CONTEXT-AWARE ANALYSIS, GEOVISUALIZATION AND VIRTUAL GLOBES FOR MANAGING EARTH RESOURCES

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ABSTRACT:

Managers of natural and cultural resources increasingly require geospatial tools and techniques for inventory, monitoring and preservation. Web-based virtual globes, advanced methods of image analysis and geovisualization provide resource managers with: 1) access to current, high resolution satellite and airborne remote sensing imagery; 2) the ability to extract and edit features of interest; and 3) novel digital displays in 2D, 3D and 4D animations. These geospatial techniques benefit scientists, managers, policy makers, educators and public citizens. Researchers at the Center for Remote Sensing and Mapping Science (CRMS), Department of Geography have applied integrated geospatial tools for resource management in state, federal and tribal conservation areas of the Southeastern United States the past 25 years. Recently they have worked with the Southeastern Cooperative Wildlife Disease Study (SCWDS) at The University of Georgia on several projects that involve geospatial analysis and geovisualization to assess wildlife diseases and the geographic distribution of invasive wildlife species such as feral swine (*Sus scrofa*).

1. INTRODUCTION

1.1 Web-based Virtual Globes

The release of World Wind Version 1.2 on August 6, 2004 by the U.S. National Aeronautics and Space Administration (NASA) introduced an open source virtual globe that provided a 3D interface to seamless global remote sensing data (http://worldwind.arc.nasa.gov/). The geovisualization technology allowed users to zoom in from a space altitude and whole-earth view to any location to view Landsat 30-m imagery draped on Shuttle Radar Topography Mission elevation data. Although NASA World Wind required the program download of a large file (16 Mb for Version 1.4), Windows 2000 or XP, 2 Gb of free disk space, a compatible 3D graphics card and access to the internet, NASA reported in September, 2004 that over 60,000 copies of World Wind were distributed in one week (NASA, 2005).

A virtual globe released by Google Earth in June of 2005 also required users to download free software and follow simple instructions for installation on their desktops. News spread and soon millions of users world wide had quickly learned how to navigate, search and display satellite and airborne image data using the virtual globe interface. Key to the virtual globe interfaces was the ability for users to turn on and off layers of provided geospatial information and annotation, as well as the ability to add their own georeferenced data such as personally collected GPS point locations and geo-tagged digital camera images. Microsoft joined the virtual globe phenomenon with their release of Live Local (later known as Virtual Earth and more recently renamed Bing Maps) in December 2005 with no software download required (Olsen, 2005). The evolution towards increasingly easier-to-use interfaces with functional buttons and icons familiar to anyone who has played video games has popularized a once highly specialized and technical geovisualization capability. No longer regarded as the limited domain of computer specialists, the virtual globes viewers provided geographic information science (GIScience) technologies to all users with access to a computer and the internet. According to Butler (2006), virtual globes have changed the way we interact with special data.

The availability of free online mapping software, image/vector data and geographically tagged place names to make cartography and GIS capabilities accessible to casual users has been termed "neogeography" (Turner, 2006). Indeed, going beyond making GIScience technology available to the general public, neogeography has expanded to include the study of geospatial data sharing and use of maps to tell narratives (http://neogeography.net/forum/). For the first time traditional geography and cartography are being used by millions of people world wide to explore, share, integrate, personalize and simply play with geospatial data

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1.2 Virtual Globe Mosaic of Multi-resolution Imagery

Virtual globes provide a platform for organizing, storing, accessing and displaying multi-resolution imagery upon a seamless global base of medium-resolution satellite data. Originally provided from the U.S. Geological Survey (USGS) EROS Data Center, a Landsat Enhanced Thematic Mapper Plus (ETM+) image mosaic with 30 x 30 m pixels provides the Google Earth image backdrop for a virtual globe that can be easily rotated, panned, and zoomed by the user's mouse or laptop touchpad. As additional satellite data of higher spatial resolution are acquired, they can be added to the virtual globes to allow users to zoom in or "drill down" to increasingly higher levels of detail. For example, images are purchased by Google and Microsoft to add to their virtual globe image content from commercial satellite sensors such as Ikonos and GeoEye-1 (GeoEye, Inc.) with pixel sizes of 1-m and 0.5 m for panchromatic images, respectively, and QuickBird and WorldView-1 (DigitalGlobe, Inc.) with panchromatic images of 0.61-m and 0.50-m, respectively. Although not currently available for the entire earth, the high resolution images target cities and areas of interest such as unique and beautiful natural areas, those impacted by natural disasters or areas of mass displacement such as refugee camps (Madden and Ross, 2009). As virtual globes and similar web-based image and map search and display programs such as Google Maps become more familiar to users, they are increasingly integrated into the daily function of managers and scientists who monitor environmental conditions, processes and human impacts.

2. RESOURCE MANAGEMENT USING GEOSPATIAL TOOLS

2.1 Geospatial Monitoring and Assessment of Natural and Cultural Resources

Researchers at the Center for Remote Sensing and Mapping Science (CRMS), Geography Department, University of Georgia (www.crms.uga.edu) have cooperated with resource managers since 1984 to inventory, monitor and assess natural and cultural resources of private, state, federal and tribal lands (Welch et al., 1988, 1992; Welch and Remillard, 1994; Remillard and Welch, 1992, 1993; Madden, 2004a, 2009; Gibbs et al., 2006; Giraldo et al., 2008, 2009). For example, as part of the National Park Service (NPS) National Vegetation Inventory (NVI), geodatabases of vegetation communities, landuse/land cover, trails created by off-road vehicles and/or exotic, invasive plant species distributions were created for 21 NPS parks, preserves, historic sites and recreation areas (Welch et al., 1995, 1999, 2002a, 2002b; Welch and Remillard, 1996; Madden et al., 1999, 2003; Jordan, 2002, 2004; Hirano et al., 2003). The resulting geodatabases and summary statistics are critical for meeting NPS management objectives and allow further analysis such as rule-based fire fuel modelling, assessment of exotic plant eradication programs, developing management plans for off-road vehicle use in National Parks and predicting the impacts of exotic insect pest invasions on forest communities (Madden, 2004b, Madden et al., 2006, Allen and Madden, 2008).

2.2 Context-Aware Analysis for Resource Managers of National Parks

Recent research of the CRMS has explored the use of context-aware image analysis for feature extraction and classification in support of resource management in National Parks (Kim et al., 2008, 2009a, 2009b; Madden et al., 2009b). Expert knowledge combined with information obtained from existing GIS data can be used to analyze images within object-based image analysis (OBIA), an upcoming paradigm in image processing. The OBIA technique can be used with complex (i.e., high spatial resolution) imagery to model reality and extract geospatial information compatible with GIS (Blaschke et al., 2008). Lang (2008) states the guiding principle of OBIA is "clear as it is ambitious: to represent complex scene content in such a way that the imaged reality is best described and a maximum of the respective content is understood, extracted and conveyed to users". Object-based analysis of Earth remote sensing imagery is referred to as Geographic Object-Based Image Analysis (GEOBIA), defined as a, "sub-discipline of *Geographic Information Science (GIScience)* devoted to developing automated methods to partition remote sensing imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scales, so as to generate new geographic information in GIS-ready format" (Hay and Castilla, 2008, p. 77).

The GEOBIA segmentation and classification is well suited for mapping cultural features of buildings, roads and structures in developed areas surrounding conservation areas such as the Chattahoochee River National Recreation Area (CRNRA) located northeast of Atlanta, Georgia. This information is critical for assessing potential conflicts and boundary issues of public-private lands within the wildland-urban interface surrounding CRNRA. Data on trends in landuse/land cover are needed to assess current and future threats to Chattahoochee River water quality and quantity, trail use, impacts of increasing visitors and potential for invasion of exotic plants and animals. The CRMS conducted a pilot study to assess the use of GEOBIA to identify forest, agriculture and urban landuse/land cover conversion within a 500-m buffer area around a portion of the CRNRA using aerial photographs from 1938, 1980 and 1999 (Madden et al., 2009b).

Approximately one half of CRNRA lies within City of Atlanta counties of Fulton and DeKalb. The remainder lies within the Atlanta metropolitan counties of Cobb, Gwinnett and Forsyth. In 2006, Metro Atlanta was the ninth largest metropolitan area in the U.S. with a population of 5.1 million (U.S. Census Bureau, 2009). In the 1920s, this area was largely agricultural with many fields cleared for cotton production. Crop destruction by the boll weevil caused an agricultural depression that was followed by the Great Depression of the 1930s and forced hundreds of thousands of share croppers out of farming (Hendricks et al., 2009). Abandoned farmland was then converted to forest. As the City of Atlanta grew, development and urbanization spread out into the surrounding counties that were soon designated as the part of the Atlanta metropolitan area. Forest land was then cleared for residential and commercial development.

The land cover and landuses of areas directly adjacent to designated parks and conservation lands has a direct impact on the ecological health of park natural resources. The

Chattahoochee River of the CRNRA receives its water from the Atlanta metropolitan area and understanding the changes that have occurred in the area surrounding the CRNRA will aid resource managers tasked with protecting natural and cultural park resources. Used historically as a means of transportation to Native Americans and then as a source of power to support mills and factories located along its shore, the park now offers outdoor recreation opportunities for more than three million visitors a year (NPS, 2009). An historical record of landscape changes exists in aerial photographs and orthoimages were created in this project to provide information on changes in major landuse/land cover for 1938, 1980 and 1999.

A representative subset of the park area near Medlock Bridge was selected to test automated segmentation and fuzzy classification of the imagery. A 500-m buffer beyond the park border was created in ArcGIS and the three dates of orthoimages were subset and input to Definiens Developer 7.0 to derive polygons of forest, agriculture and urban. Training sets for several subclasses of agriculture, forest, urban and water were tested during the classification stage of GEOBIA and a series of context-aware refinement rules were developed to refine the classification. Final maps of GEOBIA segmentation and classification of 1938, 1980 and 1999 landuse/land cover within the 500-m buffer of the selected subset of CRNRA were created at 1:12,000 scale. Color-coded landuse/land cover is depicted as transparent layers over the orthoimages to provide information on the underlying features that constitute each class (Figures 1 to 3). Agriculture is shown in yellow, forest in green, urban in red, and water in blue.
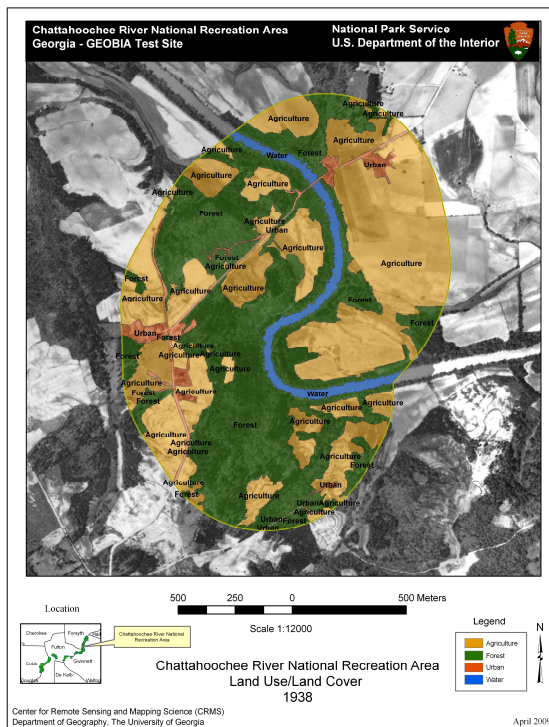

Figure 1. Results of GEOBIA segmentation and classification landuse/land cover within a 500-m buffer of a selected subset of CRNRA near Medlock Bridge shows dominate agriculture and forest in 1938.

Total overall landuse/land cover changes between 1938 and 1999 are depicted in Figures 4 and 5. Over 70% of the changes are due to three land conversions: agriculture to urban (34%), forest to urban (24%) and agriculture to forest (12%). Another 20% of the study area remained forested between 1938 and 1999. Of the remaining 10% of the study area, 5% remained stable (water to water 2% and urban to urban 3%) and 5% experienced a variety of minor landuse/land cover changes. Only 1% of agriculture lands in 1938 remained agriculture in 1999. In Figure 4, a three-digit label is used to indicate the landuse/land cover change trend. For example, a label of 222 shows patches of forest that remained forest in each of the three dates of study. A label of 223 would show patches of forest that were converted to urban in 1999. The color-coded graph of general landuse/land cover changes shows losses in agriculture over the 60-year time period were mirrored by the opposite trend in urban increases (Figure 4). Forest, however, remained a dominant land cover throughout the study period with increases following the abandonment of row-crop agriculture and some decrease in coverage with post-1980 urbanization.
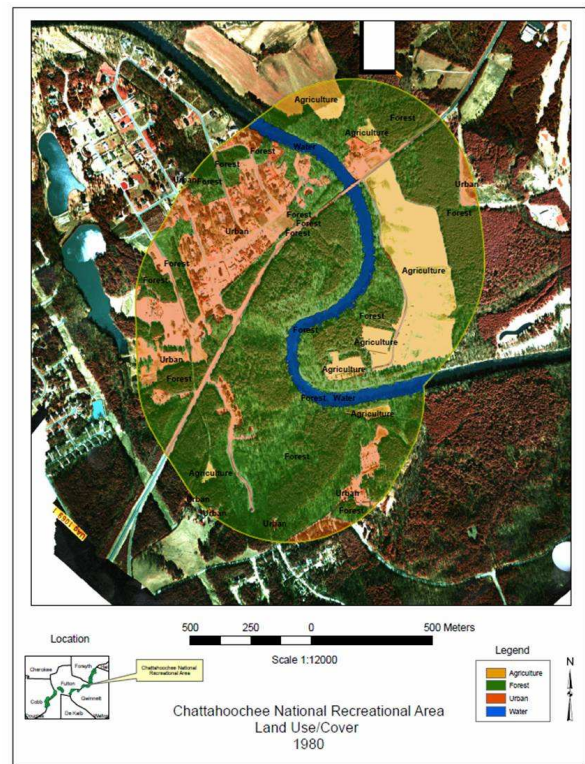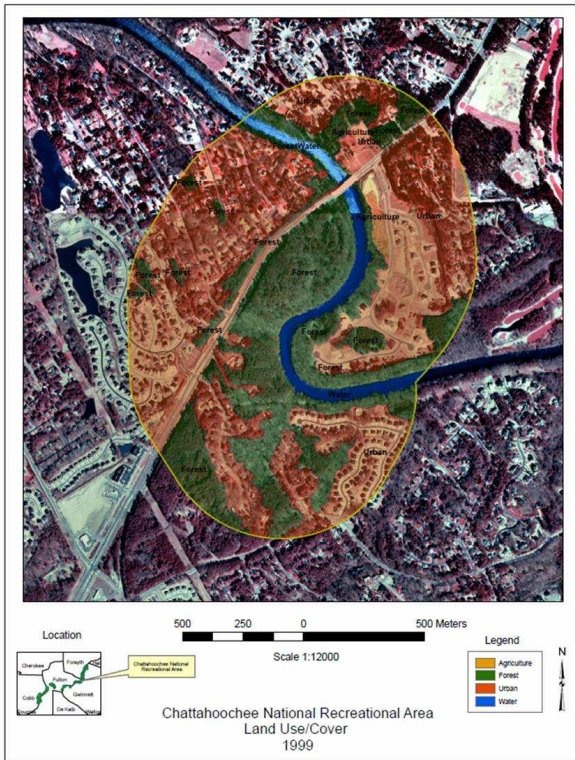

Figure 2. GEOBIA segmentation and classification of 1980 landuse/land cover within a 500-m buffer of a selected subset of CRNRA depicts conversion of agriculture to forest and the beginning of urbanization.

These results indicated the context-aware GEOBIA approach is a suitable method for determining historical trends in agriculture, forest and urban landuse/land cover changes in the area surrounding the CRNRA. Grouping image pixels into objects before classification produces databases of homogeneous landscape patches that can be used to produce clear and aesthetic-looking map products, as well as useful summary statistics compiling number and size of changing landuse/land cover patches. The resulting geodatabases in ArcGIS shapefile format are easily integrated with existing

GIS databases for further studies of spatial correlations and regression analysis to explore causal factors and driving forces that may explain the magnitude and directions of trends. Once the GEOBIA segmentation parameters are established and classification rules developed with representative pilot study areas, these techniques can be efficiently applied to the greater region to quickly map and analyze broader landuse/land cover changes over these same time periods and/or with additional dates of historical or current imagery.

Figure 3. GEOBIA segmentation and classification of 1999 landuse/land cover within a 500-m buffer of a selected subset of CRNRA depicts major land conversion to urban with decrease in forest and only one remnant patch of agriculture.

Figure 4. Changes (1938 to 1980 to 1999) in landuse/land cover within a 500-m buffer of a selected subset of CRNRA near Medlock Bridge.
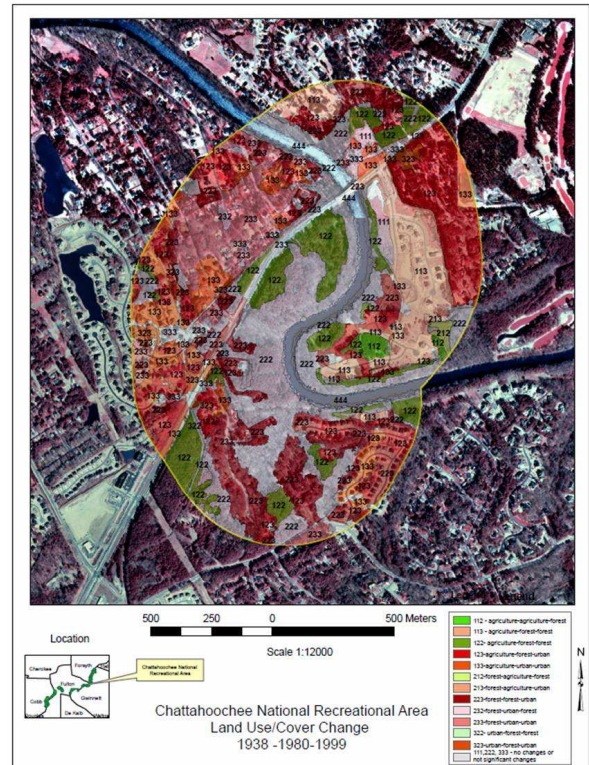

Figure 5. Changes (1938 to 1980 to 1999) in landuse/land cover within a 500-m buffer of a selected subset of CRNRA near Medlock Bridge. Classes include (1) agriculture, (2) forest, (3) urban and (4) water.

2.3 Monitoring U.S. Feral Swine Distributions using Web-based Virtual Globe Technology

Scientists of the Southeastern Cooperative Wildlife Disease Study (SCWDS) at The University of Georgia provide expertise on wildlife diseases to a large number of U.S. state and federal agencies responsible for the U.S. wildlife and domestic livestock resources. This state-federal cooperative unit is funded by state wildlife agencies and the Biological Resources Division of U.S. Department of Interior (http://www.scwds.org/) to coordinate regional wildlife research and service projects. SCWDS also is supported by Veterinary Services of the Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture (USDA) for consultation and surveillance on a national and international basis where diseases may interact among wildlife, domestic livestock, and poultry (APHIS 2009). Since SCWDS researchers work with a variety of people including wildlife managers, farmers, landowners, veterinarians, physicians and outdoor recreationists, there is a need for easy-to-use geospatial tools for monitoring wildlife distributions and the spread of diseases.

Feral swine (*Sus scrofa*), also known as wild-living pigs, include feral descendants of domestic hogs, introduced European boars and hybrids between the two (Mayer and Brisbin 1991). Native to Eurasia, domestic hogs and European boars were introduced to the U.S. as a source of food for colonists who arrived in the 16th century (McKight, 1964). Some of these non-native hogs, boars and hybrids escaped or were released from captivity and their high rate of

reproduction, general hardiness and flexibility in food and habitat requirements led to the expansion of their distribution. Feral swine continue to spread into new areas of the U.S. due, in part, to people moving and releasing them for recreational hunting. This is a growing problem in many conservation and protected areas such as National Parks and military bases in the southeastern U.S.because these exotic mammals destroy native vegetation by disturbing the soil and rooting to dig up plants to eat (Engeman et al. 2007). In Great Smoky Mountains National Park along the border of North Carolina and Tennessee., for example, wallowing and rooting threaten endemic, rare and endangered plant species. The feral swine also contaminate streams by introducing high concentrations of bacteria and cause a health concern in park areas used for recreation (NPS, 2003). Adults ranging in size from about 50 to 150 kg (Mayer and Brisbin, 1991) consume large quantities of invertebrates and vertebrates, thus directly affecting native animal populations. The rooting disrupts the forest floor and impacts small mammal populations in the park. Travelling in groups, the feral swine can act aggressively towards people and threaten park hikers and campers. Finally, there are some diseases that are transferred between feral swine and domestic pigs. For example, the pseudorabies virus is well established in U.S. feral swine populations that act as a potential reservoir for the infection of domestic swine and native wildlife (Corn et al., 2004).

There is a need for epidemiologic studies to understand risks and mechanisms of transmission of disease agents among commercial, transitional, and feral swine (Corn et al., 2009). Basic data required for these studies includes feral swine distribution maps and geographic analysis of feral swine relative to commercial domestic swine livestock. Researchers at SCWDS have compiled hardcopy, analog maps of feral swine distributions for 1982 and 1988 and the CRMS assisted in creating a digital feral swine geodatabase and hardcopy map for 2004 from reports and state maps contributed by individual state wildlife resource managers and federal wildlife agencies (Figures 6 – 8).
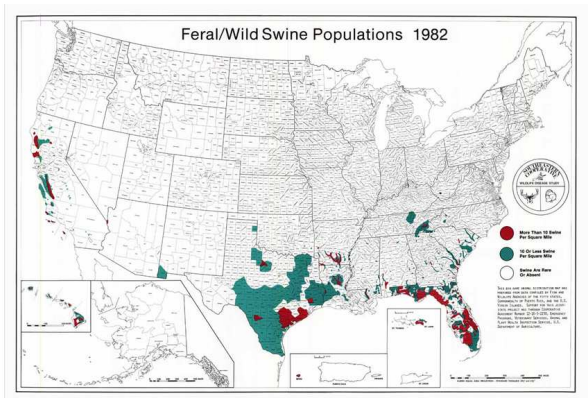

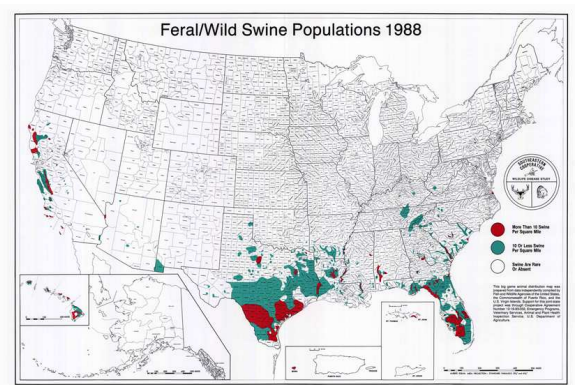Figure 6. SCWDS feral swine distribution map of 1982.

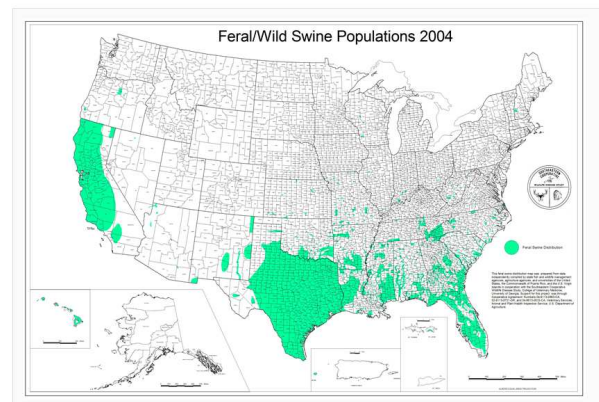Figure7. SCWDS feral swine distribution map of 1988.

Figure 8. SCWDS feral swine distribution map of 2004.

Although extremely useful in tracking the spread of feral swine populations from largely southeastern U.S. states such as Florida and Texas to western and southwestern states of California and New Mexico, the maps took considerable time and expense to compile, print and distribute. Researchers at SCWDS required a more efficient method of receiving information from individual states on current feral swine population locations, maintaining a current status of the national feral swine distribution geodatabase and distributing maps and statistics back to state and federal wildlife resource managers for use in making management decisions. To this end, the web-based National Feral Swine Mapping System (NFSM) was created in 2007 by a collaborative team from SCWDS and Information Technology Services, College of Veterinary Science and CRMS-Geography at the University of Georgia.

2.4 National Feral Swine Mapping System (NFSMS)

The SCWDS NFSMS is an interactive web-based mapping system that uses Google Maps to provide an image background to the display of the most current digital version of the National Feral Swine Map. Google Application Programming Inerface (API) and Java were used to custom program a web-based, interactive map/image display and editing capability with secure login and quality control checks. Figure 9 depicts the opening page of the NFSMS that displays an overview map of current (September 10, 2009) feral swine populations displayed as green polygons on a Google Maps image background. The web site is open to the public for viewing the overall map and zooming to a regional

level (Figure 10). Further zooming is restricted to the public to protect landowner privacy and avoid potential conflicts with illegal feral swine hunting (http://www.feralswine.org).

Optional tabs across the top of the opening web page provide secure access to state and federal agencies granted permission to login. This secure access allows only authorized users to zoom to high levels of detail, display and edit individual polygons of feral swine population distributions (Figure 11). The virtual globe image provides the environmental context for wildlife managers to assess changes in swine population boundaries.

An ArcGIS geodatabase of current feral swine distributions is maintained at SCWDS and CRMS. To serve the geodatabase over the internet, the geodatabase is first converted to Keyhole Markup Language (kml) vector format. A simple GIS vector editing interface in the NFSMS allows authorized users to add, delete or edit swine population boundaries with the image background to provide environmental context. Users also can input comments and further information on sightings or changes in populations. Map edits and comments are then sent to SCWDS for quality control checking. If the edits are deemed reliable, they are forwarded to the CRMS where point sightings and polygon population distributions are converted to ArcGIS shapefile format and incorporated into the most recent version of the feral swine distribution geodatabase. A monthly update of the U.S. feral swine distribution map is then converted to kml format by CRMS and sent to SCWDS to be web-served on the NFSMS.

Figure 9. NFSMS overview map of current feral swine populations displayed on a Google Maps image background.

Figure 10. Public access to the SCWDS NFSMS is restricted to a regional zoom level to protect landowner privacy.
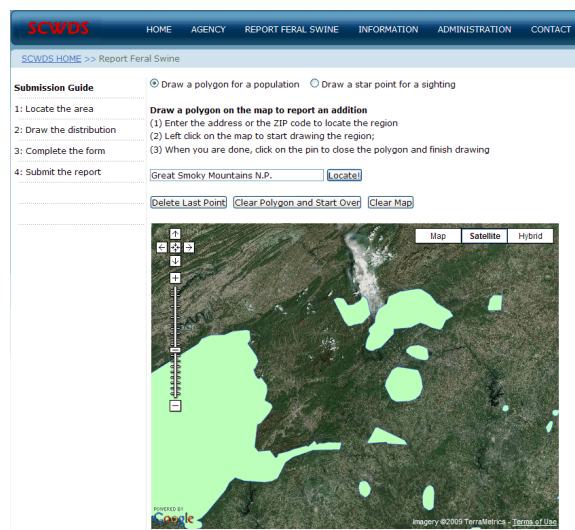

Figure 11. Authorized users can access individual polygons of feral swine distribution and use the satellite image as a reference to add, delete or update map features.

3. CONCLUSION

In summary, research at the CRMS and SCWDS at the University of Georgia was presented to demonstrate practical applications of advances in GIScience for real-world management of cultural and natural resources. Context-aware analysis of GEOBIA is being used to create and update existing geodatabases of vegetation communities, cultural landscapes and human impacts on preserved lands. Geovisualization provides resource managers with views to the future and the past for landscape reconstruction and model predictions. Virtual globes and web-based mapping allow resource managers hands-on access to geodatabases for editing, maintenance and display within a quality controlled cyberinfrastructure. It is anticipated that in the future the use of these technologies will be ported to hand-held devices for even wider acceptance by resource managers who increasingly rely on geospatial tools to be integrated with fieldwork, policy decisions and rapid response.

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