Worldwide niche and future potential distribution of *Culicoides imicola*, a major vector of bluetongue and African horse sickness viruses: SUPPORTING INFORMATION

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Appendix S1: Database of insect distribution and references

Appendix S2: Model development

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Appendix S1: Database of insect distribution and references

A geo-database of 1 381 occurrences of *Culicoides imicola*, covering 1959 to 2010, South Africa to North Europe and East Africa to China was compiled from 74 references (Table SI1). *Culicoides imicola* is part of an Imicola complex along with 10 other formally described species [1–3]. *Culicoides imicola* was firstly described in Kenya (Kieffer, 1913) and several names were eventually raised to synonymy [4]: *C. pallidipennis* (Carter et al., 1920), *C. iraqensis* (Khalaf, 1957) , *C. minutus* (Das Gupta, 1962) and *C. pseudoturgidus* (Sen and Das Gupta, 1959). The *C. imicola* taxon is well described [5,6]. In the present study, occurrences published under one of these synonymic names were subsequently named *C. imicola*.

Geographical coordinates were derived from published coordinates, locality coordinates (654 data), or maps (727 data). In the latter case, maps were imported as digital scans in ArcGIS software and georeferenced. We subsequently up-scaled the data at 10' granularity using CliMond's spatial grid [7], resulting in a geo-database of 879 distinct cells where the insect has been recorded. When several occurrences were recorded in a single 10’ cell, one record only was kept ensuring consistent resolution with climate data and removing duplicate records published several times.

Table SI1: Reported presence of *Culicoides imicola* extracted from publications on a country basis.

Country	**Number of occurrences**	**Reference**
Algeria	12	[Delécolle, unpublished data,2,3]
Angola	3	[10]
Bahrain	1	[11]
Botswana	2	[12,13]
Cape Verde	1	[14]
Chad	1	[15]
China	1	[16]
Congo	3	[17–19]
Egypt	4	[20,15]
Ethiopia	1	[15]
France	25	[8,21]
France (Reunion Island)	17	[22]
Gambia	4	[18,15]
Ghana	1	[15]
Greece	40	[23,24,8,25]
Burkina Faso	1	[26]
India	4	[27]

Country	Number of occurrences	Reference
Iran	1	[28]
Iraq	1	[12]
Israel	45	[29–32,23,15,24]
Italy	510	[33,34,8,35,36]
Kenya	54	[37,38,15,39,40]
Laos	2	[41,42]
Lesotho	1	[43]
Madagascar	2	[44,45]
Malawi	2	[12]
Mauritius	3	[46,15]
Morocco	29	[47,48,8]
Namibia	1	[12]
Nigeria	5	[18,15,49,50]
Oman	4	[11]
Portugal	85	[51,52,23,24,8,53]
Saudi Arabia	15	[54,11,55]
Senegal	6	[26]
Sicily	8	[8]
South Africa	120	[56,23,57–59,12,60,24,45,61,62,43]
Spain	283	[63–66,8,67–69,53,70]
Sudan	4	[71,72]
Sultanate of Oman	6	[73][73,74]
Swaziland	1	[12]
Switzerland	1	[75]
Tanzania	2	[39]
Thailand	13	[42]
Tunisia	10	[76,77,8]
Turkey	22	[78,8]
Uganda	2	[39]
United Arab Emirates	2	[11,8]
Vietnam	1	[42]
Yemen	4	[11]
Zimbabwe	15	[79,15,80]

Appendix S2: Model development

Parameters of temperature, soil moisture and cold stress indexes (Figure SI1) were adjusted from initial values to match modelled survival (*ie.* positive EI) with reported occurrences.

The model was firstly developed only on training dataset, and then tested on verification dataset and finally tested using the validation dataset (Figure 1). At each step the goodness of fit and sensitivity were evaluated following Anderson *et al*. [81] and Webber *et al*. [82] (Table SI2).

Training dataset

Fitted on *C. imicola*'s distribution, the Ecoclimatic Index (EI) of the "immature" CLIMEX model matched 178 occurrences of the 187 occurrences for the training dataset. The unfitted occurrences located in South Africa, Sudan and Ethiopia (respectively 6, 2 and 1 data) were located in arid areas, *ie.* aridity index below 0.2 [83,84], apparently under irrigation (Figure SI2a). These outliers fall in areas that according to Google Earth have irrigation activities (circular green structures or green patchwork against a brown background matrix) in areas with extremely little rainfall. We added an irrigation component based on the presence of irrigation equipments [85,86] to reflect impact of human activity of irrigation on microclimate (Figure SI2a). With an irrigation component the model fitted the entire 187 occurrences of the training dataset (Figure SI2b).

Culicoides imicola is widespread in the training zone (covering the native range) and the model sensitivity was significant given a high prevalence value (Table SI2). To test it, the immature model was then projected on the verification area.

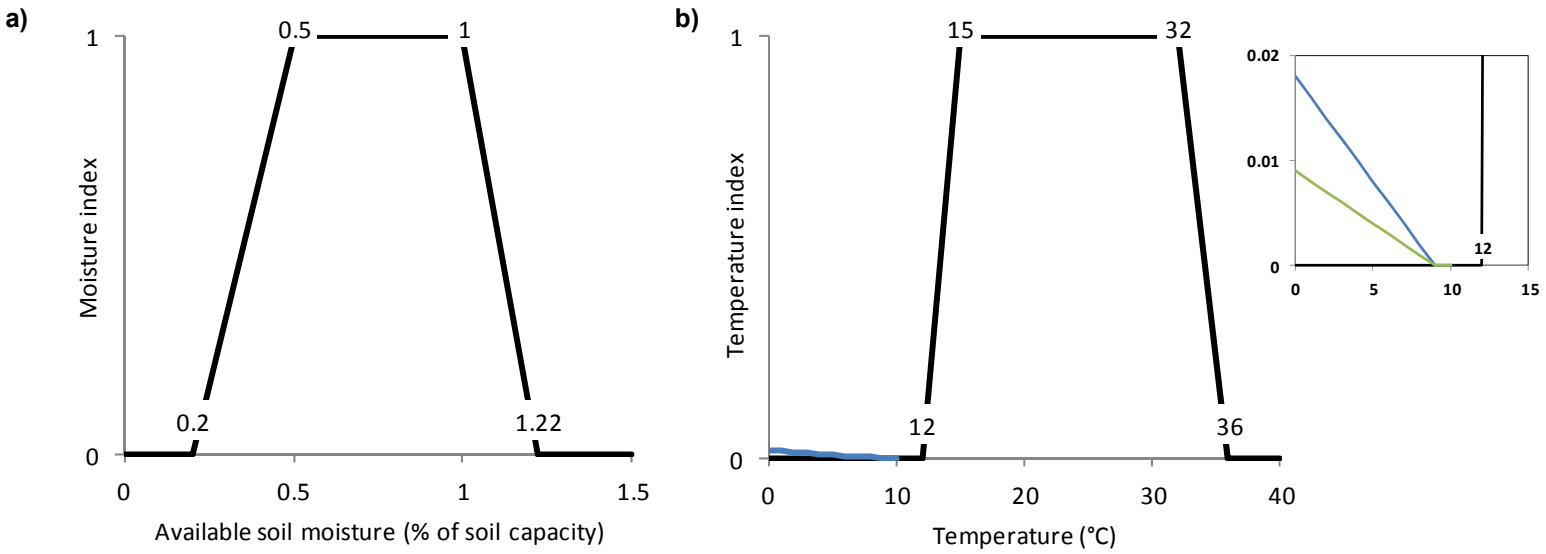


Figure SI1: CLIMEX parameters. a) soil moisture index, b) temperature index, insert: cold stress for the immature model (blue line) and for the completed model (green line)

Table SI2: Goodness of fit and sensitivity score for the different models using independent datasets. †: areas and occurrences of *Culicoides imicola* are expressed at 10' by 10' granularity. **: p-value<0.01.

Dataset	Extent (occurrences)†	Model	Suitable area†	True positive†	False negative†	Modelled prevalence, *ie.* chance expectation	Sensitivity score [confidence interval]
Training	60958 (187)	Immature	53867	178	9	0.88	0.95** [0.910 ; 0.977]
		Immature + irrigation	54532	187	0	0.89	1.00** [0.980; 1.000]
Verification	74897 (131)	Definitive	25895	105	26	0.35	0.80** [0.722 ; 0.866]
		Definitive + irrigation	30572	129	2	0.41	0.98** [0.945 ; 0.998]
Validation	21217 (561)	Definitive	5950	550	11	0.28	0.98** [0.965 ; 0.990]
		Definitive + irrigation	6713	555	6	0.32	0.99** [0.976 ; 0.996]

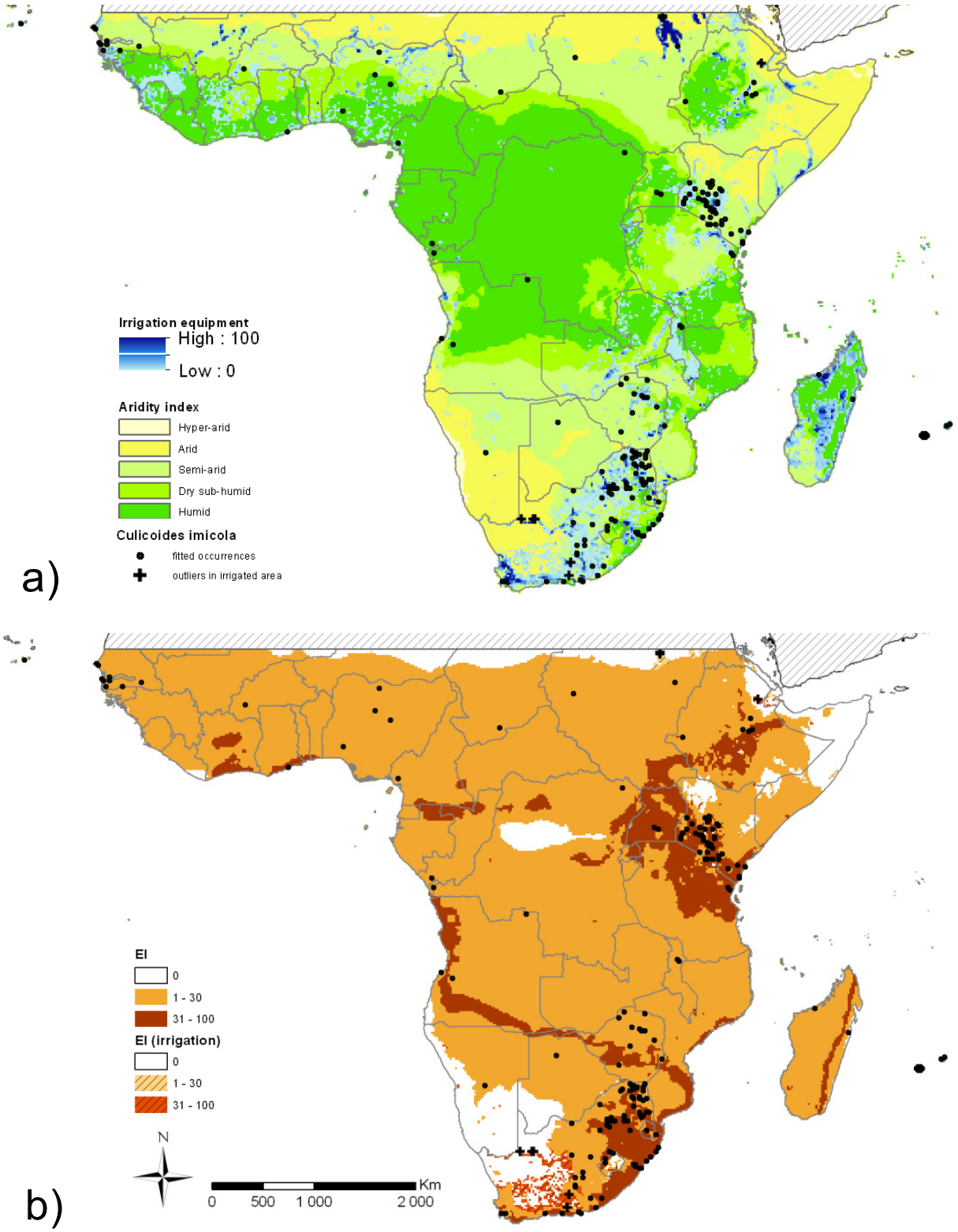


Figure SI2: Adjustment of the "immature" model in sub-Saharan Africa. a) Distribution of *Culicoides imicola*' occurrences (dots and crosses representing 187 cells at 10' resolution), presence of irrigation equipment [85,86] and aridity index [83,84] for the training zone. b) Ecoclimatic Index (EI) ranging from unsuitable (EI=0) to optimal (EI between 31 and 100) of the immature model only or with irrigation component (hatched).

Verification dataset

The projection of the immature model is shown in Figure SI3a with 5 unfitted locations highlighted with red crosses versus 126 locations correctly modelled as suitable (black symbols). All the 19 grid cells from the verification dataset located in equatorial climate (points located in China, Thailand, India and Vietnam; Figure 1) were modelled as suitable. For the 3 unfitted points located in Greece, the survival was limited by cold stress and subsequently we adjusted it by slightly reducing the impact of cold stress (parameter change in the insert of Figure SI1, completed model in Figure SI3b). The other 2 unfitted occurrences were located in the Arabian Peninsula, areas experiencing an arid climate (Figure SI3a) but where there was no evidence of irrigation to explain the presence of the insect at these locations whereas the irrigation scenario correctly reclassified 24 outliers from Egypt to the Sultanate of Oman (black crosses in Figure SI3).

The goodness of fit of the completed model is high given a small prevalence value of the verification dataset (Table SI2).

Validation dataset

The strength of our model was confirmed after projection in the validation area where the sensitivity score was also close to 1 given a prevalence value around 0.3 (Table SI2). Only 6 locations remained unfitted (highlighted by red crosses in Figure SI4) out of 561 occurrences in total. One unfitted occurrence was located in Algeria in a 10' grid cell where there was no evidence of irrigation (Figure SI4a). Four other unfitted points were located in Spain and Italy at the fringe of the suitable area which could be explained by local dispersion of the insect. The last unfitted occurrence represented the capture of one *C. imicola* in a single trap in Switzerland [75], probably the result of a rare event of long distance dispersal. The figure SI4b also highlights 10' cells in which only absences of *C. imicola* were reported [47,48,75,63,51,52,87,76,34,65,66,69,88,89,70,9,21] and illustrates the sampling effort in Europe. The European and North African absence data must be interpreted in the context of an active biological invasion. This means that some of the apparent absences may be suitable for *C.*

imicola but have not yet trapped this species due to an invasion lag or the existence of an unsuitable non-climatic habitat factor [90]. Without additional information, it is impossible to distinguish such locations from those that are climatically unsuitable. The difference between the modelled potential distribution and observed distribution is discussed in the main manuscript.

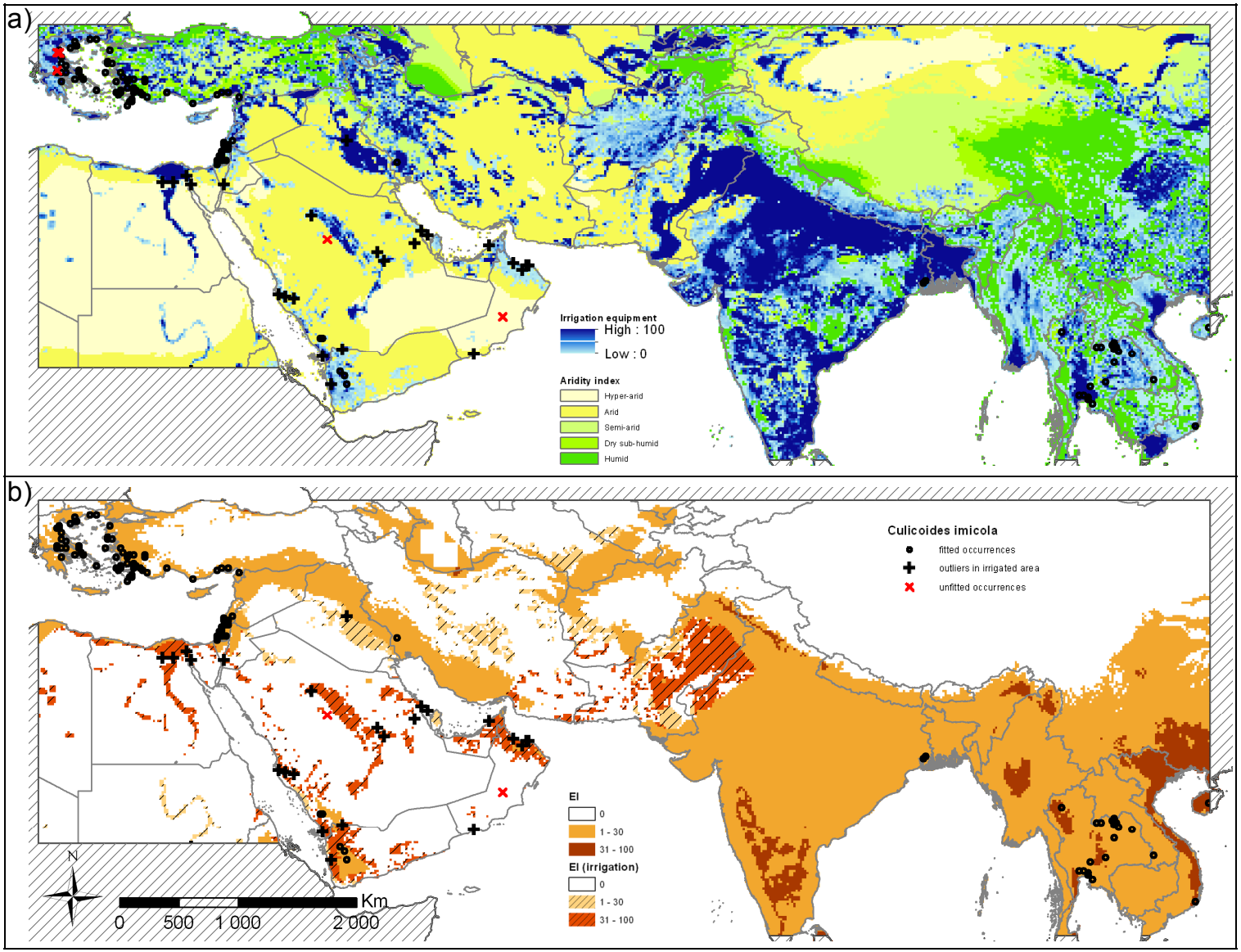


Figure SI3: Verification step in the modelling process. Distribution of *Culicoides imicola'* occurrences (10'-grid cells represented by dots and crosses, 131 occurrences in total). a) representation of fitted occurrences for the immature model only (black dots, n=105) and with an irrigation component (black dots and black crosses, n=126) for the verification zone. Unfitted occurrences are represented by red crosses (n=5 with 3 occurrences in Greece). Background highlighted irrigation equipment and aridity index. b) Ecoclimatic index (EI) ranging from unsuitable (EI=0) to optimal (EI between 31 and 100) of the completed model only or with irrigation component (hatched). Tuning the cold stress index (Figure SI1b) allowed the three previously unfitted occurrences in Greece (Figure SI3a) with the so-called completed model to be fitted correctly.

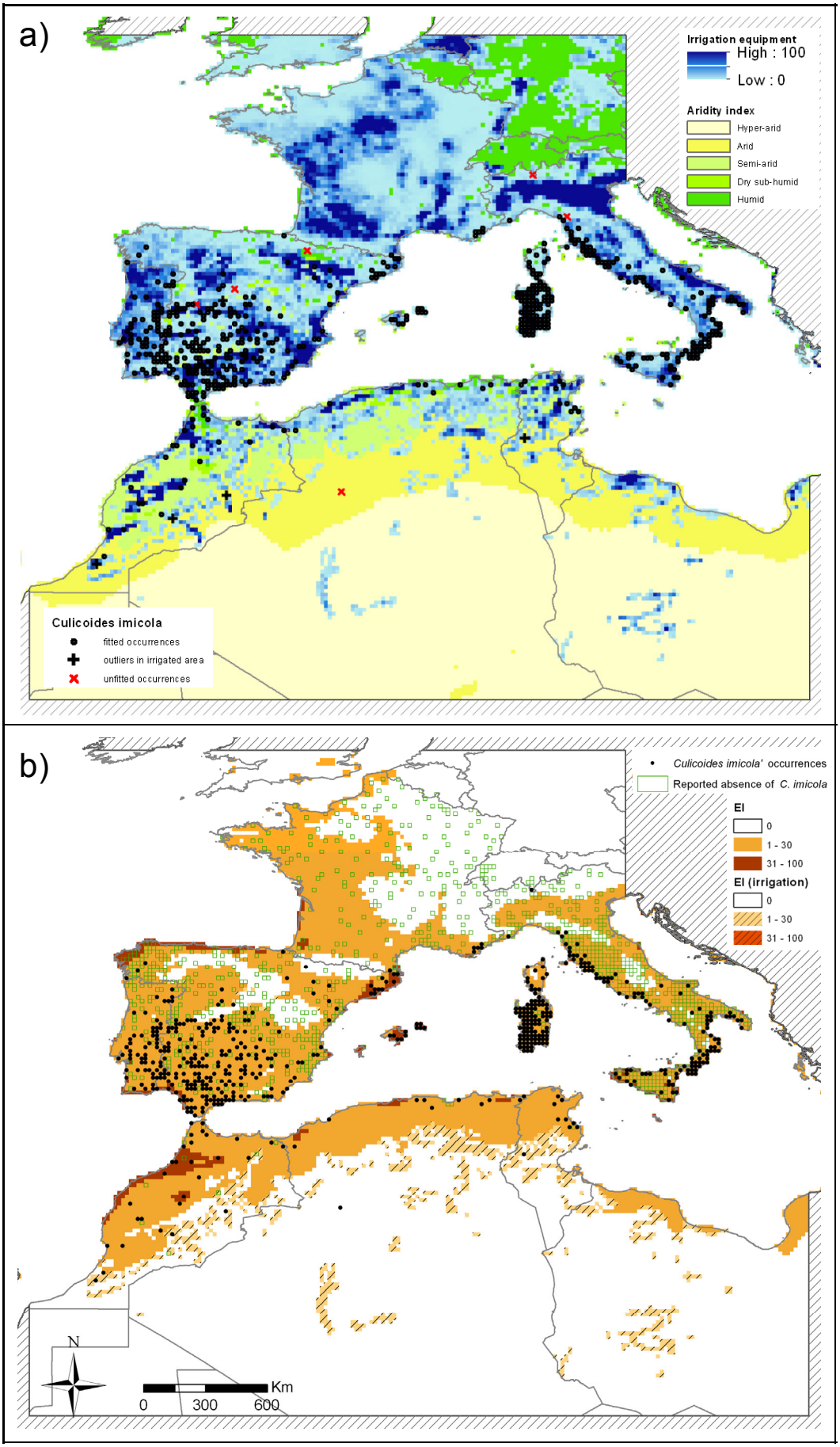
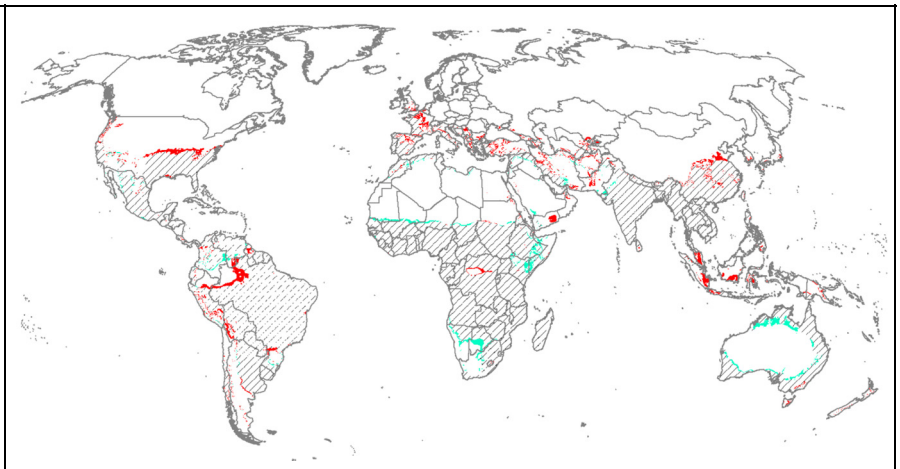
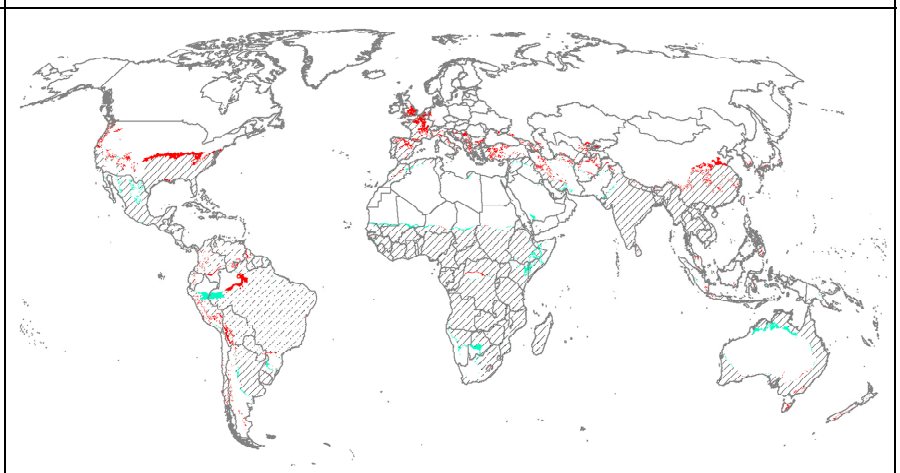
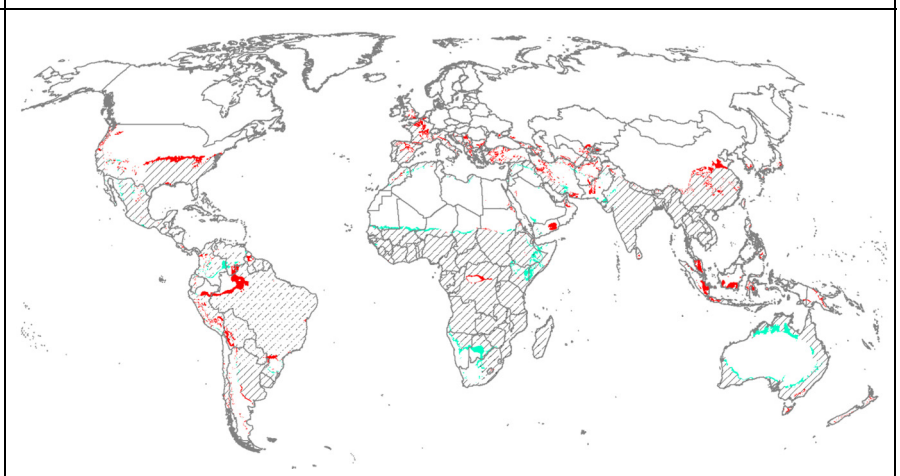
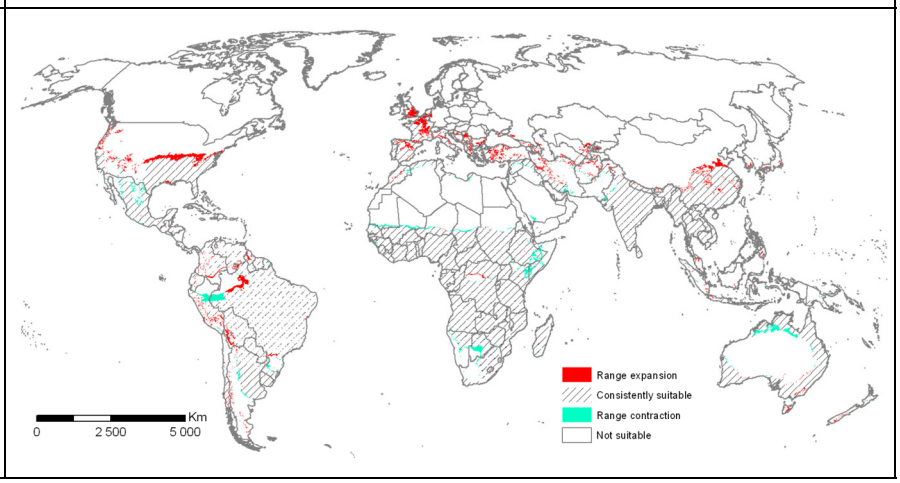


Figure SI4: Climate suitability for *Culicoides imicola* under historical conditions as represented by the CLIMEX Ecoclimatic Index for the completed model across the validation extent. a) Black crosses and dots indicated a suitable Eco-climatic Index at locations where *C. imicola* has been trapped for CLIMEX models respectively with irrigation component or without, and red crosses indicated positive *C. imicola* trap catches with a modelled unsuitable climate. Background highlighted irrigation equipment and aridity index. b) Ecoclimatic index (EI) ranging from unsuitable (EI=0) to optimal (EI between 31 and 100) of the completed model only or with irrigation component (hatched). Black dots represent trap catches of *C. imicola* and green squares the reported absence of *C. imicola*

Appendix S3: Climate change scenario projections

2030 A2 CS	
2030 A2 MR	
2030 A1B CS	
2030 A1B MR	

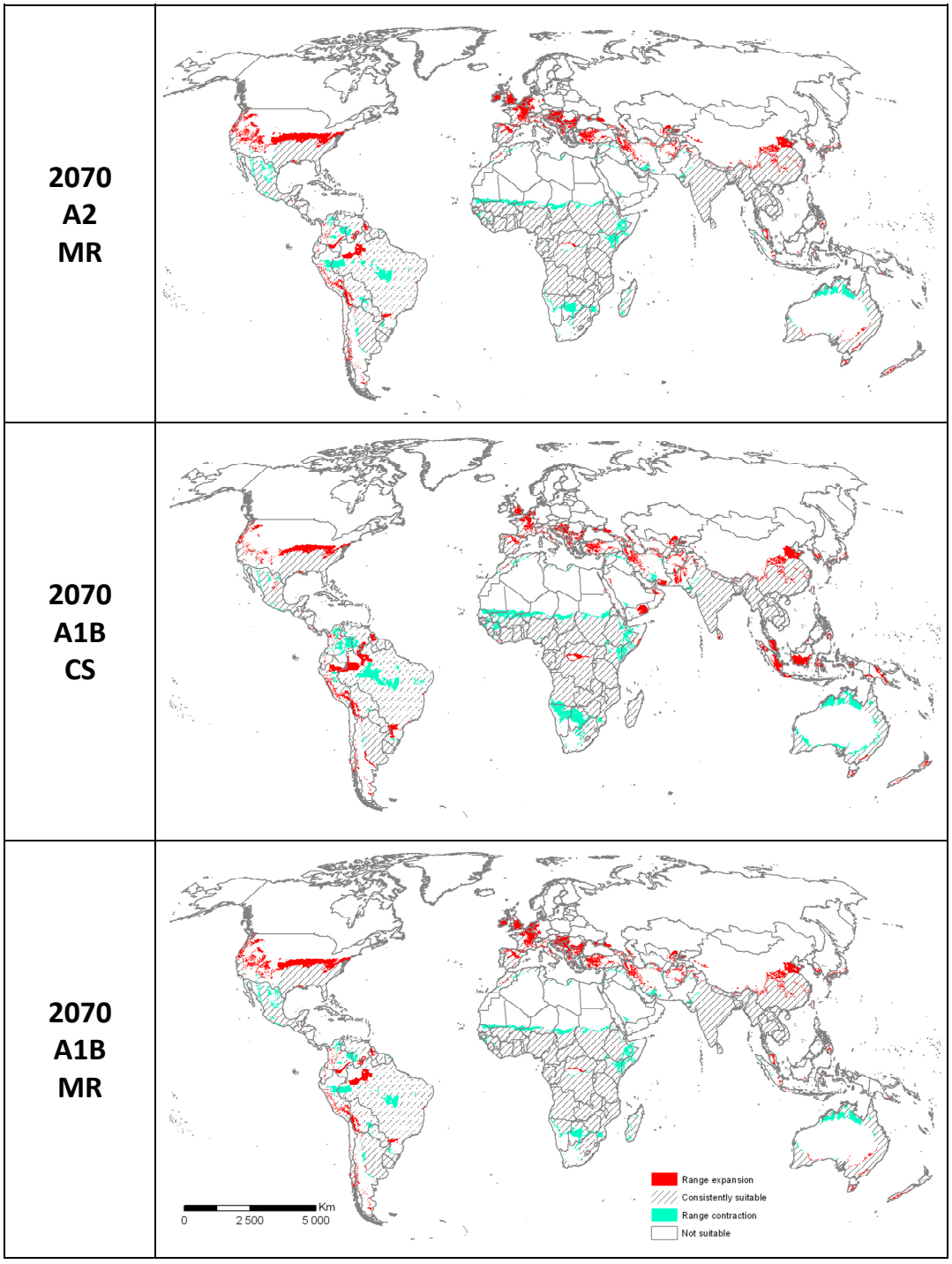
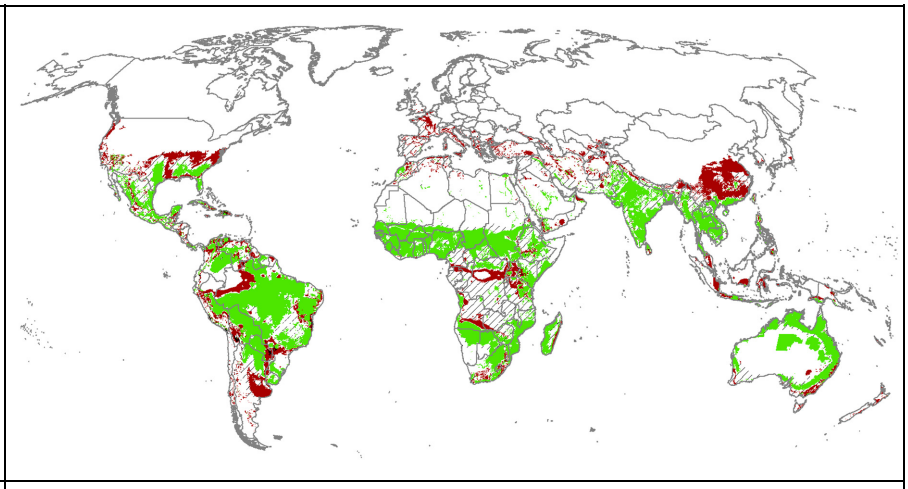
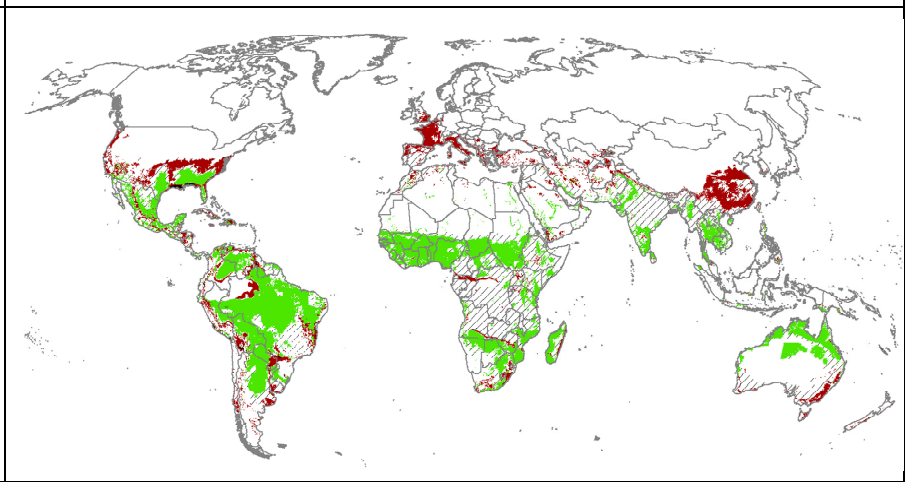
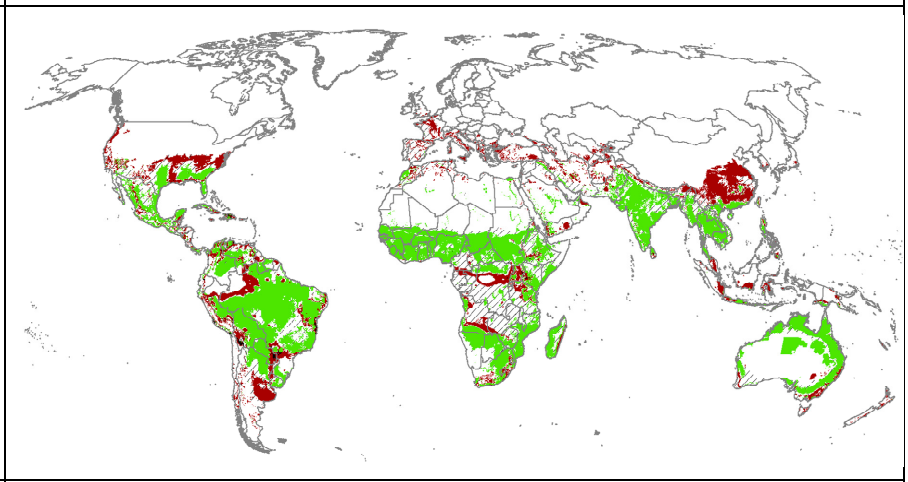
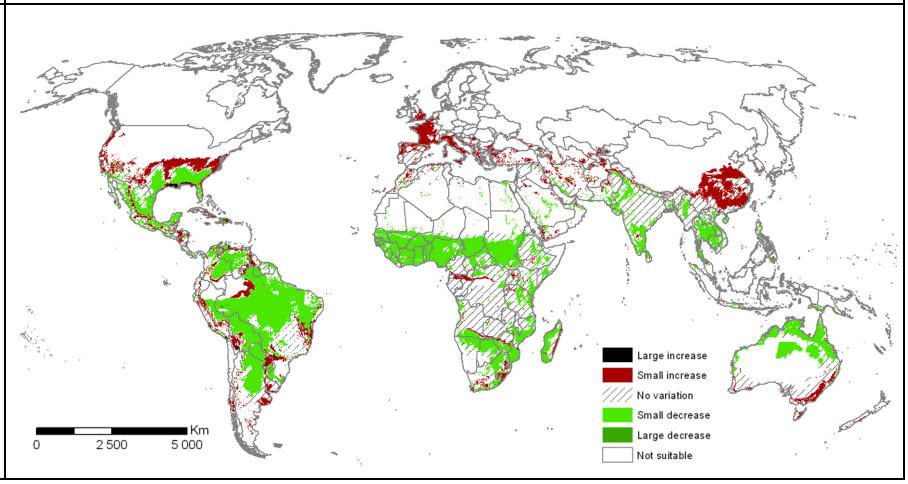


Figure SI5: Forecast variation of ecoclimatic suitability between historical climate (current EI) and 2030 or 2070 projected climate (future EI) from A1B or A2 climate scenarios using CSIRO-MK3.0 or Miroc-h climate models (respectively abbreviated as CS and MR). Qualitative variation highlighted the expansion (current EI=0, future EI>0) and the contraction (current EI>0, future EI=0) of suitable areas for the projection. The forecast of qualitative variation for 2070/A2/CS future climate was represented in Figure 3a.

2030 A2 CS	
2030 A2 MR	
2030 A1B CS	
2030 A1B MR	

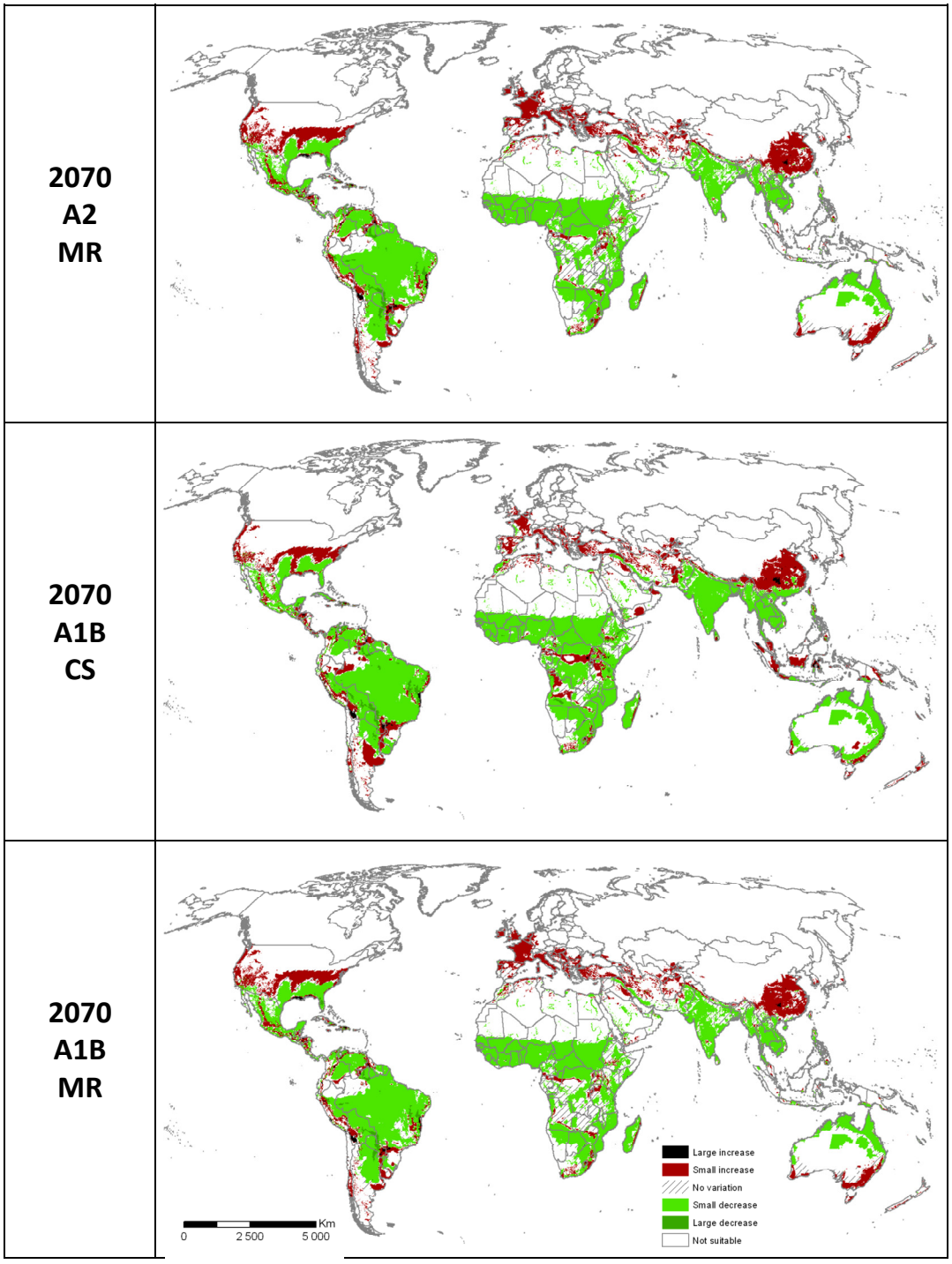


Figure SI6: Forecast variation of ecoclimatic suitability between historical climate (current EI) and 2030 or 2070 projected climate (future EI) from A1B or A2 climate scenarios using CSIRO-MK3.0 or Miroc-h climate models (respectively abbreviated as CS and MR). Quantitative variation illustrated climatic suitability increases or decreases. Small and large EI variations represented respectively differences in the range 3-30 and 31-100. The forecast of quantitative variation for 2070/A2/CS future climate is presented in Figure 3b.

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