Developing a Forest Data Portal to Support Multi-Scale Decision Making

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***Abstract*—Forests play a pivotal role in timber production, maintenance and development of biodiversity and in carbon sequestration and storage in the context of the Kyoto Protocol. Policy makers and forest experts therefore require reliable information on forest extent, type and change for management, planning and modeling purposes. It is becoming increasingly clear that such forest information is frequently inconsistent and unharmonised between countries and continents. This research paper presents a forest information portal that has been developed in line with the GEOSS and INSPIRE frameworks. The web portal provides access to forest resources data at a variety of spatial scales, from global through to regional and local, as well as providing analytical capabilities for monitoring and validating forest change. The system also allows for the utilisation of forest data and processing services within other thematic areas. The web portal has been developed using open standards to facilitate accessibility, interoperability and data transfer.**

***Index Terms*—Forest monitoring, interoperability, Earth observation, map viewer, metadata.**

I. INTRODUCTION

THE Global Earth Observation System of Systems (GEOSS) is being organised by the Group of Earth Observation (GEO), which is an umbrella group that was established in 2005 and includes over 40 international organisations, 62 nations and the European Union. The GEOSS strategy seeks to organise existing systems and services to promote interoperability using existing standards [1]. GEOSS itself is structured into nine societal benefit areas (SBAs) [2], with forestry included specifically within the SBA concerning sustainable agriculture. However, [3] noted that forest information and observations are required by all nine SBAs, e.g. for the definition of landcover/vegetation type within the Agriculture, Ecosystems and Biodiversity SBAs, for the calculation of biomass/carbon storage assessments in the Climate and Energy areas, as a factor in hydrological modeling for the Water area, and as a source of data on landcover change arising from clearfellings or natural hazards. Forestry is therefore multi-disciplinary, with changes in forest structure and composition influencing all nine SBAs and creating a need for readily accessible and useable forest data at a range of scales from local through to national and global.

Forest data and statistics are typically compiled by Forest Authorities through national forest inventory (NFI) programmes, which collect in-situ information including estimates of forest area, species composition and growing stock [4]. These data are used for strategic planning and production forecasting at national and regional levels, but they are also used to generate indicators for compliance with international reporting requirements, such as the United Nations Food and Agriculture Organization (FAO) Forest Resource Assessment, the United Nations Framework Convention on Climate Change Land-use, Land-use Change and Forestry and the Ministerial Conference on the Protection of Forests in Europe [5], [6]. Within the context of the post-Kyoto climate process, national governments are required to maintain a forest carbon accounting system that considers changes in forest stock at the sub-hectare level.

Closely related to this are the UN Reducing Emissions from Deforestation and Forest Degradation

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(REDD+) Programme and the GEO Initiative on Forest Carbon Tracking (GEO FCT). The latter supports countries that wish to implement a national Monitoring, Reporting and Verification (MRV) system though the combined use of satellite, airborne and in-situ data [7]. These systems would ultimately form the components of a global network of MRV systems, which should be fully interoperable within a distributed network of geographic information infrastructures (GIIs).

Despite these initiatives, it is acknowledged that there is frequently a distinct lack of harmonised forest information available at regional or continental scales and that in many cases data are scattered, incomplete or not readily comparable [8]. On the one hand, this can be caused by differences in forest definitions between countries [9], but from a technological point of view it is often due to the lack of inter-connection between the systems and data structures established at local, regional and global levels. Initiatives such as the INSPIRE Directive [10], GEOSS and the EuroGEOSS project (http://www.eurogeoss.eu) are making advances to standardise access to spatial information as well as providing common infrastructures permitting data to be more easily discovered, shared and re-used.

In more general terms, the increasing use of geospatial Web-based standards defined by the Open GeoSpatial Consortium (OGC) has enabled systems to become far more interoperable in general, and has greatly assisted in the exchange of spatial data. These standards apply specifically to the publication of metadata within catalogues, but are also widely used to disseminate spatial data through standard-based web services. The most important services related to this paper include Web Map Services (WMS), Web Feature Services (WFS), Web Coverage Services (WCS) and Web Processing Services (WPS).

From this growing culture of standardised, interoperable Web Services and data formats has arisen the concept of the Model Web: an approach to the encoding and wrapping of processing algorithms which allows scientific models to be exposed as Web Services in a flexible, distributed architecture [11], [12].

If models, as well as data, are semantically labeled and registered in internet catalogues, those models can be discovered, combined into complex workflows and executed over a distributed architecture. A workflow may itself be exposed as a single Web Service where the user only interacts with the initial inputs and the final outputs. Thus the delivery of the Model Web and its components promises to enhance scientific modelling by:

- improving the integration of different models across disciplines to address practical questions;
- increasing research reproducibility by recording the provenance of modelling outputs;
- permitting published models to be deployed flexibly, for example within cloud architectures;
- allowing model components and code to be discovered and re-used.

The practical challenges of achieving genuine interoperability of data, concepts and information models in an open system setting, and across multiple disciplines, are significant. The work described in the paper follows the Model Web approach by:

- using agreed semantic annotations for data and services which enable mapping by the EuroGEOSS Discovery Broker or by other search tools to concepts from other disciplines;
- publishing scientific computations as Web services which may be re-used by scientists within their own workflows;
- prioritising interoperability and open standards for all components of the portal.

There is an increasing need to develop a network of such interoperable spatial information infrastructures that provide access to spatial data in a standardized way. For instance, in the context of forestry this is required for multi-scale MRV of forest resources, monitoring the effects of forest fires on the environment, and also for Web-based analysis and spatial modeling to answer multi-disciplinary scientific questions. The paper presents components that have been developed to address these issues and which were achieved within the context of the EuroGEOSS project, whose aim is to improve interdiscplinary interoperability between scientists, research groups and society.

At the core of the project is the the EuroGEOSS Discovery Broker [12], which reads and mediates between a myriad of data standards and specifications employed by scientific communities. The broker builds bridges between distributed services and enables users to seamlessly search across disparate scientific disciplines. It is based on several of the requirements that characterise the System of Systems and the Internet of Services philosophy, which are described in [12]. The EuroGEOSS Discovery Broker provides access to multi-scale, interdisciplinary Metadata and Spatial Data Services as well as analytical models and geo-processing toolchains.

The forestry components form an integral part of the Broker, by providing the necessary data and models to analyse forest resources. At regional and national levels in Europe, the system is underpinned by the European Forest Data Centre (EFDAC), European Forest Fire Information System (EFFIS) and national data centres. At a global scale, forest data are derived from the Forest Resource Assessment (FRA) exercise on which FAO coordinates its efforts with the TREES-3 project based at the European Commission Joint Research Centre (EC-JRC) [13], [14].

The forestry web services presented here are an integral part of the EuroGEOSS Discovery Broker and they are federated and discoverable within the Broker. This means that these services can be discovered through one portal, and subsequently viewed and used by hetereogeneous scientific communities to answer integrated environmental questions. Clearly the forestry components will be of most relevance to forest scientists and authorities; however, given the importance of forest resources in many SBAs, the services and modelling tools will be needed by a wide range of thematic areas as well as for carrying out multi-disciplinary research.

The objective of this paper is to present new components which access and utilise distributed information on forest resources at different spatial scales and to demonstrate how they can be integrated into geographic information infrastructures. This objective is illustrated through the development of an INSPIRE compliant metadata catalogue for discovery of forest information, development of a Web map viewer based on OGC-standard Services and deployment of Web-based forest analysis and modeling tools.

II. Use Case Scenarios

A. Study Areas

Within the context of the EuroGEOSS project, the research presented in this paper focuses on European forestry and environmental data, with specific use-case scenarios developed for Spain. The global dimension of this research is emphasized by the scalability of the forestry data portal and is also demonstrated by its easy incorporation into the Web-based land cover validation tool that is designed to cover the tropical regions of Africa, Latin America and South-East Asia.

B. Core Data Services

The use-case scenarios presented within this paper are dependent on a number of core European forest data centres, which include the EFDAC, EFFIS and the e-Forest platform.

The EFFIS was established in 2002 by the EC-JRC as part of the EU Forest Focus regulation (EC-2152/2003). It is a modular Web-based information system that provides up-to-date fire danger forecast information to national authorities and EC services. It complements existing information collated by national forest authorities and civil protection services to provide harmonized pre- and post-fire information at a pan-European level [15]. In the pre-fire phase, the EFFIS provides access to pan-European harmonized maps of fire danger indices. These are calculated using meteorological forecast data and are updated on a daily basis and published within the information system [15]. In the post-fire phase, the system provides access to a range of historical fire information.

The EFDAC was established in 2005 following an agreement to establish a number of European Data Centres between the Group of Four (Go4), namely the European Commission Directorate-General Environment (ENV), EC-JRC, EuroSTAT and the European Environment Agency (EEA). It has been established to supply European Union decision-makers with processed, quality checked and timely policy-relevant forest data and information within the EU. The forest geo-spatial information maintained within the EFDAC is derived from the classification of satellite imagery, the analysis of satellite derived forest maps, and field based assessments of forest resources from various research projects, national forestry correspondents and international forest data sources.

The e-Forest platform is a recent addition to the EFDAC, and consists of a harmonised spatial database of detailed forest resource information derived from National Forest Inventories (NFI)

EU Member States. The NFIs are based on sampling frames that collect qualitative and quantitative field measurements, which include species occurrences, detailed measurements of trees (tree diameters and heights). The platform provides a harmonized database of forest information, which can be used to produce forest parameter estimates from pan-European level through to national and regional levels.

The three abovementioned systems publish a range of forest related spatial data that include forest cover maps, tree species distributions, information on forest health and forest fire data (e.g. location and extent of forest fires). All of these data are available as standard OpenGeoSpatial Web Services (OWS), including WMS, WFS and WCS. These services are all used by the portal discussed within this paper for viewing and analytical purposes.

The TREES-3 Action provides quantitative measurements and mapping of changes in forest resources to support maintenance and development of EU policies related to global environmental and forestry issues. The focus of TREES-3 is on Eurasian boreal forests and tropical forests, including the Caribbean and Pacific regions. Thus, while the overall scope of the project is global, there are important thematic and geographic overlaps with the data services mentioned above.

In order to document forest cover change, the TREES-3 project gathers landcover information for 20 km-square sample sites at over 4000 lat-long degree confluence points in the tropical zones of Africa, Asia, and South America [14]. This exercise constitutes the tropical section of the Global Forest Resources Assessment programme1 which is coordinated by the FAO. Multi-spectral imagery for each confluence point is processed and classified using object-based techniques to generate homogeneous landcover segments whose geometry is consistent between the sample years (e.g. 1990 / 2000) [16]. The classified segments have historically then been validated by forestry experts from the relevant countries using an editing tool written in IDL [17] thus combining specialist knowledge at the EC-JRC and expert knowledge from the countries concerned. The designated national experts verify the content of each landcover segment using high-quality imagery (currently derived from Landsat) as contextual information. It is this validation process for which the Web-based tools described later have been developed, which builds on the success of the stand-alone IDL application while widening access to the editing tools.

C. Approach: Architecture design adding multidisciplinary capabilities

This section describes the software architecture within which we deploy and integrate the three Web-based applications of the EuroGEOSS Forest Data Portal. These include the Metadata Catalogue, Web-based Viewer and the TREES-3 Web-based validation tool. A schematic overview of the system is provided in Figure 1 that demonstrates how the components can be used to search, view and analyse forest data as well as providing the capabilities to combine these resources with those from other thematic areas, such as Droughts, Agriculture or Biodiversity.

The Forest Data Portal was developed using Free Open-Source geospatial libraries and programs. It consists of GeoNetwork for the Metadata Catalogue, which is INSPIRE compliant. Geoserver was used to publish forest geo-spatial layers. The EuroGEOSS Web-based forest viewer was developed using open-source client-side JavaScript libraries. The TREES-3 Web-based validation tool employs the same suit of JavaScript libraries, with PostgreSQL and PostGIS in the back-end for data management.

The forest Web Processing Services (WPS) were implemented using PyWPS [18], [19], a Python implementation of the WPS Standard. It allows for the development of geo-processing tools with the seamless use of many geo-spatial python packages, the Geospatial Data Abstraction Library (GDAL) (http://www.gdal.org) and GRASS-GIS. The system also offers a Publication Service called the GEOSS Service Factory (GSF) [20]. This service aims at maintaining geospatial information infrastructures assisting users to publish content in existing data services. The GSF hides the complexity of standard interfaces and offers a unique entry point for content to be delivered. GSF is implemented as a WPS and it is included in the user workflow to publish generated information, for instance WPS outputs as standard data services (WMS, WFS).

III. RESULTS

The technological achievements of this project are described in three parts. The first deals with components that enable the discovery and retrieval of forest data; the second discusses the Web-based GeoProcessing tools that provide geo-spatial functionality over the Web. The latter is developed in two strands, one as tools directly implemented within the Web Map Viewer and the second within the TREES-3 Validation Tool.

A. Data Discovery and Access

The EuroGEOSS Forest Metadata Catalogue was developed as a central information component containing metadata concerning spatial and non-spatial forest information. It provides a means of increasing the visibility and retrieval of forest data. The catalogue was populated with contents from EFDAC, EFFIS and eForest. Global forestry information was also included, based on data from the FAO FRA 2010 Statistics, Eurostat and MCPFE. The metadata were imported using DC and ISO XML files and also by harvesting external Metadata Catalogues using the CSW ISO protocol, OAI DC protocol and the OGC OWS services via GetCapabilities requests which can be performed asynchronously or in real-time.

As part of the requirements, the catalogue was developed to include a comprehensive list of metadata subthemes for publishing and searching metadata. Additional customisations were made to the Metadata catalogue to provide direct links from the metadata page to the map viewer, with the option of automatically loading specific layers into the map viewer, using either a specific WMS layer end point or a WMS url. It is also possible to access the catalogue, either for harvesting purposes using CSW (Catalogue Services for the Web) or directly through a Web interface. In addition, the catalogue is registered as a federated catalogue of the EuroGEOSS Discovery Broker, which increases its visibility and ability to be queried by scientists from other research disciplines.

The Web-based Map Viewer provides the capabilities to view, query and overlay forestry, biodiversity and drought related information that are served as WMS and WFS layers within one map canvas. A specific functionality of the map viewer is its ability to connect to a wide range of WMS servers using a WMS' end-point (either a single layer or entire service). By default, the Map Viewer can connect to several WMS' that are of specific interest to the application, i.e. European forestry, biodiversity and drought spatial data, thereby allowing the user with simultaneous access to cross-thematic and multi-scale data within one application. Furthermore, it is possible for a user to access data from an external WMS, by providing a WMS end-point within the viewer (Figure 2).

Web-2.0 and OpenSearch Integration: The Web has become a collaborative environment, where increasing numbers of Web-based social networks and active users act as a data providers, representing another massive repository of geo-referenced data of great potential value. This information, while highly heterogeneous in its nature, quality and formats, provides a complementary view to scientific data and can provide better insights into the social impact of environmental and other phenomena [21]. To exploit this rich resource, we have developed another discovery service that provides a homogeneous search interface to retrieve content from social networks and crowd sourcing platforms, called the Web 2.0 Broker [21]. The Web 2.0 Broker implements the OpenSearch Geo-Time standard interface specification. To access this new discovery service we have designed and developed a web client module to be included in the Forestry Portal. This client, developed with Google Web Toolkit technology, offers a user-friendly interface to facilitate users access to the functionality of the Web2.0 Broker in a simple and visual way.

B. Web-based GeoProcessing

Two Web Processing Services (WPS) were integrated into the Map Viewer to provide specialized geo-analytical tools for forestry experts. They were developed to allow scientists to address specific questions on forest change using a standardized approach for analyzing and interpreting the data which permits the results to be comparable and reproducible.

1) Use Case 1: Forest Fires in Protected Areas: In recent years, forest fires have affected approximately 300,000 ha of forest every year across Mediterranean countries [22]. This continues to pose a significant threat to the vegetation structure and biodiversity within protected areas. Consequently, there is a need for scientists and resource managers to be able to effectively assess the impact of forest fires on protected areas and this can be achieved through the use of standardized processing and reporting tools. The resulting information can be used by scientists and managers to determine the spatial distribution of forest fires within protected areas and to assess the spatial composition of the burnt areas (forest species and/or landcover). Such information would allow them to better implement post-fire management plans and to allocate available resources.

This use-case is multi-scale and cross-thematic and it is important to highlight its importance. As previously mentioned, the results provide forest managers and authorities with the spatial distribution and composition of forest fires. However, they also provide information to scientists and resource managers from other disciplines. For instance, forest fires impact biodiversity due to a loss of habitats, fragmentation and connectivity of forests, which is of particular importance in protected areas and national parks. Furthermore, depending on the severity of fire events, the removal of forests and vegetation causes land to be more susecptible to soil erosion and potentially lead to desertification. The emissions caused by forest fires also have deleterious impacts on air quality and human health. Although the direct emphasis of the scenario is on forest resources, the results can be used across many disciplines.

Within this WPS, the user is required to select the Area Of Interest or Protected Area by means of an interactive selection within the map canvas or from the list of attributes from the Protected Area. Subsequently, the user launches the WPS, which carries out the vector intersection and overlay of the two input features. The resulting intersected geometries are rendered to the map canvas, with associated summary statistics and attributes presented to the user as combination of tables and maps. On completion of the process, the user is given a further choice to launch the GSF to publish the WPS data outputs to the EuroGEOSS Forest GeoServer and the associated Forest Metadata Catalogue.

2) Use Case 2: Monitoring Forest Change: The monitoring of forest change is becoming increasingly important at a range of scales from local through to national and global. There is an increasing requirement by Government and Forest Authorities to quantify the changes in forest cover and forest carbon stocks, and these metrics are frequently aggregated to estimate the countries anthropogenic forest-related greenhouse emissions. Due to the differences in forest definitions and forest inventory methods used by countries, it is quite challenging to obtain harmonized results that can be directly compared between countries. This can be overcome by the use of forest cover maps that are derived from satellite imagery that have been classified using consistent methodologies at European scale. These forest maps are available from the EC-JRC as WCS layers for the years 2000 and 2006 at a resolution of 25-m [23], [24] .

Within this WPS, the user is required to digitize an AOI and then to select the year of analysis (e.g. Time-0 and Time-1). The WPS then processes the Forest Map WCS to compute the percentage change in forest area between the two periods. The results are displayed to the user as graphs and statistical summaries, as well as an output WMS map showing the areas of forest loss, gain and stability between the two time periods. This computation of the changes in forest area provides forest managers and policy makers with important information relating to areas that are subject to deforestation.

As in the other use-case scenario, the user is given the possibility to invoke the GSF to publish the WPS outputs as new content available in the system data services. The GSF publishes the result for further visualization in the existing WMS implemented with Geoserver and for discovery purposes in the CSW implemented with Geonetwork.

3) Web-based validation tool: A Web-based editing tool has been developed to support the TREES-3 expert validation process described in Section 2.2, again using OGC standards for data exchange formats and geospatial Web services. The tool allows a registered expert to view and query the status of their allocated sites (completed or in progress), and to select segments where particular types of change have occurred, for overlay on ancillary contextual data. The editing and validation process is carried out entirely online, using a PostGIS database which is exposed via a Geoserver Web Feature Service and Web Map Service.

National experts log in to view the location and status of their assigned sample sites within a zoomable, draggable map. Ancillary and contextual information can be added from publicly available global mapping sources. When a site is selected for editing, data from two different years are displayed at once (Figure 3). The landcover segments are shown on the right, and the available satellite imagery is shown on the left. Segment labels are edited onscreen by selecting the required areas, selecting the new landcover from a predefined legend, and submitting the change via an HTTP request to a PostGIS database on the server. When the national expert has completed their changes, the site can be signed off as completed from this page.

The user may select specific landcover segments interactively onscreen, or can submit a query for segments which fulfil specific conditions (for example, segments can be selected where a specific type of landcover change has occurred). The geometries of any selected segments are retrieved as GML or GeoJSON from the underlying Web Feature Service, meaning that they can be overlaid on selected contextual data or, in a separate tab, on Google Earth imagery. In the example below, the EuroGEOSS Map Viewer (section 3.2) is integrated as an extra tab, allowing various WMS layers to be selected as the backdrop for these segment outlines.

IV. Discussion: Future Scope

Within this paper we have highlighted the importance of being able to access forest resource information so that it can be used by scientists and decision makers in an interoperable manner to answer multi-disciplinary questions. We have described a new Forest Data Portal that fulfills this role as a means of searching for data (and metadata), viewing it in conjunction with data from different disciplines and providing functionality for users to analyse these data using Web services as well as serving the wider community through the accessibility of the portal within the EuroGEOSS Discovery Broker.

The Forest data portal has been developed using Open Standards, which is an advantage to bridge the gaps between differing spatial scales, semantic concepts and disciplines. Furthermore, this allows for powerful and flexible analysis of forest related data to answer multi-disciplinary research questions. Following international directives like INSPIRE, we have provided the system with services that allow interoperable access to discover, view, download as well as geoprocessing functionality. Furthermore with the extension of this architecture with a publication service we also assist users to participate more actively in the maintenance of the infrastructure, increasing the visibility and availability of content by simplifying the process of publishing content.

The integration of Volunteered Geographic Information (VGI) from Web2.0 technologies offers a unique way of harnessing a vast amount of contextual information from sources such as Flickr, Twitter or YouTube. These sources are rapidly evolving and it is clear that they can be used to complement scientific data and Web processing tool chains.

The TREES-3 validation tool provides a global context of this research and is a central link between the EuroGEOSS Forest Data portal and the UN FAO databases that are being developed within the context of the EuroGEOSS project. Furthermore, the validation tool can be used by many The suite of tools described here illustrate a robust framework by which comprehensive forest information can be collected, analysed and easily accessed in an interoperable and consistent way, at a variety of spatial scales ranging from the local expert right up to the global decision maker. It also lends itself to being integrated within GII from other thematic areas for more integrated, multi-disciplinary research tasks.

The Web Processing Services that are presented within this research provide users with robust tools that yield consistent and accurate results of forest change. The advantage of deploying them as WPS is that they can be used within more complex workflows to answer integrated questions on environmental change. For instance, the analysis of forest change could be part of a modelling framework that would analyse changes in habitats, the degree of landscape fragmentation or the vulnerability of areas to erosion or desertification. As such, the scenarios presented within this manuscript focus on forestry, but their applications and use by other scientific disciplines is much wider.

Society and the scientific community increasingly need to be able to access distributed information on the environment, be it forestry, agriculture, droughts or biodiversity. While the access to these data is of fundamental importance, their value is increased when they are used within GII for geo-processing or modeling to answer interdisciplinary scientific questions and support decision making.

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