Everything happens somewhere: using webGIS as a tool for sustainable natural resource management

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Whether tracking invasive species, assessing water quality, or monitoring the spread of disease, comprehensive data collection is a key component of sustainable natural resource management. Increasingly, fostering community-based monitoring is seen as a valuable way to augment data gathering and enhance public involvement in environmental management. However, growing quantities of data and increasing interest from the public and decision makers create technical data storage and access issues. Although not yet widely used in natural resource management, Web-based Geographic Information Systems (webGIS), a hybrid of GIS and Internet technologies, are a promising option for entering and storing heterogeneous datasets, indexed by location, and making them widely available in a visual, dynamic, and interactive format. Although webGIS has the potential to increase public participation in environmental management, there are technical, institutional, and social challenges to its implementation and usage that need to be addressed, including differential Internet access, training, and privacy.

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In the early 1800s, Canadian fur traders began to notice dramatic fluctuations in snowshoe hare (*Lepus americanus*) and Canadian lynx populations (*Lynx canadensis*) (Winterhalder 1980). Almost 100 years later, ecological researchers were able to use pelt sale data generated by the Hudson's Bay Company to document an interrelated rise and fall in hare and lynx populations (Elton and Nicholson 1942; Figure 1). Today, we understand even more about this classic and frequently cited example of predator–prey cycles, and have identified large-scale factors, including climate, as playing an important role in regulating these populations and their interactions (Krebs *et al*. 2001).

The case of the lynx and the hare represents just one of many ecological issues whose resolution has required multiple types and sources of knowledge, on a variety of spatial and temporal scales. With the increasingly complex environmental challenges currently facing the world, the ability to bring together diverse information rapidly is vital. Indeed, whether referring to sustainability, adaptive management, or conservation, there seems to be a general consensus on the importance of knowledge acquisition and more effective communication between scientists, citizens, and decision makers from both the public and private sectors (eg Mangel *et al*. 1996; Clarke 2002).

Although the tools for achieving sustainability are often referred to in abstract terms, the emergence of Web-based Geographic Information Systems (webGIS) shows great promise as a concrete means of increasing ecological knowledge and enhancing communication. Geographic Information Systems (GIS) are not only a way of visualizing and analyzing data, but also of organizing both spatial and non-spatial information based on where the data were gathered, thereby providing a common field for database records. Indeed, location can be a powerful "cataloging" structure for environmental data – the equivalent of a Dewey Decimal System for natural resources, along the lines of the Alexandria Library Project (Goodchild 1997). Combining the power of GIS and the Internet, webGIS can be used to store data and help users to both enter and access information without the need for expensive GIS software, using any Web browser at virtually any time (Kowal 2002). This increased ease of access to information about natural resources could further enhance public involvement in environmental management.

Much of the discussion and debate about webGIS technologies has taken place in the context of geography and landscape planning literature (Peng 2001; Carver *et al*. 2001). However, there are tremendous advances to be made in the use of webGIS in natural resource management efforts, which depend on timely data provision for effective decision making. Here we discuss natural

In a nutshell:

- WebGIS is a new tool that allows a variety of users to interact with spatially organized data over the Web
- Sustainable natural resource management requires comprehensive data collection and equitable data access
- Location information provides a powerful way to organize and access diverse datasets, and webGIS can enhance this
- A number of challenges in its implementation and use remain to be addressed

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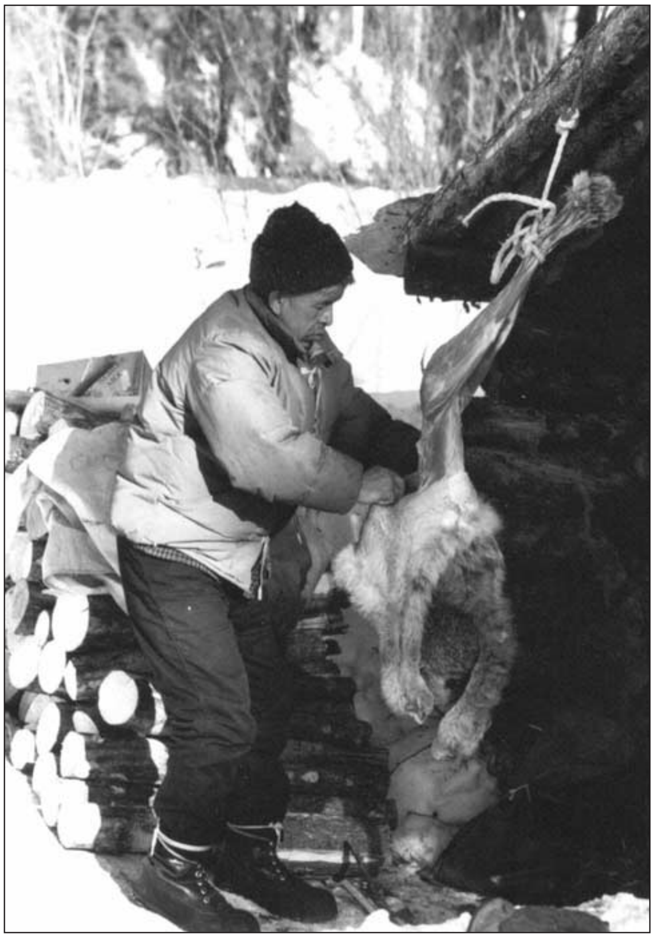

Figure 1. *Records of the number of furs traded by the Hudson's Bay Company were instrumental in helping researchers to understand the cyclical relationship between the Canadian lynx and the snowshoe hare.*

resource data management and communication needs, give an overview of webGIS technology, outline some of its advantages and disadvantages, and present examples of existing and potential applications.

Plugging in to public participation

As ecological degradation, serious public health issues, and the risk of conflict over diminishing natural resources worsen, the considerable challenges facing sustainable management efforts are becoming increasingly apparent. The original Sustainable Biosphere Initiative (SBI) set forth by the Ecological Society of America recognized the need for basic research focusing on the acquisition of ecological knowledge, the communication of that knowledge to citizens, and its incorporation into policy and management decisions (Lubchenco *et al.* 1991). More recent calls for sustainability have continued to recognize the importance of cross-disciplinary data gathering, integration, and synthesis, as well as the establishment of more effective communication strategies (Kates *et al.* 2001; Waltner-Toews *et al.* 2003). In addition, the Ecological Visions Project, recently announced by the Society and still under development, identifies ecoinformatics as one of the main challenges facing the ecological sciences (ESA 2003).

Indeed, comprehensive, sustainable natural resource management efforts call for substantial amounts of data on chemical, physical, biological, and social variables across multiple spatial and temporal scales. Collecting such a large amount of data is a major challenge. Much of the discussion about increasing data availability focuses on expanding access to data produced by other scientists (Michener *et al.* 1997). However, more and more, community-based monitoring and management efforts are being used successfully, enhancing both data acquisition and public involvement in natural resource management (Fleming and Henkel 2001). Because solutions often depend on traditional knowledge and the expertise of local, indigenous people, community-generated data may be particularly important when dealing with international natural resource issues (Getz *et al.* 1999).

Once data are collected, the question of how best to enter, store, and access them becomes increasingly important, particularly in ongoing environmental monitoring and adaptive management efforts that depend upon subsequent analysis to determine if projects are being conducted effectively. Indeed, it is difficult to judge how far we have come in securing or improving the state of our natural resources, much less foster public participation in decision making, when environmental data are not complete, comparable, or easily accessible (Mayfield *et al.* 2001).

Next generation management tools

Wired for sustainability: GIS

The use of GIS has been rapidly expanding in a multitude of fields, and with a variety of applications. In general terms, the various GIS technologies can be used to integrate spatial and non-spatial attribute data, perform analyses, and display and disseminate results in both spatial and non-spatial formats (Burrough and McDonnel 1998). In addition, GIS allows for the incorporation of data gathered from multiple spatial scales (Figure 2). Because most environmental information has a relevant spatial component, location information provides a common field for the storage of and access to data related to a particular place. The use of GIS technologies has been steadily increasing in national and international environmental management efforts, especially as graphical interfaces have evolved to make the software more user-friendly.

In spite of its power, however, GIS may be limited to high-level users, because it requires specialized software and high-speed computer hardware that can be expensive, and often involves a great deal of training (Kowal 2002). Several researchers have also raised concerns about the social implications of GIS-based resource management, arguing that it is an elitist and technocratic technology that marginalizes people, especially in developing countries, largely because of differential access to computing technology (Pickles 1995). Others have contended that it is a "contradictory technology" that can simultaneously marginalize and empower people, and the extent to which either or both occur is largely dependent on context (Harris and Weiner 1998).

Out of these arguments, a new focus on "public participation GIS" (PPGIS) has emerged. Early PPGIS efforts consisted of attempts to involve larger groups of people in the decision making process by placing an emphasis on empowering communities, usually through workshops, to create and utilize GIS technology (Harris and Weiner 1998). Today, with the prevalence of the Internet, webGIS is a driving force behind efforts to increase public participation in environmental decision making (Peng 2001).

Landsat imagery courtesy of USGS

Figure 2. *The increasing use of GIS and related technologies, such as remote sensing, has allowed large-scale factors to be more easily incorporated into natural resource research and management efforts. For example, (left) information from land use and land cover imagery covering the San Francisco Bay area is being combined with (right) riparian and benthic macroinvertebrate data collected in the field to give us a better understanding of how land use transformation impacts freshwater ecosystems.*

Wired for sustainability: webGIS

WebGIS makes dynamic mapping available via the Internet. Targeted towards mid-level users, it allows people to access geographic information in data layers that may be turned off and on, mapping tools, and often analytical tools as well. All this is possible using a Web browser, without having to own specialized GIS software (Kowal 2002). WebGIS applications usually depend on a combination of hypertext transfer protocol (http), transmission control protocol (tcp), and hypertext markup (HTML) and Java languages to provide users with Internet access to data that resides on a server. Most webGIS design packages, such as the Internet Map Server (ArcIMS) software from the Environmental Systems Research Institute (ESRI), provide a combination of map design and server software that can be used to build a customizable application (Kelly and Tuxen 2003).

Although webGIS technologies are relatively new, they are already being used in a variety of different ways (Table 1). For example, there are sites that essentially provide maps as images, such as MapQuest (www.mapquest.com), which allows users to create maps using street addresses, and sites such as the World Atlas of Biodiversity (http://stort.unepwcmc.org/imaps/gb2002/book/viewer.htm), which provides geo-

Table 1. WebGIS Resources

Software	
Autodesk MapGuide	http://www.mapguide.com
Caliper Maptitude for the Web	http://www.caliper.com
ESRI Inc's ArcIMS	http://www.esri.com/software/arcims
Intergraph GeoMedia WebMap	http://imgs.intergraph.com/gmwm
MapInfo MapXtreme	http://www.mapxtreme.com
Websites	
Bay Area EcoAtlas Information System	http://ecoatlas.org
ESRI Inc's ArcIMS site links	http://www.esri.com/software/internetmaps/visit_sites.html
National Atlas of the United States	http://nationalatlas.gov
National Oceanic and Atmospheric Administration C-CAP Data Distribution	http://www.csc.noaa.gov/crs/lca/locate.html
New York Department of Environmental Conservation Environmental Navigator	http://www.dec.state.ny.us/website/imsmaps
Sudden Oak Death Monitoring	http://www.oakmapper.org
Tompkins County, NY Interactive Mapping	http://owasco.co.tompkins.ny.us/gis
US Department of Housing and Urban Development Environmental Maps	http://hud.esri.com/emaps
US EPA EnviroMapper	http://www.epa.gov/enviro/html/em/index.html
US Geological Survey Wildfire Maps	http://wildfire.usgs.gov

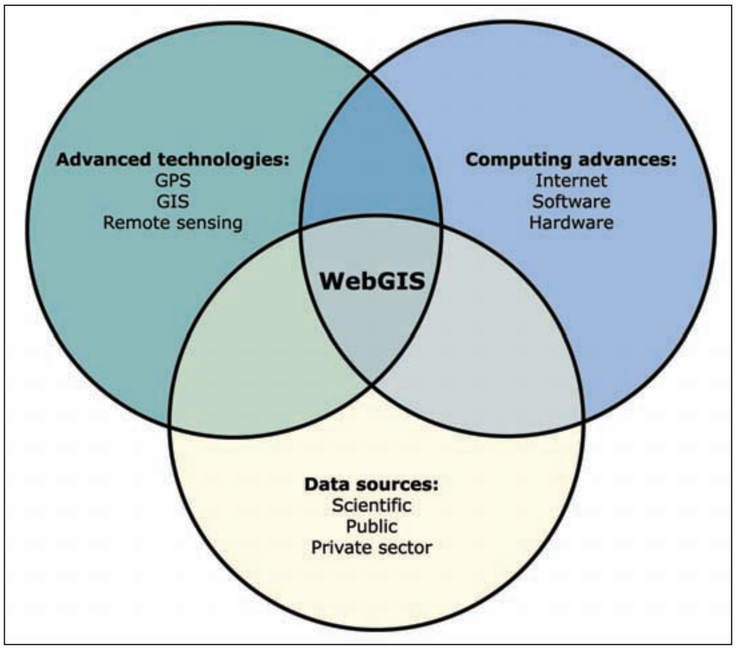

Figure 3. *Combining advanced technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), and remote sensing with increased computing capacities and multiple data sources, webGIS has the potential to aid in sustainable natural resource management.*

graphic information about a specific topic in a more interactive format. WebGIS also enables groups of researchers to access shared data (Su *et al.* 2000). Less common are webGIS sites that allow public input for a given issue, as opposed to simply providing information (Kelly and Tuxen 2003).

The capabilities of webGIS are constantly expanding. As the use of GIS, Global Positioning Systems, and wireless telecommunications technologies become further integrated, for example, more webGIS efforts will soon include real-time updates, making real-time, decision-making support possible (Xue *et al.* 2002). These types of technological advances are important developments in sustainability research, because they allow for integrated analysis that is location-specific, policy-relevant, and geographically scalable (Clarke 2002; Figure 3).

Although webGIS can offer many solutions to the problems noted above regarding conventional GIS usage (Carver *et al.* 2001), it may amplify some GIS-specific problems and create new challenges, as a result of its potential to bring GIS technology to a broader audience.

User access

WebGIS eliminates the need for GIS software and relies on Web browsers to provide a portal to geographic data, potentially making information available to a wide variety of users that might not otherwise have access (Peng 2001). However, this raises the problem of differential Internet access. Some researchers have even argued that the increases in participation may be outweighed by disparities in Web access (Carver *et al.* 2001). Although recent estimates have shown that almost 60% of North Americans have Internet access, Web usage worldwide is thought to be only 10% (Nua 2003), which hinders efforts to create participatory webGIS for global scale issues. In addition, differences in computing and bandwidth speeds can make webGIS sites difficult to navigate efficiently.

A less costly alternative to webGIS is the use of static maps and data distributed on compact disc or digital video disc. While in some cases this may be a good option, because it does not require an investment in the hardware and software required to build and serve a webGIS or high-speed Internet access, it also does not allow for real-time data updating, and can lead to confusion in updating records created by multiple users.

Private and proprietary data

Privacy issues are a key concern connected with the use of webGIS, and indeed with most Internet-based technologies, since these can make vast amounts of personal information widely available. Strategies for protecting individual privacy with webGIS include the aggregation of spatial data over a wide geographic area and the reclassification of information that may pertain to individuals (Theseira 2002). In addition, if concerns about privacy are keeping people from contributing information, spatial errors can be deliberately introduced, to prevent exact locations from being known (Kelly and Tuxen 2003).

Data copyright issues can also impede efforts to create a comprehensive webGIS application, although this is not often an issue for natural resource datasets in the US, because many geospatial data layers can be freely downloaded from state and federal agencies (Theseira 2002). For example, data from private corporate vendors, such as Microsoft's TerraServer, are proprietary (Su *et al.* 2000).

User training and education

Less tangible, but at least as significant as the technological challenges raised by webGIS, are issues related to user training and education on gathering, entering, and interacting with data. Although scientists can be skeptical of volunteer-generated data, studies have shown that, with proper training and quality assurance and control procedures, citizen-produced data can be highly accurate (Mayfield *et al.* 2001). As is the case with all shared data, efforts must be made to ensure that proper metadata (including how location information was collected and transformed – eg geographic projection) are available, allowing users to choose the level of data quality they are willing to accept for their particular needs.

Furthermore, the use of conventional GIS software may require a steep learning curve, and although webGIS applications are often simplified, there is still an assumption that people will understand the tools available to them, which may not always be the case (Kowal 2002). Some researchers have also raised concerns over the potential harm caused by distributing data to general users without access to the full context of a particular issue (Carver 2001). This is a larger issue than can be fully addressed here, especially considering that a recent National Science Foundation survey found general scientific literacy in the US to be "fairly low" (NSB 2002). Even so, it is clear that the use of webGIS for natural resource monitoring must take place in the context of other educational and outreach efforts, including general scientific knowledge, as well as issue-specific information.

These challenges can be addressed, at least in part, simply by using the full power of the Internet. For example, links to sites that provide general overviews of topics and scientific definitions can create added value for webGIS sites. In addition, efforts can be made to provide a spectrum of ready-made maps and queries for users with different abilities. For example, HTML pages with static maps may be linked to webGIS pages, so that users who are not comfortable manipulating geographic information can view and print maps, thereby making the data produced accessible to as many people as possible. This may also help with the issue of bandwidth limitations, as maps can be provided in many formats, including smaller, low-resolution images that are quick to download. Depending on the goal of the site, user-training efforts may also be helpful (Carver *et al.* 2001; Peng 2001). WebGIS can aid in the creation of "citizen scientists", an initiative that has been highly successful in several environmental monitoring efforts (Stevenson *et al.* 2003).

Social and institutional issues

Our understanding of large-scale influences that cross administrative boundaries (eg climate and land use change) is evolving rapidly. At the same time, natural resource decision making is increasingly being deferred from national to local governing bodies, especially in the US, and citizens are becoming more and more concerned about the environment. This makes it important for communities to be empowered to participate in natural resource management (Jacoby *et al.* 1997).

Although we have discussed many of the technical challenges facing webGIS usage, the success or failure of many community-based monitoring efforts is rarely due to technical issues, but is almost solely based on institutional or managerial factors (Harris and Weiner 1998). For example, while many federal and state natural resource agencies want public input, they are not necessarily equipped to deal with the rapid way the Web allows citizens to both input and retrieve information (Helly *et al.* 2001). Therefore, successful webGIS implementation could be largely dependent on institutional ability to engage stakeholders in the decision-making process and to adapt to the uncertain impacts of increased public involvement.

Byte by byte: webGIS examples

Although webGIS is a new and evolving technology, it has already been used successfully to help map the spread of Sudden Oak Death in the western US. There are many potential applications of webGIS technology to other natural resource management efforts, for example freshwater quality monitoring.

Tracking the distribution of invasive species

Sudden Oak Death (SOD) is a new disease which is affecting oak and tanoak forests throughout central coastal California and southwestern Oregon. The causal pathogen, *Phytophthora ramorum*, causes leaf and stem dieback in a range of forest shrubs and trees, and is lethal to several other tree species (Rizzo and Garbelotto 2003). The tree form of the disease has several characteristic and highly visible symptoms, including rapid crown discoloration. Because of its visibility and rate of spread, and the fact that several of the affected species are natives emblematic of California's rural past, the disease has generated widespread public concern, furthering the need for disease research, public outreach, and education.

Mapping and monitoring of the disease has been a high priority for the task force coordinating the research, management, regulation, and public education on the disease.

Figure 4. *With the OakMapper webGIS, users are able to interact with data about the distribution of SOD, submit the location of trees showing possible symptoms, and view and print both pre-made and customized maps.*

The "OakMapper" website (www.oakmapper.org; Figure 4), developed in 1999, is a webGIS application that both presents information on the currently known distribution of SOD and gathers data from the public on potential distribution of the disease. User interaction with spatially organized data is made possible by tools for interactive navigation, querying, and exporting of customized maps. Local knowledge about potentially affected trees is collected via an online form, with pictures and text that explicitly describe species and symptoms. People can report a diseased tree, whether it is located in their backyard, near a local neighborhood park, or on their favorite hiking trail.

The information collection and provision aspects of the site are popular with a diverse user community, consisting of many stakeholder groups (eg the scientific, management, regulatory, and political communities, as well as the general public). Preliminary results from the OakMapper show that it is an effective educational outreach tool for all affected counties (65% of all submissions come from affected counties). The site sees an average of about 20 visitors per day and has received 340 submissions of symptomatic trees to the database between 1999 and 2003 (about five per week).

Documenting the location where reports of trees potentially infected with *P ramorum* came from has further helped our understanding of the effective "area of influence" of our education and outreach program. This has also helped in the visualization of potential statewide distribution of SOD, and assisted managers in assessing local interest in the disease. The OakMapper site has not reached its full potential, however, due to a disconnect between the citizen-generated data and their scientific and political use. Although the data generated by the community are used in some areas as a guide for official sampling, this is not a routine practice. Even so, OakMapper is a great example of the use of webGIS in a community-based monitoring strategy, because it demonstrates the possibilities of data gathering and dissemination in the interests of a wide variety of users concerned about natural resource issues.

Freshwater quality monitoring and assessment

Richter *et al.* (2003) recently proposed a framework for sustainable freshwater management and identified collaborative dialogue as an essential component of a robust, adaptive management plan. In addition, a recent ESA report on better meeting ecological and societal needs for freshwater recommended that local groups and communities be empowered to implement sustainable water policies (Baron *et al.* 2002).

One way of increasing community involvement in freshwater issues has been the establishment of ongoing volunteer water quality monitoring efforts (Firehock and West 1995; Penrose and Call 1995; Mayfield *et al.* 2001). Indeed, in the US, the *National Water Quality Inventory* report notes that wider public involvement in freshwater quality issues is integral to program success, and that a majority of federal, state, and tribal agencies now regularly use volunteer-generated data (USEPA 2002). The *River and Watershed Conservation Directory*, compiled by the River Network, contains listings of over 3600 organizations with interests in volunteer freshwater quality monitoring efforts (River Network 2003). Not only does volunteer involvement augment data collection efforts, but providing citizens with knowledge about their freshwater resources could also lead to greater equity in prioritizing restoration and conservation activities, by keeping conservation efforts from being focused on areas where people have more expertise and/or money (Karr and Chu 1999; Figure 5).

There are also data storage and access issues to be resolved in order to develop successful water quality monitoring programs. Freshwater

Courtesy of David Kaplan, CNYDPR

Figure 5. *The use of citizen water quality monitors, such as these young people being trained by the Natural Resources Group of the City of New York Department of Parks & Recreation to collect post-restoration stream samples in the Bronx River, has been on the rise in freshwater management efforts. The use of webGIS in community-based monitoring has the potential to augment data collection efforts and increase public participation in watershed management.*

management efforts can produce huge datasets, involving chemical variables such as pH, dissolved oxygen, and metals; physical variables such as bank stability, sedimentation, and riparian characteristics; and biological variables such as taxa lists that can be hundreds of fields long (Barbour *et al.* 1999). Add to this any multi-scale spatial or temporal data, as well as any summary statistics, and a single project can have literally thousands of records.

With both researchers and communities increasingly concerned about the effective management of freshwater resources, it is vital that a mechanism be developed for broad interest groups to have input into the decision-making process. This is just one example of a natural resource issue where webGIS has the potential to foster public participation and increase equity in the freshwater resource decision-making process, by making data collection and information assessment more transparent.

■ Conclusions

There are countless historic and current examples of ecological issues that require increased knowledge acquisition, a better understanding of already existing data, and more effective communication between scientists, citizens, and decision makers. Also, although they are not always emphasized, there are many issues where the public could potentially provide input to aid scientists and decision makers, thereby increasing public participation in natural resource management. Indeed, if we are to take seriously the idea that humans are a part of ecosystems, we must develop concrete tools for involving citizens in the management process.

As shown by the success of programs such as the Audubon Society's Christmas Bird counts, and even the public response to the recent NASA space shuttle disaster, there are "citizen monitors" everywhere. At the same time, the emergence of more powerful Internet and computing technologies is providing increasingly sophisticated tools for information gathering, storage, and transmission. At its most basic level, webGIS allows users to interact with spatially organized information over the Web. Although there are challenges to be overcome, there is also tremendous potential in utilizing more fully the interactive opportunities provided by webGIS technology to increase citizen involvement in sustainable natural resource management efforts.

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