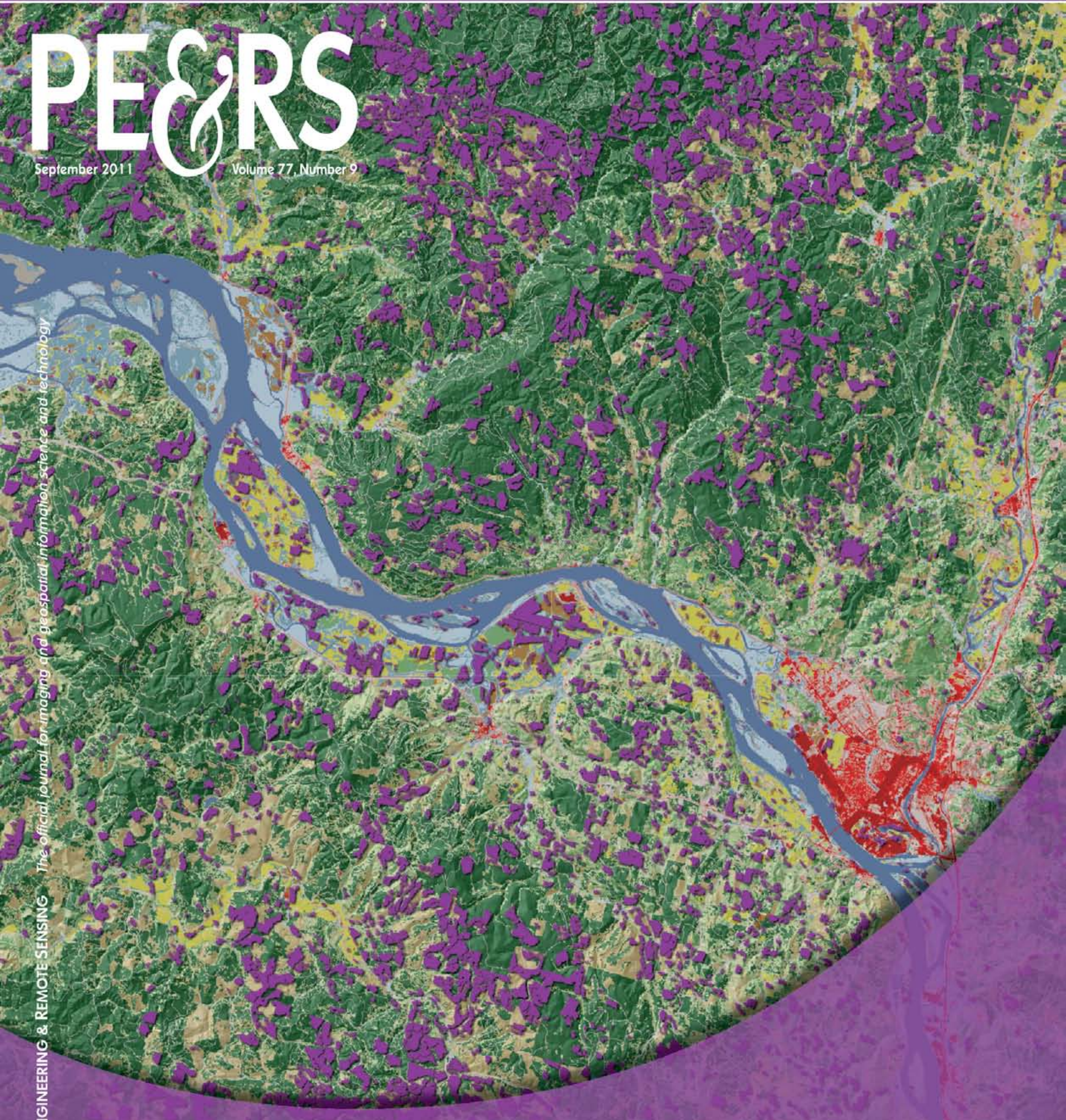
Special Issue: Haiti Earthquake, Part 1

PE&RS

September 2011 Volume 77, Number 9

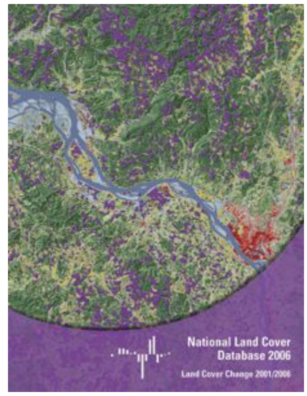
PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING The official journal for imaging and geospatial information science and technology



National Land Cover Database 2006

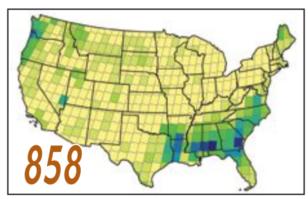
Land Cover Change 2001/2006

This month's cover shows an example of the National Land Cover Database (NLCD) 2006 Land Cover with the 2001/2006 Land Cover Change overlay (magenta) along a segment of the Columbia River near Longview, Washington. Image scale is approximately 1:250,000. The image demonstrates the detail of change captured in an area where forest harvest cycles dominate the change landscape in a major watershed. The small chart to the left of the highlight title, depicting net change, emphasizes the shifting emphasis of the NLCD program from mapping to monitoring to address the emerging issues of sustainable use that are faced by the Multi-Resolution Land Characteristics (MRLC) Consortium and its well-established user community. NLCD 2006 contains three primary Landsat-based products: land cover, land cover change from 2001 to 2006, and percent developed imperviousness. An overview of this database is described in this issue's Highlight article. Products and imagery are Web-enabled for download from the MRLC website at http://www.mrlc.gov. These products were generated by the MRLC, a group of 13 Federal programs in 10 agencies that partner to create land cover products for the United States.



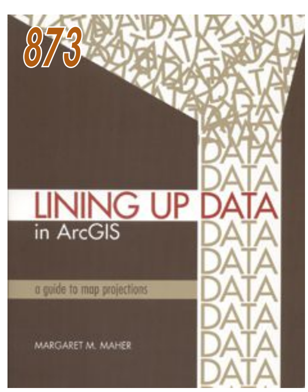
Foreword

Highlight Article



Columns & Updates

Announcements



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PE&RS
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The official journal for imaging and geospatial information science and technology

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Introduction

National Land Cover Database (NLCD) products provide a valuable tool to recognize and evaluate types of changes, their distribution and patterns, and potential consequences of changes in land cover, land use, and land condition throughout the United States. The NLCD 2006 products represent the first phase in a shift of emphasis from characterizing land cover to monitoring land cover change over time. A change in mapping interval from 10 years to 5 years has also been implemented to meet the needs of the Multi-Resolution Land Characteristics (MRLC) partners and the broader user community for more frequent updates to land cover information for the nation.

The need for consistently funded, operational land cover monitoring programs is underpinned by the reality that land cover and changes in land cover drive environmental condition (Foley *et al*., 2005). Surface energy fluxes between the land and the atmosphere drive climate and climatic change, and consequently form the foundation of policies related to mitigation of global warming and climatic change (e.g. Bala *et al*., 2007). Land cover is an important element of conservation planning and conservation plans have to be continually re-evaluated in the face of land cover change (Lewis, 1964, Benedict and McMahon, 2006). Changes in land cover lead to changes in water quality (Gilliom *et al*., 2006, Wickham *et al*., 2008), watershed runoff (Ponce and Hawkins, 1996) and rainfall patterns (Marshall *et al*., 2004). Source water protection is now an important element of the multiple barrier concepts used to protect drinking water (U.S. EPA 1997, Dougherty 2010). At its essence, source water protection is preservation of the natural elements of the landscape (Wickham *et al*., 2011). The Millennium Ecosystem Assessment (2005) elevated the importance of sustainable use of the Earth's resources to support human needs. Implicit in the concept of sustainability are assumptions of inventory and mapping of the Earth's natural resources and changes in those resources. Questions related to sustainability cannot be answered if the Earth's natural resources cannot be mapped and monitored. Shifting the emphasis of the NLCD program from mapping to monitoring addresses the emerging issues of sustainable use that are faced by MRLC agencies and their well-established user community.

Methods

The NLCD research strategy team at the USGS Earth Resources Observation and Science (EROS) Center was responsible for developing change detection protocols used to create NLCD 2006 products. The protocols are built upon the NLCD 1992 (Vogelmann *et al*., 2001), NLCD 2001 (Homer *et al*., 2004, 2007), and NLCD 1992-2001 Retrofit (Fry *et al*., 2009) mapping projects and include (1) data source preparation, (2) change analysis, (3) impervious estimation, (4) land cover characterization of change pixels, and (5) post-processing.

Source Data Preparation

Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 5 Thematic Mapper (TM) imagery, centered on nominal collection years 2001 and 2006, provided the foundation for spectral change analysis, land cover classification, and imperviousness modeling for NLCD 2006 products. To reduce imagery costs, early date Landsat scenes were selected from the MRLC scene library because the Landsat no-charge archive was not yet available when the NLCD 2006 mapping initiative began (U.S. Geological Survey, 2011).

Landsat scene pairs were selected for analysis and classification for each path/row in the conterminous United States. The Landsat data selection objective was a leaf-on scene pair for each path/row with acquisition dates within two weeks of each other (i.e., near anniversary dates) for the target years 2001 and 2006. A greater emphasis was placed on the near anniversary requirement in order to maintain phenological consistency, and this requirement resulted in a range of imagery acquisition dates from April 30, 1999 to August 19, 2003 for early date scenes and from February 11, 2005 to October 03, 2007 for late date scenes.

The intersection area of the two scenes was used to clip national ancillary layers from the National Elevation Dataset (NED) Digital Elevation Model (DEM) and nighttime stable-light satellite imagery from the National Oceanic and Atmospheric Administration (NOAA) Defense Meteorological Satellite Program (DMSP). Additional reflectance-based derivatives were prepared and used as

National Land Cover Database for the Conterminous United States

Analysis of land cover change in the continental United States from 2001 to 2006 using Landsat ETM+ and TM imagery.

By Joyce A. Fry, Dr. George Xian, Dr. Suming Jin, Jon A. Dewitz, Collin G. Homer, Dr. Limin Yang, Dr. Christopher A. Barnes, Nathaniel D. Herold, and James D. Wickham

independent variables in the land cover modeling process. All data were georegistered to the Albers Equal Area projection grid and resampled to 30x30 m^2 grid cell resolution.

NLCD 2001 Land Cover Version 2.0

For accurate comparison with the NLCD 2006 land cover it was vital that independently published NLCD 2001 land cover zones, released from 2002 through 2007, were seamless and fully integrated across the United States. To accomplish this, changes were made to include improvements from our MRLC partner, NOAA Coastal–Change Analysis Program (C–CAP), in two prototype zones (Zone 60 and Zone 41) that were published early in the project evolution. Smaller scale land cover refinements were made throughout NOAA stewardship areas. The minimum mapping unit (MMU) for the original NLCD 2001 Land Cover product was inconsistent for some MRLC zones. In NLCD 2001 Land Cover Version 2.0 this inconsistency was corrected and a 5-pixel (0.45 hectare) minimum mapping unit (MMU) was applied to all areas. These refinements and assembly of individual zones to create a seamless 2001 land cover product resulted in NLCD 2001 Land Cover Version 2.0. The NLCD 2001 Percent Developed Imperviousness Version 2.0 product contains adjustments made to realign imperviousness values with revised developed classes in the Version 2.0 land cover product.

Change Analysis

Methods developed for the NLCD 1992-2001 land cover retrofit change project (Fry *et al*., 2009) and NLCD 2006 change analysis (Xian *et al*., 2009) were integrated to capture and characterize land cover change from 2001 to 2006. The main outcome of integration of these research and mapping projects was the development of the Multi-Index Integrated Change Analysis (MIICA) method. In the MIICA model the normalized burn ratio (NBR) and normalized difference vegetation index (NDVI) ratios were calculated for each scene and then differenced for the scene pair. The change vector (CV), and the relative change vector maximum (RCVMAX) were then computed for each pixel. Finally, in a series of complex conditional statements, the MIICA model calculated global means and standard deviations for each of the four indices (dNBR, dNDVI, CV, and RCVMAX) and integrated this information to isolate spectrally changed pixels and to determine the change trajectory (i.e. biomass increase or decrease) between the two time periods. Raw output from the MIICA model is the NLCD 2006 Maximum Potential Spectral Change (MPSC) supplementary product. Only non-developed areas were analyzed using MIICA, whereas change detection in developed areas was accomplished through imperviousness analysis (next section).

Spectrally based commission error that did not represent real thematic class change was removed by comparing the NLCD 2001 Version 2.0 land cover with an intermediate 2006 land cover product. In some cases, localized modeling and manual editing were required to produce the changed pixel final product.

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Imperviousness

The main objective of the impervious analysis in the NLCD 2006 change detection was to identify areas newly urbanized since 2001 as well as areas where imperviousness increased between 2001 and 2006. Imperviousness for NLCD 2006 was classified using the commercial regression tree (RT) software Cubist ™ from Rulequest©. The approach relied on the addition of nighttime stable-light imagery from the NOAA DMSP to help determine the extent of the urban boundary and to remove estimate bias from training in non-urban areas (Xian *et al*., 2010). The overall process is divided into four main procedures: creating training datasets, modeling synthetic impervious surfaces, comparing model outputs for optimal selection, and composing the final product. Thresholds were applied to changed imperviousness pixels to extract the four NLCD 2006 developed classes according to the NLCD legend (Homer, *et al*., 2004).

Land Cover Characterization of Change Pixels

Land cover classification methods for NLCD 2006 were similar to those used for NLCD 2001 (Homer *et al*., 2004, 2007) except that a single date of imagery was used rather than three and the classification was performed on an individual path/row basis in place of zones of mosaicked scenes. The same late-date (ca. 2006) Landsat scene used for change analysis and imperviousness mapping was also used for land cover classification to preserve the close association between individual components.

Training data for the land cover classification model was sampled from a modified version of the 2001 land cover map. The modification eliminated the possibility of gathering training data in changed areas by removing all pixels identified by the MIICA model as spectrally changed from the training pool. A stratified random sampling method was used to collect approximately 100,000 data points from the training pool for each path/row. Each training data file was examined and refined to obtain an appropriate proportion of training points based on the original NLCD 2001 land cover. Typically, two or more modeling iterations were necessary to improve the overall classification. Special emphasis was placed on improving classification in areas of change.

Post-processing

To assemble the final change pixel product, developed class change pixels derived from the 2006 percent developed imperviousness layer were combined with final change pixels from the change analysis process. The next step included a "smart-eliminate" aggregation algorithm that was applied to set a 5–pixel MMU (approximately 0.45 hectare) for developed classes, a 32–pixel MMU (approximately 2.88 hectares) for agricultural classes and a 12–pixel MMU (approximately 1.08 hectares) for all other classes.

Individual path/row change pixel results were then assembled to form an intermediate seamless product for the conterminous United States. This seamless change pixel map was reviewed and edited to remove regional inconsistencies. The NLCD 2006 Land Cover Change map is one of the three primary NLCD 2006 products.

Refined NLCD 2006 change pixels were combined with the re-issued NLCD 2001 Land Cover Version 2.0 to form the NLCD 2006 Land Cover map that was then smart-eliminated to a 5-pixel MMU. This final step eliminated single pixels and patches less than 5 pixels in extent that appeared as a result of combining the separate images. The NLCD 2006 products and supplementary layers are summarized below.

Primary Products –

NLCD 2006 Land Cover - A ca. 2006 thematic land cover layer (raster) for the conterminous United States for all pixels.

NLCD 2006 Land Cover Change – A thematic land cover layer (raster) containing only those pixels identified as changed between NLCD 2001 Land Cover Version 2.0 and intermediate NLCD 2006 Land Cover products for the conterminous United States.

NLCD 2006 Percent Developed Imperviousness - A ca. 2006 continuous imperviousness estimate layer (raster) for the conterminous United States for all pixels.

Supplementary Layers –

NLCD 2001/2006 Percent Developed Imperviousness Change – A raster layer containing the difference of those imperviousness values that changed from NLCD 2001 Percent Developed Imperviousness Version 2.0 to NLCD 2006 Percent Developed Imperviousness.

NLCD 2006 Maximum Potential Spectral Change – A raster layer containing all pixels identified in the MIICA raw change detection process. Raw change includes areas of biomass increase and decrease. Only a portion of these pixels was retained as real change during final processing and post-processing protocols.

NLCD 2006 From – To Change Index – A raster layer identifying a combined 2001 /2006 land cover class index value label for each pixel in the conterminous United States based on a matrix of all possible land cover class label change combinations.

NLCD 2006 Path/Row Index – A vector layer identifying Landsat scene pair footprints that includes a Landsat acquisition date attribute and scene identification number attribute for each scene pair used during the NLCD 2006 change analysis and land cover modeling process.

Results

A change matrix simplified the task of quantifying land cover change in terms of overall change, percent of change pixels, and net gain or loss by land cover class for the conterminous United States from 2001 to 2006 (Table 1, Figure 1). Analysis indicates that 98.32

Table 1. Land cover change statistics by class with net gain/loss expressed in square kilometers (km^2) for the conterminous United States. The conversion from 30x30 m^2 Landsat pixels to land area in km^2 was computed as km^2 = number of pixels x 0.0009. Changed pixel percentages are expressed as the percentage of total changed pixels. Unchanged areas are not included in this table.

Class (Code)	FROM 2001 (km^2)	FROM 2001 (Percent)	TO 2006 (km^2)	TO 2006 (Percent)	Net Gain/ Loss (km^2)
Open Water (11)	6,180	4.56	4,551	3.36	-1,630
Perennial Ice/Snow (12)	118	0.09	0	0.00	-118
Developed-Open Space (21)	619	0.46	4,604	3.40	3,984
Developed-Low Intensity (22)	28	0.02	4,033	2.97	4,004
Developed-Med. Intensity (23)	4	0.00	2,979	2.20	2,975
Developed-High Intensity (24)	2	0.00	749	0.55	747
Barren Land (31)	3,429	2.53	4,919	3.63	1,489
Deciduous Forest (41)	10,828	7.99	5,640	4.16	-5,189
Evergreen Forest (42)	35,951	26.52	19,231	14.19	-16,720
Mixed Forest (43)	5,473	4.04	875	0.65	-4,598
Shrub/Scrub (52)	23,667	17.46	33,564	24.76	9,897
Grassland/Herbaceous (71)	20,774	15.32	33,233	24.52	12,459
Pasture/Hay (81)	8,568	6.32	2,788	2.06	-5,780
Cultivated Cropland (82)	9,398	6.93	7,465	5.51	-1,933
Woody Wetlands (90)	6,224	4.59	5,589	4.12	-635
Herbaceous Wetlands (95)	4,294	3.17	5,340	3.94	1,046

percent of the land cover modeled remained unchanged from 2001 to 2006 and 1.68 percent of the land cover mapped as changed. Areas covered by cloud or shadow in either Landsat image were not analyzed and remained unchanged. Thematic classes of evergreen forest, shrub/scrub, and grassland/herbaceous accounted for a large portion of "From 2001" mapped land cover transition (Table 1) with 35,951 km^2, 23,667 km^2, and 20,774 km^2, respectively, changing to a different class. The top three "To 2006" classes were the same but in different relative proportions with 33,564 km^2 changing to shrub/scrub, 33,233 km^2 to grassland/herbaceous and 19,231 km^2 to evergreen forest. Net gains and losses by class were also calculated (Table 1, Figure 1). Substantial net loss was mapped in all three forest classes. Agricultural, woody wetlands, water, and perennial ice/snow classes also showed a net loss in mapped area from 2001 to 2006. Considerable net gain was shown for grassland/herbaceous and shrub/scrub classes. Net gain was also observed in all developed classes, barren land and herbaceous wetlands. Higher path/row change percentages were concentrated in the southeast and northwest (Figure 2). An closer look at imperviousness change from 2001 to 2006 is provided in a separate manuscript (Xian, *et al*., in press).

A formal accuracy assessment of the NLCD 2006 land cover change product is currently underway. Interpretation of sample points is expected to be completed by December, 2011. Accuracy protocols were built on the methods developed for NLCD 1992 and NLCD 2001 (Stehman *et al*., 2003, Wickham *et al*., 2010, Stehman and Wickham, in press) and include assignment of land cover labels from two high resolution reference data sources representing the best possible match for Landsat 2001 and 2006 scene acquisition dates used during analysis.

Future Directions

NLCD 2006 is the first national-scale mapping project that assesses change for every pixel. There are no spatial gaps in the change data, the change interval has a high temporal resolution (5 years), and the thematic resolution goes beyond that of simplified legends (e.g., forest, urban, agriculture, water, and wetland). MRLC is now planning the

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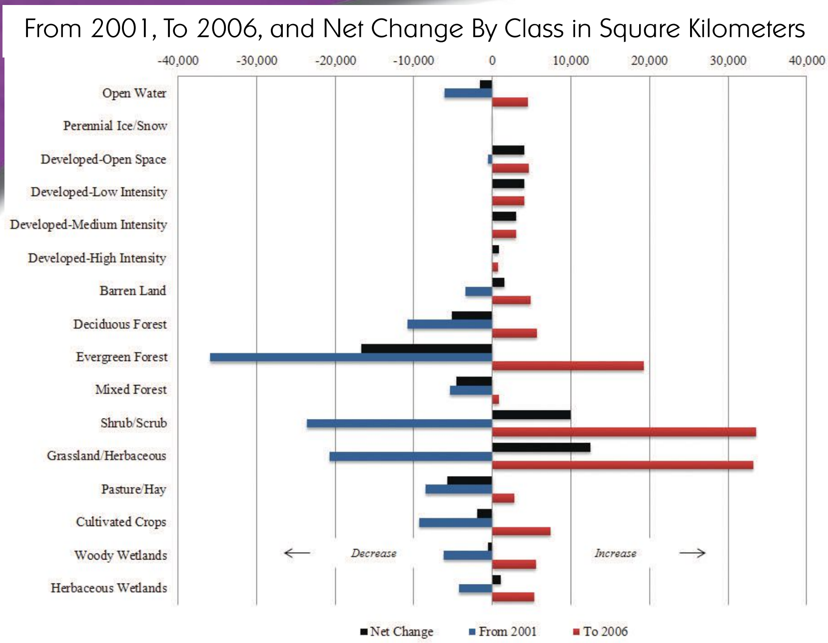

Figure 1. Land cover change from 2001 to 2006 by class showing 2001 relative loss (blue bar), 2006 relative gain (red bar), and net gain or loss (black bar) across the conterminous United States. Modeled land cover results indicate that the largest relative losses and gains occur in evergreen forest, shrub/scrub, and grassland/herbaceous classes. Unchanged areas are not included in this chart.

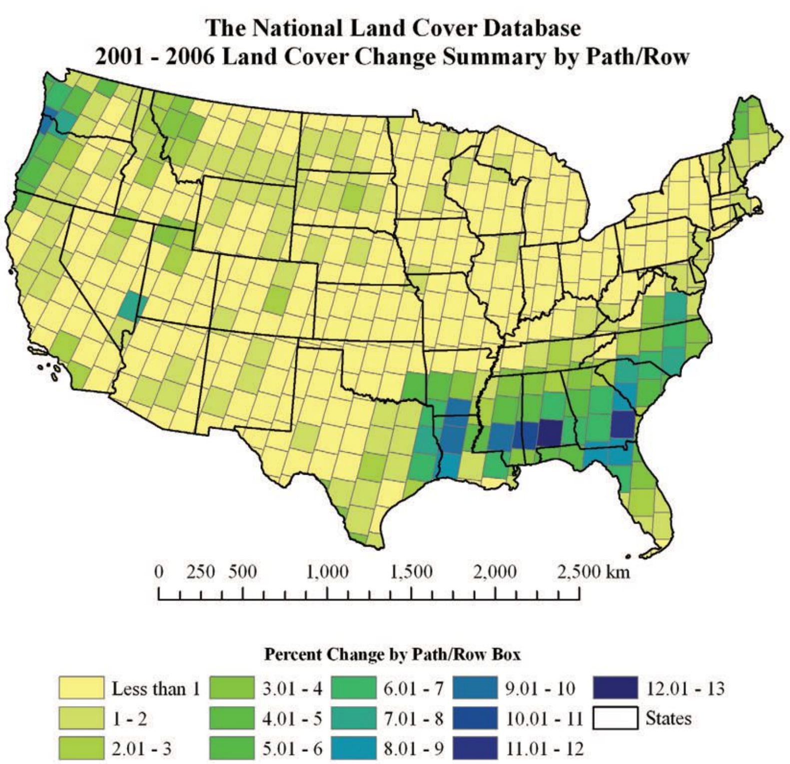

Figure 2. Spatial distribution of land cover change from ca. 2001 to ca. 2006 summarized by Landsat path/row box (image overlap areas omitted) with change reported as a percentage of all pixels in the path/row box.

next generation of NLCD based on nominal 2011 Landsat imagery. Lessons learned from the NLCD 2006 project will be incorporated into the next NLCD mapping and change detection project.

The NLCD research strategy team is revising earlier protocols to provide improved results for NLCD 2011 spectral change analysis and land cover classification products. New mapping protocols include using two scene pairs for change analysis to reduce commission error in spectral change analysis caused by seasonally variable classes. Another refinement uses cultivated cropland information from the expanded coverage of U.S. Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) cropland data layers (Johnson *et al.*, 2010) to improve separation of cultivated cropland and hay/pasture. To improve delineation of woody and herbaceous wetland classes National Wetland Inventory (NWI) data is combined with existing NLCD wetland classes and with the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database hydric soils layer. Finally, two to three dates of Landsat imagery are used to improve the land cover classification result. Our NOAA C–CAP partner mapping teams have already begun land cover mapping for 2011 using these methods in coastal Great Lakes areas and in the Middle Atlantic States. Operational production of NLCD 2011 for the rest of the continental United States is expected to commence in late 2011.

Acknowledgements

Research, development, and production efforts for NLCD 2006 data products and supplementary layers result from the cooperative efforts of several teams of dedicated individuals. Because of the number of individuals involved, they cannot all be properly acknowledged here. We would like to acknowledge the many organizations that made this work possible especially the support of the individuals and agencies of the MRLC Consortium, in addition to Federal and Federal contractor mapping teams. We would also like to acknowledge all of the organizations, agencies, and individuals who provided training data for NLCD 2006 modeling. This study is made possible in part by SGT under U.S. Geological Survey contract G10PC00044 and by ASRC under U.S. Geological Survey contract G08PC91508.

James Wickham's participation in this research has been underwritten by the U.S. Environmental Protection Agency (EPA), Office of Research and

Development (ORD). The paper has been subject to EPA-ORD peer and administrative review and approved for publication.

Endnote

The use of any trade, product, or firm name is for descriptive purposes only and does not imply endorsement by the U. S. Government. The paper has been subject to U.S. EPA Office of Research and Development peer and administrative review and approved for publication.

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CORRECTIONS: In last month's Highlight Article, *Change of Impervious Surface Area between 2001 and 2006 in the Conterminous United State*, co-author Jon Dewitz's name was incorrectly spelled Demitz. Also, the following text should have appeared at the end of the article:

James Wickham's participation in this research has been underwritten by the U.S. Environmental Protection Agency (EPA), Office of Research and Development (ORD). The paper has been subject to EPA-ORD peer and administrative review and approved for publication.

Thank you to all the ASPRS regions that participated in the Region of the Month contest.

and the Winner for the Month of JULY is...

POTOMAC REGION

the Potomac region sponsor ed 7 new members during the month of July.

In recognition of their commitment to the Society, they receive the following:

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- This special recognition in this issue of *PE&RS* of their designation as "Region of the Month," a true display of their commitment to the Society.

Potomac region

This is an ongoing regional recruitment campaign. We hope other regions will be listed here in future months.