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# Cultivation of GMO in Germany: support of monitoring and coexistence issues by WebGIS technology

Lukas Kleppin<sup>\*†</sup>, Gunther Schmidt<sup>†</sup>, Winfried Schröder<sup>†</sup>

## Abstract

**Background:** In Germany, apart from the Amflora potato licensed for cultivation since March 2010, Bt-maize MON810 is the only genetically modified organisms (GMO) licensed for commercial cultivation (about 3,000 ha in 2008). Concerns have been raised about potential adverse environmental impacts of the GMO and about potential implications on the coexistence between conventional and genetically modified production. These issues should be considered on a regional base. The objective of this article is to describe how GMO monitoring that is required after risk assessment and GMO release can be complemented by a Web-based geoinformation system (WebGIS). Secondly, it is also described how WebGIS techniques might support coexistence issues with regard to Bt-maize cultivation and conservation areas. Accordingly, on the one hand, the WebGIS should enable access to relevant geodata describing the receiving environment, including information on cultivation patterns and conservation areas containing protected species and habitats. On the other hand, metadata on already established environmental monitoring networks should be provided as well as measurement data of the intended GMO monitoring. Based on this information and based on the functionality provided by the WebGIS, the application helps in detecting possible environmental GMO impacts and in avoiding or identifying coexistence problems.

**Results:** The WebGIS applies Web mapping techniques to generate maps via internet requests and offers additional functionality for analysis, processing and publication of selected geodata. It is based on open source software solely. The developments rely on a combination of the University of Minnesota (UMN) MapServer with the Apache HTTP server, the open source database management systems MySQL and PostgreSQL and the graphical user interface provided by Mapbender. Important information on the number and the location of Bt-maize fields were derived from the GMO location register of BVL. The "WebGIS GMO Monitoring" provides different tools allowing for the application of basic GIS techniques as, for instance, automatic or interactive zooming, distance measurements or querying attribute information from selected GIS layers. More sophisticated GIS tools were implemented additionally, e.g. a buffer function which enables generating buffers around selected geo-objects like Bt-maize fields. Finally, a function for intersection of different maps was developed. The WebGIS comprises information on the location of all Bt-maize fields in Germany according to the official GMO location register of the Federal Office of Consumer Protection and Food Safety between 2005 and 2008. It facilitates, amongst others, access to geodata of GMO fields and their surroundings and can relate them with additional environmental data on climate, soil, and agricultural patterns. Furthermore, spatial data on the location of flora-fauna-habitats and environmental monitoring sites in the federal state of Brandenburg were integrated. The WebGIS GMO monitoring was implemented according to the concept for an "Information System for Monitoring GMO" (ISMO) which was designed on behalf of the German Federal Agency for Nature Conservation. ISMO includes hypotheses-based ecological effects of GMO cultivation and suggests checkpoints for GMO monitoring to test whether impacts may be observed in the receiving environment.

\* Correspondence: [lkleppin@iuw.uni-vechta.de](mailto:lkleppin@iuw.uni-vechta.de)

† Contributed equally

University of Vechta, P.O. Box 1553, 49364 Vechta, Germany

In contrast to the public GMO register, the WebGIS GMO monitoring enables mapping of GMO fields and provides relevant geodata describing environmental and agricultural conditions in their neighbourhood of the cultivation sites as well as information derived from monitoring sites. On this basis, spatial analyses should be enabled and supported, respectively. Further, the WebGIS GMO monitoring supplements PortalU which, in Germany, is the technical realisation of the Infrastructure for Spatial Information in Europe directive (Directive 2007/2/EC) released by the EU in 2007.

**Conclusions:** The article should have shown how to support and complement GMO monitoring with the help of the WebGIS application. It facilitates co-operation and data access across spatial scales for different users since it is based on internet technologies. The WebGIS improves storage, analysis, management and presentation of spatial data. Apart from the improved flow of information, it supports future long-term GMO monitoring and modelling of the dispersal of transgenic pollen, for instance. Additional information (e.g. data on wind conditions or soil observation sites) provided by the WebGIS will be helpful to determine representative monitoring sites for detecting potential GMO impacts by means of monitoring or modelling. Thus, the WebGIS can also serve as part of an early warning system. In the near future, the integration of locations of all Bt-maize fields in Germany into the WebGIS as a continuous task should be automatised. Additionally, a methodology should be developed to detect maize fields by means of remote sensing data to manage coexistence problems on the basis of actual field patterns.

## Background

Genetic engineering was introduced to improve plant breeding. It enables to establish new varieties of plant species with specific input and output traits [1]. The cultivation of GMO aims at increasing yield, but also to improve product quality [2,3]. Input traits include resistances against different herbicides or insect pests and viruses. Output traits aim to improve the quality of agricultural products, e.g. increasing fibre or lowering the fat content. Worldwide, the cultivation of GMO increased from 1.7 Mio ha in 1996 up to 134 Mio ha in 2009 [4]. According to the agricultural statistical survey 2009, for example in the USA, 90% of the cropland is used to cultivate GMO varieties of soy or cotton. In the USA, the percentage of genetically modified (GM) maize is already 85%. In Germany, GMO (99% Bt-maize MON810) were cultivated from 2005 until 2008 with a total number of 239 fields and a total acreage of 3,171 ha in 2008.

In contrast to the contained use of GM products in medicine, the introduction of GMO in agricultural ecosystems may cause unwanted, uncontrollable and irreversible impacts.

According to EU Directive 2001/18/EC, plant breeders willing to introduce GMO on the market have to accomplish a notification process including an environmental risk assessment (ERA) and a monitoring plan to the competent national and European authorities [5]. This regulatory framework is intended to implement the precautionary principle and to enable handling potential adverse environmental effects still remaining after the ERA [6]. The aim of the EU Directive 2001/18/EC is to safeguard human health and the environment and to restrict the use of GMO so that no unacceptable risks

or hazards can emerge [7]. The risk assessment is based on empirical studies with small spatial extent, encompassing laboratories tests, greenhouse experiments, small-scale field release or commercial-scale field release [8-10]. Though, there remains a wide range of uncertainty with small plot and laboratory studies. According to scientific hypotheses, adverse effects are examined in the ERA. However, ERA concentrates at the small-scale level, thus, large-scale effects are difficult to assess. Thus, monitoring of GMO at the landscape scale is required after the GMO have been released to detect adverse environmental effects at regional or larger scale [11]. Accordingly, the EU Directive 2001/18/EC [5] on the deliberate release of GMO into the environment stipulates assessment of direct and indirect effects of GMO on humans and the environment by case-specific monitoring and general surveillance. The latter has to be performed to detect potential unanticipated adverse effects whereas case-specific monitoring is set up to reduce substantial uncertainties in relevant risk scenarios identified in the ERA [5]. In Germany, the Federal Nature Conservation Agency suggests how to implement a monitoring of GMO. Three core issues have to be covered: (1) documentation of exposure, (2) monitoring impacts of the specific GMO and (3) large-scale and long term-effect relationships [12]. The results of GMO monitoring contribute to decisions regarding, e.g. further approval or refusal of the GMO or additional precautions during cultivation. In this context, GMO monitoring provides the basis for an early warning system to react at an early stage in case of reported adverse effects and decide upon counter measures. Relevant topics have to be considered for both, case-specific monitoring and general surveillance, which are, for

example, (a) combinatory effects of several genetic modifications accumulating in individual plants of a crop species such as multiple resistances in oilseed rape [13,14], (b) effects of different Bt-toxins on susceptible butterfly populations [15-17] or (c) long-term effects due to changes in farming practices [18]. The necessity of monitoring adverse GMO effects can be pointed out by means of a few indications, for example, enhanced mortality of non-target organisms [6], hybridisation with related species [19] or neighbouring non-GM crops [20] and adverse agricultural practice changes [21]. According to EU Directive 2001/18/EC [5], a set of appropriate monitoring parameters has to be defined which are described in the guidelines for GMO monitoring as, for instance, published by the Association of German Engineers [22]. These obligate test items have to be considered when integrating and compiling data from already existing environmental monitoring networks [23-25].

In this context, a Web-based geographical information system (WebGIS) is appropriate to build up a data infrastructure for GMO monitoring and data exchange [26]. The objective of the article at hand is to describe how to complement and support GMO monitoring by the implementation of a WebGIS as suggested by Aden et al. [25]. The WebGIS enables access to relevant geodata like basic environmental information, existing monitoring networks related to GMO issues, details on GMO fields and information on protected areas as well as tools for collecting, processing and mapping monitoring results. Implemented GIS tools that do not require any additional software but an Internet browser at the client's computer should help in assessment of possible GMO impacts in a spatially discriminated context. On that score, the WebGIS can facilitate the approval process. Secondly, it could be used to manage coexistence of GMO, conventional and organic farming as well as with nature conservation issues by detecting or avoiding possible conflicts already during planning stage [27]. Moreover, the Web-based application will provide spatial information on the locations of the Bt-maize fields which can be used for modelling cross-pollination of GM maize pollen at field scale, for instance, to check, e. g. whether distance regulations between Bt-maize and conventional maize fields are sufficient or not [28].

## Materials and methods

### Open source software and standards

The use of proprietary software is being determined by licences and copyrights; annual license fees may be imposed. Sharing or modification of this software is strictly forbidden. Due to the business concept of proprietary software, the source code is not accessible [29]. Open source software offers an approved alternative to proprietary software. However, there is no guarantee

that the open source software is working properly. Compared to proprietary software, open source products are prescribed to be free of charge and the source code is disclosed and free for modifications. Open source software is not confined to private use, but is adopted from business companies, public facilities as well as from authorities. It is used in all fields of information technology, for instance, as operating system (Linux, HostGIS), complementary software (hypertext transfer protocol (HTTP) Server, CMS, MapServer, WebGIS-Clientsuites), and independent GIS software (GRASS-GIS, JUMP) [29]. Open source is specified by several criteria of the Open Source Initiative [30,31].

Open source software used to build up the Web application described in the article at hand follows the standards of the Open Geospatial Consortium (OGC). This is an international organisation composed of business companies, universities and authorities. The OGC releases standards for interfaces to process various types of geodata via Internet. Standards and specifications are supposed to ensure interoperability between map services located anywhere in the world and to provide access to complex spatial information. The EU directive Infrastructure for Spatial Information in Europe (INSPIRE) [32] and the German PortalU [33] already comply with these standards.

### System architecture

Based on open source software and in accordance with the INSPIRE standards, we developed the "WebGIS GMO Monitoring". To this end, a server programme was used which provides the functionality of a "spatial" communication. Our recent developments rely on a combination of the UMN MapServer with the Apache HTTP server. The main function of the HTTP server relies on the communication with Web clients. Map servers are components that perform queries and analyses of both raster and vector data and generate and display maps in a uniform projection defined by the user. We then installed the database management system PostgreSQL enhanced with the spatial extension PostGIS. Open source database systems like MySQL and PostgreSQL are capable to save and process spatial information and related attributes in additional libraries (MyGIS, PostGIS). The spatial extension PostGIS acts as GIS back end which allows performing basic GIS operations on geodata without expensive programming. The integration of the GIS back end GRASS is an essential part of the current work. The WebGIS interactively enables advanced GIS techniques and geodata analyses. For this purpose, the user only needs a Web browser (Mozilla, MS Internet Explorer) but no additional GIS software. Finally, we installed the WebGIS-Client Suite Mapbender by CCGIS <http://www.mapbender.org> which provides the user interface. The open source product

offers various tools for navigation within maps, retrieval of metadata and queries of map contents [34]. Moreover, it is possible to integrate remote Web Map Services to build up a more extensive data infrastructure for environmental monitoring issues.

#### **GMO location register**

The Federal Office of Consumer Protection and Food Safety (*Bundesamt für Verbraucherschutz und Lebensmittelsicherheit*, BVL) is the competent authority charged with the enforcement of the Genetic Engineering Act (*Gentechnikgesetz*, GenTG) and the legislation of the European Union. The BVL, correspondingly, assesses notifications for the experimental use of GMO and also gives advice to the Federal Government as well as to the Federal States and their bodies on issues of biological safety in genetic engineering. The BVL maintains the GMO location register [35] <http://www.bvl.bund.de> as well as the GMO notification register, serving as an information platform on GMO release for the public. The BVL is committed to record information on GMO cultivation in the register by the EU Directive 2004/204/EC [36]. This is to improve monitoring of possible negative long-term effects with regard to environment, human and animal health. Additionally, the GMO location register should assure transparency and should help adjacent farmers to cultivate GM crops and non-GM crops without cross-pollination (coexistence). The GMO location register contains the identification numbers (ID) of GMO fields related to the *Amtliches Liegenschaftskataster* (ALK). However, the GMO location register is not linked with the ALK and has only very limited options for cartographic visualisation, i.e. it is only possible to map the cultivation of Bt-maize at the level of municipalities in terms of density maps [37]. A visualisation of Bt-maize fields is not possible by the location register and, thus, it is not possible to identify single GMO fields by spatial queries or mapping.

The application WebGIS GMO monitoring improves these techniques and provides corresponding information to implement required monitoring issues (GenTG, chapter 3, 15). As a first step of development and implementation, the WebGIS was designed only for the Federal State of Brandenburg. The localisation of the GMO fields in Brandenburg was enabled by identification of the land parcels where the Bt-maize was cultivated using the ID field of the ALK listed in the GMO location register. Difficulties arise when no public cadastre (ALK) is available for free to spatially reference according GM maize fields (see “Conclusions”).

## **Results**

### **Database**

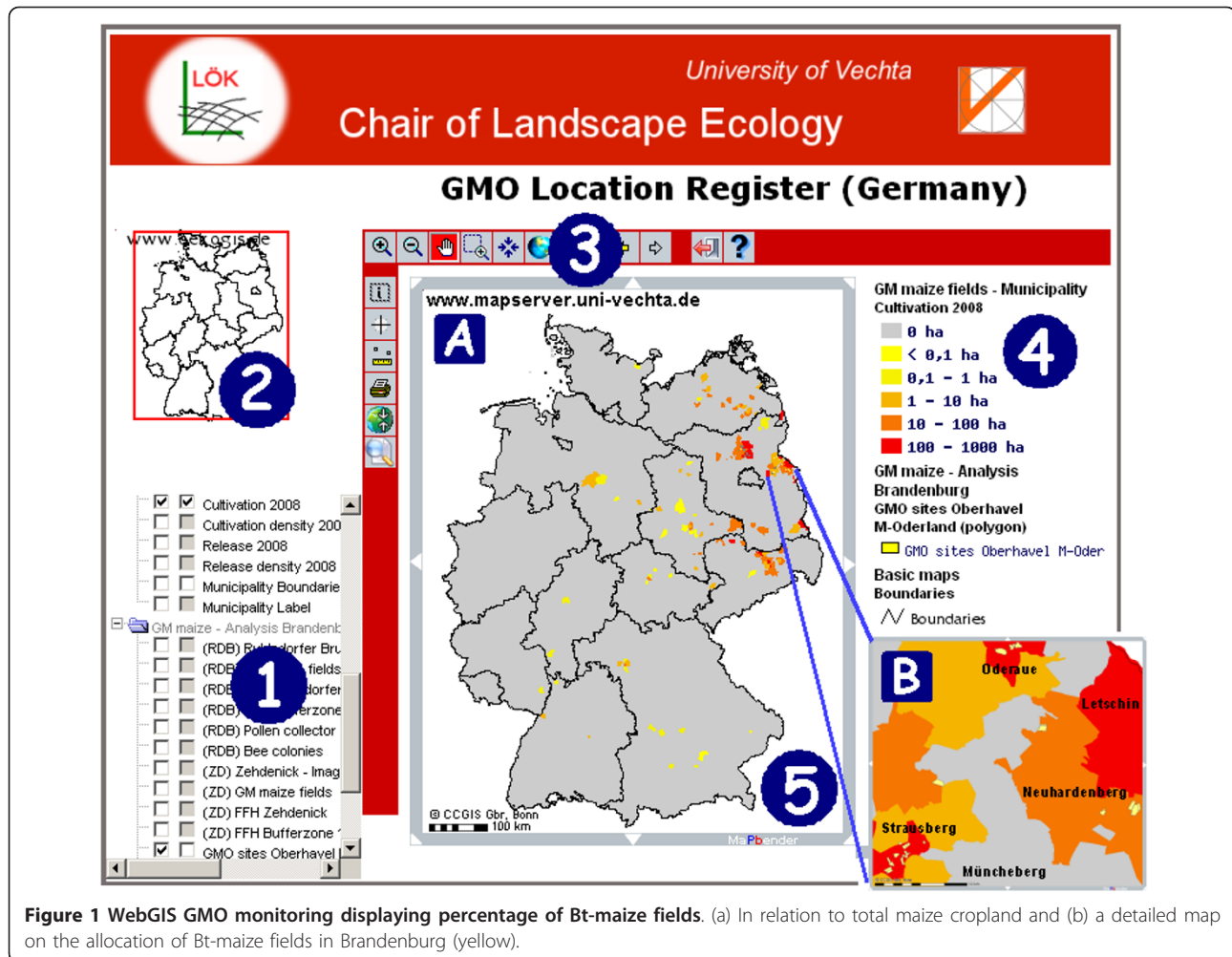
Geodata having been integrated in the WebGIS application are essential for GMO monitoring issues because in

various ways they can help detect possible impacts or coexistence problems due to GMO cultivation. The application provides maps on land use patterns of CORINE Land Cover [38], on ecological landscape units [39] and on ecoregions [40] as well as satellite images of Northern Germany, phenological data on maize plants and averaged measurements on precipitation (1961-1990), temperature (1961-1990), sunshine duration (1961-1990), wind direction and evaporation rate compiled from the German Weather Service (DWD). Furthermore, maps on cultivation intensity of several crops at district level derived from agricultural statistics (*Statistik lokal* 1999, 2003, 2007) [41] and data on Bt-maize cultivation derived from the public GMO register were integrated. In addition to the developmental stage of the WebGIS as published by Kleppin et al. (2008) [42], supplementary data were integrated in the WebGIS GMO monitoring: information on the location of fauna-flora-habitats (FFH) in the federal state of Brandenburg including a list on protected species [43], data on monitoring programmes in Brandenburg with regard to long-term soil observation sites, groundwater and surface water observation sites as well as monitoring sites within biosphere reserves [44] including a list of analysed parameters. Finally, the database was updated with information on the occurrence of the European corn borer (*Ostrinia nubilalis*) from 2005 until 2007 being the target organism for the introduction of Bt-maize. All geodata and according attributes are described by metadata which can be modified or completed if necessary. The WebGIS administrator is authorised to decide whether actual geodata may be downloaded by user request. By this, users get distinct access rights for predetermined information.

### **The WebGIS GMO monitoring**

The WebGIS GMO monitoring provides a graphical user interface based on the Mapbender software (Figure 1). A tool bar allows applying basic GIS techniques (see Figure 1, item 3), for instance, automatic or interactive zooming, distance measurements or querying attribute information from selected GIS layers. A detailed map including a scale bar and navigation buttons show the selected layers (see Figure 1, item 5). A small-scale reference map depicts the geographical location of the selected area displayed in the detailed map (see Figure 1, item 2). The layer tool enables management of geo-objects (see Figure 1, item 1). By activating the checkboxes, each layer is drawn in the map window (left checkbox in item 1) or attribute queries can be enabled (right checkbox in item 1). Corresponding to the chosen layers, legends are generated automatically (see Figure 1, item 4). The selected layers ‘Cultivation 2008’ (A) and ‘GMO sites’ (B) displayed in Figure 1 show (A) the



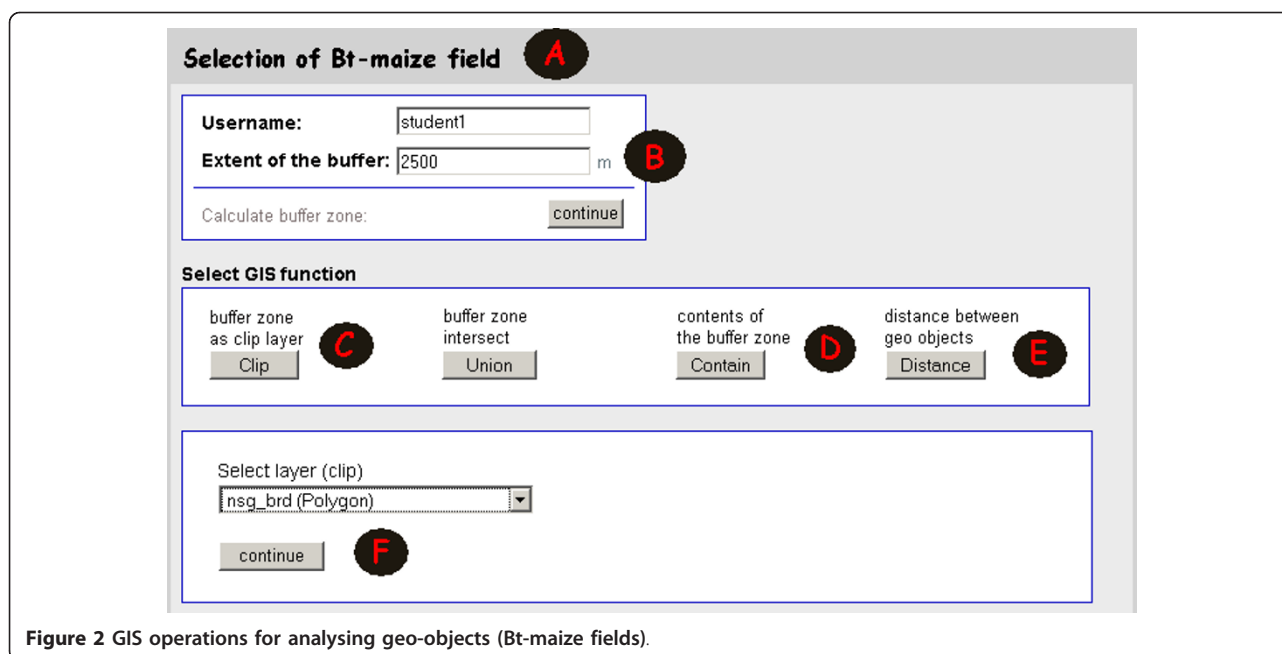


**Figure 1** WebGIS GMO monitoring displaying percentage of Bt-maize fields. (a) In relation to total maize cropland and (b) a detailed map on the allocation of Bt-maize fields in Brandenburg (yellow).

cultivation area of Bt-maize fields for each municipality in 2008, and (B) in detail single Bt-maize fields in Brandenburg which were registered by the BVL in 2008. The map on Bt-maize fields can be complemented by displaying additional geodata, like, for instance, maps on land use patterns or ecoregions as, e.g., published by Schröder and Schmidt (2001) [40]. Additionally, maps on the location of nature reserves can be overlaid with locations of Bt-maize fields. By clicking on the layer's name in the WebGIS application, available metadata describing source, date of origin and other relevant information on the data set are listed in tables.

Beyond the developmental stage of the WebGIS as reported by Kleppin et al. (2008) [42], the WebGIS GMO monitoring was improved by the implementation of sophisticated GIS tools. A buffer function allows generating buffers around selected geo-objects like, for instance, Bt-maize fields (Figure 2B). Another function ("contain") allows listing of all geo-objects being located within a certain buffer zone (Figure 2D). An "intersect" function (Figure 2C) can be used for spatially relating

different layers. Two special intersect cases were realised, such as "clip" and "union". "Clip" can be used to cut out features of one layer with one or more features of another layer. The function "union" calculates the geometric intersection of all features of two layers. The output features will then have the attributes of both layers. Further, it is possible to calculate distances between geo-objects (Figure 2E) and, finally, a query tool was implemented to identify distinct GMO fields. It is also possible to generate buffer zones around single or several (Bt-)maize fields in a given municipality by specifying a buffer name and the desired extent of the buffer zone. The username is necessary to generate unique names for both the new layer (see Figure 2B). While the buffer zone is calculated, the map file, which defines the layout of the new geo-object, is generated automatically too, and integrated into the user interface of the Mapbender software ("The WebGIS GMO monitoring"). Additionally, the new buffer zone as well as the respective SRID (Spatial Reference Identifier) and the type of the geometry are registered dynamically in



**Figure 2** GIS operations for analysing geo-objects (Bt-maize fields).

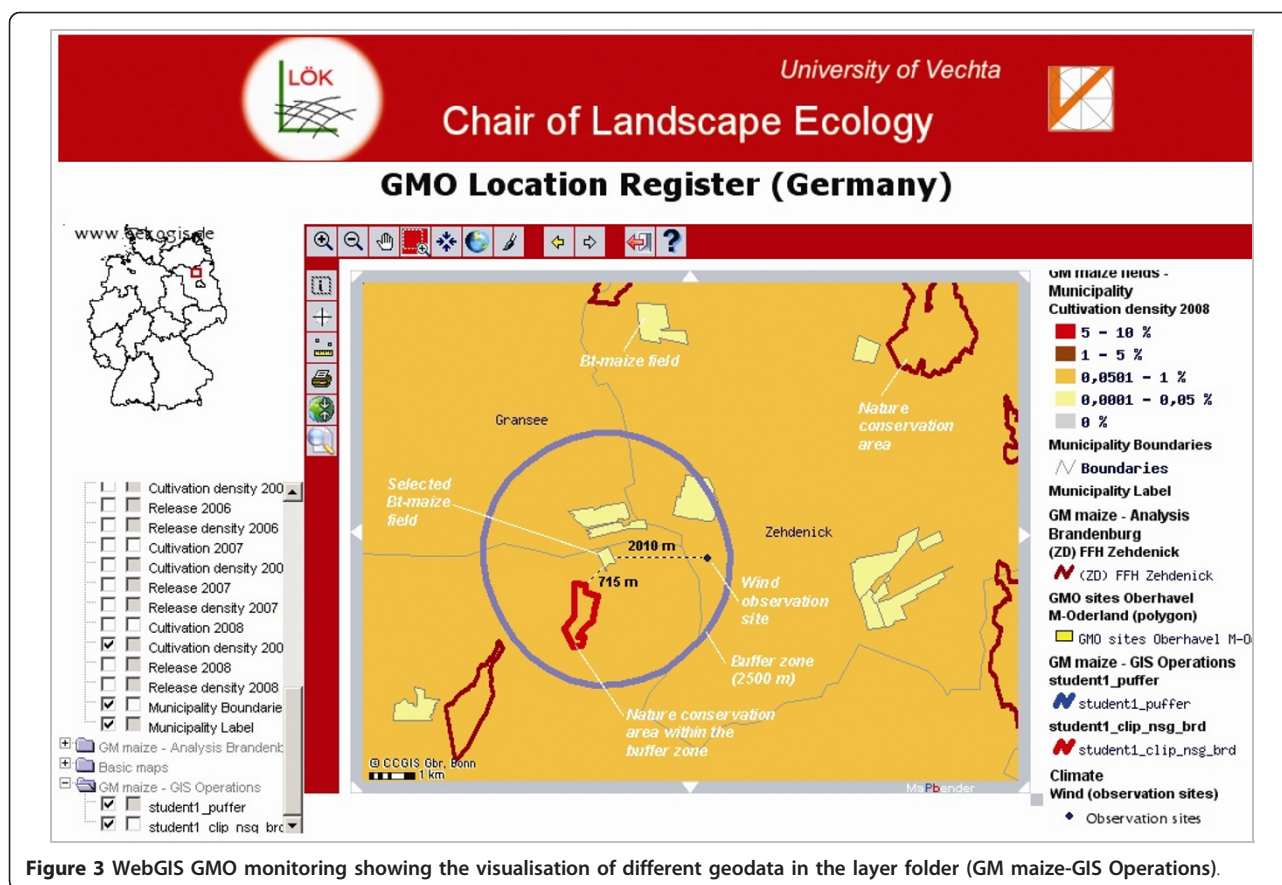
the geodatabase. For displaying the new layer it is necessary to update the webpage (Figure 3). The new buffer-layer can be intersected with other geodata stored in the geodatabase (Figure 2F). Further, an according template file provides specific information which describes the selected area or location by coordinates, name, size, etc. After log out, all files and geodata generated before are deleted in order to save storage capacity. Additional extensions for printing maps or downloading the individually generated files are under construction.

As an example, in Figure 2A, a certain Bt-maize field is selected to generate a buffer zone of 2,500 m around this field. As a result, the extent of the buffer appears in the map as a blue polygon (see Figure 3). In the next step, the user extracts geo-objects from the FFH layer by clipping with the buffer layer generated before (see Figure 2C, F). In the result, one single FFH area is highlighted (red outline) being located within the buffer zone (see Figure 3). Additionally, the extracted FFH area is linked to a query template to provide specific information, for instance, on protected species housed in this FFH area. This spatial investigation whether the Bt-maize fields are within or near a conservation area is relevant since protected non-target organisms might be affected by toxins produced by Bt-maize or a change in biodiversity might be induced. Furthermore, it is possible to calculate the distance between the selected Bt-maize field and the respective conservation area (see Figure 2E) and to identify other relevant geodata located within the buffer zone (see Figure 2D).

In case local authorities plan to conduct a case-specific GMO monitoring, buffer zones around all Bt-maize fields

of the respective municipality might be generated at first. In a second step, it could be checked automatically whether monitoring sites of related environmental monitoring networks (“Database”) are located within the buffer zones. Regarding the respective GMO, it could be checked in detail what measurements are taken at these sites in order to support analysis of possible adverse effects. For instance, data on wind conditions can be evaluated in order to determine favourable sites for technical pollen samplers [45]. Projected GM pollen loads help in assessing risks for non-target organisms (NTO) occurring in the vicinity of GMO fields. In this context, Rosi-Marshall et al. (2007) [46] found out in laboratory feeding trials that consumption of Bt-corn byproducts reduced growth and increased mortality of NTO stream insects.

Another benefit of the WebGIS GMO monitoring refers to coexistence issues. Generally, coexistence refers to the choice of consumers and farmers between conventional, organic and GM crop production. Thus, the aim is to accomplish a spatial segregation between GM and non-GM production at the landscape level which helps to avoid cross-pollination and seed contamination. Similarly, conflicts between GMO cultivation and protection goals concerning conservation reserves have to be avoided. By use of the WebGIS, farmers cultivating conventional maize are enabled to check distances to adjacent Bt-maize fields with regard to distance regulations defined in the amendment of the GenTG (150 m to conventional fields, 300 m to organic fields). This also applies to protected areas with respect to nature conservation issues (800 m in the federal state Brandenburg).



**Figure 3** WebGIS GMO monitoring showing the visualisation of different geodata in the layer folder (GM maize-GIS Operations).

The localisation of regions where Bt-maize can be cultivated without impairing conventional maize fields or nature reserves is a challenging task. In a GIS-based approach, conventional maize fields and conservation areas have to be buffered in accordance to existing distance regulations. The cropland outside the buffered area would be eligible for Bt-maize cultivation [47]. Furthermore, all FFH conservation areas in Brandenburg are documented by subjects of protection (e.g. endangered species). In order to identify all the FFH conservation areas which might probably be affected by pollen dispersal, it is necessary to generate a buffer of 800 m, as defined by the federal authorities, around these areas. In the next step, the according buffer zones must be intersected with the geometries of the Bt-maize fields to identify whether some of these Bt-maize fields are located within the respective buffer zone. Afterwards, it can be tested whether any endangered species (NTOs) occur in the respective protection areas which might be exposed to Bt-maize pollen. Laboratory tests have shown that Bt toxins may influence NTOs in growth and physical condition [48,46].

**Discussion**

GMO monitoring should take place in areas exposed to GMO, preferably cultivated fields and their environment,

but should include also regions with no or unknown GMO exposure. On a case-by-case basis depending on the GMO characteristics, the selected indicators, checkpoints and related analytical methods should consider relevant different spatial and temporal scales [49,22]. Hence, the monitoring of ecological effects of GMO must be standardised with regard to parameters, methods, survey intervals and sites so that data are comparable in terms of measurement methods and, thus, can be analysed statistically and interpreted meaningfully [22]. This comprises standards concerning molecular-biological detection methods, vegetation mapping and faunistic surveys to evaluate changes in population density and behaviour of endangered species, for example. This standardisation is to ensure a Germany-wide comparability of sampling data and to provide legal certainty for the user [50]. Accordingly, the WebGIS GMO monitoring should support realisation of particular parts of the guideline VDI 4330 [22]: “Monitoring the ecological effects of genetically modified organisms - Basic principles and strategies” (VDI 4330, part 1), “Pollen monitoring: Pollen sampling using pollen mass filters (PMF) and Sigma-2 samplers” (VDI 4330, part 3), “Pollen monitoring: Biological sampling by honey bees” (VDI 4330, part 4). In this context, Reuter et al. (2006, 2010) [23,24]

developed a concept of an information system for GMO monitoring (ISMO). The database concept encompasses three components: The "Knowledge Database" comprises information related to different levels of biological organisation being affected by GMO cultivation. Therein, scientific hypotheses regarding ecological effects of GMO as well as checkpoints for monitoring possible impacts were described in detail. The "Monitoring Database" should provide GMO monitoring data and interfaces to existing environmental information systems being of relevance for GMO monitoring issues. The WebGIS GMO monitoring is designated to be part of the monitoring database enabling data retrieval, mapping and analysis of relevant monitoring data and geodata. The "Administrative Database" structures all data necessary for the approval process. ISMO enables support by competent authorities in the notification process and post market monitoring of environmental effects [24]. Checkpoints defined by ISMO were used to compile and integrate appropriate environmental monitoring programmes in the WebGIS GMO monitoring.

Compared with the public register of the BVL, advantages of the WebGIS GMO monitoring are obviously the possibility to map registered GMO fields as well as to perform spatial analyses by additional relevant geodata useful for GMO monitoring issues and environmental risk assessment. The use of licence-free open source software for assembling the application is another advantage compared with the public register of the BVL which is based on proprietary software. The WebGIS GMO monitoring is not intended to compete with the public register of the BVL, but it serves as a supplement for more transparency regarding the localisation and management of single GMO fields and agricultural patterns.

The Federal Nature Conservation Agency provides another WebGIS application [51] which allows displaying Natura 2000 reserves as well as predefined buffer zones of 1,000 m around them. An interactive query offers additional information on the respective nature reserve, like name and site code. Specific information on protected species in general or species that might be affected by GMO cultivation individually is not provided.

Another application called "Risk Register Genetic Engineering Agriculture" [52] displays, for instance, all Bt-maize fields cultivated in 2009 and 2010 in Germany. The respective field geometries were derived by using Google Maps. Additional thematic maps were integrated on the basis of the official GMO location register of the BVL displaying static density maps of GMO cultivation on different administrative levels and for different periods and crops. However, this application just visualises GMO fields, whereas the WebGIS GMO monitoring

additionally enables performing GIS procedures. Furthermore, interactive dynamic generation of buffers and intersection with additional geodata enhance the WebGIS functionalities in terms of spatial analysis. For instance, it is possible to intersect data on Bt-maize fields with additional geodata like related monitoring sites or distribution maps of the corn borer as being the target object for Bt-maize cultivation. Furthermore, the WebGIS GMO monitoring facilitates linkage to PortalU [53] as being the German realisation of the European INSPIRE directive [33] which aims at "establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment". Accordingly, data from the WebGIS GMO monitoring will enhance the database of PortalU and enable remote geodata access without implementation of a local GIS software at the client PC.

Compared to the work published by Kleppin et al. (2008) [42], the database was complemented by additional geodata, e.g., on environmental monitoring networks and the respective information on measurement parameters. Apart from that, the WebGIS GMO monitoring was optimised and improved by the implementation of additional sophisticated GIS techniques including buffer and intersect tools. However, long-term risks of GMO cultivation are difficult to assess, in particular, because possible impacts depend on spatially varying conditions [54]. Anticipating risks is often hampered by limitations in scientific knowledge or in availability of data, in particular, in cases where a complex process of change is continuing (e.g. climate change) or a new technological context is added to an established interaction network. An increasing amount of information can be accessed via the Internet. Particular in recent years, attention has focused on the presented WebGIS technology which enables compilation and access to data, e.g., affecting the dispersal of GMO, such as wind speed and direction. However, GIS is not only used for pre-event vulnerability assessment but can be used also for improving preparedness, mitigation, monitoring and response plan activities. Thus, the use of WebGIS provides instructive links with administrative, socioeconomic and other data, and enhances communication of the results to policy makers and the public. This communication dimension is fundamental - local people need to incorporate risk awareness into their culture [55].

## Conclusions

According to Wilkinson et al. (2000) [56] and Züghart and Breckling (2003) [57] criteria for selecting monitoring sites and regions include 1) representativeness of sites cultivated with specific GMO, 2) representativeness



of ecological regions containing the spectrum of relevant indicators, 3) availability of sites already monitored within other environmental programmes, and 4) areas with environmental conditions facilitating spread or survival of GMO. The WebGIS GMO monitoring supports this task by providing data on the distribution of GMO fields as well as on the distribution of monitoring sites of different environmental monitoring programs and, thus, helps in selecting appropriate monitoring sites. Furthermore, the article at hand demonstrates that the use of the WebGIS GMO monitoring is a useful and efficient tool to assess the individual and spatial risk potential before and during GMO release since it can be used to identify coexistence problems between Bt-maize and conventional maize cultivation on the one hand and between Bt-maize cultivation and conservation issues on the other hand.

Since in the future number and location of GMO fields might change considerably, the integration of geometries of Bt-maize fields into the WebGIS should be improved by an automation of the update procedure. Difficulties arise when no free Web services on ALK data are available to locate the respective GMO fields precisely. This is the case for about one third of all federal states in Germany. A possible solution is to compile the information directly from land registry offices. But this causes additional costs and is very time consuming. In this context, access to the 'Integrated Administration and Control System' (IASC, in German: InVeKoS = Integriertes Verwaltungs- und Kontrollsystem) would be a better and more efficient solution. Referring to this, in 1992 in the course of the reform of the 'Common Agriculture Policy' (GAP) the implementation of an 'IASC' was decided. It was introduced in Germany as per regulation no. 1782/2003 on December 3th 2004 (BGBl. 1 p. 3194) in order to define cultivation premiums. However, a nationwide information system on spatial and temporal cultivation patterns integrating agricultural data of all federal states has not been established, yet. In completion with information provided by the official GMO location register, such information platform could be used for detection of potential conflict regions with regard to conventional and Bt-maize cultivation. Since access to these data is not possible so far, future work aims at detection of maize fields by remote sensing data to integrate these data into the WebGIS application.

Furthermore, pollen dispersal plays an important part in the spread of GMO. Thus, currently the dispersion model AUSTAL2000 developed by the German Environmental Protection Agency [58] is being implemented in the WebGIS GMO monitoring. The Lagrange particle model considers time-dependent emissions from road and industrial sources. Modification of this software

should enable simulation of Bt-maize pollen dispersal to quantify pollen load into conservation areas or conventional maize fields. Further, the dispersion model could help to establish a pollen monitoring network based on technical samplers or biological sampling by bees with respect to VDI 4330, parts 3 and 4 described by Hofmann et al. (2010) [45].

#### Authors' contributions

LK developed the WebGIS GMO monitoring and drafted the manuscript. GS composed the section Backgrounds and participated in the development of useful GIS operations. WS concentrated on the chapters Discussion and Conclusions. All authors read and approved the final manuscript.

#### Competing interests

The authors declare that they have no competing interests.

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