Chapter 12
The GIS Challenges of Ecoregional Conservation Planning

Gillian Woolmer

Abstract The tools of Geographic Information Systems (GIS) are well suited to the application of conservation planning, a pursuit that requires the overlay and analysis of often large volumes of geographic information, including the locations and distribution of multiple conservation targets and threats. During any conservation planning process, challenges related to the use of GIS can be expected, particularly for large planning areas that span multiple administrative jurisdictions. Challenges likely to be encountered relate to (1) the complex nature of spatial data, including data sources, access, licensing, quality, and compatibility, (2) the need to develop adequate capacity for GIS for the duration of the planning process, and (3) making spatial information generated by the GIS based planning process available to partners and stakeholders. By understanding the nature of the GIS challenges to be expected, conservation managers and GIS professionals can plan for the resources necessary to successfully achieve the goals of the planning process. In this chapter, I share the GIS experiences, challenges, and lessons learned from a multi-year, multiple-partner conservation planning effort for the transboundary Northern Appalachian/Acadian Ecoregion of North America.

Keywords Geographic Information Systems • GIS • Mapping • Spatial analysis • Spatial data

12.1 Introduction

With the analysis of information on the locations and distribution of multiple conservation targets and threats a central feature of conservation planning (Margules and Pressey 2000; O'Neil et al. 2005), a system to manage and analyze digital spatial data is critical. A geographic information system (GIS) is designed to collect, store,

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transform, analyze, and display such spatial information (Burrough 1986; Burrough and McDonnell 1998; ESRI 1997), which make the tools of a GIS ideally suited to conservation planning.

The use of GIS technologies by the conservation community has increased significantly since the mid-1990s. Today, GIS is a ubiquitous tool for conservation practitioners, a development that can be attributed to several factors: (1) the emergence of accessible desktop GIS software, (2) increased affordability of GIS-capable computers, (3) increased availability of spatial data and information that are published in GIS-compatible formats by both the public and private sectors at relatively low or no cost, and (4) increased availability of specialized GIS training at colleges and universities.

Conservation planning is a particularly challenging task when undertaken at the scale of ecoregions that transcend state, provincial, and/or country boundaries. Such projects require the collation, processing, and analysis of large quantities of complex spatial information of different types and quality, collected by various parties for different purposes, at varying levels of detail and published from multiple sources. Effective conservation planning at such scales, therefore, requires the development of a correspondingly complex information database that has been organized into a coherent, transparent system that can be readily accessed and used by multiple collaborators. Such database management tasks are not trivial and yet are frequently underestimated and not adequately planned for at the outset of many conservation planning exercises.

Conservation GIS dates back to the use of paper maps, printed aerial photographs, satellite imagery, and mylar overlays. The first national-level computerized GIS, known as the ‘Canada Geographic Information System’ (CGIS), was released in the early 1960s in Canada by the federal Department of Forestry and Rural Development (Tomlinson 1984; Wing and Bettinger 2008) to manage spatial information about soils, agriculture, recreation, wildlife, waterfowl, forestry, and land use collected for the Canadian Land Inventory (CLI). An early example of GIS relevant for conservation planning was the USGS Gap Analysis Program (GAP), launched in 1989 (Scott et al. 1993). The simple but powerful concept of overlaying information on the distributions of native species and natural communities with that of land protection status was aimed at assessing the degree to which important areas for biological diversity were represented by the network of conservation lands, and correspondingly to identify ‘gaps’ to guide future conservation action. These early approaches to GIS-based land use and conservation planning evolved rapidly into computer-driven models designed to assess threats due to land-use change (Chap. 2), optimize representation (Chap. 14), analyze connectivity (Chap. 16), and predict climate influences (Chap. 15).

When embarking on a conservation planning initiative, it is important that project leaders be well-prepared for the GIS-related challenges that may arise during the planning process to avoid any potential delays or even derailment of the process. The goal of this chapter is to review these challenges and offer guidance based on the lessons I have learned from participation in Two Countries, One Forest (2C1Forest), a bi-national, multi-stakeholder conservation planning collaborative (Bateson 2005) for the Northern Appalachians/Acadian ecoregion of North America (Chap. 1). I will cover several important issues related to the use of GIS in conservation planning: (1) the complex nature of spatial data, including data sources, access, licensing, quality, and compatibility, (2) the need to develop adequate capacity for GIS for the duration of the planning process, and (3) the importance of making spatial information generated by GIS for ecoregional conservation planning available to partners and stakeholders – a critical outreach component required to develop support for plan implementation.

The Northern Appalachian/Acadian ecoregion encompasses portions of four U.S. states (New York, Vermont, New Hampshire, and Maine) and all or part of four Canadian provinces (Québec, New Brunswick, Nova Scotia, and Prince Edward Island). This geographic context presented numerous challenges to developing a coherent plan derived from spatial data, primarily because these data were published by numerous NGOs and government agencies for multiple jurisdictions, levels of governance (two countries, multiple states and provinces), and distinct cultural and linguistic traditions.

12.2 Building a GIS for Ecoregional Conservation Planning

A major component of any conservation planning process is a GIS that is tailored to the goals of the planning effort and the extent of the planning region. The building of a GIS is often described as simply the compilation and overlaying of digital spatial data; however, a more complete definition is that a GIS is actually an organized system of interrelated geographic data, computer hardware, software, and personnel (ESRI 1997). A comprehensive view of GIS as both an information-management system and decision-support tool is essential for undertaking a successful ecoregional conservation planning project. This section will review and provide guidance on building such a GIS with a focus on the aspects related to data and personnel, which comprise the most challenging and complex aspects of the overall system. A discussion of hardware and software options is beyond the scope of this chapter, and these facets of GIS systems have seen significant and rapid improvement in recent years. Specifically, GIS-capable desktop computers tend to be affordable and accessible in most areas of the world, and a variety of GIS software application options are now available, including no-cost open source and freeware (e.g., GRASS and Quantum GIS) and proprietary software (e.g., ArcGIS by ESRI, MapInfo by Rockware), some of which can be acquired at significantly reduced cost for conservation applications through grant programs, such as the ESRI Conservation Program (www.conservationgis.org).

12.2.1 Data

Spatially explicit data provide the foundation for any ecoregional conservation planning process, and governments – nations, states and provinces, and municipalities – increasingly publish spatial information suitable for ecoregional-scale planning in

GIS formats. However, because ecoregions are largely defined by their climate and biogeography (Bailey 2004), their boundaries rarely align with or fall entirely within the boundaries of a single administrative jurisdiction. More often, ecoregions are 'transboundary' in that they span multiple political and administrative jurisdictions, and therefore ecoregional conservation planning typically requires building transboundary spatial data layers.

GIS data represent real-world features (e.g., towns, roads, land use, elevation) in digital formats as one of two abstractions (Burrough and McDonnell 1998): discrete objects (e.g., a house or recorded species location) or continuous fields (e.g., rainfall amount, elevation, or land cover). The latter are either quantitative in nature, like millimeters of rainfall or qualitative like land-cover classes. For conservation planning, many different types of spatial information will be required, and although these data can be categorized in many different ways, common types of information will likely be required. 'Base data' refers to map layers that serve as components of maps over which other spatially explicit information are placed for reference. These provide the underlying context for the planning exercise upon which other data can be positioned. Common base data themes include administrative and jurisdictional boundaries (e.g., municipalities, state/provincial/national borders, protected areas), elevation, hydrology (e.g., lakes, rivers, watersheds), populated places (e.g., cities, towns, villages, urban areas), and transportation networks (e.g., roads and railways).

Other types of spatial information that are often required for conservation planning include data on human population (e.g., census), human land uses (e.g., agriculture, mining, residential and industrial development), natural land cover (e.g., vegetation classes), and geology. Desired biological information includes the locations and distributions of rare and endangered species, other focal species, communities, ecosystems, and processes that may have been selected as important conservation features.

Five steps are essential to building a transboundary GIS database for a conservation planning project: (1) determine the required map scale and data resolution, (2) find and access the datasets, (3) assess the quality of the datasets, (4) assess the compatibility of the datasets, and (5) combine datasets to create single transboundary GIS data layers. These steps are described below using examples from the Northern Appalachian/Acadian ecoregion conservation planning initiative (Trombulak et al. 2008).

Data Scale and Resolution For any project that involves spatial analysis, it is critical to use GIS data that represent features at an appropriate scale or resolution for the task. For conservation planning across large landscapes, such as ecoregions, the most appropriate spatial data are those that represent geographic features either as vector data ranging between the map scales of 1:25,000 and 1:100,000 or as raster data with cell sizes ranging between 25 and 100 meters. Choosing the appropriate scale and resolution of GIS data for conservation planning involves a balance between meeting broad-scale and local-level conservation objectives. For example, while it may be quite useful to discern individual trees or houses for planning at the scale of a municipality, working with data at a higher resolution than forest blocks and residential areas is seldom necessary from a regional perspective. In fact, dealing with data that are too fine-scale for ecoregional planning can restrict the GIS process unnecessarily through the need to append thousands of data tiles and handle enormous volumes of data. Spatial data need only possess the spatial accuracy and information accuracy required to capture the degree of local variation in the geographic distribution and types of features on the landscape that is necessary for the results of a conservation planning process to be believable, relevant, and implementable at the scales at which local decision makers and land-use planners operate (Rejeski 1993).

The optimum scenario for transboundary ecoregional planning is to obtain existing published GIS data layers that contain features mapped at the appropriate scale and cover the full extent of the planning region. While digital spatial data for such large regions can be found as part of freely available continental or global datasets, most such datasets contain geographic features represented at relatively coarse scales. Examples include the North American Environmental Atlas (1:10,000,000; National Atlas 2009) and the global Vector Map Level 0 database (1:1,000,000; NIMA National Imagery and Mapping Agency 2000). This trade-off between spatial extent and resolution is not always the case; the Protected Areas Database of the U.S. (PAD-US Protected Areas Database of the United States 2010), for example, is far more comprehensive than most state databases. Yet, in general, using already-amalgamated data from multiple jurisdictions that have large geographic extents often comes at the expense of the grain of such data. Even then, regional or global datasets are not often available at a suitable scale, and the only option in that case is to 'stitch together' the more local datasets of the appropriate map scale that have been published by the individual jurisdictions that comprise the planning region (Chap. 18).

Published spatial data between the scales of 1:25,000 and 1:100,000 exist for most jurisdictions in North America, Europe, and Australasia. However, for other regions of the world, spatial data at these scales may not be freely available. Under such circumstances, it is necessary either to use GIS data from less detailed continental or global datasets or, if possible, obtain data from other sources such as NGOs, natural resource extraction companies working in the region, or for-profit digital data producers.

Searching for, Accessing, and Using Data Although any good web search engine can be used to search for spatial data, the best tools for locating high-quality spatial data are web-based GIS clearinghouses and portals. These provide a variety of ways to search for data, using a combination of keyword, interactive maps, and thematic data listings, and they promise the highest likelihood of identifying base and environmental data layers. The clearinghouses and portals that were most useful for identifying GIS data for the Northern Appalachians/Acadian ecoregion are listed in Table 12.1.

In the U.S., any spatial data generated through tax monies is generally distributed freely, unless security or other sensitivity concerns (e.g., rights of private landowners) exist. In Canada, however, the tradition of cost recovery for the distribution of government-published spatial data makes the situation markedly different.

Table 12.1 Government and private GIS clearinghouses and portals used to find published GIS data for the Northern Appalachian/Acadian ecoregion

Government	
Canada	
National	
GeoConnections Discovery Portal	http://geodiscover.cgdi.ca
GeoBase – Canadian Council of Geomatics	http://www.geobase.ca
GeoGratis – National Resources Canada	http://geogratis.cgdi.gc.ca
Provincial	
Nova Scotia 'GeoNOVA'	http://www.geonova.ca
Prince Edward Island	http://www.gov.pe.ca/gis
New Brunswick – Service New Brunswick	http://www.snb.ca/gdam-igec/e/2900e.asp
USA	
National	
GeoData.Gov	http://gos2.geodata.gov/wps/portal/gos
State	
New York State GIS Clearing house	http://www.nysgis.state.ny.us
Vermont Center for Geographic Information	http://www.vcgi.org/
New Hampshire 'GRANIT'	http://www.granit.unh.edu
Maine Geographic Information Systems	http://megis.maine.gov/
Private	
ESRI	
Geography Network	http://www.geographynetwork.com
Geography Network Canada	http://www.geographynetwork.ca

For example, digital census data in the U.S. are distributed freely online by the U.S. Census Bureau, whereas in Canada, GIS and statistical data for the finest level of census units can be acquired only at a price. If these data are required for large areas, like the Northern Appalachian/Acadian ecoregion, it can cost thousands of dollars. However, a trend is emerging in Canada toward making many types of government published spatial data freely available through federal and provincial portals; examples include the GeoNova portal for Nova Scotia and the Land Information Ontario (LIO) portal.

If a required data layer does not exist, transboundary digital datasets need to be created from scratch, which may involve digitizing hardcopy maps, interpreting and georeferencing orthophotos, or classifying satellite images. For example, a road data layer can be created by digitizing road features from aerial photos, slope and aspect can be derived from a digital elevation model, and species distributions can be derived from predictive habitat suitability models (Guisan and Zimmermann 2000). In any case, the potential need to purchase good-quality data must be factored into the costs of any conservation planning project, whether a needed layer involves a simple fee purchase from a vendor or paying someone to create, reclassify, or model it.

Regardless of the costs involved, data access and use may require a data license with a publisher to protect both intellectual property and remove the publisher of any potential liabilities that result from data use (Longhorn et al. 2002). Such data licenses are likely to restrict data use and re-distribution, requiring the user to specify exactly how the data will be used and for what purpose. The location where the data will reside and the names, or positions, of staff that will have access to the data may also be required. This type of data licensing helps the publisher, often a government agency, ensure that data are not used for inappropriate applications and reduce risk of data being re-distributed, intentionally or unintentionally, to other parties without permission.

Data licenses are legal documents and, like any other, should be managed and stored securely with minimal risk of loss so they can be accessed and referenced as needed. Conservation planning is often a multi-year process that involves collaborations among multiple organizations and leads to new analyses years after a data license was acquired. Therefore, data licenses need to be revisited frequently to ensure compliance and to renegotiate licenses to permit additional uses.

Data Quality Quite apart from the challenges of obtaining the variety of desirable GIS data for conservation planning, a further complexity is introduced once the data are in hand and interpretation is required. Practitioners will need to understand how a dataset was created and evaluate the quality of the data it contains. For this reason, it has become standard for data publishers to produce metadata – 'data about data' – to accompany a dataset. Metadata come most commonly as an additional file to the digital GIS layer, for example as a text file, an HTML files, or in the case of ESRI format GIS files, as an XML file. GIS metadata allow the user to determine if a dataset is suitable for their specific needs and allows for GIS data to be searchable through GIS clearinghouses and portals. The two most widely used GIS metadata standards – the ones by the U.S. Federal Geographic Data Committee (FGDC Federal Geographic Data Committee 2000) and the International Organization of Standards (ISO International Organization of Standards 2010) – stipulate what types of information about a dataset must be included in GIS metadata, including information about the data publisher, data quality, spatial reference, data attribute fields, and attribute codes.

Because conservation planning involves decisions about particular pieces of geography, it is important to understand the nature and quality of the underlying data at any given location. In this vein, GIS data may represent discrete features or may represent derived information. For example, spot height elevation data on a topographic map represent actual on-the-ground field observations, whereas a continuous elevation surface dataset in the form of a digital elevation model (DEM) is not created from a continuum of direct observations. Rather, elevation values for locations between discrete elevation observations are modeled using interpolation techniques. The quality of an interpolated surface depends on the accuracy, number, and distribution of known data points and the suitability of the interpolation method (Aronoff 1995). Continuous thematic data, like land use, are frequently derived from the interpretation and classification of satellite images. The accuracy of such classifications can be evaluated (Stehman and Czaplewski 1998) and can be surprisingly low. The 1992 U.S. National Land Cover Dataset (NLCD) derived from the Landsat TM images, has only 80.5% and 59.7% accuracy rates for the general and detailed land cover classification levels (Yang et al. 2001), meaning that even at the coarsest grain of classification, land cover was incorrectly classified 19.5% of the time.

Likewise, habitat suitability models meant to predict the distribution and status of a species are generally derived from characteristics associated with point locations of animal occurrences and are not always assessed for their accuracy (Groves 2003). This underscores the importance of not accepting all data at face value, and instead highlights the need to examine the manner in which data are collected and understand the quality of information associated with modeling efforts prior to using them. Knowing how a dataset was created or derived and the accuracy of the derivation method will allow the user make choices about which datasets are best to use.

Additional complexities related to data accuracy are illustrated by two map layers that are widely used for conservation purposes – protected areas and natural heritage databases. Having accurate and up-to-date information on the protected status of a given land base is key to understanding the degree to which conservation targets are protected in the planning area and where additional conservation measures are needed. Acquiring this information for an ecoregion spanning multiple jurisdictions is complicated by the fact that accurate and complete spatial data on the locations of protected areas for a nation, state, or province are often not managed by a single agency because multiple agencies have responsibility for managing these lands. For example, Canadian national parks are managed by the federal agency Parks Canada, while provincial parks are managed by provincial natural resource agencies (with a similar hierarchy for different protected area designations in the U.S.). Some provinces and states have an agency that maintains GIS data but others do not, sometimes making it necessary to acquire data from multiple agencies even within a single jurisdiction. In recent years, global and regional protected areas datasets have been published to combat this challenge, by compiling data from multiple jurisdictions into a single database. For example, the World Database on Protected Areas (WDPA World Database on Protected Areas 2009), the Protected Areas Database of the United States (PAD-US Protected Areas Database of the United States 2010), and the North American Environmental Atlas (National Atlas 2009) are assembled from multiple governmental (e.g., provinces, states, countries) and private (e.g., non-governmental organizations) sources.

However, some databases are more comprehensive than others in the sense of what gets included as a protected area. For example, while the most recent PAD-US contains over 700,000 terrestrial protected area polygons assembled from states and participating agencies, the 2009 WDPA, which incorporates an earlier version of PAD-US, only has 6,770 for the United States and 112,725 for the entire globe. This discrepancy derives from the stricter definition for protected areas used by the WDPA. Continental efforts such as the North American Environmental Atlas seek to harmonize data across neighboring country boundaries for the very purpose of aiding conservation planning at multiple scales. These efforts are more inclusive than the WDPA and rely on how each country defines their protected areas and how frequently they update their GIS data. Conservation lands are not limited, however, to those under government jurisdiction. Privately owned lands in North America, Europe, and elsewhere with conservation easements or 'servitudes' need to be assessed for their conservation value (Jenkins 2008). As with protected areas, these lands can be classified according to established protected area classification schemes, such as those defined by the International Union for Conservation of Nature (Dudley 2008) or the U.S. GAP Analysis Program (Crist 2000). Information about the location of these privately owned lands has historically been difficult to gather and tends to change rapidly because new easements are constantly being purchased. Fortunately, in the U.S. a multi-partner initiative is underway to track and map lands protected by conservation easements through the National Conservation Easement Database (NatureServe 2009a).

All of this illustrates the complexities involved in the interpretation and use of seemingly straightforward data on the locations of protected areas. Every conservation planning project should consider the source of these data in the context of the scale of the study (e.g., local-global), the definitions of protected area status employed (e.g., IUCN or GAP codes), and the age and accuracy of the dataset.

Obtaining spatial data on rare species, focal species, and ecosystems provides an additional example of challenges inherent in interpreting and applying GIS data for conservation planning. First, the availability of suitable data depicting occurrence, distribution, and/or abundances of such conservation features varies from place to place around the world. In many parts of the world, databases of the known locations of rare, threatened, and endangered species are maintained. For example, in the U.S. and Canada information from Natural Heritage Programs within the majority of states and provinces can be accessed centrally through NatureServe (NatureServe 2009b; NatureServe Canada 2009). However, because such data are not always collected systematically, the strength of a given dataset depends on collection effort; hence, the most robust datasets of this nature tend to be spatially biased in relation to access (e.g., roads, rivers, populated areas; Pressey 2004). Moreover, data gaps that result from unsurveyed areas can lead to false interpretation of species absences. An additional consideration is that the distribution of rare species, focal species, and/or ecosystems may not be entirely based on actual field observations but derived from computer-based models. When modeling species occurrences and suitable habitat, it is important for conservation planners to evaluate sources of species distribution data, including potential biases of locality information, and to determine the need to improve the underlying data (Akcakaya 2004; Mackenzie et al. 2006). Where efforts to collect such information have not been consistent across a landscape, it is important for conservation planners to acknowledge and account for the inherent limitations of this information (Pressey 2004).

Data Compatibility A significant challenge for building transboundary GIS data layers is indentifying GIS datasets from adjacent administrative jurisdictions and multiple agencies that are compatible and can be appended together to create GIS layers for the full extent of the planning region. The most compatible datasets are those that contain geographic features represented in the same data model (vector or raster), at the same scale or resolution with similar data accuracy, have comparable dates of data collection and/or publication, and have been created for the same purpose.

The compatibility of feature attributes and attribute codes must also be considered for datasets to be combined across boundaries. If two roads datasets have been created by different jurisdictions, for example, it is likely that different road classification schemes (based on road width, number of lanes, and surface type) and sets of attribute codes will have been used, requiring a complex cross-walk of the road class codes of the two datasets.

When harmonizing the attributes and attribute codes of datasets so they can be combined, it is important to decide how much attribute information to transfer from the input datasets to the resulting output transboundary data layer, decisions that are typically based on the intended uses for the transboundary data. For thematic datasets (e.g., land use/land cover, roads), cross-walking the attribute codes of multiple input datasets most often requires reclassifying the feature types of each input datasets to a reduced set. Such an approach will result in a loss of information, but this is often the only option in order to build a data layer from multiple sources.

One example of the process involved in ensuring that spatial datasets are comparable were the U.S. and Canadian census datasets used for the Northern Appalachian/Acadian ecoregional planning effort. The U.S. census is executed fully every 10 years, with an intermediate partial census survey from which census statistics are estimated every fifth year after a full census. With every census, a GIS dataset called the TIGER/Line Files is updated from the previous census. This dataset has a spatial accuracy and map scale of 1:100,000 and contains GIS data layers that include census mapping units (irregular polygons called census blocks), administrative boundaries, roads, rail lines, and many other geographic features (U.S. Census Bureau 2000). The Canadian census is likewise fully executed every 10 years, but 1 year after the U.S. Census, and like in the U.S., a partial intermediate census is conducted 5 years after a full census. An accompanying GIS dataset is also updated with every census, including census mapping units, administrative boundaries, and roads data. These data have a spatial accuracy of between 1:50,000 and 1:250,000 (Statistics Canada 2002a, b). The smallest census mapping unit in Canada is the Dissemination Area (DA), which is also an irregular shape and size.

Achieving a single transboundary human population data layer that covered the whole Northern Appalachian/Acadian ecoregion required the amalgamation of the smallest census mapping units with attribute fields for total population and total number of dwellings (or housing units) per census unit – statistics collected by both the U.S. Census Bureau and Statistics Canada. This data layer was created by appending the 2000 U.S. census blocks data layer with the 2001 Canadian dissemination areas data layer (Fig. 12.1). These census datasets were deemed compatible because (1) they were created for the same purpose, (2) they are mapped at comparable (although not exactly the same) map scales, (3) the dates of data collection and publication represent the most recent versions of census data available at the time our study, and (4) the key attributes – total population and number of dwellings – were present in both datasets.

Geoprocessing to Create Transboundary Datasets Appending adjacent datasets into a single transboundary GIS data layer requires that both the spatial features and associated attributes of the input datasets be combined. Conservation managers

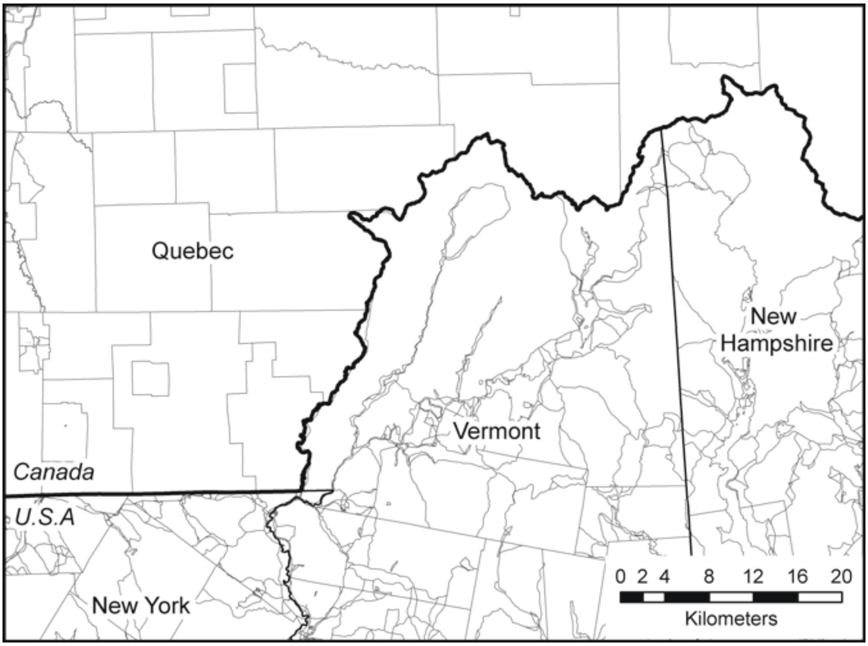

Fig. 12.1 A map of the smallest census mapping units for the Northern Appalachian/Acadian ecoregion – the 2000 U.S. census blocks and the 2001 Canadian dissemination areas – for a region at the U.S./Canadian border

need to be aware that this can entail considerable time and effort depending on input data format (raster or vector), number of input datasets, the magnitude of feature misalignments across dataset boundaries, and the congruity of feature attribute codes for cross-walking.

To illustrate, creating a seamless ecoregional data layer of census blocks for the Northern Appalachian/Acadian ecoregion required edge matching misaligned polygons because when the U.S. and Canadian census datasets were appended, topological errors occurred along the data boundary (Fig. 12.2a). The resulting data gaps and overlaps were removed through a combination of automated and manual GIS procedures (Fig. 12.2b).

When creating a transboundary roads data layers from U.S. and Canadian datasets (Fig. 12.3), on the other hand, the misalignments between road features at the border were less severe. We chose not to perform any edge matching in this instance because (1) the output roads dataset was not going to be used for any GIS applications that would require line features to be connected, such as networking applications, and (2) the misalignments were generally less than 30 m, or less than half the cell size (90 m) of the common raster analysis grid for the ecoregion. If misalignments of vector features across a data boundary are greater than half the intended raster analysis cell size, edge matching is recommended so that misalignments are not carried forward when the transboundary vector layer is converted to raster format for analytical purposes.

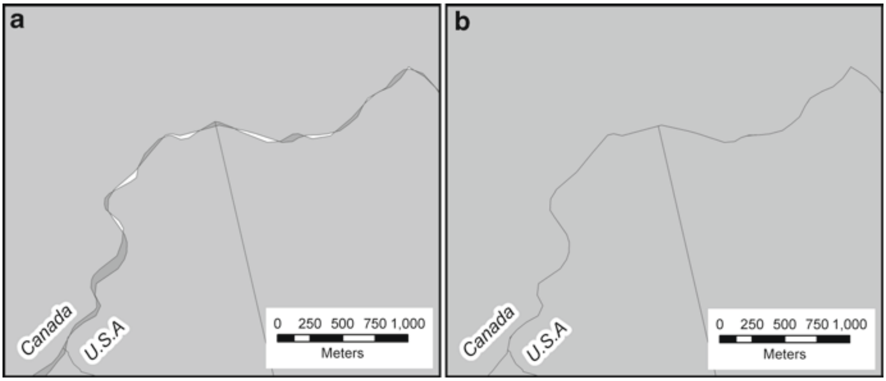

Fig. 12.2 Edge matching to align census mapping units at the boundaries of the datasets to a common edge: (**a**) polygon features before edge matching, showing data gaps in white and overlaps in darker grey, and (**b**) polygon features after edge matching

Cross-walking feature attribute codes across multiple datasets generally requires reducing the codes that represent feature classes in the input datasets to a smaller set of classes in the output dataset. The output set of feature classes may be derived from one of the input datasets or may be a new, simplified set of feature classes. For example, when we created the transboundary roads GIS layer, reconciling the 45 road categories in the U.S. TIGER/Line Files roads dataset with the Canadian roads dataset (DMTI Spatial 2009) that contained only 6 categories necessitated the reduction of the input road classes to four output roads classes (Table 12.2).

All conservation planning ultimately requires characterization of land cover and land use (LULC). Creating the transboundary LULC data layer in the Northern Appalachian/Acadian ecoregion was not straightforward. We had to combine five input datasets from different sources, all with different sets of LULC classes, two of which were in raster format and three in vector format. For the U.S. portion of the ecoregion, we used the 1992 National Land Cover Dataset (NLCD), a 30-m raster dataset published by the USGS. Because no equivalent to this dataset exists nationally for Canada, LULC datasets had to be sourced for each of the four provinces within the ecoregion. To combine LULC datasets, we cross-walked the input LULC attribute codes of the five input datasets by reducing them to a set of 15 LULC categories, which were derived from the 24 classes of the U.S. NLCD dataset. This required that we significantly condense the LULC classes of the input datasets, some of which contained up to 64 LULC categories (Table 12.3).

12.2.2 GIS Capacity

Any conservation planning initiative requires a team that includes personnel who are skilled in GIS and who can dedicate time towards the management and analysis of large volumes of spatial data. Additional GIS-related tasks necessary to the planning process

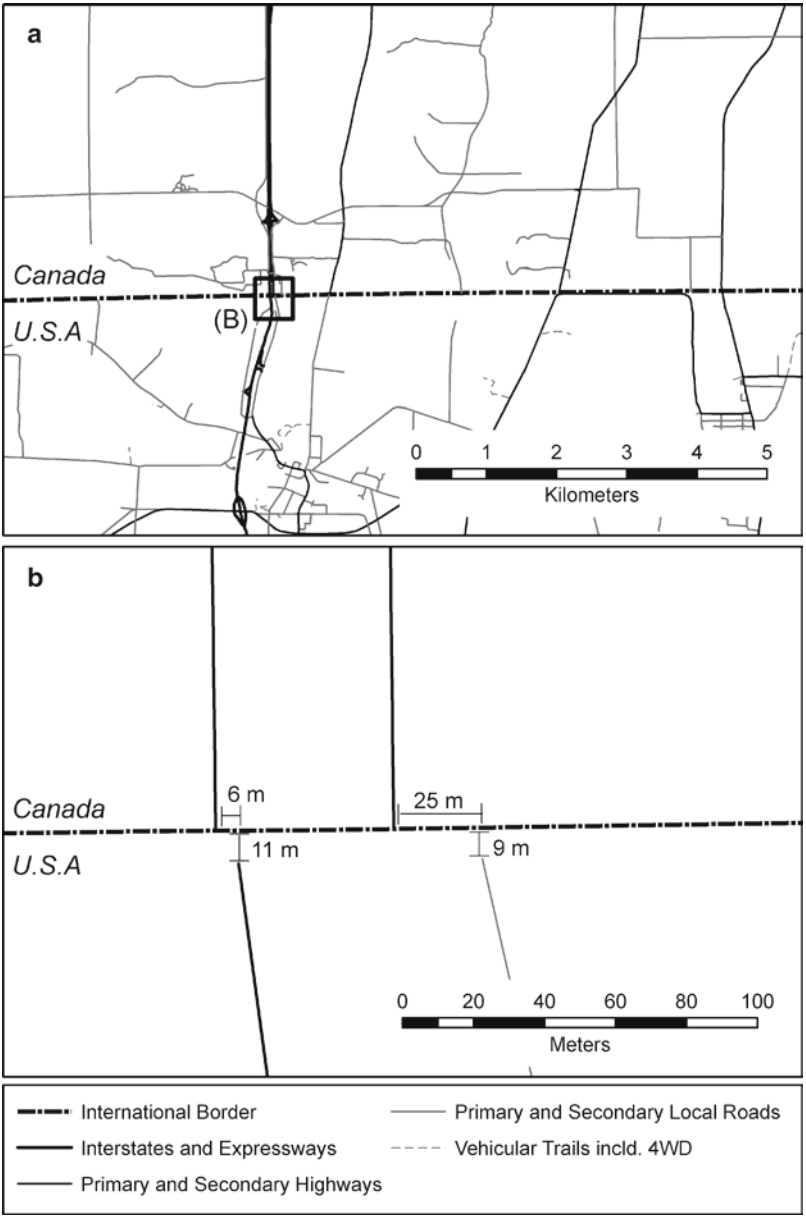

Fig. 12.3 A map of the U.S./Canadian border showing (**a**) the transboundary roads GIS data layer comprised of roads data from the U.S. and Canada, and (**b**) the misalignment distances between features across the data boundary

Table 12.2 The cross-walk table for the road-class attribute codes of two GIS roads data layers from the U.S. and Canada

U.S. input	Transboundary output	Canada input
TIGER/line files road classes	Transboundary roads data layer road classes	DMTI spatial roads road classes
Primary highway with limited access	1 – expressways and interstates	
A11, A12, A13, A14, A15, A16, A17, A18		1 – expressway
Road with special characteristics		
A63		
Primary road without limited access	2 – principle and secondary highways	2 – principle highway
A21, A22, A23, A24, A25, A26, A27, A28		3 – secondary highway
Secondary and connecting road		
A31, A32 A33, A34, A35, A36		
Secondary and connecting road A37 and A38	3 – major and local roads	4 – major road 5 – local road
Local, neighborhood, and rural road		
A41, A42, A43, A44, A45, A46, A47, A48		
Road as other thoroughfare A70, A73		
Road with special characteristics		
A60, A61, A62, A64		
Vehicular trail (4WD)	4 – vehicular trails incld. 4WD	6 – trail
A51, A52, A53		
Road as other thoroughfare		
A71, A72, A74		

include cartographic support for the production of maps for meetings, presentations, and reports, and interactive mapping support to facilitate active map-based collaborations during the workshops necessary to engage participants (Chaps. 4 and 11).

Ideally, a conservation collaborative involving multiple organizations, agencies, and/or research institutions working at an ecoregional scale will include a number of professionals who share data and collaborate on GIS-related analyses. Individuals contributing GIS expertise may include full-time paid technicians, analysts, and researchers, with additional mapping, analyses, and models produced by consultants as needed. Indeed, it is becoming increasingly common for graduate students to emerge from M.Sc. and Ph.D. degrees with technical GIS expertise, which has translated into a general increase in GIS-related capacity for conservation planning projects.

Our experience in the Northern Appalachian/Acadian ecoregional planning initiative underscored the importance of GIS capacity across multiple organizations, because one person alone was not able to support the full GIS needs of the

Table 12.3 The land use/land cover (LULC) classes in the LULC transboundary GIS data layer created for the Northern Appalachian/Acadian ecoregion and the number of LULC classes from each of the five U.S. and Canadian datasets that were combined to create each output LULC category

LULC classes in output transboundary dataset	Number of LULC classes in input datasets				
	U.S.	Canada			
	NLCD	Quebec	New Brunswick	Nova Scotia	PEI
Open water	1	4	5	4	1
Ocean	1	–	–	–	–
Residential	3	1	1	3	2
Commercial or indust. or trans.	1	1	7	6	2
Bare rock/sand/clay	1	0	2	12	1
Quarries, mines, gravel pits, peat bogs	1	1	4	3	1
Regenerating forest	1	6	7	1	7
Deciduous forest	1	1	5	1	1
Conifer forest	1	3	8	1	1
Mixed forest	1	1	8	1	2
Shrubland	1	1	2	13	1
Agriculture/plantations/ cultivated	5	6	6	3	1
Forested or shrub wetland	1	1	4	3	2
Emergent herbaceous wetlands, marsh or open bogs	1	1	1	11	1
No data/unclassified	1	1	3	0	0
Total number of classes per dataset	21	28	63	62	23

collaborative. Having at least some continuity of core GIS personnel for the duration of a conservation planning process is a real advantage, in that it helps maintain and retain a GIS history. GIS personnel transitions can result in loss of project knowledge related to data acquisition, treatments, compilation, and analyses. Such knowledge loss can be reduced by keeping good metadata, documenting data processing and analytical procedures, maintaining well-organized databases, storing data licenses securely, and managing staff transitions so as to overlap outgoing and incoming staff to facilitate knowledge exchange.

12.3 Distributing Outputs of Conservation Plans

The goal of an ecoregional conservation plan is to provide a scientifically sound conservation vision for an ecoregion. For such a vision to have any chance of being realized, it must be embraced and implemented by multiple individuals, organizations, and agencies across the region (Chap. 4). GIS plays a critical communication role because of the ease of interpreting GIS-generated maps as compared to raw data (Theobald 2009). To increase the probability of implementation, the conservation plan must be communicated clearly to those responsible for conservation management in the planning region, including government, industry, NGOs, and private landowners. One way to facilitate such communication is to ensure that the results of a conservation plan, accompanied with associated reports, maps, and GIS data, are easily accessible to these audiences.

12.3.1 Making GIS-Based Information Accessible

While papers, books, and reports are useful for communicating in-depth information regarding the methods, results, and implications of conservation planning exercises, the map-related information associated with such publications is unavoidably static and limited in the amount of information it contains. Distribution of GIS-based map layers generated by conservation planning efforts, on the other hand, provides a more direct means of enabling users to create customized products that meet their specific needs.

When detailed, GIS-based spatial information has been generated from a planning process, it is important to find a means to make that information available in such a way that it can be explored by different users, all of whom may be operating at different scales. Until recently, agencies and organizations that publish GIS-based spatial information most commonly distributed their data products in GIS-compatible digital file formats. While appropriate for the community of GIS professionals, such a distribution model unfortunately means that GIS data and the spatial information they contain are inaccessible to those without access to GIS resources. Increasingly, agencies and organizations that publish spatial information are communicating to broader audiences via web-based portals that include interactive map viewers. As our own experience in the Northern Appalachian/Acadian ecoregion demonstrated, presenting analyses at meetings stimulated interest by participants in obtaining results in map format customized for their local geographies to support their specific conservation activities. Given the dispersed nature of the collaborative network of 2C1Forest and the limited resources of the affiliated organizations that have strong GIS and mapping capacity, a web-based mapping solution appeared to be the most effective way to communicate and disseminate the data that had been generated.

12.3.2 Developing a Web-Based Mapping Tool

The solution my colleagues and I identified for distributing the results of GIS-based information that had been created for the ecoregion was to create the Northern Appalachian/Acadian Ecoregion Conservation Planning Atlas, or the ‘2C1Forest

Atlas' (Two Countries, One Forest 2009), an online mapping tool that would allow users to interact with GIS data and create custom maps to meet their specific needs.

The earliest web-based mapping tools available to the public were those that provided users with driving directions. These kinds of tools have become more numerous and sophisticated, and by 1998 almost every GIS company had a web-based mapping product (Li 2008). However, early applications were relatively slow and had limited functionality. Major advances in mapping technologies over the last 10 years, along with increased internet access speeds, have made it possible to develop more complex web-based mapping tools with dramatically improved functionality.

To develop and sustain a web-based mapping application, it is necessary to (1) define the purpose of the application and needs of the users, (2) develop content, (3) design and develop the application, and (4) host and maintain the application throughout its intended lifespan. To develop our atlas, we formed a seven-person Atlas Project Team made up of GIS professionals from the various organizations that published the related data, a 2C1Forest staff person with communications skills and authority over the 2C1Forest web site where the project was to be hosted, and a potential atlas user with no mapping or GIS skills.

Application Purpose and User Needs Because the development of an internet mapping application represents a significant investment of resources, it is vital to clearly define its purpose prior to the commencement of design or development. For example, the purpose of the 2C1Forest Atlas was to communicate the GIS-based results of ecoregional-scale conservation planning analyses conducted by 2C1Forest and partners for the Northern Appalachian/Acadian ecoregion to conservation practitioners in the region.

The Atlas Project Team was aware that the GIS and mapping skills of the potential users of the Atlas varied greatly, ranging from users who were merely comfortable surfing the internet to those who were experienced GIS professionals. However, to more accurately assess the GIS and technical capacity of our intended audience, we conducted a user needs assessment using a questionnaire sent to members of the 2C1Forest community by email. The questionnaire asked about their organization's size, scope of work, GIS capacity, types of spatial data used and needed, and speed of internet connection.

As expected, we discovered that our users possessed a wide range of GIS skills. We found that the majority of organizations that responded (57 of 63, or 90.2%) had GIS software in their organizations and used it regularly (74.6%). A small proportion either didn't use their software (3.2%) or used it only occasionally (12.7%). Moreover, 34.7% of the organizations were without internal GIS expertise, indicating that at least one-third of organizations concerned with conservation and land-use planning in the Northern Appalachian/Acadian ecoregion needed to outsource their GIS and mapping needs. We also learned that the biggest barriers to organizations using GIS for conservation planning were limited staff time, a lack of funding for GIS products and services, the high cost of GIS software, difficulty in obtaining data, and low data quality. On the other hand, 68% of respondents had experience using online mapping tools, with only one indicating that they had never even used Google Earth, and 77% of respondents most often worked with a high-speed internet connection.

Atlas Content It is important when developing a web-based mapping tool that the intended content is well-planned, including not only the GIS data to be provided but also the associated contextual and supporting materials to help the user interpret the data. The Atlas Project Team learned that the initial GIS data to be provided must be complete and ready to be added before development of an atlas begins. Development of web-based mapping tools can be expensive; because GIS data can take considerable time to create, if they are not completed at the start of atlas development, significant delays and costs will likely be incurred.

Purchased data or data governed by licensing agreements cannot be added as content to an internet mapping application without the consent of the publishers. For example, we were unable to add data on protected areas in Canada due to licensing restrictions that existed at the time. By contrast, we were able to add the LULC data because we revisited the data licenses with the publishing agencies and they gave permission to include the transboundary LULC data layer we created. The rationale for this decision was that it would be impossible for users to derive the original licensed data from the derived transboundary dataset. To meet the atlas content needs of GIS professionals with access to GIS software and hardware, the GIS data files from the conservation planning process were posted on the 2C1Forest website in compressed downloadable file formats, accompanied by full Federal Geographic Data Committee (FGDC Federal Geographic Data Committee 2000) standard metadata.

Design and Development Even conservation organizations that have good scientific expertise and technical capabilities for GIS do not generally have the capacity to design and build an efficient online mapping application. For this reason, we chose to contract the development of the 2C1Forest Atlas to a private firm specializing in internet mapping. We investigated partnerships with a number of universities and consulting groups but ultimately chose to work with DM Solutions Group (DMSG 2009), an Ottawa-based consulting firm specializing in internet mapping using the free open-source software program MapServer (Kropla 2005; Ojeda-Zapata 2005). Additionally, DMSG had experience working with the Canadian Federal Agency, GeoConnections (GeoConnections 2008), which provided funding for the Atlas under their 2006 Regional Thematic Atlas program.

As a result of a planning session guided by DMSG, we determined that the Atlas should (1) be user friendly for non-GIS users, (2) adopt a simple 'stress free' look and integrate well with the 2C1Forest website, (3) feel like a hardcopy atlas in that it should contain multiple maps accessed through an index page, with each map accompanied by contextual materials to help with interpretation, and (4) allow users to easily customize, save, and share maps. From start to finish, the design and development of the Atlas took 9 months. This relatively rapid pace was facilitated by the fact that the Atlas had a well-defined user audience and publication-ready data content prior to the start of development.

Hosting and Maintenance For an internet mapping application to remain live and functional, hardware maintenance, regular backups, and the regular implementation of software updates are essential. Otherwise, if a web-based tool becomes unstable, it will be deemed unreliable and ultimately abandoned by the user audience. For the 2C1Forest Atlas, we chose to use the same consulting group that developed the Atlas to provide hosting and maintenance for an annual fee. This was the most cost-effective option compared to developing sufficient in-house capacity for all of these tasks. The application was designed with an initial 5-year lifespan because (1) internet mapping technologies are developing rapidly, and new technologies would likely be available after a 5-year period, (2) the base data layers from which many of our conservation data were derived (e.g., census data, roads data, and LULC data) would be updated and published by the end of 2012, and (3) this corresponded with a planned evaluation of the content and design of the Atlas to determine its ongoing usefulness to the user community.

Regional GIS-based atlases also need to be considered in the context of rapidly emerging web-based mapping projects that collate and provide data at greater and greater spatial scales to support larger conservation communities. In 2009, three new web-based mapping tools designed for this purpose emerged in North America. Two of these were specifically designed to provide web-based mapping tools for users to add their own spatial conservation information and data, inspired by the recognition that most conservation organizations do not have the capacity to develop their own web-based mapping applications. The first of these is the Conservation Registry (The Conservation Registry 2010), developed by Defenders of Wildlife, which enables users to register their conservation projects, with the idea that the more conservation groups that use the tool, the better understanding the conservation community will have about where conservation activities are occurring. Thus, the Conservation Registry essentially maps conservation capacity.

The second tool is Data Basin (Data Basin 2009), developed by the Conservation Biology Institute. This is essentially a GIS data warehouse and viewing tool. It allows users to post their GIS-based conservation data with accompanying contextual information, such as images and reports, while also allowing users to search for data and create custom maps that combine any of the datasets posted to the site. It also has the capacity to support online collaborative mapping workspaces, a functionality that can potentially support planning collaborations without the need for GIS analysts, hardware, and software.

12.3.3 Outreach and Training

Once an online mapping tool is completed, targeted outreach activities are necessary to inform the intended users about the new tool and its associated benefits. Outreach strategies will vary depending on intended audience and available resources. For the 2C1Forest Atlas, we (1) launched the Atlas with a live demonstration at an annual 2C1Forest conference, (2) delivered seven 1-day workshops in the Northern Appalachian/Acadian ecoregion in Spring 2008, training 114 individuals from conservation NGOs, land trusts, foundations, colleges, universities, and government agencies, (3) delivered presentations and demonstrations at professional conferences, and (4) informed potential users about the Atlas through emails and newsletters.

12.4 Lessons Learned

The collaborative mapping and analysis efforts of 2C1Forest and partners for the Northern Appalachian/Acadian ecoregion offer several lessons about GIS-related challenges that are likely to be encountered during any effort at landscape-scale conservation planning.

First, conservation managers must be prepared to dedicate the necessary resources to support the GIS needs of the planning process for the duration of the planning project with respect to GIS software, hardware, data, personnel, and expert modeling.

Second, published transboundary GIS data layers of the appropriate scale and resolution for ecoregional planning that seamlessly cover the geographic extent of the planning region are rare. Therefore, transboundary GIS data often need to be created by combining multiple datasets published for adjacent administrative jurisdictions. This has potential consequences for quality and resolution of the resulting transboundary data layer.

Third, when a transboundary GIS data layer is created from multiple input datasets, it is important that the input datasets be maximally compatible. The most compatible datasets are those that contain geographic features represented in the same data model (vector or raster), at the same scale or resolution with similar data accuracy, have comparable dates of data collection and/or publication, have been created for the same purpose, and use the same or similar attributes and attribute codes.

Fourth, information about the locations of ecological features that are the focus of conservation interest (e.g., species, habitats, and ecological processes) can be hard to find and are generally incomplete. Thus, conservation planners must anticipate and plan for the resources required to create complete datasets either through field observations or the development of predictive distribution models.

Fifth, data access and use can be restricted by data licenses. Data licenses are legal documents and should be managed and stored securely. It is likely that licenses will need to be accessed for years after they are acquired, and if they are lost or misplaced, considerable staff resources may be required to recover or renegotiate a license.

Sixth, for a collaborative conservation planning initiative to be successful, multiple organizations within the collaborative should collectively bring GIS resources to the project and not rely on any single organization to support the full GIS needs of the planning process.

Seventh, in the event a turnover in GIS staff occurs, the risk of loss of GIS knowledge regarding the conservation planning process can be minimized by adhering to the practice of documenting how data are processed and analyzed, creating standard metadata for the final versions of all datasets created, and maintaining an organized GIS database. Facilitating an overlap between outgoing and incoming personnel is also recommended to permit project knowledge transfer.

Finally, for the results of a conservation plan to be used and its recommendations implemented, it is important to make the map-based information generated during the process accessible to stakeholders and decision makers not only as GIS data files, but through the use of an interactive web-based mapping interface whereby access to the information is not reliant on in-depth GIS training.

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