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***Cover Letter**

We here submit a manuscript which extends the work presented at 2011's Spatial Ecology and Conservation meeting. We believe that this will be of interest to site managers, field conservationists and data providers because of the Web-based approach which allows fast and easy assessment of land cover change without requiring expensive software or datasets, and which will help aggregate resources for meta-analysis and consistency checking. The framework is designed to cope flexibly with future sources of high-resolution Earth Observation data and uses open standards to ensure interoperability and accessibility.

Thank you for your attention,

Lucy Bastin

Highlights

Web-based tools and mapping services can be used for quick visual assessment of land-cover change.

This can increase extent, coverage and quality of shared land-cover change maps.

We produce a new Web tool that is cheap, simple and has been successfully used by conservationists.

This could be used to monitor sites and inform conservation priorities.

Uncertainty information supplied by users helps identify inconsistencies and potential errors.

Open-source mapping and services for Web-based land-cover validation

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Abstract

Monitoring land-cover changes on sites of conservation importance should allow problems to be detected, solutions to be developed and the effectiveness of actions to be assessed. However, the remoteness of sites or a lack of resources means these data are frequently not available. Remote sensing may provide a solution, but large-scale mapping and change detection may not be appropriate, necessitating site-level assessments. These need to be easy to undertake, rapid and cheap. We present an example of a Web-based solution based on free and open-source software and standards (including PostGIS, OpenLayers, Web Map Services, Web Feature Services and GeoServer) to support assessments of land-cover change (and validation of global land-cover maps). Authorised users are provided with means to assess land-cover visually and may optionally provide uncertainty information at various levels: from a general rating of their confidence in an assessment to a quantification of the proportions of land-cover types within a reference area. Versions of this tool have been developed for the TREES-3 initiative (Simonetti, Beuchle and Eva, 2011) which monitors tropical land-cover change through ground-truthing at latitude / longitude degree confluence points, and for monitoring of change within and around Important Bird Areas (IBAs) by Birdlife International and the Royal Society for the Protection of Birds (RSPB). In this paper we present results from the second of these applications. We present further details on the potential use of the land-cover change assessment tool on sites of recognised conservation importance, in combination with NDVI and other time series data from the eStation - a system for receiving, processing and disseminating environmental data. We show how the tool can be used to increase the usability of earth observation data by local stakeholders and experts, and can assist in evaluating the impact of protection regimes on land-cover change.

Keywords:
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1. Introduction

Monitoring sites of conservation importance such as Protected Areas (PAs), Alliance for Zero Extinction (AZE) sites and Important Bird Areas (IBAs) is a priority for evaluating whether funding decisions and management strategies are succeeding in protecting biodiversity around the world. Site-based conservation is thought to be appropriate for some 80% of threatened mammals, birds, tortoises and turtles, and amphibians (Boyd *et al.* 2008) and monitoring of such sites allows problems to be identified, solutions to be developed and the effectiveness of interventions to be assessed. Whilst field-based monitoring might be ideal, limited resources, remoteness of sites or political instability means that this is not a practical option for many sites. Earth observations by remote sensing, on the other hand, are effective for large scale assessments and greatly ease repeated assessments which are needed to identify changes in ecosystems as well as trends in anthropogenic pressures. Remote sensing is becoming more and more a tool for biodiversity science and conservation (Turner et al. 2003).

1.1. Mapping land-cover

Land-cover is the observed biophysical cover of the Earth's surface, describing both vegetation and man-made features. The monitoring of land surface can nowadays be done at the resolution of less than one metre, but interpretation of the captured images remains a challenge. Land-cover maps, especially at a global scale, e.g. Global Land-cover 2000 (GLC 2000, Bartholome & Belward, 2005), MODIS (Friedl *et al.*, 2002) and GlobCover (Bicheron *et al.*, 2008) are often derived from a supervised classification of remote sensing data, where reference locations are made available to a decision-tree classifier (see e.g. Friedl et al., 2002 and McIver and Friedl, 2002) that is further applied to the whole dataset. The classification process then uses the probabilities of membership to a given class defined by the spectral signature for each pixel. Land-cover data can be further improved by using prior knowledge on the likelihood of a given class to appear at a certain location. A mangrove, for example, cannot be found more than a few kilometres away from the coast.

However, these large-scale land-cover assessments exhibit large uncertainties. For annual products such as MODIS, a confidence value can be attributed to each pixel by looking into the temporal variations of the spectral classification within a year. Gross *et al.* (2012) found large uncertainties in classification accuracy in all African biomes with the exception of deserts and rainforest over the years 2003-2009 in Africa (Figure 1). When compared, available land-cover products show significant differences (see i.e. Herold et al., 2008), in particular across cropland and forest domains as demonstrated by Fritz *et al.*, (2009). Aside from the impact of the use of different satellite sensors and different classification methodologies, the main obstacle to harmonized products is the lack of the *in situ* validated data needed for calibrating the products, as well as for validating the resulting maps. Strahler *et al.* (2006), in their recommendations for evaluation and accuracy assessment of global land-cover maps, advocate the setting up of a universal validation dataset as the first step in ensuring consistency in land-cover maps.

1.2. Assessing land-cover change

The further use of land-cover maps for quantifying and possibly forecasting the extent of changes occurring on the Earth's surface is subject to even greater difficulties because of an absence of regularly updated and validated land-cover data. Many products are released every 5 years with a delay of a few years after the last reference year. A notable exception is the annual MODIS land-cover product which is released on an annual basis, but presents a number of serious limitations for our purposes (Gross et al., 2012). Errors in identification of land-cover classes make the use of these broad scale maps for site-based monitoring impractical. However, the increasing availability of images at the optimal operational resolution for measuring actual land-cover changes (Mayaux et al 2008), means that it is now possible to undertake monitoring of land-cover change for biodiversity assessments without having to wait for validated land-cover products, something that is overdue (Buchanan et al. 2009). For example, Beresford et al. (in prep) quantified the benefits of formal protection of IBAs using visual interpretation of Landsat images from multiple time periods using sampling at points placed in a grid across sites (following Brink & Eva 2009). This illustrates how the rapid, simple visual interpretation of images using a basic interpretation tool (Simonetti et al., 2011), without the costs of dedicated image analysis software, can contribute to conservation monitoring.

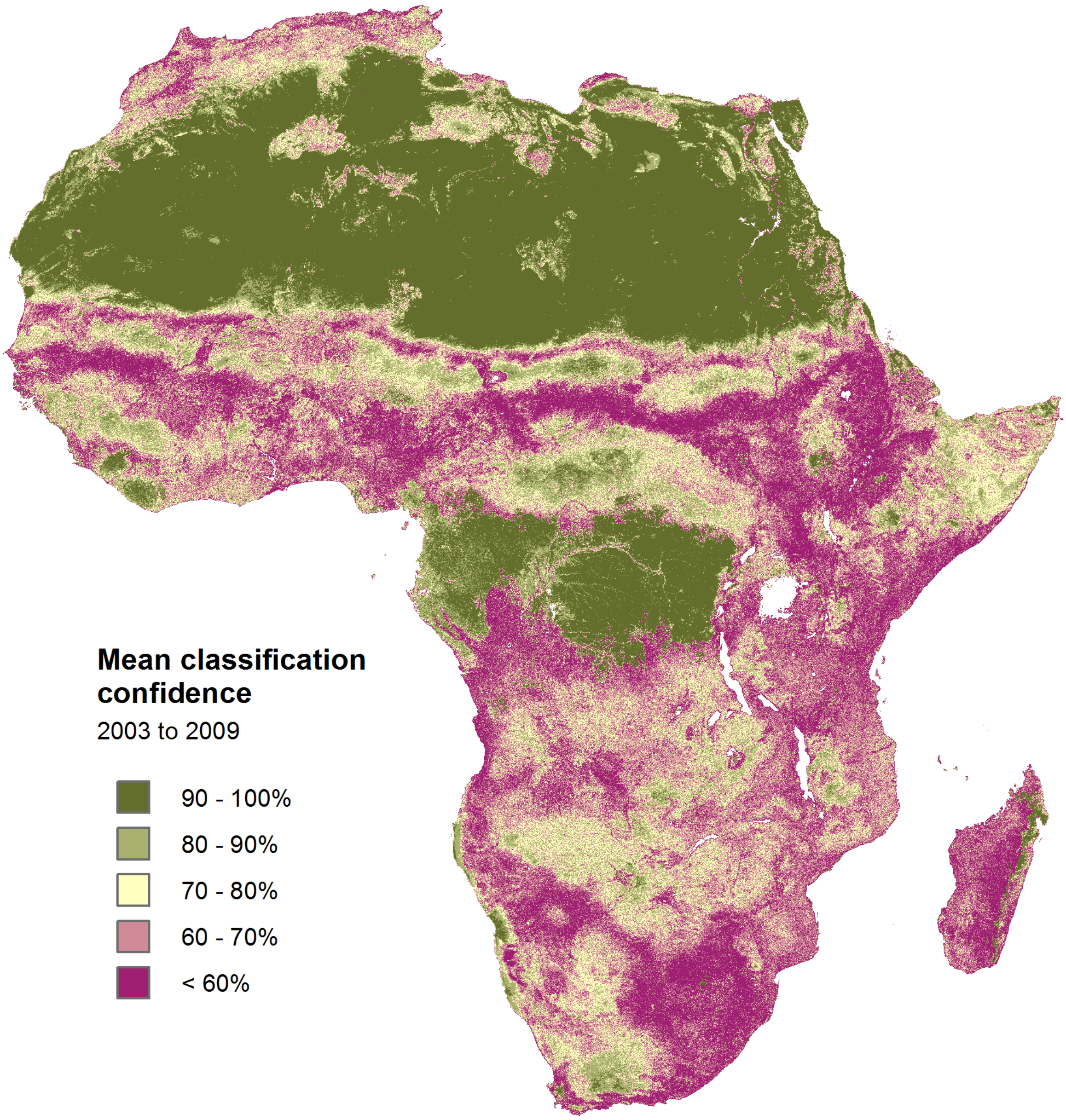

Figure 1. Mean classification confidence layer calculated from the annual confidence layers of the MODIS land-cover product showing for each pixel the averaged probability that the correct land-cover label was assigned between years 2003 and 2009. (Gross et al., 2011).

2. Land-cover validation and the World Wide Web

The frequent disagreements in the definition and interpretation of land-cover data and the desire for a tool to assess changes have motivated the development of several Web based applications for use by people (park rangers, citizens, scientists and others) with access to ground truth information.

With the growing use of volunteers for providing observations used for scientific work, observations from all possible locations can be gathered rapidly, at the global scale, and at very little cost. The Geo-Wiki application (www.geo-wiki.org) developed by Fritz et al. (2009) is an example of a crowd-sourcing system for validating global land-cover using citizens. Disagreement maps between different global land-cover products are provided on the site to highlight areas where validation of the global products is needed using information on Google Earth. In contrast to the Geo-Wiki, which is open to all and investigates the level of disagreement between existing forms of land-cover information, we will here discuss a Web-based application designed for a more targeted group of users, which focuses on mapping and monitoring land-cover change rather than on identifying the disagreements between existing products and ground truth. The tool also allows the documentation of uncertainties in the validation process.

With an increasing demand for distributed models and databases and growing use of open, interoperable Web services, the potential to integrate complex data and modelling resources from many sources is huge. New architectures and services allow end-users (including park managers, decision-makers and researchers) to easily access the means to assess, monitor and forecast the state of, and pressure on, sites of conservation importance (e.g. protected areas) at the global scale. Foremost in this movement towards data sharing is the Group on Earth Observations Biodiversity Observation Network (GEO BON), the biodiversity arm of the Global Earth Observation System of System of Systems (GEOSS).

In this paper, we present a Web-based tool for visual assessment of land-cover change based on Landsat images. This tool permits the rapid generation and sharing of up-to-date land-cover data including estimates of uncertainty, facilitating more robust and accurate quantification of changes within and around sites of conservation importance.

3. Methods

Buchanan et al. (2009) suggested some requirements of a remote sensing-based biodiversity observation system that we tried to follow. These included prioritisation toward sites of conservation value, temporal and spatial resolutions of monitoring appropriate for practical conservation, sustainability (to allow long-term indices to be developed), flexibility to utilise new types of Earth Observation (EO) data as they become available, strong involvement of local stakeholders and conservationists, and robustness and ease of implementation. Additionally, we recognised that the system required a centralised database to record observations so that data can be backed up and easily combined to produce national, regional or global trends. Key requirements of a Web-based toolkit for the rapid assessment of land-cover change, or for validation of previously mapped land-cover or land-cover change, were identified from user feedback (Beresford et al., in prep.). Some of these requirements related to the technical side of building a tool that meets user needs, and others to the use of the tool. To increase the potential uptake of the tool for operational use, we gave user requirements priority over technical ease.

We developed a tool that was spatially targeted to Important Bird Areas (a global network of sites appropriate for the long term conservation of birds (e.g. Fishpool and Evans 2001), and valuable for other biodiversity (Pain et al 2005)), but which could be used on any sites (many IBAs are also PAs and some are AZEs). We ensured that it had flexibility in sampling, utilised historical EO data for baseline assessments, was flexible in the remote sensing data that it could use, was simple to use and understand without extensive training, was based on open access software, and had a central repository for data. The tool also allows a variety of experts to easily classify the same set of samples, in order to capture the variation in opinion within and between expert groups. Similarly, it is useful to allow an expert to record their own uncertainty about a classification. This helps in targeting the acquisition of (potentially expensive) extra resources to refine the classification. One of the main reasons for uncertainty may be that there is genuine mixing or transitional change within a sample area, and it is important to separate this mixing (about which an expert may be certain) from uncertainty stemming from other sources such as cloudy or unclear imagery.

Supplementary contextual information (such as a localised NDVI[1] signature for the sample area), can be extremely useful in giving insight into vegetation health and change over time, and assisting an expert in their choice between several possible classifications. Therefore, wherever such information is available it should be used, and ideally it should be derived from reputable, up-to-date sources which use standardised and well-documented methods of calculation – often a challenge in the internet environment. Finally, an important consideration is the hosting of the satellite and other data used for these classification tools. The application which we describe here uses Landsat imagery from the Global Land Survey (GLS) which is hosted in the form of REST Web Map Services by Environmental Systems Research Institute (ESRI). This allows great flexibility in the areas which can be validated, since a user may design and upload a set of reference points anywhere on the globe. However, the trade-off is that the user has limited control over the temporal granularity and processing of the imagery, and exact dates for images are not always available. The alternative is for a user to acquire and host their own imagery as a Web Map Service, which allows greater specificity for certain study areas, but requires more investment in terms of technical expertise, investment, bandwidth and disk space. This approach simply requires a re-configuration of the tool to add the URL of the resulting WMS to its list of available maps. In most cases a combination of the two approaches is likely to be most fruitful, with supplementary imagery hosted locally where appropriate.

3.1. Technical implementation and functionality

The work was derived from an IDL-based tool generated by Simonetti et al., (2011) which was made available to experts, referred to as "validators", to help them in performing the validation of land-cover data. Our aim was to use the existing IDL tool as a template, incorporating the well-tested features and trying to address any extra requirements specified by the experienced user community.

While the IDL application was extremely successful in engaging validators and national experts, it has a number of limitations as it requires users to attend a workshop or to load data and software locally, requires users to send back their edits, cannot provide contextual information such as Google Earth imagery, does not provide means to capture data uncertainties and does not allow the users to deal with data mixture (e.g. heterogeneous land-covers).

A questionnaire was circulated to 27 expert users during two international validation workshops, and their answers were used to inform development of the Web-based tools. Besides the need for

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[1] NDVI is calculated by subtracting the red channel from the near-infrared (NIR) channel and dividing their difference by the sum of the two channels, as follows: NDVI= (NIR - RED) / (NIR + RED)

Web-based tools in order to access remote databases, other requirements identified were extensions of the existing tools to allow the user to specify their certainty about a classification, and to record mixing of land-covers within segments.

3.2. Technical implementation

An existing PostGIS[2] database was coupled with GeoServer[3], UMN MapServer[4] and bespoke javascript/php code to generate a browser-based interface that can be accessed by authorised users to view and edit data from a centralised source. The Web-based application gives access to Landsat GLS data via WMS (from ESRI's REST-based service) to allow a flexible wall-to-wall sampling approach (albeit with satellite data of variable quality) at any location specified by the user. Sample locations can be uploaded, labelled by the experts for a selection of time periods according to a user-specified legend and downloaded from the PostGIS database as a csv-format file.

4. Results

In this section we present the completed tool and explain its operation, with specific attention to the various sources of information that are federated in the interface to assist validators with their decisions. We also explain how validators can report classification uncertainty can report in order to focus further correction efforts, and the way in which mixed land-covers can be recorded.

4.1. The Web based land-cover classification tool

A demonstration video can be viewed at:
http://landcover-change.jrc.ec.europa.eu/validation/videos/Birdlife_editor.html

An expert who logs in is presented with a map showing their allocated sites (Figure 2).

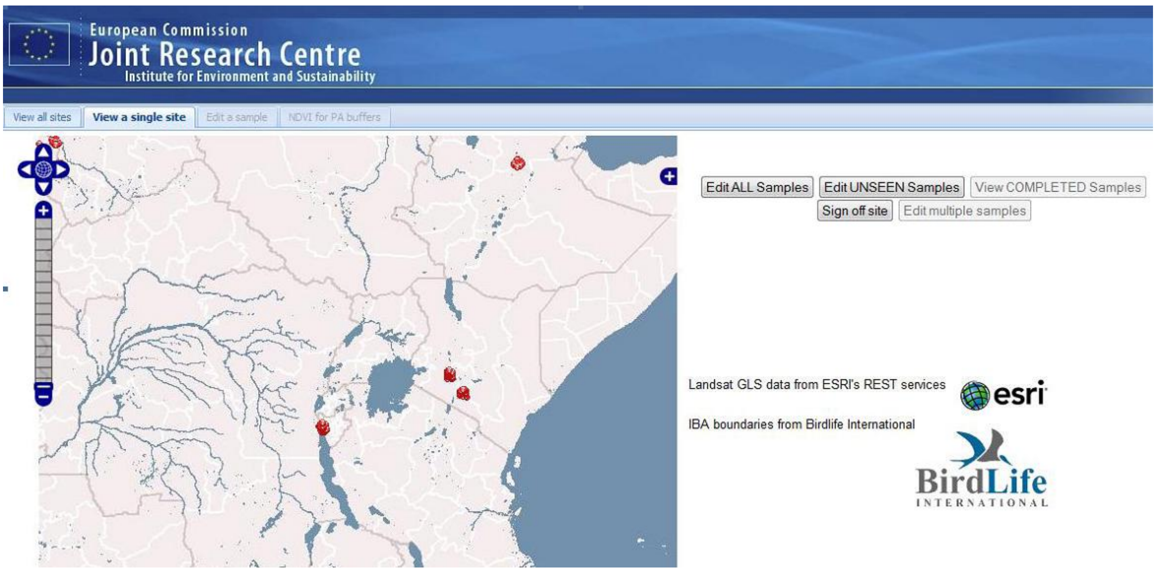

Figure 2. Important Bird Areas in Kenya made accessible to a registered user.

[2] http://www.postgis.org/
[3] http://www.GeoServer.org/
[4] http://www.mapserver.org/

Where a site (for example, an IBA) has well-defined boundaries which can be made available through a Web service, this polygon is displayed along with the collection of reference sample points, and any satellite data which may be available for the area (Figure 3).

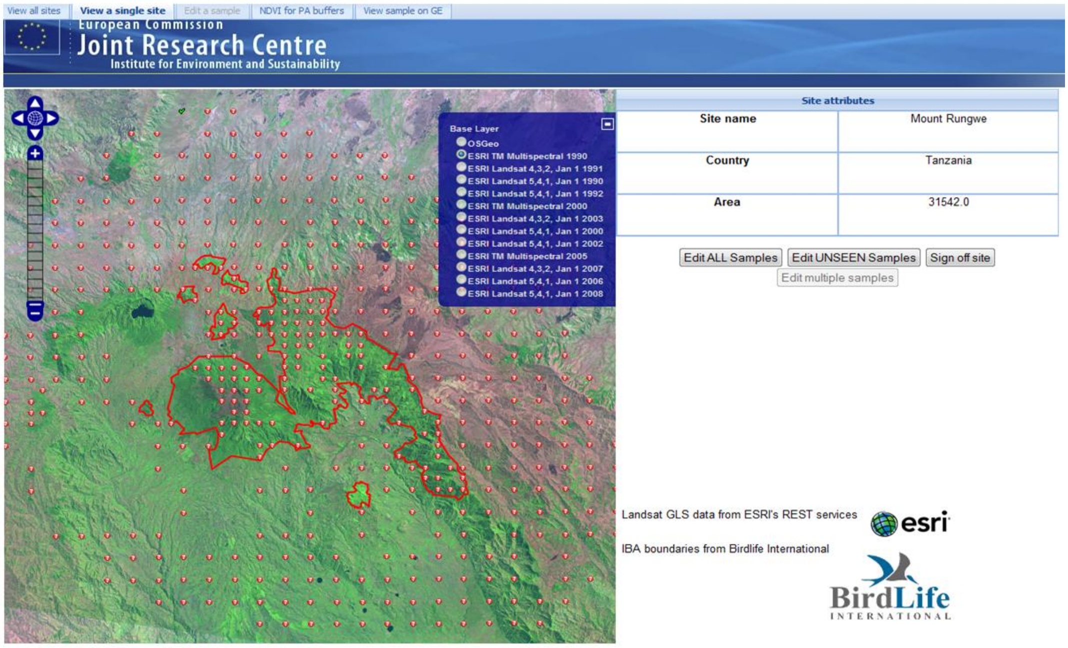

Figure 3. Reference points and boundaries of an Important Bird Areas as seen by a registered user

The buttons on the right take the user to the editing screen (Figure 4) to view an individual reference point. Here, the Landsat imagery for three time periods is shown, with the sample box overlaid. The aim is to classify the contents of the red sample box, which covers 300m x 300m (90 ha).

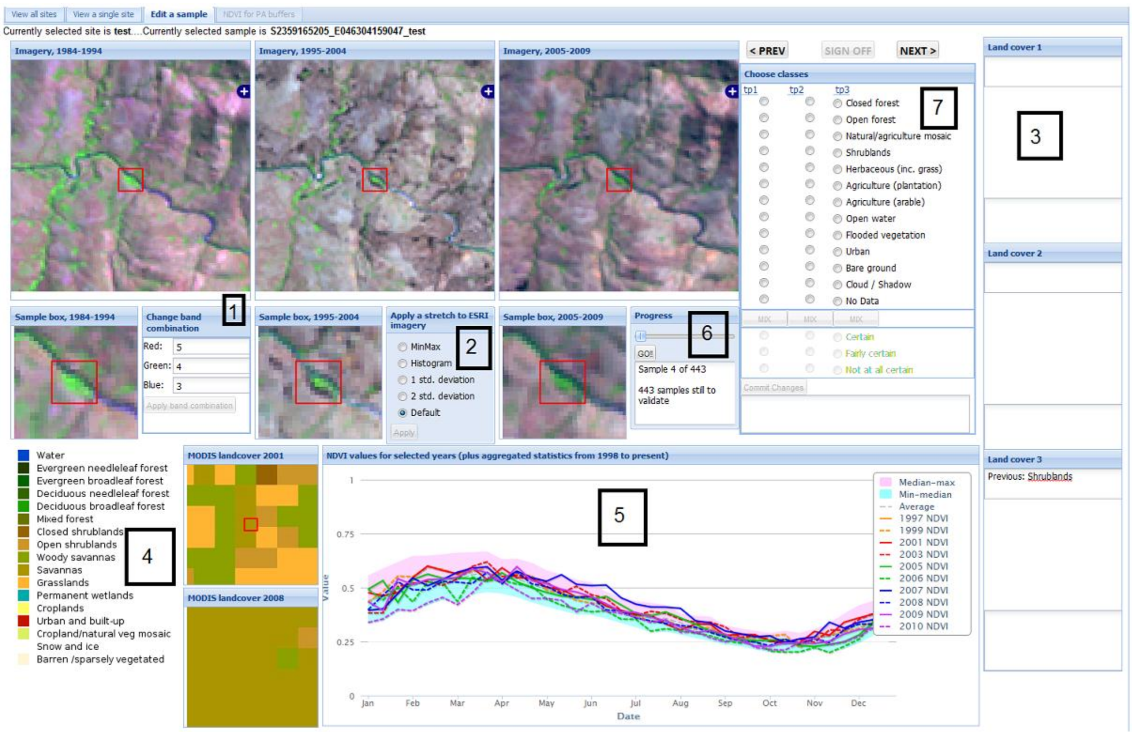

Figure 4. Screen capture of the editing window. Numbered boxes refer to sections in text.

In Figure 4, the following analytical tools are identified by numbers:

1. *Band combination adjuster*. The user may change the Red, Green and Blue bands of the Landsat data, and apply the updated colour composition to all map windows. Different band combinations are of value for identifying different classes of vegetation, soil moisture and land-use: for example, with Landsat TM data, the representation of bands 4, 3 and 2 as red, green and blue respectively allows healthy or dense vegetation to be easily distinguished by its level of 'redness' , while urban areas stand out in contrast, taking on cyan shades, and ice/cloud shows as white or light cyan. By contrast, a 7, 4 and 2 combination gives a more 'natural' appearance, with green vegetation, and is particularly useful for analysing the effects of fire.

2. *Stretch tool*. Allows min-max, histogram and default stretches on the Landsat WMS imagery. Stretches of this type increase contrast in specific ranges of the recorded data, and so allow the identification of different land-cover types whose reflectance varies characteristically within those ranges.

3. *Existing classification windows*. These will display any existing classifications for each time period.

4. *MODIS Land-cover Map for context*. The reference point to be validated is overlaid on MODIS data from two different years for context.

5. *SPOT VEGETATION NDVI signals for all available years (i.e. from 1998 up to present)*, overlaid on the historical maximum, mean and minimum for this area. If the user hovers over the name of a year in the legend and clicks it, they can switch lines on and off to make the graph clearer. The value of contextual NDVI information is further discussed in section 4.1 below.

6. *Slider to move between sample points*. A user can jump ahead to a selected sample point by using this slider - alternatively, the 'Prev' and 'Next' buttons can be used to step through samples one by one.

7. *Legend panel* where the user selects the labels for the current sample. This is further discussed in the next section.

The user may also choose to use a Google Earth plug-in which overlays the sample box on the 2D and 3D Google Earth imagery (Figure 5). This can be useful to get an idea of recent conditions, though it should not necessarily be treated as the truth. The tool can be configured to display imagery from any source which is available as a WMS, simply by making some changes to the database on the server.

The legend panel allows users to choose the land-cover for each sample, and to record their certainty about what is contained in the box. It is possible to record mixed land-covers if necessary. To begin with, the land-cover which the expert believes to be the dominant (majority) one within the sample box must be chosen (Figure 6). Several other items then become active, including the 'Mix' button and the 'Commit changes' button.

Figure 5. 2D/3D Google Earth visualisation of the environments around the selected reference point.

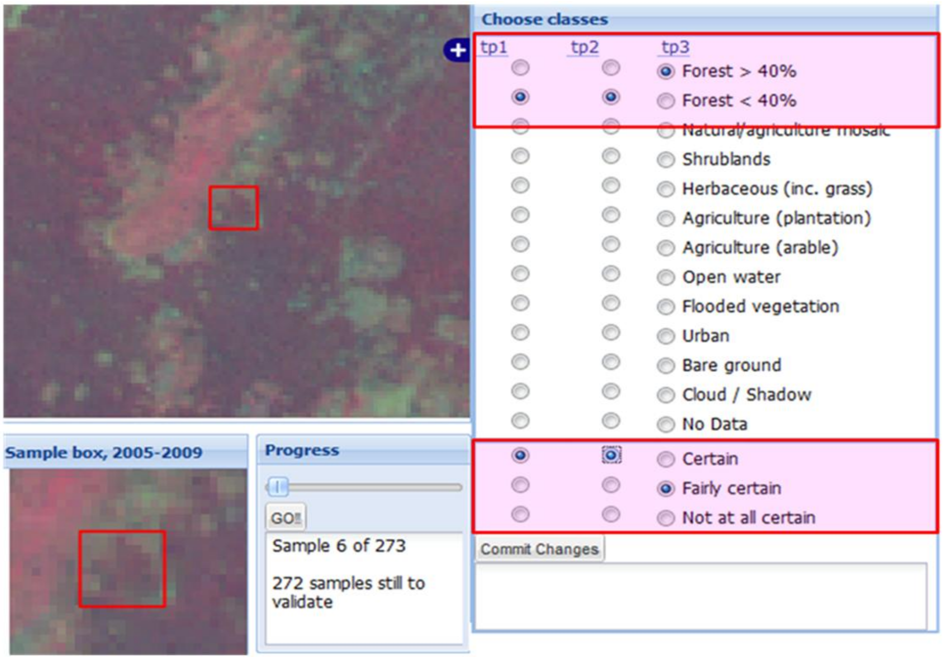

Figure 6. The interface for supplying land-cover and certainty information.

There are three main ways in which land-cover can be recorded using this tool:

1) dominant land-cover only;

2) dominant land-cover plus expert's certainty of classification;

3) land-cover with mixing (with or without associated expert uncertainty).

Approach 1) is the traditional method which was available within pre-existing tools. It is easy to interpret and analyse, but lacks sensitivity to fine-scale changes. In particular, this approach can be problematic when attempting to monitor gradual change such as forest loss, since a homogeneous classification will only identify the trend at the point when a new land-cover becomes dominant.

The addition of a categorical certainty qualifier (2) does not greatly increase the processing time of samples, and provides additional information about the likely accuracy of the output. This can be particularly useful in focusing efforts on acquisition of extra imagery or information to improve areas whose classification is recorded as uncertain.

Approach 3), which can be used to record up to three different land-cover types and their relative proportions within each sample area, is more time consuming, but also more likely to identify gradual or small-scale changes in land-cover. This aspect of the tool is perhaps best targeted at specific land-cover types; for example, if the aim is to investigate encroachment of artificial land-cover into natural vegetation, mixing need only be recorded in sample locations containing artificial land-cover types. Figure 7 shows the interface through which users can supply mixture information. A user may, *in addition* record their overall certainty using the interface.

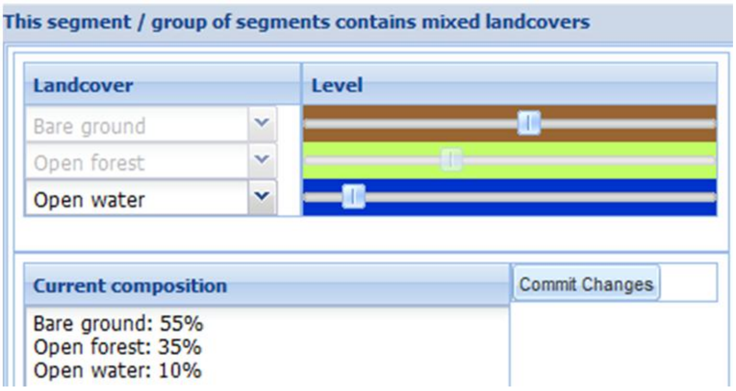

Figure 7 The interface through which users can specify percentages of mixed land-cover.

The mixture information, once submitted to the database can be reported back to the user in a variety of ways. The easiest is to show a simple summary for each sample box. Aggregate information can also be generated and displayed in the same way – for example, to show overall proportional changes between years.

4.2. Benefits of NDVI for assessing vegetation changes in land-cover

Nearly all remote sensing techniques for monitoring green vegetation are based on vegetation indices. The Normalized Difference Vegetation Index (NDVI) is one of the most well-known and commonly used indices to detect and monitor vegetation presence through multispectral remote sensing data. The (dimensionless) index is directly related to photosynthetic capacity and hence to the energy absorption of plant canopies, and can be used as a proxy of vegetation density and vigour. For land-cover monitoring applications, NDVI is often used as a temporal vegetation signature. It characterizes the phenology of the vegetation, (i.e., its floristic composition and density), but is also affected by local environmental conditions (e.g. rainfall seasonal repartition and amount, temperature, altitude, slope, and soil type).

Comparing NDVI signatures over time (i.e. comparing the signature of one pixel with its signature in the past) or in space (i.e. comparing the signatures of neighbouring pixels) allows us to highlight and interpret modifications of the shape of the signature. These may result from inter-annual variations or from more dramatic changes such as land degradation or land-cover change. This approach is used in the framework of the study to monitor protected areas, as well as to highlight the possible pressure on surrounding areas. Figure 8 shows how the validation tool can retrieve NDVI values over the Web from a monitoring system (described below) and can then display the average NDVI for the core of the protected area as well as the average NDVI recorded in each concentric buffer zone around the protected area. NDVI profiles are computed by the eStation[5], a collecting and processing service designed to automatically deal with the reception, processing, analysis and dissemination of key environmental parameters derived from remotely sensed data. More precisely, the NDVI data are derived from 10-day global coverage composites at 1 km resolution obtained from the VEGETATION instruments onboard the SPOT satellites, by the eStation developed at the Joint Research Centre (JRC) of the European Commission.

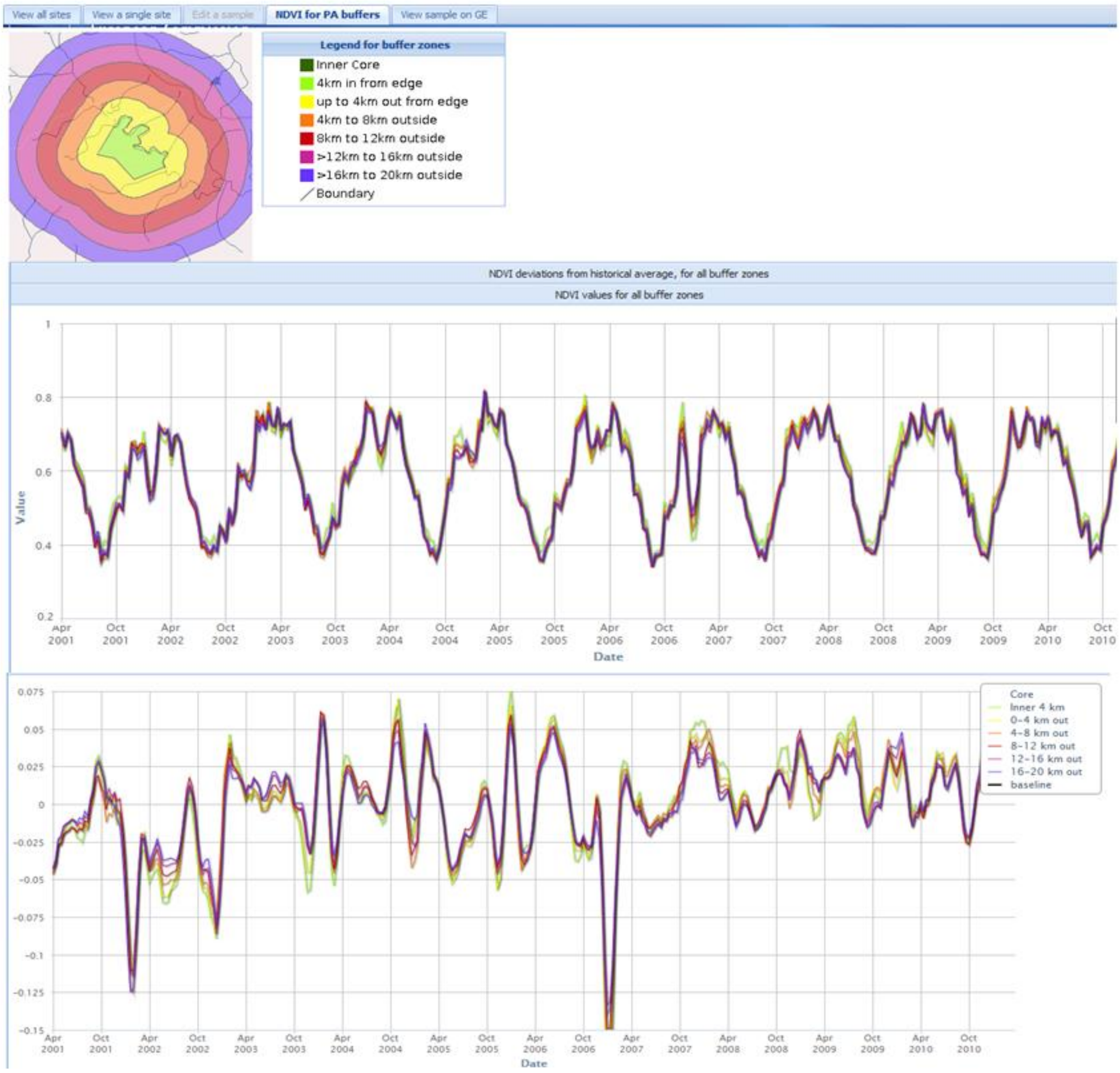

Figure 8. Spatio-temporal series of NDVI data in a protected area and its surroundings. The upper graph shows the average value for each buffer zone, while the lower graph shows the deviation of each zone from its historical average.

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[5] http://estation.jrc.ec.europa.eu/

4.3. Benefits of context information using Google Earth imagery

The availability of a direct link to Google Earth imagery is a major advantage of the Web-based tool. Google Earth imagery varies widely in quality, and in some regions is so poor as to provide no additional information, but in many areas it can be used to identify land-cover with a high degree of confidence. Moreover, the image acquisition date is provided and depending on the area, the user can visualise images at different dates using the time slider. Although the Google Earth images can be used to inform the classification of the Landsat images, land-cover should not be classified directly from the Google Earth images as changes may have occurred between the dates of the two images. Access to higher resolution Google Earth images is particularly useful for distinguishing easily confused categories e.g. identifying patches of shrub/agricultural mosaic from surrounding shrubland, and for interpreting topographic shading effects from rough terrain. However, the Google Earth imagery is less useful where rapid or fluctuating land-cover change occurs e.g. in coastal or seasonally flooded areas. The addition of recent and historical fire data may also be of use to the interpreter, allowing a rapid assessment of whether the seasonal burning regime in an area may have modified the land-cover.

4.4. Effectiveness of a Web based approach to land-cover classification

Monitoring approaches that are intended to be widely used must be easy to use and readily accessible. The current tool should meet both criteria, being simple, stable and intuitive. These are characteristics that we hope will increase the uptake of the tool.

Tool simplicity also means that the transition between points as they are interpreted is rapid. An experienced user can classify points at a rate of approximately 50-100 points (450-900 ha) per hour, or perhaps 500 points (4500 ha) per day. Speed of classification varies with a number of factors including:

1. User experience: classification speed increases over an initial training period but then plateaus for regular users.
2. Land-cover type: less easily confused categories (e.g. open water) are quicker to classify than more easily confused land-cover types (e.g. mosaic of natural and agricultural vegetation).
3. Reference to Google Earth imagery: classification is quickest if no reference to Google Earth imagery is required.
4. Variability of land-cover types within a sample: reference points with large areas of single land-cover types are quicker to process than highly variable areas with mixed land-cover.
5. Temporal variation: points where land-cover has clearly not changed between images are quicker to classify than points where different land-cover types or mixtures of land-cover types are present in each image.

5. Analysis of validation data – consistency checking

To assess accuracy of land-cover classifications and consistency between users in the use of the tool, two experienced users were given a set of 440 sample points covering a range of land-cover types. Their classifications for the 2005-2009 time period were compared with classifications from high quality Google Earth imagery from a similar time period (2006-2009). Overall classification accuracies using merged land-cover categories (see figure 9) were 87.7% and 85.0% for each of the two users independently. In 79.1% of cases, both users agreed on a land-cover type which was also the land-cover identified from the Google Earth imagery, and in 89.5% of cases, at least one user recorded the same land-cover type as shown on Google Earth. However, there was variation in both accuracy and user agreement between different land-cover categories (figure 9). Although overall classification accuracy between users was similar, there was considerable variation in their recorded levels of certainty (Table 1). User 1 tended to be more certain than user 2, but for both users, accuracy decreased with increasing uncertainty, suggesting the recording of certainty may be consistent within, but not between, users.

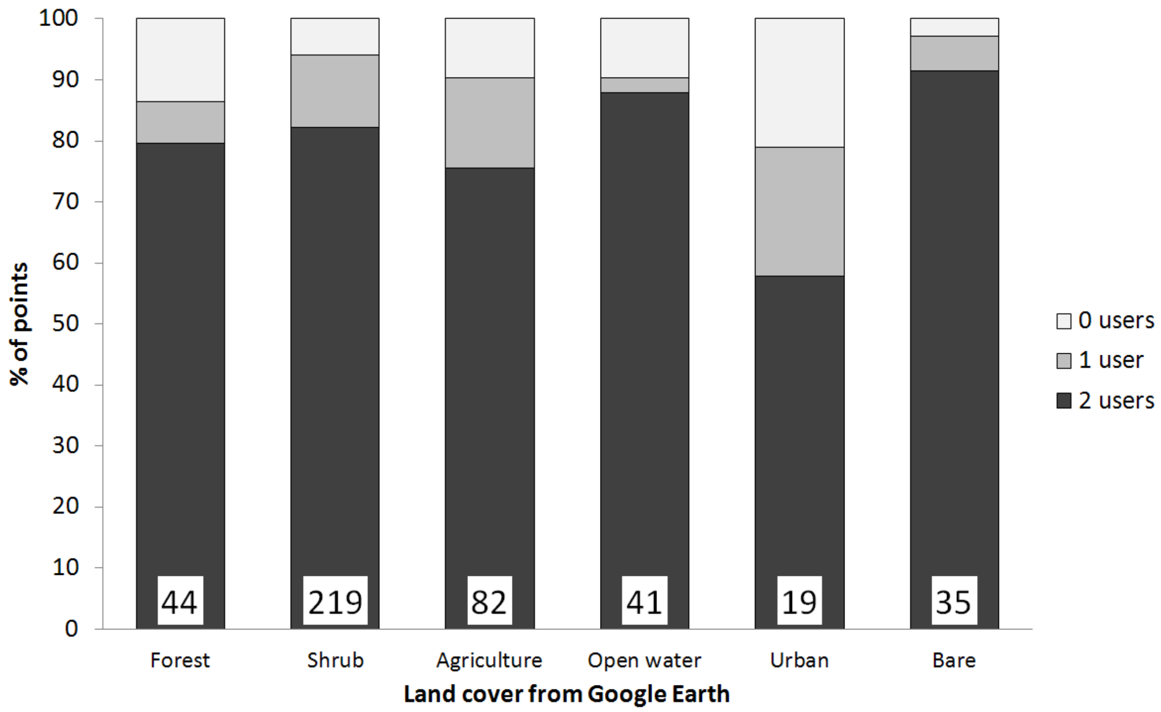

Figure 9. Percentages of sample points where 0, 1 or 2 experienced users recorded the same land-cover type as that identified from Google Earth. Similar land-cover categories have been merged (open and closed forest; agriculture and agriculture/natural vegetation mosaic; shrub, herbaceous and flooded shrub and herbaceous). Numbers on bars indicate sample sizes.

Table 1. Number of sample points classified "correctly" (same land-cover as identified from high resolution Google Earth images) and "incorrectly" by two experienced users, broken down by their recorded certainty level. Similar land-cover categories have been merged as described in the caption to Figure 9.

	user 1			user 2		
	No. of points incorrect	**No. of points correct**	**% correct**	**No. of points incorrect**	**No. of points correct**	**% correct**
Certain	21	282	93.07	18	184	91.09
Fairly certain	29	101	77.69	40	175	81.40
Not at all certain	4	3	42.86	8	15	65.22
Total			87.73			85.00

6. Discussion and conclusions

The tool presented here allows end-users with a minimum of training in image processing to easily submit an area of interest and analyse current and possible changes in land-cover by accessing remote sensing data held at remote locations. Accurate assessments of land-cover change are essential in a number of applications, including estimating current (and extrapolating to predict future) threats and pressure to biodiversity from shifting human populations and changes in agricultural practices; assessing compliance with and success of land management schemes; quantifying the fragmentation and loss of remnant habitats; calculating economic metrics such as carbon storage, to name just a few. Finer scale assessments of land-cover and land-cover change, as undertaken using this tool, can produce mapped information at a scale appropriate for site-level management, can build 'ground truth' libraries to assist with automated classification, and can also allow larger-scale land-cover maps to be validated and improved upon. The adopted architecture minimises the need to exchange large sets of data over the internet by focusing on a defined area and allows end-users to be independent from a specific working environment, as only a Web browser is required. These requirements are particularly critical for experts from developing countries who are unlikely to have access to expensive information systems yet are, at the same time, the only ones with access to recent ground truth observations. The dependence of the Web-based tool on the internet may also, however, be an Achilles' heel while many developing countries have a basic and unreliable ICT infrastructure.

The tool has only very recently been developed, but current testing suggests it is easy to use and appropriate for rapid assessment of land-cover. Further use will give a fuller indication of the benefits and problems associated with this tool. The accuracy of interpretation and agreement between observers is good, although it does vary between land-cover types. Further training or experience with the tool may improve this agreement. The certainty that observers attach to their interpretations may also converge over time, as currently there is some discrepancy in the way that this feature is used.

In terms of the development of the tool, further efforts will focus on improving several aspects of the tool, in particular the:

- addition of new functionalities;
- improved sharing of the information produced by the validators;

- integration of the tool within a broader set of services currently deployed by the JRC to assess and monitor protected areas at the global scale.

6.1. Addition of new functionalities

The eStation provides end-users with a broad range of ecological indicators, from fire occurrences to seasonal assessments of water availability, which can easily be made available in the Web client. However, the eStation is only now in the process of becoming a Web Processing Service (WPS) that will allow other applications to easily query the database. Though many indicators are already available for hundreds of protected areas, the means to compute the requested indicators on demand for a novel reference area designed by the end-user is not yet available. For similar reasons, end-users of the Web client can at present display only pre-computed historical NDVI records, but ongoing developments will allow the extraction of more targeted information for data exploration.

Further Web-based sources of satellite, aerial and contextual data which may be aggregated using the tool need to be identified. High-resolution imagery, in particular, is increasingly becoming available and the Web client will have to be able to ensure access to new data. Provided that the data are accessible through standard interfaces, this is simply a matter of configuration. Similar challenges are encountered with the constant growth of historical records. The forthcoming launch of the Sentinel 2 satellite by the European Space Agency which will provide high-resolution (10, 20, and 60-metre) optical imaging will demand new solutions that service the huge processing needs and tackle the challenges presented by handling multi-resolution information generated through novel processing chains.

6.2. Further distribution of validated land-cover change data

In contrast to the pure citizen-science approach, open to anyone willing to assess land-cover change, the tool described in this paper is targeted at people with a basic level of training in image processing or interpretation, to minimize errors and uncertainties in the information produced. This selective approach has an impact on the visibility of the efforts made by the end-users, since at the time of writing the outcomes are not automatically or immediately made available to the public. The Web-based strategy adopted for the validation tool should greatly ease the promotion of the tool and encourage further consistency checks with recognised experts where uncertainties are highest. The benefits of the validation process can be maximized only through a coordinated approach which regularly identifies gaps and encourages the experts to share the fruits of their efforts.

6.3. Integration of the land-cover validation tool in a larger context

The tool has initially been used to assess land-cover change on Important Bird Areas, and it is intended that it be promoted through the BirdLife Partnership to assess land-cover change on more IBAs. This will contribute directly to the essential monitoring of these sites. However, the validation tool was developed within a larger framework, the setting up of a Digital Observatory for Protected Areas (DOPA[6]), aiming at deploying a set of Web services for assessing, monitoring and possibly forecasting the state and pressure of protected areas at the global scale. DOPA is currently the responsibility of the Joint Research Centre in collaboration with other international organizations including the Global Biodiversity Information Facility (GBIF), the UNEP-World Conservation

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[6] http://dopa.jrc.ec.europa.eu/

Monitoring Centre (WCMC) and Birdlife International, its partner organisations. Conceived as a set of distributed databases combined with open, interoperable Web services including the eStation, DOPA relies heavily on accurate land-cover information to assess the state of protected areas (Dubois et al., 2011). As more ground information is collated and interpreted, so maps showing land-cover change and its associated uncertainties will potentially become available to the other services planned in the frame of the DOPA. This will be particularly valuable for the services dealing with habitat modelling and climate change impact, as well as with those dealing with governance and management issues. The integration of this broad variety of information into meaningful and robust indicators will clearly present new challenges.

We suggest though that even before the above developments are implemented, this tool will be useful to conservation biology and land-cover validation. It addresses a recognised need for a tool to monitor sites of conservation importance in a cost effective manner.

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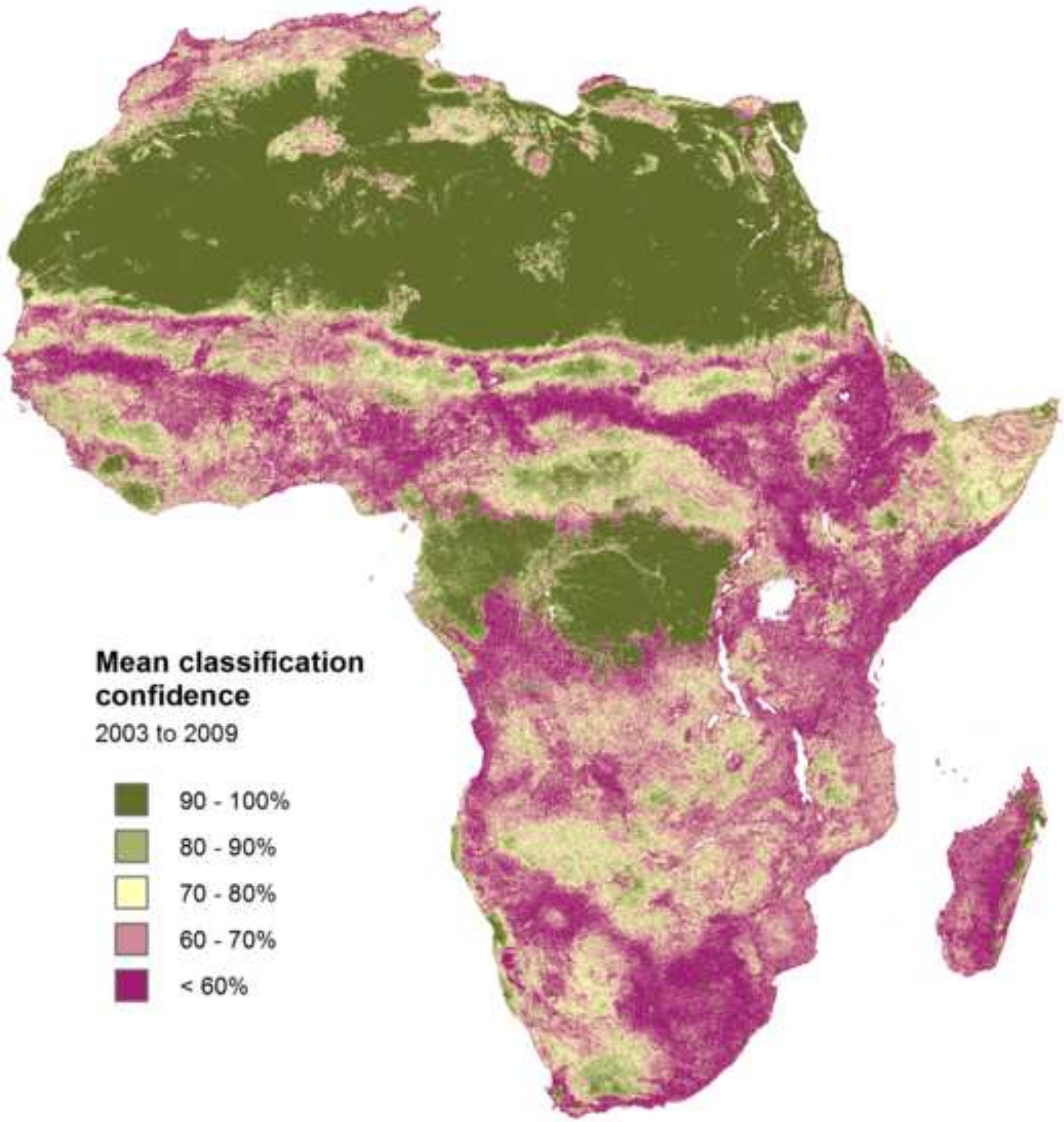

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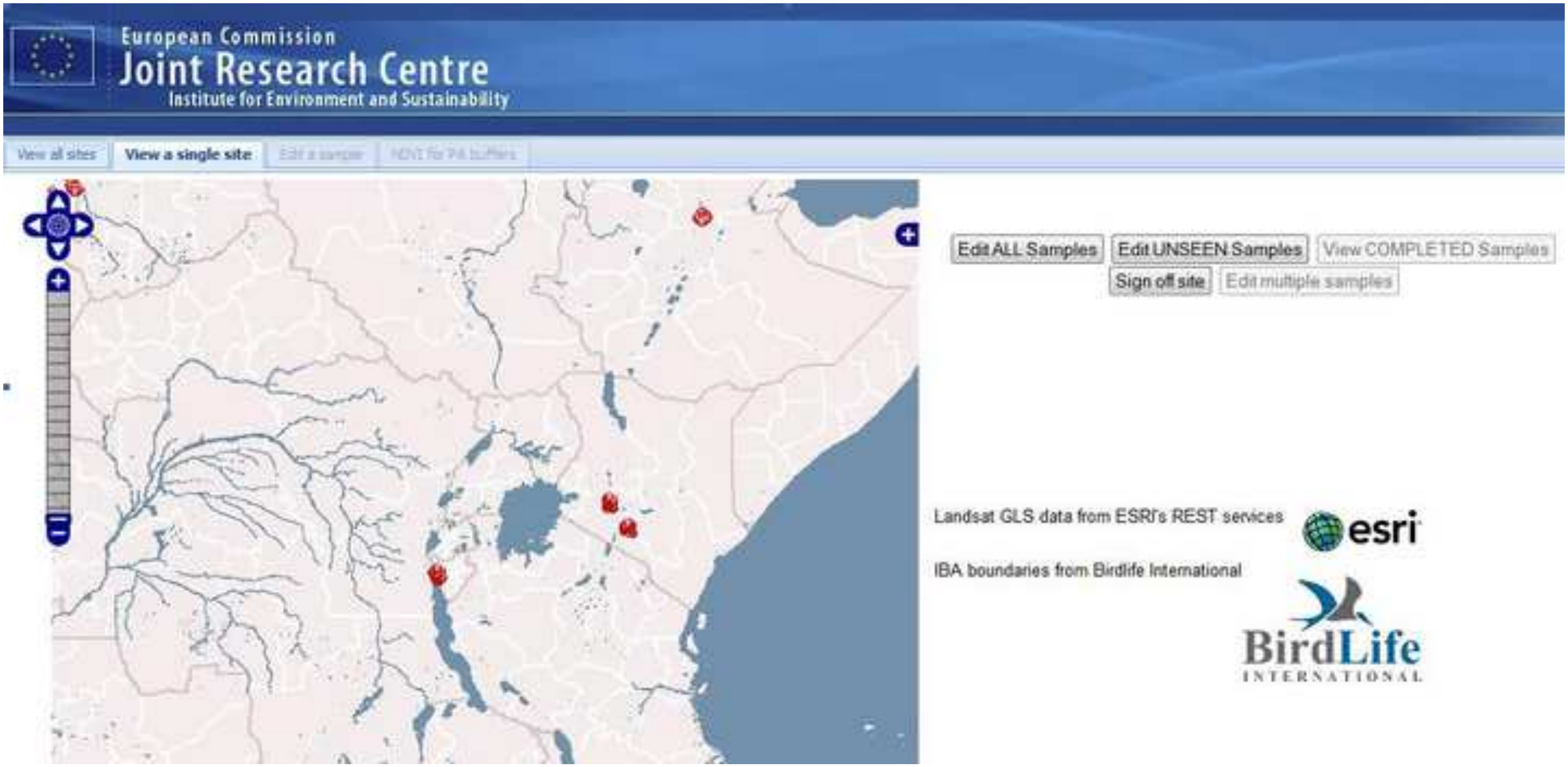

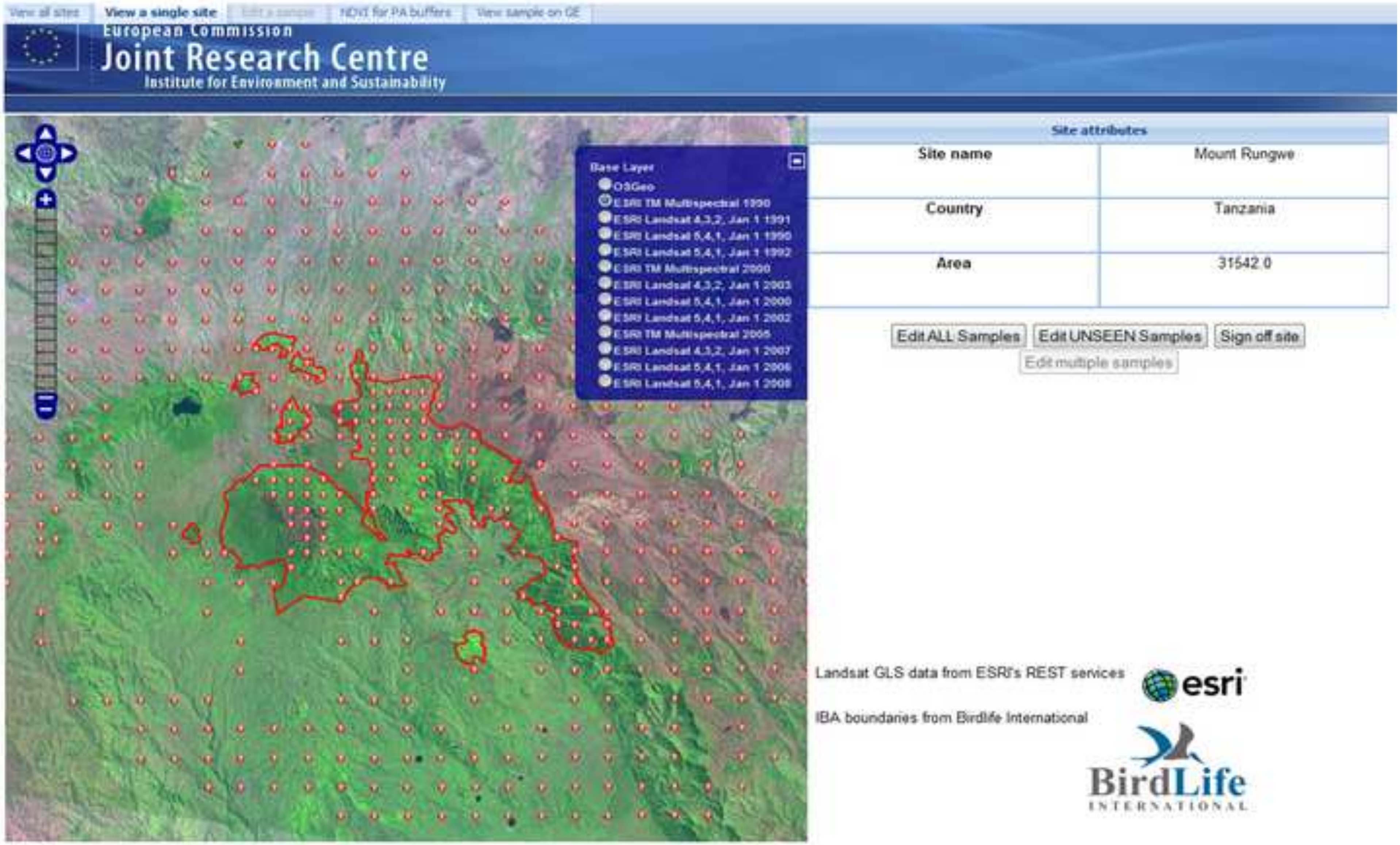
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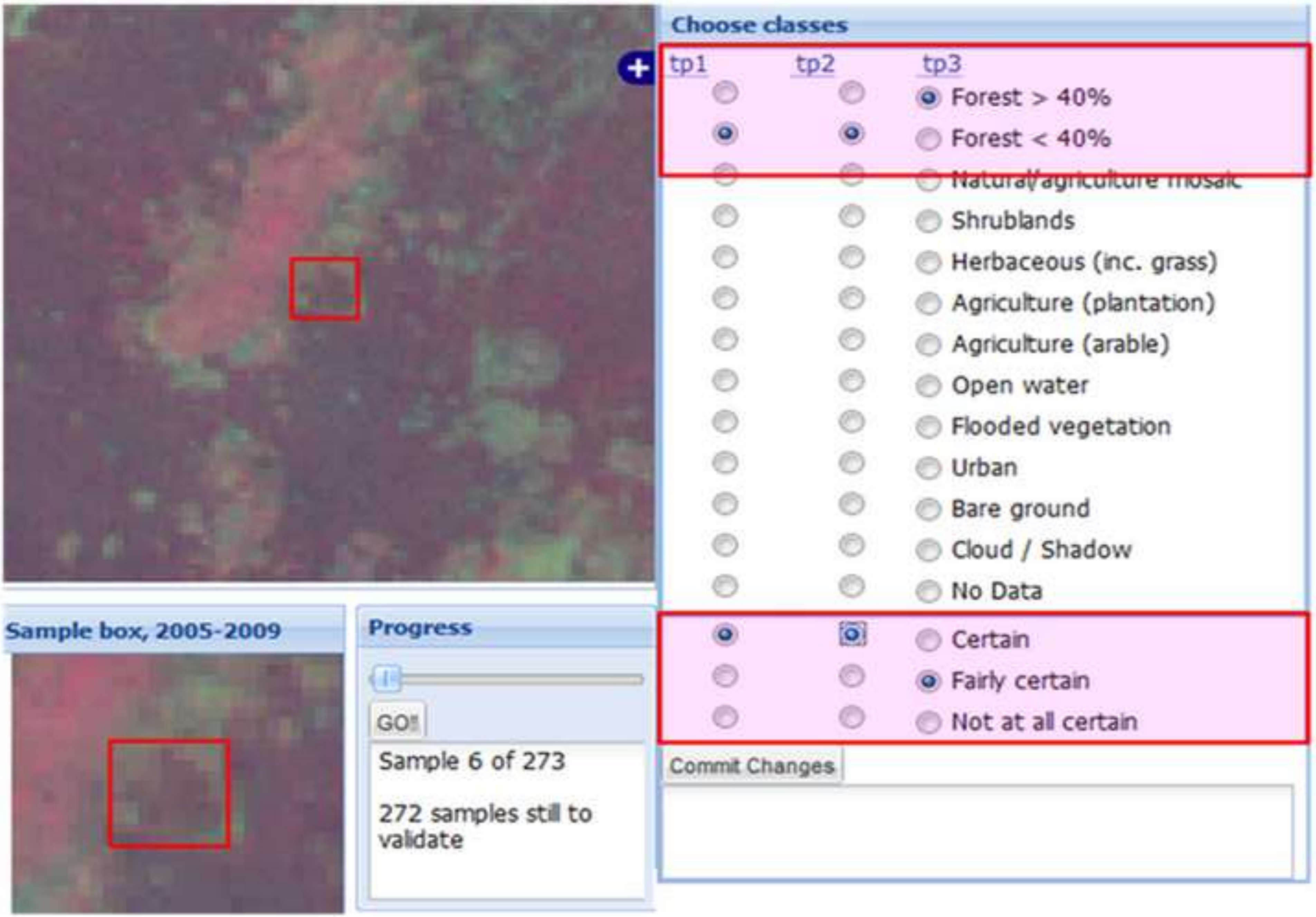

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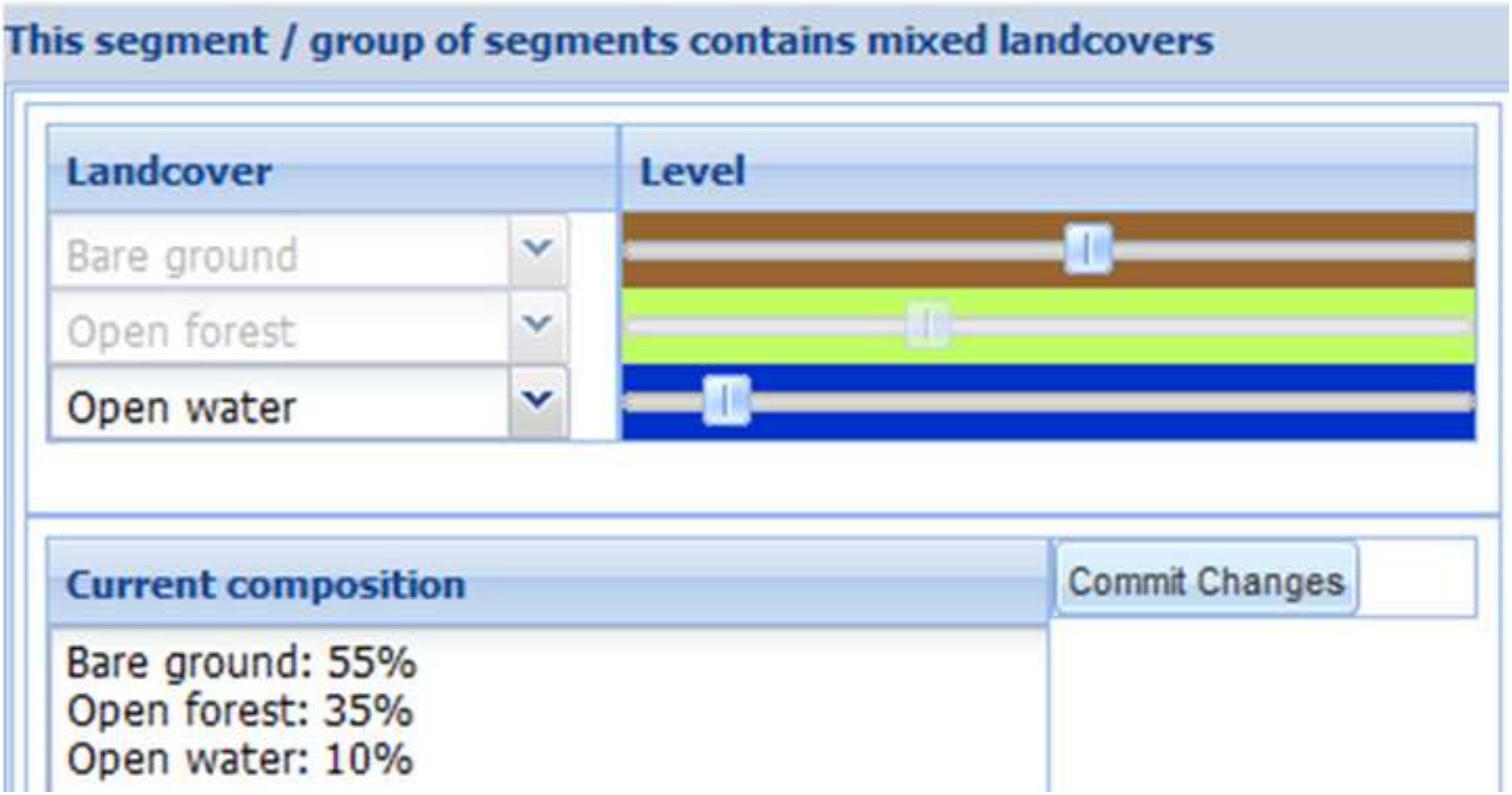

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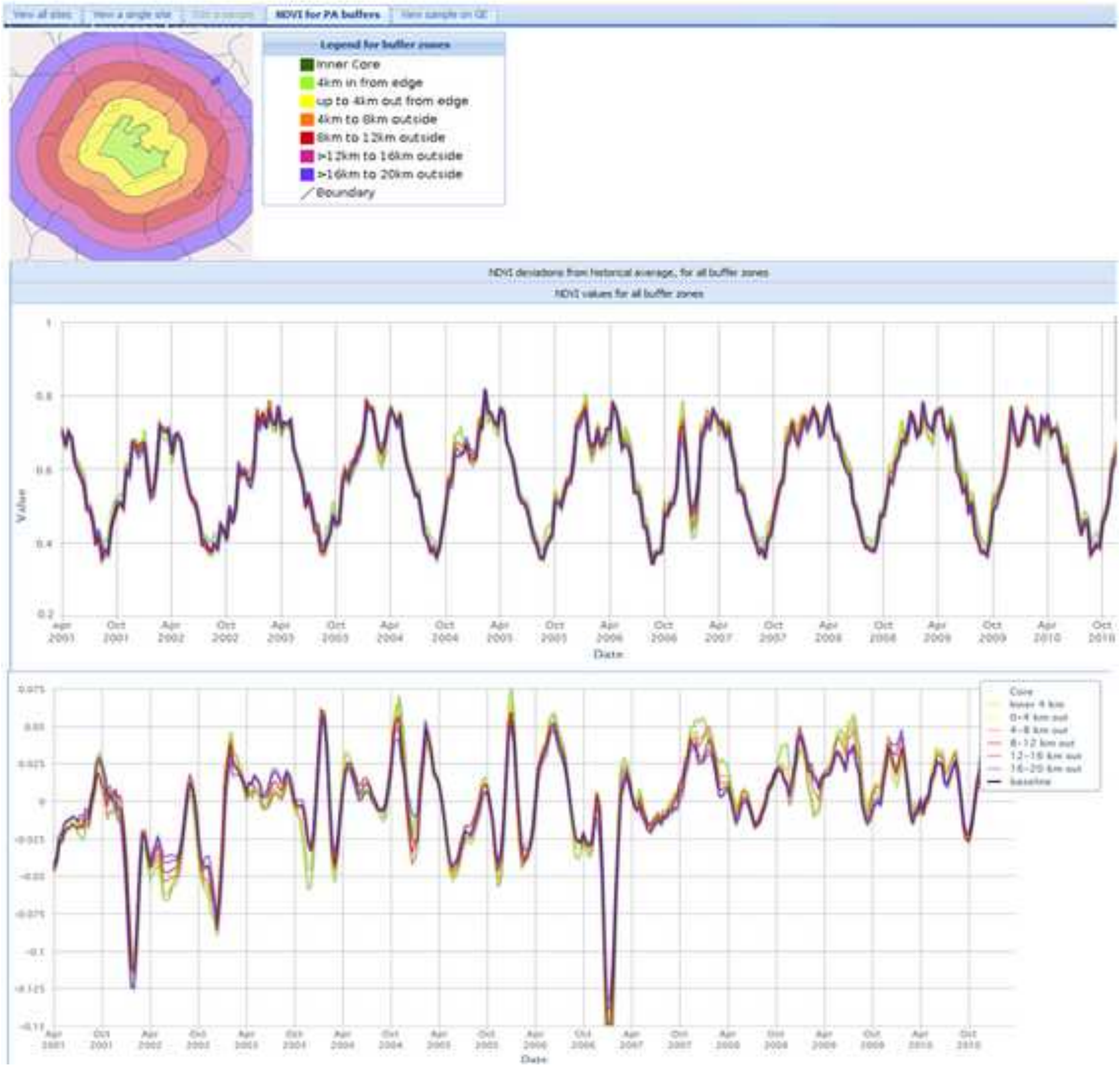

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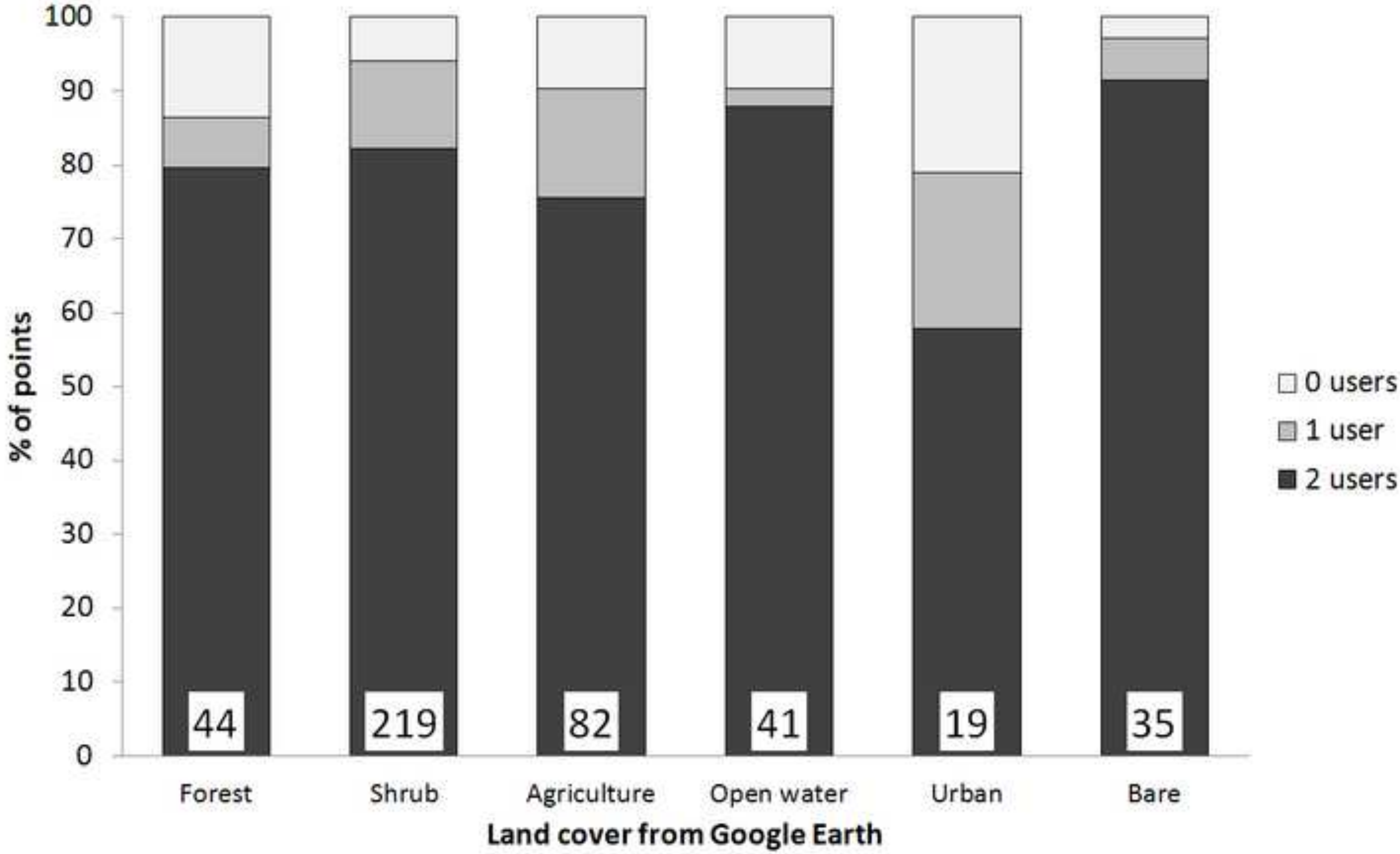

Table

Table 1. Number of sample points classified "correctly" (same land-cover as identified from high resolution Google Earth images) and "incorrectly" by two experienced users, broken down by their recorded certainty level. Similar land-cover categories have been merged as described in the caption to Figure 9.

	user 1			user 2		
	No. of points incorrect	**No. of points correct**	**% correct**	**No. of points incorrect**	**No. of points correct**	**% correct**
Certain	21	282	93.07	18	184	91.09
Fairly certain	29	101	77.69	40	175	81.40
Not at all certain	4	3	42.86	8	15	65.22
Total			87.73			85.00