Use of mapping and statistical modelling for the prediction of bluetongue occurrence in Switzerland based on vector biology

Vanessa Racloz[(1)], Patrick Presi[(1)], Penelope Vounatsou[(2)], Heinzpeter Schwermer[(1)], Simona Casati[(3)], Tullio Vanzetti[(3)], Christian Griot[(4)] & Katarina D.C. Stärk[(1)]

Summary

Due to the spread of bluetongue (BT) in Europe in the last decade, a sentinel surveillance programme was initiated for Switzerland in 2003, consisting of serological sampling of sentinel cattle tested for BT virus antibodies, as well as entomological trapping of *Culicoides* midges from June until October. The aim of this study was to create a 'suitability map' of Switzerland, indicating areas of potential disease occurrence based on the biological parameters of Obsoletus Complex habitat. Data on *Culicoides* catches from insect traps together with various environmental parameters were recorded and analysed. A multiple regression analysis was performed to determine correlation between the environmental conditions and vector abundance. Meteorological data were collected from 50 geo-referenced weather stations across Switzerland and maps of temperature, precipitation and altitude were created. A range of values of temperature, precipitation and altitude influencing vector biology were obtained from the literature. The final combined map highlighted areas in Switzerland which are most suitable for vector presence, hence implying a higher probability of disease occurrence given the presence of susceptible animals. The results confirmed the need for an early warning system for the surveillance of BT disease and its vectors in Switzerland.

Keywords

Bluetongue, *Culicoides*, Geographic information system, Map, Sentinel surveillance, Vector biology.

Utilizzo della mappatura e della costruzione di modelli statistici per prevedere la comparsa della bluetongue in Svizzera basandosi sulla biologia dei vettori

Riassunto

In seguito alla diffusione della bluetongue (BT) in Europa nell'ultima decade, in Svizzera nel 2003, è stato avviato un programma di sorveglianza che consiste nel campionamento di bovini sentinella, il cui siero viene testato per la ricerca di anticorpi contro il virus della BT contemporaneamente all'utilizzo di trappole entomologiche per la cattura di Culicoides *attive da giugno ad ottobre. Scopo di questo studio è stato creare una "mappa di idoneità" del territorio della Svizzera, basata sui parametri biologici dell'habitat dell' Obsoletus Complex, che individui le aree di potenziale comparsa della malattia. Sono stati registrati e analizzati i dati relativi alle catture dei* Culicoides

(1) Federal Veterinary Office, Schwarzenburgstrasse 155, 3003 Bern, Switzerland
vanessa.racloz@bvet.admin.ch
(2) Swiss Tropical Institute, Socinstrasse 57, 4002 Basel, Switzerland
(3) Cantonal Veterinary Office, via Dogana 16 , 6501 Bellinzona, Switzerland
(4) Institute of Virology and Immunoprophylaxis, Sensemattstrasse 293, 3147 Mittelhäusern, Switzerland

unitamente ai diversi parametri ambientali. E' stata effettuata un'analisi di regressione multipla per determinare la correlazione tra le condizioni ambientali e l'abbondanza dei vettori. Basandosi sui dati metereologici raccolti da 50 stazioni meteo geo referenziate sul territorio della Svizzera, sono state create mappe delle temperature, delle precipitazioni e dell'altitudine. Dalla letteratura scientifica è stata ricavata una serie di valori di temperatura, precipitazione e altitudine che influenzano la biologia dei vettori. La mappa finale scaturita dall'integrazione dei diversi dati evidenzia le aree della Svizzera dove è più probabile la presenza dei vettori, quindi una maggiore probabilità della comparsa della malattia data la presenza di animali suscettibili. I risultati confermano la necessità di un immediato sistema di allerta rapida per la sorveglianza della BT e dei suoi vettori in Svizzera.

Parole chiave
Biologia del vettore, Bluetongue, *Culicoides*, Mappe, Sorveglianza sentinella, Sistema informativo geografico.

Introduction

Since 2003, Switzerland has implemented serological and entomological plans to detect and monitor the presence or absence of bluetongue (BT) virus by testing sentinel animals periodically and to evaluate the risk linked to the presence and abundance of *Culicoides* species (4). To date, there has been no evidence of the virus, although high numbers of *Culicoides* midges have been recorded (2). The monitoring of sentinel herds has proved to be an effective method for the surveillance of vector-borne diseases including BT in other countries, such as Australia, China and Saudi Arabia (1, 9, 18). However, sentinel herds need to be selected carefully and located in high-risk areas of disease occurrence or in a habitat that is suitable for the vectors (14). The selection of sentinel sites for BT in Switzerland was based on altitude, climatic conditions and presence of competent vector species, as well as host species. Areas with an average annual temperature of ≥12.5°C, an annual average humidity of >60%, more than three sentinel animals at an altitude of <1 100 m above sea level in summer, and farms where no insecticides have been used, were classified as 'high-risk locations' (3). Originally, a total of twelve sentinel cattle herds were selected for serological monitoring in six administrative regions (cantons) of Switzerland and seven farm locations were selected for entomological trapping in areas considered at risk for the presence of the vectors (15). The aim of this study was to integrate data collected from the entomological trapping sites, as well as climate data into a geographic information system (GIS) to create a map indicating areas of potential BT disease occurrence in Switzerland based on the biological parameters of *Culicoides* habitat. These parameters form part of the 'environmental envelope' of the vector, a term similar to 'climatic suitability envelope' (17). This concept defines how key climatic and environmental factors form a niche which is occupied by specific species.

The outputs generated through the use of mapping techniques were used to evaluate the positioning of the sentinel herds. Similar techniques have been used in other countries to optimise BT surveillance (6) or other diseases, such as malaria (8).

Material and methods

Entomological data were collected using Onderstepoort blacklight traps in seven sampling sites for 2005 and 2006. Minimum and maximum temperatures during trapping, insect abundance and diversity, host species present and altitude for each trap location were recorded. Depending on availability (monthly or yearly averages), climate data (wind speed, relative humidity, temperature and precipitation) were obtained from the Swiss Meteorological Office.

Multiple regression analysis was preformed to determine the effect of these parameters on vector abundance, which ranged from 1 to 15 664 insects per trapping night. The independent variables included in the analysis were as follows:

- altitude of farm location
- minimum and maximum temperature at trapping site

- host species present (based on the number of cattle, sheep or goats present on farm)
- relative humidity
- wind speed
- precipitation.

A negative binomial regression analysis was conducted with the objective of using its coefficients as weights in the spatial process model to map areas of increased vector suitability. Since the trapping sites were initially chosen in 'high-risk locations' with similar climatic, host density and geographic features, it was difficult to show any significance in the other parameters tested. Hence only three independent factors were used to create the suitability maps.

Thematic maps for altitude, precipitation and annual average temperature were created by using ArcGis™ (Version 8.3, Environmental Systems Research Institute, Inc., Redlands, California) through the input of all 50 meteorological stations in Switzerland. Smoothing was performed by ordinary kriging, set to incorporate three points, with the exception of the altitude map, which originated from an existing elevation model. Suitability categories (Table I) were created based on input values obtained by a literature review of Obsoletus Complex data (5, 7, 10, 11, 12, 13). These ranges of values were divided into four classes indicating low to high vector suitability for each factor. The limits for the classes used ranged from the minimum to the maximum values found in the literature (environmental envelope). Through the map calculator function of ArcGIS™, the maps were layered and categories combined to create a final vector suitability map. This map (Fig. 1) indicates areas of potential BT occurrence based on Obsoletus Complex vector biology for Switzerland.

Results

Through the analysis of entomological samples (one sample corresponded to a one-night trap collection) from seven different farms, a total of 27 256 *Culicoides* were identified for 2005 (62 samples), and 43 527 in 2006 (42 samples), of which the Obsoletus Complex accounted for 96% and 98% of the catches, respectively.

The preliminary statistical analysis showed that maximum temperature had the most significant effect on vector abundance with a rise of 1°C creating an increase of 18% in vector abundance. However, due to the lack of significance in the other independent variables, only three parameters were retained and were assigned equal weights ([altitude] + [temperature] + [precipitation]) for the creation of the combined map.

Suitability maps are presented in Figures 1, 2, 3 and 4. The blue class indicates all areas most unsuitable for vector presence, whereas the red class identifies areas most suitable for Obsoletus Complex presence.

Discussion

Until now, the occurrence of BT has been linked to areas where the vector is present and where appropriate climatic and environmental conditions are available. Through the review of literature, it was possible to collect values for parameters affecting vector biology and to analyse them using GIS techniques. Areas at risk of disease occurrence can thus be determined. The term 'environmental envelope' has been described by Purse *et al.* (13), and specifies that the environmental envelope for non-*Culicoides imicola* is quite distinct from its Old World counterpart since

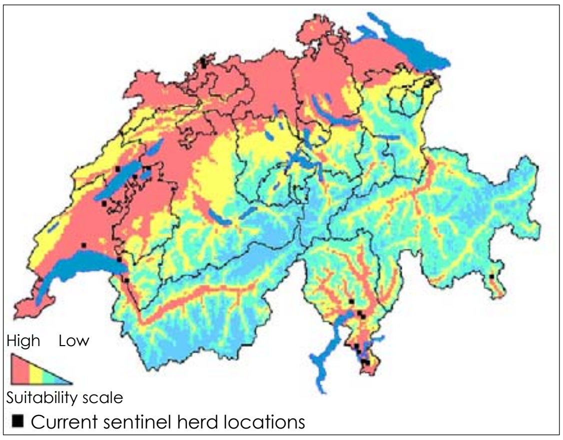

Figure 1
Final combination map: Obsoletus Complex suitability map based on temperature, altitude and precipitation values

Table I
Suitability classes used for altitude, temperature and precipitation based on values found in literature- influencing the vector biology

Parameter	High	Medium	Medium-low	Low
Altitude (m)	488-1261	10-488	–	<9 and >1261
Annual average temperature (°C)	>12	10-12	8-10	<8
Annual precipitation (mm)	815-1224	483-641	>1224	<815

they seem to occupy cooler and wetter regions compared to traditional *C. imicola* ranges. This is supported by the maps generated in this study, along with actual data from trapping surveillance in Switzerland.

Since trapping sites were selected to include suitable locations for *Culicoides* presence, it was not possible to quantify and evaluate the real association between environmental and

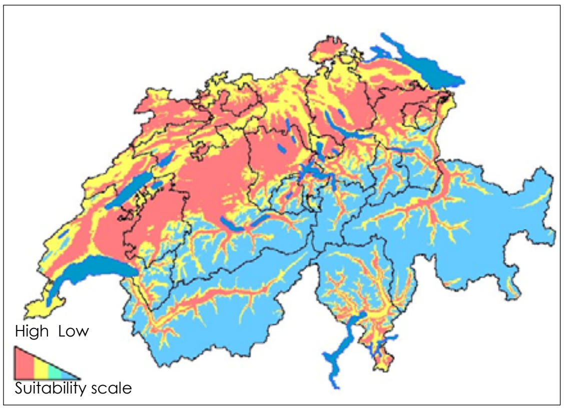

Figure 2
Altitude suitability map of Switzerland highlighting areas suitable for Obsoletus Complex habitat according to altitude

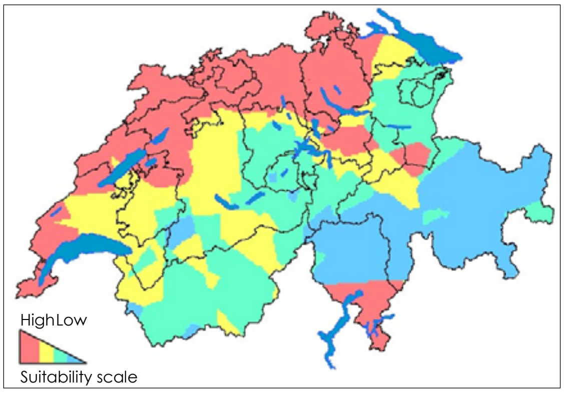

Figure 3
Temperature suitability map of Switzerland highlighting areas suitable for Obsoletus Complex habitat according to temperature

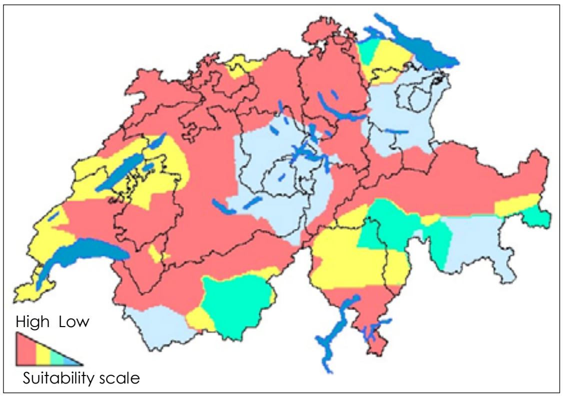

Figure 4
Precipitation suitability map of Switzerland highlighting areas suitable for Obsoletus Complex habitat according to precipitation

climatic factors or vector abundance. Sites where catches were made were very similar in altitude, temperature and precipitation and this did not enable the determination of a statistical significance with the numbers of Obsoletus Complex midges that were collected. A further limitation was that precipitation values did not differentiate between snow and rainfall. This may have caused biased results with a consequent overestimation of suitable areas, since snow is considered an unfavourable factor for vector development. This could be corrected by limiting climate data to the vector seasons. Nevertheless, the risk areas in the final map are in agreement with the initial choice of sentinel locations used in the surveillance programme (which was established prior to the creation of the maps) although it indicated an unexpected high vector suitability in the north of the country. Due to this outcome and in combination with the current epidemic in northern Europe, two further sentinel herds were added to the area of northern Switzerland, making a total of fourteen sentinel cattle herds in the serological monitoring surveillance system, nine of which are also monitored entomologically.

The recent spread of BT in northern Europe, an area in which *C. imicola* had never previously been reported, confirm the important role of novel vectors in the transmission of the disease. High abundance of Obsoletus Complex as well as a large variety of other *Culicoides* species recorded in Switzerland are comparable to values recorded in other European countries affected by BT (7, 16). Through the combined use of biological and spatial information, it is possible to determine areas which are more suitable for vector presence, hence at a higher risk for BT occurrence.

After completion of data collection planned for 2007, suitability maps will be considered a useful instrument to guide the assessment of an extensive surveillance programme in terms of a targeted sampling strategy, as well as reinforcing its role as a tool in providing support to existing surveillance programmes or by helping in prospective decision-making processes, for example for other vector-borne diseases.

Acknowledgments

The authors would like to thank M. Kuhn, B. Häsler, C. Bill and A. Cagienard for their help, and the Swiss Meteorological Office for providing climate data.

Grant support

This study was funded by the Swiss Federal Veterinary Office.

References

1. Abu Elzein E.M., Al-Afaleq A.I., Mellor P.S., El-Bashir A.M. & Hassanein M.M. 1998. Study of Akabane infection in Saudi Arabia by the use of sentinel ruminants. *J Comp Pathol*, **119**, 473-478.
2. Cagienard A., Dall'Acqua F., Thür B., Mellor P.S., Denison E., Griot C. & Stärk K.D.C. 2004. Bluetongue surveillance in Switzerland in 2003. *In* Bluetongue, Part I (N.J. MacLachlan & J.E. Pearson, eds). Proc. Third International Symposium, Taormina, 26-29 October 2003. *Vet Ital*, **40**(3), 133-136.
3. Cagienard A., Griot C., Mellor P.S., Denison E. & Stärk K.D. 2006. Bluetongue vector species of *Culicoides* in Switzerland. *Med Vet Entomol*, **20**, 239-247.
4. Cagienard A., Thür B., Griot C., Hamblin C. & Stärk K.D. 2006. No evidence of bluetongue virus in Switzerland. *Vet Microbiol*, **116,** 13-20.
5. Carpenter S., Lunt H., Arav D., Venter G. & Mellor P. 2006. Oral susceptibility to bluetongue virus of *Culicoides* (Diptera: Ceratopogonidae) from the United Kingdom. *J Med Entomol*, **43**, 73-78.
6. Conte A., Ippoliti C., Calistri P., Pelini S., Savini L., Salini R., Goffredo M. & Meiswinkel R. 2004. Towards the identification of potential infectious sites for bluetongue in Italy: a spatial analysis approach based on the distribution of *Culicoides imicola*. *In* Bluetongue, Part I (N.J. MacLachlan & J.E. Pearson, eds). Proc. Third International Symposium, Taormina, 26-29 October 2003. *Vet Ital*, **40**(3), 311-315.
7. De Liberato C., Scavia G., Lorenzetti R., Scaramozzino P., Amaddeo D., Cardeti G., Scicluna M., Ferrari G. & Autorino G.L. 2005. Identification of *Culicoides obsoletus* (Diptera: Ceratopogonidae) as a vector of bluetongue virus in central Italy. *Vet Rec*, 156, 301-304.
8. Hassan A.N., Kenawy M.A., Kamal H., Abdel Sattar A.A. & Sowilem M.M. 2003. GIS-based prediction of malaria risk in Egypt. *East Mediterr Health J*, **9**, 548-558.
9. Kirkland P.D., Zhang N., Hawkes R.A., Li Z., Zhang F., Davis R.J., Sanders D.A., Li H., Zhang K., Ben J., He G.F., Hornitzky C.L. & Hunt N.T. 2002. Studies on the epidemiology of bluetongue virus in China. *Epidemiol Infect*, **128**, 257-263.
10. Mellor P.S., Boorman J. & Baylis M. 2000. *Culicoides* biting midges: Their role as arbovirus vectors. *Annu Rev Entomol*, **45**, 307-340.
11. Osmani A., Murati B., Kabashi Q., Goga I., Berisha B., Wilsmore A.J. & Hamblin C. 2006. Evidence for the presence of bluetongue virus in Kosovo between 2001 and 2004. *Vet Rec*, **158**, 393-396.
12. Purse B.V., Mellor P.S., Rogers D.J., Samuel A.R., Mertens P.P. & Baylis M. 2005. Climate change and the recent emergence of bluetongue in Europe. *Nat Rev Microbiol*, **3**, 171-181.

13. Purse B.V., Baylis M., McCormick B.J.J. & Rogers D. 2006. Foresight 'Infectious diseases: preparing for the future', T.8.3: Hindsight and foresight on the spread of bluetongue virus in Europe. Department of Trade and Industry, Office of Science and Innovation, London, 46 pp (www.foresight.gov.uk/previous_projects/detection_and_identification_of_infectious_diseases/Reports_and_Publications/Final_Reports/T/t8_3.pdf accessed on 24 July 2007).
14. Racloz V., Griot C & Stärk K.D.C. 2006. Review of sentinel surveillance systems with special focus on vector-borne diseases. *Animal Health Res Rev*, **7**, 71-79.
15. Racloz V., Straver R., Kuhn M., Thür B., Vanzetti T., Stärk K.D.C., Griot C. & Cagienard A. 2006. Establishment of an early warning system against bluetongue virus in Switzerland. *Schweiz Arch Tierheilk*, **148**, 593-598.
16. Savini G., Goffredo M., Monaco F., Di Gennaro A., Cafiero M.A., Baldi L., de Santis P., Meiswinkel R. & Caporale V. 2005. Bluetongue virus isolations from midges belonging to the Obsoletus Complex (*Culicoides*, Diptera: Ceratopogonidae) in Italy. *Vet Rec*, **157**, 133-139.
17. Tatem A.J., Hay S.I. & Rogers D.J. 2006. Global traffic and disease vector dispersal. *Proc Natl Acad Sci*, **103**, 6242-6247.
18. Ward M.P., Flanagan M., Carpenter T.E., Hird D.W., Thurmond M.C., Johnson S.J. & Dashorst M.E. 1995. Infection of cattle with bluetongue viruses in Queensland, Australia: results of a sentinel herd study, 1990-1992. *Vet Microbiol*, **45**, 35-44.

