range of the species.

Range change statistics

	CH	Europe
Current range size [km²]	2'952	–
Future (2080) range size	848	–
Range Change 2080/2000 [%]	28.7%	–
Overlap 2000/2080 [km²]	31	–
Overlap/current range [%]	1.1%	–

The species grows very slowly, is not very shade tolerant, and depends on nutcrackers and small rodents for seed dispersal. This fact means that it can likely track climate change at a sufficient pace, due to the short distances from current occurrences to projected future suitable habitats by this "animal-assisted migration". Also, the "loss" of suitable habitats at lower altitudes is likely not caused by physiological stress, but rather by competition from upward moving spruce trees. Yet, such competitional dynamics will take hundreds if not thousands of years. In summary, despite the strong

Pinus cembra is listed in the IUCN Red List database (Farjon 2013), and listed there under "least concern". This low concern originates from the view that the species currently is: (a) well protected in many reserves, and (b) expanding upslopes and increasing in populations size.

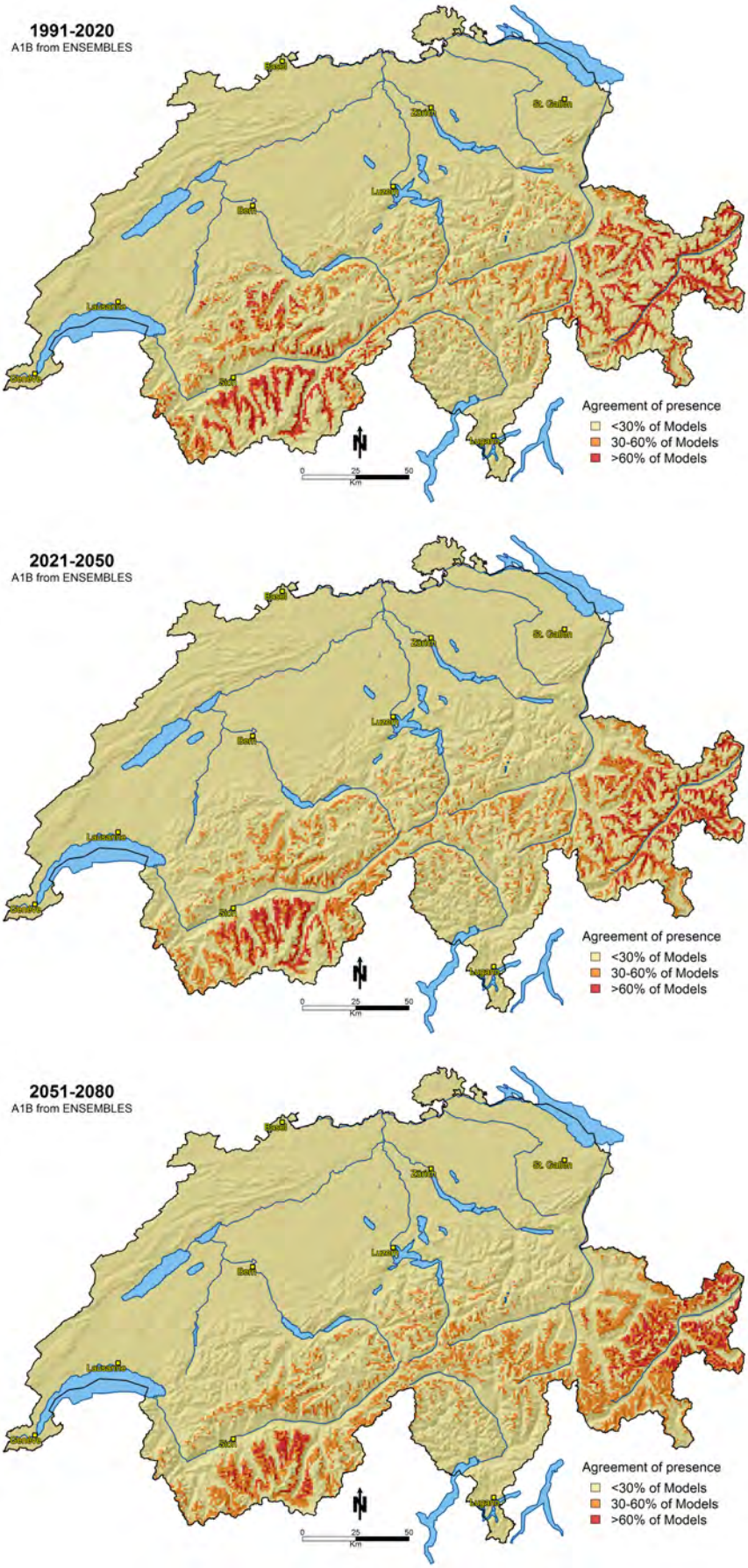


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Farjon, A. 2013. *Pinus cembra*. The IUCN Red List of Threatened Species. Version 2014-2. <www.iucnredlist.org>. Downloaded on 22nd September 2014.

Pinus nigra

Description of model and ensemble projections

The current distribution of *Pinus nigra* is not projected to really occur in Switzerland based on the pan-Alpine data basis used in the MANFRED project. The model predicts a total of 4 km^2 of suitable habitat, which can be neglected. The species occurs in more Eastern and Southern mountains at low to mid altitude, under more Mediterranean and continental climates. Within the Alps, it can be found at the South-Eastern edge of the Alps in NE-Italy, Northern Slovenia and SE Austria.

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a spread of *P. nigra* into the Valais, and finally even onto the Plateau, meaning that these regions will soon have climate conditions, under which *P. nigra* will find comparable habitats to its current range.

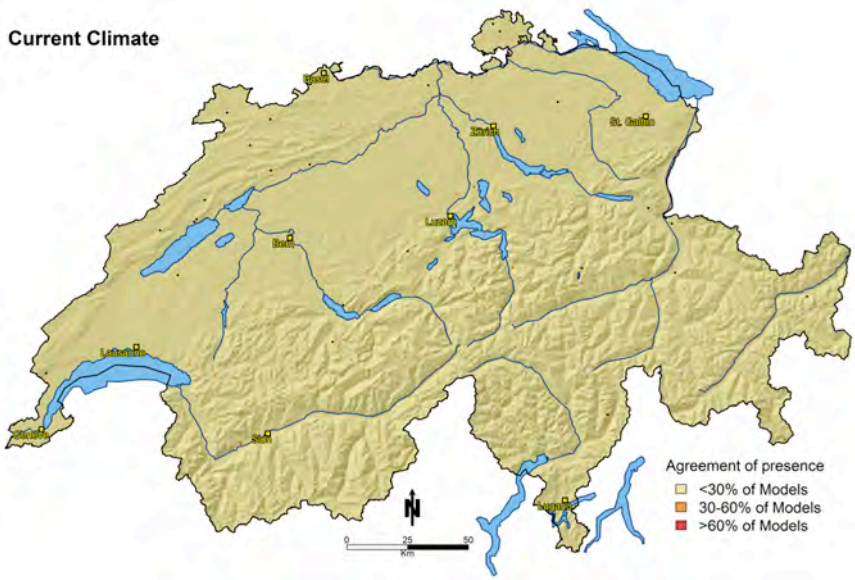


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Synthesis and Conclusions

The Alps-wide model (not shown here) fits the distribution of *P. nigra* quite well, and can therefore be considered a credible model to project the future habitat suitability of the species. The ensemble model projects a 33% overlap between the current and the future range in Switzerland (from insufficient numbers of pixels). Yet, it also finds a comparable overlap (22%) in Europe. This may be considered a sufficient overlap to conserve the species without extreme efforts.

However, the species will lose ca. 75% of its European range, despite enlarging its range into Switzerland massively. Compared to *P. sylvestris*, *P. nigra* is a bit more drought and heat tolerant, and might be a viable management alternative form this perspective.

Range change statistics

	CH	Europe
Current range size [km^2]	6	90'267
Future (2080) range size	7'568	24'877
Range Change 2080/2000 [%]	>999%	27.5%
Overlap 2000/2080 [km^2]	2	19'641
Overlap/current range [%]	33.3%	21.7%

Yet, the species likely will not migrate to Switzerland without assistance. It cannot cross the Alps and the distance around the Alps is way to far to be colonized by natural migration. It also is currently unclear, if it can thrive well on deeper soils on the Swiss Plateau under increased bark beetle risks. On the other hand, *P. nigra* has become naturalized in many regions of the US, and in New Zealand it is considered an invasive species and noxious weed. It therefore could well establish in a warmer and drier climate, once introduced.

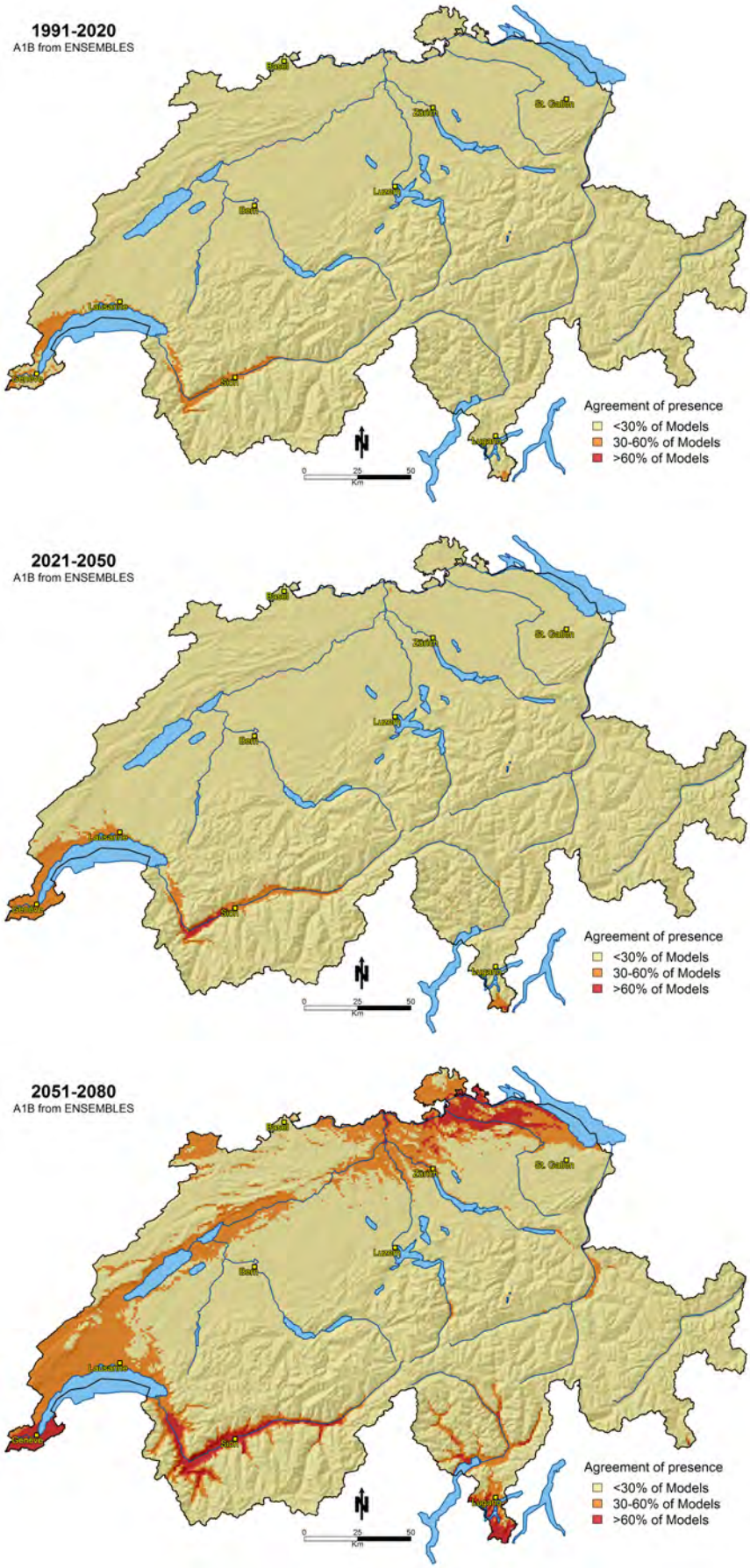


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Pinus sylvestris

Description of model and ensemble projections

The current distribution of *Pinus sylvestris* is simulated to cover most of the Swiss Plateau, the North-Eastern Jura range and the Northern Pre-Alps and lower altitudes of the interior dry valleys (Valais, Posterior Rhine valley incl. Landwasser and Bergün region, Lower Engadin. The valleys North and South of the Gotthard massive (Upper Reuss valley, Hasli valley, Leventina) are harboring significant populations of *P. sylvestris*. Yet, these populations are not modelled well with the existing model. Neither are some of the highest populations in the Jura and North-Eastern Pre-Alps.

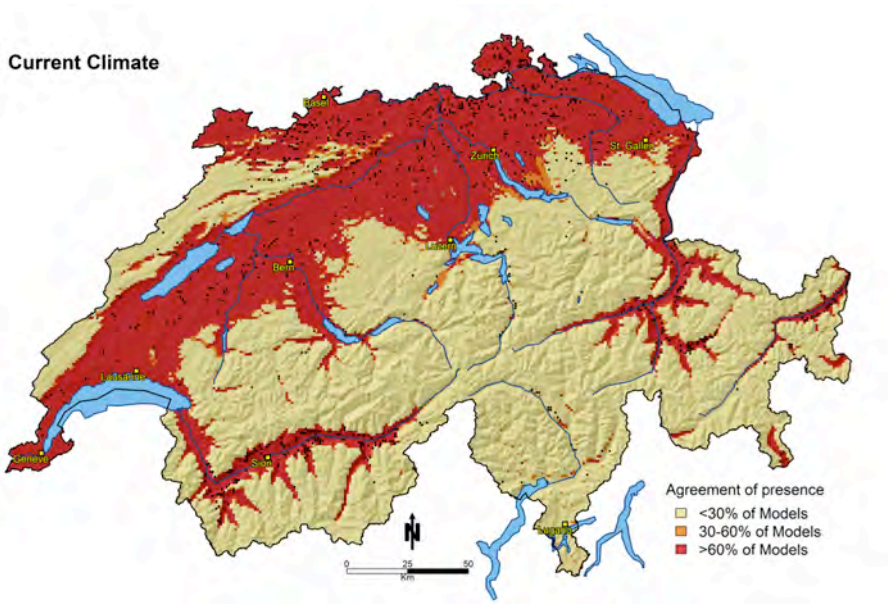


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *P. sylvestris* to higher altitudes and specifically also into the regions that were said to have false negative (predicted absence, where presence is observed). The species "escapes" to higher altitudes and invades into more valleys than it is currently distributed. On the other hand, the species doesn't really lose much suitable habitat at lowest altitudes, except in the Ticino. There, it is projected to no longer find suitable habitats.

Synthesis and Conclusions

The model fits the distribution of *Pinus sylvestris* very well, and can be considered a credible model to project the future habitat suitability of *P. sylvestris*. Only the some "Foen" (=chinook) regions are not modelled well, since this predictor is not easily available in map form. The ensemble models project a 99% overlap between the current and the future range in Switzerland and still a high overlap (59%) in Europe. This is a much higher overlap than previously modeled (2.9%, Zimmermann *et al.* 2006). The difference mostly originates from using less extreme climate scenarios in this report. Here we used the A1B scenario, which is a moderate warming scenario from the fourth IPCC assessment report (IPCC 2007). The previous simulations were based on the 3rd assessment report (IPCC 2001), where the A1FI scenario was much more extreme compared to the current A1B scenario. In addition, we used soil information (soil depth) and an assessment of calcareous/non-calcareous soil types. In addition, the species is projected to increase its range of suitable habitats in Switzerland (+44%), and in Europe, it will lose a fraction of its comparably large range, shrinking by ca. 40%.

Range change statistics

	CH	Europe
Current range size [km²]	15'302	207'621
Future (2080) range size	22'095	122'934
Range Change 2080/2000 [%]	144.3%	59.2%
Overlap 2000/2080 [km²]	15'159	122'062
Overlap/current range [%]	99.1%	58.8%

This species will not be in difficulties with on-going climate change. On the one hand, it is rather a pioneer species that grows fast and doesn't tolerate much shade. It can grow to maturity within 10-15 years, and the wind-dispersed seeds allow for comparably rapid migration (Meier *et al.* 2012). This, together with the high overlap, suggests that the species will do well in the future. However, it has difficulties, currently, in the warmest regions of the Valais. In these warmest regions, the species is observed to undergo severe mortality events in years following severe droughts. This effect is not well modelled by the current model ensemble. It is therefore likely, that on some of the warmest regions, specifically on shallow soils, the species will not do well in the future. It is, on the other hand, not so clear, how the species will do on deeper soils. Currently, it can only grow on deep soils early during a succession, or at forest edges, thus escaping the competition by more shade tolerant, late successional species. In a warmer and dryer climate, it might expand its survival on deeper soils, but will face pathogens at such locations. Only on very dry (but usually not too hot) sites, the species can be considered a late successional species, meaning that no other species can tolerate these conditions and outcompete *P. sylvestris*

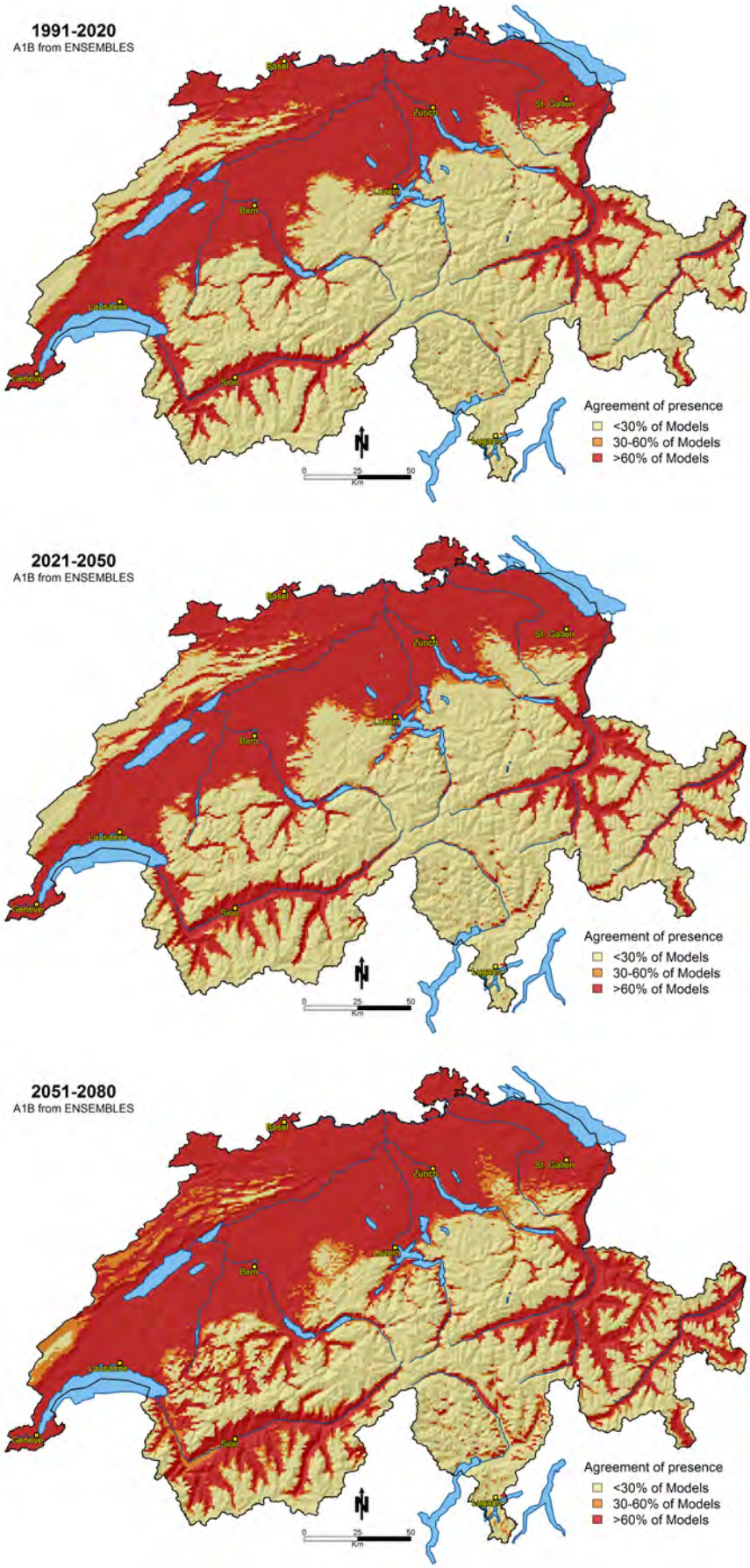


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

The species profits from two different types of seed dispersal. On the one hand it distributes the seeds by wind, using its seed wings. There is a short-winged form that can distribute seeds up to 150m away from the source. The long-winged form reaches seed dispersal distances up to 1000m, which can be considered very far. On the other hand, there is significant secondary distribution by small rodents, birds or by water transport.

Among all 113 pine species described, it is the one with the largest geographic distribution. It has spread throughout Northern Eurasia, but has also become invasive in several parts of North America and South Africa, specifically.

References

IPCC (2001) *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Zimmermann NE, Bolliger J, Gehrig-Fasel J, *et al.* (2006) Wo wachsen die Bäume in 100 Jahren? In: *Wald und Klimawandel* (ed. Wohlgemuth T), pp. 63-71. WSL, Birmensdorf, Schweiz.

Populus tremula

Description of model and ensemble projections

The distribution model of *Populus tremula* is modelled to cover all lower altitudes in Switzerland under current climate conditions up to an elevation of ca. 1400 m a.s.l. and partly even beyond. The species is not demanding with regards to soil conditions and can grow on almost every soil. It also is projected to occur in the more oceanic climates north of the Alps, as well as in the more continental interior Alps, or the sub-mediterranean to insubric regions south of the Alps.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread to higher altitudes, meaning that these altitudes soon represent suitable conditions for the species up to ca. 2000 m a.s.l. and even beyond.

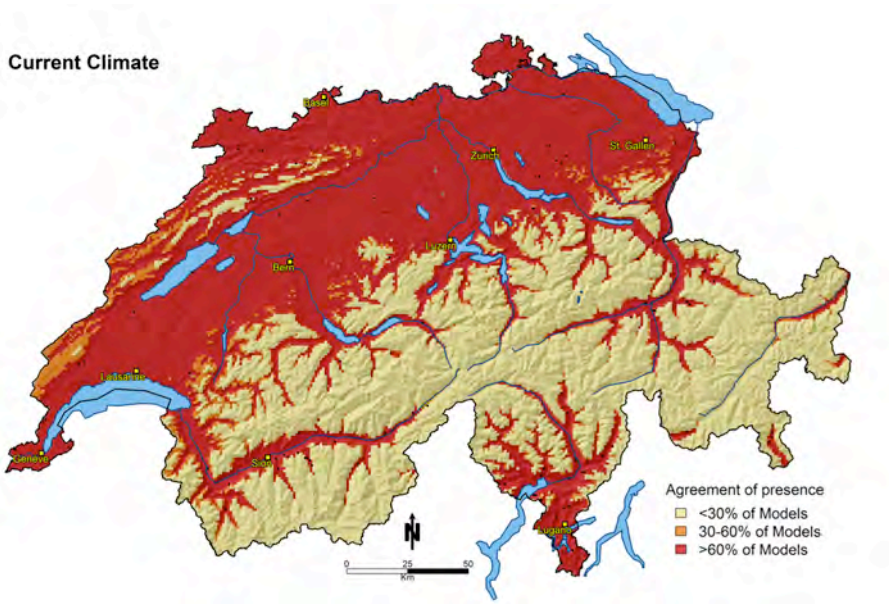


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Synthesis and Conclusions

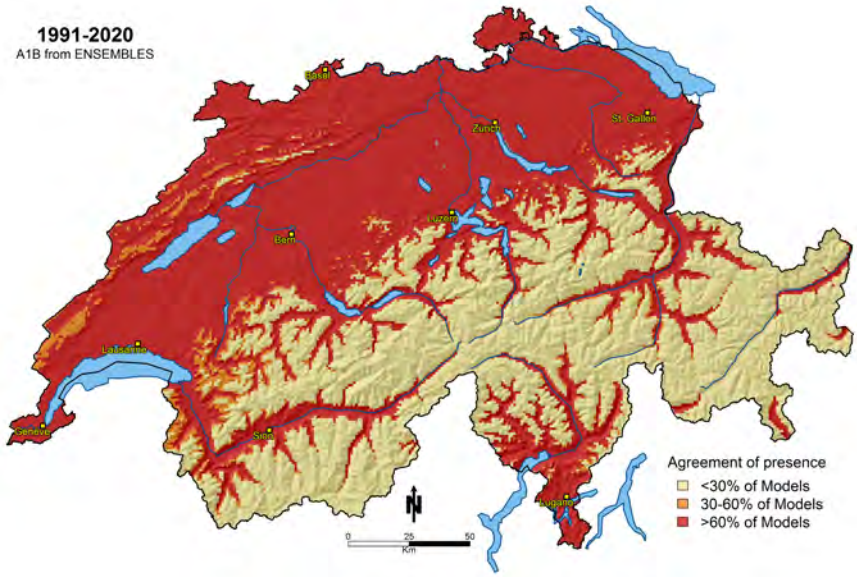
The model fits the distribution of *P. tremula* well, and can be considered a credible model to project the future habitat suitability of the species. The ensemble models project a 100% overlap between the current and the future range in Switzerland and a range size increase of ca. 36%. No similar statistic is available for Europe.

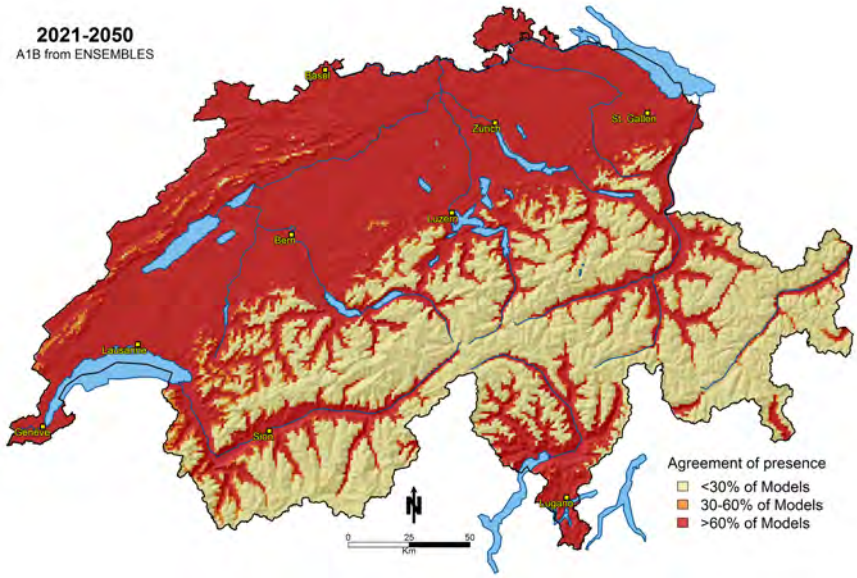
Range change statistics

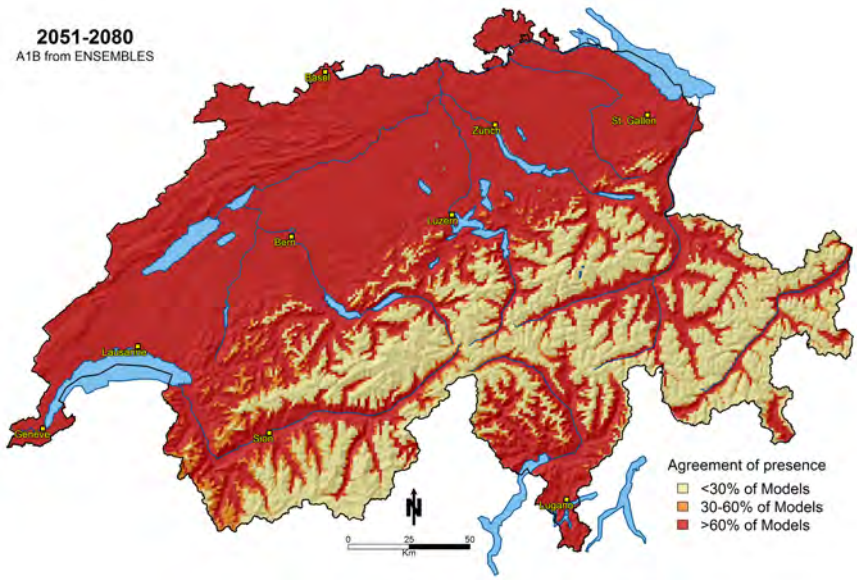
	CH	Europe
Current range size [km²]	21'145	–
Future (2080) range size	28'756	–
Range Change 2080/2000 [%]	136.0%	–
Overlap 2000/2080 [km²]	21'145	–
Overlap/current range [%]	100%	–

The species will not suffer much threat from climate change. It is the fastest growing species in Europe, and reaches its maximum size already at the age of 60 (usually reaching merely 100 years of age). It is very shade intolerant, and cannot even regenerate under its own canopy. Under darker canopies such as beech, oak or spruce forests, regeneration is neither possible. Yet, it has very effective wind-based seed dispersal, which allows the species to rapidly spread across large landscape. In a simulation study that has compared realistic migration rates of many different tree species in Europe under combined climate and land use change scenarios, *P. tremula* was least affected by time lags in the response to simulated climate change (Meier *et al.* 2012). It was almost able to track climate change at the projected climate velocity, and thus didn't show much difficulties in re-adjusting to changing climate conditions.

P. tremula is a true pionieer species with no specific requirements regarding soil conditions, given that it is not too cold. The species will face least difficulties in response to climate change. It has currently not much economic value in Switzerland, although in other regions (e.g. Italy) it is planted for fiber production. Due to its easy regeneration under almost all future temperature and moisture conditions, it might receive more economic attention in a warmer and drier climate on the Swiss Plateau. It has very high ecological value as food source for many native butterfly species, especially not yet grown to full size.







References

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Prunus avium

Description of model and ensemble projections

The current distribution of *Prunus avium* is modelled to cover most of the Swiss Plateau, all low elevations of the Northern and Southern Pre-Alps, as well as of the Interior Alps. The species naturally inhabits primarily the subalpine region, and is planted widely on the Plateau. It reaches upper distribution limits at ca. 1700 m a.s.l. in Switzerland and is growing almost everywhere, given that there is sufficient nutrient supply. Above altitudes of ca. 1000 m a.s.l. the species is rather only found at forest edges, and is no longer mixed in. It requires warmer conditions to compete against other species, as it is rather rarely found above 1000 m.

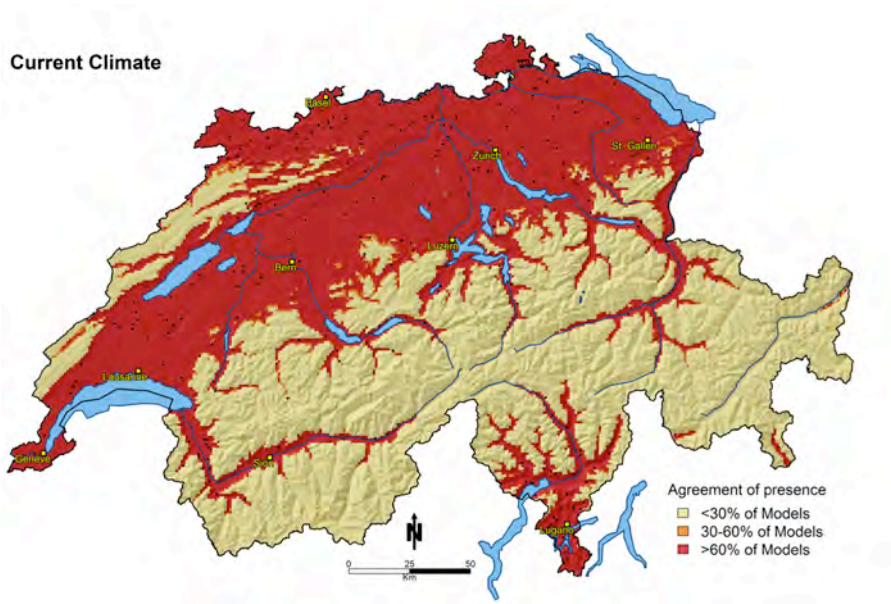


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *P. avium* on the Swiss Plateau, meaning that these regions soon represent climate conditions that are suitable for the species. *P. avium* therefore spreads to higher altitudes, and covers e.g. all of the Jura, with the exception of few of the very highest peaks by the end of the 21st century.

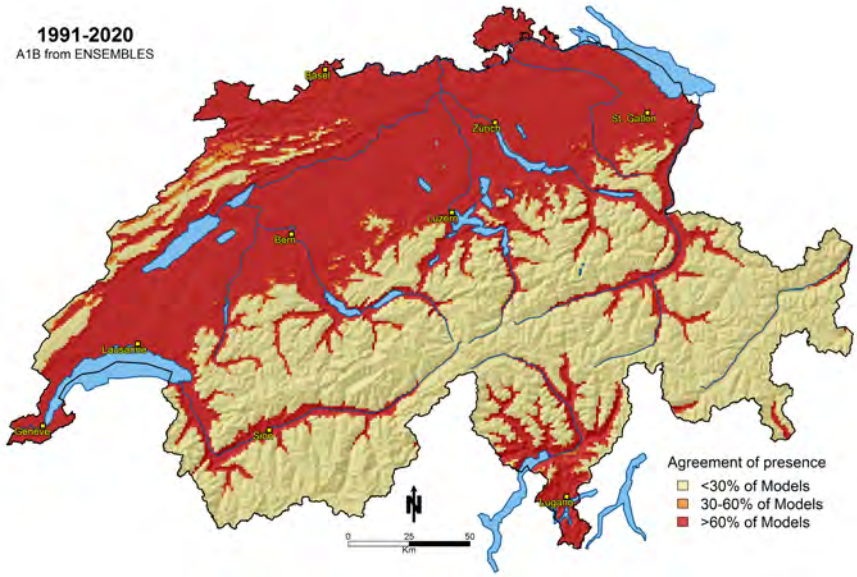
Synthesis and Conclusions

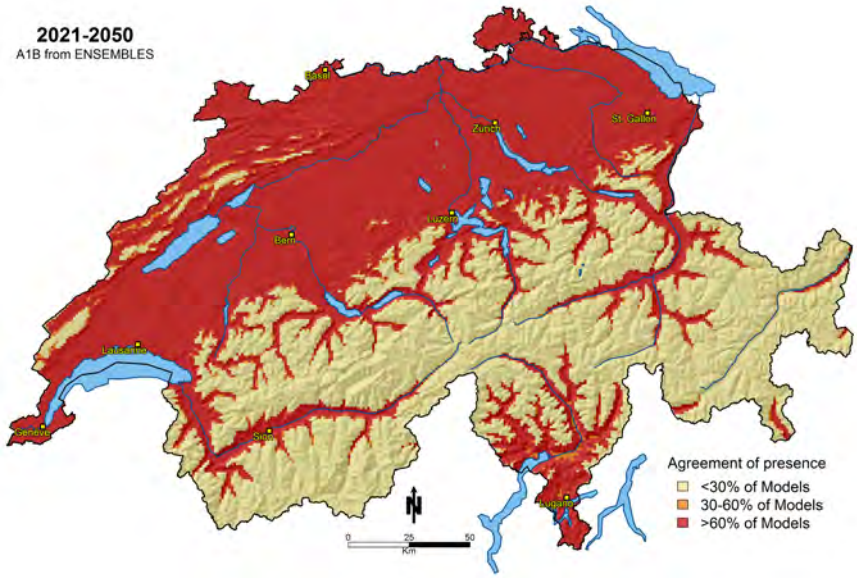
The model fits the distribution of *P. avium* well, and can be considered a credible model to project the future habitat suitability of the species. The ensemble models project almost complete overlap (99.6%) between the current and the future range in Switzerland and even still a 42% overlap in Europe. This is a sufficient overlap to assume no major threat to *P. avium* from climate change in Switzerland. This is likely due to the fact that the species does not reach its warm limit under current climate conditions. It therefore still spans to the lowest altitudes after climate warming, and it increases therefore its range in Switzerland by ca. 35%. In Europe, the species does not show the same tendency, and rather loses ca. 30% of its current range. This indicates that the drier conditions in a future Europe generally pose a certain threat to the species by the end of the Century. The species grows comparably fast and reaches ages of ca. 80-100 years. This is the main reason for its capacity to respond to climate change, as it can migrate well (from rapid seed dispersal by birds) and grows fast to maturity.

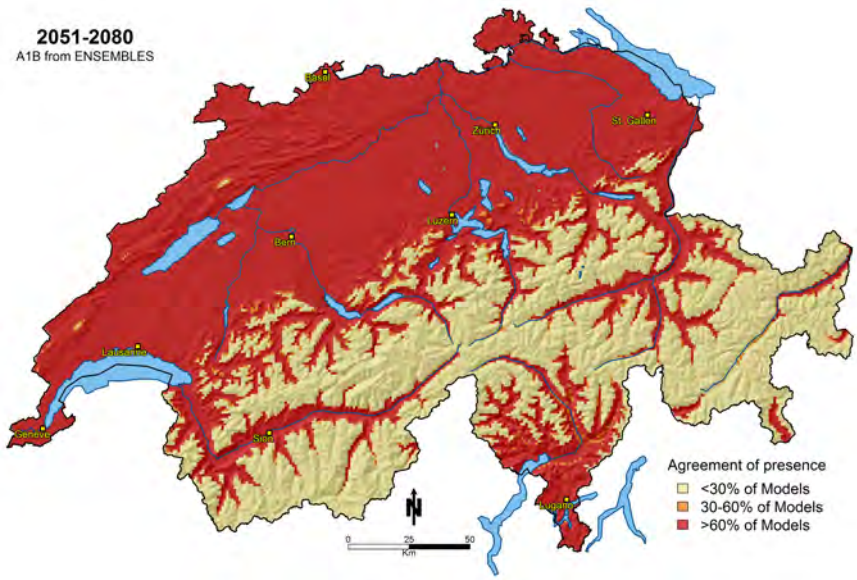
Range change statistics

	CH	Europe
Current range size [km²]	19'039	99'818
Future (2080) range size	25'638	70'058
Range Change 2080/2000 [%]	134.7%	70.2%
Overlap 2000/2080 [km²]	18'962	41'684
Overlap/current range [%]	99.6%	41.8%

The species does not have a particularly strong economic importance in Swiss forests. Rather, it is used as a precious wood for furniture such as tables, but not in large quantities, and is therefore not planted. Its cultivar form is used economically in orchards for edible cherry harvesting (with economic importance), and also the wild form represents an important food source for different bird species. The early flowering before leaf flush of beech or oaks adds to the cultural services forests with *P. avium* provide to humans.


1991-2020
A1B from ENSEMBLES
Basel
Zurich
St. Gallen
Luzern
Bern
Lausanne
Geneve
Sion
Lugano
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km


2021-2050
A1B from ENSEMBLES
Basel
Zurich
St. Gallen
Luzern
Bern
Lausanne
Geneve
Sion
Lugano
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km


2051-2080
A1B from ENSEMBLES
Basel
Zurich
St. Gallen
Luzern
Bern
Lausanne
Geneve
Sion
Lugano
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km

Prunus padus

Description of model and ensemble projections

The current distribution of *Prunus padus* is modelled to cover mostly scattered parts of the Swiss Plateau. The species naturally inhabits riverine forests, moist forests and forest edges on the Swiss Plateau. The species also occurs in interior valleys, but finds less frequently the required wet or moist soils in these drier climates.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a slight shift to higher altitudes of *P. padus* on the Plateau, mostly in Eastern Switzerland, which seems to be too high (and cold) under current climate. It does, however, not really shift that much to higher altitudes, likely also due to the soil requirements, as it does not frequently grow on slopes.

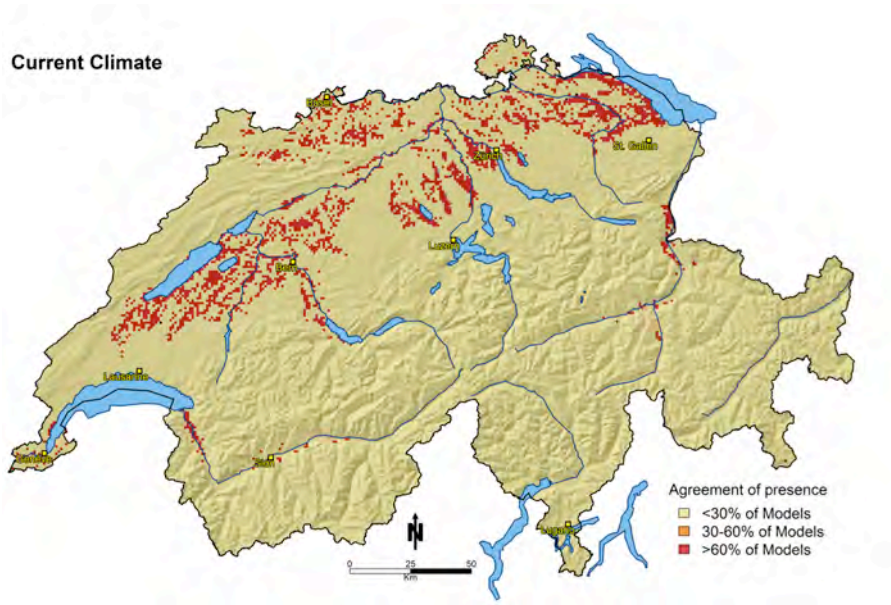


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Synthesis and Conclusions

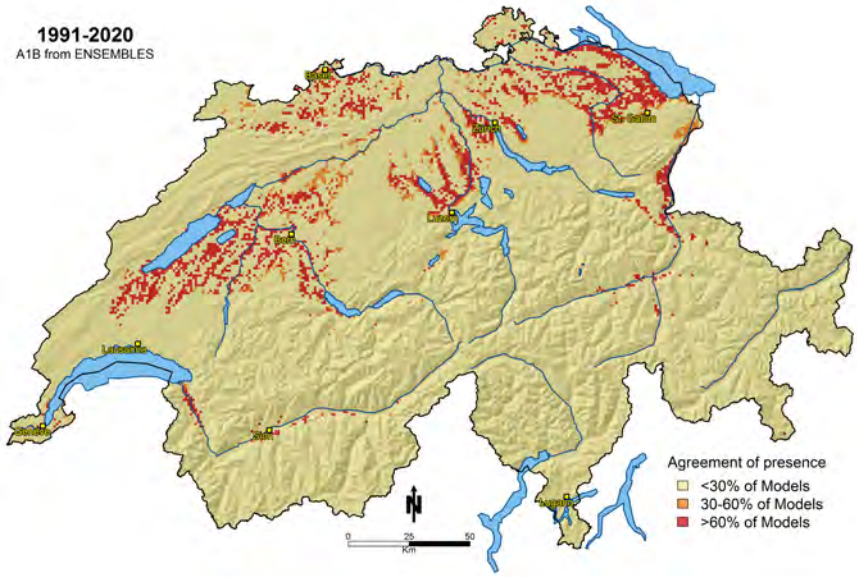
The model fits the distribution of *P. padus* moderately well, and can be considered a useful model to project the future habitat suitability of *P. padus*. The model suffers a bit from too few observations for building an even better model. The ensemble models project a 68% overlap between the current and the future range in Switzerland, while no data is available for the European scale. In addition, there is merely no difference between future and current range sizes (+1%), thus the species maintains its range largely, and keeps a strong overlap between current and future ranges. This may primarily originate from a strong control of soil parameters in the model.

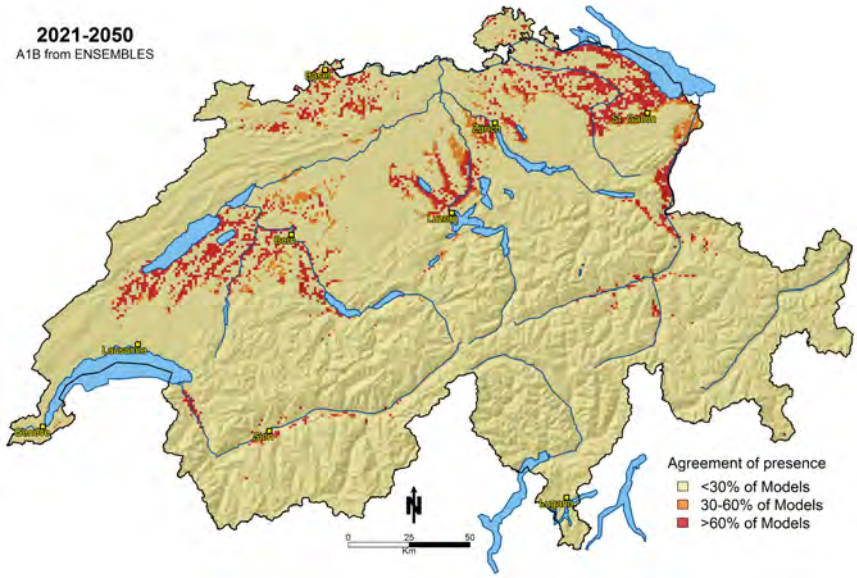
Range change statistics

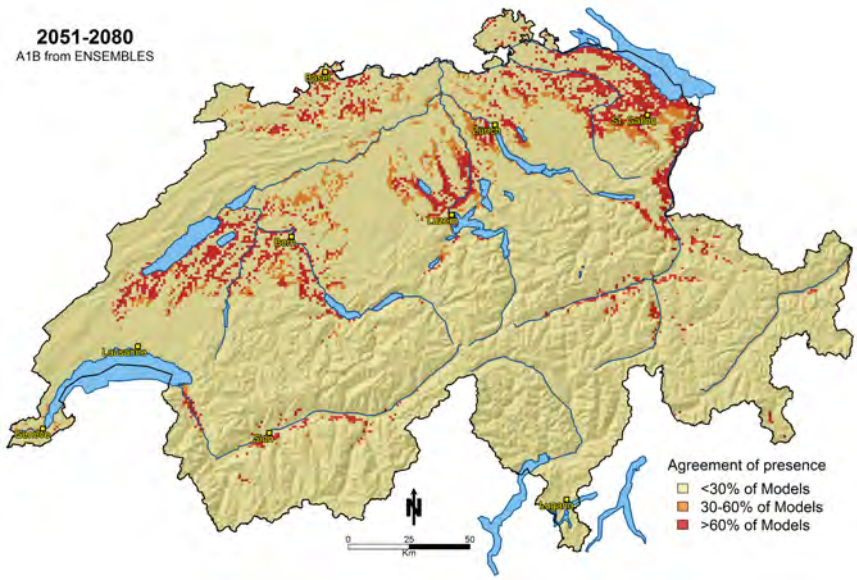
	CH	Europe
Current range size [km²]	2'675	
Future (2080) range size	2'709	
Range Change 2080/2000 [%]	101.3%	
Overlap 2000/2080 [km²]	1'827	
Overlap/current range [%]	68.3%	

P. padus does not have specific economic or ecological value in forests. It indicates groundwater, and thus is usually only found in moist and flat areas (see patchy distribution in Figure 1). Alternatively, it can grow on river embankments with sufficiently close distance to groundwater and it so helps stabilizing such embankments. *P. padus* has few known pests, but doesn't pose a real threat to forest management when infested. It's an important food source for some bird species, and adds to the beauty of forests with its large inflorescence.

The species is likely affected by climate change, but not heavily threatened by the projected amount of change by the end of the 21st century. The species grows well under a warmer climate, as long as there are soils with groundwater available. It would disappear quickly, if groundwater levels were sinking.


1991-2020
A1B from ENSEMBLES
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km


2021-2050
A1B from ENSEMBLES
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km


2051-2080
A1B from ENSEMBLES
Agreement of presence
<30% of Models
30-60% of Models
>60% of Models
0 25 50
Km

Quercus ilex

Description of model and ensemble projections

The current distribution of *Quercus ilex* is projected to be largely absent in Switzerland. Only in the Valais, there are some regions (mostly Central Valais) suitable, yet with high uncertainty as simulated by the ensemble projections of the different statistical models. In the Ticino, no suitable habitat is simulated from the National Forest Inventory points of the countries around the European Alps.

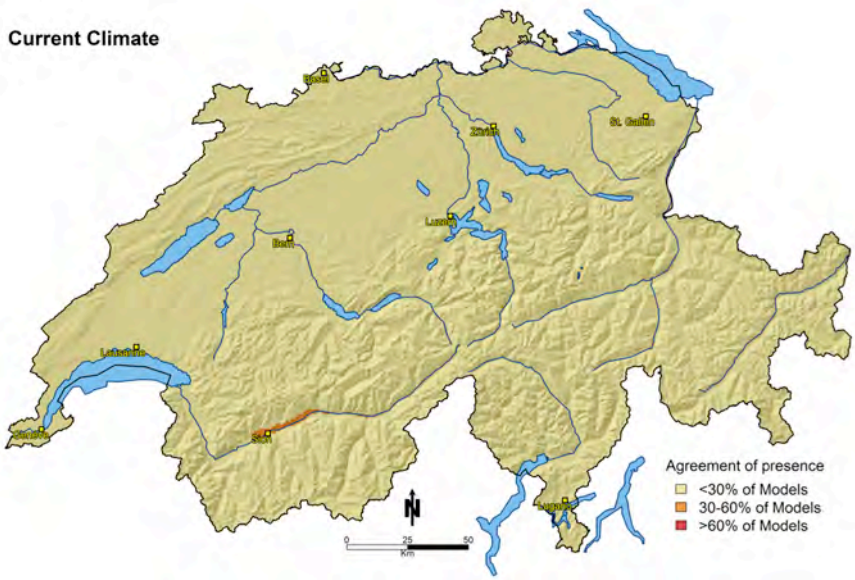


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a slight increase of the simulated range – again with high uncertainty, meaning that these regions represent soon climate conditions, under which *Q. ilex* is currently not being observed. These regions are mostly in the Valais and in the Geneva region. In these two regions, very few pixels are simulated to be certainly suitable in be the end of the Century.

Synthesis and Conclusions

The model fits the distribution of *Quercus ilex* well across the Alps (MOTIVE study, not shown here), and can be considered a credible model to project the future habitat suitability of *Q. ilex*. The ensemble models project a 60% overlap between the current and the future range in in Europe. In Switzerland, the overlap is 100% for areas where at least 30% of the models project presence. Also, the species will likely conserve +/- its range (-19%), and will spread northwards, notably onto the Atlantic coast in France, North of the Pyrenees. In Switzerland, a minority of models (30-60%) projects a considerable increase of suitable habitat area. However, since this is not projected by >60% if the models, these projections remain vary uncertain.

Range change statistics

	CH	Europe
Current range size [km²]	87	93'827
Future (2080) range size	590	75'705
Range Change 2080/2000 [%]	678%	80.7%
Overlap 2000/2080 [km²]	87	57'019
Overlap/current range [%]	100.0%	60.8%

The species is currently very dominant in the Mediterranean region, and can be considered an iconic species of Mediterranean forests. It is evergreen, and as such is sensitive to long lasting soil frosts and to air temperatures below ca. -15° to -17°C. If temperatures drop below this threshold, then the leaves are damaged.

The species is long-lived, slow growing and rather a late successional species. It has been demonstrated to spread very slowly (ca. 30m/yr) from plantations at the Atlantic coast in Southwestern France over the last 130 years (Delzon *et al.* 2013). These plantations represent locations north of its native range. Such slow migration rates are typical for late successional, stand dominating trees that grow to old ages with a slow growth rate (Meier *et al.* 2012). Such migration rates are far below the rates of lateral climate change velocity of >1000m/yr, and will not be sufficient to track climate change. On the other hand, the species is migrating, and is very dominant in its current range. Unless very severe drought events are occurring over the next decades in the current range of the species, it will likely be able to slowly adapt its range Northwards, although with a severe time lag. It is not one of the threatened species, but rather represents a winner of climate change.

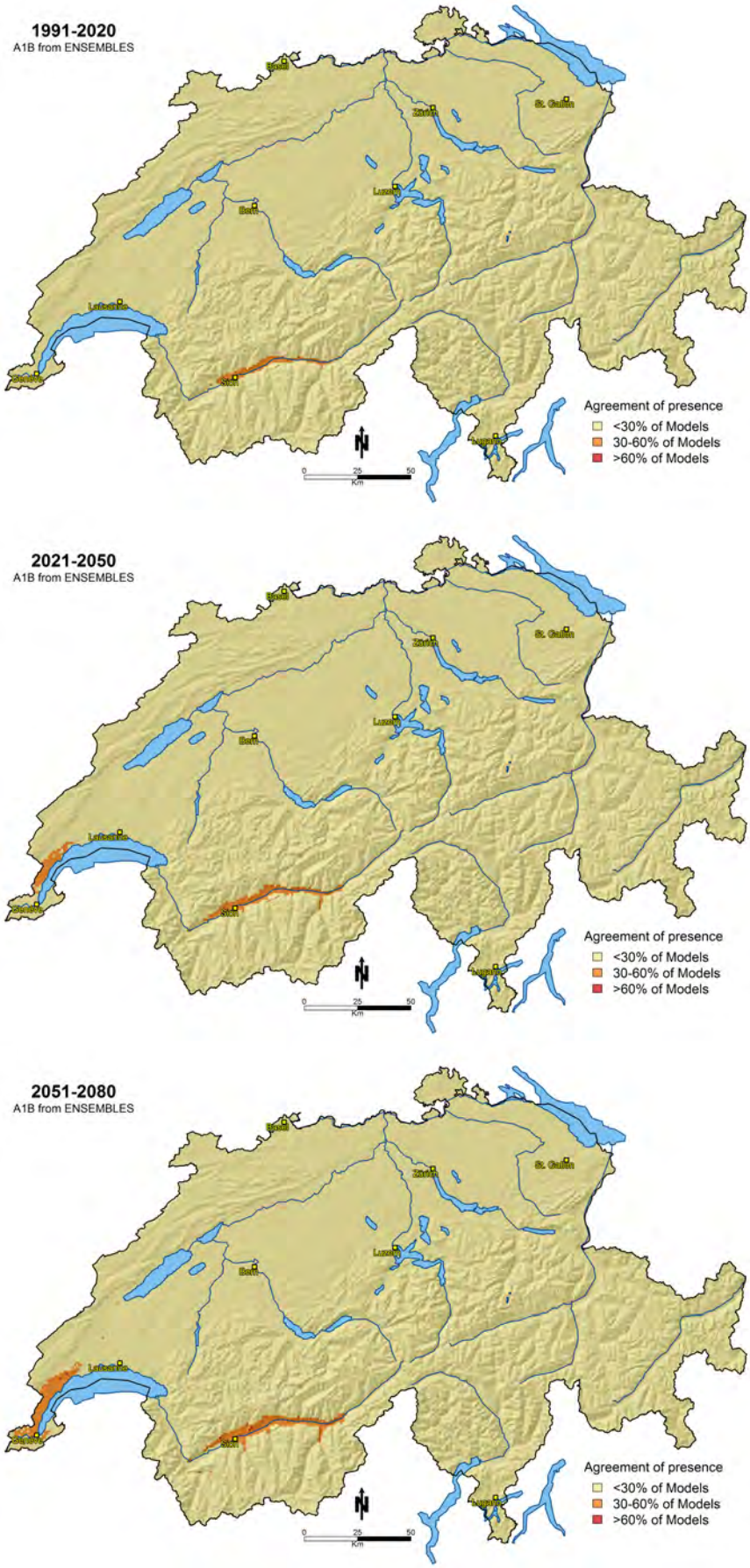


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Delzon S, Urli M, Samalens J-C, *et al.* (2013) Field evidence of colonisation by Holm oak, at the northern margin of its distribution range, during the Anthropocene period. *Plos One* **8** e80443.

Meier ES, Lischke H, Schmatz DR, Zimmermann NE (2012) Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* **21**, 164-178.

Quercus spp

Description of model and ensemble projections

The current distribution of *Quercus spp.* is modelled to cover the warmer (low altitude) parts of the Swiss Plateau, the low altitude regions of the interior Alps, and the warmest parts of the Ticino. The species is not projected to climb very high in altitude along Jura and Alps. The observed distribution of the genus in colder locations is not simulated well.

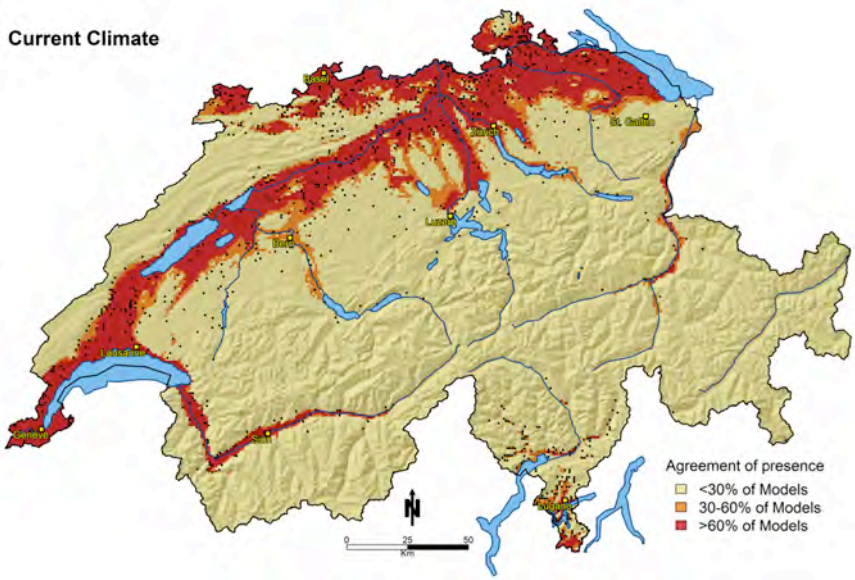


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *Quercus* on the Plateau, in the Ticino and in the interior Valleys, meaning that these regions will soon represent climate conditions, under which *Quercus* can be expected to grow well. In all regions the genus is projected to expand to higher altitudes, e.g. reaching almost the highest peaks in the Jura and in the southern Ticino. The most massive spread is projected to occur after 2050, meaning that until then no strong expansion is modelled. This is especially visible for the Jura Region. While the simulation under current climate resembles a mixture of the three involved species, the future projections rather conform with the simulations of *Q. robur*, the most frequent among the three most abundant species in Switzerland (*Q. robur*, *Q. petraea* and *Q. pubescens*).

Synthesis and Conclusions

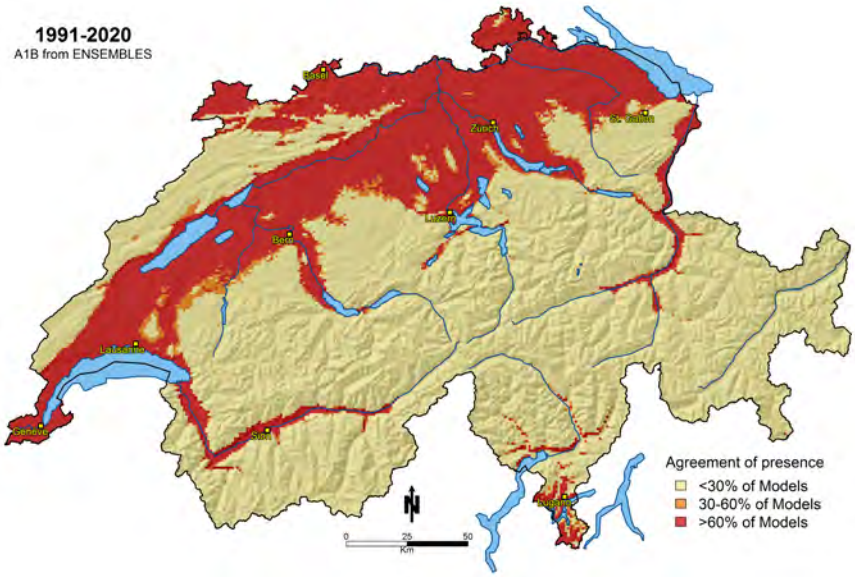
The model fits the distribution of *Quercus* well in general, although under current climate it does not represent the coldest observations well. Under future climate conditions, the model resembles much the most cold-adapted species (Q. robur) and therefore the overall genus model seems to perform well and can be considered a credible model to project the future habitat suitability of Oaks. The ensemble models project a 99%% overlap between the current and the future range in Switzerland and a strong expansion of the range (+200%) under future climate conditions.

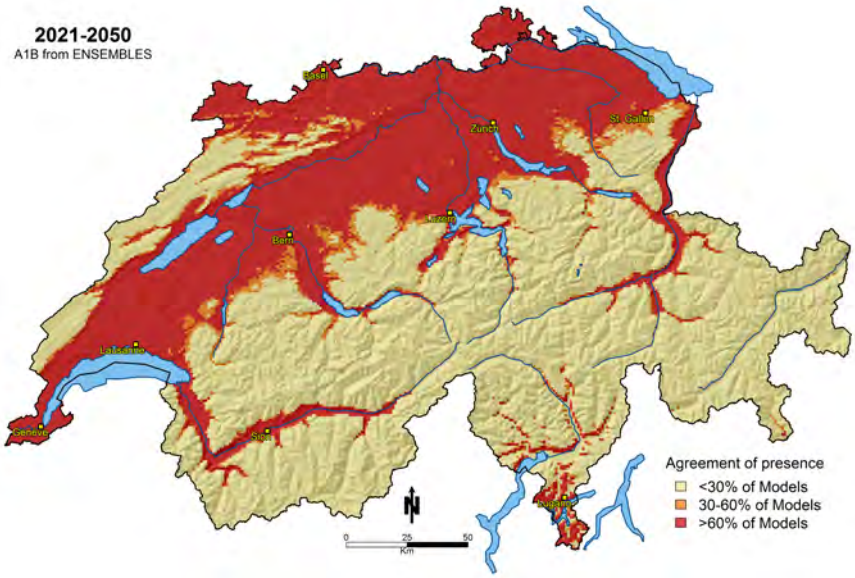
Range change statistics

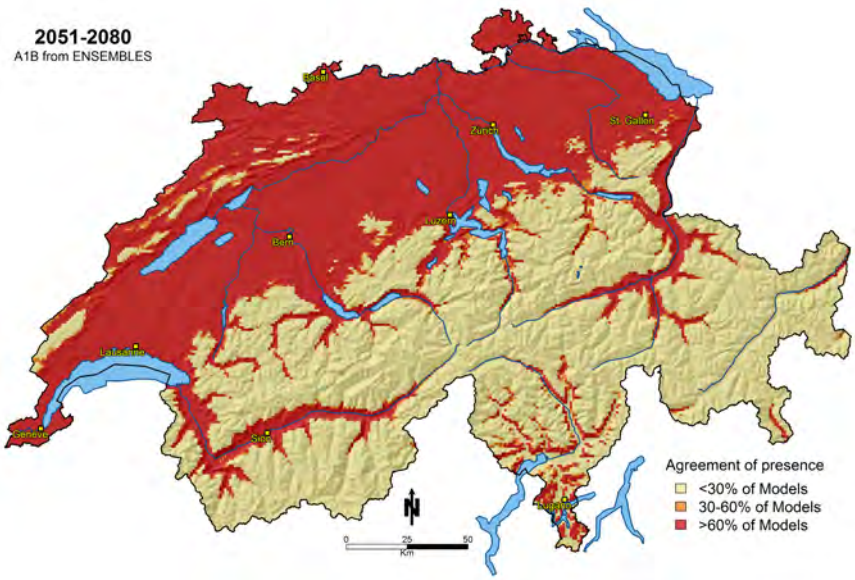
	CH	Europe
Current range size [km²]	6'522	–
Future (2080) range size	19'542	–
Range Change 2080/2000 [%]	299%	–
Overlap 2000/2080 [km²]	6'477	–
Overlap/current range [%]	99.3%	–

The genus colonizes dry and warm habitats in general, but especially Q. robur can also tolerate temporally inundated conditions. Many oak forests are of human origin in Switzerland (except the driest *Q. pubescens* forests on rocky outcrops along the Jura, the insolated slopes at low altitudes of the Valais, and of the Ticino. Oaks in general tolerate disturbance by (frequent) cutting (coppicing), which favors oaks over other, less tolerant species such as beech or maple. Yet, on drier and variably dry sites, the species can dominate due to its tolerance to variable drought levels. *Q. robur* is the most cold-tolerant (spring frost), while *Q. pubescens* is the most drought-tolerant among the three most abundant Oak species (Bonfils et al. 2015). All three abundant Oak species inbreed often with each other.

Oaks are very well adapted to the expected climate change and the associated abiotic and partly also biotic effects. The genus is quite drought tolerant, can grow on acidic and alkaline (though a bit less well for *Q. robur*) soils, and it is very tolerant to disturbance. This is partly due to its high genetic variability and partly due to its high capacity to re-sprout after being browsed, coppiced or damaged (Bonfils *et al.* 2015). The species can be considered a winner of climate change, and will likely spread strongly on the Swiss Plateau, which it has done already earlier during warm phases of the Holocene (Lang 1994).







References

Bonfils P, Rigling A, Brändli U-B, *et al.* (2015) Die Eiche im Klimawandel - Zukunftschancen einer Baumart. In: *Merkblatt fuř die Praxis, Nr. 55*, p. 12. Eidg. Forschungsanstalt WSL,, Birmensdorf.

Lang G (1994) *Quartäre Vegetationsgeschichte Europas: Methoden und Ergebnisse* Fischer, Jena [etc.].

Quercus petraea

Description of model and ensemble projections

The current distribution of *Quercus petraea* is modelled to cover most of the Swiss Plateau and the Northeastern Jura region. In addition, the species also is modelled to grow in the Valais, the Anterior Rhine valley and abundantly in the Ticino. Some projected regions of high habitat suitability are likely slight over-predictions by the model (e.g. Anterior Rhine valley, Hasli, and Upper Reuss valley), although there are some scattered observations in these regions.

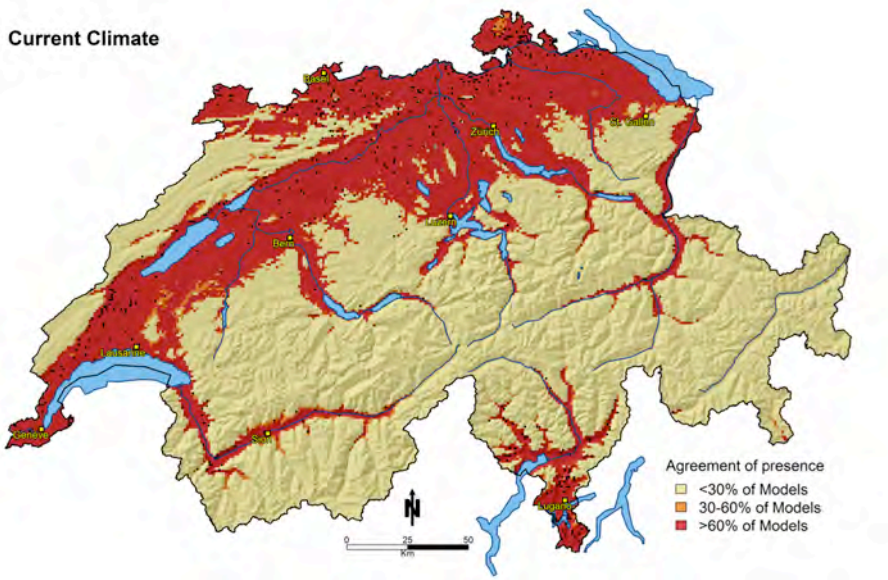


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *Q. petraea* on the Plateau, in all valleys of the Alps and in the Ticino, meaning that these regions represent soon climate conditions, under which *Q. petraea* is currently not being observed. The species migrates to higher altitudes, but doesn't lose suitable habitats at low altitudes by the end of the Century.

Synthesis and Conclusions

The model fits the distribution of *Quercus petraea* well, and can be considered a credible model to project the future habitat suitability of *Q. petraea*. The ensemble models project a 100% overlap between the current and the future range in Switzerland and still comparably high overlaps (52%) in Europe. This is a much higher overlap than previously modeled (45%, Zimmermann *et al.* 2006). The difference mostly originates from using less extreme climate scenarios in this report. Here we used the A1B scenario, which is a moderate warming scenario from the fourth IPCC assessment report (IPCC 2007). The previous simulations were based on the 3rd assessment report (IPCC 2001), where the A1FI scenario was much more extreme compared to the current A1B scenario.

Range change statistics

	CH	Europe
Current range size [km²]	13'891	131'264
Future (2080) range size	23'406	123'815
Range Change 2080/2000 [%]	168%	94.3%
Overlap 2000/2080 [km²]	13'891	68'053
Overlap/current range [%]	100%	51.8%

Also, the species will expand by the end of the Century its range of suitable habitats in Switzerland (+68%), and still largely maintain its European habitat suitability range (-5%). The species colonizes dry and warm habitats, but occasionally also dominates on more mesic conditions (given it is warm). It does not grow on very wet soils (such as e.g. *Q. robur*). Many oak forests are of human origin. Oaks in general tolerate disturbance by (frequent) cutting (coppicing), which favors oaks over other, less tolerant species such as beech or maple. Yet, on drier and variably dry sites, the species can dominate due to its tolerance to variable drought levels. *Q. petraea* interbreeds frequently with both *Q. robur* and *Q. pubescens*.

The species can be considered a winner of climate change. It is one of the likely future species on the Swiss Plateau by the end of the Century given the projected warming. Under this warming scenario, the species will not require human assistance, and will likely be one of the canopy trees. It is already widely present, although not in high abundance. From these locations (near ridges, at forest edges, or at shallow and rocky sites) it can spread onto deeper soils harboring currently more mesic site conditions during the warming of the current Century. Due to the abundant animal dispersal of seeds, it will likely be able to colonize these regions without much assistance from humans. Both the close-by distance and the high overlap between current and future range guarantee that the species will likely be able to adjust to the ongoing climate change. Yet, the species requires protection from browsing during the regeneration phase.

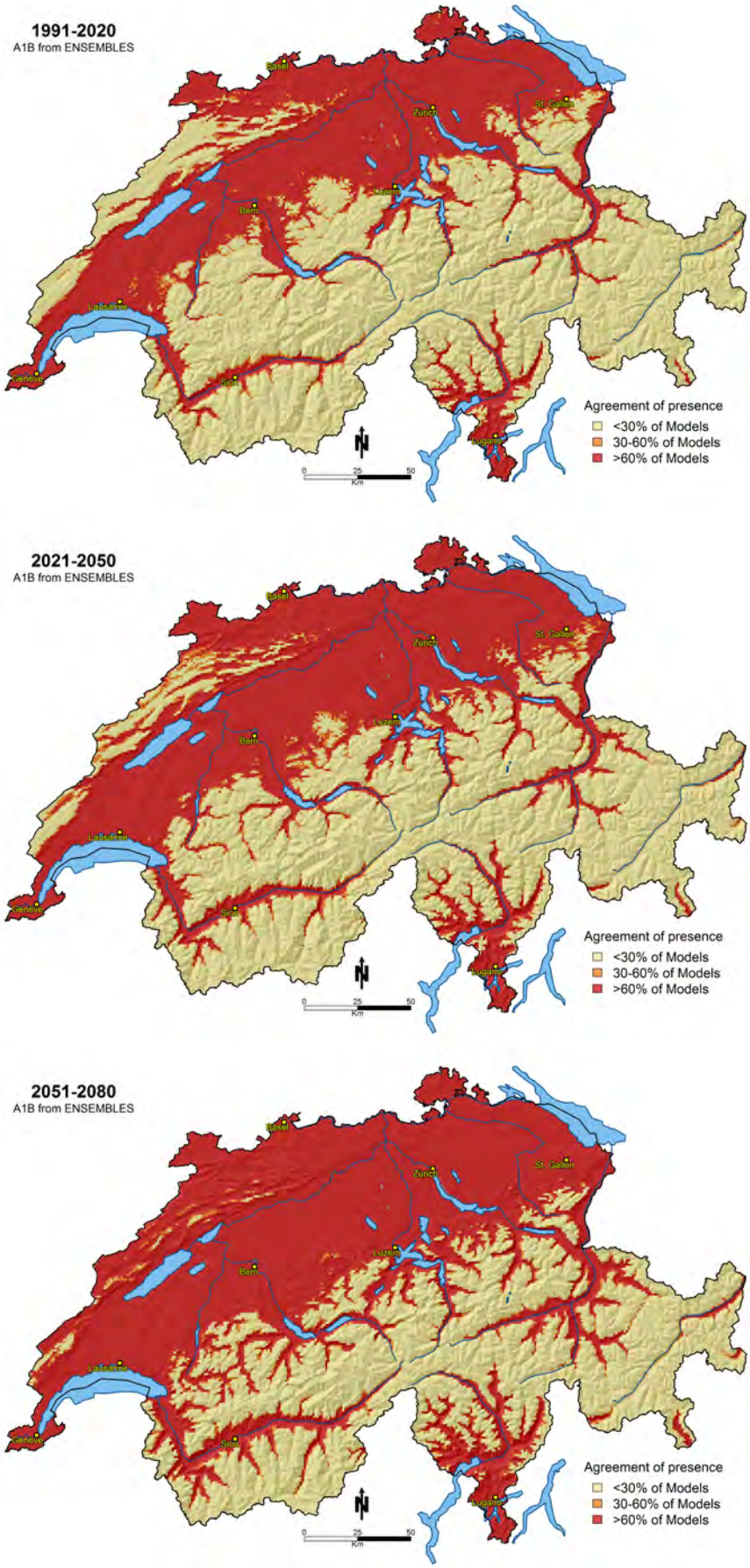


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

IPCC (2001) *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Zimmermann NE, Bolliger J, Gehrig-Fasel J, *et al.* (2006) Wo wachsen die Bäume in 100 Jahren? In: *Wald und Klimawandel* (ed. Wohlgemuth T), pp. 63-71. WSL, Birmensdorf, Schweiz.

Quercus pubescens

Description of model and ensemble projections

The current distribution of *Quercus pubescens* is projected to cover most of the low altitudes of the Ticino, and the Valais, as well as some South-facing regions of the Jura and Geneva regions. The rest of the Swiss Plateau is not modelled to harbor suitable habitats, with the exception of very few sites close to big lakes. In addition, the species also grows at slightly higher altitudes in the inner Alpine valleys and in the Northern part of the Ticino. The species naturally inhabits primarily the colline region, and is not used commercially on the Swiss Plateau. North of the Alps, the sites that are colonized by Quercus pubescens are usually azonal rocky habitats that provide low water availability and productivity with high insolation, which increases water stress.

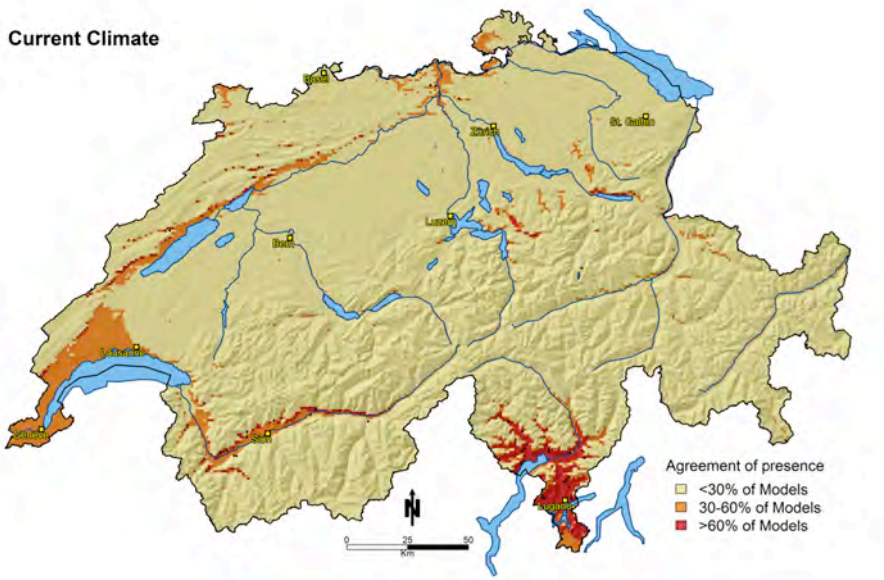


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a spread of the species on the Swiss Plateau, meaning that these regions represent soon climate conditions, under which no presence of *Q. pubescens* is currently being observed. The species thus spreads much and increases its range in Switzerland. However, these predictions of spread are associated with a comparably high degree of uncertainty.

Synthesis and Conclusions

The model fits the current distribution of *Q. pubescens* well, despite being based on few observations only. It can therefore be considered a credible model to project the future habitat suitability of *Q. pubescens*. The ensemble models project a 100% overlap between the current and the future range in Switzerland and still an overlap of 71% in Europe. The range is expected to expand a lot in Switzerland, due to a massive spread onto the Swiss Plateau and to higher elevations. In Europe, the species is also expected to increase its range size, but only to a smaller degree, adding 43% in addition to its current range.

Range change statistics

	CH	Europe
Current range size [km²]	281	55'660
Future (2080) range size	12'088	79'602
Range Change 2080/2000 [%]	>999%	143.0%
Overlap 2000/2080 [km²]	281	40'039
Overlap/current range [%]	100%	71.9%

Most likely, the species is not particularly threatened by climate change, and will find sufficient suitable and additional habitat, both in Switzerland and in Europe. The species is more often found on calcareous soils, but also grows (less well) on acidic soils. *Q. pubescens* is also very tolerant to browsing, and can recover more easily from such damages than other species. It can thus be considered very tolerant to different forms of stress and to climate change in general. On the other hand, the species is not very competitive in multispecies communities, and will thus only be able to spread on the Plateau, if the other – more dominant – species such as Fagus sylvatica are suffering from increasing drought due to increase heat and reduced summer precipitation. Also, the species will not easily spread where *Q. robur* and *Q. petraea* find suitable habitats, as *Q. pubescens* is more drought tolerant but less competitive than the other two oak species (Bonfils *et al.* 2015).

Quercus pubescens is often hybridizing with *Q. petraea* and therefore many populations consist of hybrids among the two proper species. It is thus not often easy to identify locally, what "species" is present, or to what degree the two closely related species contribute genetically to the local population.

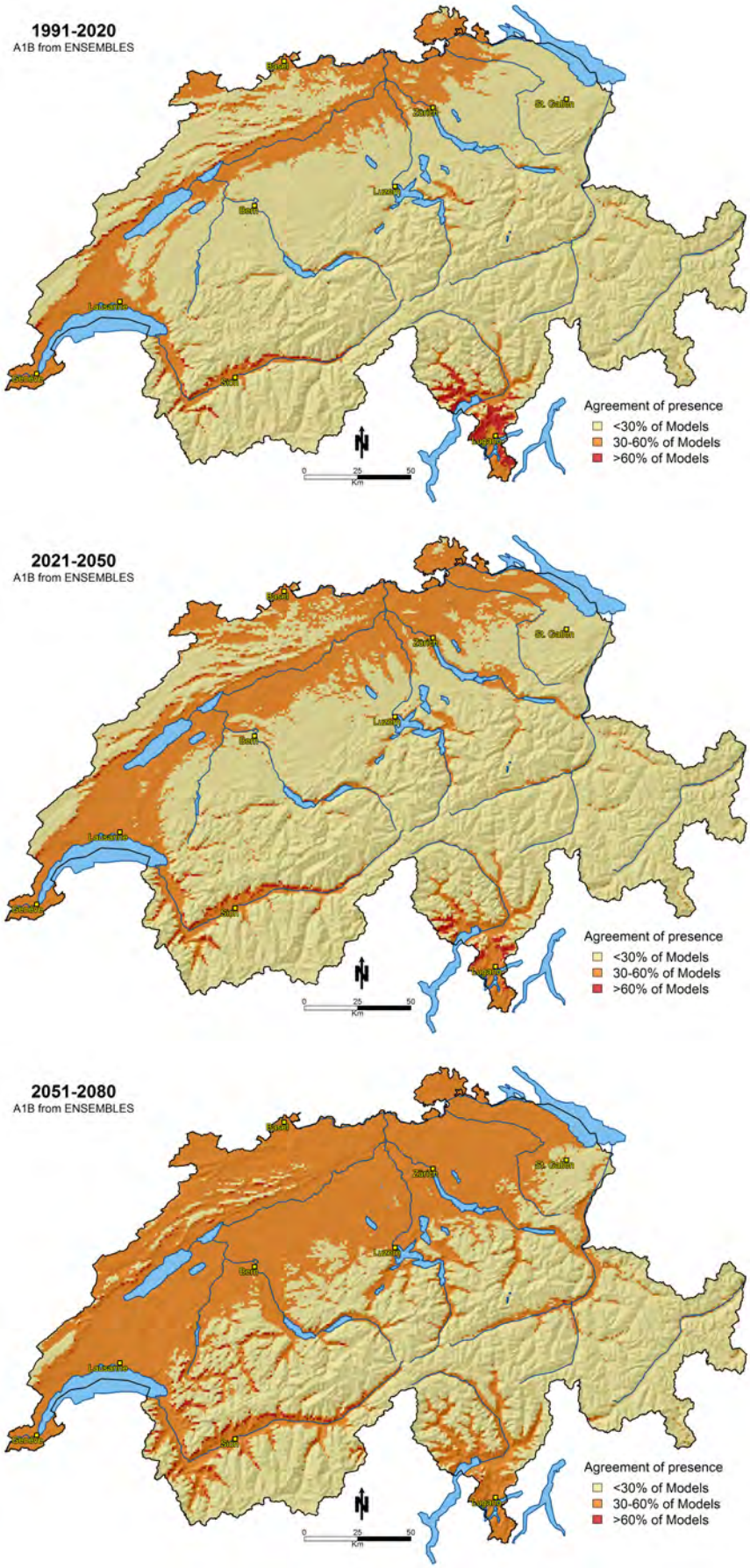


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

References

Bonfils P, Rigling A, Brändli U-B, *et al.* (2015) Die Eiche im Klimawandel - Zukunftschancen einer Baumart. In: *Merkblatt für die Praxis, Nr. 55*, p. 12. Eidg. Forschungsanstalt WSL, Birmensdorf.

Quercus robur

Description of model and ensemble projections

The current distribution of *Quercus robur* is modelled to cover most of the Swiss Plateau the low altitude regions of the interior Alps and of the Ticino and Misox. The species is not projected to climb very high in altitude along Jura and Alps. The species is predicted to occur throughout all of Switzerland's low altitudes, but doesn't seem to climb very high into Jura and Alps.

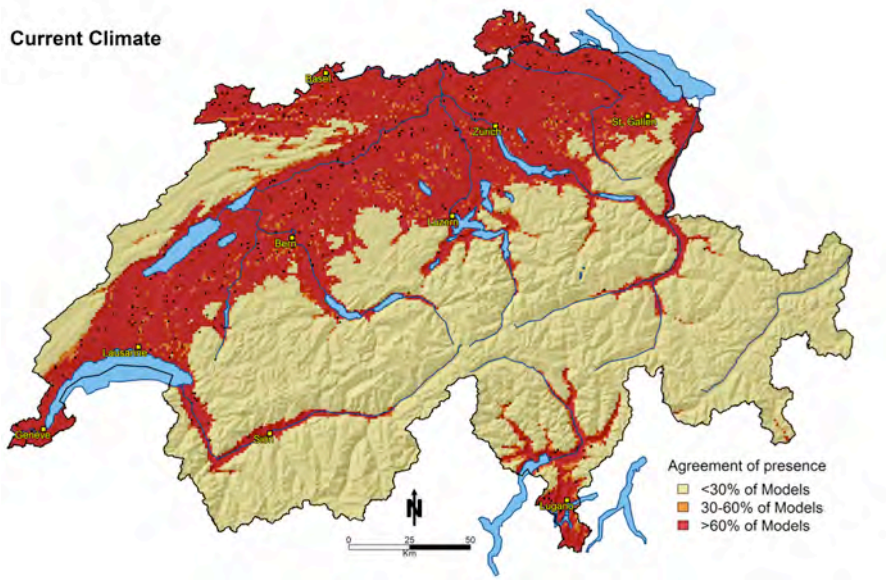


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from LFI forest inventory data of Switzerland.

Under expected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a rapid spread of *Q. robur* on the Plateau, in the Ticino and in the interior Valleys, meaning that these regions will soon represent climate conditions, under which *Q. robur* can be expected to grow well. In all regions the species is projected to expand to higher altitudes, e.g. reaching almost the highest peaks in the Jura and in the southern Ticino. The most massive spread is projected to occur after 2050, meaning that until then no strong expansion is modelled. This is especially visible for the Jura Region.

Synthesis and Conclusions

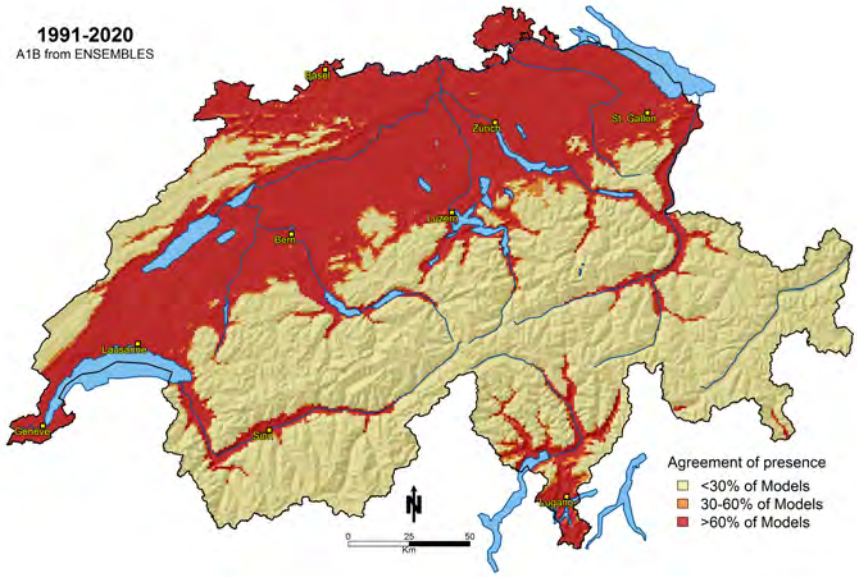
The model fits the distribution of *Q. robur* well, and can be considered a credible model to project the future habitat suitability of *Q. robur*. The ensemble models project a 99%% overlap between the current and the future range in Switzerland and still considerably high overlap (60%) in Europe. This is a much higher overlap than previously modeled (Zimmermann *et al.* 2006). The difference mostly originates from using less extreme climate scenarios in this report. Here we used the A1B scenario, which is a moderately high warming scenario from the fourth IPCC assessment report (IPCC 2007). The previous simulations were based on the 3rd assessment report (IPCC 2001), where the A1FI scenario was much more extreme compared to the current A1B.

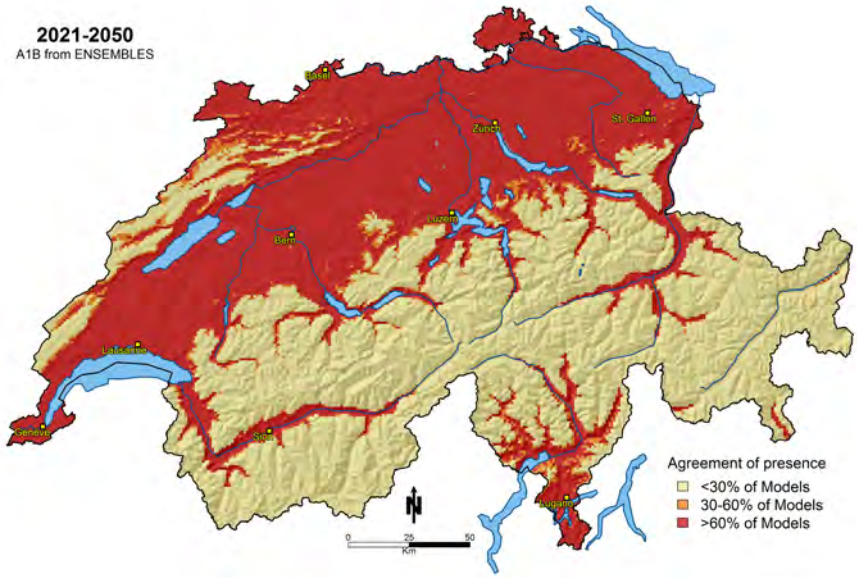
Range change statistics

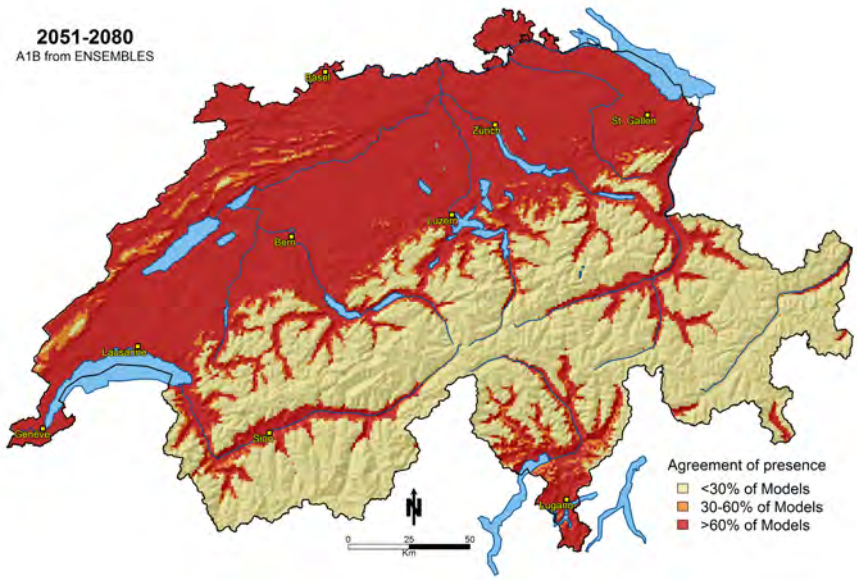
	CH	Europe
Current range size [km²]	15'146	177'871
Future (2080) range size	22'225	186'918
Range Change 2080/2000 [%]	146.7%	105.1%
Overlap 2000/2080 [km²]	15'036	106'206
Overlap/current range [%]	99.3%	59.7%

The species is expected to lose +/- no habitat in Switzerland that is currently suitable, and also in Europe it loses only 40% of the currently suitable habitat. On the other hand, the gain in suitable habitat is considerable (+47%), while in Europe the overall range is more or less maintained (+5%). The species colonizes dry and warm habitats, but occasionally also dominates on more mesic conditions (given it is warm). It can grow on very wet soils and especially on soils that are partly inundated and partly dried out during a growing season. Many oak forests are of human origin. Oaks in general tolerate disturbance by (frequent) cutting (coppicing), which favors oaks over other, less tolerant species such as beech or maple. Yet, on drier and variably dry sites, the species can dominate due to its tolerance to variable drought levels. *Q. robur* is the least cold-sensitive among the three most abundant Oak species (*Q. robur*, *Q. petraea* and *Q. pubescens*). *Q. robur* inbreeds often with *Q. petraea* and also (less frequently) with *Q. pubescens*.

Oaks are very well adapted to the expected climate change and the associated abiotic and partly also biotic effects. The species is quite drought tolerant, can grow on acidic and alkaline (though a bit less well) soils, and it is very tolerant to disturbance. This is partly due to its high genetic variability and partly due to its high capacity to re-sprout after being browsed, coppiced or damaged (Bonfils *et al.* 2015). The species can be considered a winner of climate change, and will likely spread strongly on the Swiss Plateau, which it has done already earlier during warm phases of the Holocene (Lang 1994).







References

Bonfils P, Rigling A, Brändli U-B, *et al.* (2015) Die Eiche im Klimawandel - Zukunftschancen einer Baumart. In: *Merkblatt fuïr die Praxis, Nr. 55*, p. 12. Eidg. Forschungsanstalt WSL,, Birmensdorf.

IPCC (2001) *Climate Change 2001: The Physical Science Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK and New York, NY, USA.

Lang G (1994) *Quartäre Vegetationsgeschichte Europas: Methoden und Ergebnisse* Fischer, Jena [etc.].

Zimmermann NE, Bolliger J, Gehrig-Fasel J, *et al.* (2006) Wo wachsen die Bäume in 100 Jahren? In: *Wald und Klimawandel* (ed. Wohlgemuth T), pp. 63-71. WSL, Birmensdorf, Schweiz.

Robinia pseudoacacia

Description of model and ensemble projections

The current distribution of *Robinia pseudocacica* is projected to primarily occur in Southern Switzerland in the lowest regions of the Ticino. This is the region where this invasive North American species has started to become naturalized. North of the Alps this tree, often planted for ornamental reasons, has not that much invaded the forests yet. Across the whole Alps, it is mostly the sub-mediterranean forests at low altitudes South of the Alps that have mostly been invaded and colonized.

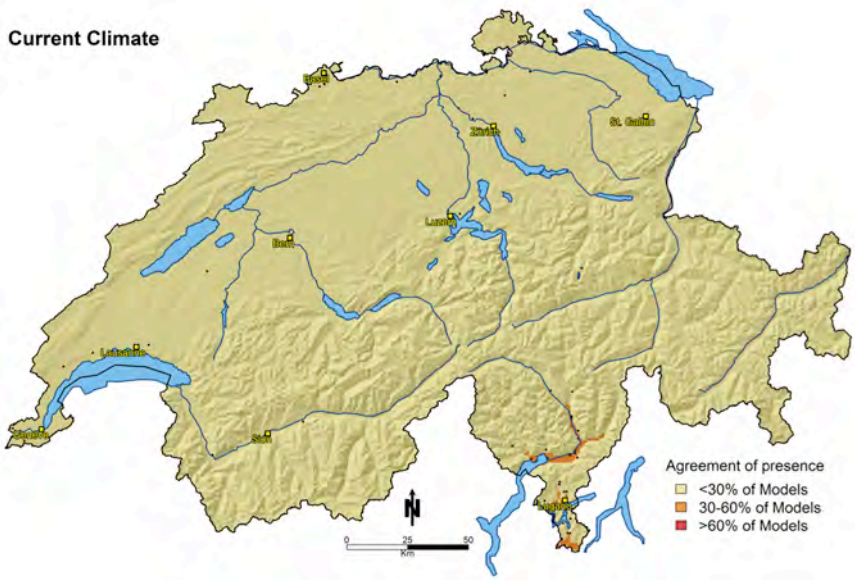


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a spread of *R. pseudoacacia* farther North in the Ticino, into low elevations of interior and dry valleys (Valais, Chur basin) and finally rapidly onto the whole Plateau. This means that these regions will soon harbor climate conditions, under which *R. pseudoacacia* will find habitats that are comparable to its current range.

Synthesis and Conclusions

The Alps-wide model (not shown here) fits the distribution of *R. pseudoacacia* quite well, and can therefore be considered a credible model to project the future habitat suitability of the species. The range statistic from this species is not very meaningful, due to the fact that pan-European models have not been fitted (no data available for ICP Level I data), and huge range expansions are projected under future climate conditions in Switzerland.

Range change statistics

	CH	Europe
Current range size [km²]	197	–
Future (2080) range size	13'776	–
Range Change 2080/2000 [%]	>999%	–
Overlap 2000/2080 [km²]	197	–
Overlap/current range [%]	100%	–

The species will likely spread, once the climate becomes warmer and drier in summers, as it has in many sub-mediterranean and colline regions already. It is an invasive, light-demanding species that rapidly colonizes ruderal habitats and forest canopy gaps. Due to its nitrogen high fixation (*Fabaceae*), it can generate nutrient rich soils that – in combination with the high light levels on the ground under *R. pseudocacica* canopies – are soon overgrown by dense herb and liana coverage, which inhibits further the regeneration of other forest trees.

The species might become a massive pest in these warm-dry, yet not Mediterranean climates. This might require specific management actions to avoid massive spreads once the climate becomes suitable for this species specifically on the Swiss Plateau.

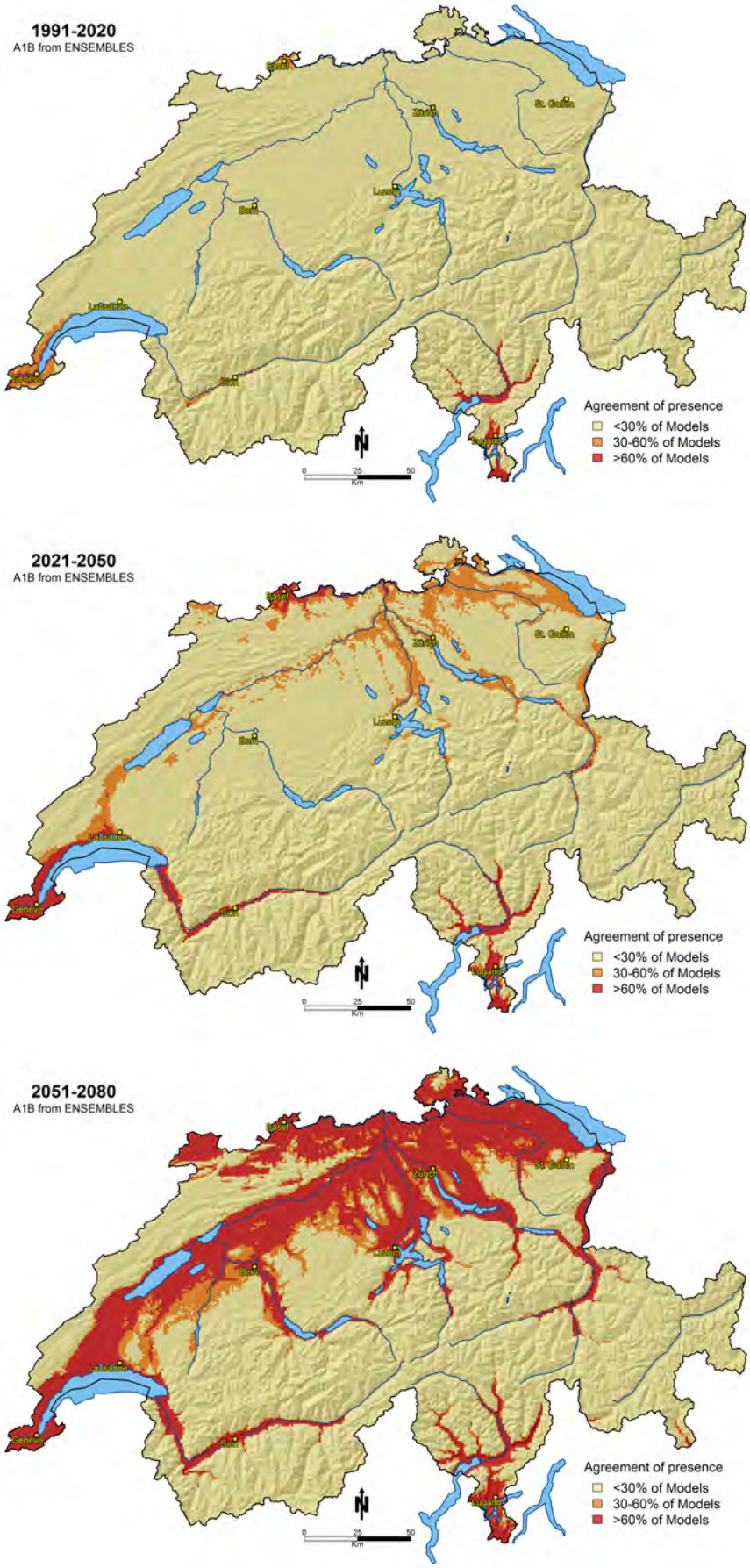


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.

Ulmus glabra

Description of model and ensemble projections

The current distribution of *Ulmus glabra* is projected to occur in a scattered manner throughout the Plateau and the Jura Mountains, as well as in Southern Switzerland in the lower regions of the Ticino. The model quality is not very good, and the different models disagree quite a bit when projecting the spatial distribution of the species. The reason for this is the very high variability of presence and absence under current conditions on the Swiss Plateau. The species is not found steadily in plots that seem suitable, and therefore some regions are not well modelled.

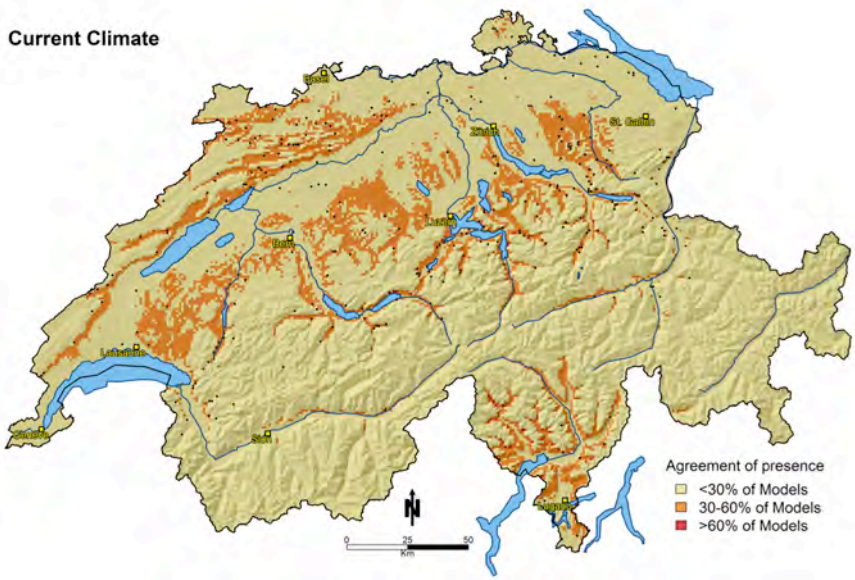


Figure 1. Current distribution (black dots) from the Swiss National Forest inventory (LFI 1) and simulated habitat suitability under current climate as calibrated from forest inventory data across the Alps (MANFRED project).

Under projected climate change using the A1B scenario, most combinations of statistical and regional climate models predict a retreat from the Plateau and from the lowest altitudes in the Ticino and a spread of *U. glabra* to higher altitudes both in the Northern Pre-Alps and in the Jura as well as in the Ticino. This means that these regions will soon harbor climate conditions, under which *U. glabra* will find suitable habitats.

Synthesis and Conclusions

The model of *U. glabra* cannot be considered a very credible model to project the current and future habitat suitability of the species. It provides the general area of the species well, but not the detailed local distribution. *U. glabra* is very demanding regarding soil conditions, and requires moist/humid, and nutrient-rich soils. The range statistic for this species is not very meaningful, due to the fact that pan-European models have not been fitted (no data available for ICP Level I data). For Switzerland, the range size is projected to remain approximately of the same size. However, there is only a very small range overlap of 5% between the current and projected future ranges.

Range change statistics

	CH	Europe
Current range size [km²]	5'954	–
Future (2080) range size	4'607	–
Range Change 2080/2000 [%]	77.4%	–
Overlap 2000/2080 [km²]	311	–
Overlap/current range [%]	5.2%	–

The species will likely spread to cooler sites, and the Swiss Plateau and the Southern Ticino will, in many places, become to dry for the species to survive. Once the climate becomes warmer and drier in summers, as it has in many sub-mediterranean and colline regions already. It is an invasive, light-demanding species that rapidly colonizes ruderal habitats and forest canopy gaps. Due to its nitrogen high fixation (*Fabaceae*), it can generate nutrient rich soils that – in combination with the high light levels on the ground under *U. glabra* canopies – are soon overgrown by dense herb and liana coverage, which inhibits further the regeneration of other forest trees.

The species need massive support through forest management, as it only grows well on humid, nutrient rich soils and is not a very good competitor. It is outcompeted in many locations and rarely reaches high abundance in forest plots, which makes it difficult for the species to accumulate critical mass for migration.

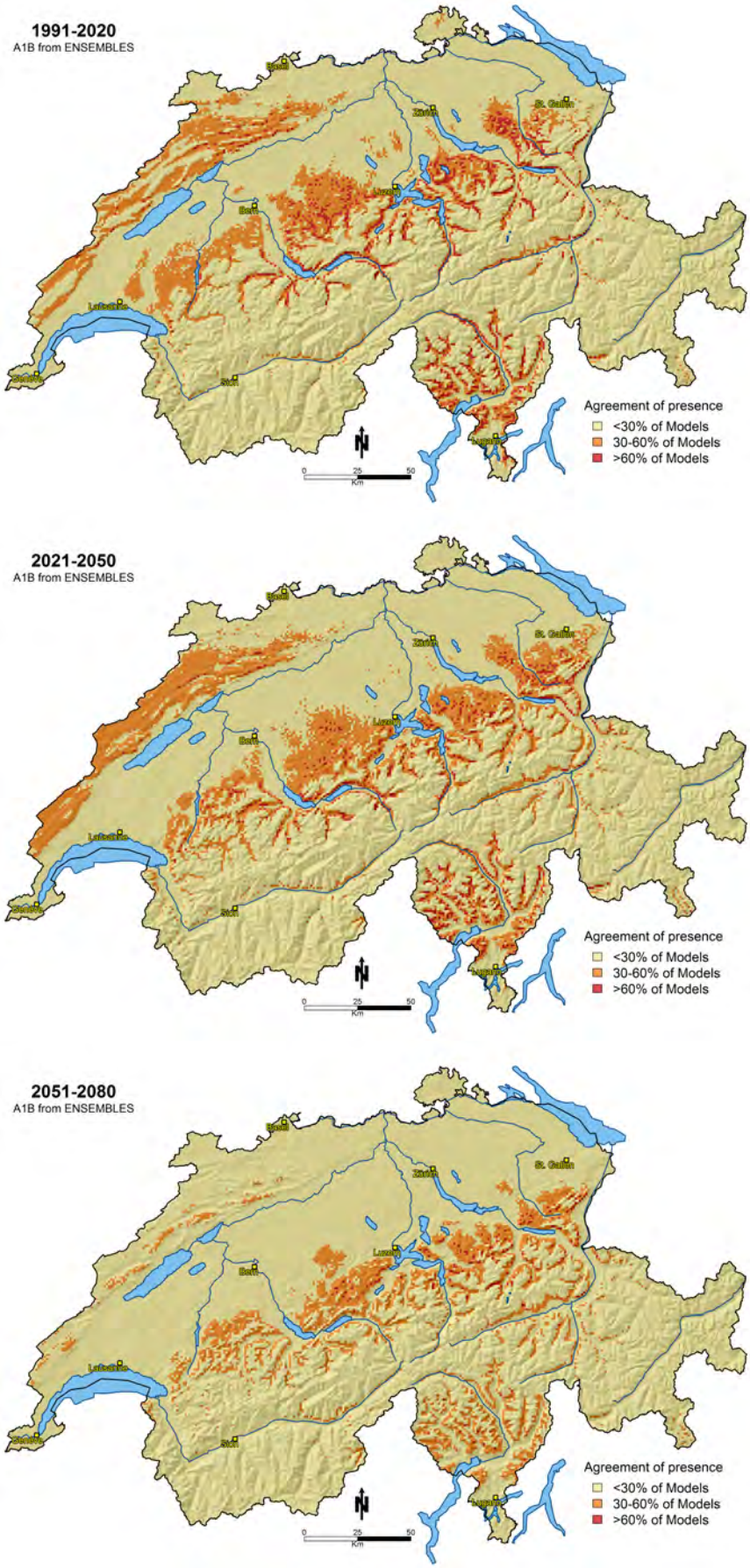


Figure 2: Ensemble of projected future ranges of suitable habitat as modeled from six RCMs and six statistical models. Light yellow colors indicate that all climate & statistical model combinations project absence of the species, while dark red colors indicate presence. Orange colors indicate uncertainty regarding habitat suitability.