Validation of an interactive map assessing the potential spread of *Galba truncatula* as intermediate host of *Fasciola hepatica* in Switzerland

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Abstract

Bovine fasciolosis, caused by *Fasciola hepatica*, is widespread in Switzerland. The risk regions were modelled in 2008 by an interactive map, showing the monthly potential risk of transmission of *F. hepatica* in Switzerland. As this map is based on a mathematical model, the aim of the present study was to evaluate the interactive map by means of a field survey taking different data sources into account. It was found that the interactive map has a sensitivity of 40.7-88.9%, a specificity of 11.4-18.8%, a positive predictive value of 26.7-51.4%, and a negative prediction value of 13.1-83.6%, depending on the source of the data. In conclusion, the grid of the interactive map (100 x 100 m) does not reflect enough detail and the underlying model of the interactive map is lacking transmission data.

Introduction

Bovine fasciolosis, caused by *Fasciola hepatica*, is widespread in Switzerland. A study by Rapsch et al. (2006) estimated a true prevalence of 18.0% in slaughtered cattle of all age groups. Median financial losses, mainly due to reduced milk production and reduced fertility, are estimated at € 299 per infected animal per year (Schweizer et al., 2005a). Nevertheless, farmers often are unaware of the disease (Schweizer et al., 2005b). In order to enhance awareness among owners and give farmers and veterinarians a decision-making tool for investigating a herd for fasciolosis, an interactive map was designed, showing the monthly potential risk of transmission of *F. hepatica* in Switzerland (Rapsch et al., 2008). The interactive map is based on risk density distribution derived from environmental factors. Geographical (soil condition, forest cover) and meteorological (temperature, rainfall) data from Switzerland and biological data of the intermediate host *Galba truncatula* and the free-living stages of *F. hepatica* were accounted for. The model’s output is an environmental relative risk measurement for the development of *G. truncatula* and the free-living stages of *F. hepatica* all over Switzerland. In order to visualise the density distribution, a grid of 100 x 100 m cells was created for the whole country and the risk density of each cell of the grid was visualised by a colour scale ranging from highest (red) to no (white) risk, representing five risk classes. The elements of the map (canton boundaries, water bodies, landform configuration, cities, forest, monthly risk, risk during the year) are grouped in layers, which can be activated or deactivated. Maps produced by means of geographical information systems (GIS) are often used in human or veterinary medicine in order to identify epidemiological patterns of disease outbreaks for example. GIS is especially helpful when trying to answer epidemiological questions concerning vector borne diseases or diseases transmitted by intermediate hosts (Rinaldi et al., 2006) and with increasing technical possibilities, the number of studies using GIS has also increased (Hendrickx et al., 2004; Simoonga et al., 2009). Risk maps for the transmission of *F. hepatica* have been designed for parts of Europe (Ollerenshaw, 1966; Rapsch et al., 2008), parts of the United States (Malone et al., 1987, 1992), Ethiopia (Yilma and Malone, 1998) or Cambodia (Tum et al., 2004). Some of the models were validated mainly by means of definite host prevalence surveys (Malone et al., 1992; Malone and Gommes, 1998; Tum et al., 2007).

The aim of the present study was to evaluate the interactive map by means of a field survey based on the presence or absence of suitable snail habitats and presence of snails.
Materials and Methods

In order to evaluate the risk model, findings of potential G. truncatula habitats and snail findings from three data sources were used and then compared to the risk map.

Data sources

Snail findings emanating from a field survey in 2010

The basis of the interactive map designed by Rapsch et al. (2008), covering the whole of Switzerland, is a 100 x 100 m grid (containing a total of 4'152'874 grid fields). During a field survey in 2010, 361 grid fields were searched for the presence of potential G. truncatula habitats deriving from 80 coordinate points in the Northeast of Switzerland chosen by a random generator (Java Random). Water bodies, forests and settlements were excluded. The region was chosen due to ease of surveillance (location of the Vetsuisse Faculty, Zurich) on the one hand and due to the overlapping with the study region surveyed by Schweizer et al. (2007) on the other. The field survey was conducted from July to October 2010. The 80 randomly chosen points were visited and the minimal area of 100 x 100 m was investigated including the randomly chosen point. Due to the topography and the landscape, it was not possible to set up identical investigation areas, so the randomly chosen coordinate points did not always lie in the middle of the investigation area but were always included. If the 100 x 100 m area around the randomly chosen coordinate points was dry and no evidence for potential G. truncatula habitats could be seen nearby, the investigation was stopped recording this area as negative. If the area around the randomly chosen point included potential habitats, e.g. drainage ditches, swampy areas or small streams as described by Schweizer et al. (2007), the coordinates of the potential habitats were recorded using a global positioning system (GPS) device (Garmin eTrex H) and the potential habitats were searched for snails for 30 minutes. This was usually an area of more than 100 x 100 m (Figure 1). Snails found were collected and frozen at –20°C until further identification by binocular loupe.

Earlier snail findings

From a regional survey in northeastern Switzerland investigating the prevalence of F. hepatica in the intermediate host, the coordinates of naturally occurring habitats were taken. Wells were excluded, as these are man-made habitats. The field surveys were conducted from 1999 to 2002 in the months of May to October. A total of 54 habitat findings in the Northeast of Switzerland were taken from the study of Schweizer et al. (2007).

Comparison of the risk map with the field survey data

For the study at hand, the risk class 0 of the map created by Rapsch et al. (2008) was defined as no risk and the risk classes 1 to 5 were summarised as risk. In order to calculate the sensitivity, specificity,
positive and negative predictive value of the map, the snail searches from three different surveys from Switzerland (Table 1) were then compared to the map predicted risk (no risk vs risk). As the interactive map models potential habitats of G. truncatula on a monthly basis, the evaluation of the map also takes the month of finding into account. The investigated fields from the field surveys were either classified negative, when no potential habitats were found or positive when either potential habitats (without snails) or habitats with snails were found (Table 2). All coordinates were rounded to the next 100 m interval, in order to match the 100 x 100 m grid of the interactive map. Subsequently, the monthly risk groups of the investigated areas were taken from the model. Multiple coordinates lying in one grid area were utilised once.

The sensitivity, i.e. the true positives divided by the true positives + the false negatives; specificity, i.e. the true negatives divided by the true negatives + the false positives; the positive predictive value, i.e. the true positives divided by the true positives + false positives; and the negative predictive value, i.e. the true negative divided by the true negatives + false negatives were calculated for the map.

Two different calculations were made in order to achieve the sensitivity, specificity and the predictive values of the interactive map. First, from all data sources the true monthly findings were compared to the modelled monthly risk group, e.g. the findings in January were compared to the January risk model. Second, from all data sources only the findings from July, August, September, and October were taken. During these months the field survey in 2010 took place. The data from July and August were then compared to the corresponding monthly risk model, whereas the data from September and October were compared to the August risk model as this model predicts the highest risk areas. As the overall model is lacking an underlying transmission model, we assumed, that the areas with the best environmental conditions for the survival and reproduction of G. truncatula, and the survival of the freeliving stages of F. hepatica, in August would also have a higher risk for transmission in the following months (taking the lag of time for reproduction of the snail into account).

Results

Classification of the grid fields

From the field survey in 2010, 271 grid fields did not contain potential habitats and were therefore negative areas. Potential habitats (positive) were found in 90 grid fields. Out of these, 14 harboured a total of 133 G. truncatula specimens. A total of 89 snails were found in risk class 1 (66.9%), two in risk class 2 (1.5%), four in risk class 3 (3.0%), 28 in risk class 4 (21.1%) and 10 in risk class 5 (7.5%). The potential habitats in risk class 0 did not contain any G. truncatula specimens. Together with the findings from Schweizer et al. (2007) and the CSCF, a total of 496 grid fields with G. truncatula specimens was found.

Validity of the interactive map

Validity based on the findings from the field survey 2010 compared per month

In 76 grid fields, consisting of swampy areas, ditches and other humid biotopes, no G. truncatula specimens were found. Nevertheless, these grid fields were classified positive, as they serve as potential habitats. When comparing the monthly-modelled risk class to the actual findings in the field (Table 3), the sensitivity of the interactive map was 88.9%, the specificity 18.8%, the positive predictive value 26.7% and the negative predictive value 83.6%.

Validity based on the findings of all data compared per month

When comparing the monthly-modelled risk groups with the actual findings in the field (Table 4), the sensitivity of the interactive map was 40.7%, the specificity 18.8%, the positive predictive value 51.4% and the negative predictive value 13.0%.

Validity based on the findings of all data from July to October

When comparing the findings from all sources from July to October...

<table>
<thead>
<tr>
<th>Risk class 1-5</th>
<th>220 (81.2)</th>
<th>80 (88.9)</th>
</tr>
</thead>
</table>

Table 2. Classification of results of the field surveys compared to the risk model.

<table>
<thead>
<tr>
<th>Interactive map</th>
<th>Field survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive (presence of potential habitats)</td>
<td>True positive</td>
</tr>
<tr>
<td>Negative (absence of potential habitats)</td>
<td>False negative</td>
</tr>
</tbody>
</table>

Table 3. Comparison of results of the field survey 2010 with the risk classes in the model (interactive map) per month.

<table>
<thead>
<tr>
<th>Interactive map</th>
<th>Number of negative grid fields* (%)</th>
<th>Number of positive grid fields* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk class 0</td>
<td>51 (18.8)</td>
<td>10 (11.1)</td>
</tr>
<tr>
<td>Risk class 1</td>
<td>34 (12.6)</td>
<td>28 (31.1)</td>
</tr>
<tr>
<td>Risk class 2</td>
<td>33 (12.2)</td>
<td>12 (13.3)</td>
</tr>
<tr>
<td>Risk class 3</td>
<td>31 (11.4)</td>
<td>11 (12.2)</td>
</tr>
<tr>
<td>Risk class 4</td>
<td>38 (14.0)</td>
<td>5 (5.6)</td>
</tr>
<tr>
<td>Risk class 5</td>
<td>84 (31.0)</td>
<td>24 (28.7)</td>
</tr>
<tr>
<td>Risk class 1-5</td>
<td>220 (81.2)</td>
<td>80 (88.9)</td>
</tr>
<tr>
<td>Total</td>
<td>271 (100)</td>
<td>90 (100)</td>
</tr>
</tbody>
</table>

*Negative grid fields, grid fields without potential habitats; positive grid fields, grid fields with potential habitats either with snails or without (but with typical vegetation).
...ings from different field surveys with respect to the main intermediate host snail *G. truncatula* of *F. hepatica*. This approach was chosen because the risk map models the potential spread of *G. truncatula* and not the spread of *F. hepatica* itself (except its free-living stages). In comparable studies, risk maps are evaluated by cattle prevalence data (Malone *et al.*, 1992; Malone and Gommes, 1998; Tum *et al.*, 2007). In Switzerland there is excessive movement of animals, especially of young stock going to alpine pastures during the summer months. If these first and second summer grazing animals become infected with *F. hepatica*, they will shed eggs and secrete antibodies into their first and second lactation (Knubben-Schweizer and Torgerson, 2015). Positive results of bulk milk antibody tests are therefore not necessarily indicative for a new infection on the premise in question but it can be derived from very different geographical regions. It would therefore be more appropriate to search for potential snail habitats and snails than to compare the risk map to prevalence data in cattle.

The search for potential snail habitats and snails poses several challenges. Even though typical habitats, as described by Schweizer *et al.* (2007), with putative suitable environmental conditions may be present, *G. truncatula* can still be absent. To the authors’ experience, this is especially true, when habitats are visited once only as the size of the

### Discussion

The interactive map of Rapsch *et al.* (2008) models areas with suitable environmental conditions for the survival and reproduction of *G. truncatula*, including survival of the free-living stages of *F. hepatica*. The risk areas modelled are corroborated by a study by Ducheyne *et al.* (2015) modelling the spatial distribution of *F. hepatica* in dairy cattle in Europe, including Switzerland.

The aim of the present study was to evaluate the risk map from Rapsch *et al.* (2008) by comparing the modelled risk areas with findings from different field surveys with respect to the main intermediate host snail *G. truncatula* of *F. hepatica*. This approach was chosen because the risk map models the potential spread of *G. truncatula* and not the spread of *F. hepatica* itself (except its free-living stages). In comparable studies, risk maps are evaluated by cattle prevalence data (Malone *et al.*, 1992; Malone and Gommes, 1998; Tum *et al.*, 2007). In Switzerland there is excessive movement of animals, especially of young stock going to alpine pastures during the summer months. If these first and second summer grazing animals become infected with *F. hepatica*, they will shed eggs and secrete antibodies into their first and second lactation (Knubben-Schweizer and Torgerson, 2015). Positive results of bulk milk antibody tests are therefore not necessarily indicative for a new infection on the premise in question but it can be derived from very different geographical regions. It would therefore be more appropriate to search for potential snail habitats and snails than to compare the risk map to prevalence data in cattle.

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### Table 4. Comparison of results of the monthly risk models (interactive map) with the results of the field surveys from January to December.

<table>
<thead>
<tr>
<th>Interactive map</th>
<th>Classification of the grid fields based on the field surveys° from January to December</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Risk (risk class 1-5)</td>
<td>233</td>
<td>453</td>
</tr>
<tr>
<td>No risk (risk class 0)</td>
<td>339</td>
<td>390</td>
</tr>
<tr>
<td>Total</td>
<td>572</td>
<td>843</td>
</tr>
</tbody>
</table>

°Field survey 2010, data from Schweizer *et al.* (2007) and findings from Centre Suisse de Cartographie de la Faune.

### Table 5. Comparison of results of the monthly risk models (interactive map) with the results of the field surveys from July to October.

<table>
<thead>
<tr>
<th>Interactive map</th>
<th>Classification of the grid fields based on the field surveys° from July to October</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Risk (risk class 1-5)</td>
<td>191</td>
<td>411</td>
</tr>
<tr>
<td>No risk (risk class 0)</td>
<td>165</td>
<td>216</td>
</tr>
<tr>
<td>Total</td>
<td>356</td>
<td>627</td>
</tr>
</tbody>
</table>

°Field survey 2010, data from Schweizer *et al.* (2007) and findings from Centre Suisse de Cartographie de la Faune.

### Table 6. Comparison of the findings from all sources in July and August compared to the corresponding risk model and the findings from all sources from September and October compared to the August risk model.

<table>
<thead>
<tr>
<th>Interactive map</th>
<th>Classification of the grid fields based on the field surveys° from July to October</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td>Risk (risk class 1-5)</td>
<td>232</td>
<td>472</td>
</tr>
<tr>
<td>No risk (risk class 0)</td>
<td>124</td>
<td>155</td>
</tr>
<tr>
<td>Total</td>
<td>356</td>
<td>627</td>
</tr>
</tbody>
</table>

°Field survey 2010, data from Schweizer *et al.* (2007) and findings from Centre Suisse de Cartographie de la Faune.
snail population depends on the cumulative environmental conditions of the previous months. For this reason, not only snail findings were assessed as positive but also potential habitats as can be seen in Figures 3 to 5.

Another challenge is the identification of the snails. Those from the present study and from Schweizer et al. (2007) were identified by an experienced person by macroscopic inspection. In questionable cases (e.g. very small snails) the identification took place under a binocular loupe. For the data from CSCF, the way the snails were identified is unknown. Misidentification cannot be ruled out, especially for very small snails.

In the current study, the infection status of the snails was not investigated as it was not of primary interest. In the study of Schweizer et al. (2007), the snails were examined using PCR to detect F. hepatica infection finding 7.0% of 4733 snails positive. The risk of infection of G. truncatula with F. hepatica depended on the source of the snails (type of habitat and type of pastured cattle, respectively).

Another challenge in this field survey was that it was not always possible to survey the grid fields due to limitations, such as slope, water course, street, building, land use etc. In such areas, it was therefore decided to choose a coordinate point and search the area around it. In the model, the surveyed area was then mapped and the number of grid fields covered by this area were analysed.

Several approaches were used to calculate the sensitivity, specificity

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Figure 2. A) Risk map for the transmission of Fasciola hepatica in Switzerland. B) Detail of figure 2A: Northeast of Switzerland, where the survey at hand has been conducted. The risk for the month of August is shown. White areas are no risk (risk class 0), red shaded areas are risk (risk class 1 to 5). Additionally, the findings of Galba truncatula searches from 3 sources can be seen, where the red dots are positive findings (either potential habitats or snails) and the white dots are areas, with no potential snail habitats.

Figure 3. Drainage ditch in a swampy area making a potentially suitable habitat for Galba truncatula.

Figure 4. A swampy area making a potentially suitable habitat for Galba truncatula, notice the rush as an indicator plant described by Rondelaud et al. (2011).
and predictive values of the interactive map. In general the model is neither very sensitive nor very specific. When comparing the monthly findings of all surveys with the monthly risk models, 40.7% of the modelled risk areas habitats were found. Additionally, in the field survey of 2010, only 18.8% of the areas of risk class 0 were without potential habitats and snails were not found in any of them. The chance of finding a potential habitat in an area where a risk is predicted by the model was 51.4% for any month of the year. In contrast, the chance of absence of habitats in an area where no risk was predicted by the model was 13.0% for any month of the year. Considering the conditions of the previous months when calculating the risk, these results were improved. Nevertheless, the sensitivity, specificity, positive and negative predictive values remained low.

As the interactive map lacks an underlying transmission model, mean monthly temperatures below 10°C result in a risk 0 classification of the affected grid field. For this reason, the interactive map does not predict any potential risk areas for the survival and reproduction of G. truncatula, and for the survival of the free-living stages of F. hepatica, during the winter months. Nevertheless, snails can overwinter and can therefore be found the whole year around (Mehl, 1932). As a result, the snails found from November to March, where the map does not show any risk areas at all, will lead to a decrease of the sensitivity and the negative predictive value for the 12-month-model.

A limitation of the interactive map is the grid size. Even though 100 x 100 m allows a resolution approaching the farm level, habitats are often much smaller. Swampland areas, drainage ditches and slow streams, which are the typical habitats for G. truncatula (Mehl, 1932; Schweizer et al., 2007) are not mapped on commercial maps (topographic map 1:25’000). This was considered by modelling the soil type (Wilson et al., 1982) in the interactive map based on the fact, that the water content is dependent on water permeability and how waterlogged it is (Rapsch et al., 2008). Furthermore, beside natural habitats, there are also man-made habitats, such as wells. Where the type of habitat was known, the wells were eliminated from the evaluation. Nevertheless, local micrometric factors and ground condition as well as man-made habitats are almost impossible to model. Besides, habitats may vary over the years. As the study at hand was based on data deriving from a 20-year period (1990 to 2010), some alteration in habitats might have occurred.

Another type of small habitat, also not considered in the interactive map, are areas characterised by spring water that generally occur on slopes. It was therefore assumed, that the implementation of small watercourses and slopes might increase the sensitivity, specificity and predictive values of the interactive map.

Conclusions

Models such as those assessing the potential spread of G. truncatula or the spatial distribution of F. hepatica can be very helpful tools for farmers and veterinarians. However, these are theoretical models. In order to validate the original Swiss model (Rapsch et al., 2008), a field-survey was undertaken. This demonstrated moderate sensitivity, specificity and predictive values of the model. The next-step revision of the model will require the environmental factors to be examined in more detail (e.g. the role of slopes). Furthermore, a transmission model is in progress, which will be integrated into the map and help to reduce the problem of missing cumulative effects over the year.

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