Distributed GIS Systems, Open Specifications and Interoperability: How do They Relate to the Sustainable Management of Natural Resources?

Rafael Moreno-Sanchez, Department of Geography and Environmental Sciences, University of Colorado at Denver, Denver, CO

Abstract—*The aim of this is paper is to provide a conceptual framework for the session: "The role of web-based Geographic Information Systems in supporting sustainable management." The concepts of sustainability, sustainable forest management, Web Services, Distributed Geographic Information Systems, interoperability, Open Specifications, and Open Source Software are defined and their relevance and relationships are explained. The potential contributions of web-based GIS systems to natural resources sustainable management is highlighted.*

Introduction

The aim of this is paper is to provide a conceptual framework for the session: "The role of web-based Geographic Information Systems in supporting sustainable management." The concepts of sustainability, sustainable forest management, Web Services, Distributed Geographic Information Systems, interoperability, Open Specifications, and Open Source Software are defined and their relevance and relationships are explained.

Due to the multi-faceted role of the natural resources, and more specifically of the forest resources, sustainable forest management necessitates decision-making which recognizes and incorporates: a) diverse ecological, economic, and social processes; b) a multitude of variables; and c) conflicting objectives and constraints. Furthermore, all these elements most be considered at different spatial and temporal scales.

One thing is to clearly defined sustainability and sustainable forest management and other is to make these concepts operational through decision-making processes, decision support systems, and management strategies. Most studies have focus on either the ecological, economic, or social aspects of the forest management. Few have aimed to address these three aspects at the same time into specific decision-making processes or support systems (Varma, Ferguson and Wild, 2000). Also, if Communication and Information Technologies (CIT) such as the World Wide Web (WWW or the web), Geographic Information Systems (GIS), or computer based decision support systems, are part of the tools used in the implementation of the concept of sustainability, the sustainability of these tools should also be addressed as part of a comprehensive sustainable management approach.

The ability of Geographic Information Systems (GIS) to deal with spatial and non-spatial information has long be recognized as a notable feature that can contribute significantly to deal with the complexity of diverse information sources, information management activities, and analyses required to develop sustainable management alternatives (Cowen, 1990; Varma, Ferguson and Wild, 2000; Wing and Bettinger, 2003).

The geo-processing principles and functionality found in GIS systems are moving out of a tightly defined niche into the information technology (IT) mainstream. Isolated, standalone systems are being replaced by integrated components, and large applications are being replaced by smaller, more versatile applications that work together transparently across networks. Of these, the World Wide Web (WWW or the web) is becoming the core medium for distributed computing in IT generally and in the geo-processing domain specifically (Hecht 2002a). In other words, GIS systems, once focused on data and tools implemented with client-server architecture, now are evolving to a Web Services model (Dangermond 2002). In this new architecture the web is used for delivering not just data, but geo-processing functionality that can be wrapped in interoperable software components called Web Services. These components can be plugged together to build larger, more comprehensive services and/or applications (Hecht 2002b). Interoperability between heterogeneous environments, systems and data is fundamental for the implementation of this Web Services model. Interoperability is achieved by complying with Open Specifications (OS).

The remainder of this paper will present each of the previously mentioned concepts and how they relate to each other. The importance of web-based GIS systems is highlighted. Finally, future directions for development and research are suggested.

Defining Sustainability and Sustainable Forest Management

Sustainability has been defined in many different ways. The fuzziness associated with its various definitions is typical of a "young paradigm" (Bosshard, 2000). Sustainability can be understood more as a journey rather than a destination. As managers aim to make the concept operational they learn from their experiences and adjust not only the methods used but the concept itself. A broad definition of sustainability is: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Sustainable forest management involves managing forests as ecosystems, and it involves an integration of: a) environmental benefits and values: b) socio-economic and cultural benefits to meet human needs; and c) institutional arrangements to formulate and implement appropriate policies and programs and to monitor their effectiveness. These three elements are dynamic and change over time. (Canadian Council of Forest Ministers, 1997).

Defining Open Specifications (OS), Interoperability, and Open Source Software (OSS)

Open Specifications (OS) provide software engineers and developers information about a given specification as well as specific programming rules and advice for implementing the interfaces and/or protocols that enable interoperability between systems. The Open GIS Consortium Inc. (OGC) (http://www.opengis.org) defines interoperability as "the ability for a system or components of a system to provide information portability and interapplication cooperative process control. In the context of the OGC specifications this means software components operating reciprocally (working with each other) to overcome tedious batch conversion tasks, import/export obstacles, and distributed resource access barriers imposed by heterogeneous processing environments and heterogeneous data."

Herring (1999) and Kottman (1999) present an in depth discussion of the OpenGIS Data Model and the OGC process for the creation of OS respectively. Software products can be submitted for testing their interfaces for compliance with OGC OpenGIS Implementation Specifications (see http://www.opengis.org/techno/implementation.htm for the most recent approved and in process specifications). Initially, the only OpenGIS Specifications that products could conform to were the OpenGIS Simple Features Specifications for CORBA, OLE/COM and SQL (McKee, 1998), now there are eleven. Within computer environments there are many different aspects of interoperability (Vckovski, 1998): a) Independent applications running on the same machine and operating system, i.e., interoperability through a common hardware interface; b) application A reading data written by another application B, i.e., interoperability through a common data format; and c) application A communicating with application B by means of interprocess communication or network infrastructure, i.e., interoperability through a common communication protocol. Besides technical issues, there are also interoperability topics at higher levels of abstraction such as semantic barriers (Harvey, 1999; Seth, 1999). A system based on the OS later described would be able to achieve a level of interoperability of the second type above described.

According to Hecht (2002a) interoperability is desirable for the following reasons: a) it allows for communication between information providers and end users without requiring that both have the same geo-processing or viewer software; b) no single Geographic Information System (GIS), mapping tool, imaging solution or database answers every need; c) there are large amounts of database records with a description of location that have the potential to become spatial data, and also, advances in several technologies (e.g. GPS integrated into mobile devices) are increasing the amount of database records with location information; d) the number of software companies offering components to deal with geographic information is growing; e) it is more efficient to collect data once and maintain them in one place. (This is particularly cost effective if communities of users can find, access and use the information online, so they don't need to access, retrieve and maintain whole files and databases of information for which others are responsible); f) the ability to seamlessly combine accurate, up-to-date data from multiple sources opens new possibilities for improved decision making and makes data more valuable; and g) the ability for multiple users, including non-GIS experts, to use a particular set of data (perhaps at different levels with different permissions) also makes the data more valuable. Gardels (1997) discusses how compliance with OGC's OpenGIS specifications and the resulting interoperability can contribute to integrating distributed heterogeneous environments into on-line environmental information systems (EIS). He points to three technical strategies (federation, catalogs, and data mining) for the integration of these systems, and how they are heavily depended on interoperability among diverse data sources, formats, and models. He concludes that properly designed geodata access and analysis tools, combined with open environmental information systems, can provide sophisticated decision support to the users of geographic information.

Two organizations have been coordinating the development of the most relevant open specifications used in creating web-based GIS systems: The OpenGIS Consortium Inc. (OGC) (http://www.opengis.org), and the World Wide Web Consortium (W3C) (http://www.w3.org). To this date the W3C has created more than forty technical specifications (http://www.w3.org/TR/). As of January 2002, the OGC has adopted nine OpenGIS Implementation Specifications and 11 candidate specifications are in the works (Hecht 2002c; a roadmap to the specifications work is presented at http://www.opengis.org/roadmap/index.htm).

Briefly, Open Source Software (OSS) are programs whose licenses give users the freedom to run the program for any purpose, to modify the program, and to freely redistribute either the original or modified program without further limitations or royalty payments (http://www.opensource.org/docs/definition.php). Among the most well known OSS projects there are the Linux operating system and the Apache web server. Some times the term Open Technologies is used to refer to these projects and others such as XML, HTML, TCP/IP, and Java technology. A comprehensive list of GIS-related OSS can be found at http://opensourcegis.org/. According to Wheeler (2002) OSS reliability, performance, scalability, security, and total cost of ownership are at least as good as or better than its proprietary competition, and under certain circumstances, they are a superior alternative to their proprietary counterparts.

Defining Web-based GIS, Web Services and Distributed GIS Systems

The Internet has changed how GIS data and processing are accessed, shared, and manipulated. Internet GIS or web-based GIS (we will use both terms interchangeably, although strictly they are not the same) is a research and application area that utilizes the Internet and other internetworking systems (including wireless communications and intranets) to facilitate the access, processing, and dissemination of geographic information and spatial analysis knowledge (Peng and Tsou, 2003).

Web Services are interoperable, self-contained, self-describing, module components that can communicate with each other over the WWW (Peng and Tsou, 2003). The OGC envisions that Web Services will allow future applications to be assembled from multiple, network-enabled geoprocessing and location services. The GIS Web Service is a vendor-neutral interoperable framework for web-based discovery, access, integration, analysis, exploitation, and visualization of multiple online geodata sources, sensor-derived information, and geoprocessing capabilities (OGC, 2001).

The development of GIS technology has closely mirrored the development of computer technologies. It has evolved from mainframe GIS, to desktop GIS, to client/server GIS architectures, to the most recent paradigm Distributed GIS or Distributed GIServices. Distributed GIServices are Web Services, they represents a dramatic departure from the traditional client/server model. Rather than relying on desktop GIS programs, Distributed GIS, when fully implemented, does not necessarily require the user to install GIS programs on the user's desktop. Distributed GIServices are built using distributed-component technology, which can connect to and interact with multiple and heterogeneous systems and platforms without the constraints of traditional client/server architectures (Montgomery, 1997). Distributed-component frameworks break up the client and server sides of an application into smart components that can interoperate across operating systems, networks, languages, applications, tools, and multi-vendor hardware. Currently there are three major infrastructures for distributed-component technology: CORBA, DCOM and .NET, and Java technology. Under a Distributed GIServices architecture, there is no difference between a client and a server. Every GIS node embeds GIS programs and geodata and can become a client or a server based on the task at hand. Furthermore, in this architecture components are interoperable and can be downloaded to create ad-hoc GIS system to satisfy specific users' needs. These systems rely on the Internet and wireless networks for data and processing communication. Users can access the GIS analysis tools and data from anywhere with Internet access or wireless data service coverage. The client could be a desktop computer, a laptop computer, a Personal Digital Assistant (PDA), or a mobile phone (Peng and Tsou, 2003). A Distributed GIS is defined as a network centric (wired or wireless) GIS tool that uses the Internet or a wireless network as a primary means of providing access to distributed data and other

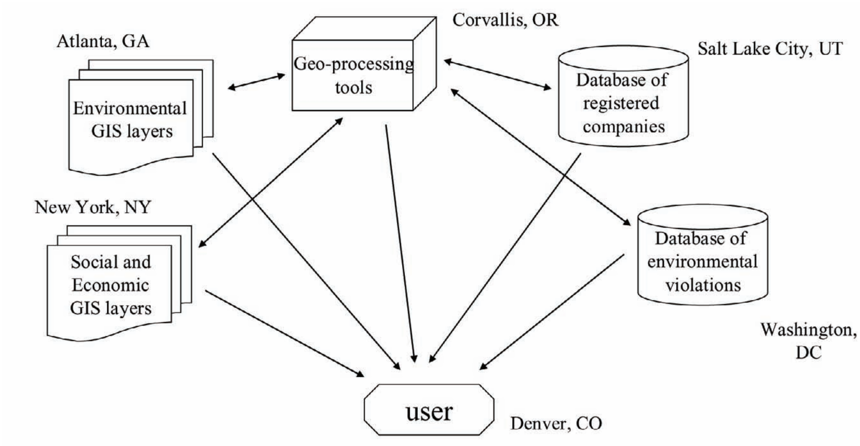

Figure 1. Example of a Distributed GIServices system. Each node in the system can serve as a client or a server and they are dynamically linked. The nodes in the system can be distributed in different geographical locations. Each data set or application is maintained in one place, any changes to them are immediately available to all the other nodes or users. All communications take place over the WWW.

information, disseminating spatial information, and conducting GIS analysis (Peng and Tsou, 2003).

Distributed GIS systems have the following characteristics: a) they make use of integrated dynamic client/server architecture, i.e. every node in the system can behave as a server or a client depending on the task at hand; b) they are web-based; c) they are composed of several nodes found in different locations, and these nodes are dynamically linked (data and applications are kept current because they are maintained at one location in the network); d) they are cross platform (not limited to any kind of machine or operating system), and interoperable (they can work transparently with other components that comply with the same Open Specifications); and e) ideally, they do not need locally installed data and GIS software. Figure 1 presents a hypothetical Distributed GIS system.

The Relevance of the Previously Presented Concepts to the Sustainable Management of Natural Resources

The evolution of GIS towards a Web Services architecture is moving us closer to the delivery of the full potential of GIS technology to contribute to address some of the most challenging informational needs for making the concept of sustainability operational. GIS has long be acknowledged as a key tool to deal with the large amounts of spatial and non-spatial data from different sources, at different spatial and temporal scales, and to carry out the analyses required to support the creation of sustainable management alternatives.

How do the technologies described in the previous sections relate to each other? Anderson and Moreno-Sanchez (2003) make a detailed presentation of these relationships. Briefly, compliance with Open Specifications enables interoperability of data and applications. Let's talk first about OS that enable interoperability at the data level. One of the most important Open Specifications (OS) for the development of web-based information systems is the Extended Markup Language (XML). XML is a World Wide Web Consortium (W3C) OS and a subset of the Standard Generalized Markup Language (SGML) [ISO 8879] (http://www.w3.org/TR/1998/). XML uses pairs of text-based tags, enclosed in parentheses, to describe the data. These tags make the information passed across the Internet "self describing" (Waters 1999). XML satisfies two compelling requirements, firstly it separates data from presentation, and secondly, it transmits data between applications. XML is a metalanguage, for example, a language that describes other languages (Boumphrey et al. 1998; http://www.xml.com). These languages are called XML schemas.

The OGC has developed the Geographic Markup Language (GML) specification (http://www.opengis.net/gml/02-069/GML2-12.html). This Open Specification is an XML schema for the encoding for the transport and storage of geographic information, including both the spatial and non-spatial properties of geographic features. In GML the geometries and attributes of geographic layers are represented within XML tags, again, this brings forth all the advantages of XML's openness, transportability, and interoperability. GML is designed to support interoperability and does so through the provision of basic geometry tags (all systems that support GML use the same geometry tags), a common data model (features/properties), and a mechanism for creating and sharing application schemas (GML 2.1.2 specification at http://www.opengis.net/gml/02-069/GML2-12.html).

GML will become the dominant format for the distribution of geographic data. For example, in Europe the British Ordnance Survey is using GML to deliver the Digital National Framework on the web and to mobile devices (Holland 2001; http://www.ordinancesurvey.co.uk/dnf/home.htm). In the hypothetical Distributed GIS system in figure 1 all geographic data would be in GML format. All non-spatial data contained in Database Management Systems (DBMS) would be input and output in XML format. All the distributed components of the system would be able to read and write GML and XML hence creating interoperability at the data level among the components.

To enable interoperability between the applications in the system, each of the distributed components in the system would have to be developed complying with OS for interprocess communication. For example, the following OS are important when developing interoperable web-based functionality (http://www.opengis.org/specs/). The Web Map Services (WMS) OGC Open Specification provides three operations protocols (GetCapabilities, GetMap, and GetFeatureInfo) in support of the creation and display of registered and superimposed map-like views of information that come simultaneously from multiple sources that are both remote and heterogeneous. The Web Map Features (WMF) OGC Open Specification describes data manipulation operations on OpenGIS® Simple Features (feature instances) such that servers and clients can "communicate" at the feature level, i.e. individual feature instead of "pictures" (like in the case of WMS) can be transferred between clients and servers. The Web Map Coverage (WMC) OGC Open Specification extends the WMS interface to allow access to geospatial "coverages" (in OGC terminology these are raster layers) that represent values or properties of geographic locations, rather than WMS generated maps (pictures).

Open Source Software (OSS) offers an alternative to proprietary web-GIS, DBMS, and web server software. The advantages and disadvantages of using these OSS to create web-based spatial information systems are detailed in Anderson and Moreno-Sanchez (2003).

A Distributed GIS system would offer the characteristics and advantages of interoperability listed by Hecht (2002a) in section three of this paper. Specific data sets (spatial and non-spatial) could be maintained in one location with the benefits of increase consistency, easy of maintenance, and security. Specific GIS geo-processing functionality could be offered as Web Services, for example a buffer function, an overlay function, or more complex spatial modeling procedures could be invoked or downloaded to integrate an adhoc GIS system to support a specific decision-making process. Individuals or companies, by simply complying with OS could develop very specific or sophisticated modular functionality that could be easily and transparently integrated into a Distributed GIS system. Up-to-date data and functionality could be seamlessly integrated from multiple sources without the need for import/export processes, download of data, or software extensions. Finally, in an ideal Distributed GIS implementation, end users would not need GIS software or data installed locally in their machines.

We can easily imagine how all the above-mentioned capabilities would be relevant for supporting sustainable natural resources management approaches. Instead of creating large decision support systems developed by a single agency, company or group of individuals, the Web Services and distributed systems approach leverages the resources (data sets, Information Technology know-how, and specific expertise) and the creativity of the whole community of interested parties in the problem. Different federal, state agencies, or private companies, would maintain specific spatial and non-spatial data sets, as well as geo-processing functionality and make them available as Web Services. For example, WMS, WFS, or WCS would be used for the distribution of spatial data. If necessary, these organizations could send or receive geographic data in GML format (or non-spatial data in some XML schema) to other nodes in the system, or authorized end users. Metadata for spatial and non-spatial data sets would be kept in XML format and would integrate a searchable directory of resources available to any of the distributed GIS system components and end users. Individuals, public and private organizations could develop interoperable components to address specific analytical or processing needs, and these components, once accepted, could be made immediately available to all the nodes in the distributed system as well as to end users. End users would not need high-end computers or expensive GIS or DBMS software to interact with the distributed system. In and ideal distributed system deployment they would not need local specialized software (a web browser would suffice) or local data.

Much work has been done on the development of web-based participatory planning systems to incorporate stakeholders input into natural resources management decision-making processes (Kangas and Store, 2003; King, 2002; Kingston, Carver, Evans and Turton, 2000; Laukkanen, Kangas and Kangas, 2001; Varma, Ferguson, and Wild, 2000). The systems created through these efforts could be redesigned to interoperate with the rest of the components in a distributed system. They could take advantage of the rest of the resources available in the system, and through their output provide input to other components such as optimization routines to generated management plans. In other words, the integration of more powerful decision-support systems would be easier in distributed-components architecture.

Conclusions

To this day all the above-mentioned capabilities have not been fully implemented in a Distributed GIS system, however, constant technological developments, and the spread of the necessary technical knowledge will make this possible in the very short term. The most popular commercial GIS software vendors are incorporating plug-ins to be able to read and write data in GML format, make use of WMS, WFS, and WCS. Sooner rather than later federal and state agencies will start to use GML as the dominant format for their data.

There is a need to develop small prototype Distributed GIS implementations to demonstrate the capabilities of this architecture, expose some of its limitations, and point to the areas that need more research to create the large distributed systems that are required to address sustainability problems at different spatial and temporal scales.

If tools such as Distributed GIS systems and Decision Support Systems are used in developing sustainable natural resources management approaches, the sustainability of these tools also must be addressed as part of the whole sustainable management approach. Little research has been done on this regard.

Finally, as for any web-based information tool, broader issues of equality, accessibility, and environmental, social and economic impacts of these technologies need to be evaluated. It has been suggested that the birth of Information Societies brought about by the use of Communication and Information Technologies could lead to new approaches to sustainability and sustainable growth (Bohlin, 2001; Ducatel, 2001). These issues are becoming of strategic importance and fundamental to long-term prosperity and security for any nation or region of the world seeking to have influence in the 21st century.

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