IMAGE-BASED CHANGE ESTIMATION FOR LAND COVER AND LAND USE MONITORING

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Abstract.—The Image-based Change Estimation (ICE) project resulted from the need to provide estimates and information for land cover and land use change over large areas. The procedure uses Forest Inventory and Analysis (FIA) plot locations interpreted using two different dates of imagery from the National Agriculture Imagery Program (NAIP). In order to determine a suitable project workflow, interpretation methods and database options were explored. The results provide useful information for the change occurring between land cover and land use types across two prototype landscapes.

INTRODUCTION

Understanding changes in land use and land cover (LULC) over space and time provides a means to evaluate the complex interactions between human and biophysical systems, to project future conditions (absent policy changes), and to design mitigation and adaptive management strategies. Understanding and modeling LULC change is evolving into a foundational element of climate, environmental, and sustainability science. Land use and land cover data are core to applications including: carbon accounting, greenhouse gas emission reporting, biomass and bioenergy assessments, hydrologic function assessments, fire and fuels management, and forest and rangeland health assessments. The lack of comprehensive and spatially-explicit historical vegetation data for the entire United States challenges the ability of scientists and land managers to understand cumulative effects of natural disturbances and human activities. By extension, our ability to understand and model future scenarios is limited by a lack of information about the disturbance processes that shape land cover changes and land use decisions by private landowners and public land managers.

A recent resolution from the National Association of State Foresters (NASF) reflects both the importance of these data and the need to generate reliable estimates of land cover and land use change. The NASF resolution suggests an enhanced Forest Inventory and Analysis (FIA) program that prioritizes the "Use of remote imagery to track harvest intensity, land-use change, and land cover change" (NASF State Forester Resolution 2009-6). The FIA program and the Remote Sensing Applications Center (RSAC) were specifically identified as partners for accomplishing this. In 2011, RSAC initiated this Image-based Change Estimation (ICE) project in response to the NASF resolution. The specific objectives of the project were to: (1) develop an efficient, repeatable workflow that could be implemented nationwide in conjunction with the FIA program for assessing LULC change from imagery, and (2) test and demonstrate the workflow in two diverse pilot study areas.

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METHODS

The study areas for the ICE project were the states of Colorado and Georgia. They were selected to provide diverse and dissimilar landscapes where the effectiveness of photo-based data collection for identifying and classifying LULC change could be evaluated. LULC change was assessed in the two states by interpreting two dates of National Agriculture Imagery Program (NAIP) imagery within plots located on each state's base FIA grid (Bechtold 2005). The circular plots were 1.44 acres (144-foot radius) in size, which ensured full coverage of the FIA subplots. The total number of plots interpreted for the study was 17,222 with 10,815 in Colorado and 6,407 in Georgia.

Both Colorado and Georgia had full, state-wide coverage of NAIP imagery for 2005 that was used for the Time 1 (T1) dataset. The Time 2 (T2) dataset consisted of four band (red, green, blue, near-infrared) NAIP imagery acquired in 2009 for Colorado and 2010 for Georgia. The spatial resolution of the imagery was 1 meter for all datasets except the 2005 Georgia imagery, which was 2 meters. The temporal scale of approximately 5 years was chosen to align with the FIA panel system and the plot revisit times by FIA field personnel.

Classification Schemes

The LULC classes for this project were based on the FIA land cover and land use classes (USDA FS 2011) for defining condition class as well as those described by Anderson et al. (1976). The classification schemes, summarized in Table 1, allowed the newly photo-interpreted data to align with previously collected FIA plot data. Along with the LULC classes, an agent of change was recorded for any plots that had a change in LULC between T1 and T2. This provided additional information about the type of change that may not have been inferred from the LULC attributes. The agent of change classes included: reforestation/afforestation, partial tree harvest, clear cut harvest, fire, development, and other change.

Photo Interpretation and Data Entry Interface

Due to the large number of plots to be interpreted, it was important to use a data collection method that allowed for rapid image viewing, interpretation, and data entry. Two software applications were evaluated and compared for this purpose: ESRI ArcMap™ and Microsoft Access®. The ESRI ArcMap interface was set up using a feature dataset within a file geodatabase.

Table 1.—Primary and secondary classes for land cover and land use used in ICE project.

Land Cover	
Tree:	Deciduous Tree, Evergreen Tree, Uninterpretable Tree
Other Vegetation:	Shrub, Herbaceous, Nonvascular Vegetation, Uninterpretable Vegetation
Water and Ice:	Water, Ice and Snow
Barren:	Soil/Sand, Rock, Paved Surface, Building Rooftop, Other Barren Land
Uninterpretable	
Land Use	
Forest:	Forest, Tree Farm
Rangeland:	Rangeland
Natural/Semi-natural:	Wetland/Riparian, River, Lake, Other Natural/Seminatural
Agriculture:	Cropland/Pasture, Orchards/Groves/Vineyards/Nurseries, Confined Feeding Operations, Other Agriculture
Developed:	Residential, Recreational, Commercial/Services, Industrial, Transportation/Communications/Utilities, Strip Mines/Quarries/Gravel Pits, Mixed Urban/Built-up Land, Canals/Reservoirs, Other Developed
Uninterpretable	

The feature dataset contained the FIA plots and the fields to be attributed. The reference imagery used was provided by image services from the Forest Service's enterprise instance of ArcGIS® Image Server. Since the FIA plot data was already in an ESRI file format, setup was relatively quick. The main limitation of using this method was the inability to customize the interface without a programming skillset.

The Microsoft Access interface was a modification of prior work conducted by Andrew Lister of the Northern Research Station FIA program. The database consisted of a data entry form attached to a main table which stored the data. One of the greatest advantages of using an Access database was the ability to easily customize the form to meet the project needs. The layout of the ICE form allowed the user to view two timeframes of aerial imagery side-by-side and enter all pertinent information for an individual plot within a single form. The form layout consisted of the imagery and data entry fields for T1 on the left and the imagery and data entry fields for T2 on the right (Fig. 1). Additionally, by using buttons placed at the top of the images, the interpreters were able to toggle between varying image scales and band combinations. Buttons on the form also gave the interpreters quick access to supplementary imagery available on Bing™ and Google Maps™.

Another design objective for the Access form was to maintain data integrity throughout the course of the project. To support this, features such as predefined dropdown lists for land cover, land use, and agents of change were implemented. Other quality control (QC) features included a "no change" button to minimize data entry errors as well as checks for missing data that prevented the user from proceeding until the fields were attributed. Along with keeping data entry consistent, these built-in QC functionalities saved a considerable amount of time.

To test the efficiency of the two applications, a total of 1,000 non-FIA plots were randomly selected from the two states. Two interpreters used both methods to view and attribute the plots. The results of the study showed that the Access approach was 28 percent more time efficient than the ESRI ArcMap approach. This improved efficiency was attributed to faster image load time and the ability to customize tools to maximize the ease of data entry. As a result of its increased efficiency and availability, the Microsoft Access approach was selected for use in the project.

Interpretation Methodology

During the early development phase of this project, a study was conducted comparing the interpretation of land cover within polygons versus at a point (i.e., the plot center). The polygon method required the interpreter to evaluate the entire plot and mentally draw boundaries around the land cover types. Using FIA guidelines for minimum mapping units (MMU), polygons representing land cover types were identified (USDA FS 2011). The class corresponding to the land cover polygon located at the plot center was recorded by the interpreter. The point method had no associated MMU for specifying a land cover type. The plot center was visually assessed by the interpreter and the land cover class it intersected was recorded for the plot. The two methods yielded different results in some cases. For example, if the plot center intersected an opening in a coniferous forest, the land cover call was evergreen tree for the polygon method and herbaceous for the point method. In evaluating the two methods, results showed a 31 percent increase in time efficiency and a 4 percent increase in agreement among interpreters when comparing the point to the polygon method. One disadvantage of using the point method is the lack of contextual information at the plot level. However, by also recording the land use class, which was necessarily polygon-based, the contextual information was made available. Based upon the results of the comparison, the point method was selected for assessing the land cover type and the polygon method was used to evaluate land use. The only attribute that used the plot boundary and not the center point was the agent of change, which was assigned only when there was an LULC change anywhere within the 1.44-acre plot area.

Figure 1.—Microsoft Access form customized for ICE project to view NAIP imagery and record plot data.

After completing the studies, the interpreters began interpreting the actual FIA plots. In order to measure consistencies among interpretations, 5 percent of the FIA plot locations were randomly selected as crosschecks. Half of these plots were repeated by the initial interpreter and the other half were assessed by both interpreters. The FIA panel system, which consists of five panels per state, was used to divide the plots between the two interpreters, with one interpreting two panels and the other interpreting three panels for each state. Photo interpretation was first completed for the state of Colorado followed by Georgia. The two interpreters worked independently of one another throughout the majority of the photo interpretation process. Plots that were difficult to assess were marked for review and later discussed between interpreters to refine class calls and to improve consistencies between them.

RESULTS AND DISCUSSION

The photo interpretation process for the ICE project took an average of 1 minute per plot and eight-person work weeks to complete all plots for Colorado and Georgia. The dominant land cover and land use types for the state of Colorado were Other Vegetation (74 percent of initial total) and Rangeland (32 percent of total), respectively. For Georgia, Tree (62 percent of initial total) was the dominant land cover class with Forest (67 percent of total) being the dominant land use class. Please see Figure 2 and 3 for more information on the land cover and land use results.

Changes occurring within the land use of forests were of particular interest for the ICE project (Fig. 4). Results show that 0.45 percent of the Colorado forest plots changed to a different class in T2. Conversion to rangeland and development had the greatest role in the forest change by making up 47 percent and 40 percent of the forest change, respectively. For Georgia, 1.14 percent of the forest plots changed land uses in T2, with the majority of these changes (73 percent) being a result of development. Additional work, including an intensified sampling of the changed plots, is underway to better quantify the changes. This information, along with other plot specific information (i.e., land cover type and agent of change) will be available in forthcoming reports.

The methodology developed for this project provides a rapid and cost-effective way to assess and estimate LULC changes across large areas and shows potential for nationwide implementation. Through the interpretation of FIA plot locations from high resolution aerial imagery, information regarding land cover and land use changes that are occurring across the United States can be made accessible to scientists and forest managers to assist in the creation of strategies and the making of informed decisions.

ACKNOWLEDGMENTS

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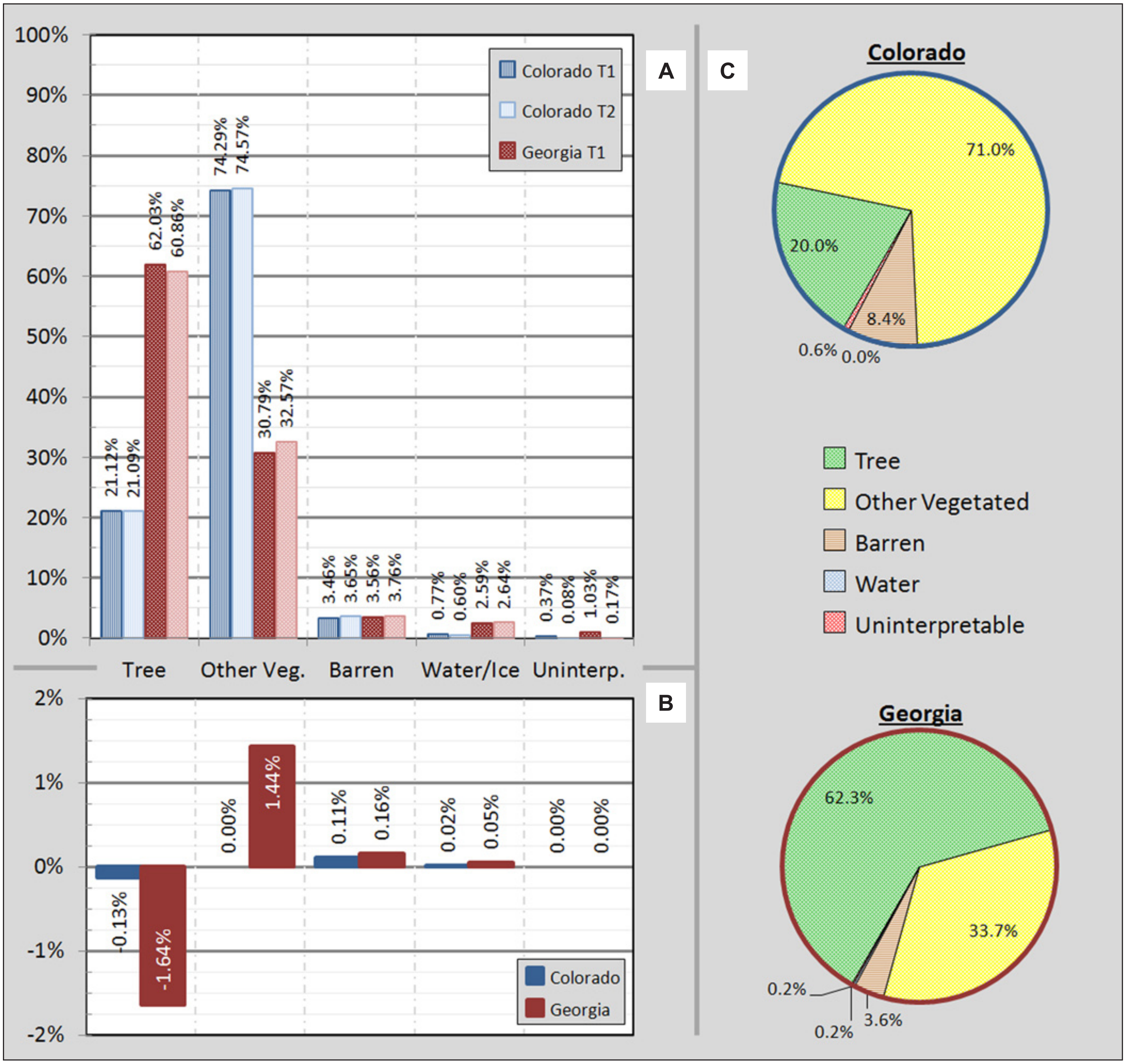

Figure 2.—Land cover data summaries for Colorado and Georgia. (A) Comparison of land cover values for T1 and T2 datasets. (B) Land cover change as a percentage of total plots. (C) Distribution of land cover change by type based on initial plot condition.

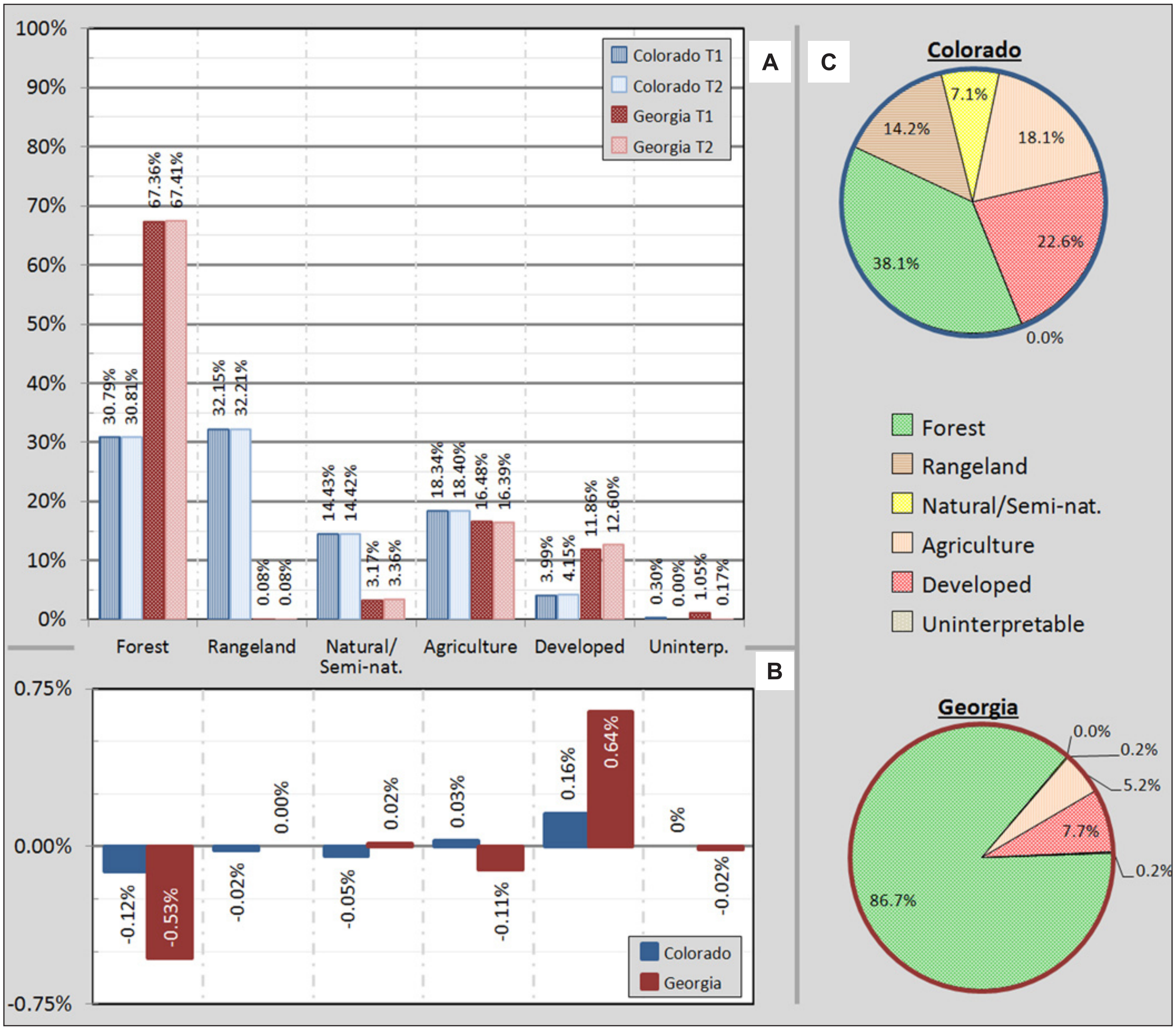

Figure 3.—Land use data summaries for Colorado and Georgia. (A) Comparison of land use values for T1 and T2 datasets. (B) Land use change as a percentage of all plots. (C) Distribution of land use change by type based on initial plot condition.

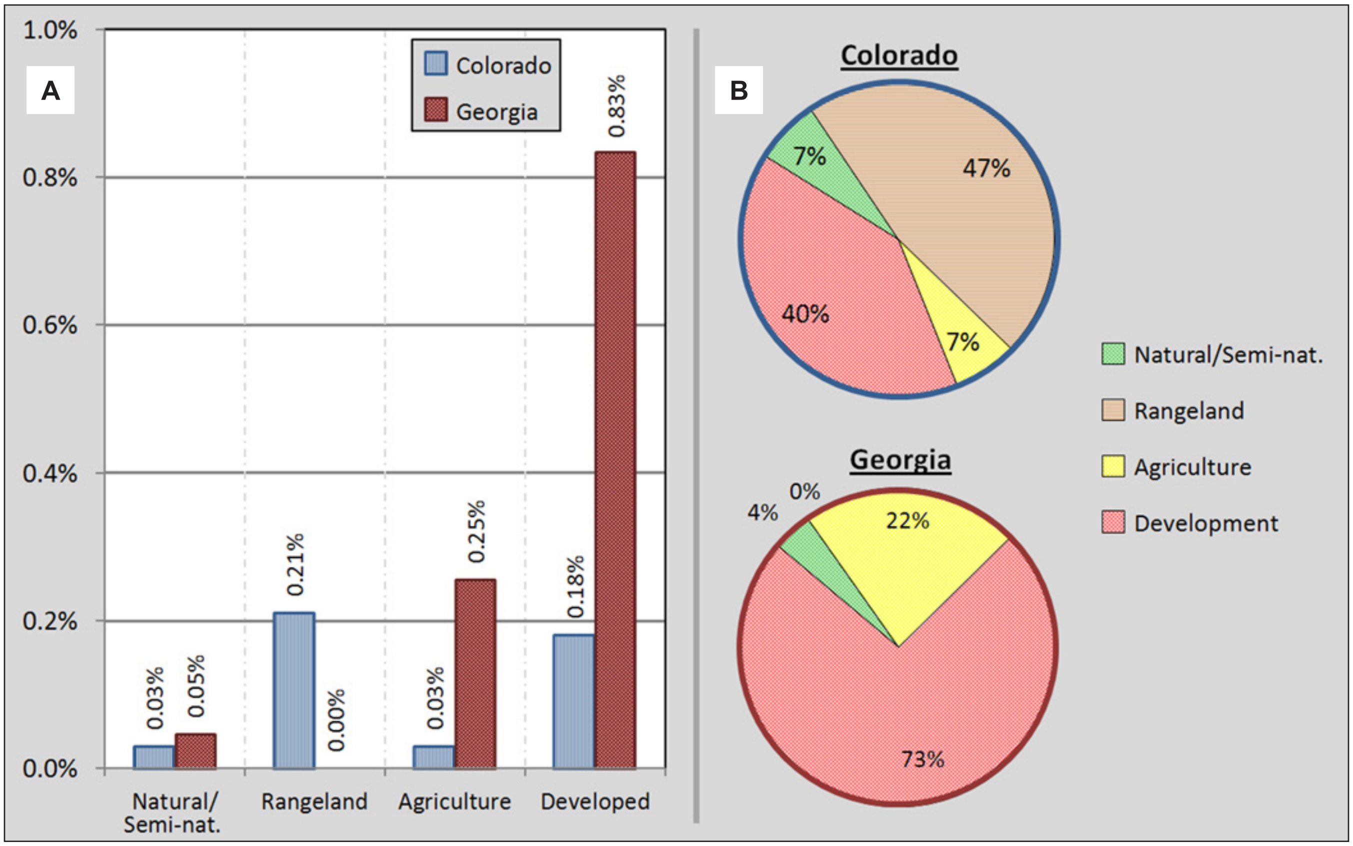

Figure 4.—Summary of changes within forested plots categorized by state. (A) Percent of forested plots that changed to other land use classes. (B) Distribution of land use types to which the changed forest plots transitioned.

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