Is Switzerland Suitable for the Invasion of *Aedes albopictus*?

Markus Neteler¹,², Markus Metz¹, Duccio Rocchini¹, Annapaola Rizzoli¹, Eleonora Flacio², Luca Engeler², Valeria Guidi³, Peter Lüthy²,⁴, Mauro Tonolla²,⁵

¹ Department of Biodiversity and Molecular Ecology, Research and Innovation Centre, Fondazione Edmund Mach, S. Michele all’Adige (TN), Italy, ² Mosquito Working Group, Department of Health, Canton Tessin, Bellinzona, Switzerland, ³ Regional Laboratory for Biosafety, Institute of Microbiology, Canton Tessin, Bellinzona, Switzerland, ⁴ Institute of Microbiology, ETH Zurich, Zurich, Switzerland, ⁵ Microbial Ecology Group, Microbiology Unit, Plant Biology Department, University of Geneva, Geneva, Switzerland

Abstract

**Background:** Over the last 30 years, the Asian tiger mosquito, *Aedes albopictus*, has rapidly spread around the world. The European distribution comprises the Mediterranean basin with a first appearance in Switzerland in 2003. Early identification of the most suitable areas in Switzerland allowing progressive invasion by this species is considered crucial to suggest adequate surveillance and control plans.

**Methodology/Principal Findings:** We identified the most suitable areas for invasion and establishment of *Ae. albopictus* in Switzerland. The potential distribution areas linked to the current climatic suitability were assessed using remotely sensed land surface temperature data recorded by the MODIS satellite sensors. Suitable areas for adult survival and overwintering of diapausing eggs were also identified for future climatic conditions, considering two different climate change scenarios (A1B, A2) for the periods 2020–2049 and 2045–2074. At present, the areas around Lake Geneva in western Switzerland provide suitable climatic conditions for *Ae. albopictus*. In northern Switzerland, parts of the Rhine valley, around Lake Constance, as well as the surroundings of Lake Neuchâtel, appear to be suitable for the survival at least of adult *Ae. albopictus*. However, these areas are characterized by winters currently being too cold for survival and development of diapausing eggs. In southern Switzerland, *Ae. albopictus* is already well-established, especially in the Canton of Ticino. For the years 2020–2049, the predicted possible spread of the tiger mosquito does not differ significantly from its potential current distribution. However, important expansions are obtained if the period is extended to the years 2045–2074, when *Ae. albopictus* may invade large new areas.

**Conclusions/Significance:** Several parts of Switzerland provide suitable climatic conditions for invasion and establishment of *Ae. albopictus*. The current distribution and rapid spread in other European countries suggest that the tiger mosquito will colonize new areas in Switzerland in the near future.

Citation: Neteler M, Metz M, Rocchini D, Rizzoli A, Flacio E, et al. (2013) Is Switzerland Suitable for the Invasion of *Aedes albopictus*? PLoS ONE 8(12): e82090. doi:10.1371/journal.pone.0082090

Editor: Stefano Merler, Fondazione Bruno Kessler, Italy

Received June 7, 2013; Accepted October 30, 2013; Published December 13, 2013

Copyright: © 2013 Neteler et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This study was financially supported by the Swiss Federal Office for the Environment (FOEN, http://www.bafu.admin.ch, Bern, Switzerland). It was also partially funded by the Autonomous Province of Trento (Italy), Research funds for Grandi Progetti, Project LExEM (Laboratory of excellence for epidemiology and modeling, http://www.lexem.eu). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* E-mail: markus.neteler@fmach.it

Introduction

*Aedes albopictus* (Skuse, 1894) (Diptera: Culicidae), the Asian tiger mosquito, is considered one of the most important invasive species world-wide [1]. In the last 30 years, it has been introduced to the USA, Europe, Africa, and the Indo-Pacific region [2] mainly through international trade of used tires and the import of lucky bamboo (*Dracaena sanderiana*). From the original points of entry *Ae. albopictus* has usually been spread passively by road traffic [1]. As an efficient vector of at least 26 arboviruses [2], including dengue, and Chikungunya, *Ae. albopictus* is considered a major risk to public health in Europe [1]. The tiger mosquito is firmly established in several countries bordering the Mediterranean, including Spain, France, Italy, Croatia and Greece [3]. Key populations of *Ae. albopictus* exist in the Netherlands, especially in greenhouse nurseries which serve as points of entry for imports of lucky bamboo plants from Asia.

*Ae. albopictus* was the vector responsible for a Chikungunya fever outbreak in the province of Ravenna (Italy) in 2007 [4] as well as single cases in France in 2010 [5]. Autochthonous cases of Dengue were registered in France and Croatia in 2010 [6,7]. In Switzerland, *Ae. albopictus* was recorded for the first time in summer 2003, in the Canton of Ticino [8,9] within a monitoring program started in 2000 by the local Mosquito Working Group (Gruppo Lavoro Zanzare, Canton of Ticino) [10]. Efforts to control and eliminate *Ae. albopictus* from the Swiss territory were unsuccessful. In 2007 it became firmly established in urban areas bordering Italy and started to expand towards northwards [10]. At the end of 2012, a total of 50 communities were reported to be infested by *Ae. albopictus* (Fig. 1).
Distribution models for *Ae. albopictus* predict a further expansion in European countries, backed-up by general globalization, and especially climatic changes, increasing public health risks [11,3,12,13]. In order to early identify the most suitable control options for timely prevention and control of *Ae. albopictus*, it is necessary to identify and predict which are the most suitable areas for its potential introduction and establishment.

The spatial distribution and colonization of new areas by *Ae. albopictus* depend on several environmental parameters, such as winter and summer temperatures, and precipitation patterns. *Ae. albopictus* is known to be sensitive to low temperature [14,11,15], especially for overwintering. As shown previously [13,16,17], January mean temperature can be used as a threshold to estimate the survival chances of overwintering diapausing eggs, whereas the annual mean temperature can be used as a threshold to estimate population stability. The suitability of an area to the survival of *Ae. albopictus* populations can also be determined by growing degree days (GDD) derived from temperature time series [16]. Growing degree days are defined as the degrees exceeding a given threshold (11°C for *Ae. albopictus*) accumulated for all days in a given year [14]. Furthermore, *Ae. albopictus* can not survive in arid areas; 500 mm precipitation per annum is considered the minimum threshold value [18,19]. Many areas in Europe receive sufficient precipitation for *Ae. albopictus* to survive, including Switzerland, with mean annual precipitation ranging from 840 mm to 1,900 mm [European Climate Assessment and Dataset (ECA&D), http://www.ecad.eu/, [20]]. Here we use the same environmental limits as established and used in previous studies [13,14,11,16,17]. For a detailed comparison of the different approaches refer to [21].

In order to predict the possible spread of the tiger mosquito it is crucial to consider the current climatic conditions and expected future scenarios. In fact, even the more optimistic climate scenarios predict that mean annual temperatures increasing over the next few decades across the country [22]. This predicted climatic change may lead to an increase in the spatial distribution of *Ae. albopictus*. The aim of this study was to identify the most suitable areas in Switzerland for the invasion and establishment of *Ae. albopictus* considering both current and future climate conditions. To assess the potential distribution areas, two different climate change scenarios for Switzerland for the periods 2020–2049 and 2045–2074 were considered.

**Materials and Methods**

**Study Area**

The study area comprises the entire territory of Switzerland (between 45° N and 48° N latitude, 5° E and 11° E longitude; see Fig. 1). The overall area of approximately 41,300 km² is characterized by a great diversity of landscapes and climates. The country is topographically divided in three main regions: the Jura Mountains, the Swiss Plateau and the Alps. The majority of the territory (60%) is occupied by the Alps, and the population (about 8 million people) lives mainly on the Swiss Plateau. In general, the Swiss climate can be considered as temperate, but it
can vary considerably between regions because the Alps act as a climate barrier between northern and southern Switzerland. In addition, the Mediterranean Sea influences the climate of southern Switzerland, characterized by much milder winters than the northern part of the country.

Data Sources for Current Conditions

A general problem in spatial modeling with environmental and meteorological variables is the uneven distribution of meteorological stations, which is particularly problematic for a complex terrain such as that characteristic for Switzerland. An alternative to meteorological stations is remote sensing which can obtain temperature time series with a high spatial resolution. A sensor especially designed for this kind of environmental monitoring is MODIS (Moderate Resolution Imaging Spectroradiometer) on board the satellites Terra and Aqua [16]. For MODIS on Terra, data are available from March 2000 onwards; for MODIS on Aqua, data are available from July 2002 onwards. Land Surface Temperature (LST) from MODIS is captured with four records per day, at approximately 1:30 am, 10:30 am, 1:30 pm, and 10:30 pm local time (Greenwich Mean Time +1:00). After a short processing time of one week after image acquisition, the MODIS products are provided to the public free of charge. The spatial resolution of the MODIS LST products is 1,000 m, allowing for a detailed analysis on national and regional level. With a temporal resolution of 4 values per day and spatial resolution of 1000 m, this dataset is well suited for a spatialized risk assessment of *Ae. albopictus*. Gridded datasets derived from meteorological station records are usually only provided with a spatial resolution of 20 km or coarser [23,20]; this spatial resolution is not adequate for topographically complex terrain such as found in Switzerland.

Figure 2. Growing Degree Days and number of days over 11 °C at *Ae. albopictus* trapping sites. The number of Growing Degree Days (years 2009 and 2011) plotted against the number of days with at least 11 °C at trapping sites with absence/presence of *Ae. albopictus* in Canton of Ticino, Switzerland. The density function plots combine the absence and presence data for the respective years. doi:10.1371/journal.pone.0082090.g002
Accordingly, precipitation values were not considered in our establishment of the tiger mosquito (i.e. 500 mm/year \cite{18,19}).

The original data resolution is 0.25 degrees. The ECA&D (Climate Assessment and Dataset, http://www.ecad.eu/, \cite{20}) using the time series aggregation functions of GRASS GIS \cite{21} delivered as comma separated values (CSV) files with regional estimates (three regions: northeastern Switzerland (CHNE), western Switzerland (CHW), and Switzerland south of the Alps (CHS)) for projected future change for winter (DJF: December–February), spring (MAM: March–May), summer (JJA: June–August), and autumn (SON: September–November). The CH2011 data set consists of three parts: lower, medium and upper estimates of changes in temperature and precipitation relative to the reference period 1980–2009. Future conditions are available for three scenario periods (2020–2049, 2045–2074, 2070–2099), and the A1B, A2, and RCP3-PD emission scenarios. The A1B and A2 scenarios do not assume great efforts to limit or reduce climate change. The A1B scenario presumes a very rapid economic growth with the introduction of innovative and more efficient technologies, and equilibrium between fossil-intensive and no fossil energy sources. Depending on the season and region considered, the medium estimates of the A1B emission scenario foresee a warming of 0.9–1.4°C by the period 2020–2049, 2.0–2.9°C by 2045–2074, and 2.7–4.1°C by 2070–2099, as well as a decrease in summer mean precipitation by 10–17% by 2045–2074 and 18–24% by 2070–2099. The A2 emission scenario also includes an assumption about economic growth and technological progress, but at a slower rate and more heterogeneously. It predicts an increase in the seasonal mean temperature of 3.2–4.8°C by the end of the century (period 2070–2099) and a reduction in summer mean precipitations by 21–28%, depending on region. In contrast to A1B and A2 scenarios, the RCP3-PD emission scenario (peak and decline, also referred to as RCP2.6) presupposes the implementation of mitigation measures aiming at reducing the anthropogenic greenhouse gas emissions in the next decades, with a likely stabilization at an annual mean warming of 1.2–1.8°C and a summer drying of 8–10% by the end of the century (period 2070–2099) \cite{22}. In this study, we focused on the well known A1B and A2 scenarios and did not consider the more aggressive mitigation scenario RCP3-PD following \cite{27,28}.

### Data Sources for Future Conditions

Data on projected future temperature and precipitation regimes for Switzerland were obtained from the Swiss Climate Change Scenarios CH2011 (http://data.c2sm.ethz.ch/dataset/ch2011/seasonal_regional/download.html) \cite{22,26}. This data set is considered in our models.
central year 2060), using the seasonal and regional data tables for north-eastern, western, and southern Switzerland, respectively, following the spatial division of the Swiss Climate Change Scenarios (CH2011).

Software

The explicit use of Free and Open Source Software (FOSS) conforms with the scientific principles of reproducibility and transparency [29], particularly for ecological and environmental modeling. For this project, spatial data processing was performed with the open source software packages GRASS GIS [http://
Aedes albopictus Suitability

Temperature thresholds for *Ae. albopictus* survival and establishment were based on [14], [30] and [13]. As in [13], a gradient of suitability was used instead of a simplified yes/no classification. The threshold for survival probability of adults was set to 11°C at the 1st September, with a margin of one month. Totally unsuitable conditions were thus defined if 1,350 GDDs were reached only after day 274 of the year (October 1st), and totally suitable conditions if 1,350 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 1,350 GDDs were reached after October 1st, all areas to 1.0 where 1,350 GDDs were reached before August 1st, and areas where 1,350 GDDs were reached between August 1st and October 1st were linearly scaled with (274 - day of year)/60. A statistical assessment using data for 2009 and 2011 (the year 2010 was unusually cold; pers. comm. Meteoswiss) following [14,16] with trap data from Ticino confirmed that the threshold of 1,350 GDDs proposed in these studies is also appropriate for this canton. Figure 2 shows GDD plotted against the number of days over 11°C at the *Ae. albopictus* trapping sites in Canton Ticino, Switzerland (absence/presence of *Ae. albopictus*; years 2009 and 2011). For the years 2009 and 2011 the absence and presence data were combined to estimate a density function indicating the separation of absence and presence at the GDD threshold of 1,350 GDD as described in earlier publications.

The suitability analysis for the current conditions was performed for both the mean values over the years 2003–2011, and for 2011 only. Maps for adult suitability and overwintering suitability were also calculated using the A1B and A2 climate change scenarios for the period 2020–2049 and 2045–2074 on regional and seasonal level. The modeled deviation was then added to current conditions (the average over the years 2003 to 2011).

![Figure 5. Comparison of models for current habitat suitability.](image)

**Figure 5. Comparison of models for current habitat suitability.** In contrast to previously published approaches based on ECA&D, high resolution temperature data allow for the correct detection of areas suitable for *Ae. albopictus* in valleys. Dots in the maps for Canton Ticino indicate known presence of *Ae. albopictus*. doi:10.1371/journal.pone.0082090.g005

![Figure 6. Suitability indicators for *Ae. albopictus* in Switzerland.](image)

**Figure 6. Suitability indicators for *Ae. albopictus* in Switzerland.** The maps in the first column are based on averages for the years 2003–2011; the maps in the second column are based on temperature values for 2011 only. The coloring scheme shows the gradient of suitability, from 0.0 (unsuitable areas: white colored) to 1.0 (highly suitable areas: red colored). GDD: growing degree days filtered for days above 11°C. doi:10.1371/journal.pone.0082090.g006
Overall suitability for current and future conditions was estimated by calculating the mean of the separate suitability indicators according to [13].

Results and Discussion

The knowledge of a possible future spread of this mosquito species in areas not yet invaded and colonized is essential for implementing early prevention and control strategies.

Temperature is a significant parameter influencing the spatial distribution and population dynamics of *Ae. albopictus* [14,15], especially in mountainous areas [31]. We generated potential distribution maps for *Ae. albopictus* considering the current climate conditions of Switzerland as well as the available future climate change projections.

Results obtained indicate that in the near future and based on our current knowledge on the bionomics of the species in alpine environment, the area suitable for the Asian tiger mosquito will expand considerably (Fig. 3), enabling the mosquito to invade northern regions of the country. Compared to 2003–2011, the size of the suitable area is estimated as three times as large for 2020–2049 and twelve times as large for 2045–2074. The modeling of habitat suitability is dependent on the specific thresholds for the used parameters January temperature, annual temperature, and day of year when 1,350 GDDs are reached (Fig. 4). Modifying the threshold for January temperature would only result in substantial changes if the threshold value would be lowered below $-1^\circ$C. In contrast, lowering the threshold value for the annual temperature a few Kelvin would result in a substantial increase in the area regarded as suitable for this vector. Similarly, moving the threshold value when 1,350 GDDs are reached by about a week,
also results in a substantial increase in the area regarded as suitable for the Asian tiger mosquito.

The ability of diapausing eggs to survive the winter season is crucial for the establishment of new populations, allowing the populations’ persistence from one season to the next. This overwintering ability is related to the January mean temperature [32]. Considering the average temperature from 2003 to 2011, areas where *Ae. albopictus* encounters conditions for overwintering are the southern and central parts of the Canton of Ticino (Fig. 5), as well as areas near Lake Geneva (Fig. 6). Considering only temperatures of the year 2011, the potential distribution areas are wider including also marginally suitable sites within the Swiss Plateau (Fig. 6). The inability of diapausing eggs to survive the winter season in some regions, as the Rhône valley in the Wallis, reduces the risk of an establishment of tiger mosquito. This is consistent with other studies indicating that the dominant limiting factor for the survival and establishment of *Ae. albopictus* is the egg survival which is determined by January mean temperatures [16,17]. However, our predictions are currently based on available estimates of temperature thresholds. More detailed estimates based on field observation and laboratory experiments carried out under controlled conditions should be available soon (A. Rizzoli, pers comm.).

Adult survival is mainly determined by mean annual temperatures, with 11°C as the lower limit for population establishment [14]. Our results show that suitable areas for adult survival and for successful life cycle completion in Switzerland are less restricted than the overwintering areas. In northern Switzerland, parts of the Rhine valley, both upstream and downstream of Lake Constance, as well as areas surrounding Lake Neuchâtel appear to be suitable for adults of *Ae. albopictus*, but are currently too cold in winter for the survival of eggs. Highly suitable areas for adult mosquitoes are

---

**Figure 10. Suitability indicators for adult *Ae. albopictus* in Switzerland in 2060 (2045–2074).** The maps in the first column are based on temperature estimates for the climate changes scenario A1B, the maps in the second column are based on temperature estimates for the climate changes scenario A2. The coloring scheme shows the gradient of suitability, from 0.0 (unsuitable areas: white colored) to 1.0 (highly suitable areas: red colored).

doi:10.1371/journal.pone.0082090.g010

**Figure 11. Suitability indicators for overwintering of *Ae. albopictus* in Switzerland in 2060 (2045–2074).** The maps in the first column are based on temperature estimates for the climate changes scenario A1B, the maps in the second column are based on temperature estimates for the climate changes scenario A2. The coloring scheme shows the gradient of suitability, from 0.0 (unsuitable areas: white colored) to 1.0 (highly suitable areas: red colored).

doi:10.1371/journal.pone.0082090.g011

**Figure 12. Combined suitability indicators for *Ae. albopictus* in Switzerland in 2060 (2045–2074).** The maps in the first column are based on temperature estimates for the climate changes scenario A1B, the maps in the second column are based on temperature estimates for the climate changes scenario A2. The coloring scheme shows the gradient of suitability, from 0.0 (unsuitable areas: white colored) to 1.0 (highly suitable areas: red colored).

doi:10.1371/journal.pone.0082090.g012
the Canton of Geneva and areas surrounding Lake Léman, the main Rhône valley in the Canton of Wallis and the Canton of Ticino including the entire southern part, the region of Locarno, and the district of Riviera (Fig. 6).

According to our analyses of the potential expansion of *Ae. albopictus* considering the future Swiss climate scenarios, the areas identified as currently suitable for *Ae. albopictus* will expand, as presented in Figs. 7–12, which show the simulated lower, medium and upper estimates of changes in temperature. The predicted decline of precipitation (A1B and A2 climatic scenarios) of up to 20% still does not drop below 500 mm/year, the threshold under which the establishment of the tiger mosquito is prevented. The ECA&D data show a current minimum of annual precipitation of 840 mm/year for Switzerland. The temperature data show low to significant differences for future scenarios compared to the present day. For the years 2020–2049, the predicted possible spread of the tiger mosquito does not differ significantly from its potential current distribution (Figs. 3, 7, 8 and 9). However, important expansions are obtained if the period is extended to the years 2045–2074, when *Ae. albopictus* may invade large new areas (2003–2011: 840 mm²; A1B: 10,810 km²; A2: 10,420 km², see also Fig. 4). Highly suitable regions for adult survival in the period 2045–2074 will comprise the whole Swiss territory, except the Alpine regions, i.e. central Switzerland, lateral Wallis valleys, and the Canton of Graubünden (Fig. 10). However, a part from the Canton of Ticino and areas surrounding Lake Geneva, regions highly suitable for adult survival remain only marginally or moderately suitable for the overwintering of eggs (Fig. 11). The overwintering suitability is predicted to increase substantially in neighboring countries, particularly in France. These areas may in the future act as a source for further invasion of *Ae. albopictus*. In western Switzerland, the areas around Lake Geneva could be invaded soon from France through mosquitoes especially imported through road transport. Neighboring regions in Italy, where *Ae. albopictus* is widely distributed [33], also provide sources for the continuous introduction of this invasive species to southern Switzerland (Bernasconi 2010, pers. comm.). A major traffic axis of international transport connects Italy to the Canton of Ticino and hence to northern Switzerland. *Ae. albopictus* may thus reach northern areas of Switzerland along this important traffic artery. For example, adult specimens of *Ae. albopictus* were recently trapped in the Upper Rhine Valley in south-west Germany, in a rest area along the A5 highway entering Germany from Switzerland [34,35]. Some areas suitable for *Ae. albopictus* are at the same time characterized by a high density of humans, being relevant for the probability of observing an outbreak of diseases transmitted by *Ae. albopictus*. The canton Ticino has a mean population density of 119.8 humans/km²; the majority of the population resides in areas where the vector is established with the district of Mendrisio, near the Italian border, being the area with high density of mosquitoes and of human population (455.9 humans/km²). The canton of Geneva, an area where the mosquito is not yet established but which is at major risk of establishment, has a human population density of 1,633 humans/km² (base year 2012; source: http://www.ti.ch/ustat).

The areas where *Ae. albopictus* is currently present in Switzerland (Fig. 1) are in line or in agreement with the highly suitable areas predicted by our models using current climate and environmental variables. Other studies modeling the possible spatial distribution of *Ae. albopictus* in Europe show similar data for Switzerland [12,13] despite the lower resolution compared to our models (Fig. 5). This is the first time that an accurate distribution model for *Ae. albopictus* has been established for Switzerland. High resolution distribution models based on LST data from satellites have also been successfully created for the tiger mosquito for the Province of Trento and other north-eastern regions of Italy [17,16].

In conclusion, various parts of Switzerland offer or will offer climatic conditions suitable for *Ae. albopictus*. Even though many potentially suitable areas are not yet invaded, the current distribution in Europe and the spread patterns suggest that the tiger mosquito might well appear in these areas within the next few years.

**Acknowledgments**

We gratefully acknowledge N. Patocchi from the “Fondazione Bolle di Magadino”, Switzerland, PD Dr. O. Petriini for scientific support, and the “Centro Sistemi Informativi”, Canton Tessin, for providing Swiss altimetry data. We thank Dr. Heidi C. Hauffe for her valuable comments on an earlier version of the manuscript. We are grateful to the NASA Land Processes Distributed Active Archive Center (LP DAAC) for making the MODIS LST data available. We acknowledge the E-OBIS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu).

**Author Contributions**

Conceived and designed the experiments: MM MM AR EF LE MT. Performed the experiments: MM MN DR EF LE PL VG MT. Contributed reagents/materials/analysis tools: MM MN EF LE PL VG MT DR AR. Wrote the paper: MN MM DR AR VG PL.
13. Caminade C, Medlock JM, Ducheyne E, McIntyre KM, Leach S, et al. (2012). Suitability of European climate for the Asian tiger mosquito Aedes albopictus: recent trends and future scenarios. J R Soc Interface 9: 2708–2717.

14. Kobayashi M, Nihei N, Kurihara T (2002) Analysis of northern distribution of Aedes albopictus (Diptera: Culicidae) in Japan by geographical information system. J Med Entomol 39: 34–41.

15. Delatte H, Gimonneau G, Triboire A, Fontenille D (2009). Influence of Temperature on Immature Development, Survival, Longevity, Fecundity, and Gonotrophic Cycles of Aedes albopictus, Vector of Chikungunya and Dengue in the Indian Ocean. J Med Entomol 46: 33–41.

16. Neteler M, Roiz D, Rocchini D, Castellani C, Rizzoli A (2011) Terra and Aqua satellites track tiger mosquito invasion: modeling the potential distribution of Aedes albopictus into new areas of Trentino, Northern Italy. Int J Heal Geogr 10: 49.

17. Roiz D, Neteler M, Castellani C, Arnoldi D, Rizzoli A (2011). Climatic factors driving invasion of the tiger mosquito (Aedes albopictus) into new areas of Trentino, Northern Italy. PLoS ONE 6: e14800.

18. Mitchell CJ (1995) Geographic spread of Aedes albopictus and potential for involvement in arbovirus cycles in the Mediterranean basin. J Vector Ecol 20: 44–58.

19. Eritja R, Escosa R, Lacientes J, Marques E, Roiz D, et al. (2005) Worldwide invasion of vector mosquitoes: present European distribution and challenges for Spain. Biol Invasions 7: 87–97.

20. Haylock MR, Hofstra N, Tank AMGK, Klok EJ, Jones PD, et al. (2008) A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. J Geophys Res - Atmospheres 113: D20119.

21. Fischer D, Thomas SM, Neteler M, Tjaden N, Beierkuhnlein C (in press). Climatic suitability of Aedes albopictus in Europe referring to climate change projections: Comparison of mechanistic and correlative niche modelling approaches. Euro Surveill Bull Eur Sur Mal Transm Eur Commun Dis Bull.

22. MeteoSwiss ETH, NCCR Climate, OcCC (2011) Swiss Climate Change Scenarios 2011. Available: http://www.ch2011.ch/pdf/CH2011summaryEN.pdf. Accessed 2013 Oct 23.

23. Mitchell TD, Jones PD (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int J Clim 25: 693–712.

24. Neteler M (2010). Spatio-temporal reconstruction of satellite-based temperature maps and their application to the prediction of tick and mosquito disease vector distribution in Northern Italy. PhD thesis, University of Hannover [PhD thesis]. Hannover, Germany: University of Hannover.

25. Neteler M, Bosman MH, Landla M, Metz M (2012). GRASS GIS: A multi-purpose open source GIS. Environ Model Softw 31: 124–130.

26. Fischer AM, Weigel AP, Buser CM, Knutti R, Künsch HR, et al. (2012) Climate change projections for Switzerland based on a Bayesian multi-model approach. Int J Clim 32: 2348–2371.

27. Van Vliet J, den Elzen MGJ, van Vuuren DP (2009) Meeting radiative forcing targets under delayed participation. Energy Econ 31, Supplement 2: S152–S162.

28. Mora C, Frazier AG, Longman RJ, Dacks RS, Walton MM, et al. (2013). The projected timing of climate departure from recent variability. Nature 502: 103–107.

29. Rocchini D, Neteler M (2012) Let the four freedoms paradigm apply to ecology. Trends Ecol Evol 27: 310–311.

30. Roiz D, Neteler M, Castellani C, Arnoldi D, Rizzoli A (2011). Climatic factors driving invasion of the tiger mosquito (Aedes albopictus) into new areas of Trentino, Northern Italy. PLoS ONE 6: e14800.

31. Roiz D, Rosà R, Arnoldi D, Rizzoli A (2010) Effects of temperature and rainfall on the activity and dynamics of host-seeking Aedes albopictus females in northern Italy. Vector Borne Zoonotic Dis 10: 811–816.

32. Hawley W (1988) The biology of Aedes albopictus. J Am Mosq Control Assoc Suppl 1: 1–39.

33. Romi R, Toma L, Severini F, Di Luca M (2008) Twenty years of the presence of Aedes albopictus in Italy—From the annoying pest mosquito to the real disease vector. Eur Infect Dis 2: 98–101.

34. Werner D, Krenfeld M, Schaflffer F, Kampen H (2012) Two invasive mosquito species, Aedes albopictus and Aedes japonicus japonicus, trapped in southwest Germany, July to August 2011. Euro Surveill Bull Eur Sur Mal Transm Eur Commun Dis Bull 17(4): pii = 20067.

35. Kampen H, Krenfeld M, Zieke D, Werner D (2013) Further specimens of the Asian tiger mosquito Aedes albopictus (Diptera, Culicidae) trapped in southwest Germany. Parasitol Res 112: 905–907.