Commentary: A cautionary tale regarding use of the National Land Cover Dataset 1992

Wayne E. Thogmartin, Alisa L. Gallant, Melinda G. Knutson, Timothy J. Fox, and Manuel J. Suárez

Abstract Digital land-cover data are among the most popular data sources used in ecological research and natural resource management. However, processes for accurate land-cover classification over large regions are still evolving. We identified inconsistencies in the National Land Cover Dataset 1992, the most current and available representation of land cover for the conterminous United States. We also report means to address these inconsistencies in a bird-habitat model. We used a Geographic Information System (GIS) to position a regular grid (or lattice) over the upper midwestern United States and summarized the proportion of individual land covers in each cell within the lattice. These proportions were then mapped back onto the lattice, and the resultant lattice was compared to satellite paths, state borders, and regional map classification units. We observed mapping inconsistencies at the borders between mapping regions, states, and Thematic Mapper (TM) mapping paths in the upper midwestern United States, particularly related to grassland–herbaceous, emergent-herbaceous wetland, and small-grain land covers. We attributed these discrepancies to differences in image dates between mapping regions, suboptimal image dates for distinguishing certain land-cover types, lack of suitable ancillary data for improving discrimination for rare land covers, and possibly differences among image interpreters. To overcome these inconsistencies for the purpose of modeling regional populations of birds, we combined grassland–herbaceous and pasture–hay land-cover classes and excluded the use of emergent-herbaceous and small-grain land covers. We recommend that users of digital land-cover data conduct similar assessments for other regions before using these data for habitat evaluation. Further, caution is advised in using these data in the analysis of regional land-cover change because it is not likely that future digital land-cover maps will repeat the same problems, thus resulting in biased estimates of change.

Key words accuracy assessment, Geographic Information System, land cover, National Land Cover Dataset, NLCD, observer differences, remote sensing

Digital land-cover maps are in wide use in wildlife research for assessing the regional influence of land use and land cover on ecological properties and systems (e.g., Scott et al. 1996, Roseberry and Sudkamp 1998, Thogmartin 1999, Gustafson et al. 2002). These digital land-cover classifications typically are derived from remote sensor data, such as from the Advanced Very High Resolution Radiometer (AVHRR), Landsat MultiSpectral Scanner (MSS) and Thematic Mapper (TM), and

Système pour l'Observation de la Terre (SPOT) (e.g., Moore and Bauer 1990, Rivard et al. 1990, Loveland et al. 1991). Despite the wide use of these products, too little caution is used when applying them for habitat assessments. We draw particular attention to the United States Geological Survey 1992 National Land Cover Dataset, or NLCD 92 (Vogelmann et al. 1998*a*,*b*; 2001; available on the internet at http://landcover.usgs.gov/natllandcover.html), not because it is more problematic than other, remotely derived digital land-cover data but because it is arguably the most widely used and current national digital representation of the United States (Riitters et al. 2000, Yang et al. 2001).

NLCD 92 Background

The NLCD 92 project evolved from an effort to use TM data to develop "a generalized, consistent, seamless, and reasonably accurate land-cover-data layer" for one region of the country (Vogelmann et al. 1998*a*). The approach was then scaled up for the remainder of the conterminous United States, a process illuminating important issues relative to consistency in a project of national scope, including:

- *Timing of imagery.* Different land-cover classes are most distinguishable during different portions of the growing season. Simultaneous optimization for all land-cover types is difficult, and desired image dates often are replaced by dates that meet data-quality requirements (e.g., $\leq$10% cloud cover).
- *Image date discontinuities.* Neighboring scenes represent different satellite overpass dates (always for east–west adjacencies and often for north–south adjacencies) and may correspond with large dissimilarities in phenologic and moisture conditions among scenes.
- *Hardware–software limitations.* A maximum of 18 TM scenes could be processed at the time that NLCD 92 was in progress, but the number of scenes required to cover the conterminous United States exceeded 400. Therefore, geographic partitioning was required, with implications for edge-matching during the creation of the final land-cover map.
- *Thematic class ambiguity*. Conceptual and spectral overlap in land-cover classes is difficult to avoid for large-area mapping projects and increases the chance for misclassification.
- *Interpreter management*. Consistency in data handling is a greater challenge when numerous image interpreters are required for a project.

Both "leaf-off" and "leaf-on" TM data were acquired for NLCD 92. The Multi-Resolution Land Characteristics Consortium (MRLC) grouped scenes into mapping regions and applied an unsupervised clustering algorithm for each unit to either the leaf-off or leaf-on mosaics (i.e., edge-mapped images), depending upon which phenological stage was most useful for distinguishing cover types for that region (Loveland and Shaw 1996, Vogelmann et al. 2001, and see http://www.epa.gov/mrlc/pubs.html). The MRLC generated 100 clusters for each region, based on 4 TM spectral bands (visible-red [band 3], near-infrared [band 4], and mid-infrared [bands 5 and 7]). Ideally, clusters were assigned membership in 1 of 21 land-cover classes approximating the Level II land-use/land-cover categories defined by Anderson et al. (1976). Usually, clusters represented multiple land-cover classes and required further processing. The MRLC used a variety of ancillary information to help assign land-cover class labels and to refine clusters (e.g., aerial photographs, leaf-on and leaf-off mosaics, topography, human census, soil characteristics, other land-cover classifications, and wetlands data).

Unlike most large-area land-cover classifications, NLCD 92 includes an accuracy assessment. This was performed using aerial photographs (Zhu et al. 2000, Yang et al. 2001). Assessments have been completed for the East, Midwest, Upper Midwest, and Pacific Northwest portions of the country (L. Yang, United States Geological Survey, personal communication, and see online http://landcover.usgs.gov/accuracy/); the remaining regions are in progress. As with the data classification procedures, certain issues inherent to the assessment process could affect the quality of the accuracy assessment. The inability to precisely locate common points between photos and imagery could introduce registration errors into the accuracy assessment, and differences in dates between classification and evaluation data could make it difficult to determine the "true" class for cover types that are dynamic on an annual or intra-annual basis (e.g., crop types in areas where crop rotation or double-cropping is practiced; Yang et al. 2000).

The NLCD 92 metadata claims the classification should be suitable for applications such as "assessing wildlife habitat, water quality and pesticide runoff, and land-use change." Our interest in bird-habitat association models led us to evaluate this claim. We are modeling regional abundance of birds in the Upper Midwest, particularly in an area described by the North American Bird Conservation Initiative (NABCI) as Bird Conservation Region 23 (BCR23, Prairie-Hardwood Transition; US NABCI Committee 2000).

The NLCD 92 classification for the mapping unit that encompassed the Prairie–Hardwood Transition had an overall accuracy of 60% (or 79%, if one compensates for geo-registration error by basing the accuracy assessment on the immediate neighborhood of pixels surrounding a point, rather than on a single pixel; L. Yang, United States Geological Survey, personal communication). This level of accuracy implies that use of these data is best reserved for regional as opposed to local analyses. Because land-cover-specific accuracy is more germane to most habitat applications, we were interested in how well individual classes were mapped at a regional scale. We used the NLCD 92 classification to derive landscape composition and configuration variables at scales consistent with our statistical models. During this exercise we identified peculiarities in the NLCD 92 classification that required further examination. We identified various patterns and incongruities in the occurrence of individual land-cover classes that are likely associated with image-processing characteristics and that have the potential to affect regional-scale analyses.

Methods

The Prairie–Hardwood Transition was forested in the north and agricultural in the south, and was bisected by Lake Michigan. We created a regular lattice over the Prairie–Hardwood Transition in a Geographic Information System (GIS), ArcView 3.3 (Environmental Systems Research Institute, Redlands, Calif.), with each lattice opening, or cell, covering 800 ha (Figure 1). For every lattice cell in the Prairie–Hardwood Transition, we calculated the proportion of each of the 21 land-cover classes of the NLCD 92 classification. We generated maps for

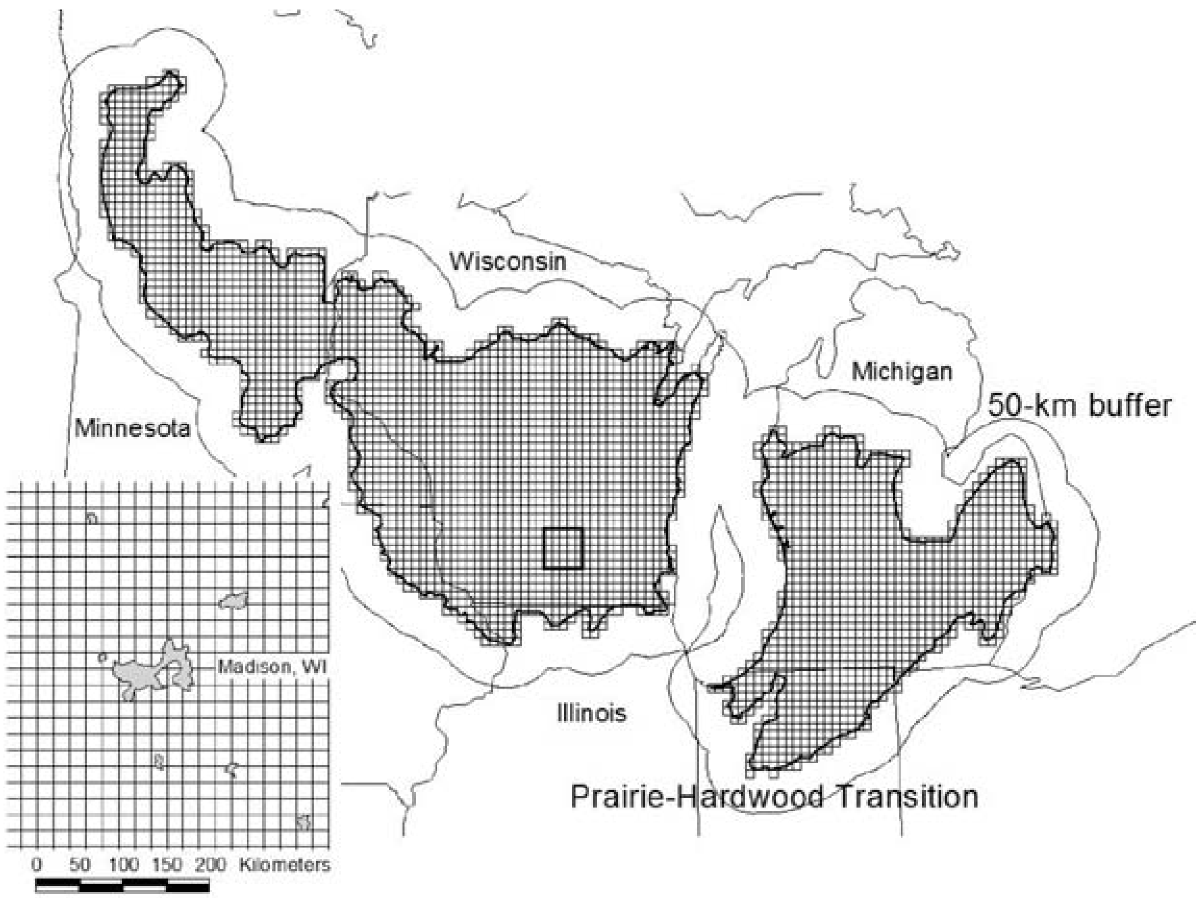

Figure 1. Schematic of lattice structure comprised of 800-ha cells for which land-cover classes from the National Land Cover Dataset 1992 were summarized for the Prairie–Hardwood Transition.

the resultant proportions and assessed these maps relative to GIS coverages of Thematic Mapper paths, state boundaries, and NLCD 92 regional classification units (Figure 2).

Results

We identified patterns in grassland–herbaceous, emergent-herbaceous wetlands, and small-grain land covers appearing to be influenced by inconsistencies in the classification of Landsat TM imagery (Figure 3). We observed obvious classification seams in the emergent-herbaceous wetlands and grassland–herbaceous land covers that were coincident with the TM paths. For instance, no grassland–herbaceous land cover was mapped west of TM path 27 and east of TM path 22 in the Prairie–Hardwood Transition. Grassland–herbaceous, emergent-herbaceous wetlands, and small-grain land covers all exhibited seams along the west edge of TM path 21 (Figure 3).

The inconsistency in mapping was not strictly limited to patterns associated with TM paths as there also appeared to exist additional problems related to differences among states. For instance, the mapped proportion of emergent-herbaceous wetlands in Minnesota was ≥7 times that occurring in the other states in the Prairie–Hardwood Transition (Figure 4), despite the occurrence of central Minnesota and central Wisconsin in the same ecoregion (North Central Hardwoods; Omernik 1987). Grassland–herbaceous and small-grain were mapped in the Driftless Area of northeastern Iowa but not in the adjacent Driftless Areas across the state border.

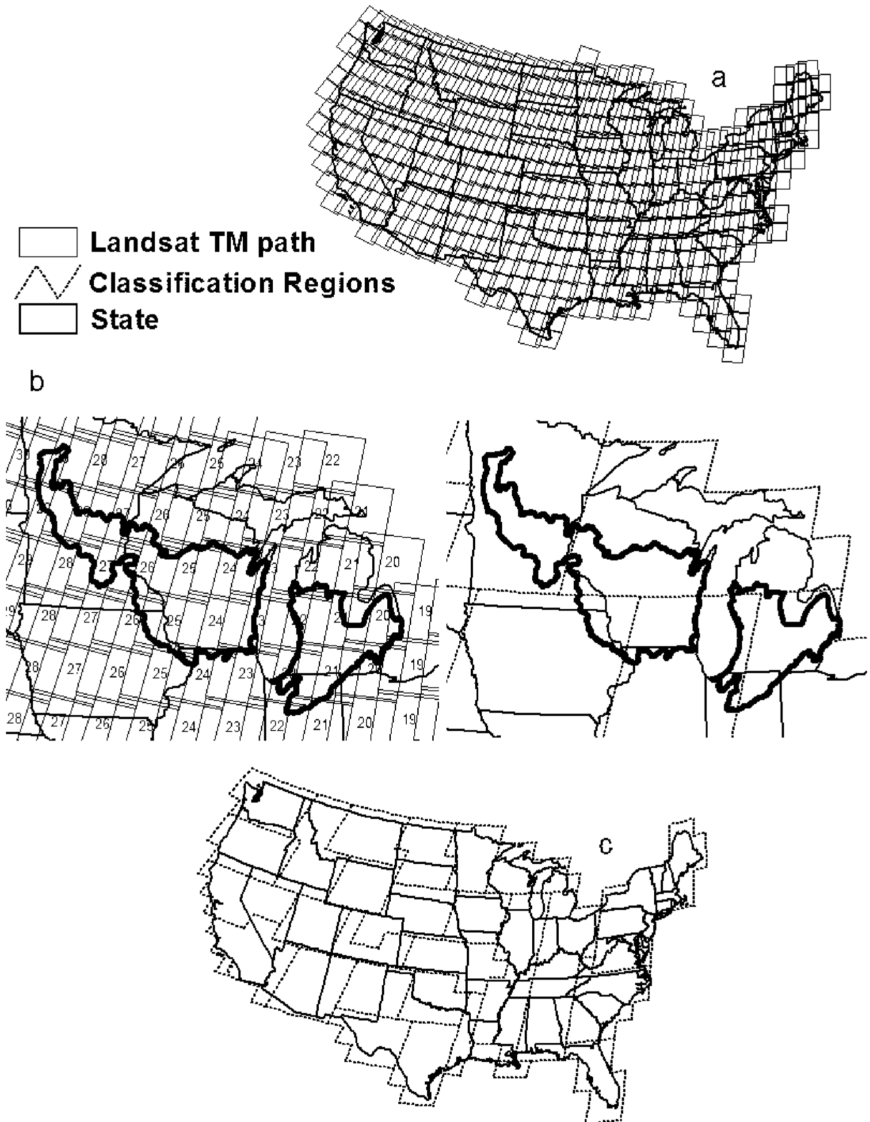

Figure 2. Landsat TM paths (a) and mapping regions (c) used by the United States Geological Survey for processing and classifying imagery for the United States, along with a specific focus on the Prairie–Hardwood Transition (b).

Discussion

We found significant spatial inconsistencies in how some land-cover types were mapped in the Prairie–Hardwood Transition. For example, we observed distinct TM scene boundaries in maps of the grassland–herbaceous cover type. There is a good possibility the discrepancies noted along TM scene boundaries actually were related to differences between mapping regions, as the problematic TM paths (i.e., 21, 25, and 26) lie along boundaries of mapping

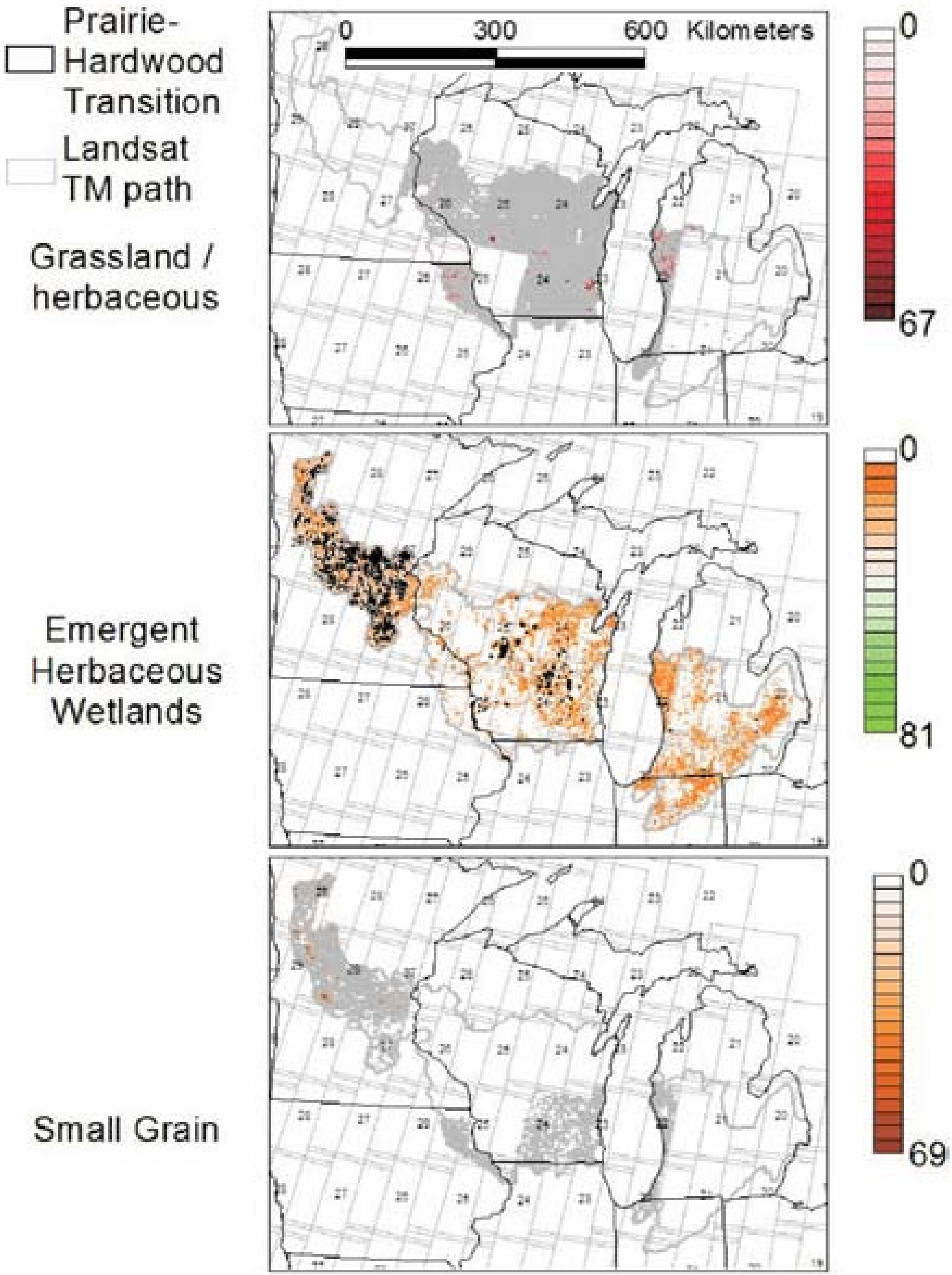

Figure 3. Percent of 800-ha landscapes in grassland–herbaceous, emergent-herbaceous wetland, and small-grain land cover in the Prairie–Hardwood Transition. Cells exhibiting the highest proportion of emergent herbaceous wetlands are lined in black.

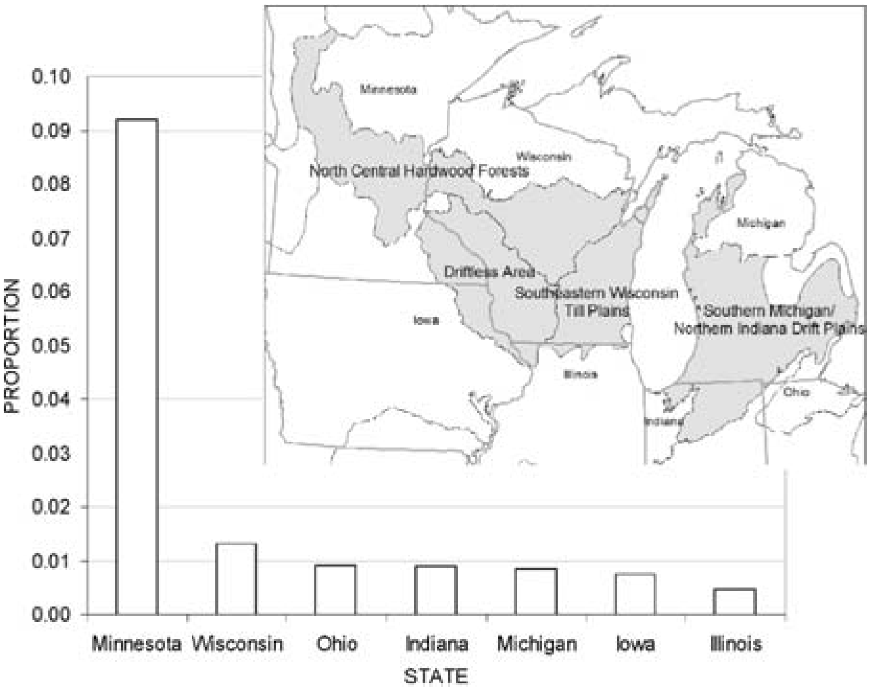

Figure 4. Proportion of land use in emergent-herbaceous wetlands for states in the Prairie–Hardwood Transition. The inset map shows the set of ecoregions (Omernik 1987) associated with this bird conservation region.

regions (Figure 5). These discrepancies along TM scene boundaries likely are partly reflected in lower accuracy rates; the grassland–herbaceous cover class had the lowest accuracy rate (97% error of omission and 91% error of commission; L. Yang, United States Geological Survey, personal communication) of all land-cover classes in the Upper Midwest mapping region. Emergent-herbaceous wetlands, which exhibited similar problems, were assessed as having 59% errors of omission and 44% errors of commission for the Upper Midwest portion of NLCD 92 (L. Yang, United States Geological Survey, personal communications).

The availability and quality of ancillary data also may have affected NLCD 92 classification results. For instance, the emergent-herbaceous wetlands cover class displayed boundary-related discontinuities in the land-cover map, but these discontinuities corresponded not only to TM scenes but also to state borders. Presumably, since central Minnesota and central Wisconsin occur in the North Central Hardwood Forests, they should have roughly corresponding measures of emergent-herbaceous wetland. A possible explanation for the 7-fold difference between Minnesota and Wisconsin lies with a key ancillary data source, the digital wetland maps developed by the National Wetlands Inventory (NWI). Wisconsin opted not to participate in the NWI program; hence, no NWI data were available for training NLCD 92 pixels.

The mapping problems we observed were associated with rarer land covers; emergent-herbaceous wetlands, grassland–herbaceous, and small-grain land cover comprised 2.6%, <0.1%, and 0.5%, respectively, of the land cover in the Prairie–Hardwood Transition. Conceivably, the selection of image dates was not targeted for distinguishing among rare land-cover classes. Also, given the unsupervised clustering approach used to develop the NLCD 92 classification, it makes sense that rarer land-cover classes, unless they possess a highly unique spectral signature, would have their relatively few pixels subsumed within clusters representing other cover classes. Furthermore, the degree to which a cover class might be identified as spectrally unique by a clustering algorithm was related to the other pixels in the dataset. Therefore, the mapping regions designated for processing the TM data might have affected how well a single cover class could be distinguished. Minnesota, Iowa, and Wisconsin may have exhibited different levels in the frequency of cover classes because each largely fell into different mapping regions (Figure 2).

Finally, some mapping problems might be attributable to differences among image interpreters. Yang et al. (2000) indicated that inconsistency among image interpreters was a largely unknown source of error in the digital mapping of land cover. Ornithologists, however, are familiar with a similar sort of inconsistency among individual observers in bird-count data (Sauer et al. 1994, Kendall et al. 1996) and have accounted for these discrepancies in their analyses (Link and Sauer 2002). Though no evaluation of interpreter agreement was conducted

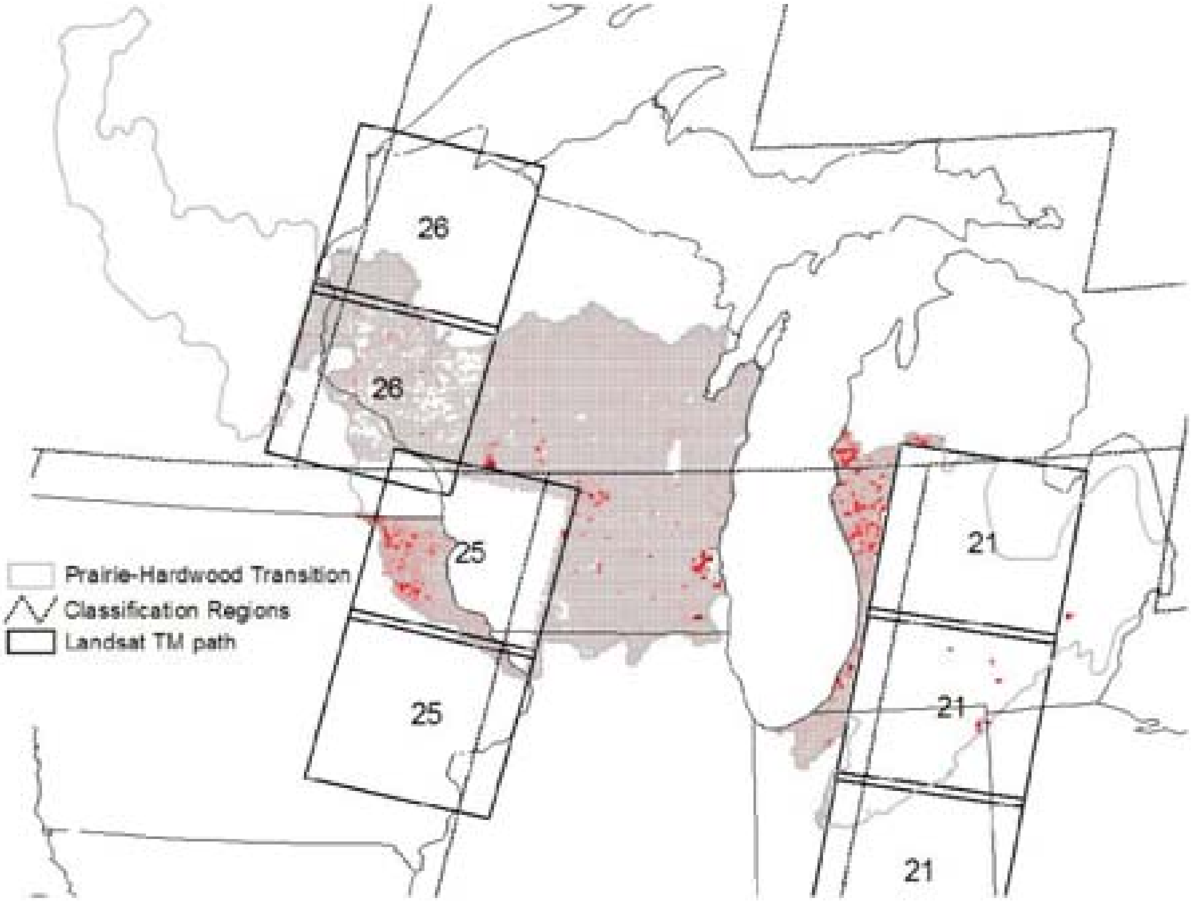

Figure 5. Discrepancies in the mapping of grassland–herbaceous land cover potentially associated with mapping regions. Grassland–herbaceous (see Fig. 3) was not mapped at the same frequency in the mapping region for which Thematic Mapper path 21 was associated, whereas to the west of a line marking the westernmost boundary of path 21, grassland–herbaceous is mapped extensively throughout. Similar artifactual results are evident for Thematic Mapper paths 25 and 26.

for the NLCD 92 classification, a comparison of agreement between 2 photo-interpreters contributing to the accuracy assessments of the NLCD 92 classification measured agreement at 79% in 1 mapping region and 84% in another, and showed that disagreement primarily was limited to specific cover types (Yang et al. 2000).

Despite its shortcomings, the NLCD 92 classification is still useful, especially if the deficiencies are recognized. For instance, the NLCD 92 classification was instrumental in successfully modeling regional populations of a rare forest bird (Thogmartin et al. 2004). For modeling populations of grassland-associated birds, we combined pasture–hay and grassland–herbaceous land covers. When distinctions among specific land-cover classes are unnecessary, combining land-cover categories should improve accuracy levels of land-cover classifications by minimizing classification errors (DeFries and Los 1999). However, loss of specificity in herbaceous land covers is an obvious disadvantage when modeling grassland specialists (e.g., sedge wren, *Cistothorus platensis*; Herkert et al. 2001).

An effort already is under way to develop the next iteration of the conterminous United States land-cover map (using year 2001 data), and substantial improvements have been made in overcoming many of the difficulties encountered in the creation of the NLCD 92 classification (Homer et al. 2002). With the future availability of a new land-cover map, many users will be tempted to conduct change-related analyses. We anticipate the potential for biased analyses because of the problems we have identified with the NLCD 92 classification (Loveland et al. 2002), and we encourage users to conduct analyses similar to ours to determine whether the data are suitable for change detection, habitat analyses, or other applications.

Conclusions

The NLCD 92 classification is the most current land-cover map available for the conterminous United States and thus is likely to be a popular source of information for a variety of applications. Though the United States Geological Survey is providing accuracy assessments for each mapping region, our analysis reveals that there can be distinct patterns in how these errors are distributed spatially. We suggest that the classification be used cautiously, and that it is important to learn about characteristics of the data before application. We recommend that analyses similar to ours be conducted for other regions when errant patterns in land classification may bias analytical results. Compensatory measures, such as aggregating confused classes, can be used to overcome some data shortcomings. Finally, users of regional land-cover assessments should be cognizant of the following disclaimer—that a digital-mapped product is "not guaranteed to be correct or complete, and conclusions drawn from such information are the responsibility of the user" (http://edc.usgs.gov/disclaimer.html). This is true for all interpreted remotely sensed data.

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