SWISS-TIGER

Assessing the potential distribution of the tiger mosquito *Aedes albopictus* in Switzerland

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1 Motivation

The Asian tiger mosquito (*Aedes albopictus*) is an efficient vector of at least 22 arboviruses, among them dengue and chikungunya viruses. This invasive species has been introduced to Europe as well as Africa and the American, Indo-Pacific and Australian regions. Changes in the pattern of distribution of the tiger mosquito may affect the potential spread of infectious diseases transmitted by this species. In Europe, the tiger mosquito is well established in Mediterranean countries. As of 2011, the tiger mosquito has been observed as far north as the Netherlands. In Switzerland, the tiger mosquito has invaded the canton Ticino. In the near future, the tiger mosquito might invade Switzerland also from the West in the Geneva area. Therefore, predicting areas suitable for future establishment and spread is essential for planning early prevention and control strategies.

Ae. albopictus is sensitive to low temperature (Kobayashi et al. 2002, Medlock et al. 2006, Delatte et al. 2009), with regard to both its overwintering ability and its ability to form stable summer populations. As shown previously (Roiz et al. 2011, Neteler et al. 2011, Caminade et al. 2012). January mean temperature can be used as threshold condition to estimate the survival chances of overwintering eggs. Annual mean temperature can be used as threshold condition to estimate the survival chances of adults. The suitability to support *Ae. albopictus* populations can additionally be determined with growing degree days derived from temperature time series. Furthermore, *Ae. albopictus* can not survive in arid areas, but most areas in Europe receive sufficient rainfall for *Ae. albopictus* to survive (> 500mm/year). The assessment of the potential distribution of *Ae. albopictus* in Switzerland is based on these known environmental constraints.

2 Study area

The study area considered in the SWISS-TIGER projects comprises the entire territory of Switzerland (Fig. 1). This country is characterized by the Alps which occupy most of the area, furthermore the Swiss Plateau and the Jura are part of it. The overall area is approximately 41,300 km^2. The population (about 8 million people) is mainly concentrated on the Swiss Plateau.

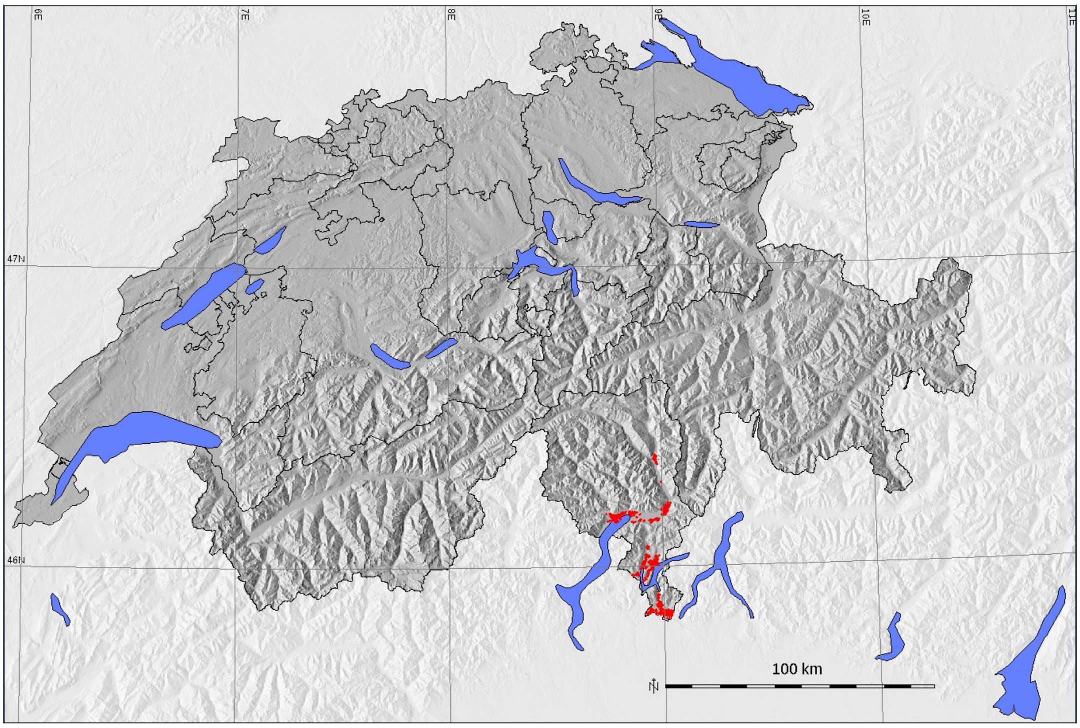

Fig. 1: Territory of Switzerland with cantons, sites with *Ae. albopictus* presence shown in red

3 Methodology

3.1 Temperature time series

Land surface temperature (LST) data recorded with the MODIS sensors onboard the TERRA and AQUA satellites were used as temperature time series. With its temporal resolution of 4 values per day and spatial resolution of 1 km, this dataset is well suited for a spatialized risk assessment of *Ae. albopictus*. Gridded datasets derived from meteorological station records are usually only available with a limited spatial resolution of 20 km or coarser. This spatial resolution is not adequate for topographically complex terrain such as found in Switzerland. With regard to temporal resolution, certain environmental indicators such as growing degree days can only be calculated with at least one data point per day.

Land surface temperature data obtained with remote sensing can contain gaps due to cloud cover. These gaps needed to be filled by reconstructing any missing LST values, before environmental indicators could be derived from this data. LST reconstruction was achieved with a combination of statistical (principal component analysis, multiple regression) and spline-based surface interpolation methods including auxiliary parameters related to land surface temperature. The inclusion of elevation as one of the auxiliary parameters allowed to increase the spatial resolution to 250 m. The final dataset used in this study consists of four temperature maps per day from July 8, 2002 onward.

3.2 Precipitation

Average annual precipitation was calculated from the European Climate Assessment and Dataset (ECA&D, http://www.ecad.eu/, Haylock et al. 2008) using the time series aggregation functions of GRASS GIS. The original data resolution is 0.25 degree.

3.3 Future climatic conditions

For the assessment of data how temperature and precipitation may change over the 21st century in Switzerland, the Swiss Climate Change Scenarios CH2011 was obtained (http://data.c2sm.ethz.ch/dataset/ch2011/seasonal_regional/download.html). This data set consists of three parts: lower, medium and upper estimates of changes in temperature and precipitation relative to the reference period 1980-2009. This has been done for three scenario periods (2020-2049, 2045-2074, 2070-2099) and the A1B, A2 and RCP3PD emission scenarios.
In this study, the A1B and A2 climate change scenarios for the years 2035 and 2060 were considered, using the regional data tables for Northeastern Switzerland CHNE, Western Switzerland CHW, and Southern Switzerland CHS.

3.4 Software: Open Source approach and GRASS GIS

The explicit use of Free and Open Source Software (FOSS) is in conformance with the scientific principles of reproducibility and transparency (Rocchini and Neteler 2012), particularly for ecological and environmental modeling. For this project, spatial data processing was performed with the open source software packages GRASS GIS (http://grass.osgeo.org) and MRT (Modis Reprojection Tool, https://lpdaac.usgs.gov/tools/modis_reprojection_tool). Statistical modeling was performed with R: A Language and Environment for Statistical Computing (http://www.R-project.org).

4 Results

Temperature thresholds for *Ae. albopictus* suitability were based on Kobayashi et al. (2002) and Caminade et al. (2012). As in Caminade et al. (2012), a gradient of suitability is used instead of a simplistic yes/no classification. The usage of a gradient considers also the uncertainty in the temperatures as well as spatial uncertainty. The calculated gradients range from 0.0 (unsuitable) to 1.0 (suitable). Areas with suitability values between 0 and 1 are moderately suitable, and *Ae. albopictus* may or may not survive in these areas.

4.1 Overwintering suitability

The threshold for survival probability of overwintering diapause eggs was set to 1° C for mean January temperature with a margin of 2° C. Totally unsuitable conditions were thus defined as < -1° C, and totally suitable conditions as > 3° C. Suitability maps ranging from 0.0 to 1.0 were created by setting all areas < -1° C to 0.0, all areas > 3° C to 1.0, and areas with a mean temperature between -1° and 3° C were linearly scaled with (temperature + 1.0) / 4.0.

4.2 Suitability for adults

The threshold for survival probability of adults was set to 11° C for mean annual temperature with a margin of 2° C. Totally unsuitable conditions were thus defined as < 9°C, and totally suitable conditions as > 13° C. Suitability maps ranging from 0.0 to 1.0 were created by setting all areas < 9° C to 0.0, all areas > 13° C to 1.0, and areas with a mean temperature between 9° and 13° C were linearly scaled with (temperature - 9.0) / 4.0.

4.3 Suitability for adults based on Growing Degree Days

The threshold for survival probability of adults based on 1350 growing degree days (GDDs) was set to September 1st with a margin of 1 month. Totally unsuitable conditions were thus defined if 1350 GDDs were reached only after the 274th day of the year (October 1st), and totally suitable conditions if 1350 GDDs were reached before the 214th day of the year (August 1st). Suitability maps ranging from 0.0 to 1.0 were created by setting all areas to 0.0 where 1350 GDDs were reached after October 1st, all areas to 1.0 where 1350 GDDs were reached before August 1st, and areas where 1350 GDDs were reached between August 1st and October 1st were linearly scaled with (274 - day_of_the_year) / 60.

These suitability analyses were performed for both the averages over the years 2003 – 2011, and for 2011 only. The results for all suitability indicators are shown in Figure 2.

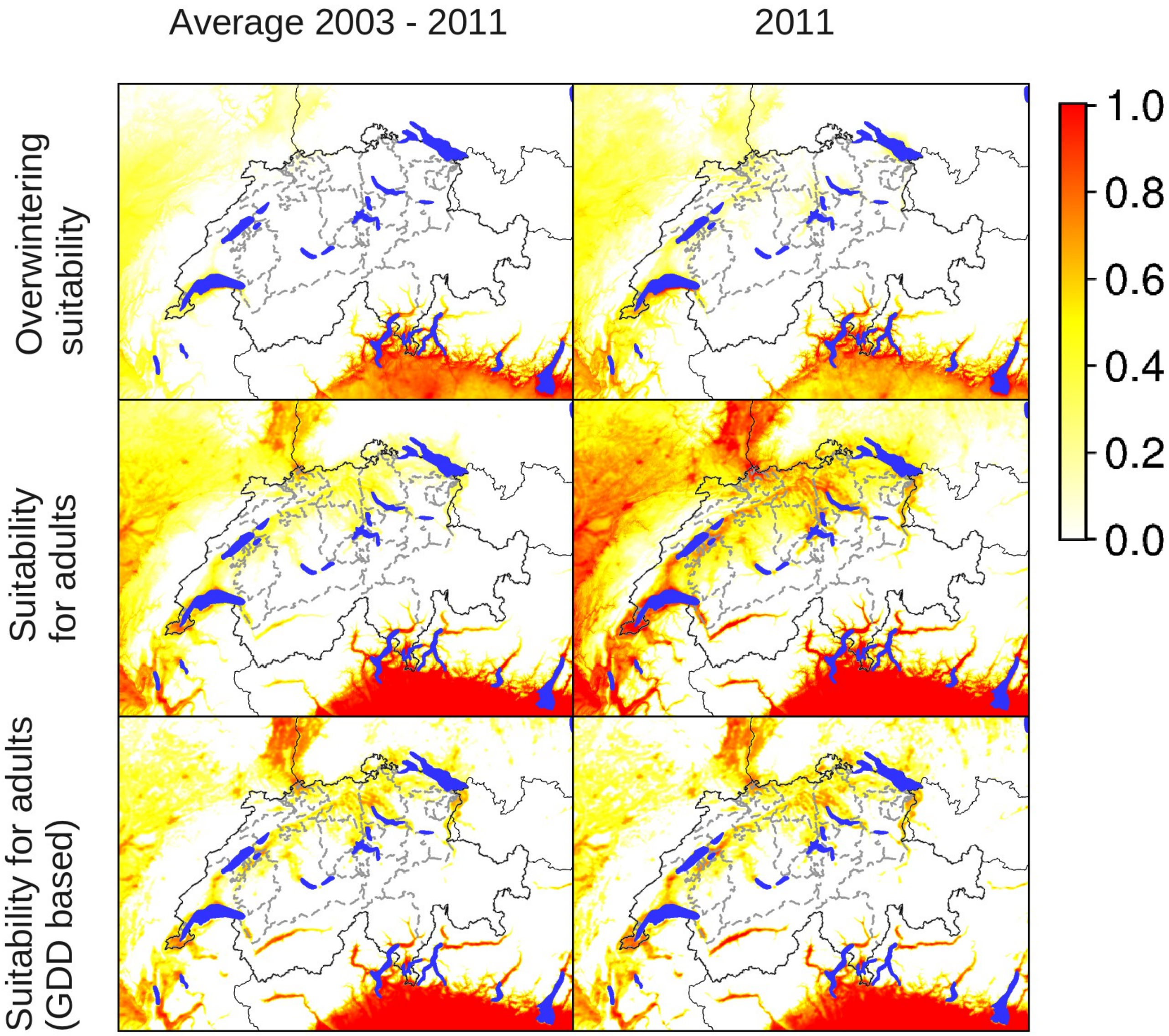

Figure 2: Suitability indicators for *Ae. albopictus* in Switzerland. The maps in the first row are based on averages for the years 2003 – 2011, the maps in the second row are based on temperature values for 2011 only. For easy comparison, the coloring scheme was adopted from Caminade et al. (2012). See also Appendix A.

4.4 Future suitability: years 2035 and 2060

Maps for adult suitability and overwintering suitability were also calculated using the A1B and A2 climate change scenarios for the years 2035 and 2060 (see Appendix B and C).
Concerning precipitation, the predicted decline of up to 20% would still not reach the minimum precipitation of 500 mm/year needed for the establishment of the tiger mosquito (the ECA&D data show a current minimum of annual precipitation of 860 mm/year for Switzerland).
The temperature data show low to significant differences for future scenarios compared to the present day situation. The resulting maps are shown Figures 3-6 and in the Appendixes B and C for the simulated lower, medium and upper

estimates of changes in temperature.

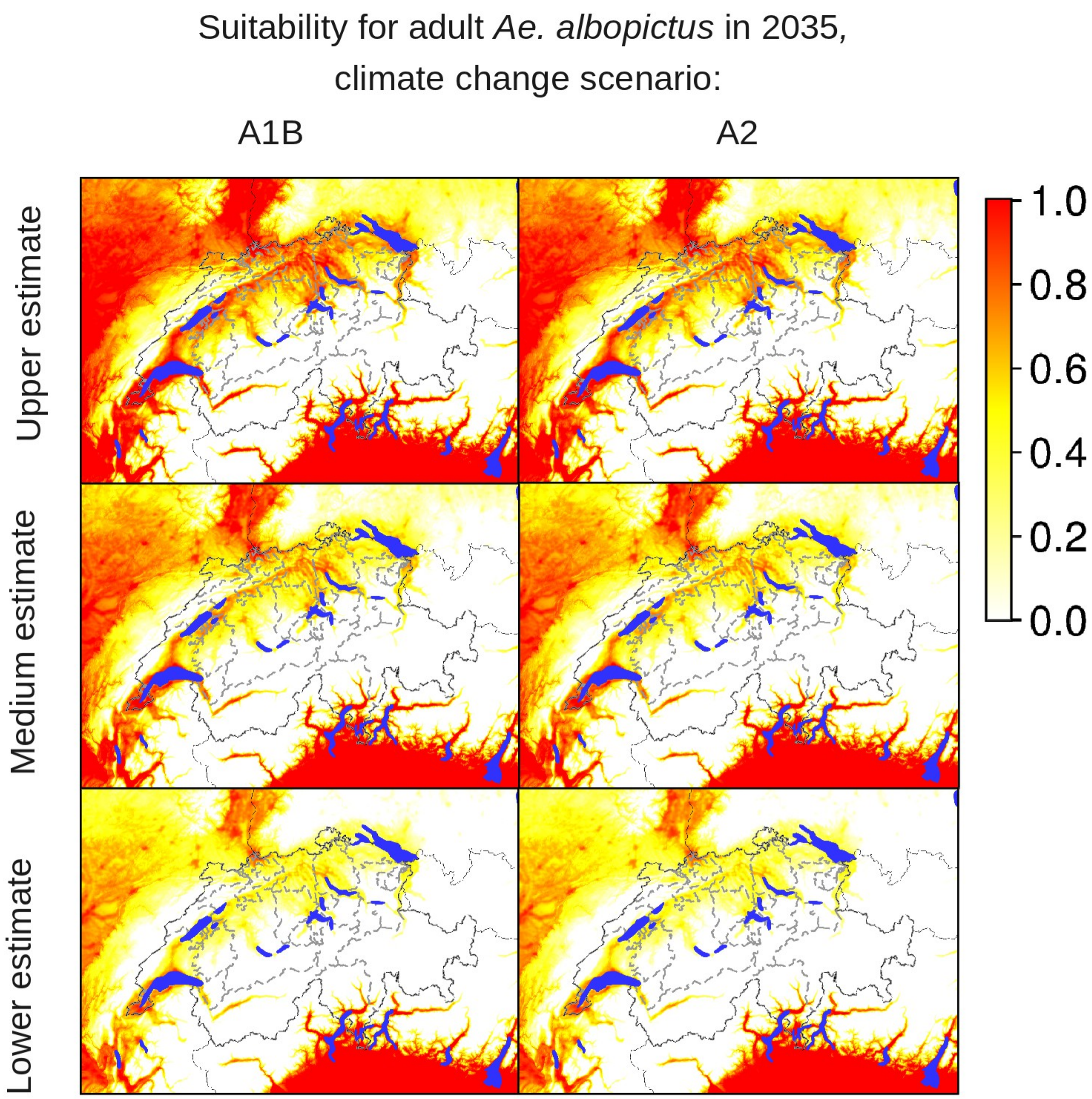

Figure 3: Suitability indicators for adult *Ae. albopictus* in Switzerland in 2035. The maps in the first row are based on temperature estimates for the climate changes scenario A1B, the maps in the second row are based on temperature estimates for the climate changes scenario A2. See also Appendix B.

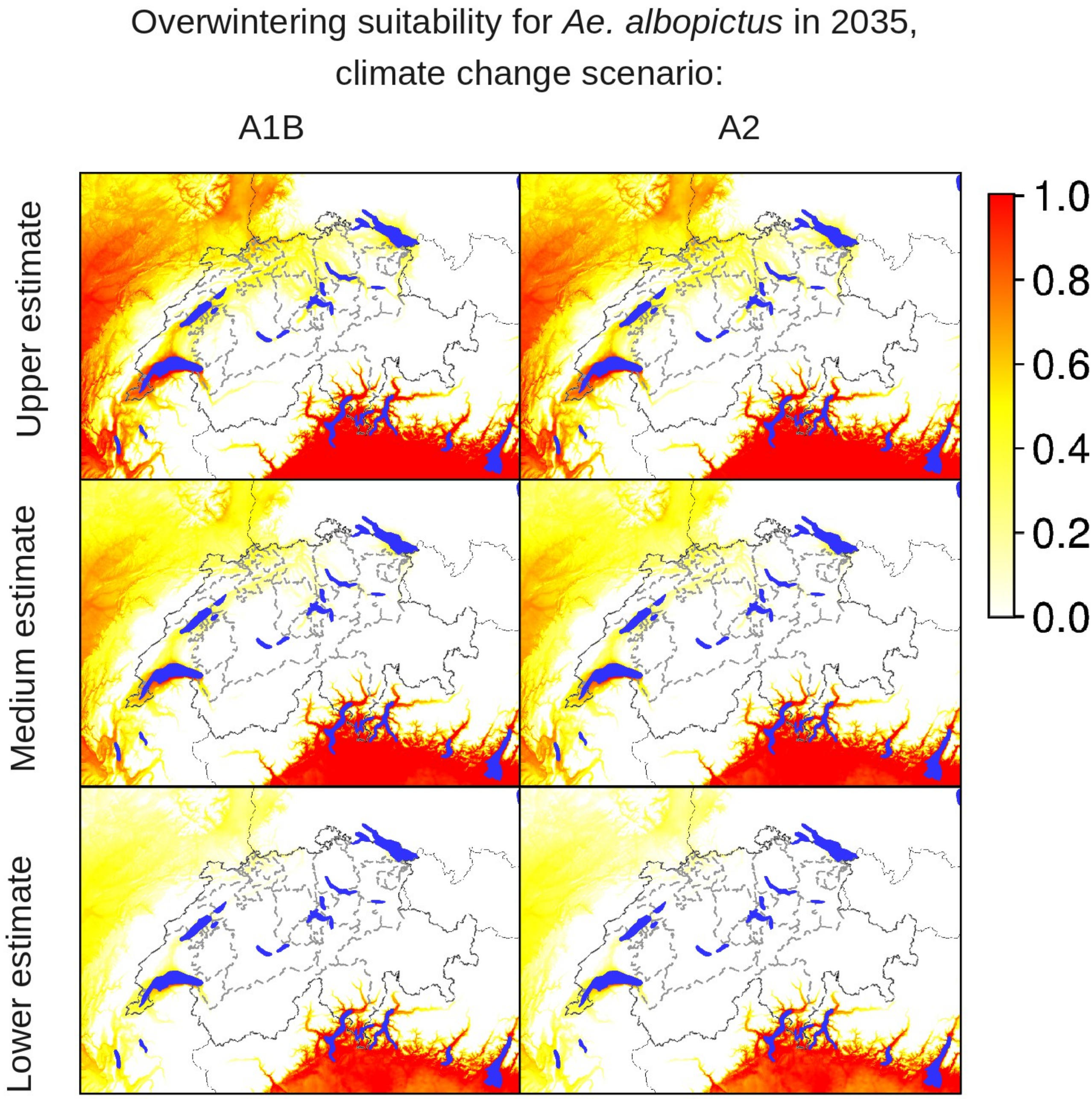

Figure 4: Suitability indicators for overwintering of *Ae. albopictus* in Switzerland in 2035. The maps in the first row are based on temperature estimates for the climate changes scenario A1B, the maps in the second row are based on temperature estimates for the climate changes scenario A2. See also Appendix B.

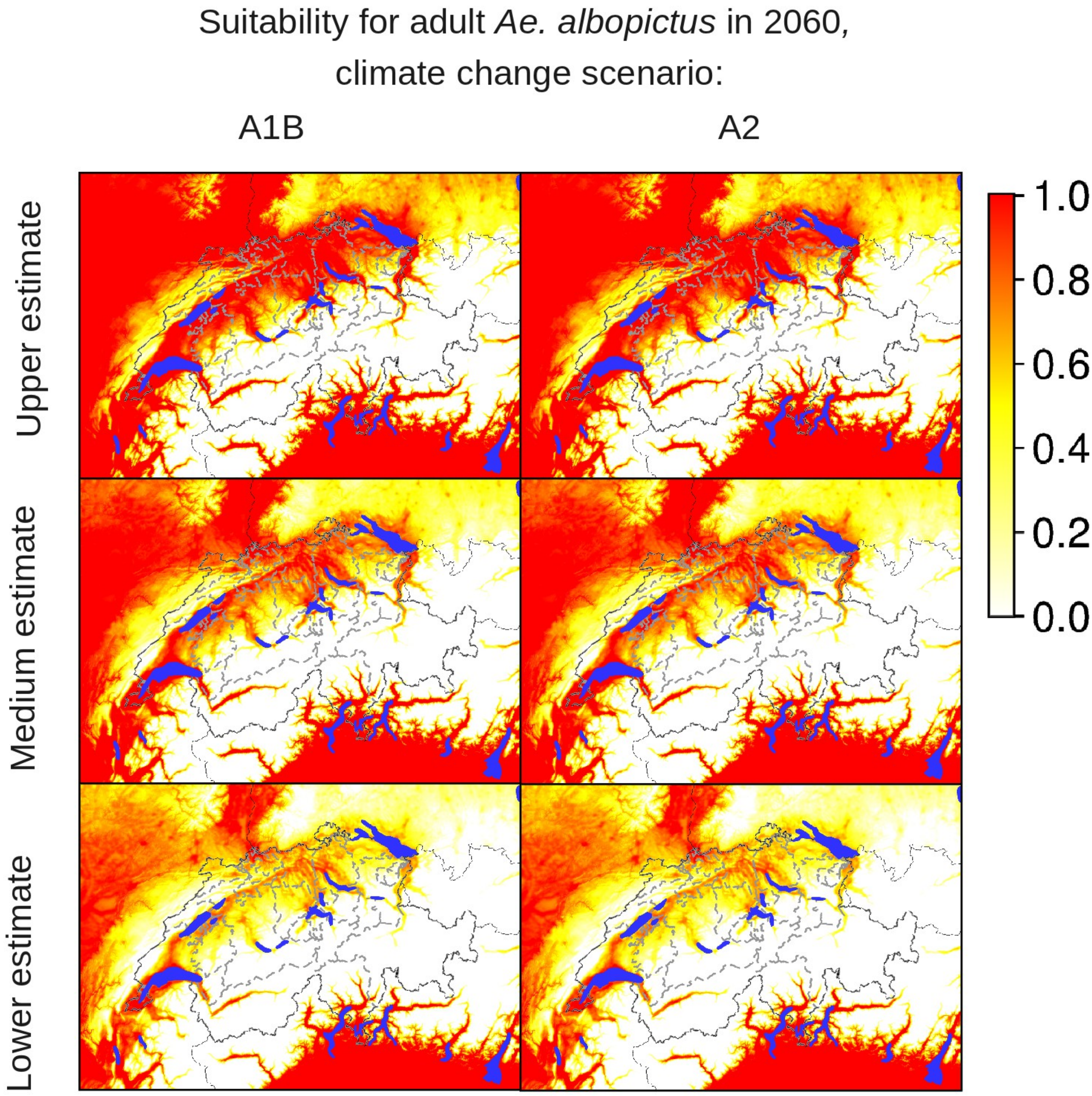

Figure 5: Suitability indicators for adult *Ae. albopictus* in Switzerland in 2060. The maps in the first row are based on temperature estimates for the climate changes scenario A1B, the maps in the second row are based on temperature estimates for the climate changes scenario A2. See also Appendix C.

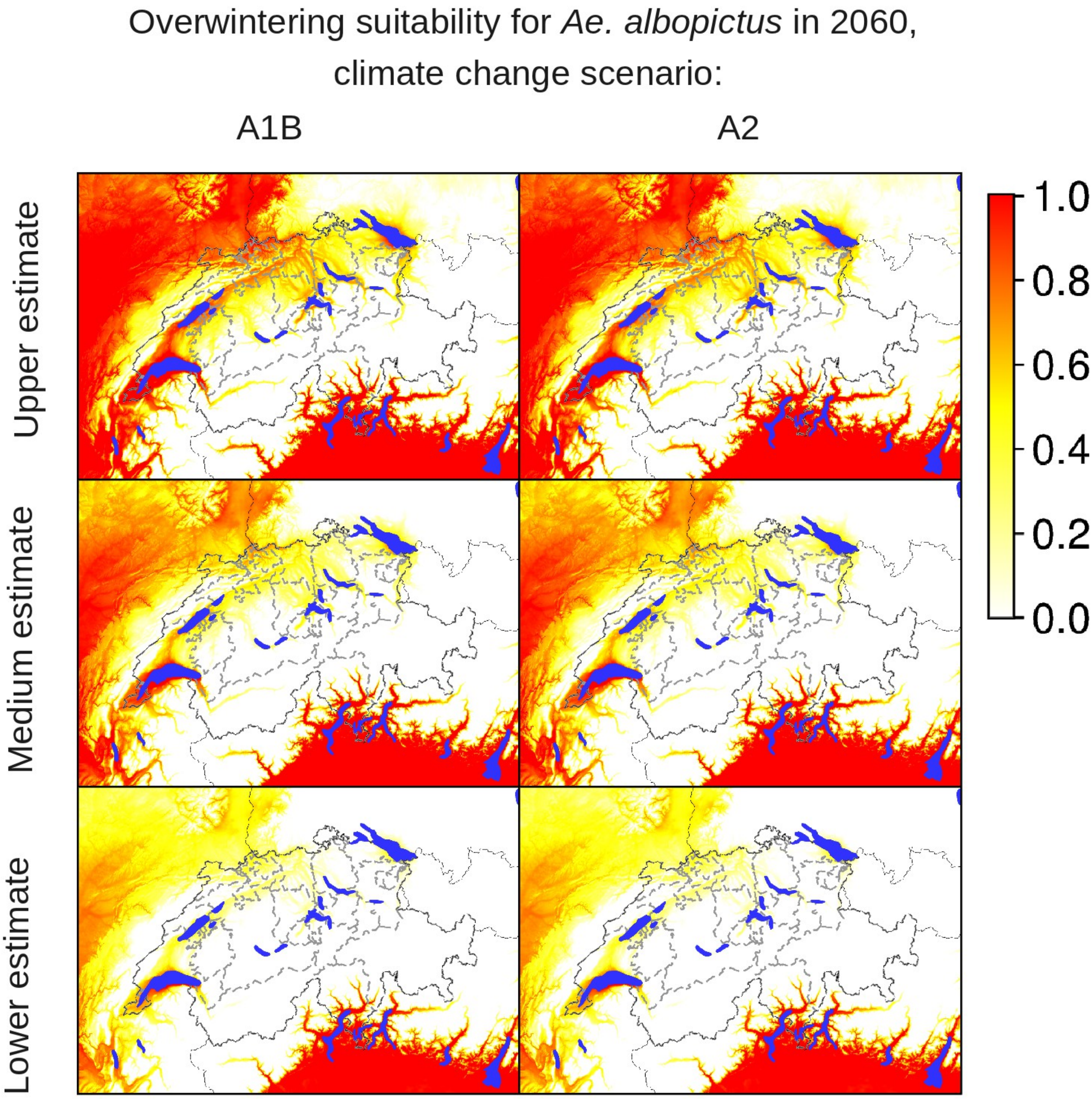

Figure 6: Suitability indicators for overwintering of *Ae. albopictus* in Switzerland in 2060. The maps in the first row are based on temperature estimates for the climate changes scenario A1B, the maps in the second row are based on temperature estimates for the climate changes scenario A2. See also Appendix C.

5 Discussion

Various parts of Switzerland have been identified as climatically suitable for *Ae. albopictus*. Even though many potentially suitable areas are not yet invaded, also due to the limited flight range of this mosquito in its life-time, the current distribution in Europe and the spread patterns let suggest that the tiger mosquito might well appear in these areas within the next few years.
In particular, western Switzerland the areas around Lake Geneva could be

invaded soon from France through mosquitoes especially imported through the transport of goods. The area south of Lake Geneva seems to be suitable for overwintering diapause eggs of *Ae. Albopictus*.
In northern Switzerland, parts of the Rhine valley, both upstream and downstream of Lake Constance, as well as surroundings of Lake Neuchâtel appear to be suitable for adult *Ae. albopictus*, while being currently too cold in winter for diapause eggs to have a chance of survival.
In southern Switzerland, especially the canton Ticino remains affected by the tiger mosquito.

A comparison with published ECDC risk maps is difficult because the spatial resolution of their risk maps is too low to allow detailed statements for countries such as Switzerland. In general, the suitability seems to increase in the northern parts of Switzerland, but stays in the range of medium suitability. Smaller high-risk areas are not recognizable in these published ECDC risk maps.

The simulation of future situations with the assumption of increasing temperatures shows increasing suitability in general. Considering the A1B and A2 climate change scenarios, the overwintering suitability is predicted to slightly increase around Lake Geneva. The overwintering suitability is predicted to increase substantially in neighboring countries, particularly in France. These areas may in future act as a source for further invasion of *Ae. albopictus*.

6 References

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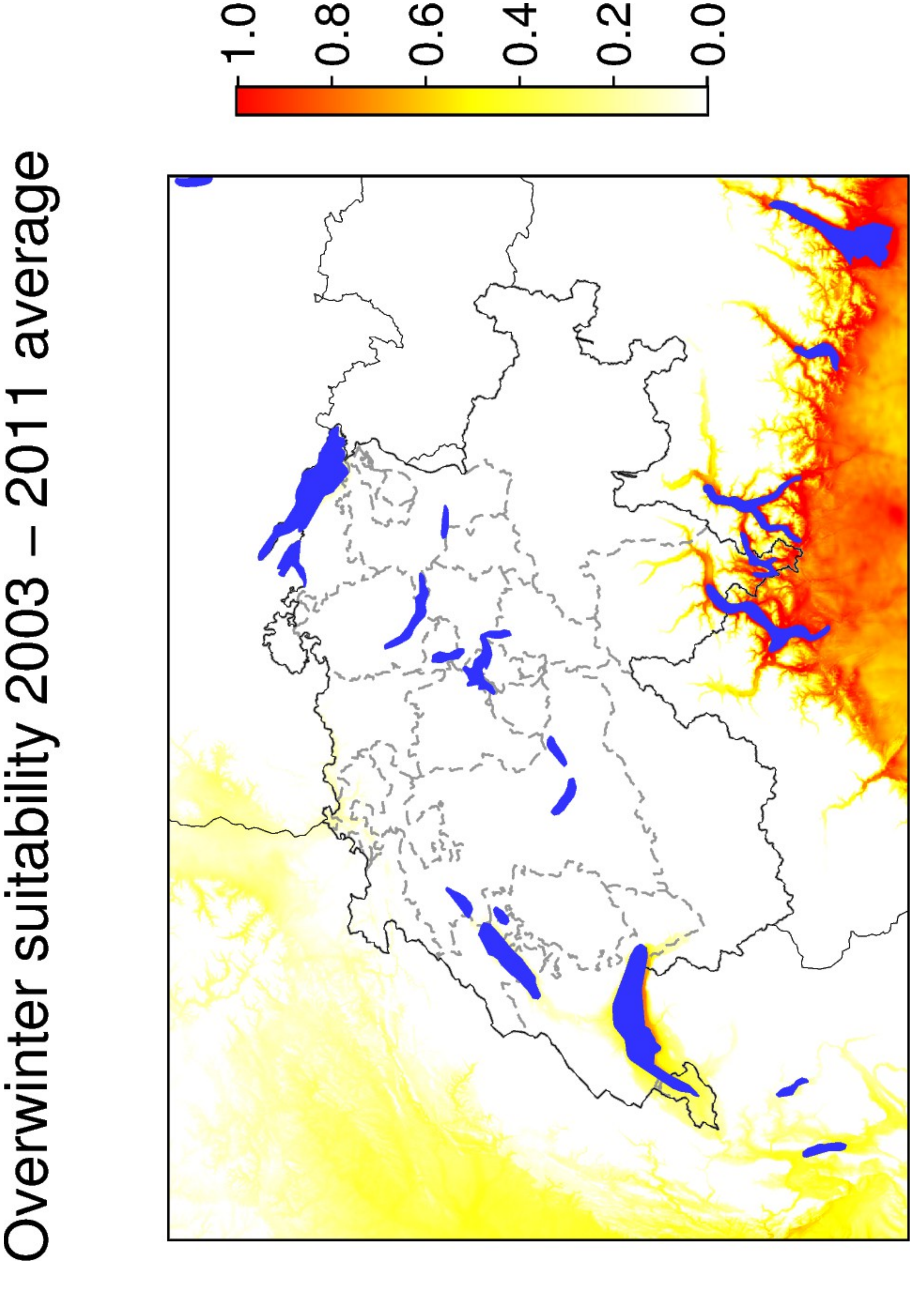
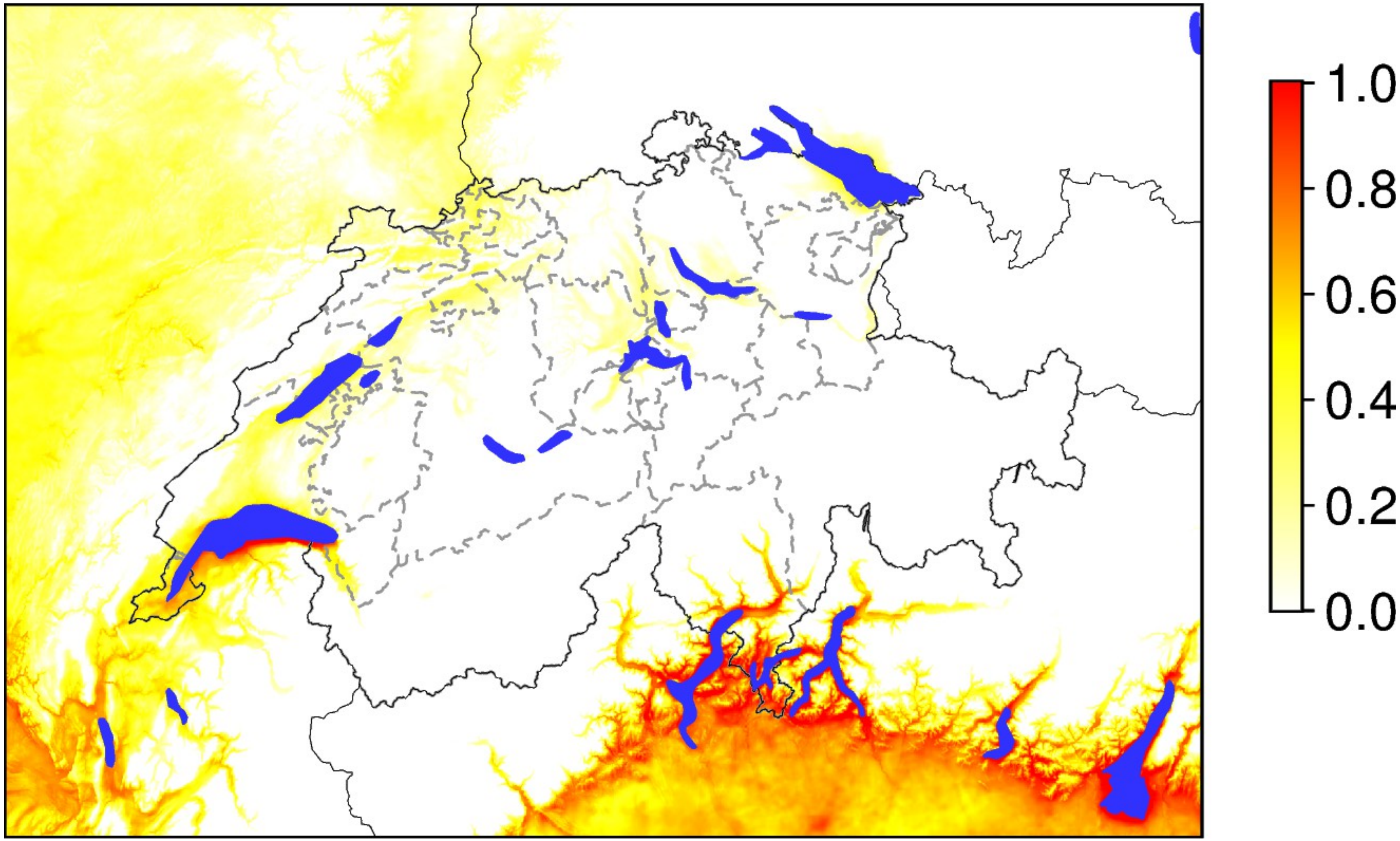
6.1 Appendix A: current conditions

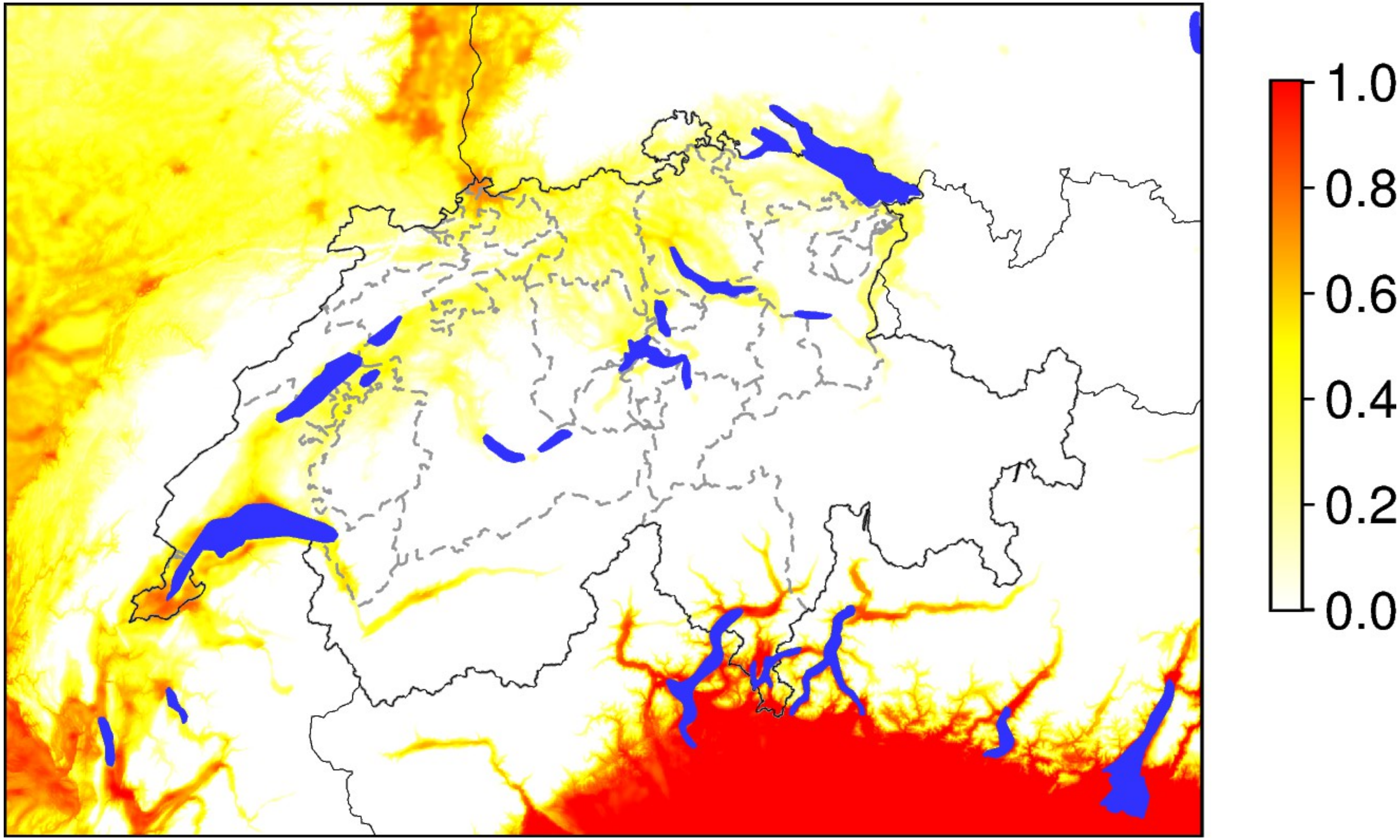
Suitability maps for current conditions



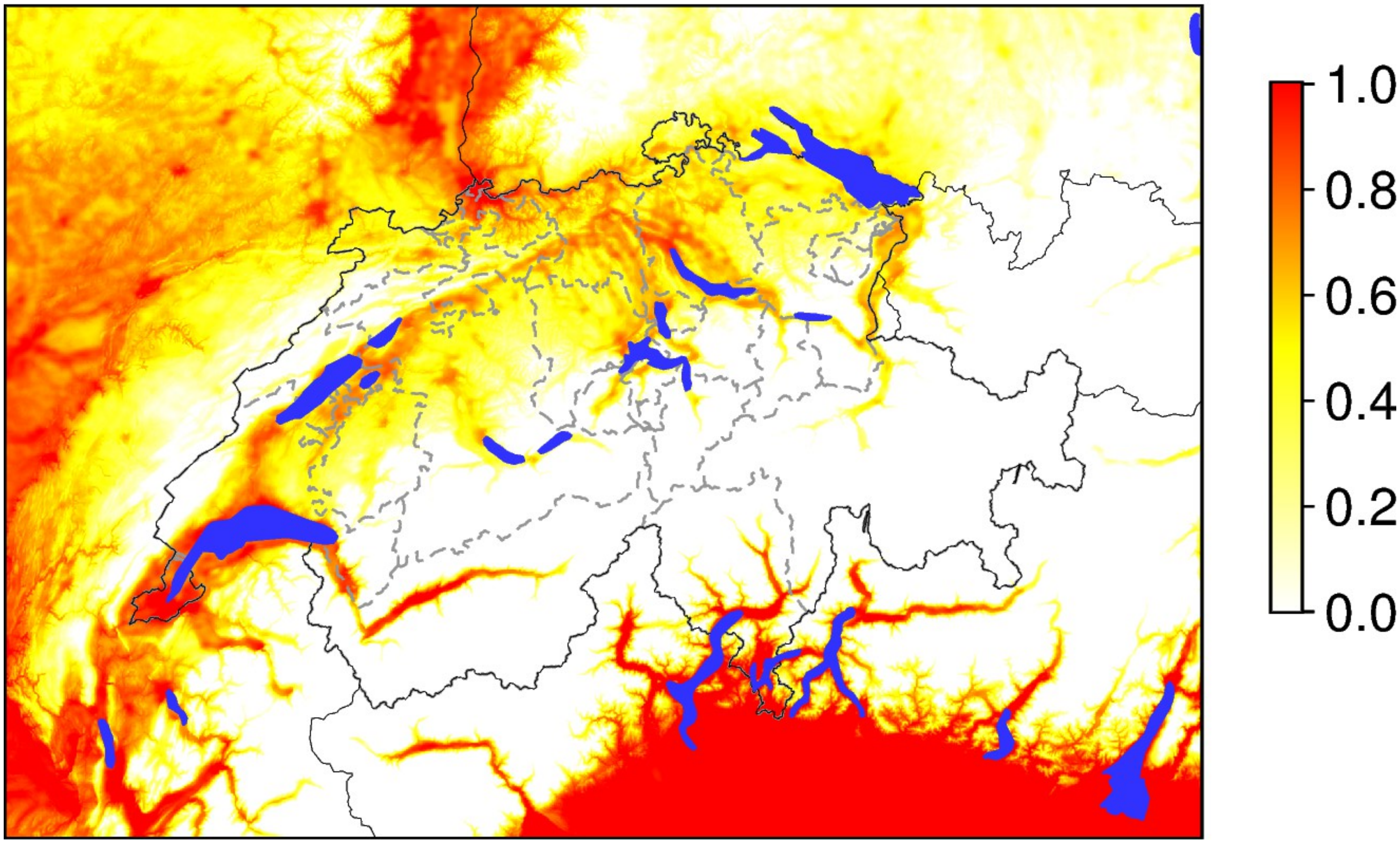
Overwinter suitability 2011

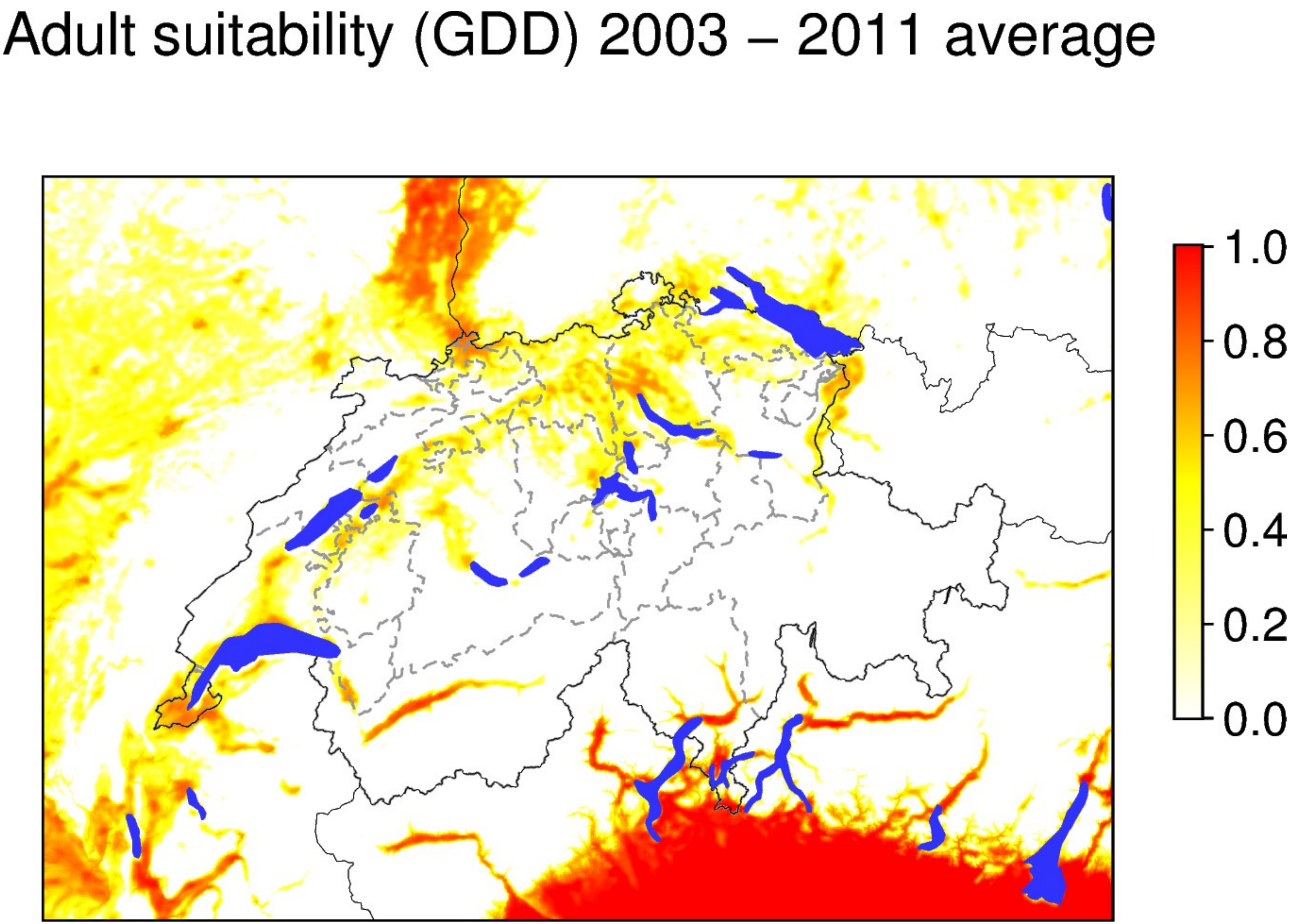


Adult suitability 2003 – 2011 average

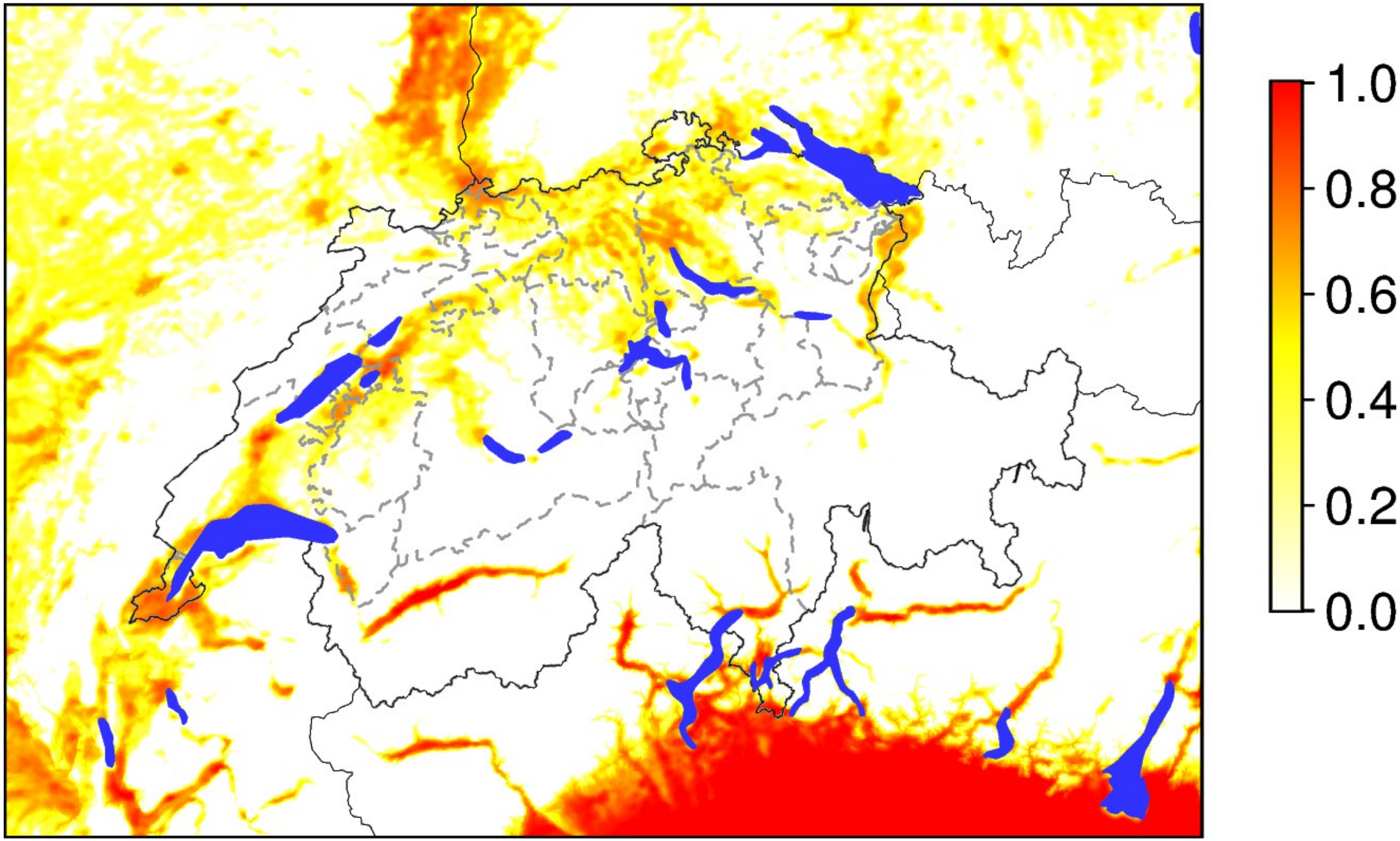


Adult suitability 2011



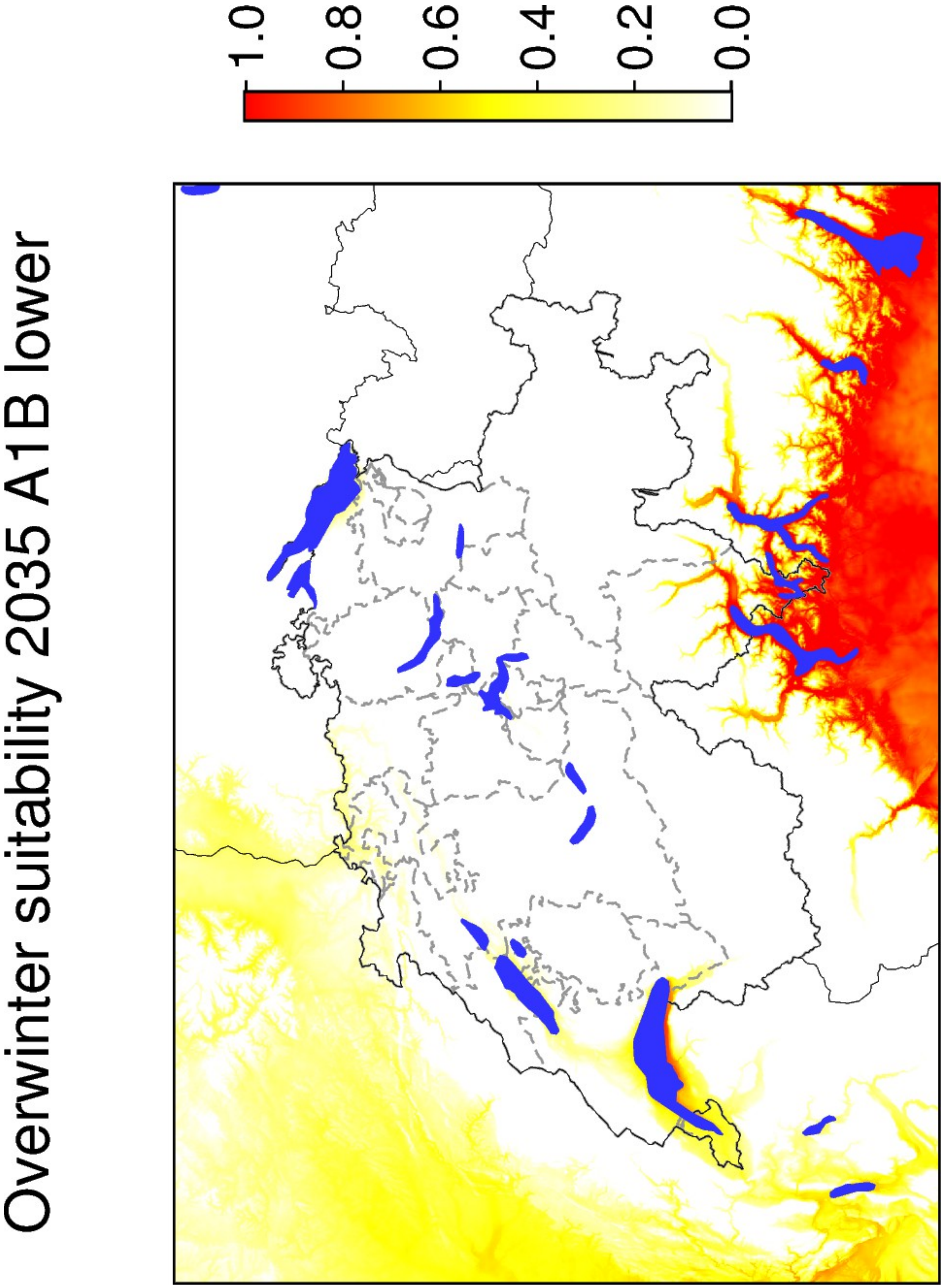

Adult suitability (GDD) 2003 – 2011 average
1.0
0.8
0.6
0.4
0.2
0.0

Adult suitability (GDD) 2011

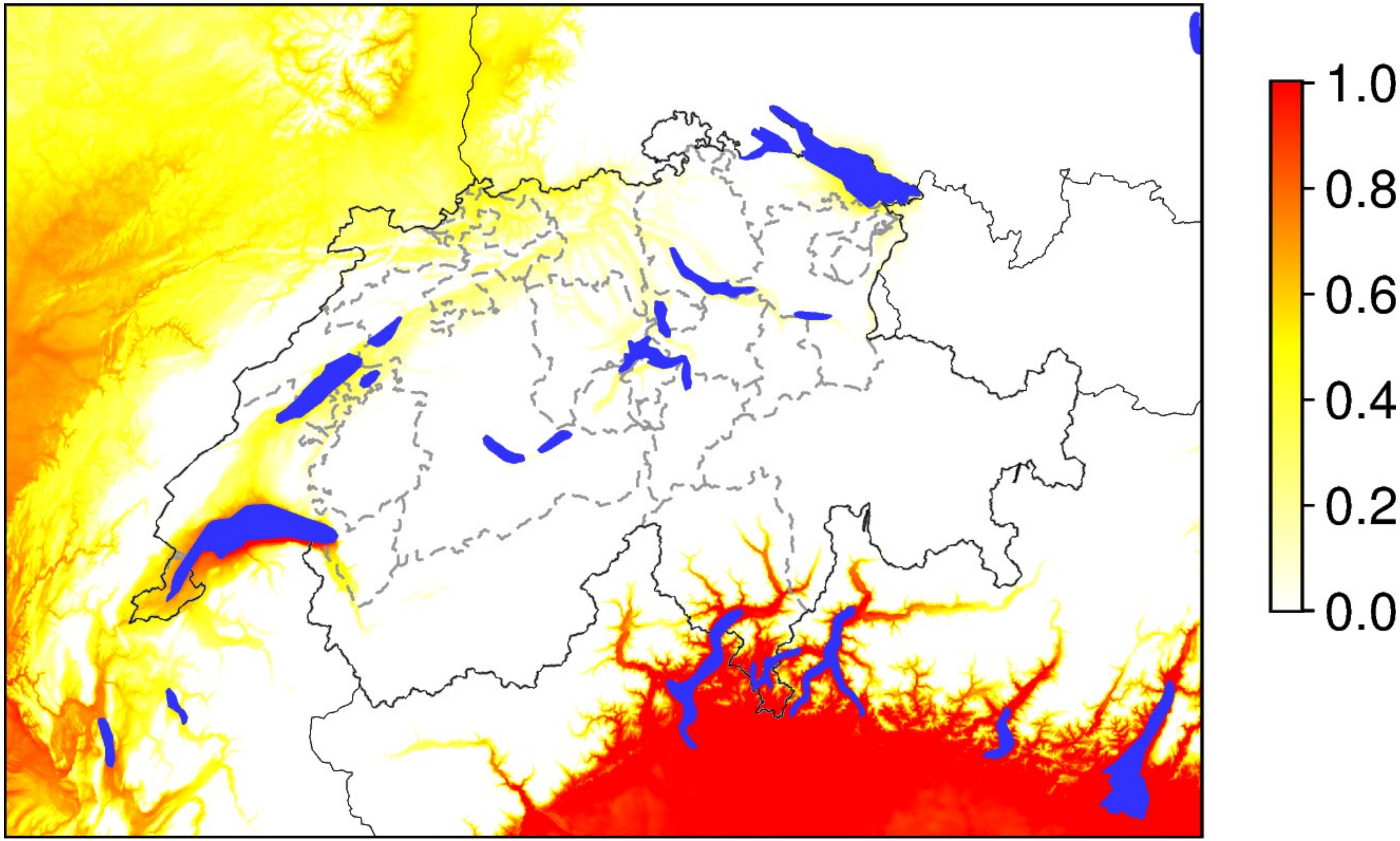


6.2 Appendix B: Year 2035

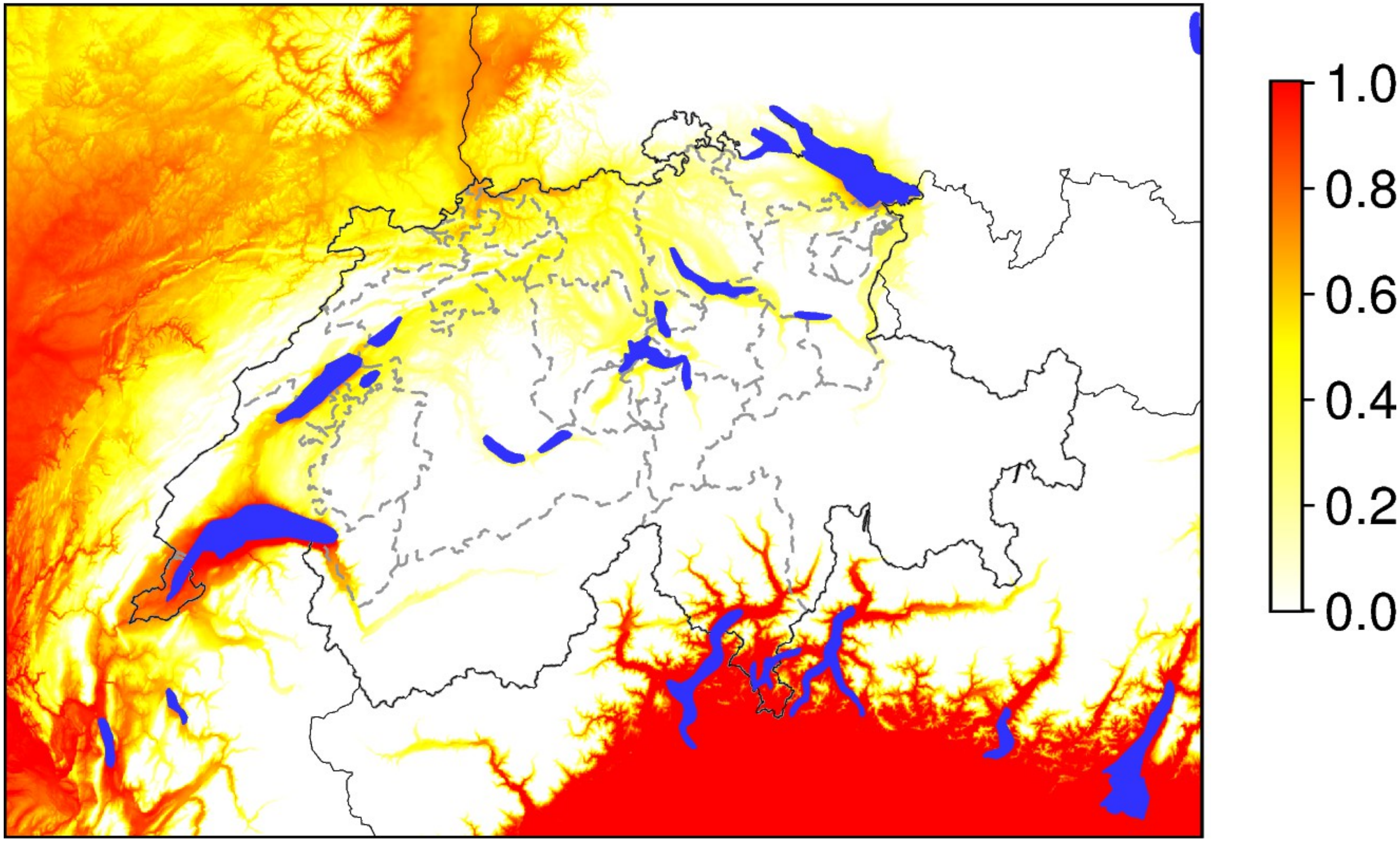
Suitability maps for the year 2035 based on climate change scenarios A1B and A2



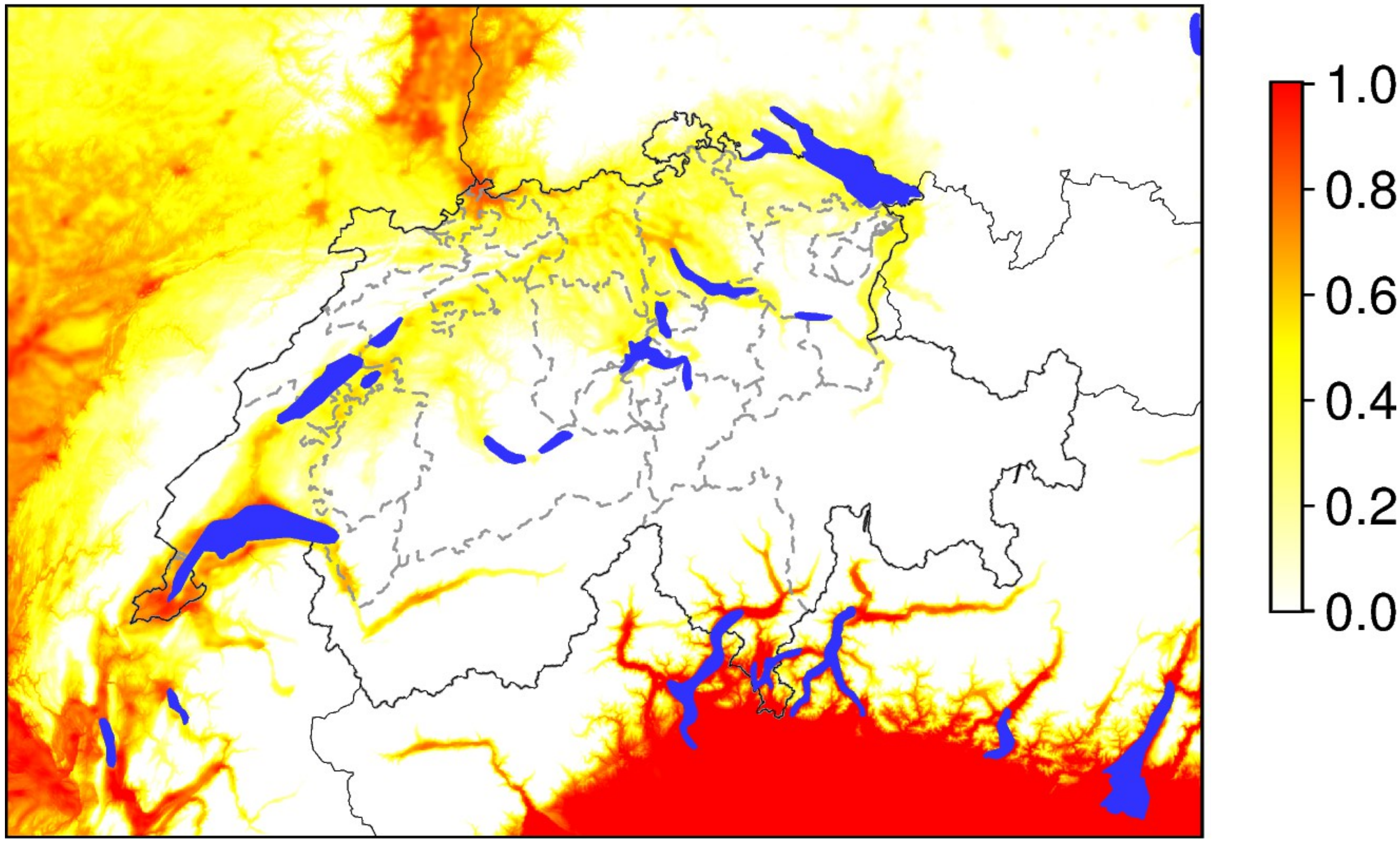
Overwinter suitability 2035 A1B medium



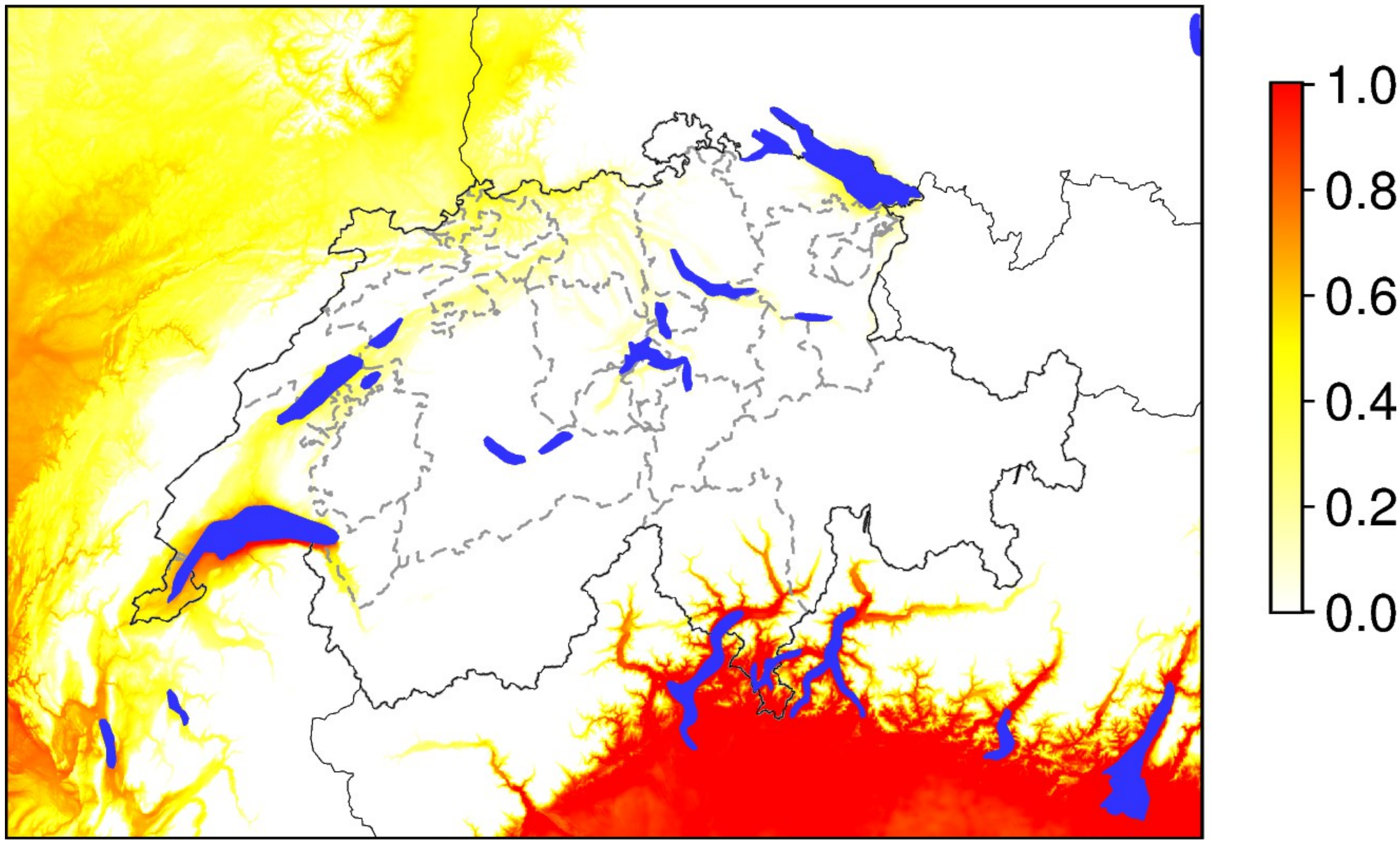
Overwinter suitability 2035 A1B upper



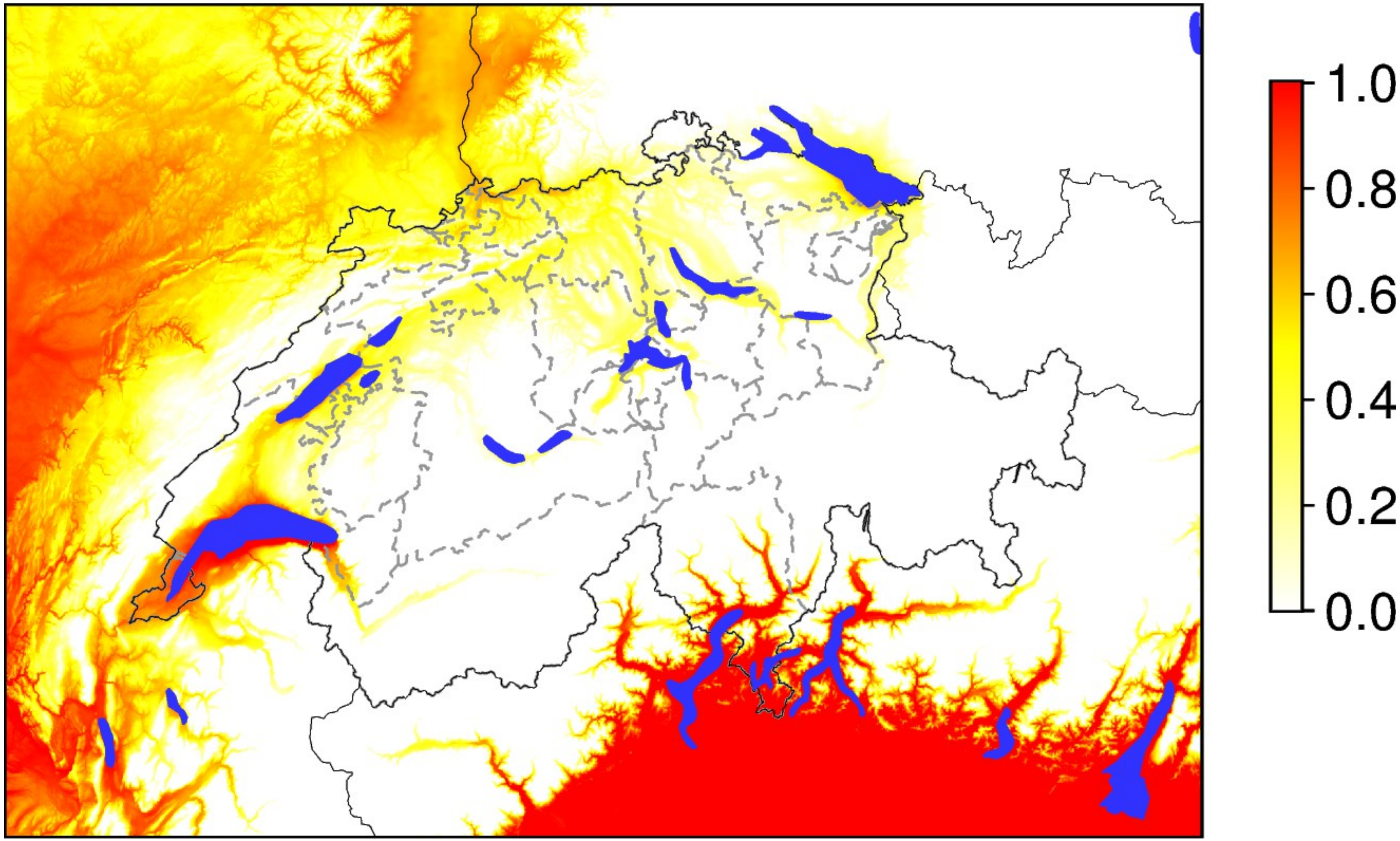
Adult suitability 2035 A2 lower



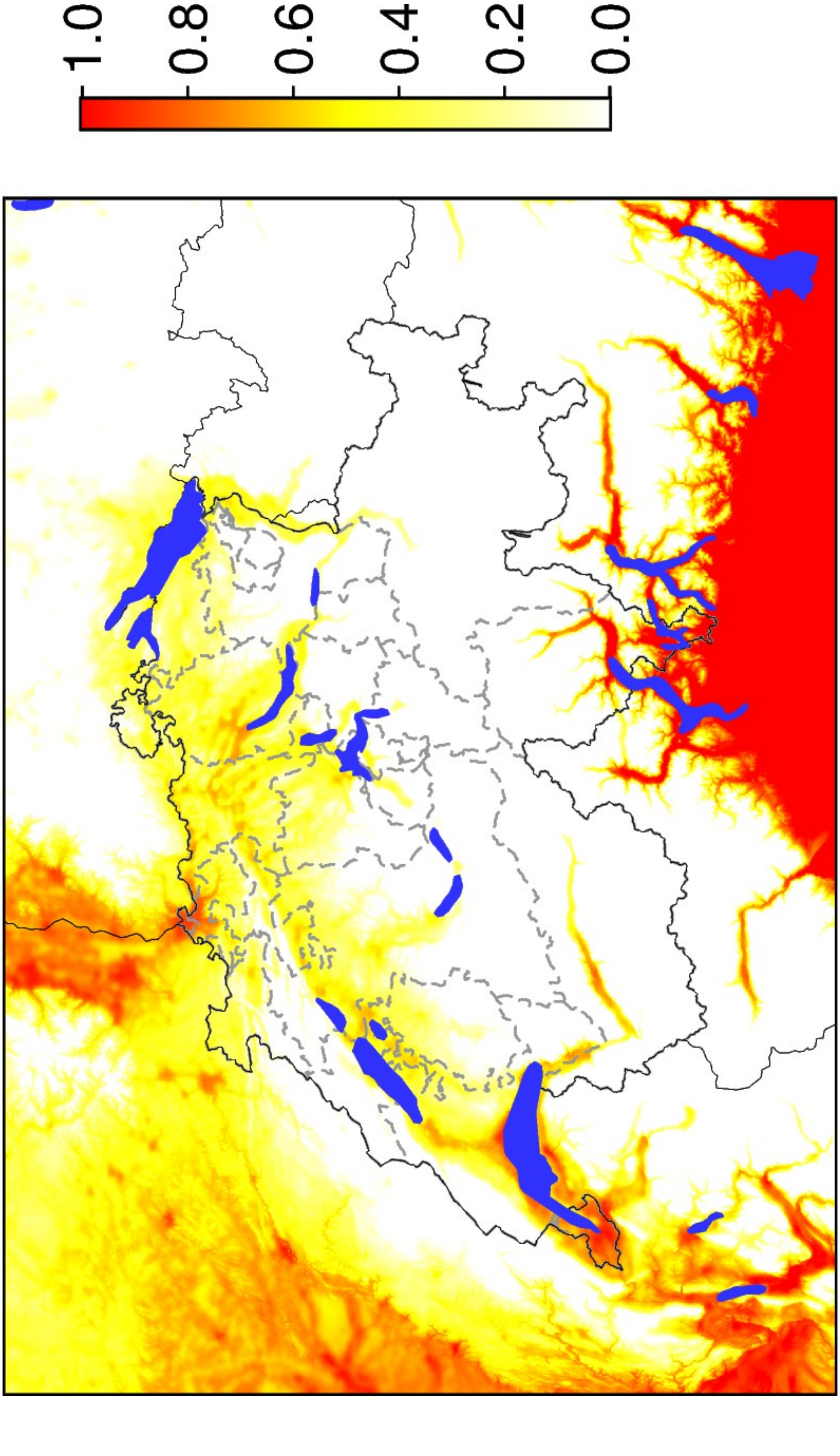
Overwinter suitability 2035 A2 medium



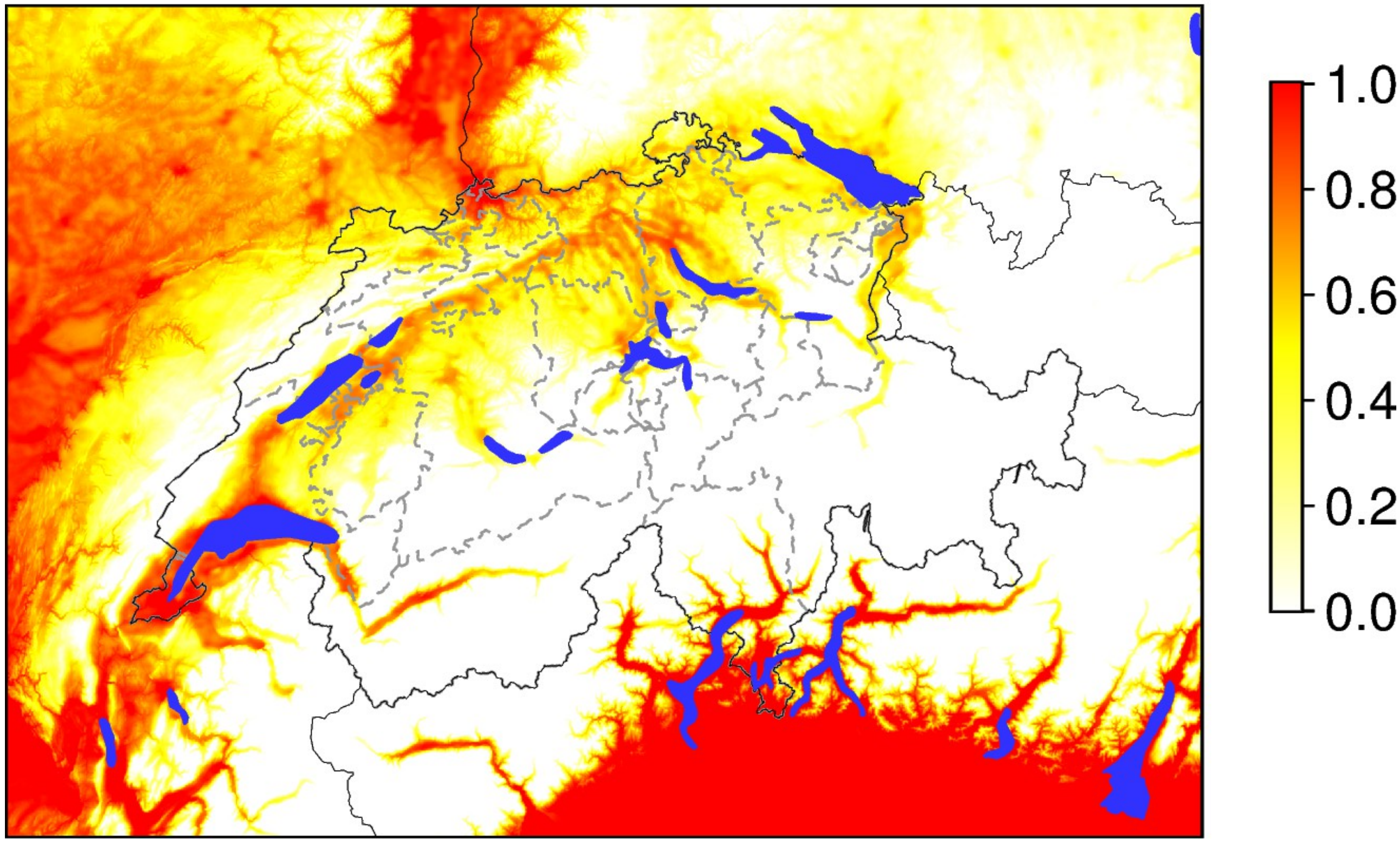
Overwinter suitability 2035 A2 upper



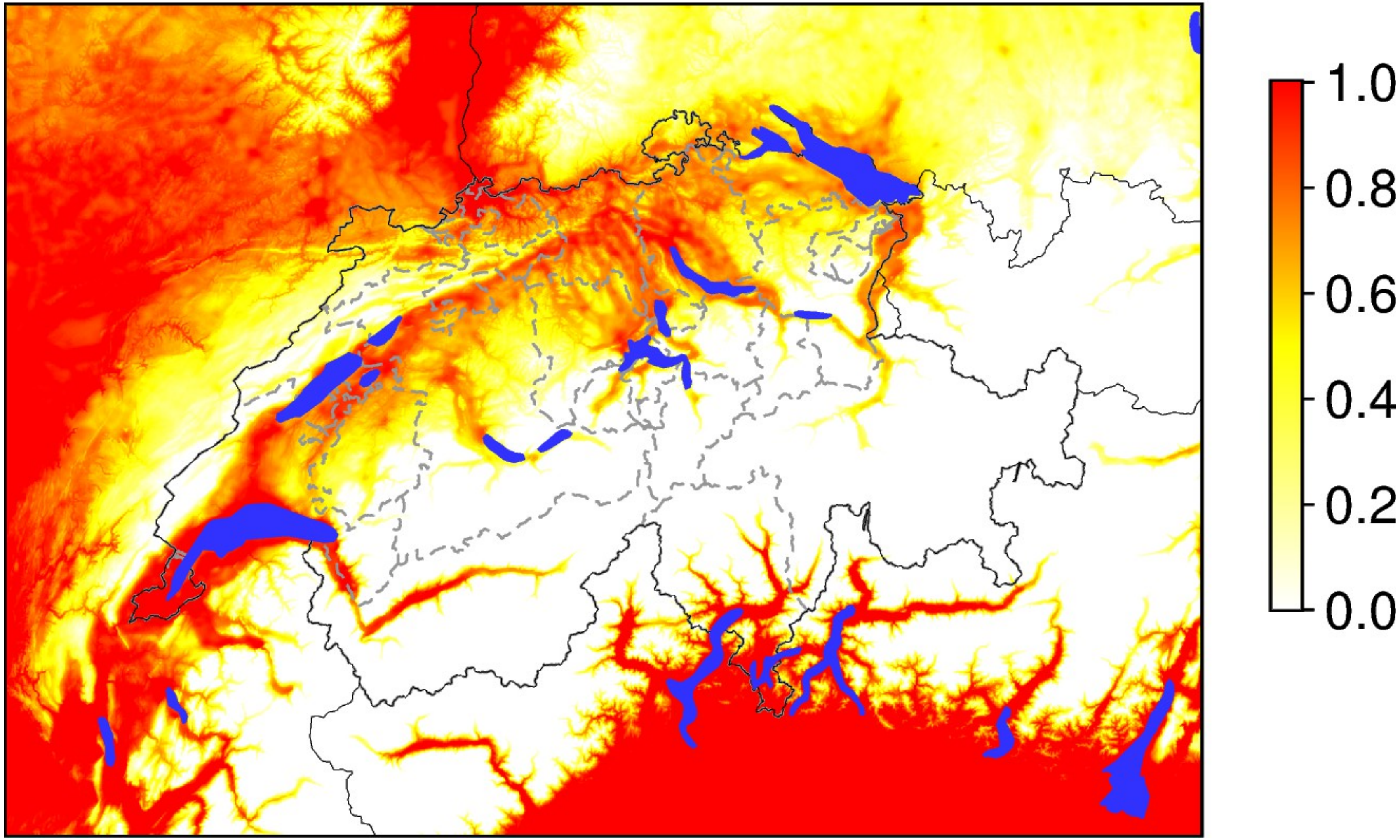
Adult suitability 2035 A1B lower



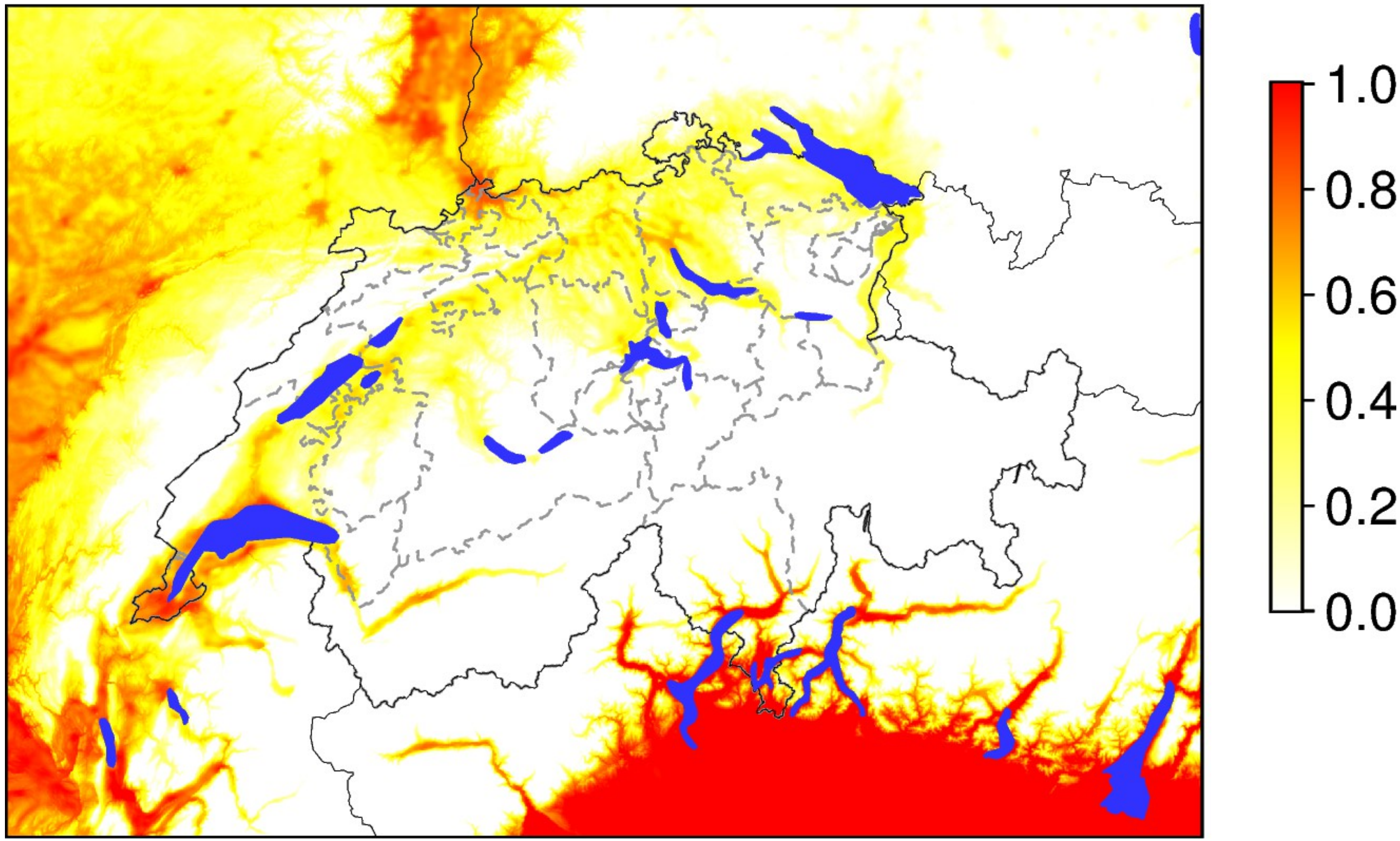
Adult suitability 2035 A1B medium



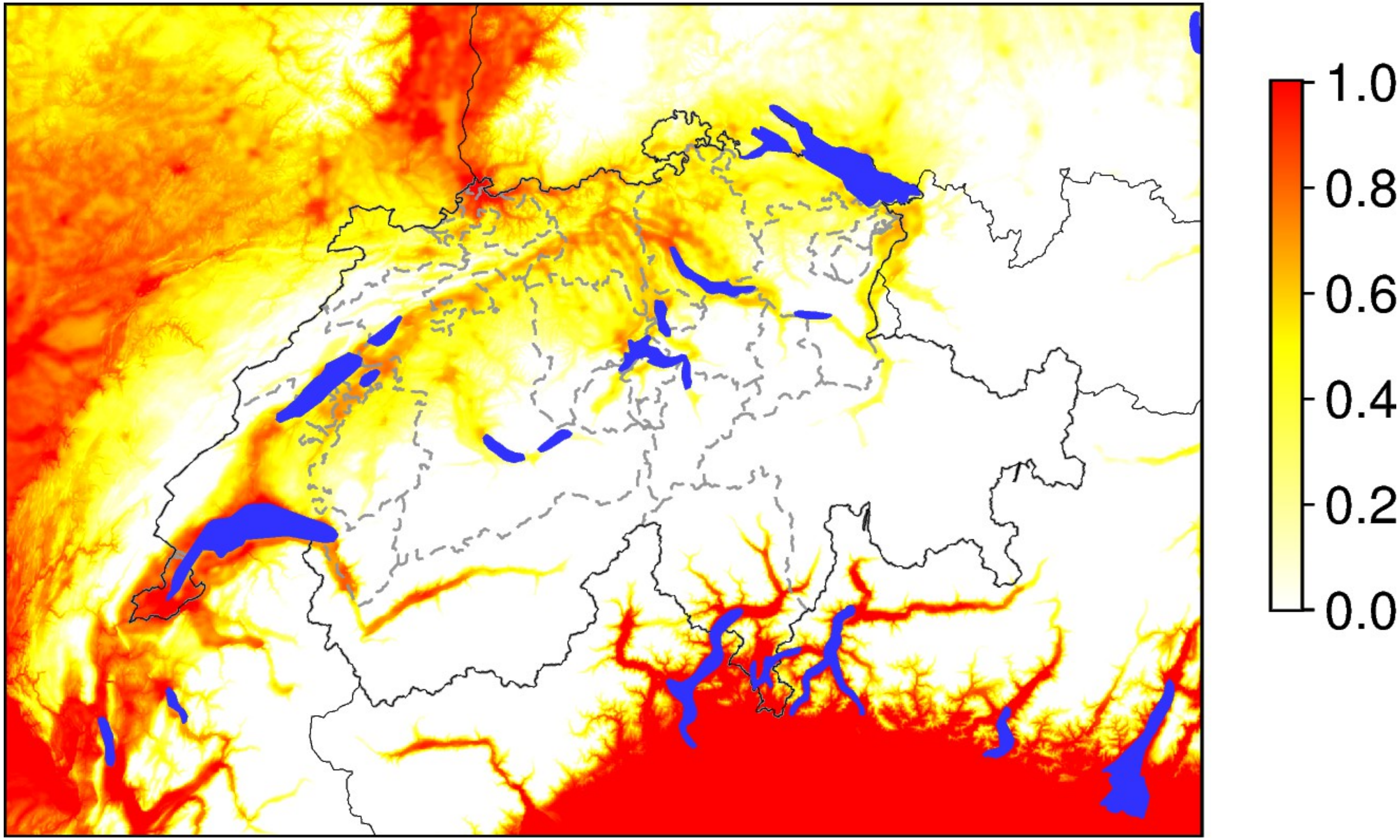
Adult suitability 2035 A1B upper



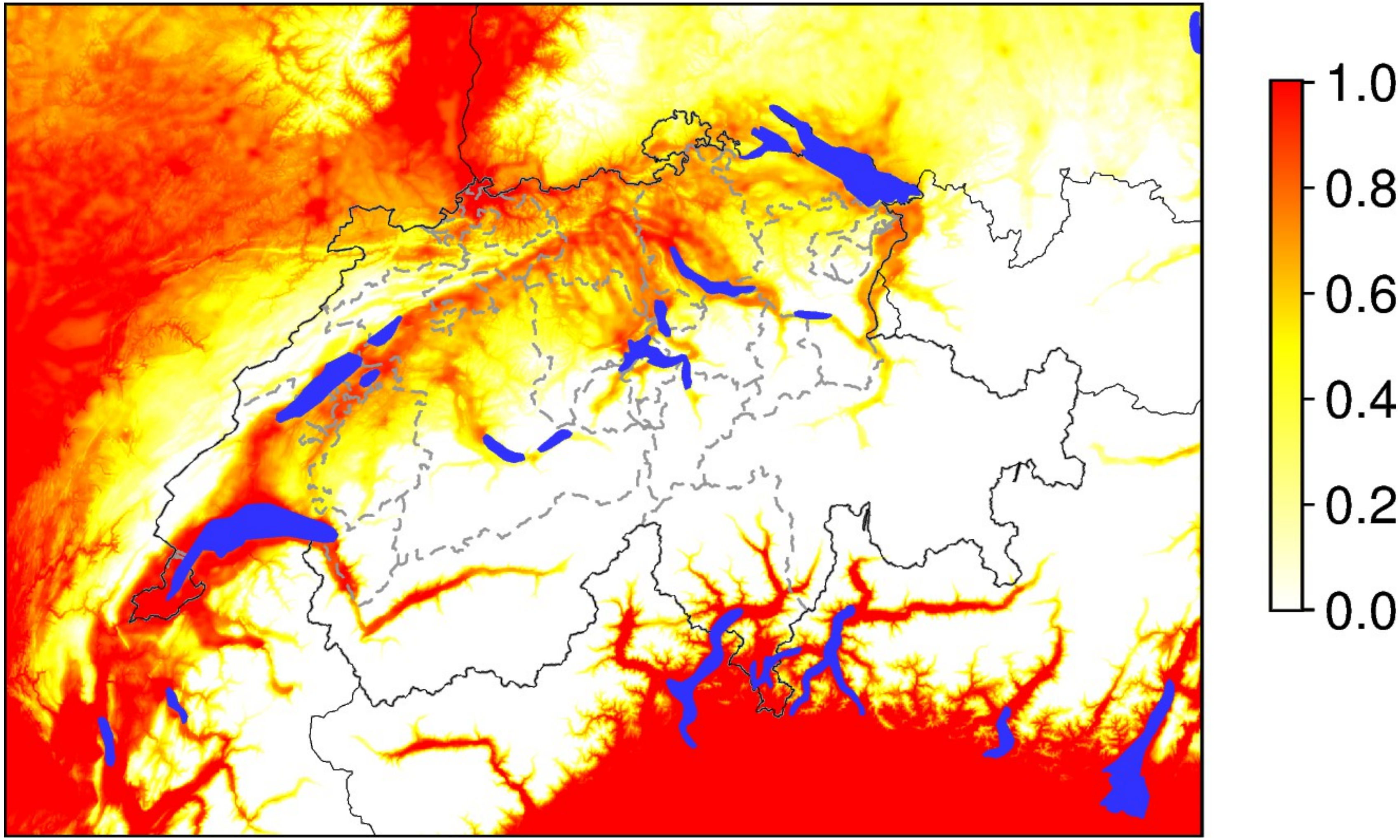
Adult suitability 2035 A2 lower



Adult suitability 2035 A2 medium

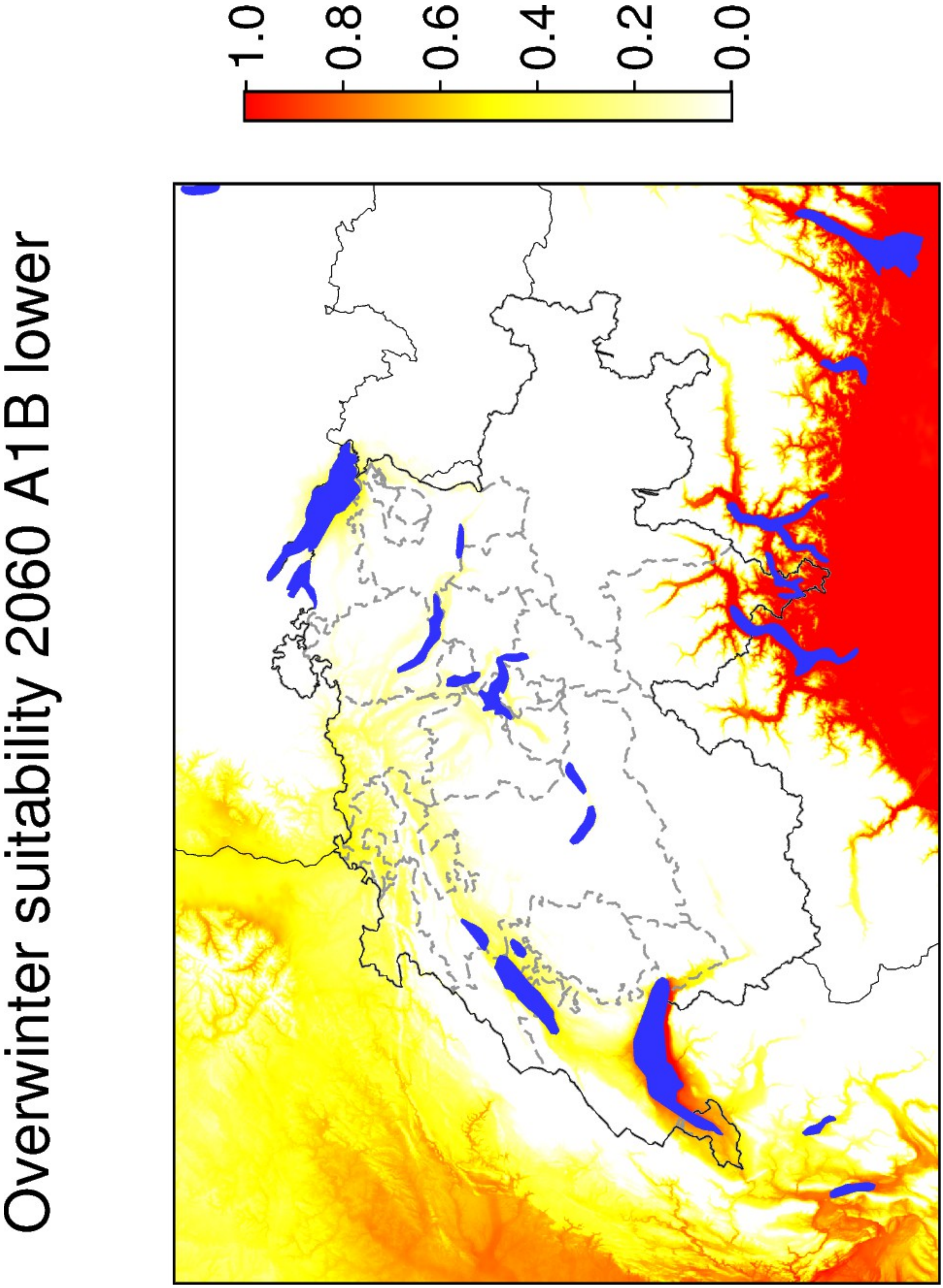


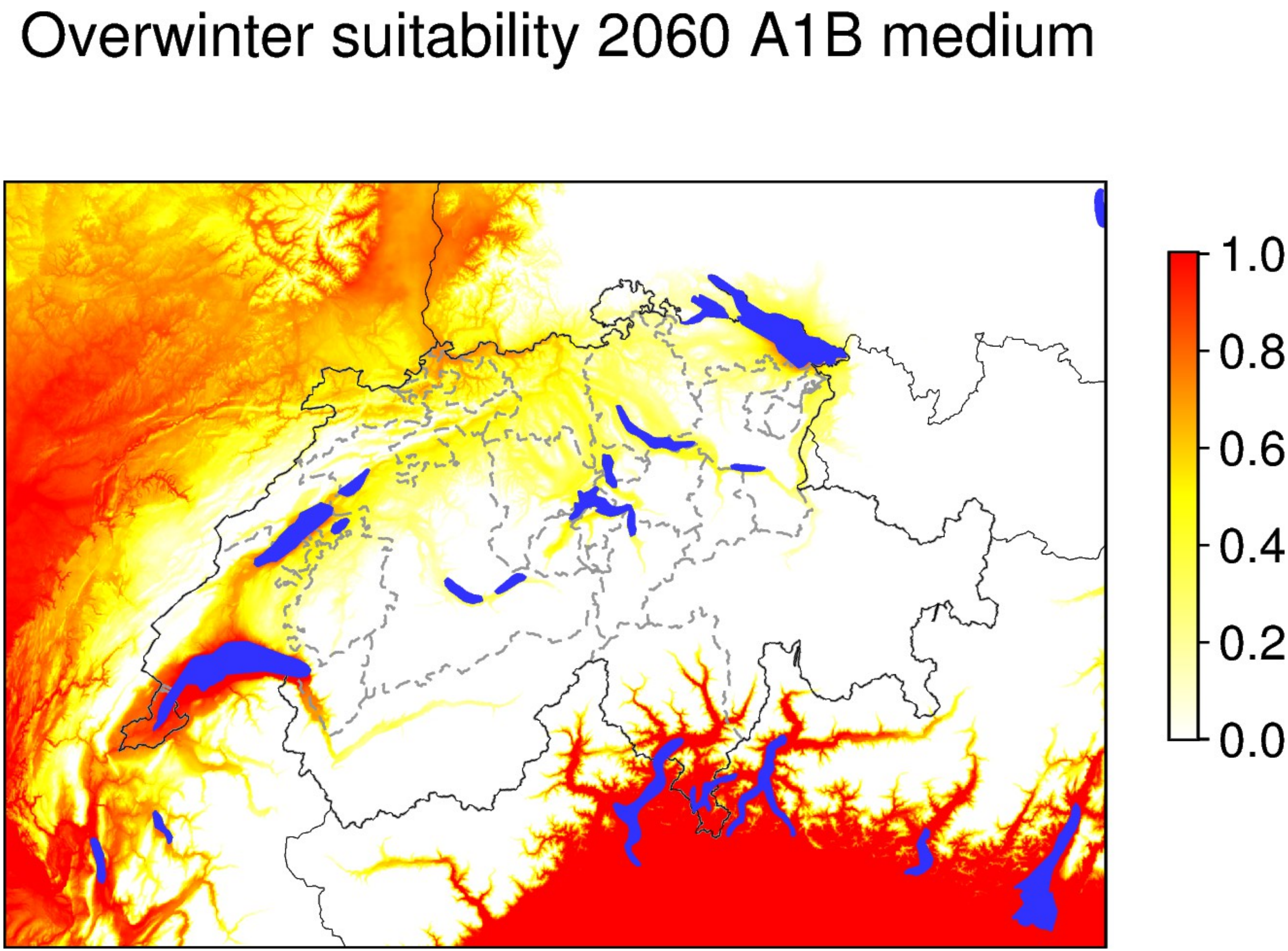
Adult suitability 2035 A2 upper



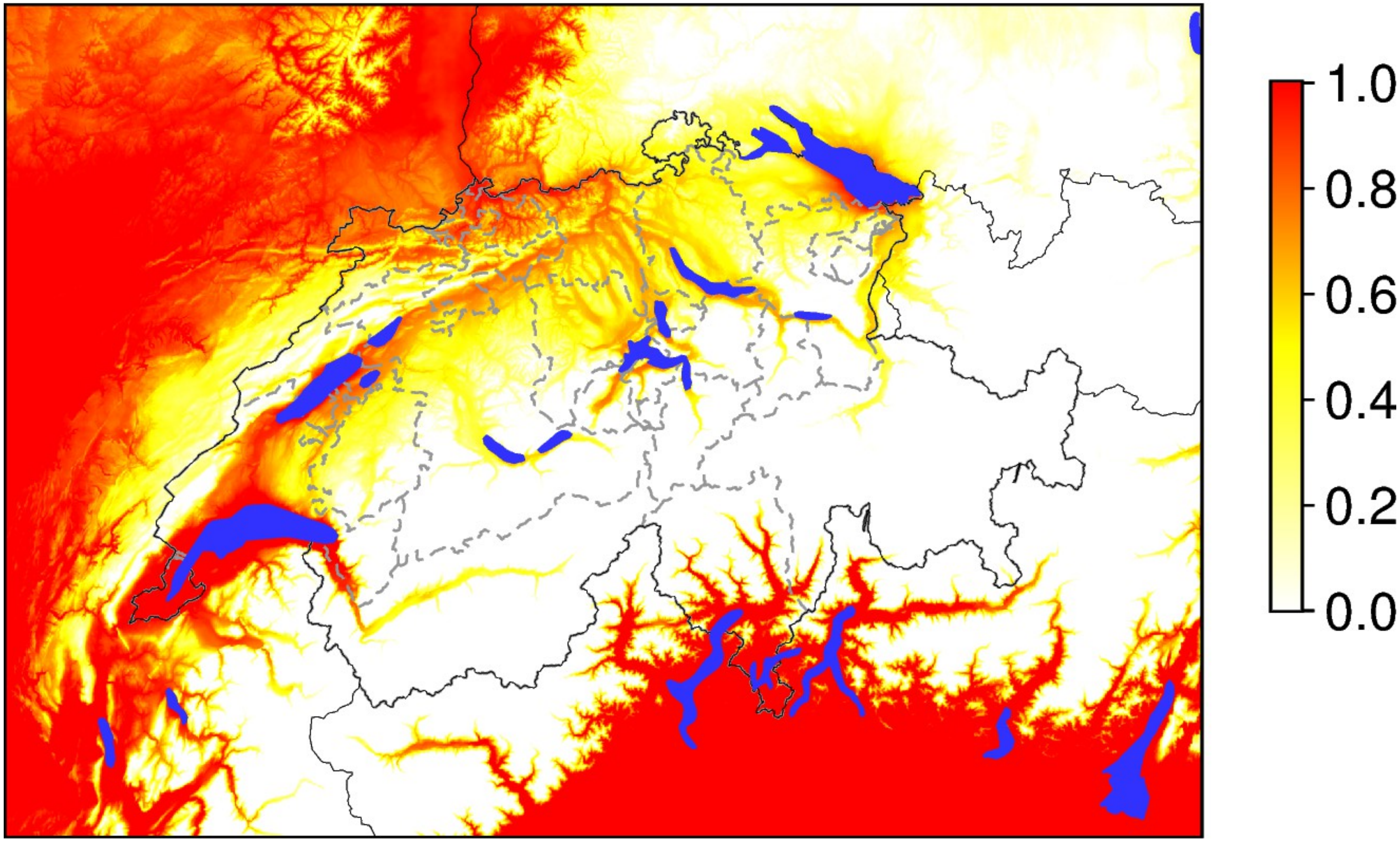
6.3 Appendix C: Year 2060

Suitability maps for the year 2060 based on climate change scenarios A1B and A2

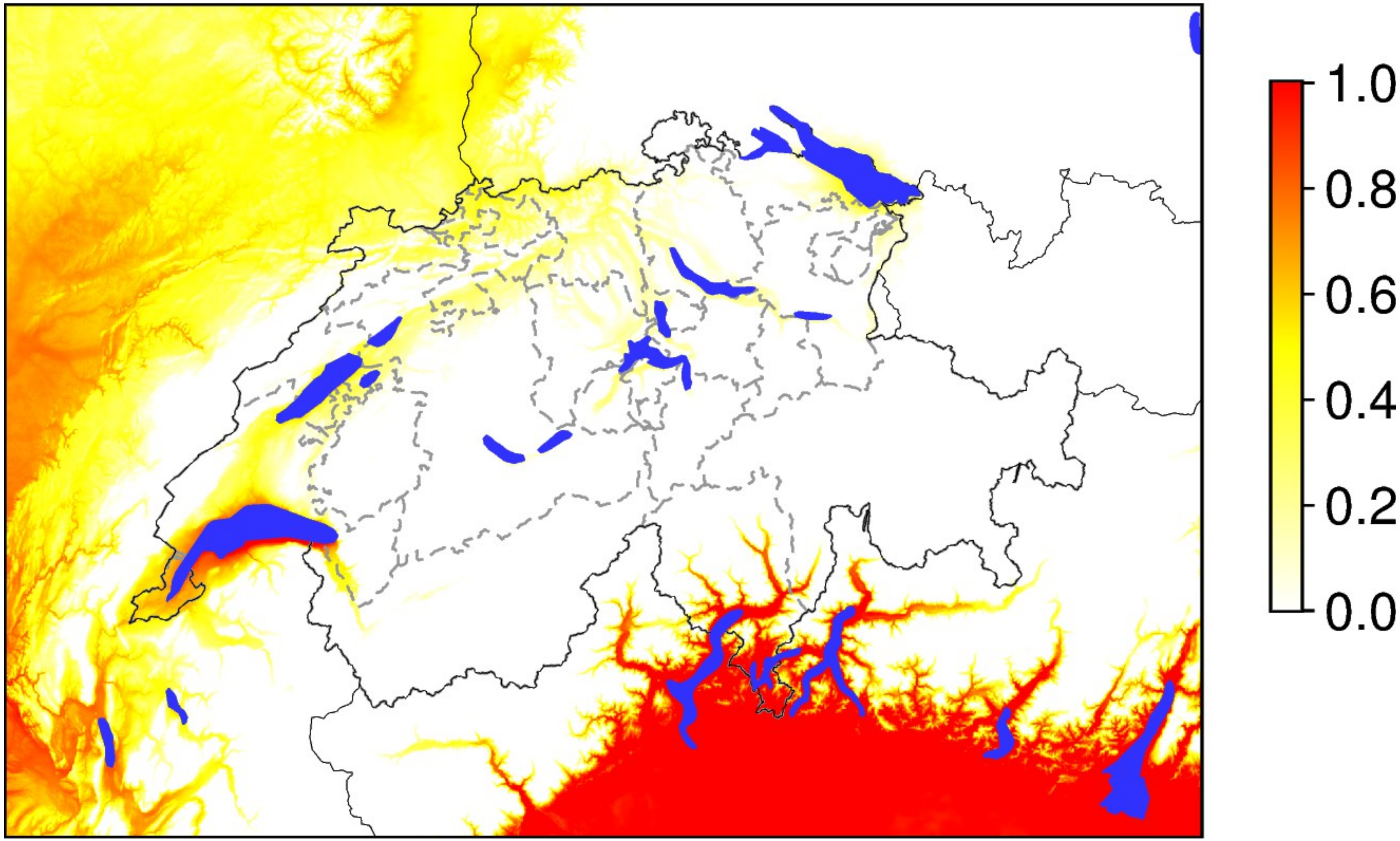



Overwinter suitability 2060 A1B medium
1.0
0.8
0.6
0.4
0.2
0.0

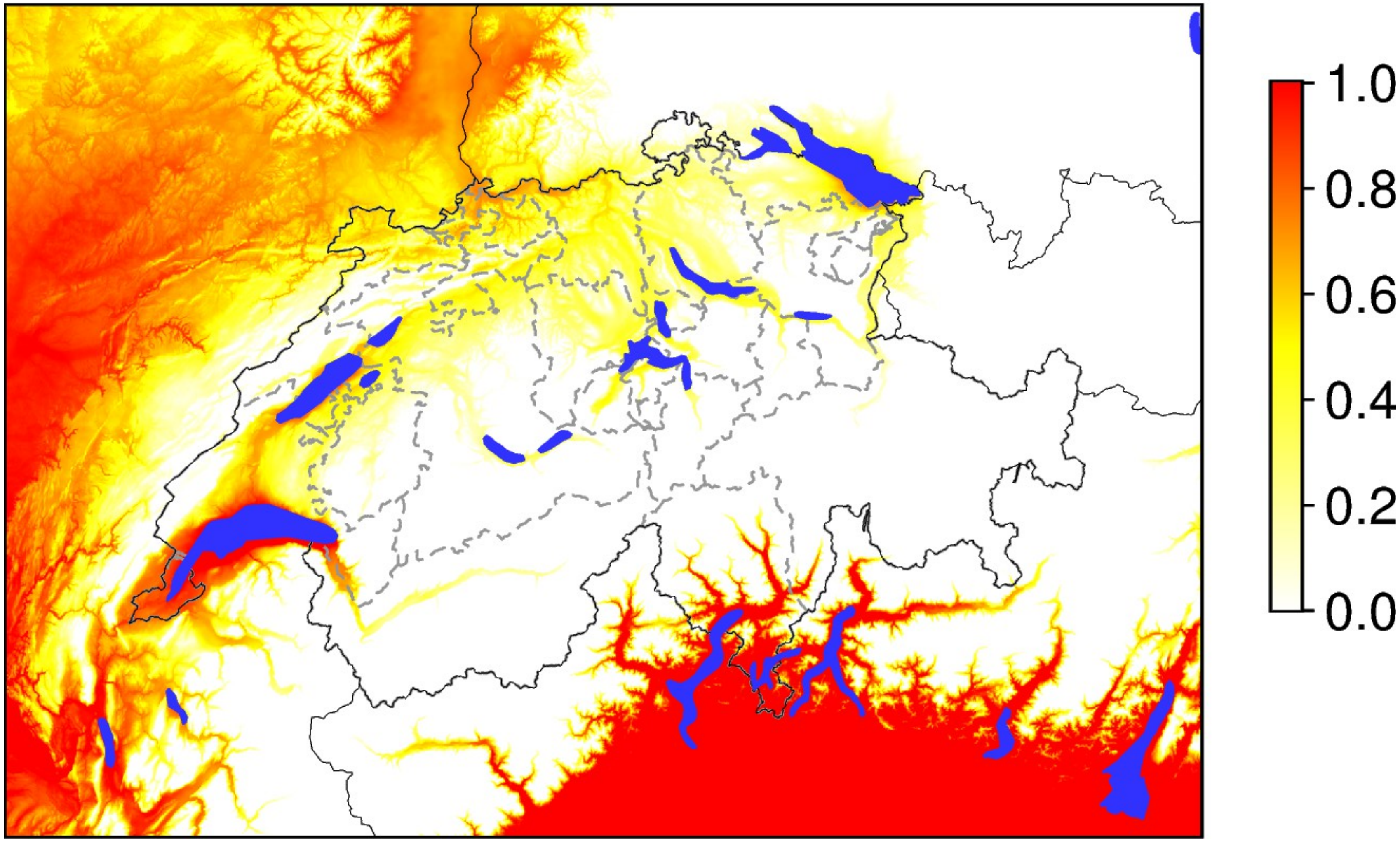
Overwinter suitability 2060 A1B upper



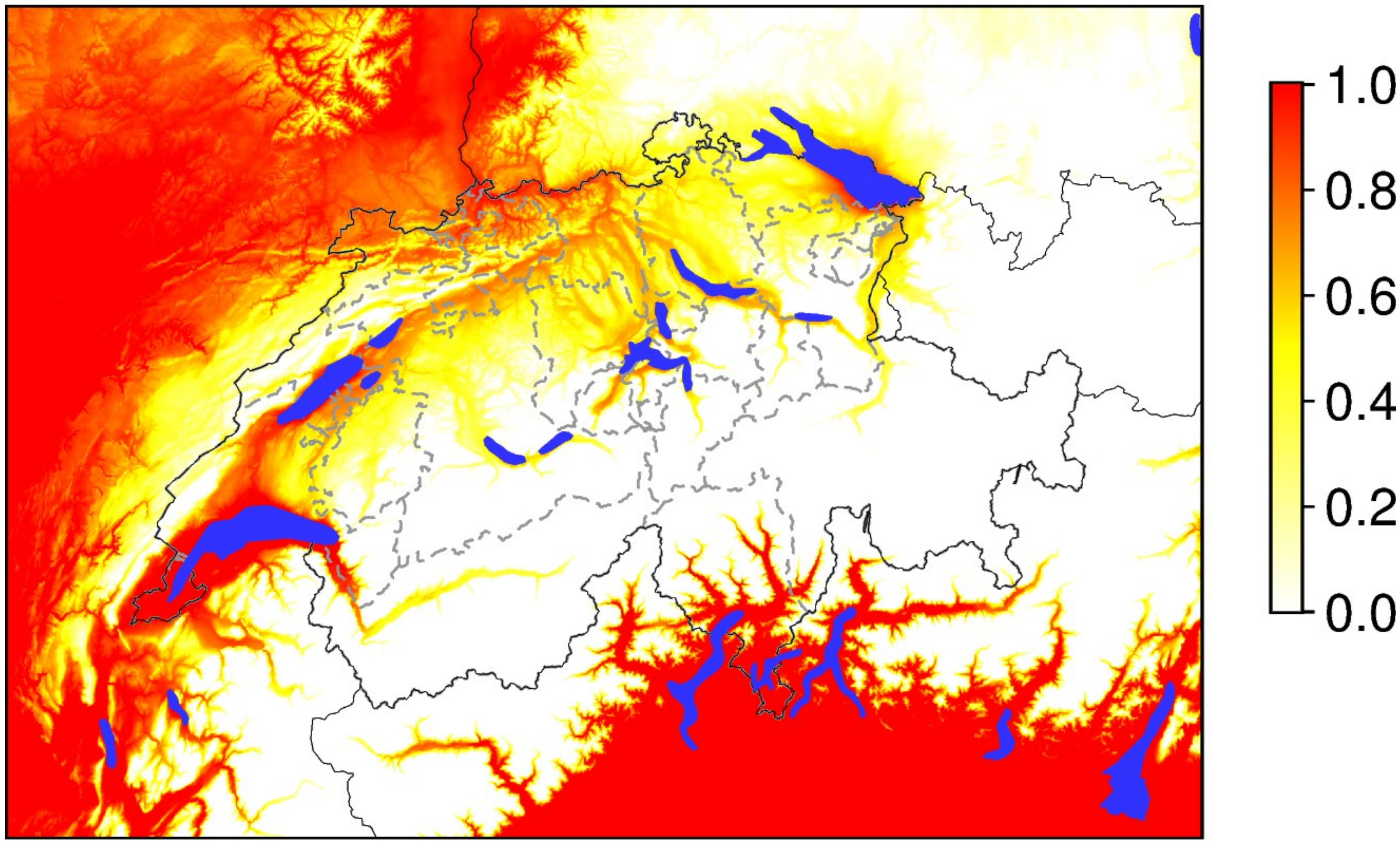
Overwinter suitability 2060 A2 lower



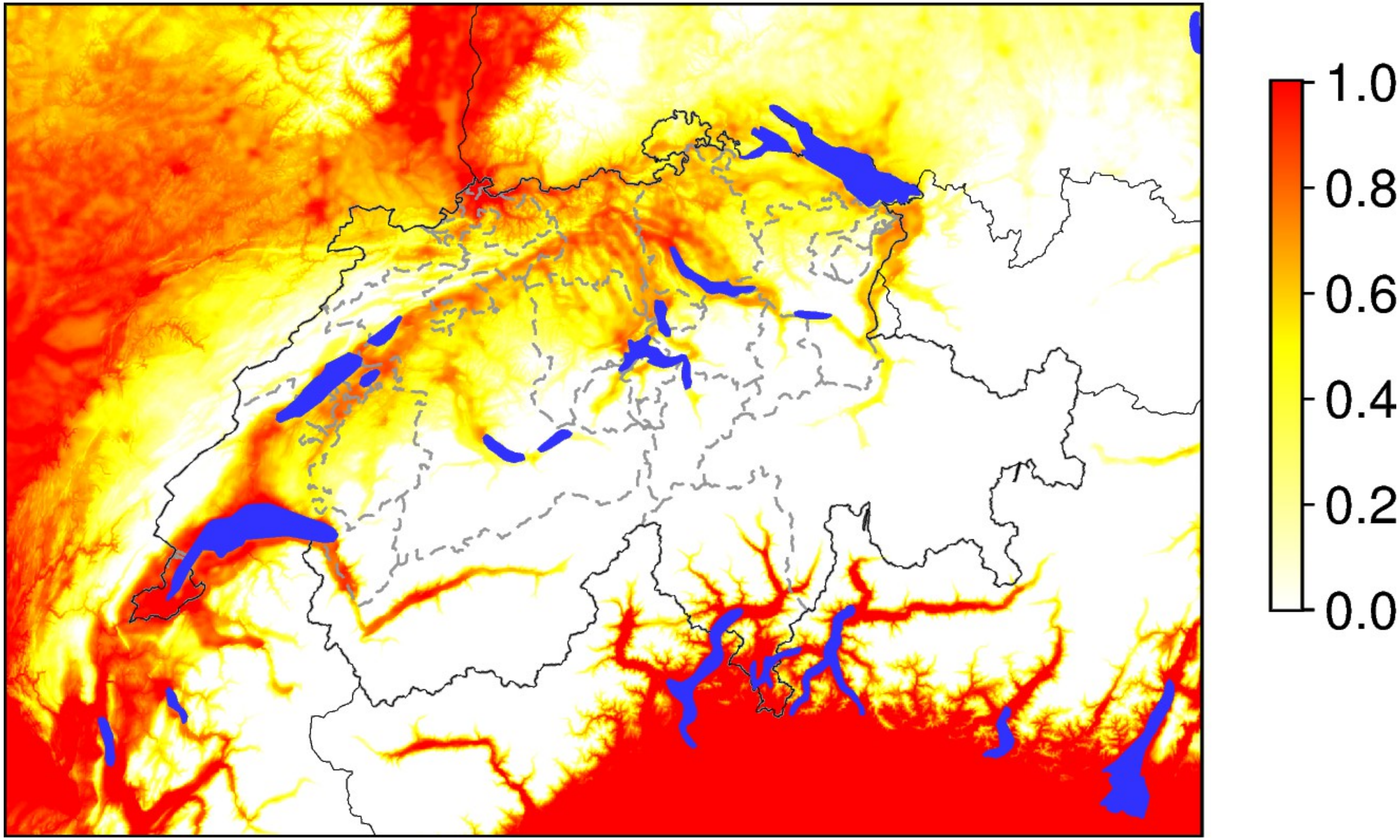
Overwinter suitability 2060 A2 medium



Overwinter suitability 2060 A2 upper



Adult suitability 2060 A1B lower



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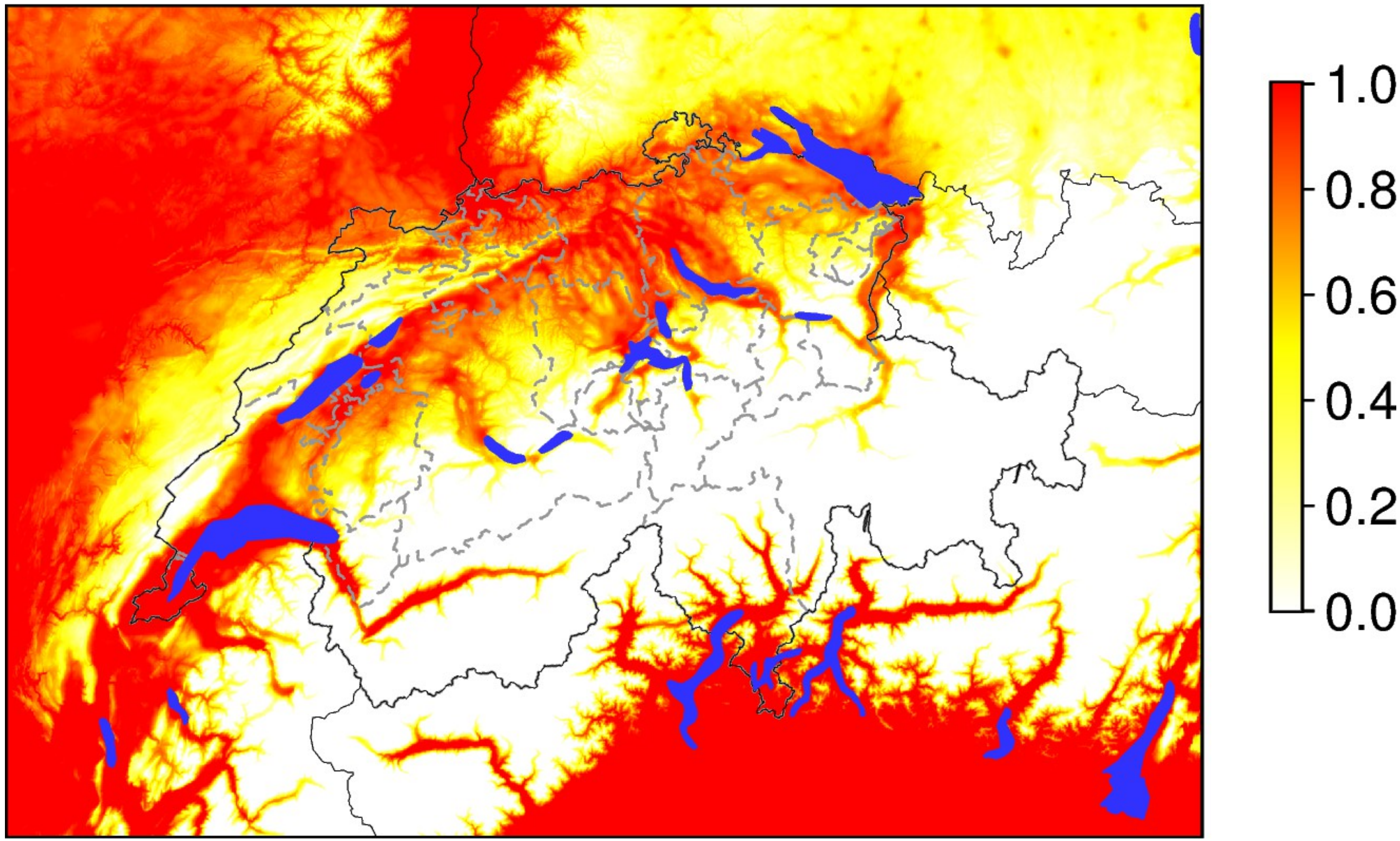
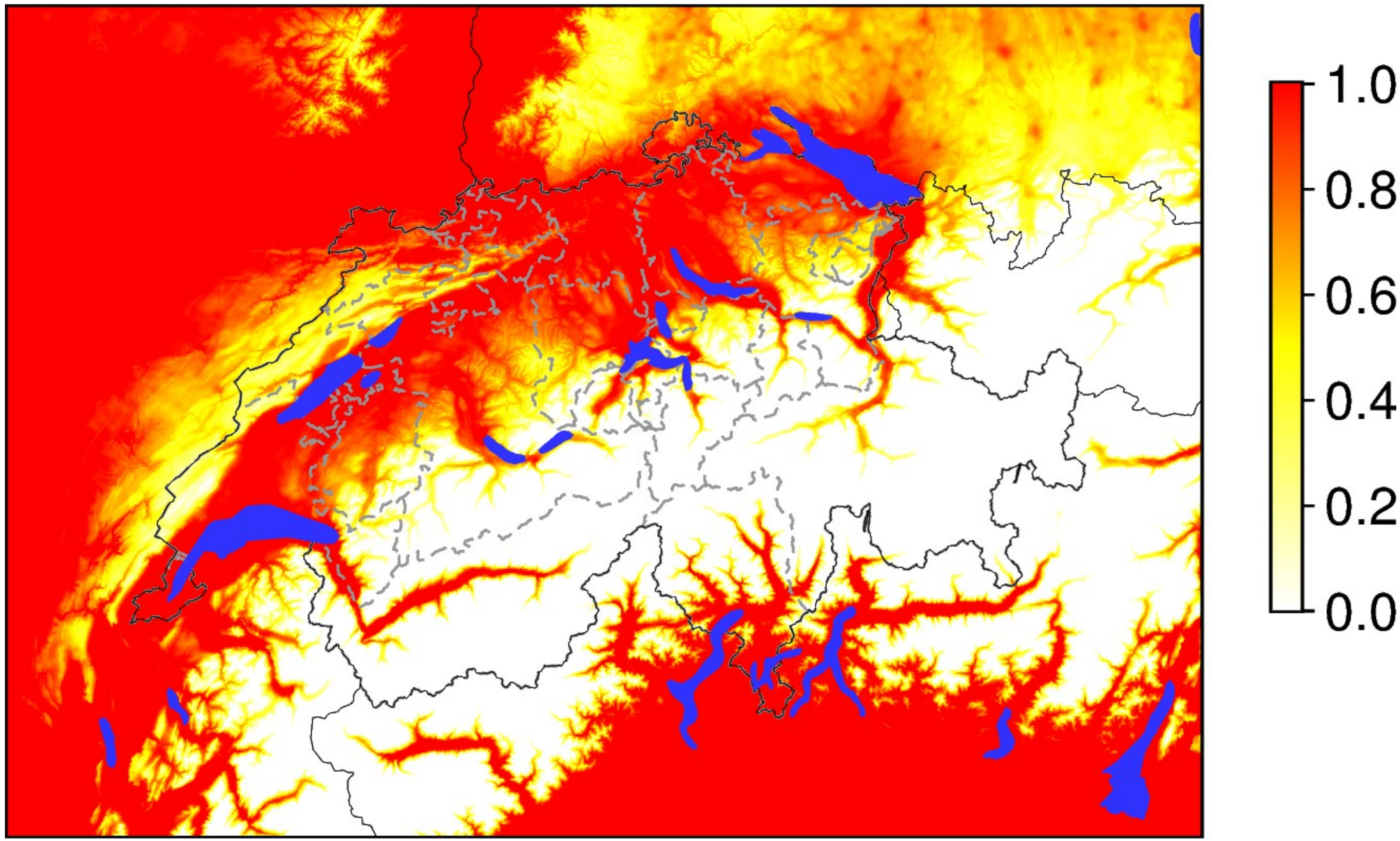


Adult suitability 2060 A1B upper



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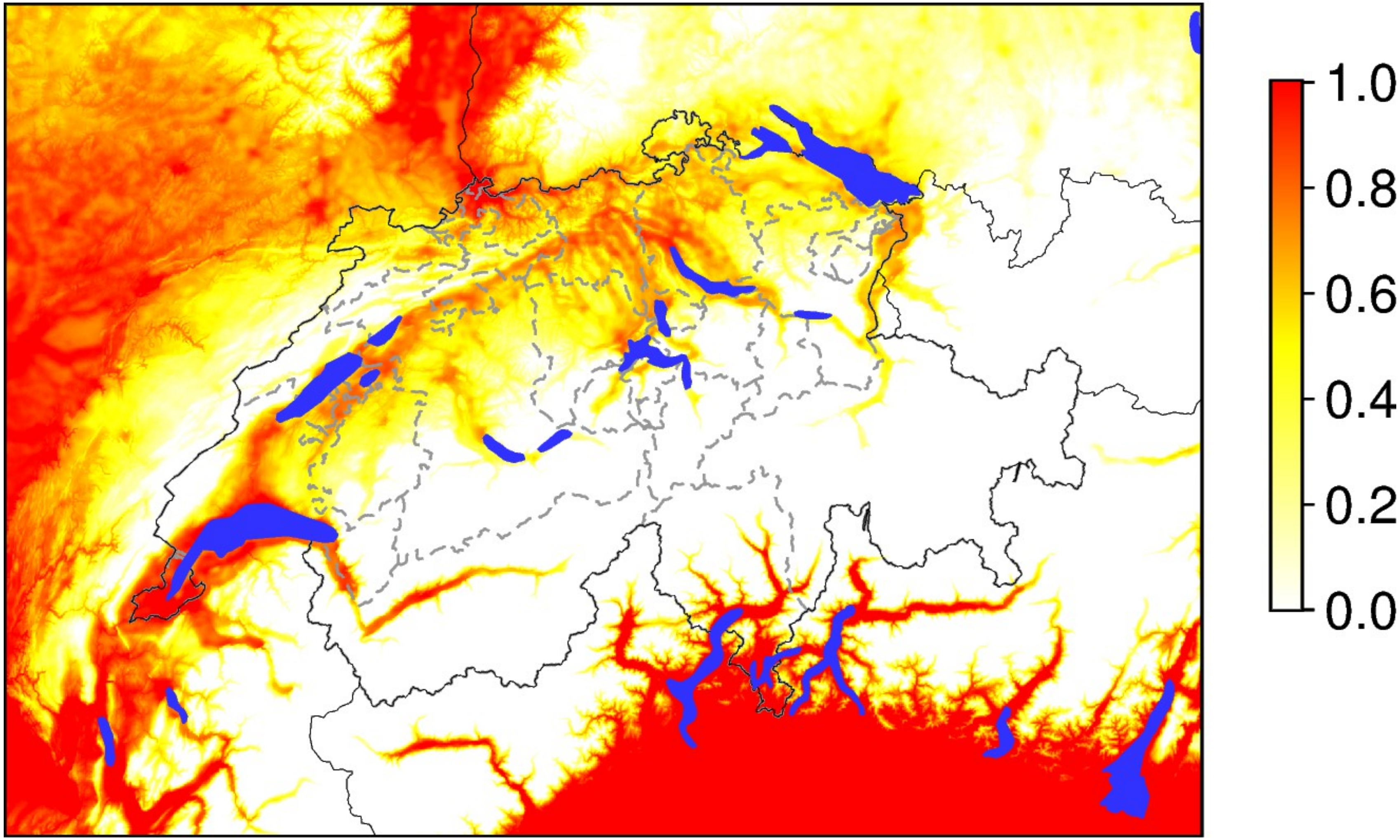

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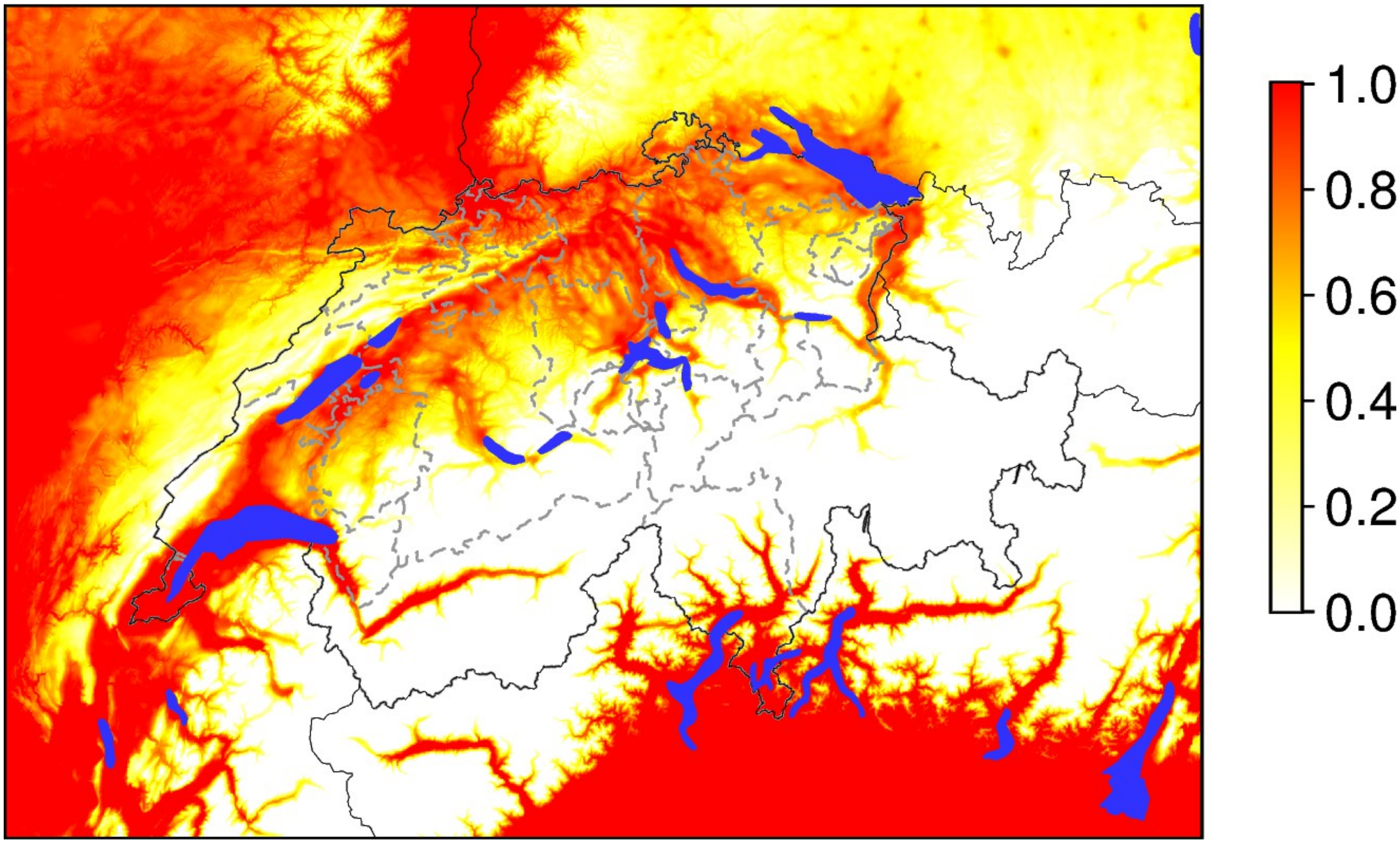

Adult suitability 2060 A2 upper