Fall 2011

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Great Plains Research 21 (Fall 2011):231–43
2011 Published by the Center for Great Plains Studies, University of Nebraska–Lincoln

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ABSTRACT—Land-cover and land-use change usually results from a combination of anthropogenic drivers and biophysical conditions found across multiple scales, ranging from parcel to regional levels. A group of four Level III ecoregions located in the U.S. northern Great Plains is used to demonstrate the similarities and differences in land change during nearly a 30-year period (1973–2000) using results from the U.S. Geological Survey's Land Cover Trends project. There were changes to major suites of land-cover; the transitions between agriculture and grassland/shrubland and the transitions among wetland, water, agriculture, and grassland/shrubland were affected by different factors. Anthropogenic drivers affected the land-use tension (or land-use competition) between agriculture and grassland/shrubland land-covers, whereas changes between wetland and water land-covers, and their relationship to agriculture and grassland/shrubland land-covers, were mostly affected by regional weather cycles. More land-use tension between agriculture and grassland/shrubland land-covers occurred in ecoregions with greater amounts of economically marginal cropland. Land-cover change associated with weather variability occurred in ecoregions that had large concentrations of wetlands and water impoundments, such as the Missouri River reservoirs. The Northwestern Glaciated Plains ecoregion had the highest overall estimated percentage of change because it had both land-use tension between agriculture and grassland/shrubland land-covers and wetland-water changes.

Key Words: Northern Great Plains, land cover, land-use change, land-use tension, weather variability

Manuscript received for review, January 2011; accepted for publication, July 2011.

INTRODUCTION

The Great Plains of North America extends from south-central Canada through northeast Mexico, with a majority of the region within the United States. This region of semiarid and subhumid grasslands and shrublands is bounded by the Rocky Mountains to the west and broad transition zones on the north, south, and particularly the east, where long-term wet and dry periods may alter the best economic use of the land. Thus, the area extent of what is included in the Great Plains has been the subject of debate (Rossum and Lavin 2000).

Early definitions of the Great Plains focused upon natural vegetation and climate (Webb 1931; Borchert 1950). More recent definitions and descriptions are characterized by the region's major economy and land use (Borchert 1987; Riebsame 1990; Gutmann et al. 2005; Parton et al. 2007). Most such treatments of the Great Plains tend to view the region in its entirety and potentially miss subregional biophysical and human conditions that may substantially impact contemporary land use at a finer geographical scale. Gutmann et al. (2005:85) stated that the balance between cropland and pasture in the Great Plains remained "virtually stable" between the 1920s and 1990s, but Drummond (2007) indicated that cropland gained an estimated 5,159 km^2 from grassland/shrubland between 1973 and 1980 in just two large Level III ecoregions (Omernik 1987) that cover 324,274 km^2. The use of the scale of an individual state can also mask finer-scale area changes. Hiller et al. (2009) present a detailed accounting of agricultural land change across Nebraska's history but never identify what subregions of the state changed the most or changed the least from presettlement conditions.

The use of large-scale analysis may also generalize conditions that are important to land use in one subregion and not be a leading factor in another. Irrigated cropland is a major component of land use in the central and southern Great Plains and issues dealing with such water use are needed in any discussion of the broader region (Riebsame 1990; Parton et al. 2007). Land use in the northern Great Plains, such as in the Dakotas, relies little on irrigation, and drivers affecting irrigation elsewhere may not be a factor influencing land change in this part of the Great Plains. A similar situation arises with the impacts of urbanization within the Great Plains. Urban growth in the Colorado Front Range impacts land use in the adjacent Great Plains (Parton et al. 2003). Other metropolitan areas within the larger region may also experience similar conditions (Parton et al. 2007). Urbanization, however, is not much of an issue in the Northern Plains, and land dynamics associated with these processes have had little impact on this subregion.

Although Great Plains land use is primarily agriculturally dominated, either by crop or grazing land, and contemporary land-cover and land-use change mostly reflect these major uses, there are regional differences that include other land covers and uses (Drummond and Auch 2010). The Northern Plains has noticeable amounts of surface water, ranging from the large Missouri River reservoirs to hundreds of glacial lakes to tens of thousands of human-made livestock watering impoundments. This subregion of the Great Plains also has substantial amounts of wetland cover that differentiates it from much of the overall larger region. Changes associated with these land covers range from those that are induced by partially anthropogenic–partially interannual weather variability (i.e., farming temporary or seasonal wetlands when possible, dealing with persistently flooded former agricultural land, managing the water storage of the Missouri River reservoirs) to those that are induced much more by climatic variability (i.e., water to wetland land-cover or wetland land-cover to water). These types of changes tend to be lost in discussions about land changes in the greater Great Plains region.

One of our goals is to demonstrate that at the intermediate scale of U.S. EPA Level III ecoregions, change in amounts and types of contemporary land use and land cover occurred across a subregion of the Great Plains, driven and influenced by an interweaving of biophysical and human conditions. We chose four ecoregions found in the Northern Plains because they provide an east-to-west transect from the humid, tallgrass prairie to the semiarid shortgrass prairie. These ecoregions also provide an opportunity to compare and contrast glaciated Great Plains ecoregions with a nonglaciated ecoregion. This is different from Drummond (2007), who compared two semiarid shortgrass-prairie, nonglaciated ecoregions. The major difference in that study was the heavy irrigation in one of the ecoregions compared to the other. Our Northern Plains study examines contemporary land change across both a precipitation gradient and substantial differences in soil capacity for cropping.

Our other goal is to explore how the biophysical and human drivers change across the study period. A single anthropogenic driver may not impact even smaller regions the same across time. Human drivers heavily influence "land-use tension" (or competition among land uses) where competition is possible. Short-term climatic variability (interannual weather cycles) also produce temporal pulses that influence changes in land use and more

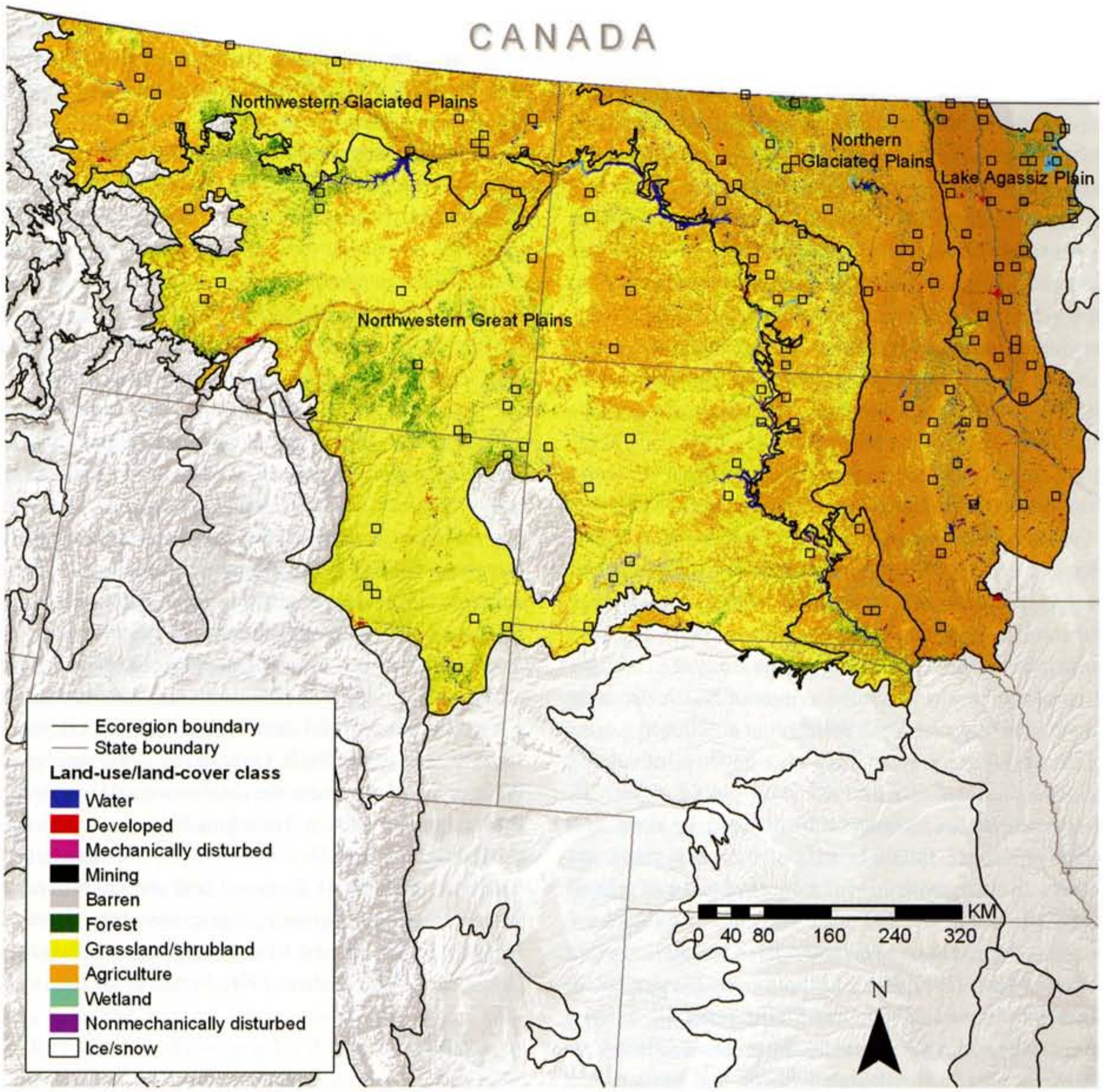

Figure 1. U.S. Northern Great Plains Level III ecoregions and land cover. The Land Cover Trends sample blocks are the hollow squares seen across the ecoregions.

directly land-cover relationships among water, wetland, agriculture, and grassland/shrubland. The Northern Plains provides a good case study in which to observe these types of land changes.

We examine recent land changes in the Northern Plains by using a number of sources. Thematic and spatial land-cover and land-use data are from the U.S. Geological Survey's Land Cover Trends project. The study period is from 1973 to 2000, the length of the Landsat satellite observation record when the Land Cover Trends project was initiated. The USGS data will be augmented with a spatial USDA soils dataset. Information about the drivers of land change in the Northern Plains will come from available literature to document the highlights of change. Together, all the sources will be woven to tell the general story of land change in the study area during the temporal period of interest.

STUDY AREA DESCRIPTION

The four northern Great Plains Level III ecoregions are the Lake Agassiz Plain, Northern Glaciated Plains, Northwestern Glaciated Plains, and the Northwestern Great Plains (Fig. 1), and include parts of six states. North

Dakota is completely within the study area, as well as nearly all of South Dakota and the eastern two-thirds of Montana. Lesser areas are found, in descending order, in northeastern Wyoming, western Minnesota, and extreme north-central Nebraska. The study area covers approximately 689,544 km^2 or about 8.9% of the conterminous United States based on ecoregion boundary area.

Elevation rises from east to west and land forms are generally rolling plains, with subregional and local differences. The Lake Agassiz Plain ecoregion has the most level terrain whereas the Northwestern Great Plains ecoregion has areas of high dissection, such as the South and North Dakota badlands and the west bank tributaries of the Missouri River. Glaciation has had major impacts on the land forms. The three eastern ecoregions were glaciated (approximately half of the study area), while the Northwestern Great Plains ecoregion was not. The Northern Glaciated Plains and Northwestern Glaciated Plains ecoregions have geologically young landscapes that have immature drainage systems. These manifest themselves in substantial numbers of wetland depressions and permanent lakes that make that part of the study area a major portion of the "prairie pothole" region of North America (Johnson and Higgins 1997; Johnson et al. 2005).

The study area's soils were also heavily influenced by glacial events. Soils derived from glacial drift, till, or from lake-basin sedimentation tend to be deep and productive. Those found in glacial outwash areas are generally thinner, with higher concentrations of gravel and sand (Bryce et al. 1998). The unglaciated plains west and south of the Missouri River tend to have shallow soils with clayey textures and lower productivity (Sayler 2010).

Precipitation in the Northern Plains generally follows a decreasing gradient from east to west. The southeastern areas of the Northern Glaciated Plains and most of the Lake Agassiz Plain have average annual precipitation amounts around or above 500 mm. The western areas of the Northwestern Great Plains and the Northwestern Glaciated Plains receive on average 300–400 mm of precipitation annually, although some pockets receive even less (PRISM Group 2010). Evaporation is about half of that found in the southern Great Plains (Owensby 2004).

The study area's natural vegetation is predominantly grassland communities, although shrublands are found in the more western parts of the region. The Lake Agassiz Plain and eastern portions of the Northern Glaciated Plains were covered with tallgrass prairie that transitioned into mixed-grass communities farther west. Shortgrass prairies are found in western sections of the Northwestern Glaciated Plains and Northwestern Great Plains ecoregions (Bryce et al. 1998; Woods et al. 2002; Chapman et al. 2001; Chapman et al. 2004; Brooks 2010). Other natural vegetation includes herbaceous wetland communities and scattered riparian forest found along the region's major rivers.

Euro-American settlement and the genesis of contemporary land use started during the second half of the 19th century and was initially completed by 1920. Settlement generally proceeded east to west, with areas having the highest annual precipitation and better soils having the longest occupation (Schell 1961; Malone and Roeder 1978; Larson 1978; Robinson 1995). Generally, glaciated land with level to undulating surfaces and deep soils provided the basis for crop agriculture and was converted to agricultural land cover. In the eastern Dakotas, grasslands remained only in localized areas where the glaciers left heavy deposits of rock, gravel, and sand. The primary use for these areas became grazing land for livestock. Ranching became the common land use as precipitation amounts diminished westward. Soil capacity for cropping, however, still played a role even in these areas, such as the western half of the Northwestern Glaciated Plains in northern Montana where alternating summer fallowing allowed for successful small-grain farming (Bryce et al. 1998; Woods et al. 2002). Only in the Northwestern Great Plains ecoregion, where the combination of low precipitation and poorer soils, did ranching become the ecoregional dominant land use (Bryce et al. 1998; Woods et al. 2002; Chapman et al. 2004). Regional land use was still adapting to the physical and human geographies of the Great Plains in 1973 and continued to do so during the study period (Riebsame 1990; Hudson 1996; Parton et al. 2005).

METHODS

The land-cover change data for this study comes from the USGS Land Cover Trends project. This research activity was initiated to better understand changes in contemporary land cover and land use at a regional scale (Loveland et al. 2002). A stratified random sampling approach was used to create statistically rigorous estimates of land-cover and land-use changes across the conterminous United States from 1973 to 2000 on an intermediate regional scale. The goal was to detect change at ±1% at an 85% confidence level (Loveland et al. 2002). A 10 km × 10 km grid was placed over the conterminous United States and samples were stratified by Omernik Level III ecoregions and randomly drawn for each of the 84 ecoregions (Omernik 1987; U.S. Environmental Protection Agency 1999; Stehman et al. 2003).

Five dates of Landsat satellite imagery (circa 1973, 1980, 1986, 1992, and 2000) were acquired for each sample "block." Each sample block was manually interpreted from the Landsat imagery using ERDAS Imagine© software. The Landsat interpretation was augmented by two dates of higher-resolution aerial photography from the early 1990s (the National Aerial Photography Program) and the early to mid-1980s (the National High Altitude Photography Program).

The interpretations were classified into 11 modified Anderson Level I land-cover and land-use classes (Anderson et al. 1976; Loveland et al. 2002). No classification scheme is purely land cover or land use but usually a mixture of both.

For this study, the most important land-cover classifications from the Land Cover Trends project are agriculture (cropland, including hay land, and intensely used pasture), grassland/shrubland (less intensely used rangeland grazing land and idled cropland planted to perennial grasses), water (permanent lakes, reservoirs, and persistent water devoid of wetland vegetation), and wetland (wetland vegetation or conditions). No formal accuracy assessment of the Land Cover Trends project's interpretations has been made, because most remote-sensing-based accuracy assessments use higher-resolution aerial photography to validate coarser-resolution satellite imagery, and we used aerial photography as part of the initial interpretations.

For this study, the data from the four Level III ecoregions of interest were combined to get the estimates of land-cover change for the overall Northern Plains, but data were also used separately to show ecoregional differences.

Data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database were included in the post-interpretation analysis to help better understand the change results. The crop capability index for soils that is produced within this database was intersected with the ecoregions to give a summary of the land capacity for cropping by ecoregion. The values of the index range from 1 to 8, with 1 to 4 being areas basically suitable for cultivated crops. Suitability decreases as the index increases in value. Classes 5 through 8 have increasingly more restrictions that limit their use, with the exception of pasture or grazing (Natural Resources Conservation Service 1994).

RESULTS

We estimate that 8.5% of the combined four Northern Plains ecoregions changed land cover at least once during the study period. This equates to an estimated 58,692 km^2 (±12,609 km^2) of overall change. This was less than the cumulative totaling of the four time intervals, however, as some land had more than one change during the study period but occupied the same space and thus was counted only once for overall change. The Lake Agassiz Plain had the least amount of change in both percentage and absolute area, whereas the Northwestern Glaciated Plains had the greatest percentage of change (Table 1), not only in the Northern Plains but also for the overall Great Plains (Taylor 2010). Although the Northwestern Great Plains had considerably less percentage change than its neighbor to the north and east, this ecoregion had a slightly greater absolute amount of area change because of its much larger size (Table 1).

In all four Northern Plains ecoregions, the first two time intervals saw less change than the last two intervals (Table 1), even when the percentages were normalized to annual amounts to overcome unequal temporal spans (Table 2), although the Northwestern Great Plains annualized rate returned to the pre-1986 levels during the last time interval. The ecoregions generally had greater change after 1986, yet differences in rates of change remained among them. The annualized change rate (Table 2) in the Northwestern Glaciated Plains rose considerably during the last two time intervals when compared to the first two. Change in the Northwestern Great Plains spiked in the third interval. The Northern Glaciated Plains had its highest change during the last time interval.

Ten types of change accounted for 95% of the gross change detected (where the same area could be counted more than once for change) (Table 3). Seventy-five percent of the combined gross change resulted from conversions between agriculture and grassland/shrubland land-covers. The leading land-cover change during the study period was the conversion of agriculture to grassland/shrubland. Most of this change occurred in the Northwestern Great Plains and the Northwestern Glaciated Plains ecoregions. A second set of changes involving wetland and water transitions accounted for another 13% of the combined gross change and occurred primarily in the Northern Glaciated Plains and Northwestern Glaciated Plains ecoregions. Other changes affected smaller areas and tended to be more ecoregion specific. Most of the agriculture-to-wetland, wetland-to-agriculture, and agriculture-to-water transitions occurred in the Northern Glaciated Plains. A majority of the changes between grassland/shrubland and water happened in the Northwestern Great Plains. This ecoregion was also the only one where a substantial disturbance event (wildfire

TABLE 1
ESTIMATED OVERALL PERCENTAGE OF SPATIAL CHANGE BY ECOREGION AND ABSOLUTE AREA CHANGED

	Percentage change (%); Area change (km²)				Overall spatial percentage change, 1973–2000; Area change (km²) (No double counting)
Ecoregion	**1973–1980**	**1980–1986**	**1986–1992**	**1992–2000**	
Lake Agassiz Plain	0.3 (±0.1); 101 (±34)	0.2 (±0.1); 98 (±49)	0.7 (±0.3); 278 (±119)	0.5 (±0.2); 210 (±84)	1.4 (±0.4); 569 (±163)
Northern Glaciated Plains	1.4 (±0.3); 2,003 (±429)	1.4 (±0.3); 1,949 (±418)	2.4 (±0.5); 3,330 (±694)	4.2 (±1.0); 5,846 (±1,392)	7.5 (±1.4); 10,601 (±1,979)
Northwestern Glaciated Plains	2.6 (±0.6); 4,203 (±970)	2.6 (±0.7); 4,158 (±1,119)	6.1 (±1.3); 9,830 (±2,095)	6.6 (±1.5); 10,627 (±2,415)	13.6 (±2.2); 21,853 (±3,535)
Northwestern Great Plains	2.2 (±0.7); 7,448 (±2,370)	2.0 (±0.8); 6,810 (±2,724)	3.0 (±1.2); 10,533 (±4,213)	2.7 (±1.0); 9,381 (±3,479)	7.4 (±2.0); 25,669 (±6,933)

TABLE 2
ESTIMATED ANNUAL PERCENTAGE CHANGE OF ECOREGION

Ecoregion	**Percentage change, annualized**			
	1973–1980	**1980–1986**	**1986–1992**	**1992–2000**
Lake Agassiz Plain	>0.1 (± >0.05)	>0.1(± >0.05)	0.1 (±0.05)	0.1 (± >0.05)
Northern Glaciated Plains	0.2 (± >0.05)	0.2 (± >0.05)	0.4 (±0.1)	0.5 (±0.1)
Northwestern Glaciated Plains	0.4 (±0.1)	0.4 (±0.1)	1.0 (±0.2)	0.8 (±0.2)
Northwestern Great Plains	0.3 (±0.1)	0.3 (±0.1)	0.5 (±0.2)	0.3 (±0.1)

that was classified as "nonmechanically disturbed") was identified that impacted the change statistics, although its variability was quite high (Table 3).

There were also temporal differences in the major types of changes. Agriculture had net gains from grassland/shrubland land-cover in all the ecoregions during the first time interval and in three out of four in the second time interval (Fig. 2). In the third time interval, however, this pattern was substantially reversed, and grassland/shrubland gained from agriculture. This reversal continued during 1992–2000 but at greatly reduced amounts. Net changes between wetland and water land-covers had both temporal and regional variability (Fig. 3). There was a heterogeneous mix among the ecoregions during the first and third intervals, where either wetland or water had net gains from the other depending on more subregional weather conditions. The area of water land-cover increased in all ecoregions, however, during the second and fourth time intervals, especially between 1992 and 2000 in the Northwestern Glaciated and Northern Glaciated Plains ecoregions. A somewhat similar temporal pattern can be seen in net changes between grassland/shrubland and water land-covers, with water usually gaining from grassland/shrubland but with a substantial

TABLE 3
MAJOR TYPES OF LAND COVER AND LAND USE CHANGES AND ESTIMATED AREA AFFECTED (KM^2)

Type of change	Lake Agassiz Plain	Northern Glaciated Plains	Northwestern Glaciated Plains	Northwestern Great Plains	*Northern Great Plains Combined*
Agriculture to grassland/ shrubland	297 (±134)	3,386 (±1,180)	14,688 (±3,103)	17,239 (±10,193)	**35,610 (±10,610)**
Grassland/shrubland to agriculture	104 (±56)	1,915 (±602)	9,027 (±1,947)	11,013 (±3,342)	**22,059 (±5,947)**
Wetland to water	20 (±13)	3,244 (±814)	3,172 (±1,388)	493 (±483)	**6,929 (±2,698)**
Water to wetland	10 (±6)	1,107 (±325)	1,212 (±514)	722 (±744)	**3,051 (±1,589)**
Agriculture to wetland	26 (±21)	1,356 (±758)	113 (±53)	33 (±33)	**1,528 (±865)**
Nonmechanically disturbed to grassland/shrubland	0	0	0	1,390 (±2,029)	**1,390 (±2,029)**
Grassland/shrubland to water	0	252 (±150)	159 (±110)	703 (±462)	**1,114 (±722)**
Water to grassland/shrubland	1 (±2)	14 (±11)	47 (±38)	846 (±610)	**908 (±661)**
Wetland to agriculture	28 (±33)	624 (±196)	69 (±28)	0	**721 (±257)**
Agriculture to water	5 (±5)	484 (±307)	87 (±55)	23(±19)	**721 (±257)**

reversal in the trend between 1986 and 1992 primarily in the Northwestern Great Plains and to a lesser extent in the Northwestern Glaciated Plains (Fig. 4). The Lake Agassiz Plain had almost no water and grassland/shrubland land-cover transitions.

Northern Plains ecoregions share similar physical and anthropogenic management characteristics that result in similar land covers and land-cover conversions such as grassland/shrubland to agriculture and agriculture to grassland/shrubland. Each ecoregion also has different amounts of precipitation, soils, glacial history, and settlement patterns that distinguish it from the others. The result is that Northern Plains ecoregions' land-use and land-cover changes are variations on a theme, with the amounts of different types of changes found in greater abundance in certain ecoregions or several ecoregions than in others.

DISCUSSION

The leading types of land-cover and land-use change in the study area between 1973 and 2000 can be placed within into two major suites: one that was primarily the result of the land-use tension between crop and grazing agriculture land use and the other caused by lengthy periods of wetter and drier weather. The land-cover transitions within both suites showed temporal variability because the study period was long enough to capture changes in both agriculture and weather cycles.

Land-use tension is created by the competition between or among two or more land uses, given the general biophysical conditions that result in the greatest economic gain for the landowner. Competing land uses must generate similar incomes or little tension between them would exist. The competition is typically viewed across a temporal scale where potential land change is seen as a competitive advantage, especially during times of changing or unpredictable economic conditions (Napton and Loveland in press). Land-use tension also spans spatial scales, from the regional down to the parcel level. In the U.S. Southeast, the main land-use tension is between forestry and agricultural land uses (Healy 1985; Napton et al. 2010). In the Northern Plains, the land-use tension is between crop cultivation and livestock grazing uses.

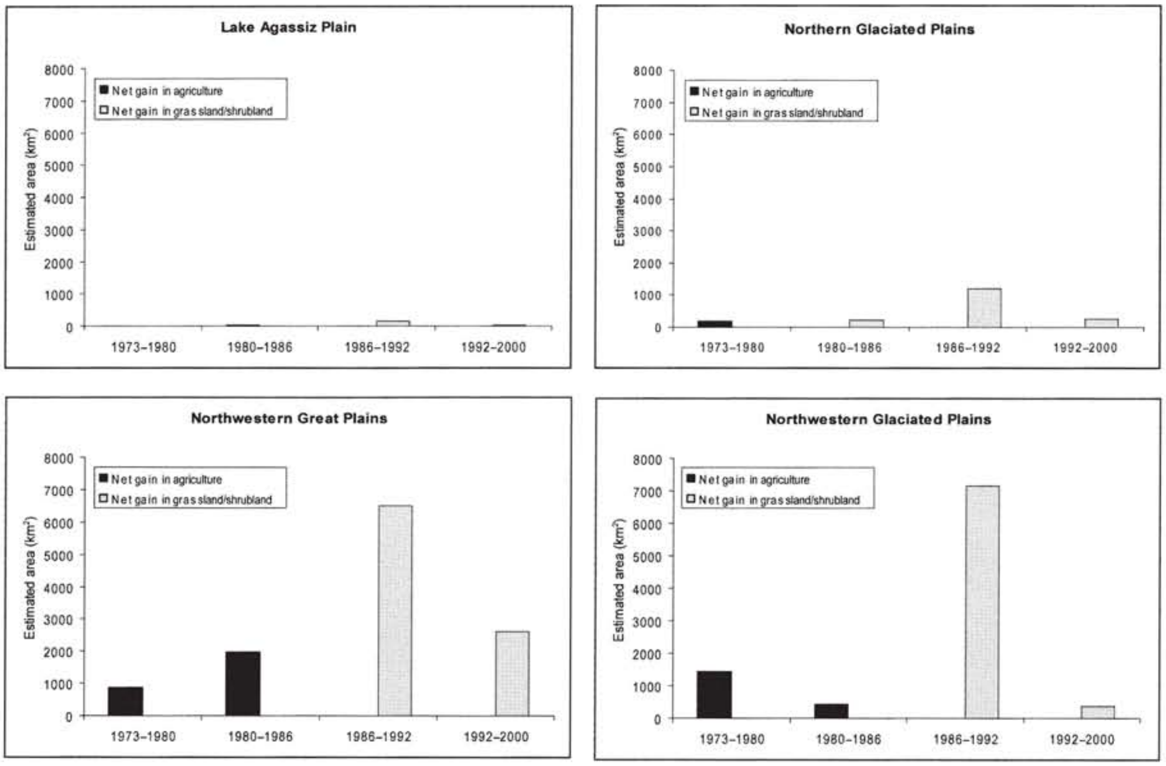

Figure 2. Estimated area of net gain in agriculture versus grassland/shrubland land-covers.

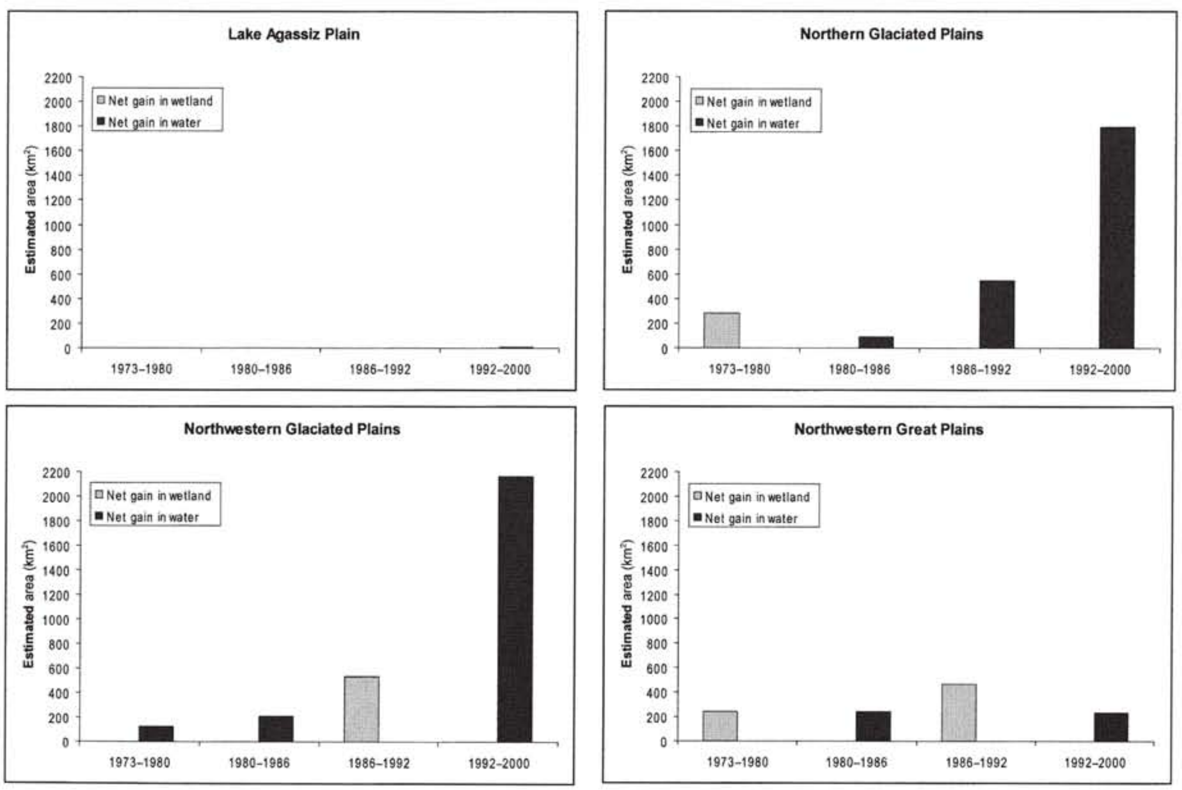

Figure 3. Estimated area of net gain in wetland versus water land-covers.

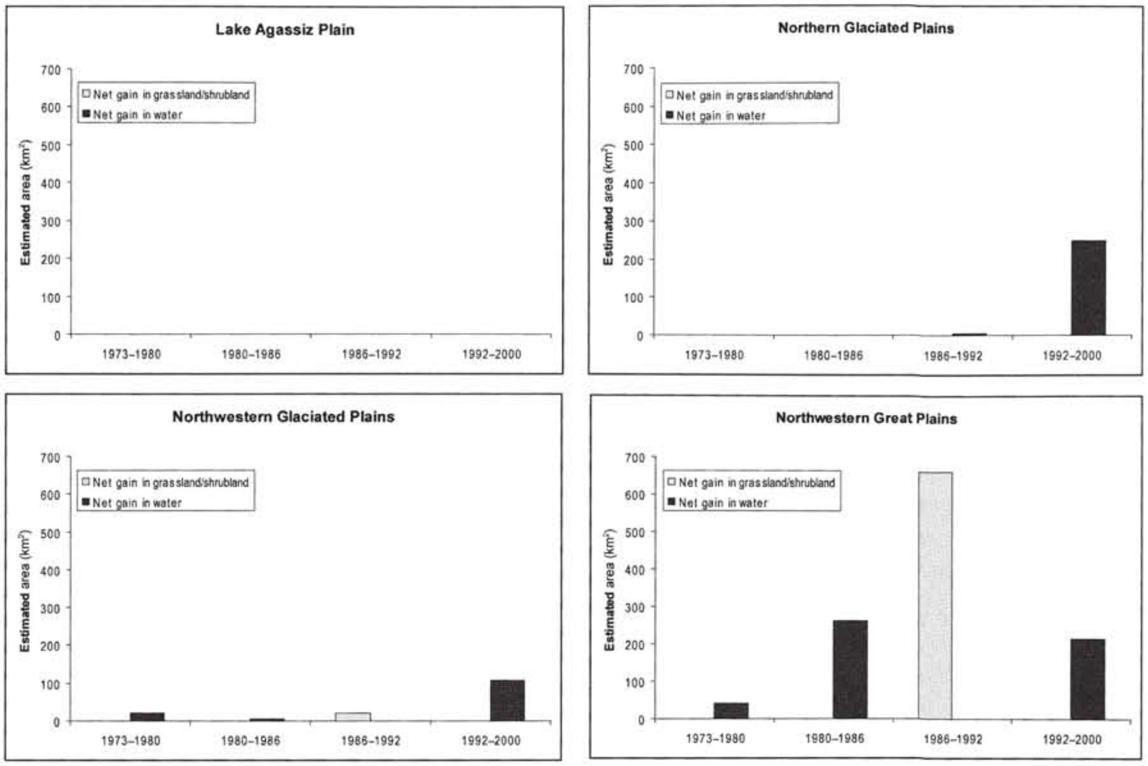

Figure 4. Estimated area of net gain in grassland/shrubland versus water land-covers.

This regional land-use tension between agriculture or grassland/shrubland land-cover use during the study period was greatly influenced by anthropogenic drivers. Grassland/shrubland-to-agriculture conversion was the leading change during the first two time intervals, especially between 1973 and 1980, when changes in drivers occurred. These altered drivers, all favoring increased cropping, included a major commodity price spike caused by foreign countries' large grain purchases, governmental policy that favored enlarged farming operations, and increasing farmland prices driven by high inflation rates (Danbom 1995; Stam and Dixon 2004; Conklin 2008:132–34). Grassland/shrubland-to-agriculture conversion was most common in the Northwestern Glaciated Plains and the Northwestern Great Plains, ecoregions that each had higher amounts of grassland/shrubland to convert because of lower overall land capacity for cropping (Fig. 5). The newly converted land had been "economically marginal" for farming (Deal 2006) until the above drivers facilitated change. Grassland/shrubland grazing land that remained unchanged in these two ecoregions may have been considered so economically marginal for cropping that even with the above drivers landowners would not convert them.

The situation was different, however, by the third time interval, as the 1980s "farm crisis" had played out with low commodity prices and substantial numbers of highly leveraged crop producers (Fig. 2). The U.S. Department of Agriculture's Conservation Reserve Program (CRP) was established in 1985 to retire highly erodible land from production (agriculture to grassland/shrubland land-cover change) and to help reverse the agricultural economy's malaise (Sullivan et al. 2004). Its implementation during the 1986 to 1992 interval is clearly seen in all the ecoregions (Fig. 2). The Conservation Reserve Program was the single greatest driver of land change in the Northern Plains during the study period.

The land-use tension between agriculture and grassland/shrubland land-covers had again changed somewhat by the end of the fourth time interval. The CRP had matured as a federal program, with less land being newly enrolled than during its heyday, although grassland/shrubland land-cover still had a net gain from agriculture (Fig. 2). New or changed drivers (improved crop types including bioengineered varieties, biofuel production, greater availability of crop insurance, and higher commodity prices) were helping to convert grassland/shrubland to agriculture in the Northern Plains (Higgins et al. 2002; Stubbs 2007). This was possibly reflected in the lower net gains of grassland/shrubland land-cover from agriculture during this interval.

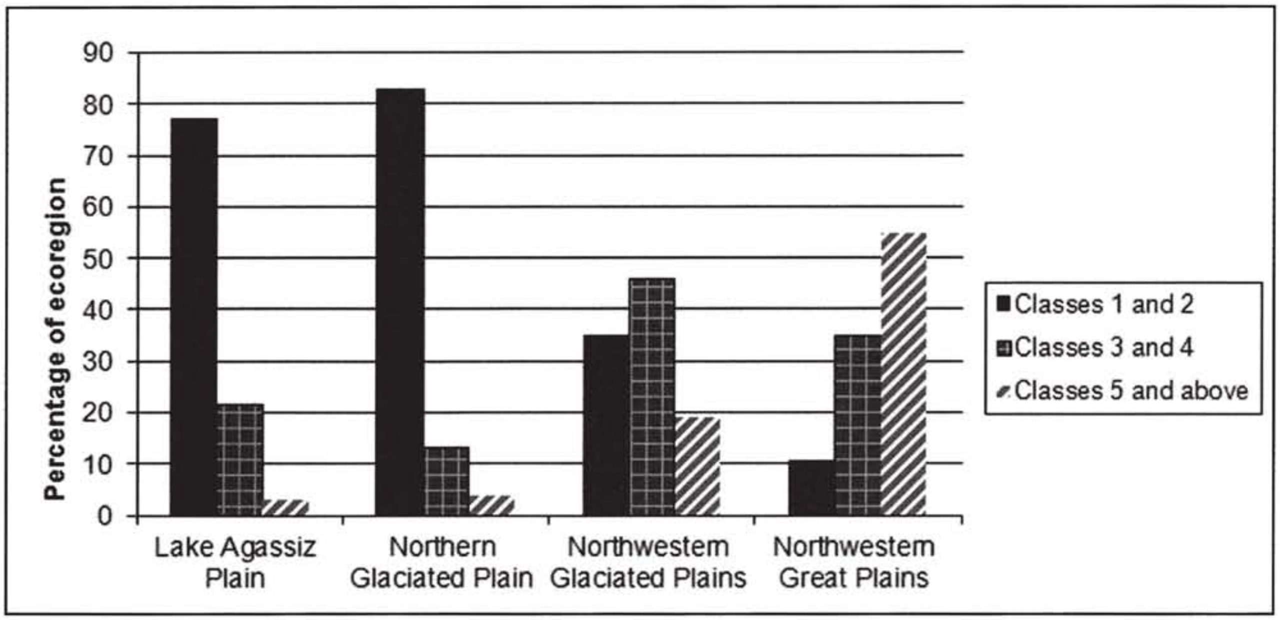

Figure 5. Percentage of ecoregion in the northern Great Plains by crop-capacity class groupings. Lands in classes 1 and 2 are best suited for crop agriculture. Lands in classes 3 and 4 are less suited for crop agriculture but still could be cropped. Lands in classes 5 and above have little to no potential for crop agriculture. Crop-capacity groupings are from the Natural Resources Conservation Service.

The other major suite of land-cover changes was primarily driven by interannual weather variability, although anthropogenic management could also be found in these changes. Most of these transitions were ephemeral in nature. Water and wetland land-covers increased and decreased because of wet and dry weather cycles with noticeable interregional variation across the time intervals. Each ecoregion gained water land-cover from wetlands, however, during the 1992 to 2000 interval because of a series of wetter years in the mid- to late 1990s. Lake Agassiz Plain had little wetland-to-water change because most of its wetlands had been drained before our study period (Aadland et al. 2005). Research by Garbrecht and Rossel (2002) concluded that the Northern Plains did have a significantly wetter decade during the 1990s, and Kirby et al. (2002), Todhunter and Rundquist (2004), Shapley et al. (2005), and the South Dakota Game, Fish, and Parks (2010) give more localized examples of how cyclic drought-and-deluge temporal spans affect land cover and land use in the study area.

Other, mostly weather-driven land-use and land-cover transitions included agriculture-to-wetland, agriculture-to-water, and grassland/shrubland-to-water land-cover transitions. Many temporary and seasonal wetlands were cropped, especially in the Northern Glaciated Plains and Northwestern Glaciated Plains, but during wetter than normal years these wetlands could not be farmed and stayed out of production (Kirby et al. 2002). Water gain from agriculture and grassland/shrubland land-covers could represent a longer-term but still cyclic change where a number of larger glacial lake basins experienced flooding during the study period. Water bodies such as Lake Thompson and Waubay Lakes in South Dakota, Devil's (Spirit) Lake in North Dakota, and numerous smaller lakes gained in size from the mid-1980s onward. These lakes may persist at larger surface areas for years (Todhunter and Rundquist, 2004; Shapley et al. 2005; South Dakota Game, Fish, and Parks 2010).

Other changes between grassland/shrubland and water may be short-term, such as those affecting the water status of impoundments that ranged in size from a single-pixel (60×60 m) stock dam to the great reservoirs on the Missouri River. The stock dams would be full of water during wetter or more normal precipitation years but could dry up and become vegetated during droughts. Many new stock dams were also created from grassland/shrubland land-cover during the study period. The Missouri River reservoirs' volumes fluctuated because of variable snowpack melt from the Rocky Mountains and runoff from Northern Plains watersheds. The major water-to-grassland/shrubland spike during the third interval (Fig. 4) was the result of a series of drought years both in the Rockies and the Northern Plains that substantially reduced runoff into the reservoir system (U.S. Army

Corps of Engineers 2004:8). Exposed reservoir land grew a grassland/shrubland land-cover that was flooded again when runoff returned to more normal conditions and the reservoirs refilled.

CONCLUSIONS

In conclusion, the amounts and types of change in land cover and land use in the Northern Plains depended on the various combinations of anthropogenic drivers and biophysical conditions found in the four ecoregions during the study period. The Lake Agassiz Plain experienced the least change because it had already been altered the most from its presettlement conditions (Loveland and Hutcheson 1995). This ecoregion's biophysical attributes allowed it, under the U.S. land rent theory system, to reach its "highest and best use" (Napton and Loveland in press). The greatest land-use tension was found in the ecoregions that had the highest proportion of economically marginal land where landowners could respond to changes in anthropogenic drivers. This was especially true in the Northwestern Glaciated Plains, which has the highest amounts of class 3 and 4 crop-capacity lands that could be brought into or retired from cultivation depending on the various drivers (Fig. 5). Cyclic weather variations, less linked to anthropogenic drivers, also resulted in land-cover change in the four ecoregions, especially in the remaining, less-altered core of the U.S. prairie pothole region where wetland and water land-cover conditions fluctuate regularly.

This study documents recent land-use and land-cover changes in the Northern Plains but also strives to further indentify intermediate-scale regional differences in change within the context of human and natural driving forces. Discussing how to better understand the future role of land-use change in "earth system dynamics," Lambin et al. (2001:267) said that we "must not only capture the complex socio-economic and biophysical drivers of land-use change but also account for the specific human-environment conditions under which the drivers of change operate." Our study captures the major strands of complex interplay of socioeconomic and biophysical drivers necessary to develop an enriched understanding of how human ; interact with the environment.

Land-cover and land-use change is expected to continue in the Northern Plains; our study period was just a slice of time in a longer continuum. Post-2000 land-use tension between agriculture and grassland/shrubland land-covers is underway as anthropogenic drivers continue to modify or develop, particularly in the Northwestern Glaciated Plains (Garrett-Davis 2004; Stubbs 2007). Climatic variability may continue to cause land-cover changes, especially if human-induced climatic change increases variability (Johnson et al. 2005; Millett et al. 2009). Ecoregional change variability may also continue as these regions offer their own combinations of resources and conditions to their current human inhabitants. Further monitoring and research is warranted as land-use and land-cover conditions continue to change.

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