DISSERTATION

TRENDS AND PROCESSES OF LAND COVER CHANGE IN THE WESTERN HIGH PLAINS ECOREGION

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY MARK DRUMMOND ENTITLED TRENDS AND PROCESSES OF LAND COVER CHANGE IN THE WESTERN HIGH PLAINS ECOREGION BE ACCEPTED AS FULLFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

TRENDS AND PROCESSES OF LAND COVER CHANGE IN THE WESTERN HIGH PLAINS ECOREGION

The goal of this study was to better understand the agricultural land use processes and land cover changes affecting the semi-arid Western High Plains ecoregion in the United States Great Plains. Globally, the processes of agricultural expansion and loss have had widespread effects on land cover and ecosystems that are an ongoing concern of land change research. To improve the understanding of regional land change, three main topics were addressed: 1) the contemporary patterns and key processes of agricultural change in the conterminous United States; 2) the rates, causes, and processes of land cover change in the Western High Plains ecoregion between 1973 and 2000; and 3) the primary driving forces of contemporary land cover change in the Western High Plains, including the dynamics of water resource access. Land cover change estimates for the ecoregion were derived using a stratified random sample of 10 x 10 km blocks and remote sensing change detection. Land use was examined using the Census of Agriculture. Results of the study indicate that patterns of land change vary by region and time period depending on socioeconomic driving forces and environmental context. In the Western High Plains ecoregion, net grassland loss occurred from 1973 to 1986 as agricultural land expanded in response to market opportunities. Agricultural expansion affected 1.9% of the ecoregion. Processes of land change became substantially different after 1986. Between 1986 and 1992, grassland expanded and became the dominant land cover, driven in large part by the cropland retirement policies of the Conservation Reserve Program (CRP). Agricultural declines affected 7.3% of the ecoregion, primarily as cropland was converted to grassland cover. Between 1992 and 2000, net grassland expansion was less than 1%, although there was a high rate of gross change in the location of grassland and agriculture that had only a limited effect on net change. The primary driving forces of land cover change were enabled by water resource access, which had a substantial influence on grassland extent and pattern.

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CHAPTER 1

INTRODUCTION TO THE DISSERTATION

This dissertation shows that the analysis of agricultural expansion and decline is useful for understanding the patterns and processes of land change in ecoregions. This is accomplished through an assessment of available land use data, prior case studies, and a sampling strategy for regional land cover change analysis. In the sampling strategy, 45 randomly selected 10^2 km land cover samples in the Western High Plains ecoregion (Figure 1.1) are analyzed for change using five dates between 1973 and 2000. The main results are presented in three chapters written as scientific papers for specific journals identified below.

Human activities have caused changes in the physical, chemical, and biological make-up of Earth and have affected the functioning of its natural systems. Land use and land cover changes are important measures of the status of these impacts at local, regional and global scales. However our understanding of recent and historical changes and their primary causes is still limited (Skole 2004). There is increasing realization that a more thorough understanding of change may be acquired through integration of socioeconomic analyses of land use and driving forces, such as the primary land use factors that cause regional change, with examinations of land cover and ecosystems. Accordingly there have been recent calls to systematically understand the rates, causes, and consequences of land use and land cover change (Loveland et al. 2002). The purpose of this research is to contribute to this understanding by analyzing the major trends and processes of land use and land cover change that occur across the Western High Plains ecoregion. Agriculture is the dominant land use in the ecoregion, including areas of cropland irrigation that use groundwater from the underlying High Plains Aquifer complex. Changes in the patterns and causes of agricultural change may be having a significant impact on grasslands and other land cover in the Western High Plains. The interaction of agricultural land use and land cover change that is examined in this study should contribute to a better understanding of regional change.

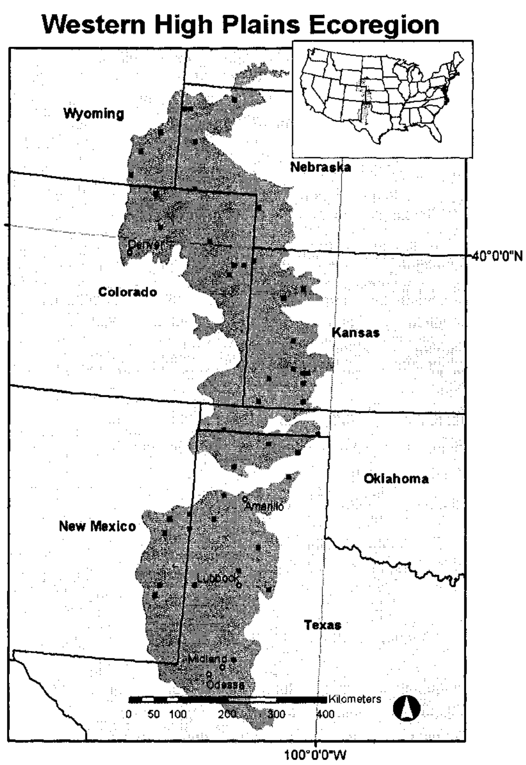

Figure 1.1. The Western High Plains study area. It extends across parts of eight states and covers approximately 287,000 sq. km. A statistical sample of forty-five 10 x 10 km land cover blocks (shown) were examined for five dates from 1973 to 2000.

Research Questions

1) What are the regional patterns and processes of change affecting United States agricultural regions?
    a. Are historical processes of agricultural expansion and loss key factors of contemporary regional change, post-1950?

2) What are the estimated rates and trends of land cover change in the Western High Plains ecoregion from 1973 to 2000?
    a. What are the primary regional land cover dynamics in the ecoregion?

3) What are the causes of land cover change in the Western High Plains?
    a. What are the primary socioeconomic forces that drive change, including the impact of water resource access on land cover change in the Western High Plains ecoregion?

Agricultural processes of change are important at regional, national, and global scales because of the extent of their influence on land cover as well as the numerous consequences on other social and environmental conditions. Cropland cultivation is the principal mode of global vegetation clearance (Ramankutty and Foley 1999). Conversely, farmland abandonment in eastern North America caused reforestation and a substantial carbon sink during part of the 20th century (Houghton and Hackler 2000). The processes of agricultural expansion, abandonment and intensification are linked to land cover changes that influence biogeochemical cycles (Ojima et al. 1994), hydrology (Mahmood and Hubbard 2002), climate and weather changes (Pielke 2005) and habitat loss (Tilman et al. 2002).

Farmland use is extensive in many regions of the conterminous United States (Figure 1.2). For example, the intensively cultivated Corn Belt covers large areas of several upper Midwestern states. Vast areas of federally-managed lands in the West are used for livestock grazing. Water consumption by cropland irrigation is prevalent in the central and western Great Plains among other regions. Such land use changes can transform regional land cover and ecosystem health. This research focuses on contemporary land use and land cover changes in the Western High Plains and grasslands of the western Great Plains. The Plains grasslands are the most endangered ecosystem type in the U.S. (Samson et al. 2004). Understanding the characteristics of land use and land cover change in the area will contribute to understanding the status and trends of the grassland ecosystem.

The semi-arid Western High Plains ecoregion has undergone several transformations of land use and land cover. The region has transitioned from predominantly natural grassland to extensive livestock grazing to dryland agriculture to locally intensive irrigated cropland. Groundwater from the High Plains aquifer complex, which includes the immense Ogallala aquifer, became readily accessible to farmers in the region with the introduction of new technology. After World War II, high capacity pumps and lightweight aluminum pipes allowed an irrigation expansion. The intensification of agriculture characterized by a vertically-integrated industrial production of irrigated corn, large confined cattle operations, and meat-packing plants raise questions about the contemporary effect on land cover (Opie 2001).

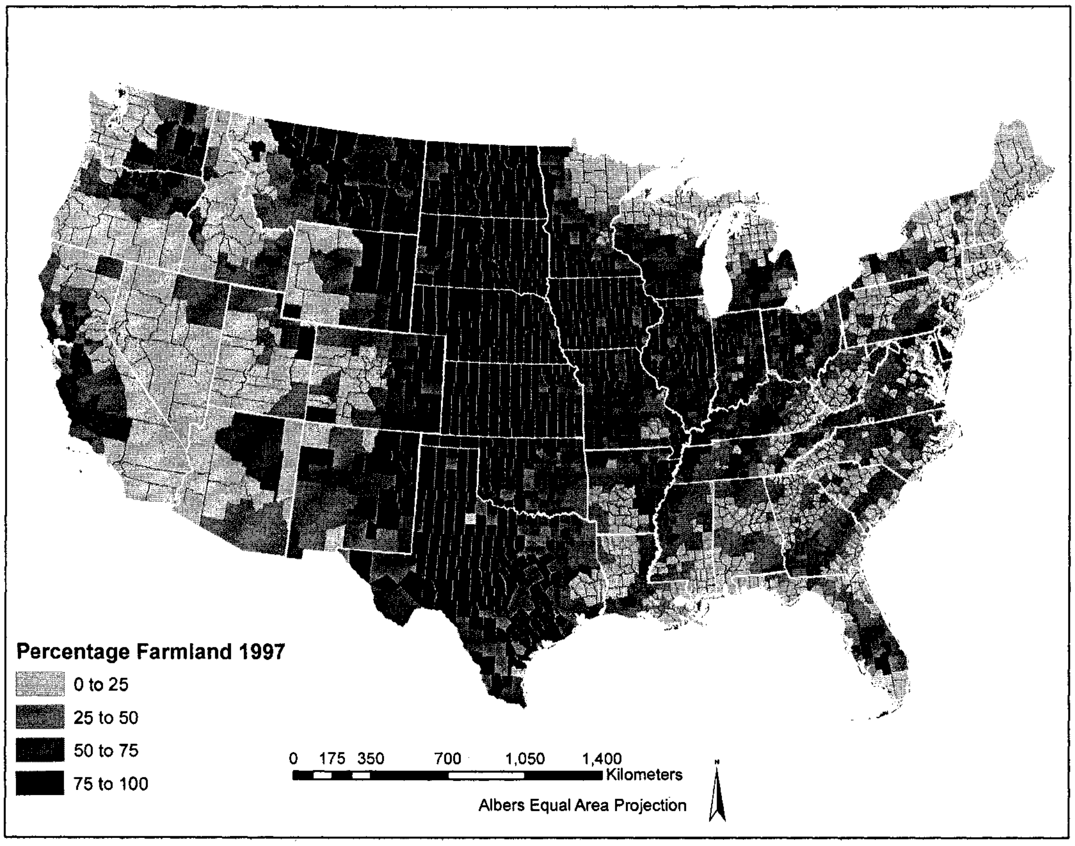

Figure 1.2. Farmland percentage in conterminous U.S. counties, 1997 (USDA 1997).

The High Plains aquifer that underlies much of the study region has declined over the past six decades of groundwater pumping, raising serious concerns about imminent depletion. During the 1980s, groundwater depletion was predicted to occur in many areas within 3 to 20 years (Walsh 1980). Conservation efforts, new irrigation technology, regulation, and improved cropping practices are some of the techniques that may extend water use in some areas. However, there have been reports of farmland abandonment caused by groundwater depletion, and of farmers switching to less water intensive crops (Walsh 1980). Part of this research examines successive changes in land use and land cover that may relate to changes in the pattern of water availability.

This study is informed by recent empirical and theoretical understandings of agricultural processes of expansion and abandonment (Lambin et al. 2001; Mather 1992; Mather and Needle 1998). The concepts of expansion and abandonment are used throughout the dissertation to organize the results and discussion.

OBJECTIVES AND METHODOLOGY

The overall goal of this study was to better understand the regional characteristics and processes of land cover change. This goal was attained through research related to the following objectives:

1. To understand the historical and regional context of land use change. This involved the identification of broad-scale processes of change that affect agricultural regions. Agricultural land use data between 1950 and 1997 from the U.S. Census of Agriculture was examined.

2. To determine the contemporary trends and processes of land cover change in the Western High Plains ecoregion. This was accomplished primarily through the use of a U.S. Geological Survey statistical sampling methodology (Loveland et al. 2002;

Stehman et al. 2003; Griffith et al. 2003; Sohl et al. 2004). Forty-five randomly selected sample blocks in the Western High Plains ecoregion, stratified by the U.S. Environmental Protection Agency Level III ecological regions (Omernik 1987), were examined for change. Five dates of 10 x 10 km sample blocks, nominally 1973, 1980, 1986, 1992 and 2000 were mapped from Landsat MSS, TM, and ETM+ satellite data.

3. To examine the primary factors that enable land cover change in the Western High Plains ecoregion, such as farm policy and economic opportunities that drive change. A spatial analysis of the associations between water availability and successive changes in land cover between 1973 and 2000 was also conducted to understand the role of water resource access.

The research methodology included three general approaches to meet the above objectives (Figure 1.3). The first was to carry out field exploration of current land use in the region. Land use type and location were documented for selected sites across the ecoregion in the summer of 2002. The second was to analyze agricultural census data (USDA 1997), population data (U.S. Bureau of the Census 2001), and previous research to identify the historical context of regional change. The third was to analyze five different dates of remotely sensed imagery from c.1973, 1980, 1986, 1992 and 2000 in the Western High Plains in order to map and quantify land cover change for the 45 sample locations. Sample sites are 10x10km and were randomly selected. The sample blocks are part of a U.S. Geological Survey nationwide sampling strategy to document land cover change (Loveland et al. 2002). In this approach, the conterminous United

States was divided into a 10km^2 grid and sample selections were stratified by Omernik (1987) ecoregions.

Land conversions for each sample block and the spatial association with historical patterns of Ogallala aquifer decline were also examined using a Geographic Information System and areal summaries of the successive land changes for selected categories of water access.

Monitoring studies have frequently relied on aggregated statistics of the relative proportions of land use and land cover types for each time step to describe change (Herzog and Lausch 2001; Pontius Jr. et al. 2004). The estimates of regional land cover change used in this study allow an understanding of net and gross changes, among other spatial and temporal dynamics of change. By linking geographically referenced data useful for understanding site-specific change with the more detailed census data on land use types, this study intends to improve the understanding of regional trends and driving forces of land change.

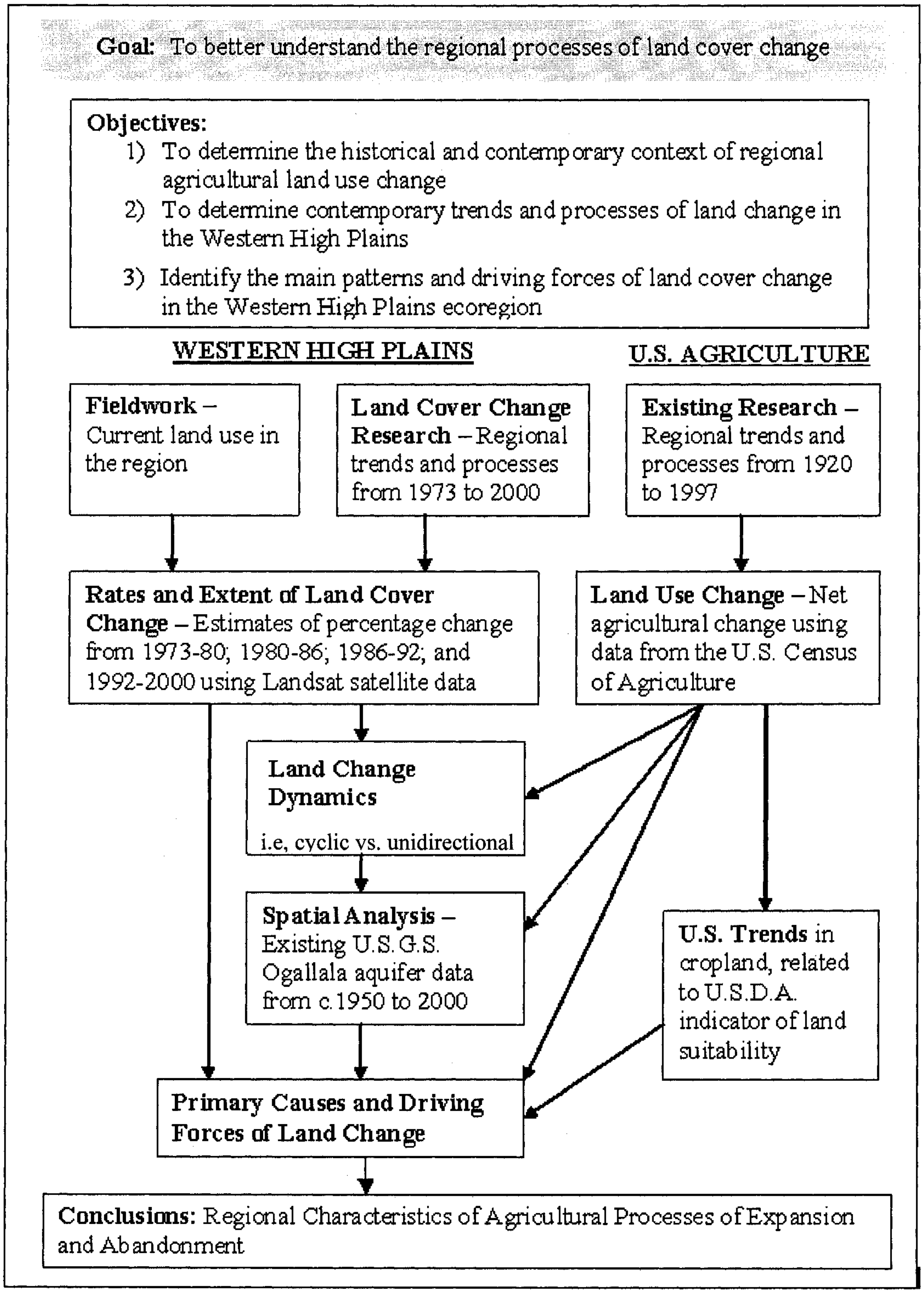

Figure 1.3. Research methodology of the study.

FORMAT OF THE DOCUMENT

The dissertation is divided into six chapters. Chapters three, four, and five are research papers intended to be submitted to selected journals during 2006. All three journals, listed below, require manuscripts to be less than 8500 words and have an abstract and a list of key words. The specific format of each journal was standardized to fit the dissertation requirements. Figures and tables were placed within the text for the dissertation rather than at the end of the paper, such as in the standard manuscript submission format.

Chapter 1 is the introduction to the research themes, questions, and objectives.

Chapter 2 is a short summary of scientific literature on regional land cover expansion and abandonment.

Chapter 3 examines the broad-scale processes of conterminous United States agricultural land use change between 1950 and 1997. The patterns and processes of land use change are explored using county agricultural census data and Omernik Level III ecoregions (Omernik 1987). Changes in farmland, cropland, woodland, and rangeland are examined at the national and regional scale. This chapter sets the historical and regional context for interpreting changes in the agricultural Western High Plains and other ecoregions by examining the dynamics of expansion and abandonment of agricultural land use. This chapter was written for the journal entitled Land Use Policy.

Chapter 4 examines the trends and outcomes of land cover change in the High Plains from 1973 to 2000. The emphasis of the paper is on the rates and patterns of land cover change as they relate to processes of agricultural expansion and abandonment. This chapter was written for the journal entitled Great Plains Research.

Chapter 5 examines the driving forces of land cover change by examining land use dynamics, regional case studies, and the spatial associations between indicators of water resource access and land conversion. Water resource availability enables intensive agricultural production; however, numerous socioeconomic forces interact with the physical factors of land use location to drive change. This chapter was written for the Journal of Land Use Science.

Chapter 6 is a short conclusion written as a reflection on the dissertation process and on the lessons learned while pursuing a Ph.D.

REFERENCES

Griffith, J.A., S.V. Stehman, and T.R. Loveland. 2003. Landscape trends in Mid-Atlantic and southeastern United States Ecoregions. Environmental Management, 32:572-588.

Herzog, F. and A. Lausch. 2001. Supplementing land-use statistics with landscape metrics: some methodological considerations. Environmental Monitoring and Assessment, 72:37-50.

Houghton, R.A. and J.L. Hackler. 2000. Changes in terrestrial carbon storage in the United States. I: The roles of agriculture and forestry. Global Ecology and Biogeography, 9:125-144.

Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X.B. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skanes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, and J.C. Xu. 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change- Human and Policy Dimensions, 11:261-69.

Loveland, T.R., T.L. Sohl, S.V. Stehman, A.L. Gallant, K.L. Sayler, and D.E. Napton. 2002. A strategy for estimating the rates of recent United States land-cover changes. Photogrammetric Engineering and Remote Sensing, 68:1091-1099.

Mahmood, R. and K.G. Hubbard. 2002. Anthropoogenic land-use change in the North American tall grass-short. Climate Research, 21:83-90.

Mather, A.S. 1992. The forest transition. Area, 24:367-379.

Mather, A.S. and C. Needle. 1998. The forest transition: a theoretical basis. Area, 30:117-124.

Ojima, D.S., K.A. Galvin, and B.L. Turner II. 1994. The global impact of land-use change. Bioscience, 44:300-304.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers, 77:118-125.

Opie, J. 2001. John Wesley Powell was right; resizing the Ogallala High Plains. In: C. Miller (ed.), Fluid Arguments: Five Centuries of Western Water Conflict, U. of Arizona Press, Tucson, pp.223-247.

Pielke Sr., R.A. 2005. Land use and climate change. Science, 310:1625-1626.

Pontius Jr., R.G., E. Shusas, and M. McEachern. 2004. Detecting important categorical land changes while accounting for persistence. Agriculture, Ecosystems and Environment, 101:251-268.

Ramankutty, N. and J.A. Foley. 1999. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography, 8:381-396.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin, 32:6-15.

Skole, D.L. 2004. Geography as a great intellectual melting pot and the preeminent interdisciplinary environmental discipline. Annals of the Association of American Geographers, 94:739-743.

Sohl, T.L., A.L. Gallant, and T.R. Loveland. 2004. The characteristics and interpretability of land surface change and implications for project design. Photogrammetric Engineering & Remote Sensing, 70:439-450.

Stehman, S.V., T.L. Sohl, and T.R. Loveland. 2003. Remote Sensing of Environment, 86:517-529.

Tilman, D., S. Polasky, K.G. Cassman, P.A. Matson, and R. Naylor. 2002. Agricultural sustainability and intensive production practices. Nature, 418:671-677.

U.S. Bureau of the Census. 2001. 2000 Census of Population and Housing: Summary File 1 United States. U.S. Bureau of the Census, Washington, D.C.

U.S. Department of Agriculture (USDA). 1997. Census of Agriculture, Geographic Area Series, AC97-CD-Vol 1. U.S.D.A. National Agricultural Statistics Service, Washington, D.C.

Walsh, J. 1980. What to do when the well runs dry. Science, 210:754-756.

CHAPTER 2

HISTORICAL BACKGROUND: THE PROCESSES OF AGRICULTURAL EXPANSION AND LOSS

INTRODUCTION

This summary of background literature introduces the key concepts and the historical context that informs the rest of the research. A brief historical introduction is given on the primary patterns and processes of agricultural land expansion and loss that affect the conterminous United States. Agricultural expansion is defined as any net increase or relocation of farmland use. Loss of agriculture is the decline or abandonment of farmland use.

Land use and land cover is another major theme of the dissertation. Land use is defined as the proximate human activities and management of land, which directly cause modification and conversion of land cover (Ojima et al 1994). Land cover is the natural and human-constructed physical make-up of the land surface, which is directly affected by land use change. Land cover changes can have substantial affect on the structure and pattern of the biophysical land surface, which impacts carbon dynamics and climate

(Houghton and Hackler 2000; Skinner and Majorowicz 1999), hydrological cycles (Goudie 1994), and ecosystem function (Haberl et al. 2001).

Although people have noted the human impact on land and environment throughout history, there was a substantial imbalance of observations that touted the generous benefits that were derived from human alteration of the environment (Myer 1996). George Perkins Marsh provided the first synthesis and interpretation of prior literature on the impacts of human activities in 1864, titled Man and Nature: or, Physical Geography as Modified by Human Action. The act of clearing forests for agriculture and cities, the fouling of waters, and the exploitation of wild habitats cause intentional changes as well as unintentional and detrimental changes to the earth (Marsh [1864] 1965). Nearly 100 years later a second synthesis of human impact brought together numerous geographers, ecologists, and other scientists to give a retrospective analysis of the temporal and spatial breadth of human actions, titled Man's Role in Changing the Face of the Earth (Thomas 1956). More recently, The Earth as Transformed by Human Action (Turner et al. 1990), and Land-Use and Land-Cover Change: Local Processes and Global Impacts (Lambin and Geist 2006) greatly expanded the survey of human-influenced changes to the biosphere at global and regional scales. One of the observations that come from a familiarity with these volumes, aside from the sheer magnitude of changes to the biosphere, is the dynamic nature of human activities, their causes, and their consequences. That said, a relatively narrow review of literature on the expansion and loss of agricultural land relevant to this research follows. However, the extent and effects of land use and land cover change are much broader than those only of agriculture.

EXPANSION AND LOSS OF AGRICULTURAL LANDS PRIOR TO 1950

Cropland

Prior to 1850, most cropland was located east of the Mississippi River (Ramankutty and Foley 1999). Early examples of cropland loss include outright abandonment of cotton fields in the Southeast during the Civil War era, which caused afforestation (Buttrick 1917). However, these changes likely occurred across a smaller total area than the subsequent migration of croplands from east to west.

Cropland in the eastern United States underwent a relatively rapid abandonment and westward migration to lands more suitable for large-scale production. Throughout the late 1800s, the total area of U.S. cropland increased steadily with westward expansion into the forests and grasslands of the Midwest and the Great Plains. Expansion continued beyond the period of intensive western settlement into the 1920s (Marschner 1959). Extensive cropland abandonment began by 1910 in New England and by 1930 in the Mid-Atlantic region, before occurring in the southeastern U.S. (Ramankutty and Foley 1999).

Farmland abandonment occurred across large areas of the East because many regions had significant physical constraints to agriculture. Unproductive soils, steep topography, and climate factors are the primary causes of cropland abandonment in the region (Hart

1968). Soils in many areas of the southeast are acidic and have low organic content, limiting crop productivity (Hudson 2002). Evapotranspiration rates, precipitation amounts, and the length of the growing season are among the important climate factors related to abandoned croplands in the region (Ramankutty and Foley 1999). They were often abandoned after marginal soils were depleted or economic changes made traditional crops unprofitable (Buttrick 1917). The less accessible lands may have also been preferentially abandoned over those that were near transportation and markets (Flinn et al. 2005).

The fate of cropland conversion is an important consideration for understanding the implications of landscape change. Lands that are converted to other uses have different implications for regional ecosystem function than those abandoned to return to natural cover. Once eastern croplands were abandoned, they were often planted to pasture before all farm use eventually ceased (Buttrick 1917), creating a successive decline of land use intensity. Some farmlands in the East were also abandoned outright, either in part or whole, while others were converted to urban development, mining, or silviculture (Hart 1968). In the early 1900s, timber companies recognized the need to plant abandoned fields to commercial forest stands before they were overgrown with less profitable native species or brush (Buttrick 1917).

Woodlands, Farmland

Historically, most farms in the eastern U.S. included some woodland acreage (Hart 1968). Woodlands on farmland provided a ready source of firewood and lumber (Flinn et al. 2005).

From 1910 to 1959, woodlands on farmland declined by approximately 31 million acres in 31 eastern states (Hart 1968). However, the loss of any supplemental income from its transfer out of farm ownership would not have had substantial economic impact on the overall operation (Hart 1968). Woodlands were historically important to farm culture, although they were marginal to farm profit. The outcome of woodland loss is difficult to ascertain without land cover analysis. Woodlands could have been converted to peri-urban development, harvested and replanted to timber or simply abandoned.

Rangeland and Pastureland

Most agricultural lands in the Midwest and Great Plains were converted from natural forests and grasslands, although in some cases they were already modified by prior use. For instance, in the Texas Panhandle, grasslands were primarily used for livestock grazing until the early 1900s. Rangeland subsequently became more valuable as cropland and was parceled out to farmers (Hudson 2002). Ranching is still the most extensive land use in the Great Plains (Engle and Bidwell 2000).

Other Factors of Expansion and Abandonment

Regional abandonment of newly cultivated lands outside of the eastern U.S. was less extensive but included semi-arid lands that were subjected to periodic drought and areas with soil limitations. Cropland abandonment and relocation occurred in some areas of the northwestern Great Plains as farmers learned to judge the soil conditions, and later through improved soil surveys (Roet 1985).

Poor wheat prices in the 1920s did not deter farmers from expanding. The total area of wheat in the southern plains increased 200 percent between 1925 and 1931 as farmers tried to increase profits during the economic decline (Helms 1992).

Technology, particularly through the diffusion of the farm tractor, also impacted regional and national land use and land cover prior to 1950. The effect of technology included an increase in productivity, farm size, and a decline in farm workers. The area of farmland available for commercial agriculture increased because less land was needed to feed draft animals (Olmstead and Rhode 2000). Cropland abandonment of the East and expansion to the relatively level expanses of the Midwest and Great Plains were driven by improved mechanization that allowed more land to be cultivated by fewer laborers. In 1920 there were less than 300,000 tractors, however by 1950 there were more than 3 million (Olmstead and Rhode 2000).

THE POST-1950 PROCESSES OF AGRICULTURAL LAND USE CHANGE

The pattern and processes of land use change post-1950 differ from the previous time period. By 1920, land clearance for agriculture caused a 40% reduction in U.S. forest and woodland area. Those forests have made a net recovery of 6% due largely to farmland abandonment in the East (Houghton and Hackler 2000). Since 1950, agricultural expansion and land clearance have occurred primarily in the Intermountain shrublands (Hart 2001; Greene and Stager 2001) and the western Great Plains (Riebsame 1990). This suggests a continuing but limited relocation of cropland to Western states. More recently, rangeland conversion to irrigated cropland in the arid West was linked to urbanization of Eastern croplands under a “replacement lands argument” (Greene and Stager 2001). The expansion is a concern because of agricultural intensification in an area of limited water availability.

Some recent decline of cropland (Figure 2.1) in areas of the Great Plains is caused by economic conditions. For example, when wheat imports from Canada are more profitable for U.S. grain mills than buying from local producers in marginal areas, they cannot compete with the imported crops (Hudson 2002). Future changes in crop varieties, agricultural practices, and markets may offset or accentuate these types of land use changes.

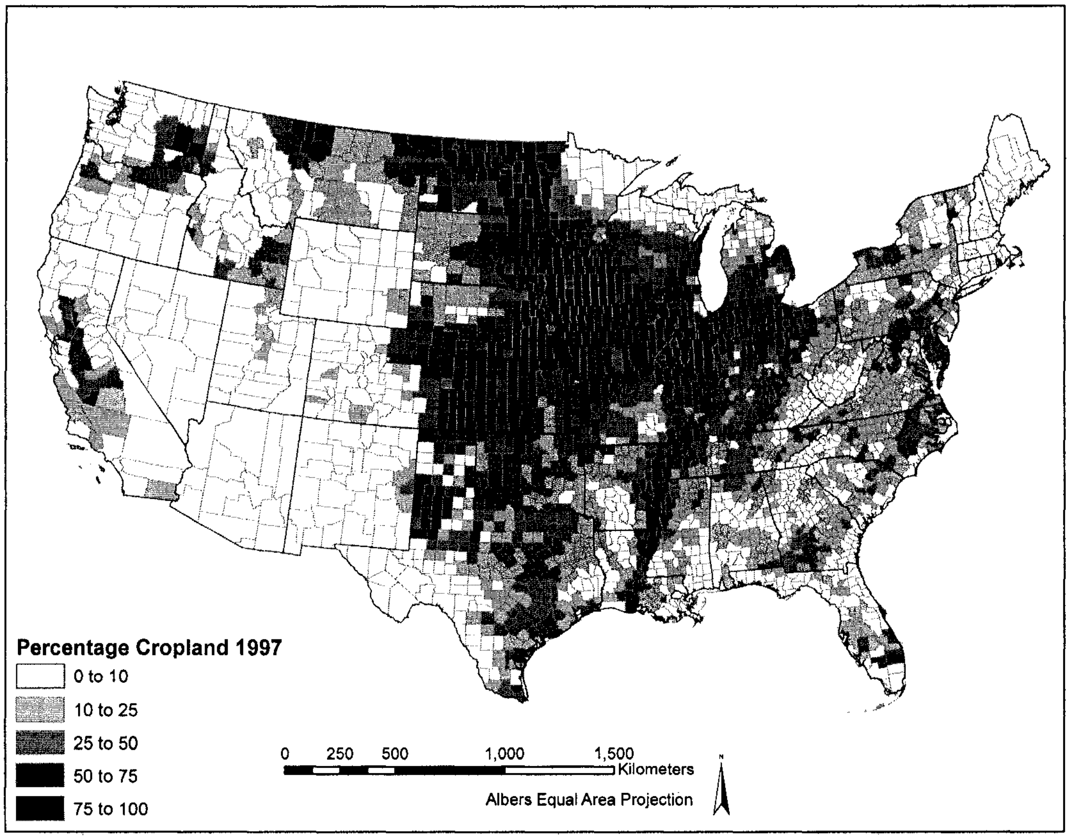

Figure 2.1. Cropland percentage in conterminous U.S. counties, 1997 (USDA 1997).

The Conservation Reserve Program

In the early 1970s, expansion of Great Plains cropland occurred unchecked in response to an expanding grain export market. This eventually resulted in a greater emphasis on conservation of marginal croplands through government land retirement programs such as the Conservation Reserve Program (CRP) (Figure 2.2) (Riebsame 1990). The cropland impact of the expanded global markets during the early 1970s was estimated as a conversion of 3.6 million acres of grassland and 400,000 acres of woodland during 1974 (Helms 1990). The CRP policy was designed to take marginal and highly erodible lands out of production by paying farmers to plant permanent vegetation cover.

However, land slippage, also referred to as land leakage, can occur that partially negates land conservation efforts if farmers' plant in new areas to make up for lands and revenue lost to the CRP (Wu 2000; Leathers and Harrington 2000). The importance of CRP land slippage is disputed by other research that suggests current estimates of slippage are unreliable in part because of economic and site factors that contribute to regional variation of cropland expansion and abandonment (Roberts and Bucholtz 2005).

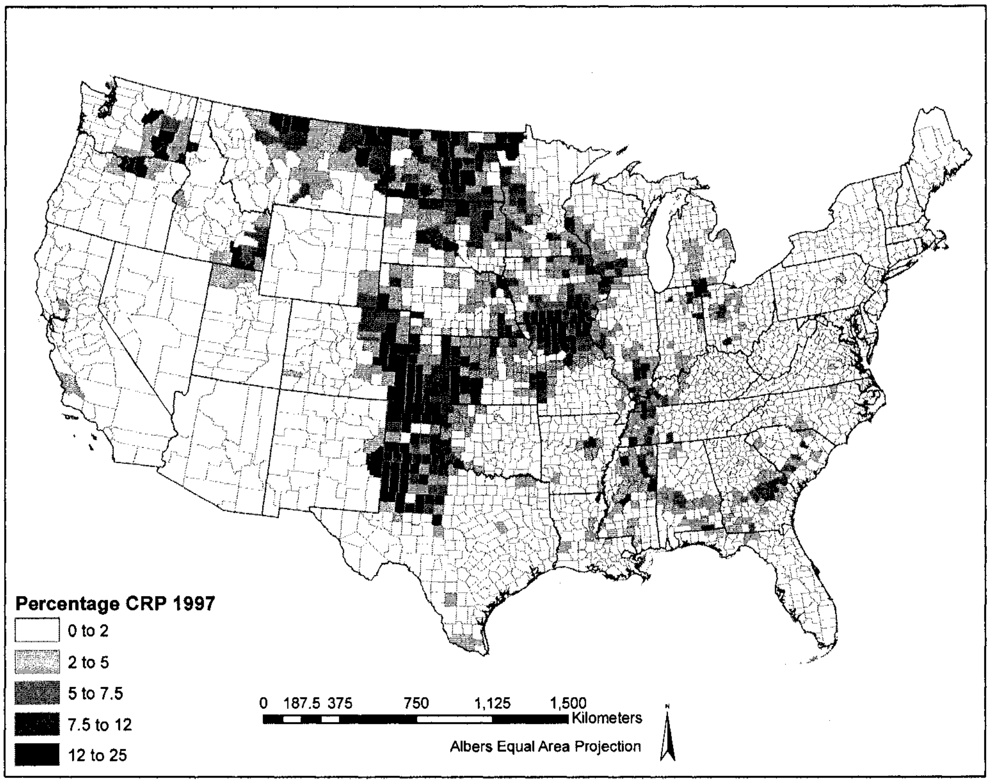

Figure 2.2. CRP percentage in conterminous U.S. counties, 1997 (USDA 1997).

Urbanization

In the U.S., there has been recent debate about loss of good quality agricultural soils to urban growth (Imhoff et al 1998). However, loss of agricultural lands to the pressures of urbanization and recreational housing is likely small and not affecting production on the best soils (Hart 2001).

Agricultural land declines occurring at the urban fringe may have multiple causes, foremost the intentional sale of marginal lands that have little direct local impact on agricultural production. Nevertheless, recent urbanization of prime farmland in some locations may be linked to expansion onto marginal cropland (Platt 1991; Greene and Stager 2001). In the Great Plains, rural population and the number of commercial farms have declined steadily since peaking in 1930, while urban populations have increased every decade since 1900 (Riebsame 1990).

Intensification of agricultural production

Average farm size in the northern and central Great Plains also tripled between 1930 and 1980 (Baltensperger 1987), essentially driven by a technologically advanced industry. Since 1950, technology and new strains of crop have caused yields of cotton and soybeans to more than double. Corn yields have increased nearly four-fold although without higher profits for farmers (Heinz Center 2002).

Irrigation expansion has played an important role in the increased crop yields, including areas of sufficient rainfall where the timing of precipitation or the soil type benefits from supplemental irrigation (Figure 2.3). Center-pivot irrigation technology, which expanded in the mid-1960s, essentially boosts the productivity of lower quality land and has allowed expansion onto sandy soils and hillier topography (Lichtenberg 1989).

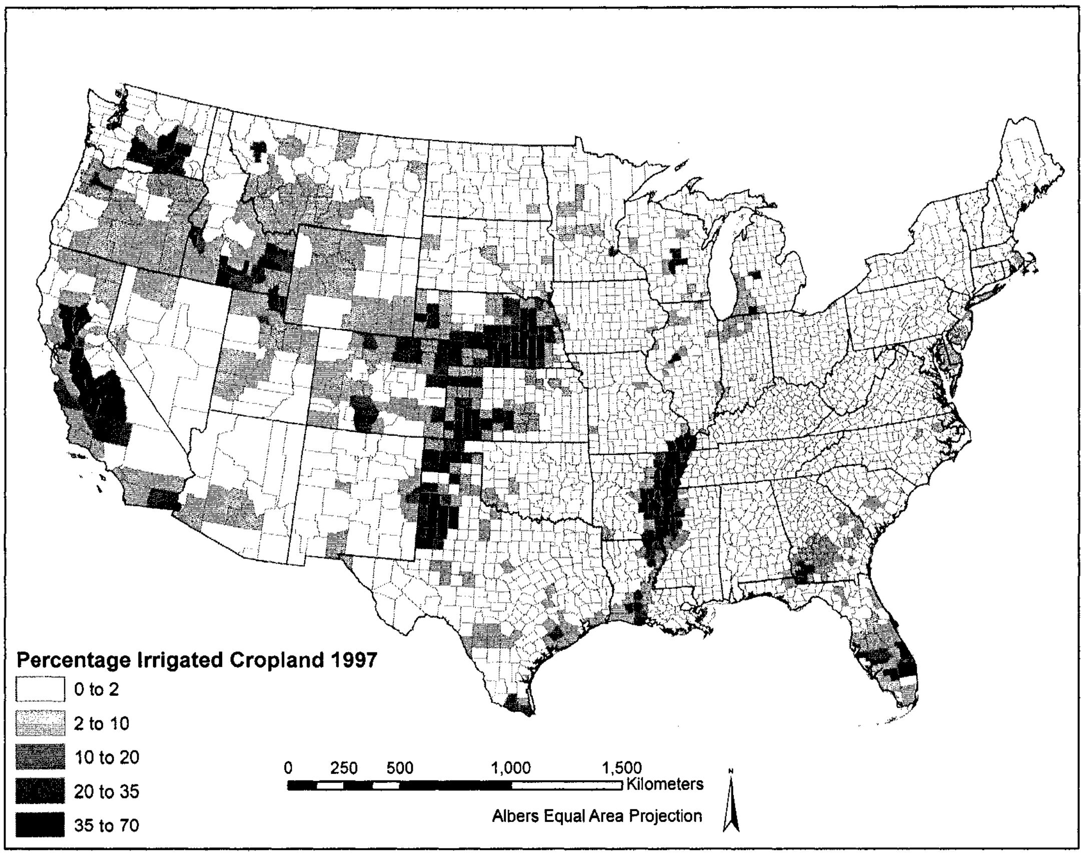

Figure 2.3. Irrigated cropland percentage in conterminous U.S. counties, 1997 (USDA 1997).

Meat consumption is a primary driving force of agricultural expansion and loss (Waggoner and Ausubel 2002). Vertical integration of agricultural industry that aligns feed production, feedlot operations, and meatpacking plants has expanded. Consumer preference for predictable quality and quantity of agricultural products helps to drive this industrialization of livestock production (Hart and Mayda 1998). Currently, animal feed production accounts for approximately one-third of U.S. cropland (Waggoner and Ausubel 2002). This industrialization has caused substantial relocation of dairy, hog, cattle, and feed-grain production to the High Plains. Some areas such as the panhandle of Oklahoma are culturally open to large feedlots and their impacts, which may be less acceptable elsewhere (Harrington and Lu 2002).

Conclusion

A definitive accounting of current cropland extent is not possible because of yearly fluctuation in production and because of inherent methodological differences in various government programs that track land use (EPA 2003). However, the temporary cropland losses that relate to fluctuations in production are primarily driven by abandonment of poor quality lands during economic decline (Hart 2001).

Future agricultural expansion, driven by global population growth, is anticipated to impact many of the world's ecosystems (Matson 1997). However, future population growth in the U.S. is expected to be relatively level, perhaps leaving the expansion or loss of American cropland area increasingly dependent on export markets.

REFERENCES

Baltensperger, B.H. 1987. Farm consolidation in the northern and central states of the Great Plains. Great Plains Quarterly, 7:256-265.

Buttrick, P.L. 1917. Forest growth on abandoned agricultural land. The Scientific Monthly, 5:80-91.

Engle, D.M. and T. G. Bidwell. 2000. Plains grasslands. In: Jemison, R. and C. Raish (eds). Livestock Management in the American Southwest: Ecology, Society, and Economics, pp. 97-152.

Environmental Protection Agency (EPA). 2003. Draft Report on the Environment Technical Document EPA600-R-03-050, U.S. EPA Office of Research and Development and the Office of Environmental Information, Washington DC 20460.

Flinn, K.M., M. Vellend, and P.L. Marks. 2005. Environmental causes and consequences of forest clearance and agricultural abandonment in central New York, USA. Journal of Biogeography, 32:439-452.

Goudie, A. 1994. The Human Impact on the Natural Environment. Third Edition. MIT Press, Cambridge, Mass., 454p.

Greene, R.P. and J. Stager. 2001. Rangeland to cropland conversions as replacement land for prime farmland lost to urban development. The Social Science Journal, 38:543-555.

Haberl, H., K-H. Erb, F. Krausmann, W. Loibl, N. Schulz, and H. Weisz. 2001. Changes in ecosystem processes induced by land use: Human appropriation of aboveground NPP and its influence on standing crop in Austria. Global Biogeochemical Cycles, 15:929-942.

Harrington, L.M.B., and M. Lu. 2002. Beef feedlots in southwestern Kansas: Local change, perceptions, and the global change context. 2002. Global Environmental Change, 12:273-282.

Hart, J.F. 1968. Loss and abandonment of cleared farm land in the eastern United States. Annals of the Association of American Geographers, 58:417-440.

Hart, J.F. and C. Mayda. 1998. The industrialization of livestock production in the United States. Southeastern Geographer, 38:58-78.

Hart, J.F. 2001. Half a century of cropland change. The Geographical Review, 91:525-543.

The H. John Heinz III Center for Science, Economics and the Environment (Heinz Center). 2002. The State of the Nation's Ecosystems: Measuring the Lands, Waters, and Living Resources of the United States. Edinburgh: Cambridge University Press, pp. 288.

Helms, D. 1990. New authorities and new roles: SCS and the 1985 Farm Bill. In: Napier, T.L. (ed.), Implementing the Conservation Title of the Food Security Act of 1985. Ankeny, Iowa: Soil and Water Conservation Society, pp. 11-25.

Helms, D. 1992. The Development of the Land Capability Classification. In: Readings in the History of the Soil Conservation Service, Washington, DC: Soil Conservation Service, pp. 60-73.

Houghton, R.A. and J.L. Hackler. 2000. Changes in terrestrial carbon storage in the United States. I. The roles of agriculture and forestry. Global Ecology & Biogeography, 9:125-144

Hudson, J.C. 2002. Across This Land: A regional geography of the United States and Canada. Baltimore: Johns Hopkins University Press, pp. 474.

Imhoff, M.L., W.T. Lawrence, D. Stutzer, and C. Elvidge. 1998. Assessing the impact of urban sprawl on soil resources in the United States using nighttime "city lights" satellite images and digital soils maps. In: Perspectives on the Land Use History of North America: A Context for Understanding our Changing Environment: USGS/BRD/BSR-1998-0003, pp13-22.

Lambin, E.F. and H. Geist, eds. 2006. Land-Use and Land-Cover Change: Local Processes and Global Impacts. The IGBP Series. Springer-Verlag, Berlin, 222p.

Leathers, N. and L.M.B. Harrington. 2000. Effectiveness of Conservation Reserve Programs and land "slippage" in southwestern Kansas. Professional Geographer, 52:83-93.

Lichtenberg, E. 1989. Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains. American Journal of Agricultural Economics, 71:187-194.

Marsh, G.P. [1864] 1965. Man and Nature; or, Physical Geography as Modified by Human Action. Belknap Press of Harvard University Press, Cambridge, Mass.

Marshner, F.J. 1959. Land Use and Its Patterns in the United States. Agriculture Handbook No. 153, U.S. Department of Agriculture. U.S. Government Printing Office, Washington D.C., 277p.

Matson, P.A., W.J. Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science, 277:504-509.

Myers, W.B. 1996. Human Impact on the Earth. Cambridge University Press, Cambridge, UK, 253p.

Ojima, D.S., K.A. Galvin, and B.L. Turner II. 1994. The global impact of land-use change. Bioscience, 44:300-304.

Olmstead, A.L. and Rhode, P.W. 2000. The diffusion of the tractor in American agriculture: 1910-60. NBER Working Paper No. W7947. http://ssrn.com/abstract=245736 .

Platt, R.H. 1991. Land Use Control: Geography, law, and public policy. Englewood Cliffs, New Jersey: Prentice Hall, 505p.

Ramankutty, N. and J.A. Foley. 1999. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography, 8:381-396.

Riebsame, W.E. 1990. The United States Great Plains. In: Clark, W. C., B. L. Turner, R. W. Kates, J. Richards, J. T. Mathews, and W. Meyer (eds). The Earth as Transformed by Human Action. Cambridge, UK: Cambridge University Press, pp. 561-575.

Roberts, M.J. and S. Bucholtz. 2005. Slippage in the Conservation Reserve Program or Spurious Correlation? A comment. American Journal of Agricultural Economics, 87:244-250.

Roet, J.B. 1985. Land quality and land alienation on the dry farming frontier, (Great Plains). Professional Geographer, 37:173-83.

Skinner, W.R. and J.A. Majorowicz. 1999. Regional climatic warming and associated twentieth century land-cover changes in north-western North America. Climate Research, 12:39-52.

Thomas, W.L., Jr., ed. 1956. Man's Role in Changing the Face of the Earth. University of Chicago Press, Chicago.

Turner, B.L., II, W.C. Clark, R.W. Kates, J.F. Richards, J.T. Mathews, and W.B. Meyer, eds. 1990. The Earth as Transformed by Human Action. Cambridge, University Press.

U.S. Department of Agriculture (USDA). 1997. Census of Agriculture, Geographic Area Series, AC97-CD-Vol 1. U.S.D.A. National Agricultural Statistics Service, Washington, D.C.

Waggoner, P.E. and J.H. Ausubel. 2002. A framework for sustainability science: a renovated IPAT identity. Proceedings of the National Academy of Sciences of the United States of America, 99:7860-7865.

Wu, J. 2000. Slippage effects of the Conservation Reserve Program. American Journal of Agricultural Economics, 82:979-92.

CHAPTER 3

AGRICULTURAL EXPANSION AND LOSS IN UNITED STATES ECOREGIONS

To be submitted to Land Use Policy

AGRICULTURAL EXPANSION AND LOSS IN UNITED STATES ECOREGIONS

Abstract

Agricultural land use expansion and loss have widespread impacts on land cover change and ecosystem condition. Regional differences in the patterns of change are related to several key processes including the intensification and industrialization of agriculture. Historical processes of agricultural expansion prior to 1950 have given way to agricultural intensification, which concentrates production onto a smaller area of higher natural resource potential. Areas with greater access to water and prime farmlands are relatively stable or have expanded. Agricultural production has declined in other areas, especially in forested ecoregions. The Great Plains remains as an exception, perhaps because of a general lack of land use competition. Instead, the public policies of the Conservation Reserve Program have driven a decline in the area of land actively used for production. The ongoing transition to fewer agricultural lands and greater regional variability in the patterns of land use intensity has substantial implications for land cover. Foremost among them is the inadequacy of our current state of knowledge concerning regional land cover change. While county-based land use census data are detailed, they

are coarse in scale and lack information on site-specific land change. Given these limitations, this analysis indicates substantial land change since 1950.

Keywords: Land use change; agriculture; ecoregion; United States; socioeconomic processes

INTRODUCTION

The processes of agricultural land expansion and loss have widespread effects on land cover and ecosystems that are an ongoing concern of land change research. Cropland expansion is a primary driving force of global change (Lambin et al. 2001; Matson et al. 1997; Houghton et al. 1999), and a principal mode of vegetation clearance (Mather 1992; Ramankutty and Foley 1999). Conversely, agricultural abandonment may have led to a forest cover transition from a mode of decreasing to increasing forest area in the United States and other developed nations (Mather 1992; Mather and Needle 1998). Abandonment of eastern U.S. cropland during the late 19th and early 20th century led to regional afforestation but also to agricultural expansion across the Midwest and Great Plains. Recent U.S. agricultural land cover has been relatively stable compared to these past trends (Ramankutty and Foley 1999; Houghton and Hackler 2000). Yet, farmlands cover nearly half of the conterminous U.S., making agricultural trends a significant determinant of land surface conditions. Contemporary shifts in farmland use and management may indicate substantial changes in regional land cover and ecosystems. The impacts may vary by region depending on the major socioeconomic and natural resource conditions. Among other factors, the patterns of change are linked to the ongoing processes of a national-scale land use transition to more intensive and industrialized agriculture.

Several recent studies have used historical census data for the analysis of environmental change and agricultural trends (Ramankutty and Foley 1999; Parton et al. 2003; Brown et al. 2005). The purpose of this analysis of agricultural census data is to examine the regional patterns and primary processes of agricultural expansion and decline that have occurred post-1950. Since 1950, a national trend towards fewer agricultural lands has been driven by technological and economic changes that cause an intensification of agricultural practices. There is regional and temporal variability in the characteristics of these changes, including the relocation of agricultural land use. Research has focused on the biological impacts of agricultural intensification (Matson et al. 1997) and carbon dynamics that are affected by agricultural abandonment (e.g. Houghton et al. 1999). There has been limited research on the regional dynamics of land use and land cover change that occur during the agricultural land use transition. Land uses, which are the proximate human activities and management of land, modify and transform land cover (Ojima et al 1994). Land cover is the natural and human-constructed physical make-up of the land surface, which is directly affected by land use change.

Geographical differences in natural resources, climate characteristics, and population generally determine a regions land use pattern and its comparative advantage for economic activities (Raup 1980). In this study, the patterns of farmland change are examined in light of current knowledge of the characteristics and causes of change synthesized from scientific literature and the cartographic analysis of agricultural land use data from the U.S. Census of Agriculture and land suitability maps from the National Resource Inventory (NRI). All data are aggregated to county boundaries and ecological regions (Omernik 1987) in order to summarize the extent, pattern, and other characteristics of agricultural land use change between 1950 and 1997 (Figure 3.1).

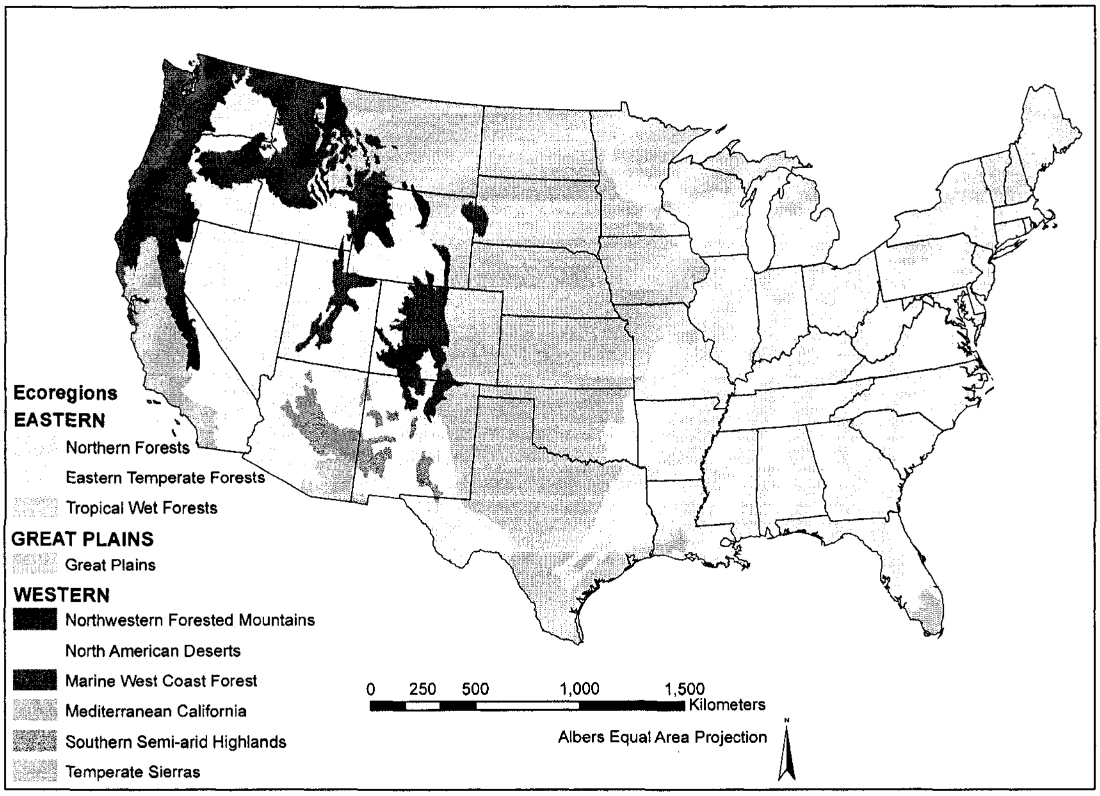

Figure 3.1. Level I ecoregions of the conterminous U.S., based on Omernik (1987).

Because land use is a major determinant of land cover and ecosystem condition, estimates of land use change from the agricultural census provide an indication of the trajectory and extent of regional impacts. The rate and direction of land use change may indicate land transitions that signal a long-term trend in regional land cover extent, which differ from short-term cyclical changes that may result in little or no net change in cover (Rudel et al. 2005). Because of the complex nature of change, which often occurs at multiple scales and in response to interacting driving forces, the study results are organized to identify major patterns and processes of farmland change that affect the U.S., its ecoregions and counties.

Historical changes in U.S. agricultural land use patterns involve large-scale migration to lands more suitable for mechanized agriculture (Mather 1992). Agricultural patterns are further influenced by economic conditions that affect the "best and highest use" of the land (Hardie et al. 2000; Gallant et al. 2004). However, even in a data rich era, there is still disagreement among various land use and land cover data on agricultural extent, intensity of use, and change (Jain and Yang 2005). Yet, the spatial characterization of historical and contemporary changes in agriculture aid in the estimation of terrestrial carbon storage dynamics (Houghton and Hackler 2000), biodiversity loss (Rudel et al. 2005), land cover impact on climate (Pielke 2005), and a host of other regional consequences of land change. Globally, agriculture has been the most extensive land use impact on regional ecosystems (Ramankutty and Foley 1999). The ecosystem impacts of agriculture are expected to expand in the future as global population increases (Tilman 1999). This analysis is intended to contribute towards the growing amount of research on land use dynamics. Similar to other recent studies (Gallant et al. 2004; Brown et al. 2005), land use patterns of change are examined using ecoregion boundaries in order to better link the summaries of change with the processes that may be most associated with broad-scale ecoregions.

Determining the regional processes of land change

Previous research has demonstrated the dynamic nature of regional land use and the agricultural sector. Regional differences in agricultural expansion and loss are driven primarily by socioeconomic driving forces and by site-specific natural resource factors. The use of available natural resources depends on numerous socioeconomic forces (Roberts and Emel 1992). Economic opportunities, population, and public policy are the primary socioeconomic drivers of land change (Rosa et al. 2004; Lambin et al. 2001).

Agricultural Expansion and Loss

Public policy has a substantial effect on agricultural change. Cropland conversion to grassland in the Great Plains since 1986 driven by the CRP, a federal policy aimed at protecting erodible lands and reducing cultivation, is one of the largest regional scale land use changes in the contemporary U.S. (Riebsame 1990).

When land use loss occurs because of policy decisions or urbanization, they may be replaced by land use expansion elsewhere. When this occurs as an unintended response to an expansion of Conservation Reserve Program (CRP) lands, referred to as land slippage, farmers may expand cropland elsewhere to replace acreage lost to the CRP (Wu

2000; Leathers and Harrington 2000). The CRP is a voluntary federal land retirement program that pays farmers to take cropland out of production. The effect of cropland expansion in response to CRP farm policy may be most prevalent in the western Great Plains, where CRP enrollment is high. Such expansions are generally considered to occur on lands that are marginal for agriculture. However, the existence of CRP land slippage is in question (Roberts and Bucholtz 2005).

There has been concern about loss of agriculture to urban growth. Raup (1980) estimated the annual urban conversion of cropland to be 600,000 acres between 1967 and 1975. Recently, there have been suggestions that cropland loss to urbanization in one region may also cause expansion in other regions due to the processes of land replacement (Greene and Stager 2001). By most indications the cumulative local impacts of cropland conversion to urban development have not been detrimental to production at the national scale (Hart 2001).

Technological advances and other factors that lead to agricultural intensification cause a decline in the area required for crop production. This may lead to an abandonment of croplands that are marginal for production or cause an expansion spurred by economic gain (Rudel et al. 2005; Angelsen and Kaimowitz 2001). The extent that excess or marginal lands are farmed may also depend in large part on population growth and the demand for U.S. exports.

Market decline and policy changes, such as in the amount of federal price supports for agricultural products, can cause temporary fluctuations in the total area of cultivation on marginal lands (Plantinga 1996; Hart 2001). During periods of favorable economic conditions, there is agricultural expansion when idled lands are returned to production. These same lands may be abandoned during difficult times.

Contemporary changes in the location of agriculture can lead to regional expansion and loss. The relocation and extent of specialized crops and feedlots has been controlled primarily by global export demand and natural resource access (Raup 1980).

Natural Resource Access

Natural resource factors that enable agricultural patterns, such as water availability and soil quality, are spatially variable. Along with other factors that determine land suitability for crops, including precipitation and topography, they enable highly productive agroecosystems or less intensive land use systems that rely on fallow periods to store soil moisture, such as in the semi-arid western Great Plains. The patterns of resource use and land conversion are made more complex by socioeconomic factors such as the fluctuation of global export markets, energy costs, technology, and government policy that affect the best and highest use of the landscape (Roberts and Emel 1992; Gallant et al. 2004).

The ability to access these resources, and the actual quality and quantity of the resource, can change over time thus affecting land use and cover. Technological advances after World War II allowed for more efficient groundwater pumping that changed the regional patterns of intensive crop production (Hudson 2002). Groundwater resource availability for crop irrigation is already declining in some areas of the western Great Plains because of considerable amounts of historical pumping of the High Plains Aquifer. This may cause a shift to less intensive uses or to outright abandonment of use in some areas (Walsh 1980).

What are the main patterns and processes of contemporary agricultural expansion and loss that impact conterminous U.S. regions, post-1950? Although the processes affecting regional agriculture and land cover can be diverse there may be geographically specific types, rates and patterns of change that can be detected using the aggregated county land use data from the agricultural census.

STUDY AREA

This study examines land use change in the conterminous U.S. using an ecoregion and county spatial framework. Ecoregions used in this study (Figure 3.1) are based on Level I ecological regions of North America (Omernik 1987). All U.S. counties were assigned to only one ecoregion depending on the majority area of the county.

MATERIALS AND METHODS

This analysis focuses on agricultural expansion and loss, primarily since 1950, using a few key indicators from the U.S. Census of Agriculture that relate to land cover changes and that may indicate the characteristics of regional land use transition. Most long-term land use data available for the nation are at the county scale (Gutmann 2000). Data aggregated to county units is limited in its utility for understanding spatial changes because of the heterogeneous nature of land use and environment (Opie 2001). When working at broad spatial scales, higher resolution data can be aggregated to the county for effective land use analysis (Gutmann 2000). In this study, data are assigned to ecological regions (Figure 3.1) based on Omernik Level I ecoregions of North America (Omernik 1987). Ecoregions provide a geographic framework for generalizing the characteristics of land use and land cover change (Loveland et al. 2002).

Agricultural land use data were used to identify patterns of regional change (Figure 3.2). Agricultural data used for this study are from the U.S. Census of Agriculture for 1920 and the census years between 1950 and 1997 (USDA 1997). The source of data for all figures and tables of agriculture are from USDA Census of Agriculture, and are not otherwise labeled with a source. The 1920 census was more generalized than categories used in the modern census, and required use of data on Improved Lands as a substitute for cropland, which could over-represent the area of cropland when compared to modern data. The definitions of land use in the census did not change significantly between 1950 and 1997. No adjustments were made for any historical modifications of the census methodology. Population data is from the U.S. Census of Population and Housing (U.S. Bureau of the Census 2001).

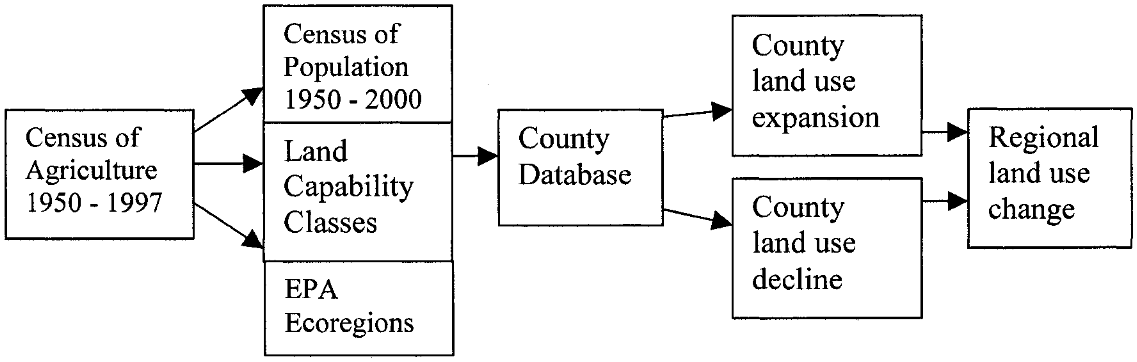

Figure 3.2. Data used to establish the patterns of land use expansion, decline, and regional change between 1950 and 1997.

Land use categories were selected for their relevance to understanding regional land use and land cover trends. Cropland, rangeland, and woodlands are three primary types of land use on farmland that also relate to land cover types. This study used the "Rangeland, Other" category as an estimate of grasslands used for livestock grazing. This category is referred to as "rangeland" in the data tables and throughout the text. "Total Cropland" is a broad census category that includes idled land, harvested area, CRP land and various other lands related to crop production. It is referred to as "cropland" throughout this paper. "Woodlands" include those farmlands used for pasture as well as woodlots used for other purposes. The "Land in Farms" category includes all lands used in the agricultural enterprise and is referred to as "farmland".

Some agricultural census data include counties in which data was withheld for privacy. This creates challenges for change analysis and can cause erroneous results for small regions. If data were withheld in one census year but are available in a preceding census year, then the preceding year was used as an estimate of the missing data. This will naturally create some error in the analysis, but is preferable to the much larger errors that could occur if a county that had 500,000 acres of cropland in 1950, had 450,000 acres in 1992, but had 0 (data withheld) in 1997. In this case, the 1992 data was used. For this reason, all census totals reported here are estimates of the county agricultural census data.

The NRI Land Capability Classification is an index of eight levels of land suitability for cultivation (Table 3.1). The Land Capability Classification was used for cartographic analyses of the spatial association with cropland patterns. The factors that determine land suitability are complex. They include temperature, precipitation, and soil conditions. Land suitability can also be affected by farm practices such as fertilizer use and no-tillage cultivation (Buringh and Dudal 1987).

Table 3.1. Cropland suitability classification, based on the US Department of Agriculture NRCS Land Capability Classification (NRCS 2000).

Land Capability Classification	Cropland Suitability	Characteristics
I, II	Prime	Slight to moderate limitations for crop production
III, IV	Marginal	Severe to very severe limitations that require special conservation practices or careful management to grow crops
V- VIII	Unsuited	Limited primarily to pasture, woodland, and wildlife cover, although some areas are also unsuited to grazing

All data were linked to a single county in the database. The county database was analyzed to identify land use expansion, decline, and total net change by ecoregion.

County data were summarized for the conterminous U.S. and for Level I ecoregions. Three categories of land suitability – prime lands, marginal lands, and unsuited lands – derived from the NRI Land Capability Classification were compared to selected census data. The area of each suitability class was calculated for each county. Assuming that cropland abandonment in rural areas is caused by low productivity inherent in the climate, soils, and topography of regions, there may be patterns of change that relate to the suitability of land for crops.

All census data were joined to spatial data of county boundaries from the U.S. Census Bureau and used for analysis in a geographic information system. Spatial associations were examined between selected categories of agricultural land use and the associated data. Land use totals and the associations with other factors are reported in tables.

RESULTS

The land use transition from agricultural expansion to intensification

The patterns of agricultural land change reveal two overall trends. Between 1920 and 1950, conterminous U.S. farmland expanded. Regional expansion occurred in the southern U.S., the Great Plains, and the West (Figure 3.3a). Farmland declined in the northeast. Between 1950 and 1997, farmland declined almost everywhere, with some scattered areas of expansion including the western Great Plains (Figure 3.3b).

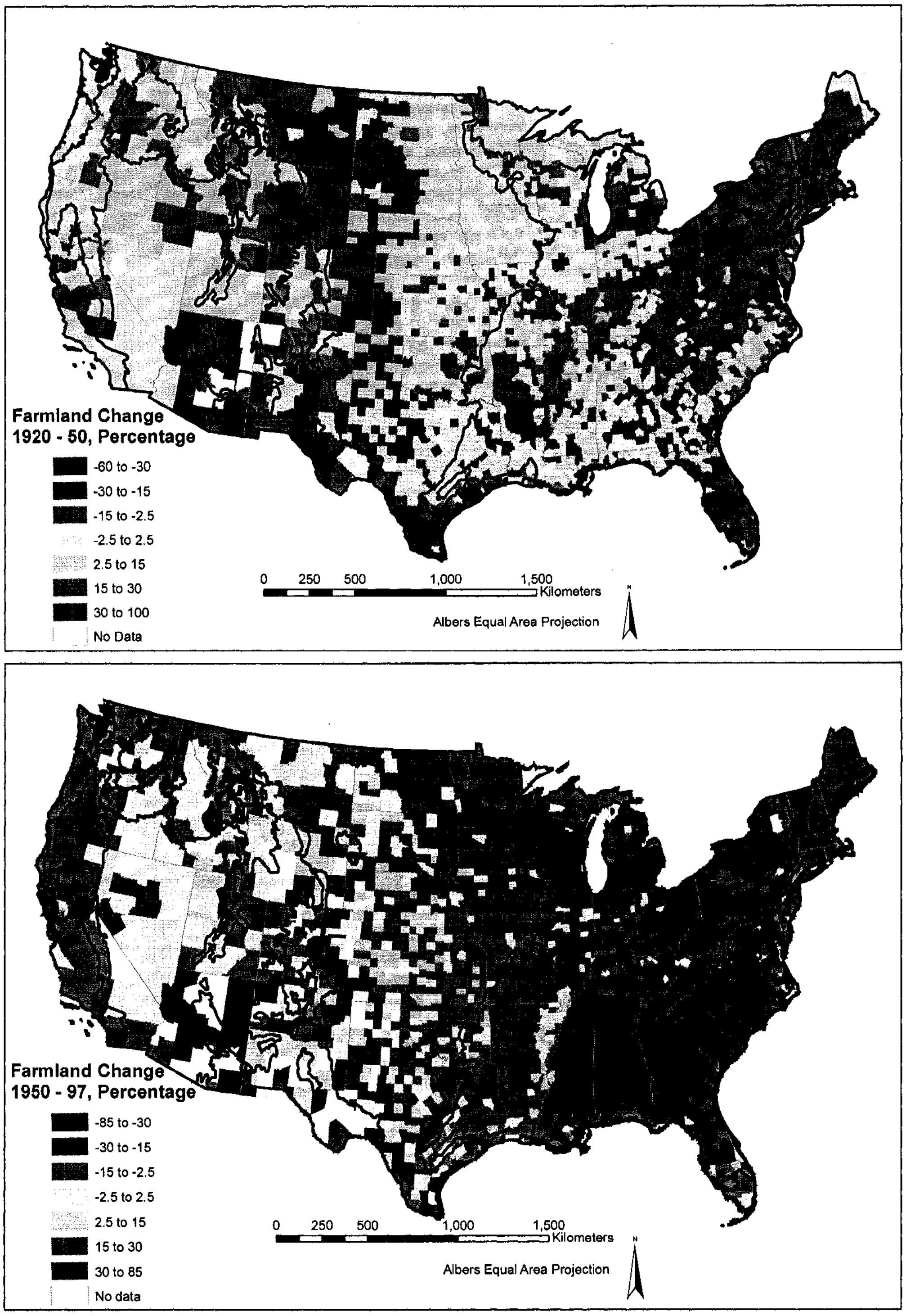

Figure 3.3. Farmland expansion and loss from 1920 to 1950 (a), and 1950 to 1997 (b).

Post-1950, substantial farmland declines occur primarily in the eastern forested ecoregions and to a lesser extent in the Great Plains and western ecoregions. The southeastern U.S. declined substantially, a reversal in the direction of change from previous trends of expansion and stability in most counties of the region. Much of the northeastern U.S. declined during both periods, from 1920 to 1950 and from 1950 to 1997, however the losses intensified in the latter period. Much of the western and southern Great Plains and the areas of more intensive agriculture in the West generally reversed direction from a mode of expansion to one of farmland loss.

In 1920, farmland covered approximately 50% of the conterminous U.S. and expanded across another 11% of land by 1950, an estimated increase of approximately 832,000 sq k (Table 3.2). The total area of farmland expanded to more than 60% throughout most of the 1950s, covering more than 4,695,000 sq k of the conterminous U.S. Since 1950, approximately 932,250 sq k of agricultural lands have left farm use, an area nearly the size of the combined states of Kansas, Nebraska, and North and South Dakota. The total area of land in farms dropped below 50% of the conterminous U.S. by the 1990s, and covered approximately 3,761,000 sq k or 49.1% of the conterminous U.S. in 1997.

Table 3.2. Farmland change between 1920 and 1997.

Farmland	**1920**	**1950**	**1997**
Percentage of conterminous U.S.	50.4%	61.3%	49.1%
Percentage Net Change		10.9%	-12.2%
Yearly Rate of Change		0.36%	-0.26%
Total sq k of Net Change		832,000	-932,250

The annual rate of expansion between 1920 and 1950 was 0.36%, although rates varied between census dates. The highest rate of change occurred between 1940 and 1950 (0.42%) when cropland expanded into the western Great Plains. The slowest rate was from 1920 to 1930 (0.16%).

Between 1950 and 1997, the annual rate of change was –0.26%. The highest rate of decline occurred between 1964 and 1974 (-0.49%), during a period of economic decline. The slowest yearly rate of change occurred from 1974 to 1978 (-0.04%). During the early- to mid-1970s the relative stability in net land cover occurred during an increase in the global and Russian demand for grain when idled lands were planted to cropland to take advantage of increased prices, perhaps also slowing the loss of farmland.

Between 1920 and 1997, at least 22% of the conterminous land cover (1.65 million sq k) was affected by change. The large area affected by expansion and loss occurred because farmland uses were transferring out of the northeastern and central parts of the East and into the southeastern, central, and western U.S. After 1950, the overall decline in agriculture was substantial.

In addition to the net land use expansion and decline for the conterminous U.S., there were directional changes at the county scale that cause various patterns and rates of change depending on the region. Overall, when the combined rates of expansion and decline are averaged for all counties from 1950 to 1974 and for 1974 to 1997, there is a 30% drop in the rate of farmland change for the latter time period. From 1950 to 1974, the average annual change ((county expansion + county decline)/total number of counties = gross change) was 14,880 sq k. From 1974 to 1997, the average annual change was 10,890 sq k, suggesting a decline in the rate of land use relocation. The rate of land use change between 1974 and 1997 is still substantial. All combined expansions and declines potentially affected 15% of the conterminous U.S. land area during the 23-year period.

Land use change, 1950 to 1997

The three major types of farmland use – cropland, rangeland, and woodland – all declined between 1950 and 1997 (Table 3.3). Cropland and rangeland loss account for approximately 21% and 9% of farmland change, respectively. Decline of woodland on farms (which includes woodland used for pasture) comprises nearly two-thirds of net agricultural change.

Table 3.3. Major agricultural land changes in the conterminous U.S.

1950 to 1997	**Total U.S. Change Percentage**	**Total Change, Sq k**	**Percentage of Total Farmland Change**	**Gross Change, Sq k**
Cropland, Total	-2.5%	-191,375	20.5%	408,700
Rangeland (Non-crop, non-forest)	-1.0%	-73,785	7.9%	578,000
Woodland, Total	-7.8%	-602,830	64.5%	615,000
Other	-0.8%	-67,000	7.2%	---

Few expansions of woodland occur nationally. The net loss of woodland (602,830 sq k) is nearly equal to the combined expansion and loss of woodland (615,000 sq k), indicating the unidirectional trajectory of this land use change. Rangeland changes are surprisingly frequent despite a relatively small amount of net change (-73,800 sq k), and result in a high amount of gross change (615,000 sq k). This may indicate actual spatial migration of rangeland use between the two dates or be more indicative of changes in land use that relate to fluctuations in livestock numbers. Cropland totals indicate a substantial amount of spatial change. Net changes of 191,375 sq k represent less than half of the gross change between 1950 and 1997 (408,700 sq k). However the patterns of expansion and abandonment of these land uses, and therefore of the potential impact on land cover and ecosystems, varies.

Cropland

Net cropland declines are extensive in the eastern ecoregions where 97% of all losses occurred. There has also been some slight net expansion in the Great Plains. Overall, the 10% net decline in cropland (191,375 sq k) affects 2.5% of the conterminous land surface. Another 1.7% of conterminous U.S. land was converted from cropland to grassland and forest cover through the CRP. As a result, the total area of net cropland conversion affected a much larger area of 4.2%. At the county scale, cropland expanded onto nearly 108,700 sq k and declined on approximately 300,000 sq k between 1950 and 1997, indicating a substantial shift in the location of cropland. Temporally, cropland declined from 1950 to 1964 (-177, 810 sq k), expanded from 1964 to 1978 (77,230 sq k), and declined between 1978 and 1997 (-90,800).

Woodland

Most woodland loss, at least 85% of the total woodland decline for the U.S., occurred between 1950 and 1974. Much of the woodland decline was in the East and the southern Great Plains. In total, farmland woodlands accounted for 11.5% of conterminous U.S. lands in 1950, but dropped below 4% by 1997. The rate of woodland transition has been steep and unidirectional. Nearly 609,000 sq k of decline was offset by only 6,000 sq k of woodland expansion. Woodlands declined in some regions because of cropland and pastureland expansion, but in most areas they left farmland use altogether. In the southern Great Plains, woodland declined by an estimated 79,740 sq k between 1950 and 1997, resulting in a rangeland increase of approximately 45,230 sq k. Rangeland and pasture grass apparently expanded in the area as woodland was cleared for livestock grazing.

Rangeland

Rangeland declined overall by approximately 74,000 sq k., affecting 1% of the U.S. Between 1950 and 1997, gross declines of more than 325,000 sq k and expansion of approximately 252,000 sq k occurred, affecting a land area nearly comparable to the gross changes in woodland. Temporally, net rangeland expanded from 1950 until the 1970s before its overall decline. Most of the net decline occurred after 1974.

Agricultural Land Use Change in Ecoregions

The agricultural census and the above farmland totals include CRP as an agricultural land use because it is still in farm ownership. However, since CRP lands are planted to grassland and forest cover, the estimated rates of change in the following section include CRP as a change in land use and land cover. This provides an indication of the extent of agricultural land use impact on land cover and ecosystem conditions.

Agricultural change that affects ecological regions is varied (Figure 3.4). Most ecoregions had absolute declines in agricultural land use between 1950 and 1997 (Table 3.4). The eastern ecoregions had high rates of decline. The Eastern Temperate Forests had the highest amount of absolute change, nearly 600,000 sq k, and the highest rate of decline (-24.8%). The Great Plains ecoregion had nearly 122,000 sq k of net agricultural change and a moderate rate of 10.3%. The western ecoregions had some of the lowest rates of change, except for the coastal ecoregions. The Mediterranean California and the Marine West Coast Forest had rates of change greater than 10%. The lowest absolute rate of change occurred in the North American Deserts (4.4%), with 71,090 sq k of change.

Woodland loss accounted for a substantial percentage of change in all of the ecoregions. There were also differences in the types of land use change. Rangeland had notable expansions in the Mediterranean California and Great Plains ecoregions. The rates of rangeland decline were highest in the eastern ecoregions. The contribution of cropland decline to the overall rates of change was lowest in the Northwestern Forested Mountains and the North American Deserts ecoregions (sometimes referred to as the Interior West).

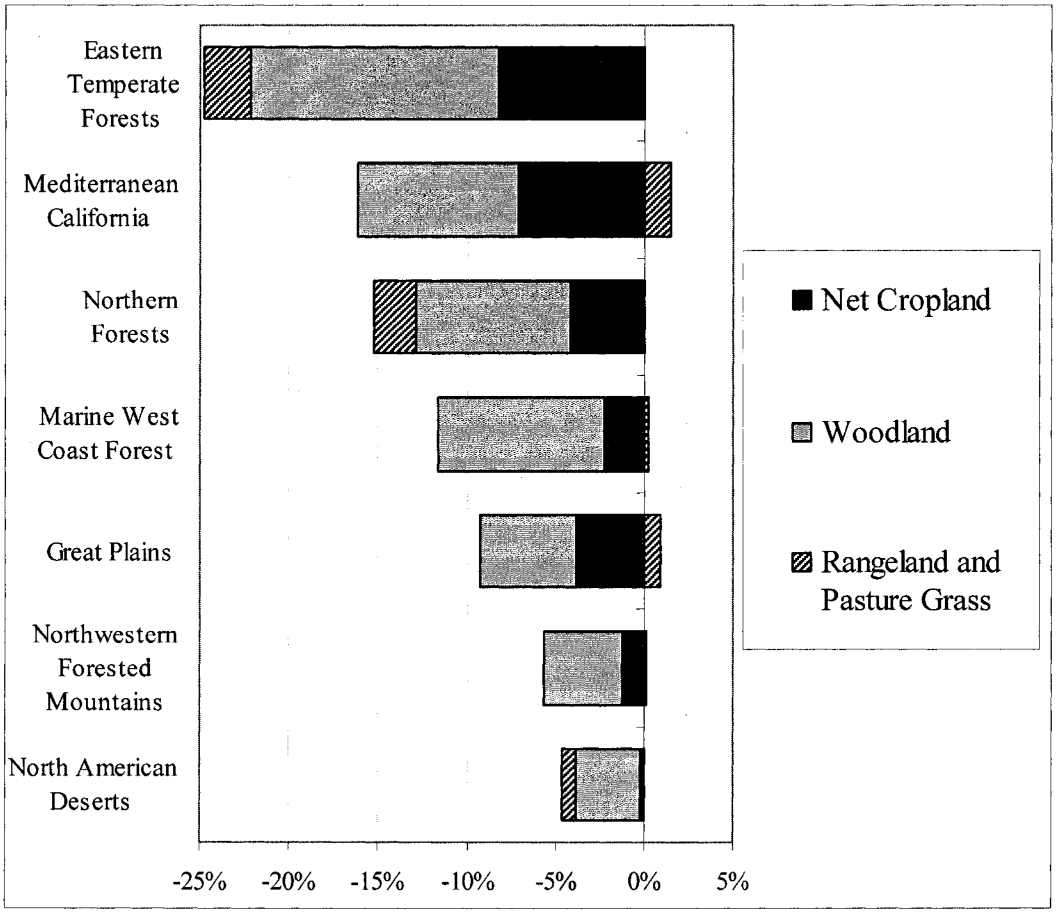

Figure 3.4. The percentage of each ecoregion affected by cropland (minus CRP), woodland and rangeland changes between 1950 and 1997. The rates of change are ranked from highest to lowest. Net Cropland includes CRP lands as a land use decline.

Ecoregions transitioned from a mode of agricultural expansion to a decline at different times. In general, the Eastern Temperate Forests, the Northern Forests and the Marine West Coast Forest had already begun to lose farmland by 1950. The other ecoregions had modest increases until the early 1960s before declining.

Most of the absolute loss of agricultural land use occurred in the major forested ecoregions (Northern Forests, Eastern Temperate Forests, Northwestern Forested Mountains, and Marine West Coast Forest), which totaled approximately 706,000 sq k. The forested ecoregions account for 48% of the total area of the conterminous U.S. and 67% of the total change. The Great Plains, which covers 30% of the U.S., accounts for 22% of total change.

Table 3.4. Absolute (sq k) and percentage net change for ecoregion land uses between 1950 and 1997. Net Cropland includes lands enrolled in the CRP. Three small ecoregions – Tropical Wet Forests (in the East), Southern Semi-Arid Highlands, and Temperate Sierras (both in the West) – are not included in this table. They are represented elsewhere in the paper, including the totals for the U.S.

Ecoregions	Area (Counties)	Net Cropland	Rangeland and Pasture Grass	Woodland	Total Change (Sq k and Percentage)	
EASTERN						
Northern Forests	383,480	-16,055	-8,865	-33,505	58,425	15.2%
Eastern Temperate Forests	2,421,900	-199,855	-64,170	-335,740	599,765	24.8%
GREAT PLAINS						
Great Plains	2,235,502	-85,972	21,321	-121,936	229,230	10.3%
WESTERN						
North American Deserts	1,498,410	-2,430	-11,910	-56,750	71,090	4.4%
Northwestern Forested Mountains	673,111	-8,439	547	-29,748	38,734	5.8%
Marine West Coast Forest	76,540	-1,745	200	-7,160	9,090	11.9%
Mediterranean California	136,390	-9,650	2,065	-12,375	24,090	17.7%

Eastern Ecoregions

The Eastern Temperate Forests, where the highest rate of agricultural loss (24.8%) occurred, had large absolute changes in all three land uses. An estimated 61.9% of U.S. net cropland loss occurred in the ecoregion. Cropland conversion to other uses affected 7.1% (-171,675 sq k) of the total ecoregion area. Additionally, 28,180 sq k of cropland, or 1.2% of the ecoregion, was converted to forest cover through the CRP.

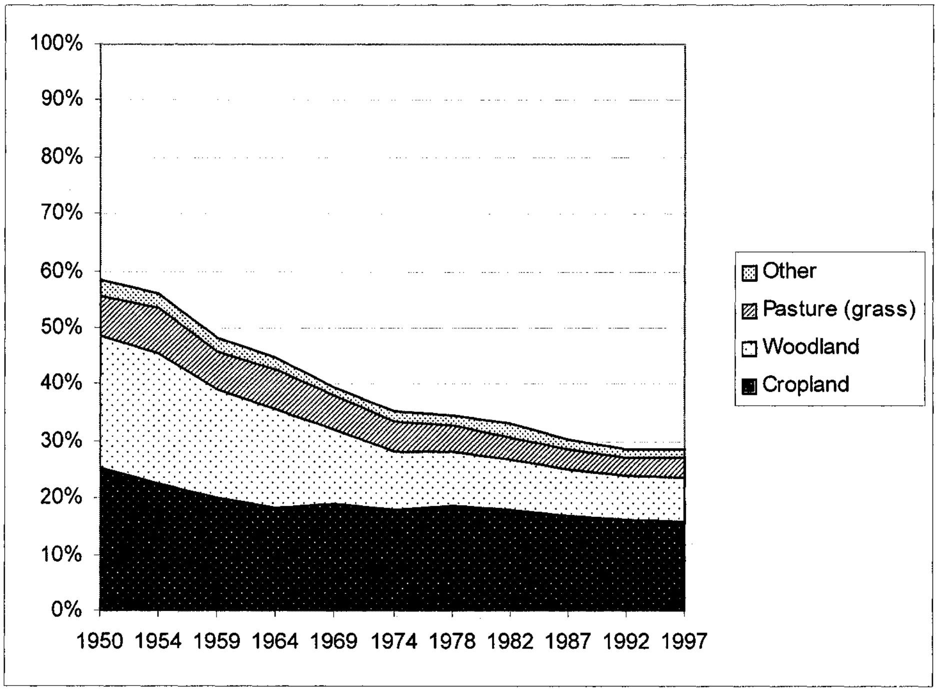

Figure 3.5. Farmland trends in the East, 1950 to 1997. Data source: Census of Agriculture

An estimated 15.2% of the Northern Forests was affected by agricultural change. Cropland declines affected 4.2% (-15,960 sq k) of the ecoregion. Land enrolled in the

CRP was minimal, at 95 sq k. The total farmland loss for all eastern ecoregions combined affected 30% of the total area (Figure 3.5)

Great Plains Ecoregion

The Great Plains, where two-thirds of the nation's grasslands are under farm ownership, has a relatively low rate of net farmland change (4.6%) except when CRP lands are included as a land change. When CRP changes are included as a decline in cropland, approximately 10.3% of the ecoregion was affected by agricultural change. The CRP has had a substantial impact on the intensity of land use and on regional grassland cover, causing a 10% decline in total cropland area that affected 91,445 sq k of the Great Plains in 1997. Cropland used for grazing, another low intensity land use, increased by more than 25,000 sq k. The Great Plains was the only ecoregion to have such an increase. Irrigation expanded by nearly 54,000 sq k, the second highest rate (2.4%).

Western Ecoregions

Cropland expansion in the North American Deserts affected 0.5% (7,525 sq k) of the ecoregion. An additional 0.7% (9,955 sq k) of the region was converted to CRP land. It is the only ecoregion with a sizable net increase in the area of harvest, estimated at 8,165 sq k. This is probably due to more than 17,000 sq k of irrigation expansion.

Rates of change in the Marine West Coast Forest (11.9%) and the Mediterranean California (17.7%) ecoregions are relatively high. The Mediterranean California has the second highest rate of cropland decline (6.6%), behind the Eastern Temperate Forests. The loss of cropland has apparently had little effect on the total area of harvest, which is stable. This is due to a high rate of irrigation expansion (4.2%) that produces a more reliable harvest; to a decline in the area of infrequently used croplands that did not negatively impact harvested acreage; and to a high rate of decline in cropland used for grazing. The CRP is minimal in both ecoregions.

The Northwestern Forested Mountains had a relatively slow rate of change (5.8%), although there was a substantial amount of cropland decline of 6,610 sq k. The CRP added an additional 1,839 sq k of change.

Other Patterns of Change

Land Suitability

Counties with 80% or more land in the prime, marginal, and unsuited category were compared for patterns of change (Table 3.5). The total area of farmland decline was relatively high for prime (16%), marginal (21%), and unsuited (19%) lands. Total cropland also declined in all three categories, by 4.5% on prime lands, by 6% on marginal lands, and by 20% on unsuited lands. A much smaller proportion of croplands are found in counties with greater than 80% unsuited lands (4.4%) than occur in marginal (37.7%) and prime (62.8%) areas.

Table 3.5. Land suitability categories and rates of agricultural land use change.

Category	1997		Net Rate of Change, 1950 - 1997		
Prime	**Percentage of Conterminous U.S.**	**Percentage of Area in Cropland**	**Farmland**	**Cropland**	**Harvested**
100%	1.5%	71.5%	-13.1%	-2.2%	4.4%
>90%	5.0%	68.2%	-14.0%	-2.5%	2.6%
>80%	8.7%	62.8%	-16.0%	-4.5%	0.3%
Marginal					
100%	0.5%	51.3%	-12.5%	-4.9%	-23.0%
>90%	1.8%	45.0%	-19.5%	-6.3%	-16.9%
>80%	5.3%	37.7%	-20.9%	-5.9%	-11.3%
Unsuited					
100%	14.7%	2.4%	-19.0%	-8.0%	-5.7%
>90%	28.6%	3.5%	-18.1%	-17.2%	-13.5%
>80%	35.4%	4.4%	-19.3%	-20.0%	-19.3%

Overall, most cropland loss in these areas occurred prior to 1964 and after 1987. One of the most interesting trends was of the area of harvest. Prime lands had at least a 0.3% increase in harvested lands, while the other categories had large declines. Marginal lands had declines of more than 11% and the area of harvest on unsuited lands declined by approximately 19%. Most of the net decline in the area of harvest occurred prior to 1964, although unsuited lands also had a 3% decline in harvest after 1987, when the CRP had taken effect. The percentage of 1997 cropland that was harvested (not shown) in the prime land counties was 87%. This was substantially higher than for marginal (66%) and unsuited (63%) lands.

The characteristics of regional cropland expansion also suggest a link to land suitability. Counties with more than half of all lands classified as prime farmland, or with at least 2% of the total county area in irrigation (which combine for less than half of all U.S. counties), account for 65% of the total cropland expansion between 1950 and 1997. An estimated 95% of the cropland increase in these counties was also harvested. However, a substantial amount of expansion also occurred on the remaining lower quality lands, totaling more than 38,000 sq k (35% of the total cropland expansion). Less than 5% of the expansion in these counties resulted in an increased harvest. Most of the expansion was in less-intensive agricultural uses.

The vast majority of harvested croplands (72%) occur on higher quality lands – those counties with 50% prime farmland or 2% irrigated area. The net decline in harvested cropland between 1950 and 1997 in these areas was only 2.5%, or 23,500 sq k. The rate of net decline of harvested area on the other, presumably lower quality, land was ten times higher at 25% (approximately 120,000 sq k). This indicates the extent to which intensive crop production is still undergoing adjustments to land suitability.

Land Retirement and cropland expansion

Unlike cropland expansion related to greater natural resource potential (prime soils and water access for irrigation) in which more than 95% of the increase in cultivated land was harvested, cropland expansion on other lands had little to do with increasing the area of harvest. As indicated above, only 5% of these croplands were harvested. Of the total cropland increase of 38,000 sq k, approximately 70% of it occurred between 1964 and 1969 along with a nearly equal increase in cropland used for grazing. An additional 30% (11,600 sq k in 358 counties) of the increase in cropland occurred after the 1982 census when it could be related to the shorter-term processes of CRP land slippage. Slippage occurs when idle or new croplands are put into production in response to a land retirement elsewhere. The total CRP in 1997 for these counties was 26,600 sq k. However, 7,500 sq k of the cropland increase (65% of the potential leakage) occurred in counties where CRP was minimal. The remaining 4,100 sq k of cropland expansion occurred in 140 counties that rely heavily on the CRP. Most of the more than 4,000 sq k of cropland expansion that could be related to processes of land slippage is in the western Great Plains where CRP and low-intensity uses are relatively common.

Intensification and Industrialization

Irrigation in the conterminous U.S. more than doubled from 1950 to 1997, expanding from approximately 103,000 sq k to more than 220,000 sq k. However, 208 counties had a decline in irrigated cropland for a combined loss of approximately 10,000 sq k. In these counties, harvested cropland also declined by approximately 12,000 sq k and the total area of cropland declined by 14,870 sq k. Most of the irrigation loss (85%) occurred in a subset of 60 counties that also had large increases in population, combining for a 24.2 million or 3.5-fold increase in population. In contrast, population totals declined or were relatively stable in most counties with large irrigation increases.

Declines in irrigation between 1974 and 1997 also have a spatial association with changes in total cropland, harvest, and farmland (Table 3.6). The association between total cropland change and irrigation change (Figure 3.6) may indicate that land abandonment and expansion has occurred in some areas where the access to surface and groundwater for irrigation has changed. Farmland change does not have a similar association with irrigation. However, the rate of farmland loss is higher in counties where irrigation has declined, and the rate of loss generally increases as irrigation decline climbs.

Table 3.6. Changes in land use intensity between 1974 and 1997, for categories of irrigation change.

	Range of Irrigation Change (Acres, x1000)								
Land Use Change	>50	25 to 50	10 to 25	10 to 1	1 to -1	-1 to -10	-10 to -25	-25 to -50	<-50
Irrigated	11.5%	3.6%	1.5%	0.5%	0.0%	-0.3%	-1.0%	-2.2%	-7.4%
Cropland	3.2%	0.8%	0.5%	-0.6%	-1.1%	0.3%	-0.8%	-1.7%	-2.5%
Harvested	4.7%	1.2%	0.6%	0.1%	0.3%	-0.2%	-1.1%	-1.6%	-3.5%
CRP	1.8%	2.1%	1.8%	1.9%	1.5%	1.5%	1.8%	1.9%	5.8%
Farmland	-2.5%	-1.9%	-2.5%	-5.2%	-4.2%	-5.8%	-7.8%	-9.7%	-9.2%

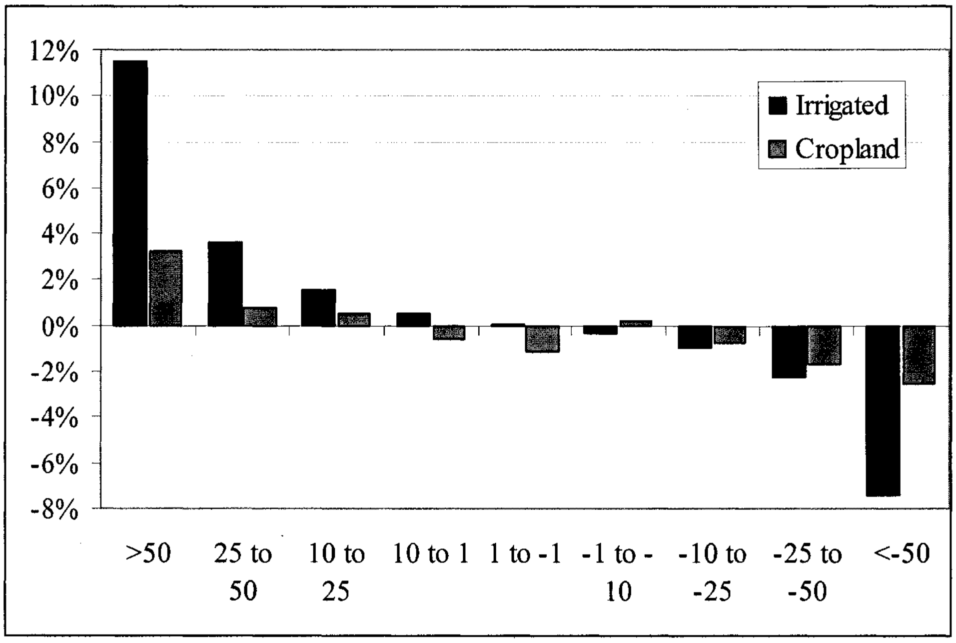

Figure 3.6. Similarities in the rate of cropland change and irrigation change. The results suggest a relationship between irrigation expansion and cropland expansion, and between irrigation loss and cropland loss. Changes in percentage cropland have a positive Pearson correlation coefficient (0.96) with the intervals of irrigation change. However, the correlation among counties is low when continuous data is used.

There is an association between livestock change and cropland. Between 1974 and 1997, combined counties with large gains in fattened cattle and hogs (>10,000 animals) had a cropland expansion of 5,800 sq k. Counties with large declines in livestock (<10,000 animals) had cropland declines of approximately 14,900 sq k. Counties with the greatest gains in livestock, of more than 100,000 animals, had an average cropland expansion of 29 sq k, although approximately one-third of those counties had cropland declines. Counties with a decline of more than 100,000 animals had an average decline in cropland of 30 sq k.

Between 1950 and 1997, changes in the percentage of croplands that are harvested (Figure 3.7) indicate that the patterns of use are regionally distinct as intensive agriculture concentrates onto lands with higher resource potential. Most areas of prime farmland and water access, identified above, are stable or have an increase in the percentage of cropland that is harvested. Regionally, the Great Plains stands out as having a substantial decline in harvested cropland relative to a small increase in the total area of cropland (Table 3.7).

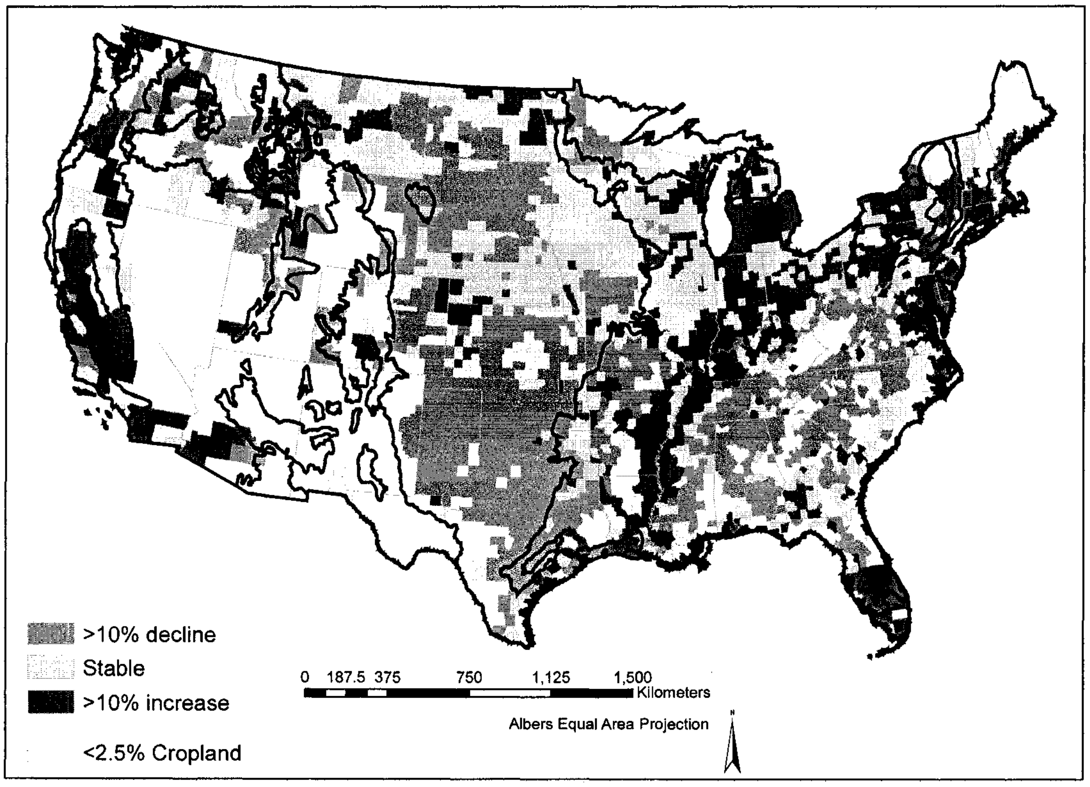

Figure 3.7. Changes in the percentage of total cropland that was harvested, 1950 to 1997.

Table 3.7. Harvested cropland as a percentage of total cropland, for regions of the U.S.

CROPLAND, 1950 – 1997	Change in Total Cropland, Sq k	Change in Harvested Cropland, Sq k	Harvested Cropland as Percentage of Total Cropland		
			1950	1997	Change
Eastern	-186,050	-84,025	69.0	75.5	6.5
Great Plains	5,470	-63,505	77.2	69.7	-7.5
Western	-10,795	4,920	60.8	67.5	6.7
Conterminous US	-191,375	-142,610	72.0	71.8	-0.2

Population

The spatial pattern of cropland change and urban extent suggests a relationship between urban growth and cropland loss in counties. Large urban areas may cause local conversion of cropland, resulting in displacement to outlying areas or in outright loss. All counties with cropland loss were ranked according to population change and divided into equal intervals of 80 counties. The correlation coefficient (Pearson) was calculated between the percentage loss of cropland that occurred from 1950 to 1997 and the percentage cropland in 1950. Correlation coefficients were also regressed against population change for each interval to illustrate the trends (Figure 3.8). The results show that cropland loss between 1950 and 1997 is increasingly correlated with the total amount of cropland in 1950 as population growth increases.

All intervals have a similar distribution of cropland percentages. However, in the more populated intervals there tends to be a higher percentage of cropland loss in the counties with higher percentages of cropland in 1950. Counties with low growth, or population loss, have a lower correlation. These results suggest that many of the counties with higher population growth are losing a greater proportion of whatever amount of cropland was present in 1950, whereas more low growth counties are losing fewer croplands.

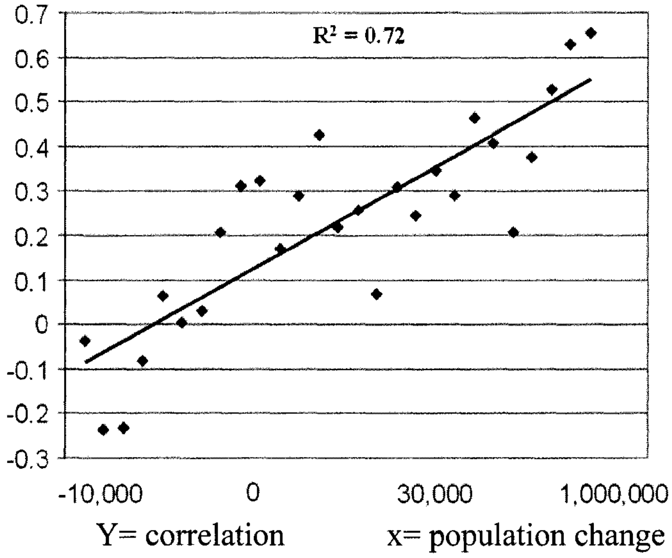

Figure 3.8. Population change and the correlation between total cropland in 1950 and cropland loss 1950 to 1997.

Nearly half of counties have trends that run counter to this association. A total of 500 counties gained in population, with an average increase of 29,270 people, while also gaining an average of 117 sq k of cropland. A total of 384 counties lost population, with an average loss of 3,250 people, but gained an average of 130 sq k of cropland. A total of 560 counties lost an average of 7,650 people and also lost 130 sq k of cropland.

DISCUSSION AND CONCLUSIONS

There is an overall trend towards fewer agricultural lands in the U.S. Understanding the regional dynamics of these changes will contribute to improved knowledge of land cover and ecosystem conditions. Large declines of agricultural land use have occurred since 1950 in many areas of the country. At the broad scale, lands that are marginal to farm production account for most of the net farmland loss. Contemporary relocation of agricultural land use at the regional scale has also occurred. The national, regional and county scale patterns of expansion and loss are likely related to several key processes, including agricultural intensification and industrialization. Several broad scale patterns and processes of change were identified and are discussed below.

The Farmland Transition

The primary modes of agricultural land change are very different before and after 1950. Between 1920 and 1950, the historical processes of farmland change were dominated by large-scale expansion in the Great Plains, western ecoregions, and the southern areas of the Eastern Temperate Forests. Agricultural abandonment occurred in the northeast. The abandonment of the northeast has been attributed to a loss of soil fertility, economic changes, and poor land suitability for cultivation (Buttrick 1917). After 1950, farmland loss was the dominant mode of change, affecting 12.2% of the conterminous U.S. Loss was most extensive in the Eastern Temperate Forests.

The eastern U.S. results from this study are generally consistent with findings from other agricultural change research (Ramankutty and Foley 1999; Houghton and Hackler 2000). However, this study included CRP land and the decline of farm woodland ownership as a land use change that may have significant implications for land cover and ecosystems.

This study took a broad view of regional changes in cropland, woodland, and rangeland that affects conterminous U.S. ecoregions.

Ecoregion Change, 1950 to 1997

One of the primary patterns of the contemporary land transition has been the loss of woodland and other lands that are marginal to agricultural production. The farm landscape has become more streamlined as agricultural land use intensifies, shedding the woodlots of traditional agriculture. The decline in woodlands, which do not make a substantial contribution to farm profits (Hart 1968), account for 65% of the net farmland loss. Woodlands were a large part of the farmland change in all ecoregions.

Contemporary cropland change has also been substantial. Between 1950 and 1997 in the U.S., the total area of cropland expansion and loss in counties, including the conversion to CRP land cover, was nearly as extensive as woodland change. Unlike the nearly unidirectional trajectory of woodland loss, cropland changes were more complex. Most of the net cropland decline occurred in the eastern ecoregions. The Great Plains also had significant changes, although they were primarily induced by CRP farm policy. The cropland expansions in the Plains were small compared to the conversion to CRP grasslands. Rangeland expanded in the Great Plains. Some of the increase was likely due to woodland clearance.

Despite the cropland declines in the western U.S. ecoregions, there was an increase in the total area of harvest. Low-intensity cropland use declined and irrigation expanded. The Mediterranean California ecoregion lost 25% of its cropland between 1950 and 1997, but the area of harvest increased slightly. The North American Deserts had an increase in cropland, although cropland to CRP conversion (which generally occurred prior to the CRP) was greater than the crop expansion.

Processes of Agricultural Expansion and Loss, post-1950

Intensification and Industrialization

The intensification and industrialization of agriculture had numerous impacts on ecoregions. Three main patterns of change were identified here. First, it caused an overall national decline in the amount of land needed for agricultural production. Agricultural intensification is one of the primary processes of the farmland transition to less agricultural land. Historically, cropland expansion was necessary to meet demands for increased production. Essentially, advances in technology, such as center-pivot irrigation and genetics, allow higher production on fewer acres of land. Second, intensification caused a relocation of land use. This has a major influence on the regional patterns of expansion, loss and stability. Most counties with prime soils and water access did not have extensive cropland declines. They also generally maintained or expanded in the area of crop production. Third, it creates distinct regions of concentrated intensive land use activities. This includes the relative increase in the percentage of cropland that was harvested, presumably caused by a decline in unproductive croplands in some areas. These patterns differ depending on the ecoregion, the inherent natural resources, and the primary socioeconomic forces.

Access to Natural Resources

The regional differences in agricultural expansion and loss are driven primarily by socioeconomic forces and by site-specific natural resource factors. Counties with access to surface water and groundwater for irrigation that had cropland expansions were likely related to an increased access to water. Other areas with natural resource access had overall declines in agricultural lands that had little if any effect on the total area of production. Where water access has declined, the total area of agricultural land use also declined. This occurred primarily in the counties overlying the High Plains (Ogallala) Aquifer where groundwater levels have declined by more than 30 m in some areas (Dennehy et al. 2002). Energy availability and economic conditions directly affect the use of water in the High Plains Aquifer area (Lacewell et al. 1978; Taylor and Lacewell 1988). Other socioeconomic forces that affect the use of water include institutional, political, and cultural factors (Roberts and Emel 1992), as well as climate variability.

Land Retirement and Abandonment

A decline in unproductive agricultural land occurs from either an outright abandonment, such as occurred historically in the eastern ecoregions, or a conversion to another land use or cover. Assuming that substantial amounts of the contemporary agricultural declines are the latter, for a conversion to occur there needs to be the possibility of greater economic gain from another land use. Without a direct measure of land rent across the U.S. for multiple time periods, changes in contemporary farmland such as explored here can indicate some broad generalities. The impact of CRP farm policy has been substantial, especially in the Great Plains. The extent of cropland conversions to CRP grassland in the Great Plains may indicate a low land rent and a lack of land use competition. More than 90,000 sq k of cropland were converted to grassland through the CRP, offsetting a relatively small cropland expansion (5,470 sq k). The CRP effectively caused a decline in cropland. The extent of the conversion to grassland might not have been as great without the economic incentive, simply because of a general lack of other conversion pressure. This runs counter to other arguments, which suggest that abandonment would have occurred on many of the current CRP lands if the program had not taken effect (Wu 2000). Some unknown amount of outright abandonment likely would have occurred without the program. However, the vast majority of CRP lands may have remained in low-intensity agricultural uses.

Land Replacement

The estimate for an upper limit of CRP land slippage, of approximately 4,000 sq k, was calculated with the assumption that cropland increase in areas of prime resources were not related to land slippage. Slippage could be occurring in those regions, but at much lower rates. Despite the relatively simple method for calculating slippage, the result generally supports the idea that slippage could be occurring. However, it is likely confined to a few areas including the semi-arid western Great Plains. Perhaps more important to the impacts on regional land use and land cover pattern, are the substantial increases in the extent of permanent vegetation cover in agricultural regions with large amounts of marginal cropland that are now enrolled in the CRP.

A "replacement lands" argument, of a displacement of agriculture to the western ecoregions because of urbanization in the eastern ecoregions (Greene and Stager 2001) might be supplemented to say that expansion occurs where water and other resources are accessible and the level of production will be high. Land can be opened up to agricultural change because of policy changes, technological advances, or market forces. This research did not explicitly assess whether conversion to urban directly impacts the amount of cropland in regions elsewhere. However, the overall trends suggest that cropland declines in the U.S. are "replaced" based on land quality and economic and technological driving forces.

Population and Urbanization

Population change has an association with cropland change. Whether there is any causal relationship, in which rural population growth causes cropland loss, is not clear. Counties in the eastern ecoregions with large population growth and cropland declines are likely experiencing competition with urban uses (Greene and Stager 2001). In rural areas, timber products may make conversion from agriculture to silviculture more profitable (Pinder et al. 1999), which could be occurring simultaneous to population change.

Implications for Land Cover

Land use changes do not necessarily result in a conversion to another land cover. However, based on the substantial amount of change in most regions, the agricultural land use transition associated with intensification and industrialization of production has widespread implications for land cover and ecosystems. The historical impact of farmland migration out of the eastern ecoregions was a reforestation of lands previously cleared for crops and pasture (Compton and Boone 2000). Many of the forested areas that were cleared for farmland in the Northeast were abandoned as land use moved to regions more suitable for agriculture prior to 1950 (Buttrick 1917). Contemporary trends may differ from the historical trends.

Cropland changes have the most obvious impact on land cover. Abandonment of cropland causes a conversion to other types of land cover. The nearly 200,000 sq k of cropland loss and conversion to CRP in the Eastern Temperate Forests has had a tremendous impact on land cover. The spatially-explicit outcome of those changes is not well understood, although conversion to urban and silviculture has likely occurred. In the Great Plains, cropland changes are dominated by the conversion to CRP grassland. There has likely been conversion of cropland to urban development. Cropland was also abandoned in rural counties where there has been a decline in intensive land use.

Grassland and shrubland conversion to cropland likely occurred in association with livestock increases and irrigation expansion, particularly in the western Great Plains.

Decline of woodland on farms may also have important implications. Woodland loss accounted for a large proportion of change in every ecoregion. The fate of woodland changes may differ depending on the ecoregion. In the eastern ecoregions in particular, they could have been cleared for development, remained as forest cover, or been converted to silviculture and a cycle of harvest and re-planting. The large amount of woodlands that left farmland management could have various implications for carbon sequestration, depending on if they were converted to other land uses or left as forest cover.

Rangeland changes may also contribute to land cover change. The rangeland gains in the Great Plains are apparently from woodland clearance in the southern part of the ecoregion. Rangeland gains in the North American Deserts may be the result of rangeland to cropland conversions (Greene and Stager 2001). Rangeland loss, especially in the Eastern Temperate Forests, likely had a similar outcome as the cropland conversion to other land uses and cover types.

Large areas of the Great Plains and Midwest were plowed up and remain in agriculture. In many regards, eastern afforestation occurred at the expense of grassland and forest loss farther west. Despite the regional increases in forest cover that occurred from agricultural abandonment, there are other regions with land cover impacts that may offset some of the gains in the East. As well, forested regions that are highly suitable for agriculture in the Midwest have lower rates of cropland loss, which limits the potential for future afforestation. When combined with questions of the land cover outcome of agricultural land use changes, including the fate of woodland loss, the large amount of land that has transitioned out of agriculture points to the need for comprehensive studies of regional land cover dynamics.

Conclusions

Loss of agricultural land since the 1950s is an important defining factor of contemporary landscapes. This study expands the understanding of the patterns of land use and land cover change, in part by bringing agricultural intensification and farmland loss further into the discussion of processes of land change. Cropland dynamics have been most studied. These results also indicate the patterns of loss and expansion of woodlands and rangeland, which have implications for land cover and ecosystem change. The study took a multi-scale view of agricultural change by examining patterns of land use across the conterminous U.S. The ecoregion framework was useful for gaining a broad-scale understanding of how land use change may affect land cover types. It became obvious during the study that finer-scale ecoregions (Level III ecoregions, Omernik 1987) generally conform to the patterns of agricultural change and would be helpful for generalizing much of the variability of change.

The declines in farmland are caused by several land use processes, often interrelated. The spatial processes of change and their impacts on regions likely differ more than could be examined in this broad overview. This study provided a synthesis of regional agricultural trends from 1950 to 1997 that helps to understand the occurrence of land use pattern and process. Farmland changes affect all ecoregions and have had various impacts on land cover and ecosystems that will continue into the future. Future directional changes could occur in some regions driven by increased demand for biofuels, or caused by advances in genetic engineering or changes in climate that allow the pattern so cropland to change or expand. By examining the historical changes in agriculture, this study may contribute to developing models and scenarios of regional vulnerability to future change.

The use of the agricultural census for understanding land cover and ecosystem change has considerable pitfalls. Most county boundaries do not follow ecosystem boundaries, ensuring errors of omission and commission when tabulating ecoregion land use totals. County data are reported as net totals, which mean that spatial changes in land use location can occur within counties but are not reported. Further analyses of agricultural patterns of change would benefit from the integration of land cover data. Agricultural census data can only provide limited insight into regional changes to land cover. Land cover analyses that use site-specific data, and that examine the outcome of land use change, are vital for understanding the impact on ecoregions.

REFERENCES

Anderson, J.F., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964, 28p.

Angelsen, A. and D. Kaimowitz. 2001. Agricultural Technologies and Tropical Deforestation. CABI Publishing, London.

Brown, D.G., K.M. Johnson, T.R. Loveland, and D.M. Theobald. 2005. Rural land-use trends in the conterminous United States, 1950-2000. Ecological Applications, 15:1851-1863.

Buttrick, P.L. 1917. Forest growth on abandoned agricultural land. The Scientific Monthly, 5:80-91.

Buringh, P. and R. Dudal. 1987. Agricultural land use in space and time. In: Wolman, W.G. and F.G.A. Fournier. Land Transformation in Agriculture. John Wiley & Sons, Chichester, p. 9- 43.

Compton, J.E. and R.D. Boone. 2000. Long-term impacts of agriculture on soil carbon and nitrogen in New England forests. Ecology, 81:2314-2330.

Dennehy, K.F., D.W. Litke, and P.B. McMahon. 2002. The High Plains Aquifer, USA: groundwater development and sustainability. In: Hiscock, K.M., M.O. Rivett, and R.M. Davison (eds.), Sustainable Groundwater Development. Geological Society, London, Special Publications, 193:99-119.

Gallant, A.L., T.R. Loveland, T.L. Sohl, and D.E. Napton. 2004. Using an ecoregion framework to analyze land-cover and land-use dynamics. Environmental Management, 34:S88-S110.

Greene, R.P. and J. Stager. 2001. Rangeland to cropland conversions as replacement land for prime farmland lost to urban development. The Social Science Journal, 38:543-555.

Gutmann, M.P. 2000. Scaling and demographic issues in global change research: the Great Plains, 1880-1990. Climatic Change, 44: 377-391.

Hardie, I., P. Parks, P. Gottleib, D. Wear. 2000. Responsiveness of rural and urban land uses to land rent determinants in the U.S. south. Land Economics, 76:659-674.

Hart, J.F. 1968. Loss and abandonment of cleared farm land in the eastern United States. Annals of the Association of American Geographers, 58:417-440.

Hart, J.F. 2001. Half a century of cropland change. The Geographical Review, 91:525-543.

Houghton, R.A., J.L. Hackler, and K.T. Lawrence. 1999. The U.S. carbon budget: contributions from land-use change. Science, 285:574-582.

Houghton, R.A. and J.L. Hackler. 2000. Changes in terrestrial carbon storage in the United States. I. The roles of agriculture and forestry. Global Ecology & Biogeography, 9:125-144

Hudson, J.C. 2002. Across This Land: A regional geography of the United States and Canada. Baltimore: Johns Hopkins University Press, pp. 474.

Jain, A.K. and X. Yang. 2005. Modeling the effects of two different land cover change data sets on the carbon stocks of plants and soils in concert with CO2 and climate change. Global Biogeochemical Cycles, 19:1-20.

Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X.B. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skanes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, and J.C. Xu. 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change- Human and Policy Dimensions, 11:261-69.

Leathers, N., and L.M.B. Harrington. 2000. Effectiveness of Conservation Reserve Programs and land "slippage" in southwestern Kansas. Professional Geographer, 52:83-93.

Loveland, T.R., T.L. Sohl, S.V. Stehman, A.L. Gallant, K.L. Sayler, and D.E. Napton. 2002. A strategy for estimating the rates of recent United States land-cover changes. Photogrammetric Engineering and Remote Sensing, 68:1091-1099.

Mather, A.S. 1992. The forest transition. Area, 24:367-379.

Mather, A.S. and C. Needle. 1998. The forest transition: a theoretical basis. Area, 30:117-124.

Matson, P.A., W.J Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science, 277:504-9.

Natural Resources Conservation Service (NRCS). 2000. National Resources Inventory, 1997. U.S. Department of Commerce, Washington, DC.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers, 77:118-125.

Ojima, D.S., K.A. Galvin, and B.L. Turner II. 1994. The global impact of land-use change. Bioscience, 44:300-304.

Opie, J. 2001. John Wesley Powell was right; resizing the Ogallala High Plains. In: C. Miller (ed.), Fluid Arguments: Five Centuries of Western Water Conflict. U. of Arizona Press, Tucson, pp.223-247.

Parton, W.J., M.P. Gutmann, and W.R. Travis. 2003. Sustainability and historical land-use change in the Great Plains: The case of eastern Colorado. Great Plains Research, 13:97-125.

Pielke Sr., R.A. 2005. Land use and climate change. Science, 310:1625-1626.

Pinder III, J.E., T.E. Rea, and D.E. Funsch. 1999. Deforestation, reforestation and forest fragmentation on the Upper Coastal Plain of South Carolina and Georgia. American Midland Naturalist 142:213-228.

Plantinga, A.J. 1996. The effect of agricultural policies on land use and environmental quality. American Journal of Agricultural Economics, 78:1082-91.

Ramankutty, N. and J.A. Foley. 1999. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography, 8:381-396.

Raup, P.M. 1980. Competition for land and the future of American agriculture. In: Batie, S.S. and R.G. Healy (eds), The Future of American Agriculture as a Strategic Resource. Washington D.C., Conservation Foundation, pp.41-77.

Riebsame, W.E. 1990. The United States Great Plains. In: Clark, W. C., B. L. Turner, R. W. Kates, J. Richards, J. T. Mathews, and W. Meyer (eds). The Earth as Transformed by Human Action. Cambridge, UK: Cambridge University Press, pp. 561-575.

Roberts, M.J. and S. Bucholtz. 2005. Slippage in the Conservation Reserve Program or Spurious Correlation? A comment. American Journal of Agricultural Economics, 87:244-250.

Roberts, R.S. and J. Emel. 1992. Uneven development and the tragedy of the commons: competing images for nature-society analysis. Economic Geography, 68:249-271.

Rosa, E.A., R.York, and T. Dietz. 2004. Tracking the Anthropogenic Drivers of Ecological Impacts. Ambio, 33:509-512.

Rudel T. K., O.T. Coomes, E. Moran, F. Achard, A. Angelsen, J. Xu, E. Lambin. 2005. Forest transitions: towards a global understanding of land use change. Global Environmental Change, 15:23-31.

Taylor, J.G. and R.D. Lacewell. 1988. Economic experience and perceptions of US High Plains farmers 1979-1984. Journal of Environmental Management, 26:261-275.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America, 96:5995-6000.

U.S. Bureau of the Census. 2001. 2000 Census of Population and Housing: Summary File 1 United States. U.S. Bureau of the Census, Washington, D.C.

Walsh, J. 1980. What to do when the well runs dry. Science, 210:754-756.

Wu, J. 2000. Slippage effects of the Conservation Reserve Program. American Journal of Agricultural Economics, 82:979-92.

CHAPTER FOUR

TRENDS AND PROCESSES OF LAND COVER CHANGE IN THE AGRICULTURAL HIGH PLAINS, 1973 – 2000

To be submitted to Great Plains Research

TRENDS AND PROCESSES OF LAND COVER CHANGE IN THE AGRICULTURAL HIGH PLAINS, 1973 – 2000

Abstract

Recently, agricultural land cover has declined in the Western High Plains ecoregion after a period of cropland expansion that occurred prior to 1986. The type and rate of contemporary land cover change in the Western High Plains ecoregion varied depending on a few key processes of agricultural land use change. Between 1973 and 1986, cropland expanded when trade opportunities increased. This caused an increase in the total area of agricultural land cover that affected 1.9% of the ecoregion. Between 1986 and 1992, grassland became the dominant land cover when agricultural land declined by 7.3%. A large extent of former cropland was converted from agriculture to grassland at a relatively rapid pace, caused in part by the land use response to incentives of the Conservation Reserve Program (CRP). Between 1992 and 2000, the net loss of agricultural land cover was low at 0.3%. However, spatial dynamics in the location of grassland and cropland caused a high rate of overall change that affected 4.7% of the ecoregion.

Key words: land cover change; agriculture; Great Plains; ecoregion; remote sensing

INTRODUCTION

Understanding regional land use and land cover dynamics, including the rates, causes and consequences of change, is a major theme of environmental change research (Lambin and Geist 2006). Globally, agricultural land use has had the most extensive impact on land cover (Ramankutty and Foley 1999), although the extent and processes of change may vary markedly depending on the region. In the Western High Plains, a semi-arid grassland and shrubland ecoregion in the western Great Plains (Figure 4.1), agricultural land use is the major human influence on regional land cover patterns. Although at least half of the ecoregion is in grassland according to the National Land Cover Data (Vogelmann et al. 2001), grassland cover change in the Western High Plains has been significant beginning with population increase and cropland expansion in the late 19th century. Because of the dynamics of agricultural expansion and decline, increasing urbanization, energy development, and other proximate human actions, the rates and processes of land use change that affect the regional land cover may evolve over time.

In the conterminous U.S., the total area of farmland has declined since the 1950s as agricultural intensification, globalization, and other processes impact land use dynamics. Because agricultural land use change and the associated conversion of land cover likely differ significantly by region, it is important to monitor and assess those changes at various scales and locations to understand the processes of land change. The purpose of this paper is to examine the land use and land cover dynamics of change between 1973 and 2000 in the Western High Plains ecoregion in order to develop a better understanding of the trends and processes affecting the region.

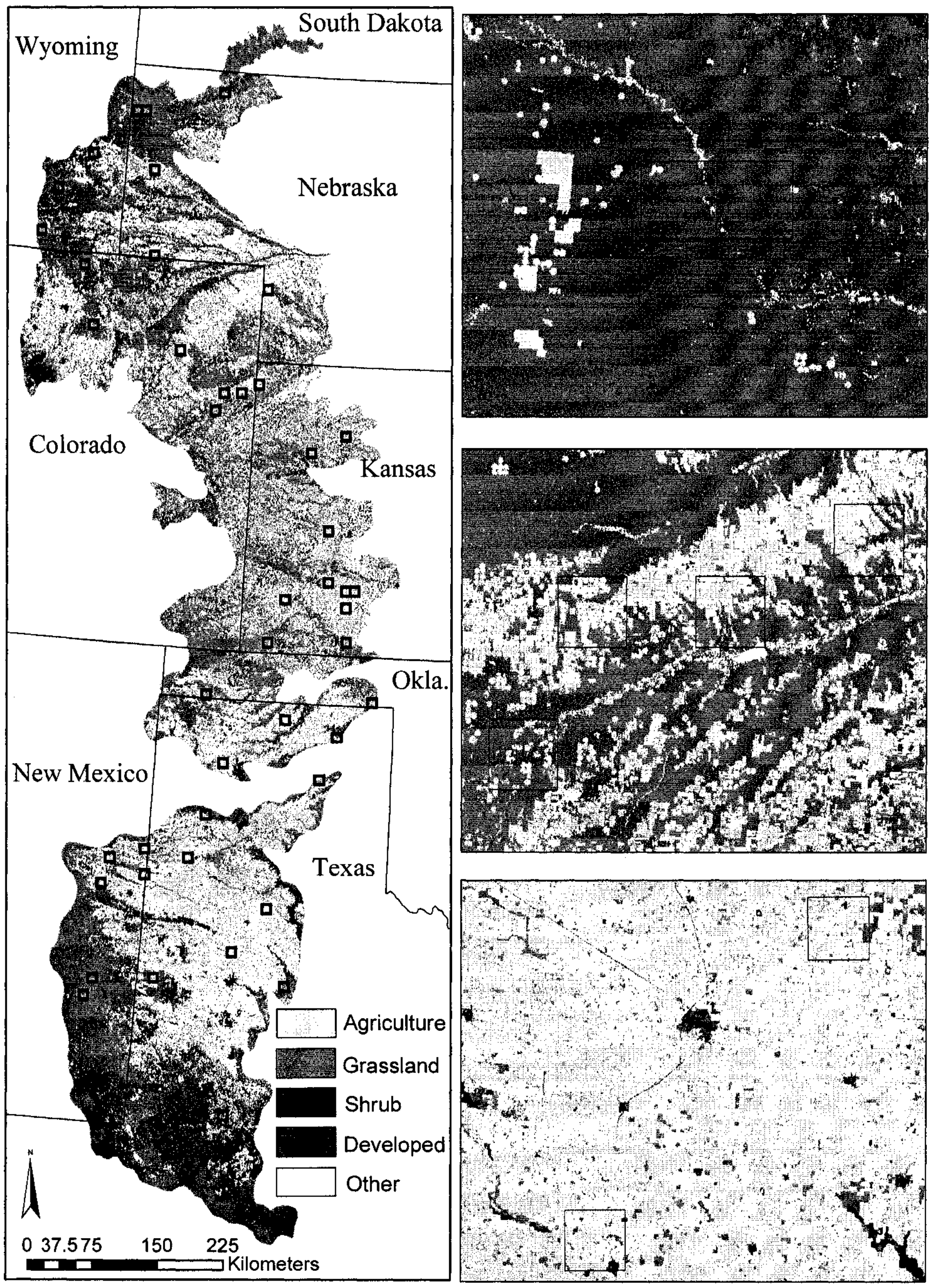

Figure 4.1. The Western High Plains ecoregion study area and the location of the forty-five land cover samples. Three examples of landscape pattern are shown, which range from primarily grassland (top) to extensive areas of agriculture in the bottom example (1992 National Land Cover Data, Vogelmann et al. 2001).

The spatial and temporal changes in land cover have not been systematically monitored at the regional and national scales. Specific sectors of land use, primarily agriculture (USDA 2000) and forestry (FIA 2000), are regularly assessed. Spatially explicit representations of land use, helpful for ecosystem assessments, are not readily available. Instead, most national land use data is collected for and aggregated to coarse-scale political boundaries such as counties. Land use trends and land resource assessments are also reported through the National Resources Inventory program (NRI 2000) for non-federal lands, which account for approximately 78% of the conterminous U.S. Land cover at the national scale has been mapped several times over the past three decades using remotely sensed data, but using different methodologies that make change detection problematic (Gallant et al. 2004). A few recent efforts have developed coarse-scale maps of land use percentages based on census data and land cover pattern for single time periods (Ramankutty and Foley 1999; Hurtt 2001). Despite the advances in remote sensing technology and geospatial analysis, there are major obstacles to monitoring land use and land cover change across large regions for multiple time periods (Sohl et al 2004). However, it is evident from ongoing assessments that land use change can be remarkably dynamic over time (NRI 2000).

Agriculture is one of the major sectors of land use that has transformed many regions of the globe. Anticipated global population growth, and the cropland expansion that would result, could cause extensive future loss of natural land cover and ecosystem services in some nations (Tilman 1999). In contrast, the total area of United States agricultural land use, similar to other developed countries, has been declining since the 1950s when farmland covered more than 60% of the conterminous land area (Figure 4.2). The total area of farmland dropped below 50% by the 1990s, while intensive and industrialized agriculture increased. In the eastern U.S., historical cropland and pasture loss led to a transition from a mode of forest decline to wide-scale afforestation (Mather and Needle 1998). The extent of contemporary land cover change in the Great Plains may be less dramatic than in the forested East, however, the region is undergoing significant transformation linked to agricultural intensification, Conservation Reserve Program (CRP) policy (Riebsame 1990), population change (Parton et al. 2003), and other socioeconomic and environmental factors. The agriculturally-driven changes in the Western High Plains study area occur not only within the context of the Great Plains and the nation, but also increasingly within the context of global competition and trade. For example, some developing countries can produce and export crops for significantly less cost that U.S. producers (Mattison and Norris 2005), which may indirectly cause a decline in the extent of U.S. cropland (Shnepf et al. 2006).

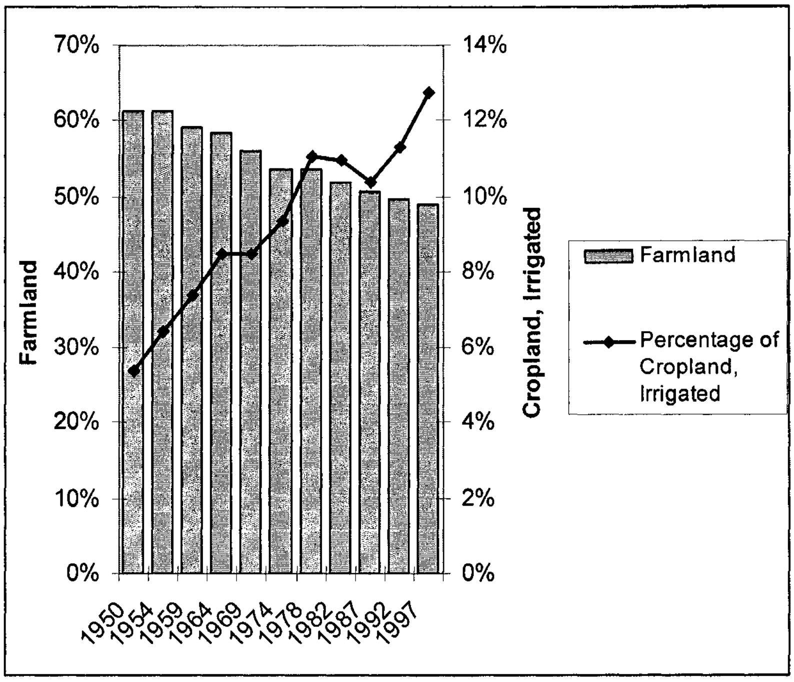

Figure 4.2. Since the 1950s, U.S. farmland has declined overall (USDA 1997), although because of differing environmental, natural resource, and socioeconomic factors the rates and processes of change may vary by region. Irrigation has expanded, which may affect the dynamics of agricultural land change in areas with large amounts of accessible water. Other areas that are marginal for agriculture because of poor soil conditions, lack of rainfall, or a loss of water access may have declines in the area of cropland.

In this study, the dynamics of regional land cover change are analyzed using a sampling approach that allows detailed estimates of change across large regions. The characteristics and trends of land cover change are examined using remotely sensed data and randomly selected 10 x 10 km spatial samples of Landsat satellite data stratified by ecological region (Loveland et al. 2002). Land use data on agriculture – the major sector of land use in the region – and population are analyzed using the U.S. Census of Agriculture (USDA 1997) and the U.S. Decennial Census of Population and Housing (U.S. Bureau of the Census 2001). The goals are to assess the regional trends of land cover change in the Western High Plains; to gain insight into the dynamics between land cover conversion and the primary land uses; and to understand the major socioeconomic processes that influence the ecoregion.

The Western High Plains ecoregion, one of 84 conterminous U.S. ecoregions (Omernik 1987), is a major agricultural area in the semi-arid western Great Plains. Approximately 25% of the ecoregion is planted and harvested each year primarily in wheat, corn, sorghum and cotton crops (USDA 1997). Much of the semi-arid region receives less than 20 inches of rain and is subjected to periodic drought cycles. The Dust Bowl of the 1930s, when tremendous dust clouds caused social and environmental problems, is perhaps an extreme example of a land use impact that will likely not be repeated at that scale (Hargreaves 1976). Despite extensive dryland farming and intensive irrigated agriculture that impact the western prairie regions, much of the nation's remaining grassland cover occurs along the western plains from western Montana and eastern North Dakota to Texas.

American agriculture has undergone a transformation of scale and technology, which affects agricultural regions including the semi-arid Great Plains, causing variable patterns of agricultural intensification and decline. Underlying the contemporary agricultural transformation in the Western High Plains ecoregion are the large groundwater resources of the High Plains (Ogallala) Aquifer. Approximately 96% of groundwater withdrawals from the 450,660 km^2 aquifer are used to irrigate crops (Dennehy et al. 2002). Intensive irrigation of corn, cotton and other crops has created profitable agricultural conditions. Industrial meat and dairy production has also moved into the region to take advantage of the dry climate, local feed grains, and water resources (Hart and Mayda 1998; Harrington and Lu 2002). Decades of groundwater pumping, coupled with the slow recharge rates of most of the aquifer, has likely left the region vulnerable to social and environmental change. Streams in the region are also vulnerable to drought and overuse. In the southern half of the ecoregion, average stream flows can be as low as 90% of historical averages (Wahl and Tortorelli 1997). Where water is not accessible, there are large areas of dryland wheat and rangeland grazing that has persisted for decades.

The Western High Plains ecoregion has undergone several land use transitions over the past 100 years from extensive areas of grassland and rangeland use, to the expansion of a dryland-cropping regime, to the more recent and locally-intensive irrigated crops. Currently 90% of the region is under farmland ownership and half of all agricultural land is identified as cropland by the agricultural census (USDA 1997). Cropland irrigation enabled by the High Plains Aquifer accounts for nearly 30% of all U.S. agricultural water use (Dennehy et al. 2002). The expansion of large cattle feedlot operations in the region is part of the reason for an increase in intensive agriculture in the High Plains (Harrington and Lu 2002). However, several irrigated areas of feed-grain and cotton production that overlay the immense High Plains Aquifer have experienced changes in water access caused by groundwater depletion and economic fluctuations that may affect land use and cover (Walsh 1980). Our understanding of the range of land use and socioeconomic processes affecting regional land cover has been limited, in part because of the lack of integrated environmental and socioeconomic analyses, and partly because there has not been a focus on systematically understanding regional dynamics and processes of land change. Despite the increased availability of earth observation data, analyses of regional processes that integrate socioeconomic factors with patterns of landscape change are few (Burgi et al. 2004; Skole 2005). This research adds to our understanding of land change by focusing on regional processes of agricultural change that operate in ecoregions and identifies the dynamics of pronounced changes in regional land cover.

STUDY AREA

Substantial areas of the grassland and shrubland of the Western High Plains have been cleared for crops and modified by livestock grazing. The major patterns of grassland and agriculture (Figure 4.1) indicate the land cover variability that relates to the prevailing agricultural system, historical land use, and biophysical factors. Early commercial agriculture expanded from predominantly large cattle ranches to greater amounts of dryland crops including cotton and wheat (Hudson 2002). Sugar beets and other specialty crops were important in some locations. Today, the region is characterized by a mix of traditional rangeland and cropland uses along with industrialized livestock production and irrigation. Wheat, feed corn, soybeans, grain sorghum, alfalfa, and cotton cover substantial areas of the shortgrass steppe once dominated by blue grama and buffalo grass.

Population is increasing in urban areas of the Great Plains and is evident in places such as the Denver-Front Range urban corridor, which is a densely populated area of the Western High Plains that parallels the Rocky Mountains. Population in the area has increased by about 400% since 1950 (U.S. Bureau of the Census 2001). Urban populations have increased steadily in the Western High Plains, while rural population totals have remained relatively stable since 1970.

Rangeland grazing and dryland crops are the most extensive uses in the ecoregion. Drought is a regional concern and can negatively impact crop production. However streamside irrigation and groundwater pumping, primarily from the underlying Ogallala formation of the High Plains Aquifer complex, have enabled intensive agriculture and the development of an agricultural-industrial complex based on irrigated feed grains and large feedlot operations. Confined animal feeding operations (CAFOs) have become increasingly concentrated in southwestern Kansas and nearby areas of Oklahoma and Texas (Harrington and Lu 2002). Several meatpacking operations moved from the Corn Belt region and central Texas to the Western High Plains beginning about 1960, and are in close proximity to CAFOs.

The High Plains Aquifer is the largest groundwater complex in the United States (Dennehy et al 2002). Substantial pumping of the aquifer since the 1940s has resulted in water-level declines of up to 45m in some areas (McGuire et al. 2003), which can have serious consequences in areas already naturally low in volume. Recharge is generally minimal in relation to pumping rates. Near the western edge of the ecoregion, the potential annual recharge is less than 6 mm (Dugan and Zelt 2000. As a result, some areas, especially in the southern part of the ecoregion, have experienced water resource depletion that makes even short-term use of the groundwater unsustainable. Other areas have large underground supplies, despite declines in aquifer thickness, but farmers no longer have easy access to once shallow aquifer depths. This potentially increases the cost of extraction and use. Pumping costs increase as water-levels decline (Terrell et al. 2002). However, conservation measures and improved irrigation technology may be slowing the rate of aquifer decline (McGuire et al. 2003). Oil and natural gas extraction is locally and regionally important, including the large Hugoton Oil Fields in southwestern Kansas that provide fuel for nearby groundwater pumps.

Developed lands cover about 1% of the 287,000 sq k of the ecoregion, and include much of the Denver-Front Range urban corridor. Population increases from 1950 to 2000 caused a 35% decline of farmland near the expanding urban interface (Parton et al. 2003).

Farm policy, through the CRP, has had a large effect on regional land use beginning in 1986. Former croplands converted to grassland through the CRP cover nearly 9% of the Western High Plains ecoregion (USDA 1997).

METHODS

Remotely sensed data from the Enhanced Thematic Mapper Plus (ETM+), the Thematic Mapper (TM), and the Multi-spectral Satellite (MSS) sensors on board the series of Landsat earth observation satellites are the primary source of data for the change analysis. A statistical sampling design is used, stratified by U.S. Environmental Protection Agency (EPA) Level III ecological regions (Omernik 1987), to estimate land cover changes between five dates, nominally 1973, 1980, 1986, 1992 and 2000. The ecoregion framework is used to facilitate an understanding of the geographic phenomena associated with land use and environment (Omernik 1987; Loveland et al. 2002; Stehman et al. 2003). County agricultural data from the U.S. Census of Agriculture (USDA 1997) and the U.S. Census of Population and Housing (U.S. Bureau of the Census 2001) are integrated into the analysis to provide an understanding of the land use characteristics of expansion and abandonment during the three decades of the study period. Agricultural census data offer detailed summaries of land use at five-year intervals (and historically at 10, 4 and 5-years), aggregated for each county from the individual responses of farmers.

Land Use and Land Cover Data

Recent strategies for including census data in land use change analysis have used three general approaches: data summary, spatial correlation, and data merging. Data summaries of population and agricultural data were used recently to examine processes of cropland loss to urban growth (Parton et al. 2003). Spatial correlation between population census data on housing density and satellite-derived land cover data were used to examine demographic trends (Radeloff et al. 2000). Merging of census with land cover data have been used to develop maps of land use (Ramankutty and Foley 1999; Hurtt et al. 2001; Kerr and Cihlar 2003).

In this study, land cover change estimates are compared to previous case studies and regional summaries of agricultural census data in order to identify land use processes that may affect the rate and trajectory of land cover change. Summaries of agricultural census data were chosen that relate across historical census years, and that relate to land cover analysis. The census definition of major farmland categories has remained relatively consistent over the study period. The census category of 'Land in Farms' (referred to as farmland) includes all agricultural land that was part of the farm operation, including grazing acreage. The census designation of 'Total Cropland' (referred to as cropland) includes all cultivated, harvested, idle, and failed croplands. Rangeland, excluding woodlands used for grazing, is also taken from agricultural census data. The census data were adjusted to account for several counties that had data withheld for privacy reasons. Adjustments were calculated for approximately 1% of the total data population by selecting the closest previous year of available data.

Census categories and land cover data are not directly comparable. For instance, farmland totals in the agricultural census include cropland and grassland (rangeland and pasture), which makes comparisons with the land cover categories problematic. Because of the differences in definition between the county-based agricultural census categories and the map-derived land cover estimates, a direct measure of consistency between the two sources was not sought. A total of 89 counties were summarized in the agricultural census data from 1974 to 1997. Counties on the study area boundary with at least 50% of the county area within the study region were included in the analysis.

Knowledge of the long-term consequences of land use change depends, in part, on appropriate site-specific mapping that takes ecosystem patterns into account rather than political boundaries (Opie 2001). Satellite remote sensing data are highly suited for conducting systematic regional studies of land cover that allow comparison to other ecosystem patterns. Historical Landsat satellite data and ancillary data including aerial photography and topographic maps were used to classify the land cover at a 60m minimum mapping unit. All land cover was mapped using a raster format and 60m pixels. A land cover classification scheme modified from the well-known Anderson classification system for remote sensing data was used (Anderson et al. 1979). Land cover data were compiled as part of a US Geological Survey study (titled Land Cover Trends) and were verified with an intensive review process using multiple image analysts (Loveland et al. 2002; Stehman et al. 2003; Sohl et al. 2004). Maps were compared with other regional statistics of land use and land cover, using the 1992 National Land Cover Data (Vogelmann et al. 2001) as the main reference source because of its similarity in land cover classes.

To select sample locations for the study, the region was subdivided into a 10 x 10 km grid. Forty-five sample locations were randomly selected for the ecoregion using a statistical sampling approach. The goal of sample selection is to provide an adequate level of precision (+/-1%, 85% confidence interval) in estimating the rates of land cover change (Stehman et al. 2003). Sampling estimates are subject to uncertainty, however approaches that use a complete census of land cover also face problems of inadequate precision (Stehman et al 2003). The extent of land cover change was calculated based on the total study area, which includes the entire 10 x 10 km grid. Land conversion types were determined from transition matrices for each sample and time period. Land cover conversions were then compared to land use data at the ecoregion scale to interpret the impact of the major processes of change.

Fieldwork was conducted in July 2002 to document and georeference current land use and land cover locations in 80% of the sample blocks. This information aided in the mapping of land cover, but also in gaining a first-hand perspective on the socioeconomic and biophysical characteristics of the ecoregion.

RESULTS

Land Cover Change, 1973 to 2000

Land cover change varies considerably among the four time periods (Table 4.1). The rate of all land cover conversions combined (gross change) affected an estimated 1.86%, 0.78%, 7.69%, and 4.79% of the ecoregion for the respective time period (1973-1980, 1980-1986, 1986-1992 and 1992-2000). The lowest and highest amounts of absolute change occur in adjacent time periods. The low occurred between 1980 and 1986, when an estimated 2,243 sq k of the ecoregion underwent land cover conversion. The highest absolute amount of change occurred between 1986 and 1992, when nearly 22,200 sq k changed. Confidence intervals that are greater than the target of +/-1% of overall change occur in the time periods with higher amounts of change, between 1986 and 1992 (6.0% to 9.4%) and between 1992 and 2000 (3.7% to 5.9%). Larger confidence intervals generally indicate that there is greater variability of rates of change among the 45 sample units, which also suggests that the ecoregion estimates for those time intervals could be improved by increasing the number of samples. The annual rate of change was most rapid during the 1986 to 1992 period (1.3%) when the CRP was initiated, and slowest between 1980 and 1986 (0.1%) during an economic slowdown in agriculture.

Table 4.1. Rates of land cover change for the ecoregion. Estimated gross changes range from a low of 0.8% (1980 to 1986) to a high of 7.7% (1986 to 1992). Confidence intervals give an indication of variability of rates among the forty-five samples. Annual rates of change are also given.

Estimated Rates of Change	1973 to 1980	1980 to 1986	1986 to 1992	1992 to 2000
Gross Change (Sq k)	5,366	2,243	22,198	13,825
Rate of Change - for each time period	1.86%	0.78%	7.69%	4.79%
-- 85% Confidence Interval	+/-0.60	+/-0.32	+/-1.70	+/-1.09
Annual Rate	0.27%	0.13%	1.28%	0.60%

When the cumulative spatial changes for all time periods are combined as the total footprint of change (Table 4.2), an estimated 11.5% (33,131 sq k) of the ecoregion was affected by at least one land cover conversion during the study period. Several locations changed multiple times. The multiple changes per land unit are mostly caused by cyclic changes between grassland and cropland. For example, a farmer who converted grassland to cropland in the 1970s who also enrolled the same cropland in the CRP at a later date would cause two changes, from grassland-to-agriculture between 1973 and 1980 and from agriculture-to-grassland between 1986 and 2000. This type of scenario was relatively common. The total area undergoing two changes was estimated at 2.1%. Three land cover changes on the same unit of land were rare (0.1%). A single land cover change was most common (9.2%). An estimated 88.5% of the Western High Plains did not undergo any land cover change between 1973 and 2000.

Table 4.2. Number of changes in land cover. In total, an estimated 11.5% of the region was affected by land cover change during at least one of the four time periods.

Number of Changes	Sq k	Percentage
Persistent (No Change)	255,620	88.5
One Change	26,696	9.2
Two Changes	6,059	2.1
Three Changes	377	0.1
Four Changes	0	0.0
Total Footprint of Change	33,131	11.5

Grassland and agriculture combined comprise an estimated 97.6% of regional land cover. Smaller total areas of forest, developed land, and wetlands account for most of the remaining cover. Agriculture was the dominant land cover in 1973, at 53.6% compared to 44.1% for grassland (Table 4.3). By the year 2000, grassland became the dominant cover at 49.8%. Agricultural land cover declined to 47.8% or slightly more than 143,800 sq k. The agricultural census totals for rangeland indicate that more than 116,000 sq. k, or about 42% of the ecoregion, is used for livestock grazing (USDA 1997).

Table 4.3. Land cover estimates for the Western High Plains ecoregion. The grassland/shrub class is referred to as grassland throughout the text

Land Cover Class	ESTIMATES OF TOTAL LAND COVER (Sq k and Percentage)				
	1973	1980	1986	1992	2000
Agriculture	154,880	159,055	160,075	138,985	138,070
	53.6	55.1	55.4	48.1	47.8
Grassland/Shrub	127,410	123,125	122,065	143,110	143,843
	44.1	42.6	42.3	49.6	49.8
Forest	2,436	2,436	2,436	2,436	2,436
	0.8	0.8	0.8	0.8	0.8
Developed	1,273	1,398	1,427	1,457	1,639
	0.4	0.5	0.5	0.5	0.6
Wetland	1,126	1,105	1,104	1,106	1,070
	0.4	0.4	0.4	0.4	0.4
Natural Bare	769	755	756	754	754
	0.3	0.3	0.3	0.3	0.3
Water	630	631	631	634	644
	0.2	0.2	0.2	0.2	0.2
Mining	224	246	257	266	292
	0.1	0.1	0.1	0.1	0.1
Mechanically Disturbed	6	1	2	0	4
	0.0	0.0	0.0	0.0	0.0

A comparison with the 1992 NLCD is shown in Table 4.4. There is a close correlation (Pearson product moment correlation coefficient of 99.97), between the 1986 land cover estimates and the NLCD, before large areas of cropland were converted to CRP grassland. Land cover estimates from 1992, the closest year to the NLCD, have a lower correlation (98.79). Both correlations are high because both the NLCD and the sample-based estimates from this study capture the large differences in extent between the two dominant land covers and the other minor land cover classes, which each comprise less than 1% of the ecoregion. The NLCD mapped 6.7% more agricultural land than the 1992 estimates from this study. The difference between estimates of the 1986 agricultural land cover and the NLCD is much closer at 0.9%. This suggests a possible methodological difference in the way that CRP lands were mapped between the NLCD and this study. It is notable that the 1992 agricultural census totals for pastureland (42%) and all other agricultural land uses (46%) are within 8% and 2% of the 1992 sample-based estimates of grassland and agriculture, respectively. Since the agricultural census totals for rangeland exclude grasslands that are not used for grazing, it is expected that the census total would be less than the land cover estimate. The differences between the sample estimates and the NLCD may also be due to mapping errors, which are inherent in any regional land cover map. The NLCD was used as an example here because it is perhaps the most accurate regional map of land cover that is available at a similar spatial resolution to this study, and is widely used. It also matches one of the sample dates (1992).

Two examples of the differences between the sample data and the regional NLCD data are shown in Figure (4.3). The comparisons indicate that the sample data reduces the errors of commission and omission for both agriculture and grassland cover. Other mapping errors for the less frequent land cover types may also be reduced. The primary reasons for the differences between the sample data and the NLCD are related to the different objectives and methods of the studies. Whereas the NLCD provides a land cover map of the entire country, the sample data is focused on change analysis and on the detailed patterns across a much smaller area.

Table 4.4. Comparison between the percentage of land cover for the sample estimates used in this study and the 1992 National Land Cover Data (Vogelmann 2001).

Land Cover Class	Sample Estimates 1986	Sample Estimates 1992	1992 NLCD
Grassland	55.40	49.60	56.27
Agriculture	42.30	48.10	41.37
Developed	0.49	0.50	0.99
Natural Bare	0.26	0.26	0.48
Forest	0.84	0.84	0.34
Water	0.22	0.22	0.32
Wetland	0.38	0.38	0.20
Mining	0.09	0.09	0.02

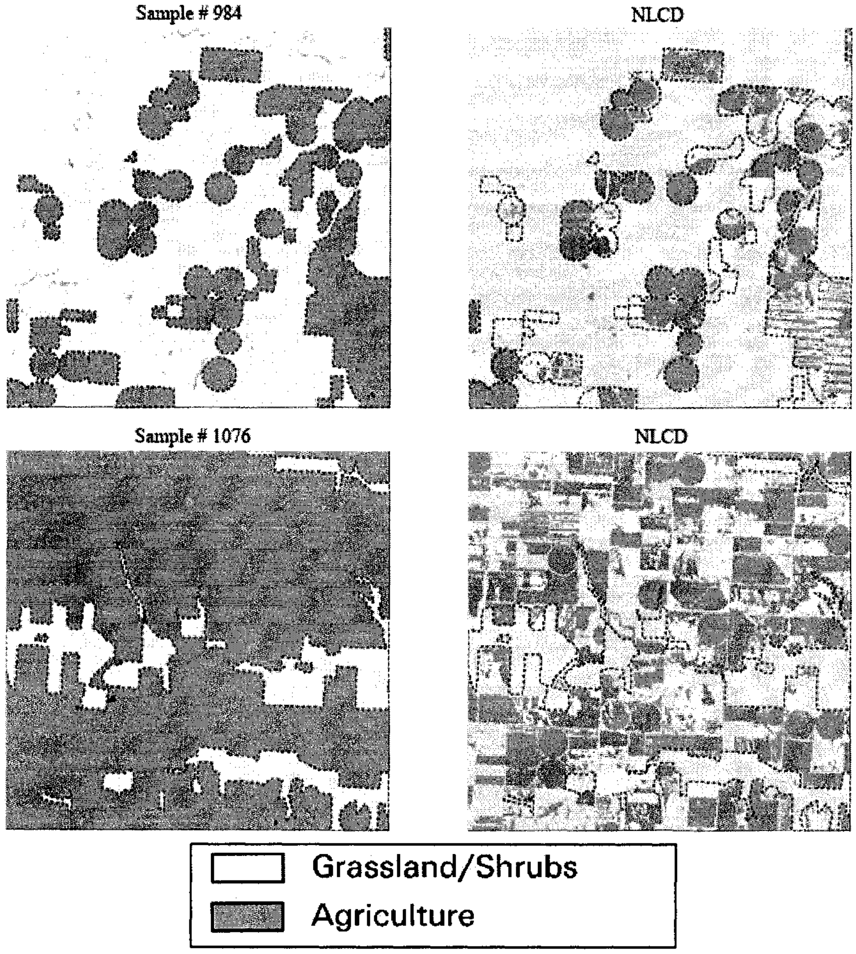

Figure 4.3. Comparison of the same two locations between the 1992 sample data from this study and the wall-to-wall 1992 National Land Cover Data (Vogelmann et al. 2001). The top example is primarily a grassland setting. The bottom example is primarily agriculture. The outlines of land cover pattern from the sample data are overlaid onto the NLCD for comparison.

Land Cover Trends

Two main trends related to grassland and agriculture were identified from the land cover sample analysis; (1) a net expansion of agricultural land cover between 1973 and 1986 when it increased from 53.6% to 55.4%, and (2) a net loss of agricultural land cover between 1986 and 2000 when it declined from 55.4% to 47.8% (Figure 4.4). Overall, from 1973 to 2000 there was a net agricultural decline in the ecoregion of 5.8% mirrored by a similar amount of net grassland increase (5.7%). Grassland change is due almost entirely to conversion to agriculture (Table 4.5). Other types of land cover change were minimal, but included the conversion of grassland and agriculture to developed land, which affected an estimated 0.13% of the ecoregion over the study period. The land cover trends in the ecoregion are dominated by the changes among grassland and agriculture. However the extent, direction, and characteristics of change vary among the four time periods indicating substantial differences in the pattern and processes of change.

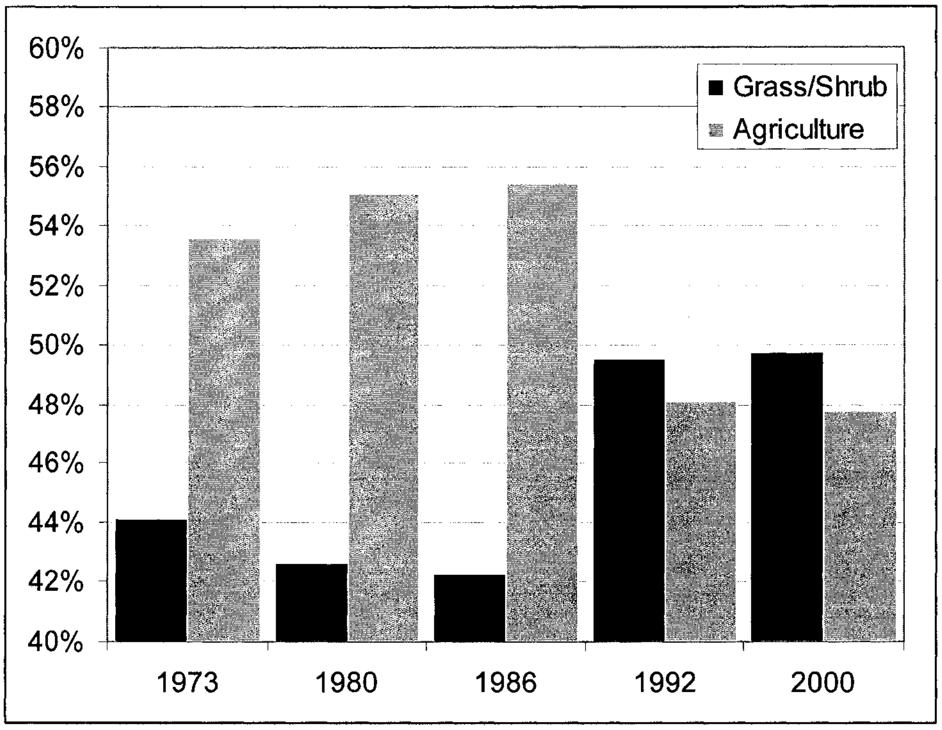

Figure 4.4. The major land cover trends in the ecoregion, 1973 to 2000. The percentage of grassland and agricultural land cover is shown.

Prior to 1986, agricultural expansion was primarily unidirectional (Figure 4.5), causing 1.9% of the ecoregion to be converted to agriculture primarily from grassland. Loss of agricultural land cover was relatively minor. The highest gross rates of change occur after 1986, when the CRP was implemented. The two time periods after 1986 have very different net rates of change. Between 1986 and 1992, changes in agricultural land cover were highest (7.7%). Spatial changes among grassland and agriculture were at their slowest during this period, causing a nearly unidirectional trajectory of change. Cyclic changes among grassland and agriculture, which result in little net change, were of limited consequence until the 1992 to 2000 period. Agriculture declined by a net rate of 0.3% between 1992 and 2000, yet the rate of gross change was 4.7%. The small net loss masks an overall high rate of gross change. Most of the land conversion during this time interval likely occurred as a change in the location of CRP grassland and cropland. However, an estimated 1,300 sq k of the conversion from grassland to agriculture occurred when established grasslands (non-CRP) were cleared for cultivation. Between 1973 and 2000, there is nearly a 45% difference between gross and net change, primarily because of the spatial changes among CRP land and cropland that occurred after 1992.

Table 4.5. The temporal characteristics of the primary land conversions.

Land Cover Conversion	**ESTIMATES OF CHANGE (Sq k)**				
	1973 to 1980	**1980 to 1986**	**1986 to 1992**	**1992 to 2000**	**1973 to 2000**
Agriculture to Grassland	453	580	21,606	7,208	22,742
Grassland to Agriculture	4,718	1,613	539	6,318	6,084
Agriculture to Developed	103	14	14	41	172
Grassland to Developed	22	15	16	141	194
All Others	70	21	23	117	222
Agricultural Expansion - Total	**4,735**	**1,615**	**540**	**6,345**	**6,135**
Agricultural Loss - Total	**555**	**595**	**21,620**	**7,260**	**22,945**
Net Change in Agriculture	**4,180**	**1,020**	**-21,080**	**-915**	**-16,810**
- Rate	1.5%	0.4%	-7.3%	-0.3%	-5.8%
Gross Change in Agriculture	**5,290**	**2,210**	**22,160**	**13,605**	**29,080**
- Rate	1.8%	0.8%	7.7%	4.7%	10.1%

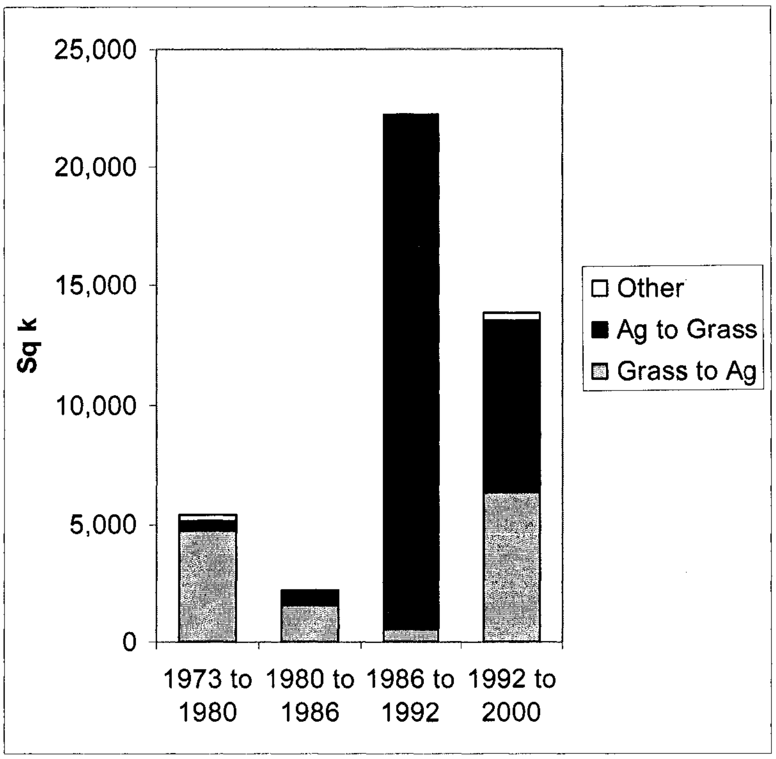

Figure 4.5. Cyclic changes (ha) between grassland/shrub and agricultural land cover, and unidirectional changes for each time period.

Land Use Dynamics, 1950 to 2000

Land cover changes in the WHP occur within the context of national-scale and Great Plains agriculture. Without a comparable analysis of land cover change at those scales, agricultural census data was used to identify the overall trends in land use. Farmland use declined between 1950 and 1997 in the U.S and the Great Plains, although loss of farmland was much lower in the Western High Plains ecoregion (Figure 4.6). The Great Plains had a slight increase in cropland. In the Western High Plains, cropland increases were substantial. In spite of an overall decline in farmland, cropland expansion still occurred in the ecoregion. Much of the cropland increase was likely irrigated. Intensive irrigated crop production increased at all three scales, and especially in the Western High

Plains where the increase was nearly 8%, even while marginal lands were taken out of production beginning in 1986 through the CRP for a total area nearly equal to the expansion of irrigation. The result was an intensification and expansion of cropland in some areas of the Western High Plains along with a relatively recent conversion of marginal cropland to CRP grassland.

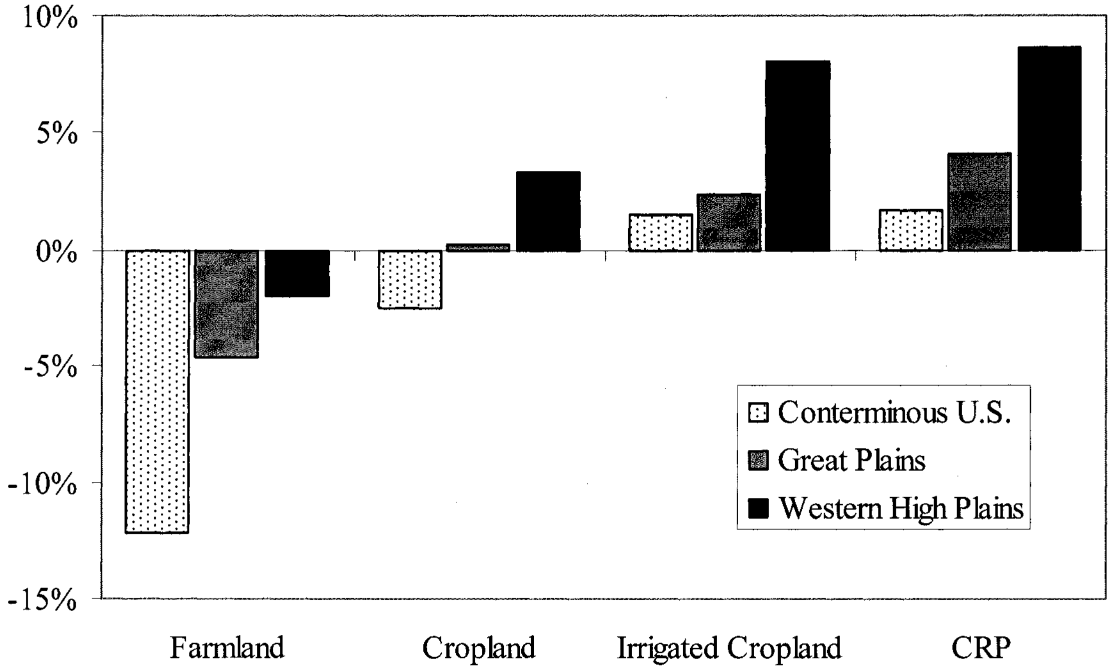

Figure 4.6. The percentage change in total area used for farming between 1950 and 1997 (USDA 1997).

Compared with the U.S. as a whole, there was a relative stability in the total area of farmland in the Western High Plains. Between 1950 and 1997, farmland in the ecoregion declined by 2.0% (5,670 sq k) compared with a conterminous U.S. decline of 12.2%. In 1950, farmland uses covered 91.7% (253,775 sq k) of the region and declined to 89.6%

(248,105) by 1997. However, the relative stability of total agricultural land use is the result of nearly 25,000 sq k of expansion and decline among the major farmland uses. Between 1950 and 1997, cropland use expanded by 3.3%, from 42.3% to 45.6% of the ecoregion, an increase of approximately 9,200 sq k. Rangeland use declined by nearly 5% (13,545 sq k), from 46.9% to 42% of the ecoregion by 1997. Woodland on farms declined from 0.8% to 0.2% of the ecoregion, a loss of approximately 1,700 sq k. The approximately 3.3% increase in cropland was offset by rangeland decreases and a small decline in woodland. The net result was a 2% decline in the total area of agricultural land use between 1950 and 1997.

Population and land use in the Western High Plains

Approximately 65% of the total population of the Western High Plains occurs in seven of the 89 counties, and all in Colorado (Denver, Adams, and Weld) and Texas (Lubbock, Ector, Midland, and Randall). Between 1950 and 2000, population increased by 138% in these seven counties. All other counties combined also increased by nearly 20%. Although, rural counties with agricultural industry tended towards an increase while many of the already sparsely populated counties saw declines. For instance, the sixty most-rural counties that have 10,000 or fewer inhabitants combined for an approximately 10% decline.

Cropland use declined in the seven highest populated counties. The total area of cropland decreased by 7% between 1950 and 1974, and was relatively stable thereafter. Most of the overall decline in the area of harvested cropland also occurred prior to 1974, with a decrease of approximately 23%. More recent decreases in the total area of farmland, since 1974, appear to be from a loss of rangeland that affected approximately 11% of the area. The net loss of cropland in the urban counties prior to 1974 was more than matched by an expansion of rural cropland. Between 1950 and 1997, cropland in the 60 most-rural counties, where population had declined overall, increased by 9.6%. By 1997, cropland covered nearly half (49.5%) of the area. The area of harvested cropland was also at its highest point since 1950, reaching 28.7% in 1997. A rangeland decline of 7.2% in the most-rural counties is likely associated with the cropland expansion. In comparison, a total rangeland loss of 19.2% in the urban counties since 1950 was associated with an overall loss of farmland.

Low-intensity land use

The apparent stability of farmland use is also masked by the conversion of cropland to CRP grassland. Between 1990 and 2000, CRP totals averaged slightly more than 24,300 sq k and covered 9% of the region. This is the highest percentage for any EPA Level III ecoregion in the U.S. In the Western High Plains, the year 2000 had more CRP than any previous year, with approximately 26,300 sq k of land enrolled in the program. National totals declined. Another approximately 7.5% of the ecoregion is in idle and fallow land, a low intensity use of cropland. The patterns of low intensity land use, which includes CRP and fallow and idle land, contrast sharply with those of intensive agriculture.

Changes in the intensity of land use

Trends in the total area of irrigation, harvested cropland, and crop types indicate an accelerating pattern of intensification up to 1978. After 1978, some areas continued to expand while others declined (Figure 4.7). Between 1950 and 1978, irrigated cropland increased steadily from 4.2% to 13.5% of the ecoregion. Totals declined to 9.9% in 1987 when conterminous U.S. irrigation also declined. By 1997, irrigated cropland in the ecoregion rebounded to 12.2% (33,700 sq k), still approximately 3,670 sq k below the previous high in 1978. Harvested cropland change followed a trend similar to irrigated cropland indicating some of the importance of irrigation to crop production in the region. In 1978, approximately 27% of the ecoregion was harvested. In 1987, the area of harvest declined to 23% before increasing back to 1978 levels.

Spatial changes in intensive agriculture follow three general trends. In 1974 and 1997, the total area of irrigation in the ecoregion was similar, within less than 700 sq k. However, there were spatial changes in the pattern of expansion and loss. Counties that primarily use surface water for irrigation (>50% of the total area of irrigation) generally expanded, while counties that primarily use groundwater had two divergent trends (Table 4.6). Counties that primarily use surface water had a slight increase in irrigated cropland of 710 sq k that affected 1.7% of the total county area. Cropland expansion (0.5%) was less than one-third the irrigation increase. The overall decline in farmland was due to a rangeland decline (5.0%). Most of the irrigation in the ecoregion depends on groundwater. Counties that primarily use groundwater and that had an increase in irrigation (4,800 sq k) also had farmland and cropland expansions. Cropland expanded by 4,585 sq k (3.4% of the total county area) along with a similar increase in the area of harvest. Harvested cropland increased despite the conversion of 7.9% of the area to CRP. Groundwater counties that had a decrease in irrigation (-4,835 sq k) had substantial farmland decline (-5.5%). Although most of the absolute decline was from rangeland, cropland also declined by 1,135 sq k (1.1% of the area). Harvested cropland declines affected 2.2% of the total area. The CRP totals are also higher (13.3%), and likely impacts the area of production, although the declines in harvested cropland are relatively small compared to CRP expansion. Overall, the trends indicate a loss of crop production in the counties with irrigation loss. Counties with irrigation expansion had an increase in production along with a substantial expansion of cropland.

There is an intensification of feed corn and livestock production that is associated with irrigation and cropland expansion in areas of water availability. Between 1969 and 1997, feed corn expanded by nearly 4-fold from approximately 3,500 to 13,400 sq k. Fattened cattle, including those in large confined feeding operations, increased by 2.5 fold between 1969 and 1997. Between 1964 and 1997, the increases were greater than 6-fold, from approximately 1.6 to 10.3 million. The number of dairy cows increased by more than 8-fold (by approximately 250 million).

Table 4.6. Land use rates of change in Western High Plains counties with irrigation expansion and decline, 1974 to 1997. Results are given for counties that primarily use surface water sources, which expanded in irrigated area, and for counties that primarily use groundwater as a source of water for crop irrigation. Data on surface and groundwater use is from the U.S. Geological Survey (Hutson et al. 2004).

Irrigation and Land Use Change	**Surface Water Use (Expansion)**	**Groundwater Use**	
		Irrigation Expansion	**Irrigation Decline**
Total county area (sq k)	40,815	101,275	13,477
Irrigated area, 1997 (sq k and % county area)	4,600 11.3%	13,340 13.2%	15,760 11.7%
Change, 1974 to 1997			
Irrigation	1.7%	3.6%	-4.8%
Farmland	-4.5%	2.3%	-5.5%
Cropland	0.5%	3.4%	-1.1%
CRP	5.4%	7.9%	13.3%
Harvested Cropland	0.5%	3.2%	-2.2%
Rangeland	-5.0%	-1.1%	-4.3%

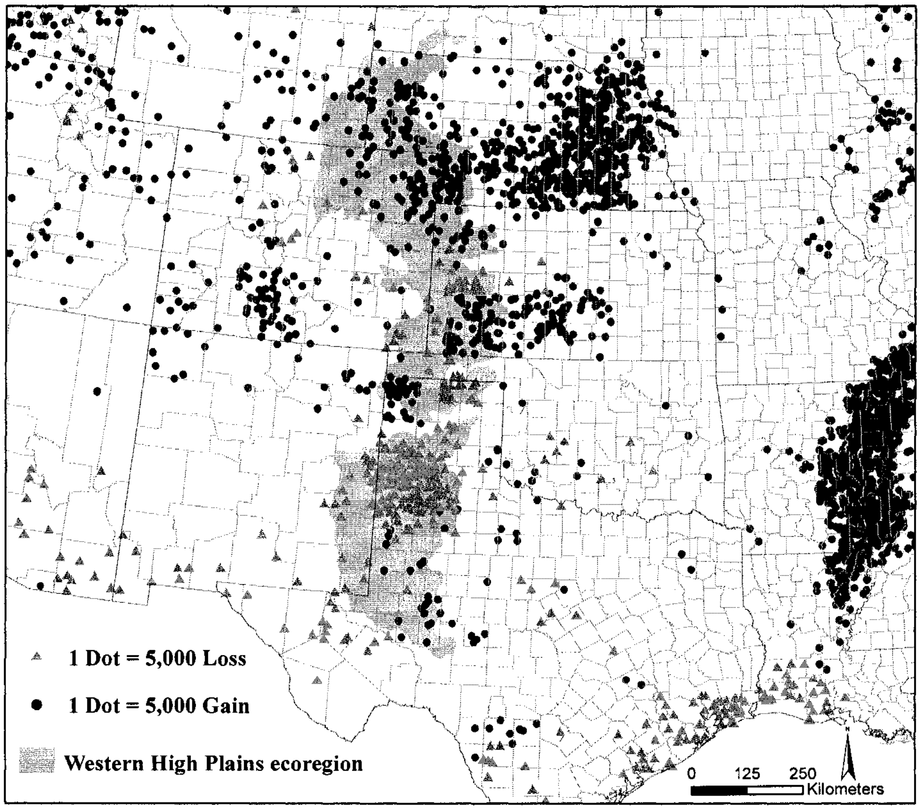

Figure 4.7. Acres of irrigation expansion and decline from 1974 to 1997 (USDA 1997). County boundaries are also shown.

DISCUSSION

Regional Trends and Processes of Land Change

Historically, the large-scale processes of land change in the Great Plains, including cropland expansion, began with the Homestead Act of 1862 that placed more than 800,000 km^2 of land with private landowners (Samson et al. 2004). Land conversion is also a contemporary concern, although data on its occurrence has been limited. This study provides regional-scale estimates of land conversion. Two important trends were identified in the Western High Plains between 1973 and 2000. The first was a net agricultural expansion and loss of grassland between 1973 and 1986. The second was a net agricultural land cover decline between 1986 and 2000 as cropland was converted to grassland cover. The major processes of land change that relate to these trends are also identified and explored below (Figure 4.8).

Agricultural Expansion

Globally, cropland expansion is one of the most extensive human impacts on land cover. In the Western High Plains, it accounts for most of the change between 1973 and 1986 when cropland expanded at the expense of grassland. The expansion was influenced by an international grain price increase during the early 1970s, which caused a 50% increase in the area of Great Plains wheat and further cropland expansion between 1979 and 1981

(Riebsame 1990). An irrigation expansion that occurred in association with substantial increases in corn production and livestock operations indicates an intensification and expansion of agriculture. These processes resulted in a net agricultural expansion that affected 1.9% (5,200 sq k) of the ecoregion. Between 1980 and 1986, the rate of agricultural land cover expansion slowed, although there was still a net increase in agriculture of more than 1,000 sq k. The deceleration of agricultural expansion occurred as economic conditions declined (Polsky 2004). Irrigated area and corn production declined as agricultural land values dropped. This suggests that at least some of the increase in agricultural land cover may have been from a dryland crop expansion.

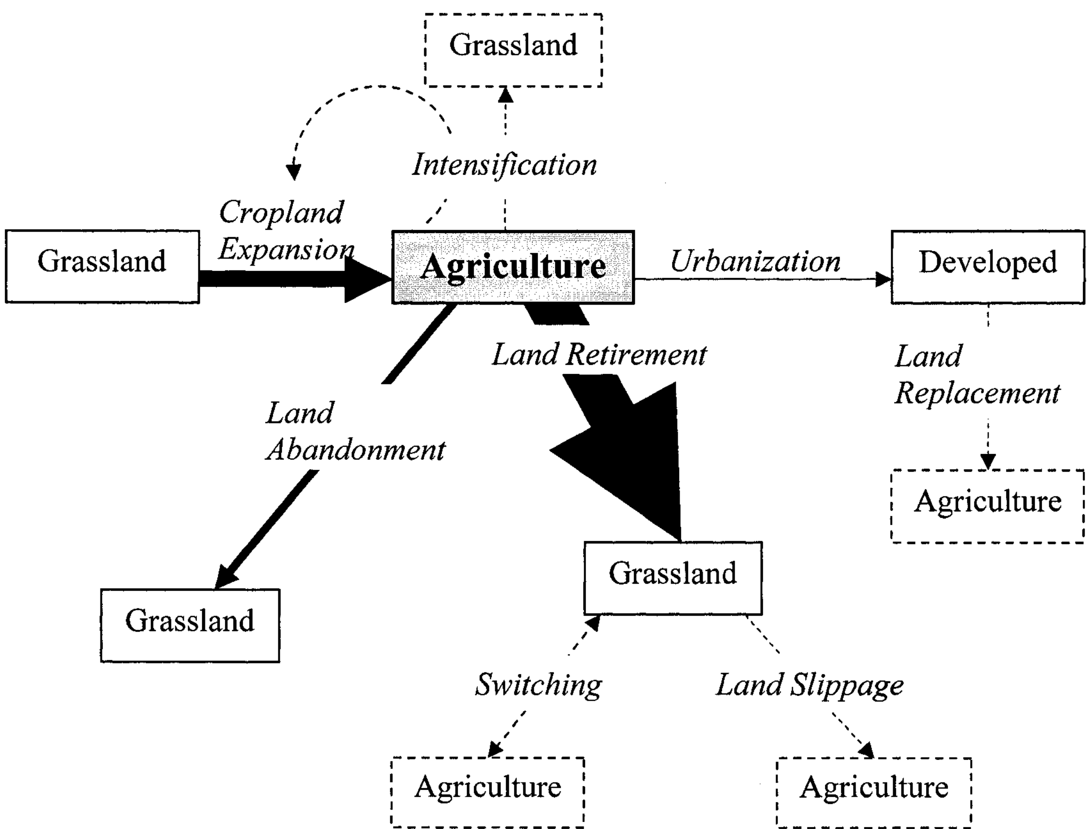

Figure 4.8. The primary processes (solid arrows) of agricultural land cover conversion. The size of each arrow indicates the relative extent of land change that occurred between 1973 and 2000. Secondary processes (dashed arrows) may indirectly influence land conversion, often in response to prior land change factors.

Agricultural Intensification

Agricultural intensification is likely associated with both the process of expansion as well as contraction of land cover. Many marginal cropland areas of the western Great Plains use the CRP, but other areas have access to good soils and water that enables intensive agriculture. In general, agricultural intensification is driven by improved mechanization, high-yield crop strains, irrigation, fertilizers, pesticides, and other inputs that increase the output of agriculture relative to changes in total cultivated area (Matson et al. 1997). The patterns of expansion and decline of irrigated cropland apparently have an impact on land cover. The agricultural census data indicate that the total area of cropland expanded where irrigation has expanded, and declined where irrigation has declined. The dominant trend of a decline in the total area of agricultural land cover does not run counter to the processes of agricultural intensification in the U.S. Marginal cropland uses, and agricultural land cover extent, may be declining in the ecoregion as the processes of agricultural intensification cause a decline in the total area of land necessary for food and fiber production.

The area in irrigated cropland also began to rebound even while croplands were converted to CRP, although the 1997 total (12.2%) was still below the high in 1978. The area of harvested cropland and corn production increased. However, between 1974 and 1997 there were substantial spatial changes in the location of irrigated cropland. It is unclear whether the high rate of CRP in counties that had a decline in irrigation (13.3% compared to 7.9% in areas with irrigation expansion) is related to groundwater depletion.

Most cropland in areas of water resource decline is expected to continue as dryland cropland (Terrell et al. 2002). However, there are indications that cropland declined in areas where irrigation has declined.

Intensification can also be associated with the industrialization of livestock production, and is prevalent in several locations including large cattle feedlots and meat-packing plants in the Garden City, Kansas area and hog confinement operations in Oklahoma (Harrington and Lu 2002). Many of the hog operations are in areas of sparse human population. Expansion of feeding operations in these areas is closely tied to water availability and cultural perceptions that allow for agricultural industries that might be discouraged elsewhere (Hart and Mayda 1998; Harrington and Lu 2002). Meat consumption is a driving force of agricultural expansion and loss. Contemporary declines in U.S. consumption of beef have a potentially negative effect on feed grain production of 2.2% annually (Waggoner and Ausubel 2002). However, global consumption of meat has been increasing and has an impact on the production of cattle and feed grain – principally corn, sorghum, barley and oats – in agricultural regions. The four-fold increase in feed corn in the Western High Plains, and the equally impressive increases in cattle, hogs, and dairy, suggests that industrialized agriculture is an important proximate cause of sustained agricultural land use.

Agricultural Loss - Land Retirement and Abandonment

Even while the Great Plains was still being settled in the early 1920s, marginal farms in the semi-arid plains were abandoned and local populations declined as farmers went bankrupt (Baker 1923). During the 1930s, cropland and entire farms were abandoned in significant numbers as drought, dust storms and economic conditions worked against farmers. Climate variability continues to impact agricultural land use and land cover change, although the magnitude of the effect of for instance, economically-driven land abandonment caused by drought, is undetermined. Contemporary processes of agricultural land expansion and decline may be more dominated by trade opportunities and farm policy changes, but they are also only part of a suite of causal factors that include climate and biophysical factors.

Substantial contemporary land use change is influenced by government policy largely in response to historical settlement patterns that established croplands in marginal areas, where land capability is limited. The Conservation Reserve Program is the nation's largest farmland conservation effort to date, affecting more than 146,000 sq k in 47 states (Leathers and Harrington 2000). The policy provides an economic incentive to take highly erodible land out of crop production by replanting to native or non-native vegetation cover, and provides a mechanism to potentially reduce overproduction on cropland (Blackburn et al. 1991). Established in the Food Security Act of 1985, the CRP began compensating farmers for participation in the following year. Initially, slightly more than 7,900 sq k were converted to CRP nationally. One year later, in 1987, CRP lands totaled more than 62,000 sq k. More than 141,000 sq k were enrolled in the program at its height in 1993 before declining nearly 10% (USDA 1997). Land enrolled in the CRP can be taken out of permanent cover and returned to cropland after a minimum of 10 years. Other land retirement efforts, such as included in the Agriculture and Food Act of 1981 and the 1983 payment-in-kind (PIK) program, designed to reduce cropland area in the early 1980s were generally not as effective as the CRP (Riebsame 1990).

After 1986, when the CRP was in effect, conversion from agriculture to grassland was most common. The net impact on land cover was a 7.6% decline in agriculture. The voluntary enrollment of cropland in the CRP, under ten- to fifteen-year contracts, resulted in large amounts of net conversion to grassland. Gross agricultural expansion dropped to its lowest amount during any of the four time periods. This is likely indicative of the economic slowdown in agriculture. Irrigation declined from an all-time high in 1978 (13.5% of the ecoregion) to less than 10% in 1987. Harvested cropland and corn production had similar declines. The processes of agricultural intensification and expansion had generally ceased in response to a declining farm economy. The CRP payments allowed excess cropland to be taken out of production and planted to permanent grassland cover, primarily in areas where lands were marginal for cultivation. In the Western High Plains, the land cover transformation resulting from CRP land retirement was rapid and it dramatically changed regional land cover.

From 1992 to 2000, the high rate of land cover conversion resulted primarily from changes in the location of CRP grassland and cropland. Grassland expanded across 0.2% of the ecoregion, a relatively slow rate of change, even though the spatial switching among the location of grassland and cropland caused gross changes of 4.8%. The total area of CRP had already been generally established in the previous time period. The changes in location may simply be related to lands that were taken out of the CRP after the enrollment period or to changes in the program. Prior to 1991, farmers had an incentive to enroll based on maximizing profits from land that might otherwise be only marginally profitable for growing crops. After 1991, the program focused on the environmental benefits of the CRP (Plantinga et al. 2001). This may have facilitated some of the change in the location of CRP land. The agricultural economy was also improving from the dismal lows of the mid-1980s.

Most ecoregion changes in land cover occurred because of the high rate of cropland conversion to CRP grassland. Whether the lands enrolled in the CRP will remain in grassland in the distant future is not well understood. Based solely on the period from 1992 to 2000, the number of future conversions to grassland could increase at a slow rate. However, the CRP could be reduced or eliminated by changes in farm policy, encouraging farmers to return many of the CRP lands to active production. The future of grassland patterns will also depend on other economic and technology factors such as trade opportunities, land quality, and crop varieties. Climate changes may also have an impact on the ability to grow crops in some areas.

Large-scale land use policies, such as the CRP, are subject to unintentional consequences. Processes of CRP land slippage occur when cropland reduction programs are left partially ineffective when new crops are planted elsewhere to substitute for lost revenue or in anticipation of higher crop prices (Leathers and Harrington 2000). There is debate about the importance of land use slippage related to the CRP (Roberts and Bucholtz 2005). In general, the decisions by individual farmers that can cumulatively cause CRP land use patterns are driven by economic, cultural, land quality and climate factors that make a cause-effect relationship unclear. There are few results to suggest that CRP land slippage has a substantial impact on the total area of grassland in the ecoregion. Further site-specific studies could reveal that there is an increase in the use of previously idled cropland. However, based on the low rates of grassland loss between 1986 and 1992, there is little evidence of substantial land cover change associated with slippage. After 1992, the high rate of spatial changes among CRP and cropland could obscure any pattern of grassland loss associated with slippage.

Urbanization and Other Development

Population loss is one of the most frequently identified issues in the Great Plains, yet the patterns of population change vary and do not necessarily lead to a decline in agricultural land use (Parton et al. 2003). Rural population loss can be linked to several factors including the consolidation and technological changes that favor farms of larger size with fewer workers. Population is increasing in urban areas of the Great Plains, although few large cities exist in the interior of the region. At the urban fringe it is often reasonable to assume that farmland losses are converted to developed land, yet the fate of most land use changes in the rural regions are unknown (Hart 1992; Parton et al. 2003). Despite loss of farmland to development, most national assessments have not indicated a detrimental loss of prime cropland to urbanization. Urban growth is important locally, at the urban-rural fringe, but is responsible for only a small fraction of net cropland loss nationally (Hart 2001). Between 1980 and 2000, the rate of exurban land conversion to development is estimated at 1.6% annually (Theobald 2005). Other modes of farmland decline are likely of greater magnitude in the Western High Plains than the permanent changes associated with urban development, but have differed through time.

Counties in the Western High Plains with large populations had more loss of productive cropland than the rural counties. However, the overall result was an expansion of cropland in the ecoregion. This is due to the large amount of rural land, where population density is less than five people per sq mile, relative to only a few highly populated counties. The processes of exurban development likely occur in the region. However, the extent of any cropland conversion is small when compared to the amount of rural land that is potentially available for expansion.

The analysis of population census data suggests that most cropland losses related to urban growth occurred prior to 1970. After 1970, rangeland losses were greater. However, it is significant that rural areas added cropland and a substantial area of harvested cropland by 1997. Processes of "land replacement" could have caused cropland expansion elsewhere in response to loss at the urban fringe (Greene and Stager 2001). It is unclear whether the expansion of cropland in rural counties was a direct result of cropland loss in urban counties, or whether they are the unrelated results of two separate processes of change – the urbanization of nearby rural lands and the expansion of rural cropland in response to economic opportunities.

Conclusions

This study provides empirical evidence, where evidence was previously limited, of the expansion and contraction of agriculture and grassland cover. The patterns and trajectories of land conversion were identified that will contribute to ongoing studies of regional and national land use. Clear indications were given showing how regions evolve in response to socioeconomic processes of change. These results can be used in further studies that project the future response of landscapes to changes in policy, technology or other driving forces of change.

There are multiple interacting causes that determine the trajectory of change or, conversely, the persistence of historical patterns. Across the Western High Plains, the processes of cropland expansion and the decline of cropland associated with recent farm policies of the CRP have caused substantial land change. During the first half of the study period, agricultural land cover in the ecoregion continued to expand until public farm policies of the CRP intervened and enrollment in the program began in 1986. The more recent decline of agricultural land cover in marginal areas contrasts sharply with other areas of irrigated feed grain production and industrialized meat and dairy operations. Future land cover changes may depend primarily on the evolution of farm policy, access to global markets, new economic opportunities for crops such as demands for biofuel, as well as the scientific and technological advances that allow croplands to expand into marginal areas.

While land use data indicated the intensity of land use and its overall direction of change, the land cover estimates provided site-specific evidence of the changes in land surface dynamics. In general, spatial information on land conversion such as the sample units used in this study improves the analysis of trends and processes of change, in part because the outcome of land cover change can be tracked between monitoring intervals. Most land use data available for the nation provides detailed information on net changes for politically-bounded units that may be more helpful as a complement to land cover analyses rather than to corroborate them. The definitional differences between land use and land cover analyses as well as the differences in methodology can be advantageous for regional ecosystem assessments. Further analysis is needed to understand the spatial relationships of land cover change to other socioeconomic and environmental factors that may impact regional land cover dynamics.

REFERENCES

Anderson, J.F., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964, 28p.

Baker, O.E. 1923. The agriculture of the Great Plains region. Annals of the Association of American Geographers, 13:109-167.

Best, L. B., H. Campa, III, K.E. Kemp, R. J. Robel, M. R. Ryan, J. A. Savidge, H.P. Weeks, Jr. and S. R. Winterstein. 1997. Bird abundance and nesting in CRP fields and cropland in the Midwest: a regional approach. Wildlife Society Bulletin, 25: 864-877.

Blackburn, W.H., J.B. Newman, and J.C. Wood. 1991. The Conservation Reserve Program: Effects on soil, water and environmental quality. In The Conservation Reserve: Yesterday, Today and Tomorrow, eds. L.A. Joyce, J.E. Mitchell, and M.D. Skold, 27-36. GTR RM-203. Fort Collins, CO:USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Burgi, M. and M.G. Turner. 2002. Factors and processes shaping land cover and land cover changes along the Wisconsin River. Ecosystems, 5:184-201.

Burgi, M., A.M. Hersperger, and N. Schneeberger. 2004. Driving forces of landscape change – current and new directions. Landscape Ecology, 19:857-868.

Cihlar, J. and L.J.M. Jansen. 2001. From land cover to land use: a methodology for efficient land use mapping over large areas. Professional Geographer, 53:275-289.

Dennehy, K.F., D.W. Litke, and P.B. McMahon. 2002. The High Plains aquifer, USA: Groundwater development and sustainability. In: K.M. Hiscock, M.O. Rivett, and R.M. Davison (eds). Sustainable Groundwater Development. London: Geological Society, Special Publications, 193:99-119.

Dugan, J.T. and R.B. Zelt. 2000. Simulation and analysis of soil-water conditions in the Great Plains and adjacent areas, central United States, 1951-80. United States Geological Survey Water-Supply Paper 2427.

Dunn, C.P., F. Stearns, G.R. Guntenspergen, and D.M. Sharpe. 1993. Ecological benefits of the Conservation Reserve Program. Conservation Biology, 7:132-139.

Gallant, A.L., T.R. Loveland, T.L. Sohl, and D.E. Napton. 2004. Using an ecoregion framework to analyze land-cover and land-use dynamics. Environmental Management, 34:S88-S110.

Greene, R.P. and J. Stager. 2001. Rangeland to cropland conversions as replacement land for prime farmland lost to urban development. The Social Science Journal, 38:543-555.

Griffith, J.A., S.V. Stehman, and T.R. Loveland. 2003. Landscape trends in Mid-Atlantic and southeastern United States Ecoregions. Environmental Management, 32:572-588.

Hargreaves, M.W.M. 1976. Land-use planning in response to drought: the experience of the thirties. Agricultural History, 50:561-82.

Harrington, L.M.B., and M. Lu. 2002. Beef feedlots in southwestern Kansas: Local change, perceptions, and the global change context. 2002. Global Environmental Change, 12:273-282.

Hart, J.F. 1992. Nonfarm farms. The Geographical Review, 82:166-79.

Hart, J.F. 2001. Half a century of cropland change. The Geographical Review, 91:525-543.

Hart, J.F. and C. Mayda. 1998. The industrialization of livestock production in the United States. Southeastern Geographer, 38:58-78.

Heimlich, R. 1985. Sodbusting: Land use change and farm programs. USDA-ERS Agricultural Information Bulletin no. 536, 28p. Washington D.C.: U.S. Government Printing Office.

Hudson, J.C. 2002. Across This Land: A regional geography of the United States and Canada. Baltimore: Johns Hopkins University Press, pp. 474.

Hutson, S.S., N.L. Barber, J.F. Kenny, K.S. Linsey, D.S. Lumia, and M.A. Maupin. 2004. Estimated use of water in the United States in 2000. U.S. Geological Survey Circular 1268, Reston, Virginia, pp.52.

Hurtt, G.C., L. Rosentrater, S. Frolking, and B. Moore III. 2001. Linking remote-sensing estimates of land cover and census statistics on land use to produce maps of land use of the conterminous United States. Global Biogeochemical Cycles, 15:673-685.

Kerr, J.T. and J. Cihlar. 2003. Land use and cover with intensity of agriculture for Canada from satellite and census data. Global Ecology & Biogeography, 12:161-172.

Lambin, E.F. and H. Geist, eds. 2006. Land-Use and Land-Cover Change: Local Processes and Global Impacts. The IGBP Series. Springer-Verlag, Berlin, 222p.

Leathers, N., and L.M.B. Harrington. 2000. Effectiveness of Conservation Reserve Programs and land "slippage" in southwestern Kansas. Professional Geographer, 52:83-93.

Loveland, T.R., T.L. Sohl, S.V. Stehman, A.L. Gallant, K.L. Sayler, and D.E. Napton. 2002. A strategy for estimating the rates of recent United States land-cover changes. Photogrammetric Engineering and Remote Sensing, 68:1091-1099.

Mather, A.S. and C. Needle. 1998. The forest transition: a theoretical basis. Area, 30:117-124.

Matson, P.A., W.J Parton, A.G. Power, and M.J. Swift. 1997. Agricultural intensification and ecosystem properties. Science, 277:504-9.

Mattison, E.H.A. and K. Norris. 2005. Bridging the gaps between agricultural policy, land-use and biodiversity. Trends in Ecology and Evolution, 20:610-616.

McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS spatial pattern analysis program for categorical maps. University of Massachusetts, Amherst, Massachusetts. http://www.umass.edu/landeco/research/fragstats/fragstats.html.

McGuire, V.L., M.R. Johnson, R.L. Schieffer, J.S. Stanton, S.K. Sebree, and I.M. Verstraeten. 2003. Water in storage and approaches to groundwater management, High Plains aquifer, 2000. U.S. Geological Survey Circular 1243, 51p.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers, 77:118-125.

Opie, J. 2001. John Wesley Powell was right; resizing the Ogallala High Plains. In: C. Miller (ed.), Fluid Arguments: Five Centuries of Western Water Conflict. Tuscon: U. of Arizona Press, pp.223-247.

Parton, W.J., M.P. Gutmann, and W.R. Travis. 2003. Sustainability and historical land-use change in the Great Plains: The case of eastern Colorado. Great Plains Research, 13:97-125.

Plantinga, A.J., R. Alig, and H. Cheng. 2001. The supply of land for conservation uses: evidence from the conservation reserve program. Resources Conservation & Recycling, 31:199-215.

Polsky, C. 2004. Putting space and time in Ricardian climate change impact studies: agriculture in the U.S. Great Plains, 1969-1992. Annals of the Association of American Geographers, 94:549-564.

Radeloff, V.C., A.E. Hagen, P.R. Voss, D.R. Field, and D.J. Mladenoff. 2000. Exploring the spatial relationship between census and land cover data. Society and Natural Resources, 13:599-609.

Ramankutty, N. and J.A. Foley. 1999. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography, 8:381-396.

Riebsame, W.E. 1990. The United States Great Plains. In: Clark, W. C., B. L. Turner, R. W. Kates, J. Richards, J. T. Mathews, and W. Meyer (eds). The Earth as Transformed by Human Action. Cambridge, UK: Cambridge University Press, pp. 561-575.

Roberts, M.J. and S. Bucholtz. 2005. Slippage in the Conservation Reserve Program or Spurious Correlation? A comment. American Journal of Agricultural Economics, 87:244-250.

Roet, J.B. 1985. Land quality and land alienation on the dry farming frontier, (Great Plains). Professional Geographer, 37:173-83.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin, 32:6-15.

Schnepf, R.D., E. Dohlman, and C. Bolling. 2006. Agriculture in Brazil and Argentina: Developments and Prospects for Major Field Crops. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture, Agriculture and Trade Report, WRS-01-3.

Skole, D.L. 2004. Geography as a great intellectual melting pot and the preeminent interdisciplinary environmental discipline. Annals of the Association of American Geographers, 94:739-743.

Sohl, T.L., A.L. Gallant, and T.R. Loveland. 2004. The characteristics and interpretability of land surface change and implications for project design. Photogrammetric Engineering & Remote Sensing, 70:439-450.

Stehman, S.V., T.L. Sohl, and T.R. Loveland. 2003. Statistical sampling to characterize recent United States land-cover change. Remote Sensing of Environment, 86:517-529.

Terrell, B.L., P.N. Johnson, and E. Segarra. 2002. Ogallala aquifer depletion: economic impact on the Texas high plains. Water Policy, 4:33-46.

Theobald, D. M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society, 10:1-34.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America, 96:5995-6000.

U.S. Department of Agriculture (USDA). 1997. Census of Agriculture, Geographic Area Series, AC97-CD-Vol 1. U.S.D.A. National Agricultural Statistics Service, Washington, D.C.

U.S. Bureau of the Census. 2001. 2000 Census of Population and Housing: Summary File 1 United States. U.S. Bureau of the Census, Washington, D.C.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources. Photogrammetric Engineering and Remote Sensing, 67:650-662.

Waggoner, P.E. and J.H. Ausubel. 2002. A framework for sustainability science: a renovated IPAT identity. Proceedings of the National Academy of Sciences of the United States of America, 99:7860-7865.

Wahl, K.L. and R.L. Tortorelli. 1997. Changes in flow in the Beaver-North Canadian River Basin upstream from Canton Lake, western Oklahoma. U.S. Geological Survey Water-Resources Investigations Report 96-4304.

CHAPTER FIVE

REGIONAL DRIVING FORCES OF GRASSLAND LOSS AND EXPANSION IN THE WESTERN HIGH PLAINS

To be submitted to Journal of Land Use Science

REGIONAL DRIVING FORCES OF GRASSLAND LOSS AND EXPANSION IN THE WESTERN HIGH PLAINS

Abstract

A resurgence of grassland cover has occurred in the western Great Plains following several years of grassland loss. This research examines the driving forces of grassland change within a socioeconomic context that includes a long-term land use transition in the United States towards fewer agricultural lands. As agricultural intensification and industrialization occur, there are spatially variable impacts on regions. This includes the formation of contrasting regions of land use stability and abandonment. However, numerous forces drive regional land change. In the Western High Plains ecoregion, several socioeconomic forces and natural factors are examined that drive the regional patterns of grassland expansion, abandonment, and stability. Natural resource access is one of the primary causes of change in the ecoregion. The changes in water access that have resulted from decades of cropland irrigation have an impact on the patterns of grassland change. Overall, market forces and farm policy have the biggest impact on contemporary patterns of grassland cover change. This paper demonstrates an integrated research method, using available land use and water resource data and a sampling strategy, for monitoring and analyzing land cover change in ecoregions.

Key words: land cover change; driving force; grassland; agriculture; Great Plains; High Plains Aquifer

INTRODUCTION

The extent of grassland cover in the United States has diminished substantially since European settlement of the Great Plains, largely due to land conversion for food, fiber, and biomass production. As a result, grassland regions are among the most fragmented and endangered ecosystems (Coppedge et al. 2001; Samson et al. 2004). In general, grassland cover has been cleared and converted to cropland where rainfall and soils are adequate (UNEP 2005). Other areas support livestock grazing or are converted to intensive agriculture when water becomes accessible for field irrigation. Globally, at least 19% of grasslands have been converted to cropland (Matthews 1983). However, the rates, causes and consequences of land cover change may vary significantly by region. Precise estimates of regional grassland change are relatively few because of the difficulty in mapping grassland and agricultural environments (UNEP 2005).

While there is a consensus on the importance of understanding the dynamics and causes of land change at a variety of scales and places (Lambin and Geist 2006), there is a need for systematic regional analyses that can be synthesized and compared among other regions, and that facilitate an improved understanding of local and global-scale changes. The purpose of this research is to examine the trends and main causes of contemporary land change in the Western High Plains ecoregion (Figure 5.1). The analysis is a component of a larger effort to understand land change across the conterminous U.S. (Loveland et al. 2002). The main focus of this paper is on the observed dynamics of grassland expansion and loss in the Western High Plains between 1973 and 2000, and the interpretation of the primary underlying causes of the land conversion.

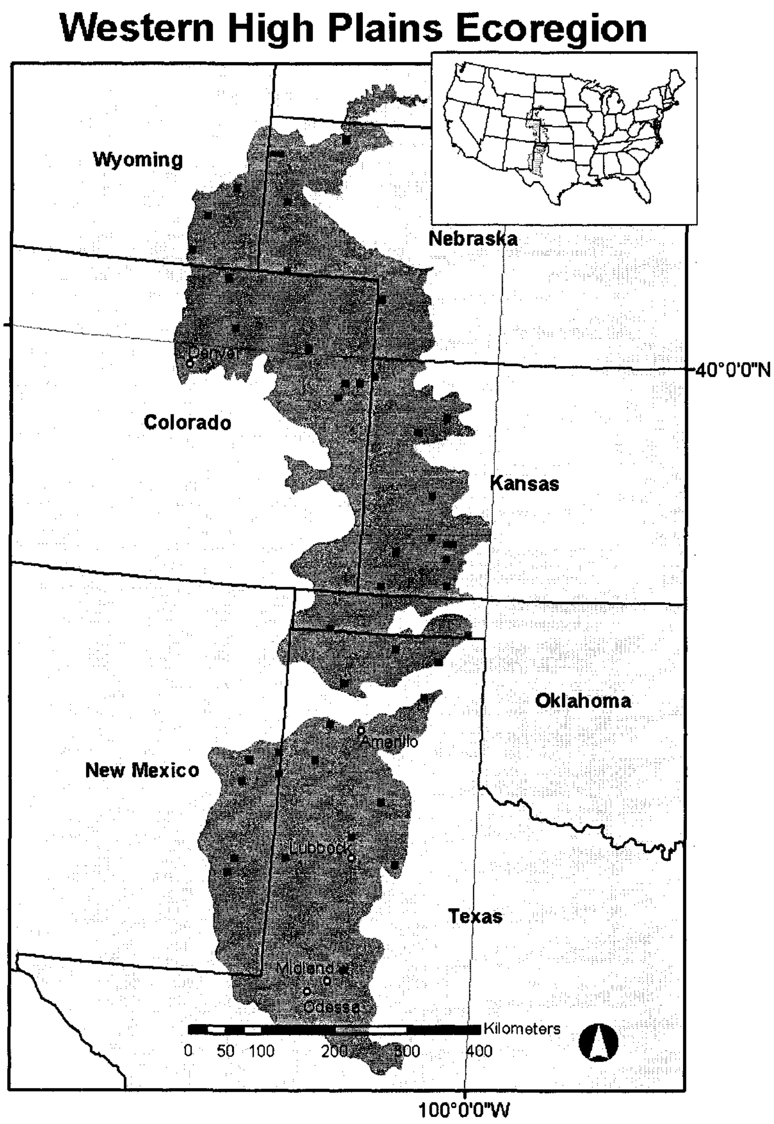

Figure 5.1. The Western High Plains study area. The ecoregion extends across parts of eight states and covers approximately 287,000 sq km. A statistical sample of 45 10 x 10 km land cover blocks (shown) were examined for five dates from 1973 to 2000.

Most of the remaining grassland cover in the U.S. is in the semi-arid western half of the Great Plains. In the Western High Plains, approximately 90% of the grasslands are in agricultural land uses including rangeland grazing, extensive dryland crops, intensive irrigated crop production, and animal feeding operations. Because of socioeconomic factors that include a decline in the total area of U.S. farmland, contemporary changes in farm policy, changes within the agricultural industry, technological and scientific advances, and increased globalization of trade, land cover in the Western High Plains may have undergone significant changes. Environmental factors, which interact with socioeconomic drivers, are also dynamic. Climate variability and drought have played a significant role in the land use decisions of farmers. Sandy soils and other land that is poor for cropland production have generally defined the area of livestock grazing (Burke et al. 1993). The pattern and availability of water resources may be particularly important for land change in the region. Contemporary access to surface water and to the diminished High Plains (Ogallala) Aquifer has enabled an expansion of intensive and industrialized agriculture. Ongoing changes to the physical and economic ability to access water may be causing modification of the High Plains landscape. The ability to access surface water and groundwater can change over time in response to its physical availability and to socioeconomic processes, including advances in pumping technology and the fluctuation of energy costs (Roberts and Emel 1992). However, there are multiple causes of land cover change in the Western High Plains

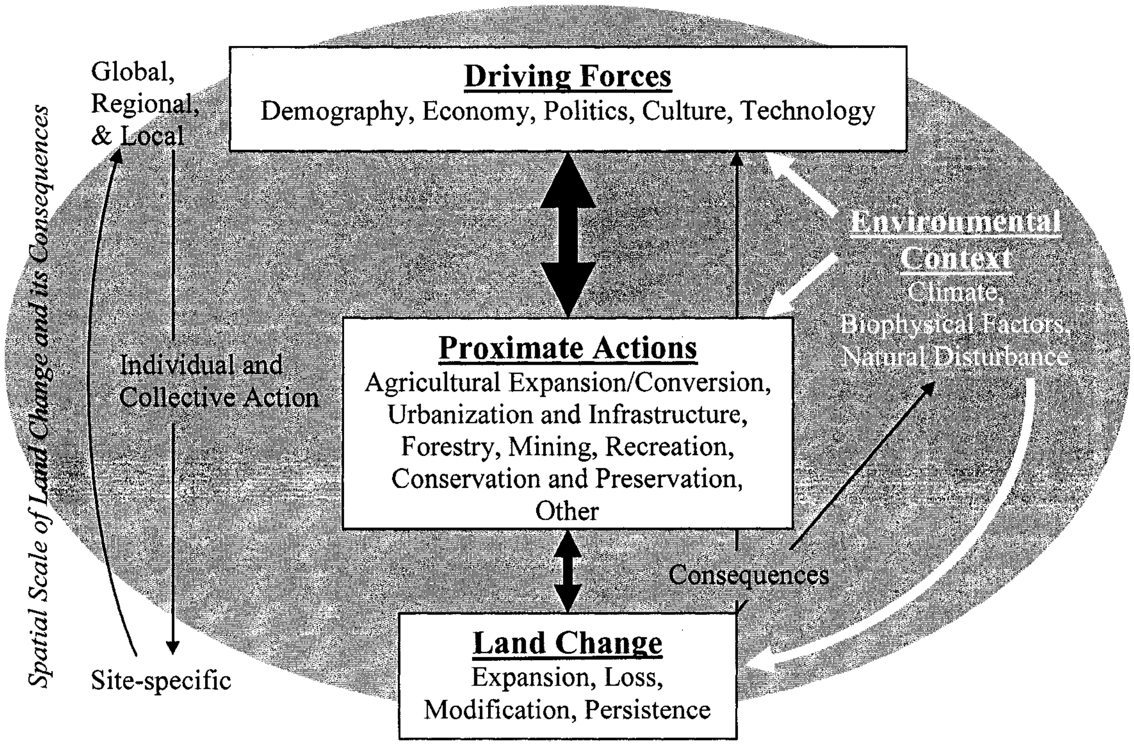

Figure 5.2. A conceptual framework for understanding the linkages between indirect socioeconomic driving forces, environmental factors, and local human action. These factors interact across a range of spatial and temporal scales to cause land change, and have consequences and feedbacks on society and the environment.

There are several underlying socioeconomic forces that drive land conversion and modification: demographic, economic, technological, political and institutional, and cultural factors (Figure 5.2). Conceptually, individuals directly cause land change at a local scale through proximate land use activities. Those actions are influenced indirectly by global, regional, and local driving forces – both socioeconomic and environmental. Generally, a cluster of several driving forces influence the local land use management decisions that directly cause land cover change (Geist et al. 2006). The actual changes to land use and land cover are site-specific, although cumulative actions may have local, regional or global impacts.

Grassland conversion in the Western High Plains may be caused by several socioeconomic factors. Population growth and land development at the urban fringe cause land conversion at the local scale (Parton et al. 2003). Ongoing changes in agriculture and recent concentration of intensive production within a few agricultural regions such as the Western High Plains may also affect the pattern of grassland. Grassland conversion to irrigated cropland has occurred in at least a few areas of the High Plains since center-pivot irrigation was widely adopted in the mid-1960s (Lichtenberg 2001), although the extent of the grassland conversion is not documented. Future global population growth could cause further land clearance in many agricultural regions as cropland expands to meet the growing demand for food and fiber (Tilman 1999).

Expansion of grassland is caused by regional socioeconomic processes including outright abandonment of agricultural land and public land use policies such as the Conservation Reserve Program (CRP). The CRP and other land retirement programs provide economic incentive to revert cropland to permanent vegetation cover. In the Great Plains, the CRP is one of the most extensive recent land use changes (Riebsame 1990). Some dryland croplands might have been abandoned even without the CRP (Wu 2000), resulting in a succession to grassland. Irrigated cropland has already declined in the southern part of the ecoregion where depletion of the High Plains aquifer is substantial (Walsh 1980; Terrell et al 2002). A switch from irrigated cropland to dryland farming is the most likely scenario where aquifer access is no longer economically feasible (Terrell et al. 2002).

Early ranching and dryland cropping practices in the region were extensive but caused a very different pattern and intensity of land use and cover from later ones that developed around the High Plains Aquifer. Agriculture in the semi-arid Western High Plains ecoregion was transformed by groundwater irrigation beginning in the late-1940s, with a larger expansion of center-pivot irrigation through the 1970s. Recently, the region has accounted for 25% of groundwater use and 20% of the total irrigated cropland in the U.S (Dennehy et al. 2002). In some locales, the historically heavy demands on surface and groundwater have caused water-levels to decline as much as 45 m in the High Plains Aquifer (McGuire 2003; Anderson and Woosley 2005). Farmers have not always been able to adapt their irrigation practices to groundwater depletion when economic conditions are poor (Taylor and Lacewell 1988). However, the depletion of High Plains groundwater has been a serious concern among farmers for decades (Kromm and White 1983).

Recent analyses of the driving forces of land change have taken several different approaches. Studies have focused on the spatial analysis of factors that directly impact land use and land cover including groundwater (Wu et al. 1999), population (Wilson and Lindsey 2005), and topography and soils (Flinn et al. 2005). Methods used to research the indirect causes of land cover change include the historical analysis of land management practices (Burgi and Schuler 2003) and the synthesis of case study literature (Geist and Lambin 2001). In this research, land use, water resource, and land cover change assessments are integrated to understand the patterns and causes of regional grassland expansion and loss. Three main questions are examined in the Western High Plains ecoregion. 1) What are the rates of grassland change between 1973 and 2000? 2) What are the primary regional socioeconomic forces that drive contemporary change? 3) What is the role of water access in grassland cover change? Although there is increasing awareness of the impacts of land use on ecosystems and land cover, there is a need for an improved understanding of the dynamics of regional change.

Identifying the relationships between land change and regional driving forces

The I = PAT formula that emphasizes the importance of population (P), affluence (A), and technology (T) for identifying driving forces and estimating potential impacts (I) provides a framework for understanding global change (Rosa et al. 2004). Driving forces have also been proposed using six general categories: population, affluence, political economy, political structure, technology, and attitudes and values (Turner and Meyer 1991). Although multiple driving forces interact to cause change, it is clear that population and economy are central elements of environmental change (Rosa et al 2004). Economic conditions are further influenced by a globalized market, which is having a major influence on land use (Burgi et al. 2004). In effect, economic opportunities, constraints and the policies that determine them are the primary driving forces of global land use change (Lambin et al. 2001).

There is a need to understand the major socioeconomic and biophysical factors that cause geographic variability of change at the regional scale (Lambin et al. 2001). In a given region there is an optimum type and intensity of land use that responds to specific markets and which cause geographic patterns to emerge when numerous individual farmers select the most advantageous use of their land (Garrison and Marble 1957). The geographic variability of natural resources, climate, and population interact to determine much of a regions competitive economic advantage (Raup 1980). In economic geography this type of land use selection criteria is often conceptualized as land rent, which is the highest level of economic gain that can be attained from the best use of land (Hardie et al. 2002; Gallant et al. 2004).

Historically, agriculture has been the most extensive land use change in many ecosystems. Intensification since the 1950s has revolutionized agricultural production and affected the extent and pattern of land use in many regions of the globe. World food production doubled between 1961 and 1996 caused by large increases in nitrogen and phosphorus input, a 2-fold increase in irrigated area, and only a 10% increase in cultivated land (Tilman 1999). Production has also increased in the United States, although the total area of cropland has declined.

The intensification of commercial agriculture that is strongly tied to external markets and subsidized by public policy has been termed as *commodification* (Lambin et al 2001). The intensification of commercial agriculture is characterized by increased investment in specialized crop and livestock production and in experimental agriculture, such as in the U.S. This differs from the types of intensification that occur in less developed countries. The globalization of markets and trade that occurs with commodification decouples local production from a proximate source of demand, which has variable effects on regional land use patterns (Lambin et al. 2001; Naylor et al. 2005).

Changes in the intensity of land use vary regionally depending on the underlying driving forces. Spatial analyses that examine the correlation between the geographical distribution of socioeconomic or biophysical factors and land use have been used recently to understand the drivers of land use change (Flinn et al. 2005; Wilson and Lindsey 2005). In the Western High Plains, the spatial association between crop type and groundwater characteristics was examined in southwestern Kansas using remotely sensed data and a geographic information system (Wu et al. 1999). A spatial approach to understanding the causes of land use provides a methodology for incorporating quantitative data into the assessment. However, not all potential driving forces have a spatial or quantitative component for linkage with specific land use locations. Considering that land use changes likely result from the interaction of multiple indirect driving forces, there is a need for analyses that synthesize quantitative and qualitative evidence to interpret regional change.

In this analysis, estimates of regional land cover change from 1973 to 2000 are derived from remotely sensed data. A statistical sampling approach is used that also allows detailed analysis of the succession of land cover conversions that occur during five time periods in response to socioeconomic and biophysical factors. Land use change and land cover conversions are compared to the pattern of water resources primarily to understand whether there are divergent trends in the region that may be associated with intensive agriculture. The contemporary land cover patterns that result from changes in water access have not been clear (Opie 2001), primarily because of a lack of integrated monitoring and assessment at the regional scale. This work builds on previous analyses in Finney County Kansas (Wu et al. 1999), extending the study of land use and land cover to the larger Western High Plains ecoregion.

STUDY AREA

The Western High Plains study area extends across parts of eight states and covers approximately 287,000 sq. km. The ecoregion is a variable mosaic of grassland, agriculture and urban and rural populations. The perennial bunchgrass blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths) dominates the plant communities of the shortgrass steppe (Coffin et al. 1996). The pattern of native grassland and agricultural use is driven in large part by physical factors. One of the important physical driving forces of the shortgrass steppe ecosystem as well as agricultural land use is precipitation, which ranges from approximately 300 mm/yr in the west to 500 mm/yr in the east. Sand soils and other unproductive soil types that receive less than 500 mm/yr of precipitation generally contain rangeland uses (Burke et al. 2000). Wheat-fallow cropping patterns that bank soil moisture occur in areas where water availability is limited but soils are suitable for crops. Streamside irrigation and groundwater pumping are common where water is readily available.

Population in the 89 counties of the ecoregion was 2.57 million in 2000, a 28% increase since 1970. The county with the highest percentage gain was Finney County in southwestern Kansas with a 113% increase over the 1970 population of approximately 19,000. Southwestern Kansas has a high concentration of irrigated feed grain production, cattle feedlots and beef processing plants that positively impacts employment (Harrington and Lu 2002) and may be responsible for the population increase. Large cattle feeding operations moved into the area, and out of the Corn Belt, because the dry climate reduced the economic impacts of animal disease (Harrington and Lu 2002).

Early commercial agriculture in the High Plains expanded from predominantly large cattle ranches established after 1860 to dryland crops including cotton, wheat and specialty crops such as sugar beets. High evapotranspiration rates that exceed precipitation contribute to a water deficit for growing most crops. Turbine pumps used for groundwater irrigation were introduced in the 1930s in the southern part of the ecoregion, beginning a modern farming and cattle ranching era (Brooks and Emel 2000). Technological advances after World War II allowed for more efficient groundwater pumping that changed the regional pattern of intensive crop production. Currently, more than 95% of the groundwater pumped from the High Plains is used for crop irrigation (Dennehy et al. 2002). However, contemporary groundwater resources are already declining in some areas of the western Great Plains because of considerable historical mining of the High Plains Aquifer and could cause a shift to less intensive uses. Substantial pumping had already occurred by 1980, resulting in declines greater than 30m in some areas (Dennehy et al. 2002).

The increasing use of center-pivot irrigation, beginning in the mid-1960s, allowed more intensive use of fields with uneven topography and sandy soils, which is unfeasible with furrow irrigation (Lichtenberg 1989). By the mid-1970s groundwater pumping had greatly expanded primarily because of inexpensive energy, favorable economic conditions, a growth in exports, and advances in irrigation technology (Nellis 1987). A drought during the mid-1950s that caused widespread crop failure also contributed to the spread of irrigation (Rhodes and Wheeler 1996). Rural electric cooperatives, which expanded in the area after 1940, provided much of the energy for early irrigation expansion (Rhodes and Wheeler 1996). In southwestern Kansas, energy for groundwater pumping is primarily supplied by local natural gas fields (Nellis 1987).

MATERIALS AND METHODS

Land cover was examined using a stratified random sampling approach and multiple dates of Landsat satellite imagery (Loveland et al. 2002; Sohl et al. 2004; Stehman et al. 2003). Forty-five sample units of five dates of satellite imagery, nominally 1973, 1980, 1986, 1992 and 2000 were mapped and analyzed for change. The 10 x 10 km samples were stratified by the U.S. Environmental Protection Agency Level III Ecoregions of the United States (Omernik 1987). Land cover was mapped using 11 general land cover classes based on the U.S. Geological Survey system (Anderson et al 1976).

The estimated rates of land cover change are reported as a percentage of the total area of the ecoregion strata. Total area was calculated as the sum population of sample blocks within the strata. The rates of net and gross change are reported. Net change provides a measure of the direction of change, such as the difference between the total area of grassland expansion and loss. Gross change gives an estimate of the spatial extent of land cover conversions regardless of the direction of change, such as the sum of grassland expansion and grassland loss or as the sum of all land cover conversions regardless of type.

Land cover data from the 1992 National Land Cover Data (NLCD) was used as a source of complete (wall-to-wall) land cover data coverage of the region (Vogelmann et al. 2001) when needed. The NLCD also used Landsat data as the primary data source for mapping and employs a similar land cover classification. However, the NLCD is not currently multi-temporal.

County data from the agricultural census was used to identify historical land use changes in farmland, cropland, rangeland and livestock (USDA 1997). Population data between 1950 and 2000 was used from the U.S. Census of Population and Housing (U.S. Bureau of the Census 2001). The census data was examined at multiple scales, 1) the Western High Plains ecoregion, 2) the Great Plains, and 3) the conterminous United States. Unless noted, all agricultural land use data is from the U.S. Census of Agriculture. All population data is from the U.S. Census of Population and Housing. County census data is a measure of the net result of changes in farmland use and population. The extent of gross land use changes cannot be determined within counties.

The High Plains Aquifer was examined using a digital map of historical changes in the saturated thickness and decline of the aquifer, from development of aquifer to 2000 (McGuire 2003). An estimate of the depth to groundwater was interpolated from a database of water well measurements acquired from the U.S. Geological Survey. In addition to water resources, a digital map of land capability for crops (NRCS 2000) was examined for spatial associations with land use and land cover.

RESULTS

Grassland Trends

Grassland and agricultural land cover combined comprise approximately 97.5% of the ecoregion during all time periods, although the area of each varies through time (Table 5.1). Forest, developed land, and wetlands make up much of the rest of the land cover, with some slight declines in the area of wetland and increases in urban cover. The largest extent of grassland occurs in 2000, covering 49.8% of the region. The smallest extent of grassland was 42.3% in 1986. Agriculture declined from a high of 55.4% in 1986 to 47.8% in 2000.

Table 5.1. Land cover totals for the Western High Plains, 1973 to 2000.

Land Cover Class	ESTIMATES OF TOTAL LAND COVER (Sq k and Percentage)				
	1973	1980	1986	1992	2000
Agriculture	154,880	159,055	160,075	138,985	138,070
	53.6	55.1	55.4	48.1	47.8
Grassland/Shrubland	127,410	123,125	122,065	143,110	143,843
	44.1	42.6	42.3	49.6	49.8
Forest	2,436	2,436	2,436	2,436	2,436
	0.84	0.84	0.84	0.84	0.84
Developed	1,273	1,398	1,427	1,457	1,639
	0.44	0.48	0.49	0.50	0.57
Wetland	1,126	1,105	1,104	1,106	1,070
	0.39	0.38	0.38	0.38	0.37
Natural Bare	769	755	756	754	754
	0.27	0.26	0.26	0.26	0.26
Water	630	631	631	634	644
	0.22	0.22	0.22	0.22	0.22
Mining	224	246	257	266	292
	0.08	0.09	0.09	0.09	0.10

Between 1973 and 1986, the regional grassland cover declined by an estimated 5,345 sq k. The rate of decline was highest between 1973 and 1980, when 1.5% of the ecoregion was converted from grassland to cropland (Table 5.2). Between 1980 and 1986, the rate of loss dropped to 0.4%. The most common change between 1973 and 1986 was grassland conversion to agriculture, when gross loss of grassland was estimated at 6,320 sq k. Gross expansion of grassland was much less prevalent, at 1,030 sq k. The net result was a 4.2% decline of the 1973 grassland area.

Between 1986 and 2000, grassland expansion was the dominant trend. Most of the net change occurred in the earlier time period, between 1986 and 1992, when grassland cover increased by 21,045 sq k or 7.3% of the ecoregion. Between 1992 and 2000, the rate of grassland expansion slowed, with an estimated increase of only 733 sq k or 0.3% of the ecoregion. The most common change over the 14-year period was the conversion from agriculture to grassland, when an estimated 28, 814 sq k of grassland expansion occurred. The expansion caused a 17.8% net increase over the 1986 grassland extent, an absolute increase of approximately 21,778 sq k by 2000.

Table 5.2. Land cover conversion, net grassland change, and total gross change for the Western High Plains, 1973 to 2000.

LAND COVER CONVERSIONS	**ESTIMATED AREA OF CHANGE (Sq k)**				
	1973-1980	**1980-1986**	**1986-1992**	**1992-2000**	**1973-2000**
Agriculture to Grassland	453	580	21,606	7,208	22,742
Grassland to Agriculture	4,718	1,613	539	6,318	6,084
Grassland to Developed	22	15	16	141	194
Agriculture to Developed	103	14	14	41	172
Other	70	21	23	117	222
Net Change in Grassland	**-4285**	**-1060**	**21,045**	**733**	**16,433**
Net Change in Grassland (%)	-1.5%	-0.4%	7.3%	0.3%	5.6%
Total (Gross) Change - Grassland	**5290**	**2210**	**22,160**	**13,605**	**29,080**
Rate of Change (%)	1.8%	0.8%	7.7%	4.7%	10.1%
85% Confidence Interval	+/-0.60	+/-0.32	+/-1.70	+/-1.09	---

Over the entire study period, the various gains and losses resulted in a 12.9% net expansion of the 1973 grassland extent. The absolute area of grassland increase was estimated at 16,433 sq k. However, the total footprint of area that was affected by all land cover changes during the four time periods was more than 29,000 sq k. The gross rate of change for all land cover conversions combined affected 1.8%, 0.8%, 7.7%, and 4.7% of the region respectively for the four time periods between 1973 and 2000. Net change of grassland cover differed from the combined gross changes during all time periods. The biggest difference occurred between 1992 and 2000 when the high rate of spatial changes in grassland and agriculture location caused a difference of 4.4% between the overall rate (4.7%) and the amount of net change in grassland cover (0.3%). The other time periods have a primarily unidirectional trajectory of change, with grassland loss prior to 1986 and a big expansion of grassland between 1986 and 1992.

The Context and Causes of Grassland Loss and Expansion

The period after about 1950, when agricultural intensification and industrialization became a prominent part of American agriculture, provides a reasonable temporal context for assessing agricultural land change trends and for comparison among various spatial scales. The period after 1950 is marked by an overall decline in conterminous U.S. farmland area. However, there is variability in those trends depending on the scale – from county to country – and on the region. This section uses census data from the agricultural (USDA 1997) and population census (U.S. Bureau of the Census 2001) to build a narrative perspective of the patterns and drivers of land change.

American Agriculture

Between 1950 and 1997, the total area of agriculture declined by 12.2%, from 61.3% of the conterminous U.S to 49.1%. Overall, farmland shrank by approximately 932,250 sq k (Table 5.3), which is 20% of the 1950 total of nearly 4.7 million sq k. Farmland declines consist primarily of woodland, cropland, and rangeland changes. Woodland declined by approximately 600,000 sq k and accounts for nearly 65% of the farmland change.

Cropland declined by 191,375 sq k, accounting for approximately 20% of the farmland decline. Rangeland declined by nearly 74,000 sq k and accounts for nearly 9% of farmland change. Most of the net loss of farmland occurred in forested regions.

Table 5.3. The rate and absolute amount of agricultural land use change from 1950 to 1997 (U.S. Census of Agriculture). The rates are based on the total area of each region. Declining rates are noted in parentheses.

Region	Farmland	Cropland	Rangeland	Woodland	Harvested Cropland	Irrigated Cropland	CRP
Conterminous U.S.	(12.2%) -932,250	(2.5%) -191,375	(1.0%) -73,785	(7.8%) -602,830	(1.9%) -142,650	1.5% 117,875	1.7% 132,360
Great Plains	(4.6%) -102,415	0.2% 5,470	1.0% 21,320	(5.5%) -121,935	(2.8%) -63,525	2.4% 53,720	4.1% 91,445
Western High Plains	(2.0%) -5,670	3.3% 9,190	(7.1%) -19,575	(0.6%) -1,780	(2.8%) -7,625	8.0% 22,010	8.6% 23,880

The net agricultural changes affected more than 12% of the total area of the conterminous U.S. Although farmland change was primarily unidirectional, approximately 1.1 million sq k of county farmland loss and 170,000 sq k of expansion occurred. As a result, the rate of combined changes is higher, with at least 15% of the conterminous U.S. affected by farmland expansion and loss during the half century. A simultaneous increase in irrigated cropland of nearly 118,000 sq k caused the percentage of irrigated cropland to more than double. Nearly 13% of cropland was irrigated by 1997 due in part to the 2.5% overall decline in cropland area, which was likely a decline in dryland uses.

The distribution of cropland change varies depending on access to water. Between 1974 and 1997, counties with greater access to water, defined as those with at least 40 sq k of irrigated cropland by 1997, had a combined increase in the total area of cropland of 1.7%.

Counties with limited water access had a 4.4% decline in cropland area. The counties with greater water access lost rangeland and woodland in addition to the expansion of cropland, resulting in a net decline in the total area of farmland. In the counties with limited access to water, approximately 30% of the decline in farmland area was due to cropland loss.

Great Plains Agricultural Land Use Change

Net changes in agricultural land use in the Great Plains indicate relative stability compared to the U.S. as a whole. The area of farmland loss in the Great Plains comprises only 11% of the total net decline in the U.S. Between 1950 and 1997 farmland declined by an estimated 5.1% (102,415 sq k), affecting 4.6% of the region (Table 5.1). Farmland changes are the result of slight increases in cropland and rangeland, and a large decline in woodland. Cropland increased by approximately 5,470 sq k, which affected 0.2% of the Great Plains. There was a larger increase in rangeland of 21,320 sq k (1.0%) and a large decline in woodland of nearly 122,000 sq k (5.5%), primarily in the wooded areas of the southern Great Plains. Although the net land use changes in the Great Plains indicate more stability than the U.S. as a whole - with only small changes in the total area of cropland and rangeland - there is regional variability not captured by the net statistics. For example, in the Western High Plains ecoregion the rate of cropland expansion (3.3%) and of rangeland loss (-7.1%) are much different than for the Great Plains as a whole.

The combined expansion and loss of Great Plains farmland is 224,500 sq k, and indicates a dynamic agricultural landscape. The extent of expansion and loss of county agricultural land use impacted approximately 10% of the total area of the Great Plains, more than twice the amount of net change. The conversion rate of cropland to CRP grassland is also high. The more than 91,000 sq k of CRP in the Plains makes up 71% of the conterminous U.S. total. Furthermore, the expansion of CRP is greater in the semi-arid areas. The rate of expansion in the semi-arid Western High Plains of 8.6% is more than double the rate for the Great Plains as a whole.

Approximately 3.5%, or more than 84,000 sq k, of the Great Plains is in irrigated cropland. Between 1974 and 1997, irrigation increased by 21.6% or slightly more than 14,600 sq k. Irrigated cropland area peaked in 1978 (37,370 sq k) and declined by 1997 (33,700 sq k), a drop of nearly 10% (Figure 5.3). In 1974, irrigation in the Western High Plains accounted for nearly half (48.6%) of the irrigated area in the Great Plains, but has dropped to around 40% since the 1980s. Between 1974 and 1997, Great Plains irrigation expanded by nearly 15,000 sq k. The Western High Plains had substantial spatial and temporal variability in the direction of change resulting in a small contribution, of 680 sq k, to the Great Plains expansion.

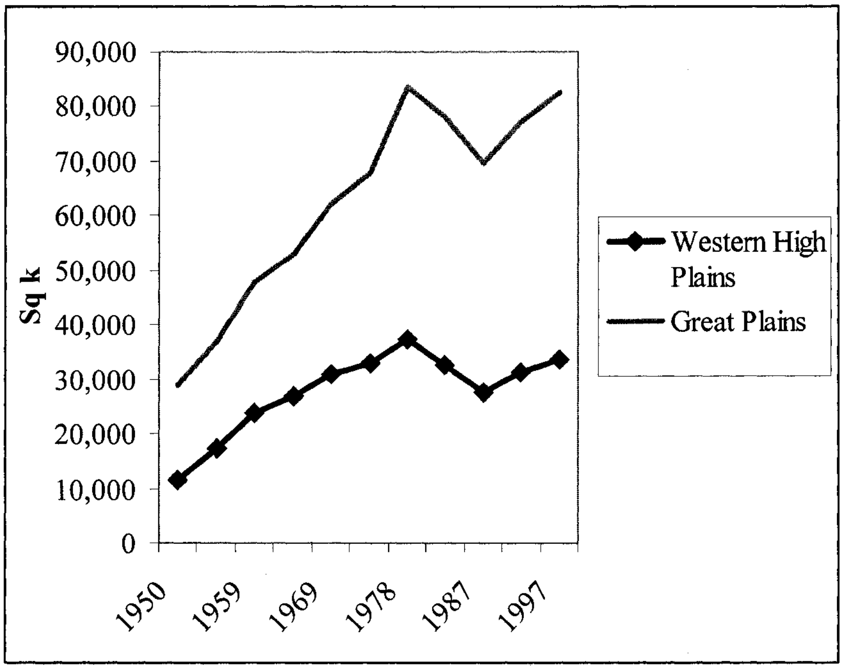

Figure 5.3. Irrigation trends in the Western High Plains ecoregion. The irrigation total for the Great Plains is shown for comparison.

Land Use in the Western High Plains Ecoregion

Between 1950 and 1997, an approximately 3.3% increase in Western High Plains cropland was offset by rangeland decreases and a small decline in woodland (Table 5.1). The overall result was a 2.0% net decline of agricultural land use in the ecoregion. Farmland covered 91.7% of the region in 1950 and declined to 89.7% by 1997. Cropland expanded from 42.3% to 45.6% of the region by 1997, while the overall area of rangeland use declined by 5% to cover 42% of the region. The relative stability of regional land use is masked by the gross expansion and loss of farmland and by the conversion of cropland to CRP grassland (Figure 5.4). Gross land use change in the ecoregion was approximately 10%. Land in CRP totaled nearly 24,000 sq k or 8.6% of the region.

Approximately 7.5% of the region remained in other low intensity uses, primarily idle and fallow land.

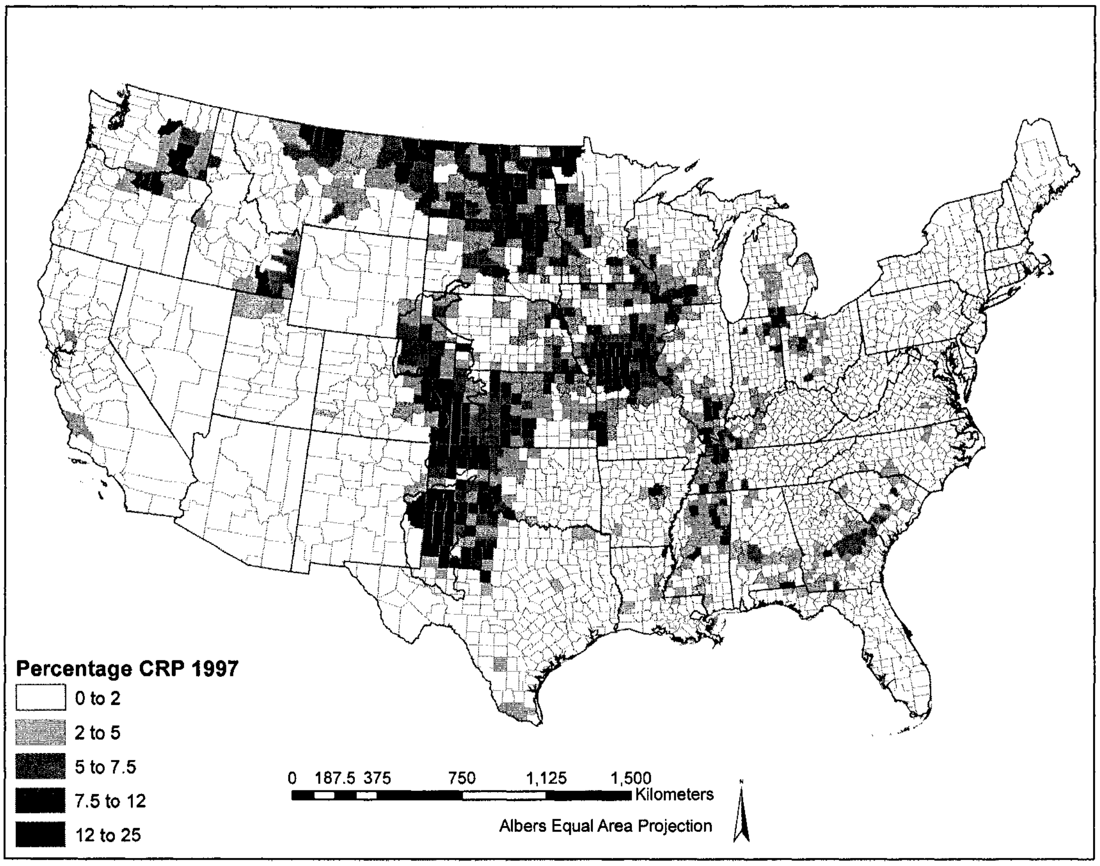

Figure 5.4. CRP percentage in conterminous U.S. counties, 1997 (USDA 1997).

Although the impact of CRP changes on the total area of crop production is unclear because of the diversity of factors that impact production, the total area of harvest was at 27% before the CRP began (in 1978 and 1982) and also in 1997 when CRP land was extensive. Harvested cropland did drop by as much as 15% after the CRP took effect, but rose substantially between 1992 and 1997. Data from the agricultural census indicates that much of the increase in harvest came from declines in fallow and failed cropland as well as a small increase in the total area of cropland.

Industrialized cattle production and other confined livestock operations have had substantial expansions in the region. Between 1964 and 1997, the number of fattened cattle increased from 1.7 million to 10.3 million and declined in many other areas of the Great Plains including the Corn Belt. Between 1964 and 1997 the total number of livestock increased from approximately 30 million animals to 300 million. The concentration of large numbers of livestock in the region is also tied to changes in irrigated feed grain (Figure 5.5). During the same time period, the production of feed corn increased by 800% or approximately 12,000 sq k. The land use data indicate that the total area of cropland also expanded by approximately 5,000 sq k. In contrast, the expansion and intensification of feed grain production occurred alongside the conversion of 24,000 sq k of cropland to CRP grassland. This indicates divergent trends in the expansion and decline of intensive agricultural land use in the Western High Plains.

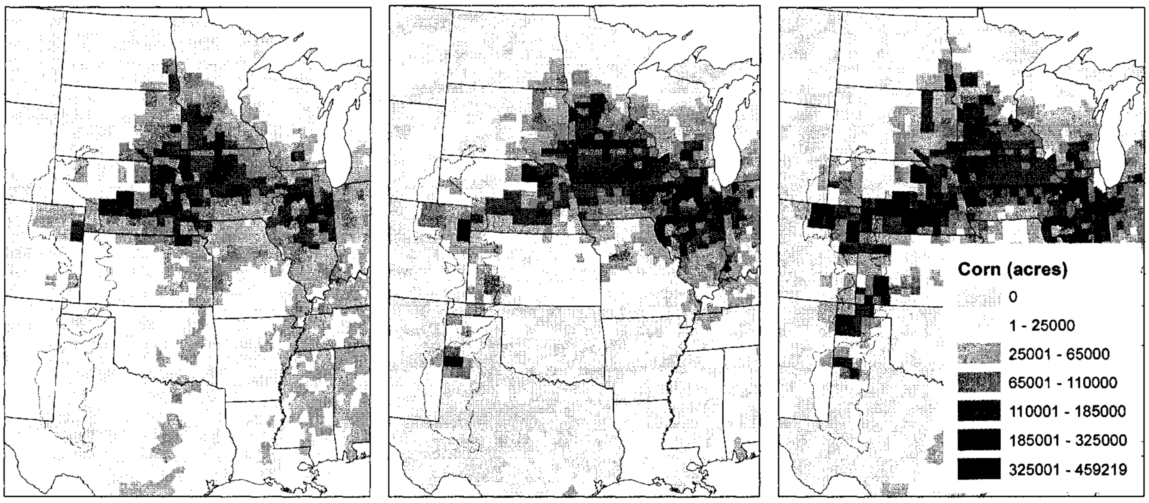

Figure 5.5. Westward expansion of corn: 1950, 1978, and 1997 in counties (left to right).

Environmental Context and Land Change

Soils and local topography, climate, and water resources play a large role in determining agricultural land use patterns and change. In areas that have been classified as unsuited for crops (USDA Land Capability Classification, NRCS 2000), including sandy soils and other unproductive soil types, grasslands from the 1992 NLCD (Vogelmann et al. 2001) account for 83% of the total land cover. Agricultural land cover from the NLCD occurs on 13% of the area, accounting for only 7% of the total area of agriculture in the ecoregion. Despite the dominance of agriculture (93%) on lands that are deemed suitable for agriculture in the USDA Land Capability Classification, most of the absolute extent of grassland also occurs in those areas. Nearly two-thirds (63%) of all NLCD grassland in the ecoregion occurs on potentially arable land. This indicates that socioeconomic factors as well as other local biophysical factors may also play a significant role in land use patterns and land cover change.

Aquifer characteristics have a spatial association to grassland and agriculture. The spatial association between depth to groundwater and land cover from the sample data show two different patterns. The percentage of agriculture increases linearly in areas that overlay groundwater depths of up to 250ft (Figure 5.6), likely indicating that greater water reserves enable more cropland. The relationship changes at depths greater than 250ft, indicating that the overlying extent of agricultural land cover is more variable in areas where the depth to groundwater is substantial. In some areas the overlying land is unsuitable for crops, but the pattern could also be related to the economic costs of pumping groundwater from greater depths

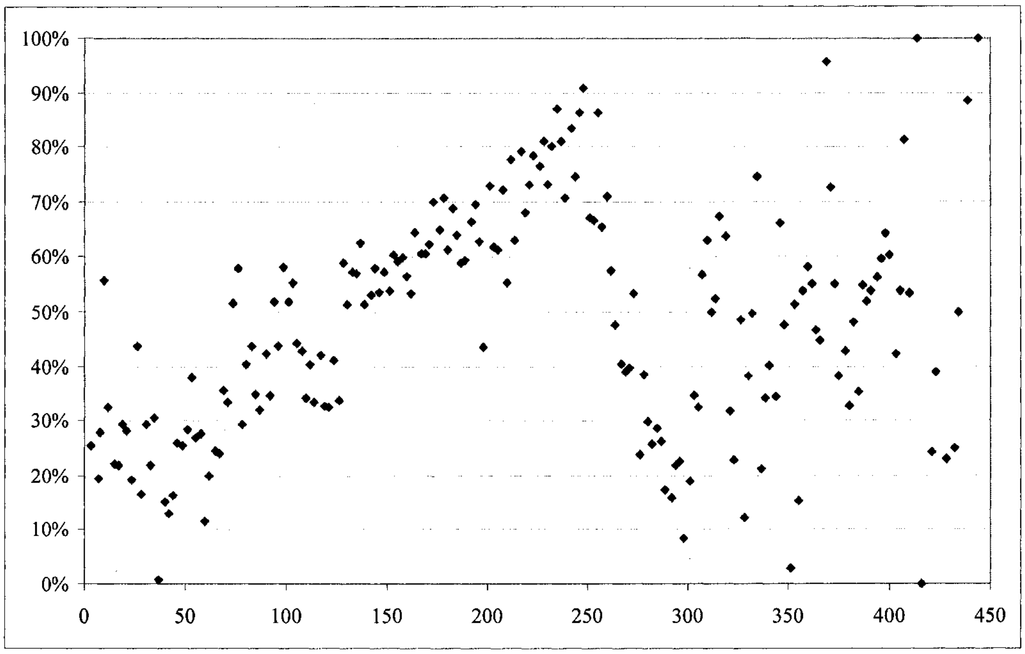

Figure 5.6. Percentage of agriculture in 2000 vs. depth to groundwater (ft) c. 1990s. There is a relationship between depth to groundwater of less than 250 ft and agricultural land cover ($r^2 = 0.79$).

Historical changes in the depth to groundwater are an indication of the patterns of water use. Land cover varies in a linear pattern in relationship to the extent of aquifer decline (Table 5.4). The percentage of NLCD grassland increases from approximately 10% in areas where the underlying High Plains Aquifer has declined by more than 150 ft, to 60% in areas without access to groundwater. Conversely, the percentage of agriculture declines from 88% to 35%. The percentage of irrigated cropland also shows a general increase as the extent of historical aquifer depletion increases, indicating the impact of groundwater pumping on aquifer decline. However, it also indicates the extent that irrigation has persisted in many areas despite the decline in water levels.

Table 5.4. Categories of High Plains Aquifer access that relate to changes in water levels (McGuire 2003) and 1992 land cover (Vogelmann et al. 2001; Qi et al. 2002).

Aquifer Water Level Changes (ft)	Grassland	Agriculture	Irrigated Cropland
<-150	10.4%	88.1%	34.5%
-100 to -150	18.0%	81.2%	38.4%
-50 to -100	28.5%	70.5%	25.6%
-25 to -50	33.8%	65.0%	23.0%
-10 to -25	38.1%	61.0%	17.7%
-10 to +25	51.2%	47.4%	5.9%
No Aquifer	60.0%	35.0%	4.9%

Intensive Land Use and Water Access

Since 1974, the total area of irrigated cropland (from the agricultural census) expanded only slightly, by 0.3% (approximately 33,700 sq k), and covered 12.2% of the region in 1997. However the trajectory of irrigated land use differs depending on the water resource situation (Figure 5.7). In general, counties that had large amounts of irrigated cropland in the 1970s have since declined in the extent of irrigation, from approximately 17% to 12.5% of the county area. Counties that were still expanding in the area of irrigated cropland during that time continued to expand, from approximately 8.7% in 1974 to 12% in 1997. Trends in counties that primarily use surface water have also generally increased.

From 1974 to 1997, there were large changes in land use associated with irrigation expansion and decline (Table 5.5). Irrigated cropland generally declined in the southern half of the ecoregion, including most of Texas which was already heavily irrigated in the

1950s. Irrigation expanded in the northern and central parts of the ecoregion including western Kansas and Nebraska and eastern Colorado. The biggest declines in irrigation occurred over the areas of the High Plains that have had the largest historical declines in groundwater. Expansion of irrigation also occurred over some areas with large amounts of groundwater decline. The irrigation expansion occurred primarily in those areas where large volumes of groundwater are still available. Farmland, total cropland, and harvested cropland all increased in the areas that had irrigation expansion. An irrigation expansion of 5,554 sq k occurred along with a 4,600 sq k expansion of cropland. Agricultural land uses generally declined in the areas of irrigation loss. An irrigation decline of 4,875 sq k occurred in association with nearly 1,000 sq k of cropland loss. There is also an association between cropland changes and livestock. Counties that expanded in cropland had a combined rate of increase in the total number of fattened cattle that was 3.4 times higher than counties with cropland loss.

Table 5.5. Land use change in counties with irrigation expansion and decline

Western High Plains Ecoregion, 1974 to 1997

Land Use Expansion

	Irrigation	Harvest	Cropland	Farmland
Sq k	5,554	4,386	4,601	1,868
Percentage	37.8%	10.8%	6.6%	1.2%

Land Use Decline

	Irrigation	Harvest	Cropland	Farmland
Sq k	-4,875	-2,854	-944	-6,132
Percentage	-26.6%	-8.7%	-1.8%	-6.2%

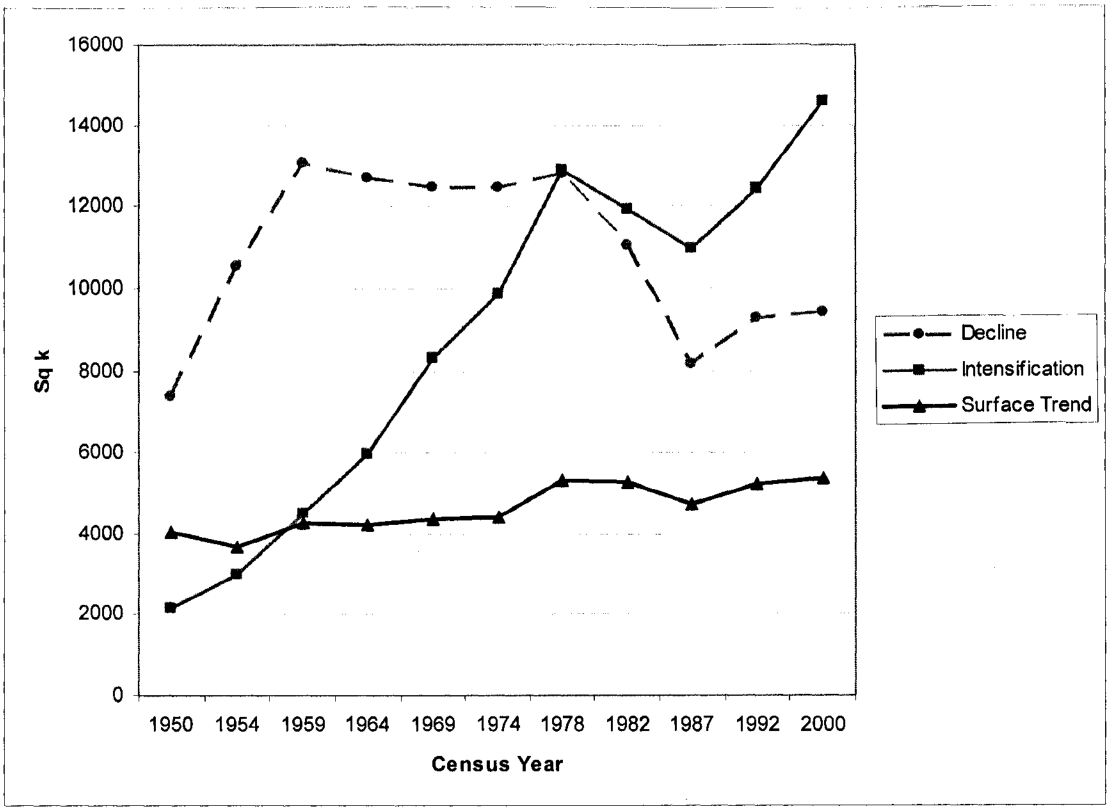

Figure 5.7. Irrigated cropland, 1950 to 1997. The southern High Plains cotton region has declined since 1974, while irrigation expanded in the rest of the ecoregion.

Groundwater Decline and Grassland Change

The association between historical groundwater decline and land cover conversion from the sample data was summarized using three categories of water access (Table 5.6). High access refers to areas where water-levels have declined by greater than 50 ft, and includes all areas of streamside irrigation. Moderate access equates to between 10 and 50 ft of groundwater decline. Low access refers to areas where water has declined less than 10 ft (assuming that there is only limited aquifer recharge) and areas where there is no aquifer access.

The data show that grassland is more persistent in areas with low and moderate access to surface and groundwater. The amount of grassland that does not change during any time interval from 1973 to 2000 ranges from approximately 10% in areas with high water access to 56% in areas with low access. Agriculture is more persistent in areas where water has been readily accessible and aquifer declines have been high. Agricultural land cover ranges from approximately 75% of the land cover in areas of high access to 29% in areas with low access. The persistence of agriculture is also high in areas of moderate access (57%). The rate of grassland stability is less than 32% for areas of moderate access. These trends indicate that aquifer characteristics and water access may have further control on grassland pattern as agricultural land use evolves in the ecoregion.

Table 5.6. Rate of land cover change between 1973 and 2000 for three categories of historical water decline and access.

Land Cover Change 1973 to 2000	Water-level Decline and Access		
	High	Moderate	Low
Persistence			
Grassland	9.8%	31.2%	55.8%
Agriculture	74.5%	56.9%	29.0%
Grassland Expansion			
Agriculture to Grassland	9.4%	4.0%	8.5%
Grassland Loss			
Grassland to Agriculture	3.4%	3.2%	1.3%
Cyclic Changes			
Ag to Grass to Ag	1.1%	3.2%	1.4%
Grass to Ag to Grass	0.1%	1.0%	0.8%
Summary			
Overall Change	14.1%	11.4%	12.3%
Net Grassland Change	6.1%	0.8%	7.1%

The overall rate of grassland change is greatest in areas of historically high water access, at 14.1%. Most of the conversions are from agriculture to grassland, with a 9.4% rate of grassland expansion. Conversions from grassland to agriculture (3.4%) result in a relatively high net grassland expansion rate of 6.1% compared to only 0.8% in areas of moderate water decline. This suggests that there may be some cropland abandonment related to changes in water access, such as caused by potential increases in the cost to pump water at greater depths.

Similar rates of grassland expansion and loss result in a low net rate of change (0.8%) in areas of moderate water access. These areas also have a high rate of cyclic changes among grassland and agriculture that total to 4.2%. The high rate of reversion back to agriculture from grassland suggests that CRP land may have been put back into cropland in these areas by the year 2000. The highest rate of grassland expansion, a 7.1% net increase, occurs in areas where water access is low. This is consistent with expectations in which dryland farmers take greater advantage of CRP income. All categories, including areas with moderate access, have a high rate of overall change.

Depth to Groundwater and Grassland Change

The increases in the depth to water that result from aquifer depletion indicate a relationship with grassland cover change. When net changes in grassland are compiled at regular intervals of depth to water, they indicate an increase in the extent of grassland expansion in the areas that overlay water depths up to 350 ft (Figure 5.8). The lower rate of grassland expansion in areas associated with depths of 350 to 400 ft indicates some of the variability of change that occurs. Some of the difference is due to a relatively high gross rate of grassland loss (10%) that offsets part of the gain.

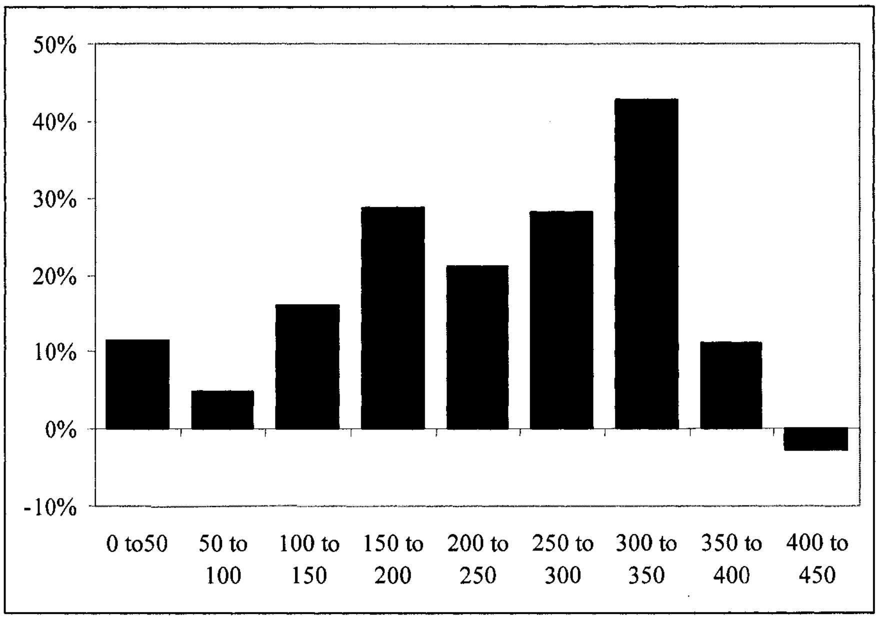

Figure 5.8. Net grassland change (percentage) from 1973 to 2000 for categories of depth to groundwater (ft).

Water Access, Land Suitability, and Grassland Trends

Aquifer characteristics have an impact on land cover that is indicated by the spatial associations with the rates and direction of grassland change. To summarize grassland trends associated with natural resource access, a simple model was identified using the maps of land suitability and historical aquifer decline. Four categories of access indicate divergent water resource situations in the region; unsuited for crops; unsuited for crops but with access to water; arable land; and arable land with access to water (Table 5.7).

Table 5.7. Land suitability and water access as they relate to grassland change (percentage and sq k) between 1973 and 2000.

Natural Resource Access	Rate of Land Conversion				Outcome of Change		
	Agriculture to Grassland		Grassland to Agriculture		Grassland Expansion	Grassland Loss	Net Change
Unsuited (no water)	1.1%	779	1.1%	794	1.2%	1.2%	0.0%
Unsuited + Water Access	3.5%	530	11.0%	1,680	5.0%	16.0%	-11.0%
Arable (no water)	13.5%	15,905	1.0%	1,196	32.0%	2.4%	29.6%
Arable + Water Access	7.2%	5,632	2.0%	1,530	66.5%	18.1%	48.4%

On all unsuited lands (from the USDA Land Capability Classification), regardless of water access, net grassland cover declined by 2.7%. On all arable lands, grassland expanded by an estimated 33%.

The net grassland loss in areas that are "unsuited for crops with water access" (-11.0%) was caused in large part by an expansion of center pivot irrigation in areas where groundwater and surface water are accessible. Grassland expanded by 530 sq k and declined by 1,680 sq k for a net loss of grassland. "Unsuited lands without water access" were relatively stable. The low rates of grassland expansion (779 sq k) and loss (794 sq k) nearly offset each other for a 0% net change in grassland cover.

The largest percentage increase in grassland (48.4%) was on "arable lands with water access". "Arable lands without access to water" had a 29.6% net increase in grassland, and have the largest amount of absolute net change (approximately 14,700 sq k).

The rates of grassland expansion and loss indicate some interesting patterns related to natural resource access that suggest a need for further study of the impacts of groundwater decline on land cover change patterns (Figure 5.9). Most notably, there is a high rate of grassland expansion in arable areas with access to groundwater.

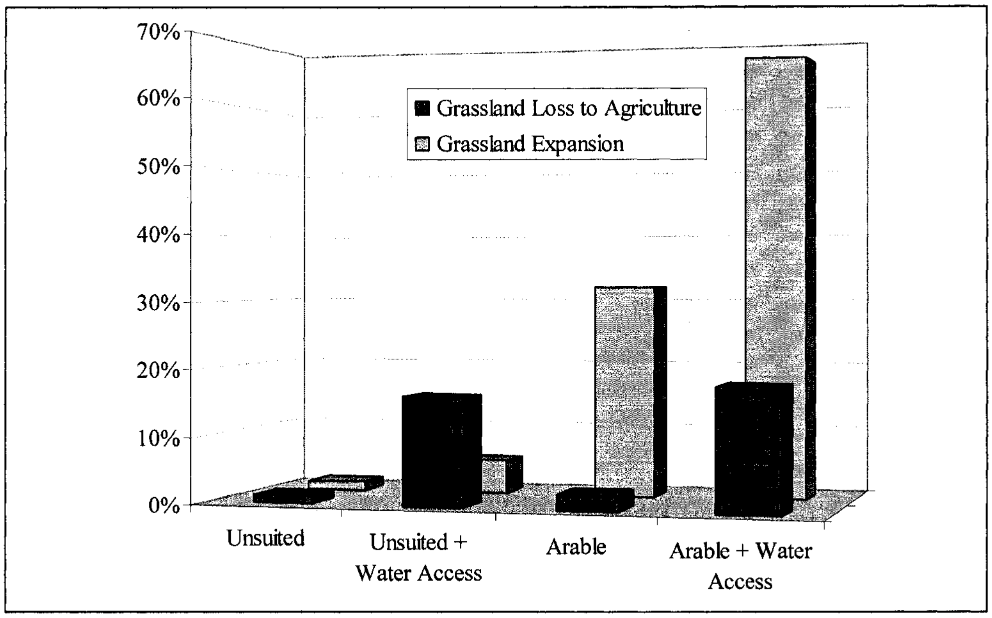

Figure 5.9. There is a higher rate of conversion from agriculture to grassland on arable lands between 1974 and 2000.

DISCUSSION

The intensification of agriculture in the conterminous U.S. that has influenced a decline in farmland area has regionally variable impacts on land use and land cover, due in large part to variability of natural resource access. The expansion and decline of irrigated cropland is one indicator of changes in water access, which may interact with a host of driving forces in a given region. The use of those natural resources, including groundwater and surface water, depends on socioeconomic processes (Roberts and Emel 1992). These concepts were explored here as spatial associations between historical groundwater access, land suitability for crops, and the changes between grassland and agriculture.

In the Great Plains, the extent of farmland, cropland and rangeland have not declined at rates similar to the U.S. as a whole. Agricultural land use declined by 4.6% in the Great Plains compared to 12.2% nationally. However, the extent of spatial changes in farmland expansion and decline, which affected a larger area of at least 10% of the Plains, suggests that there has been substantial change in the location of some agricultural uses. These changes likely have an impact on regional land cover. Another 4.1% of the Great Plains has been converted from cropland to grassland, driven by the CRP and public policy.

In the Western High Plains, the results suggest that land conversion is connected to changes in the pattern of intensive irrigated cropland and industrialized livestock production. Feedlot operations relocated to the region and irrigated corn production expanded in areas that overlay the High Plains Aquifer. The resulting pattern of land cover change has been enabled by natural resources, including land suitability and water access. Land suitability for crops is likely the most important natural resource factor shaping the regional pattern of grassland and agriculture. Climate and precipitation patterns put further constraints on cropland use not explored here. However, changes in water access are exerting control on grassland expansion and loss. Land uses have expanded where water is accessible and have declined where water access has been diminished by decades of water pumping.

The study results indicate that the macro-scale forces of population, economy, technology, culture, policy, and natural resource access drive the regional processes of grassland change. Specifically, grassland expansion, loss, and persistence in the Western High Plains are driven by a number of key socioeconomic driving forces identified below (Table 5.8 and Figure 5.10).

Driving Forces of Grassland Expansion and Loss, 1973 to 2000

Regionally, there are two driving forces that had the biggest impact on land cover change. Grassland loss was primarily caused by agricultural expansion driven by the growth of global trade and the demand for grain in the 1970s. A period of grassland expansion was caused by the CRP beginning in 1986. However, numerous forces often interact to drive change. For example, dryland crop production on marginal soils may be converted to CRP grassland when commodity profits decline or perhaps following several years of sustained drought. Cheap energy, increases in trade, and improved irrigation technology may cause a conversion from grassland to cropland in some locales. Other factors including the intensification of agriculture may have complex impacts on the direction and location of land cover change, causing expansion in some areas and abandonment in others. Technological and scientific advances in irrigation and crop genetics allow crops to expand into new areas. Genetic advancements allow corn and beans to be planted in areas that were once used only to grow wheat. Climate variability and cycles of drought likely have an important role in cropland expansion and decline, especially where abundant groundwater or surface water sources are not available for irrigation.

Table 5.8. The primary socioeconomic driving forces of grassland change between 1973 and 2000. Climate and biophysical factors play a role in all three grassland trends – loss, expansion, and persistence.

Trend	**Proximate Cause**	**Main Driving Force**	**Driving Force Type**
Grassland Loss	Grassland to Cropland	Growth of global trade and markets	Economy
		Increased demand for crops (wheat, feed corn and cotton)	
		Center pivot irrigation expansion Industrialization of meat and dairy	Technology
		Genetic advancement	Technology
	Grassland to Development	Growth of urban population	Population
		Preference for suburban, exurban environment	Culture
Grassland Expansion	Cropland to Grassland	Conservation Reserve Program policy	Policy
		Decline in water availability	Environment Culture
		Other land abandonment	Economy
Grassland Persistence	No Conversion	Dense urban population, relative to rural extent	Population
		Lack of land use competition	Economy
		Land conditions unsuited for cultivation	Environment

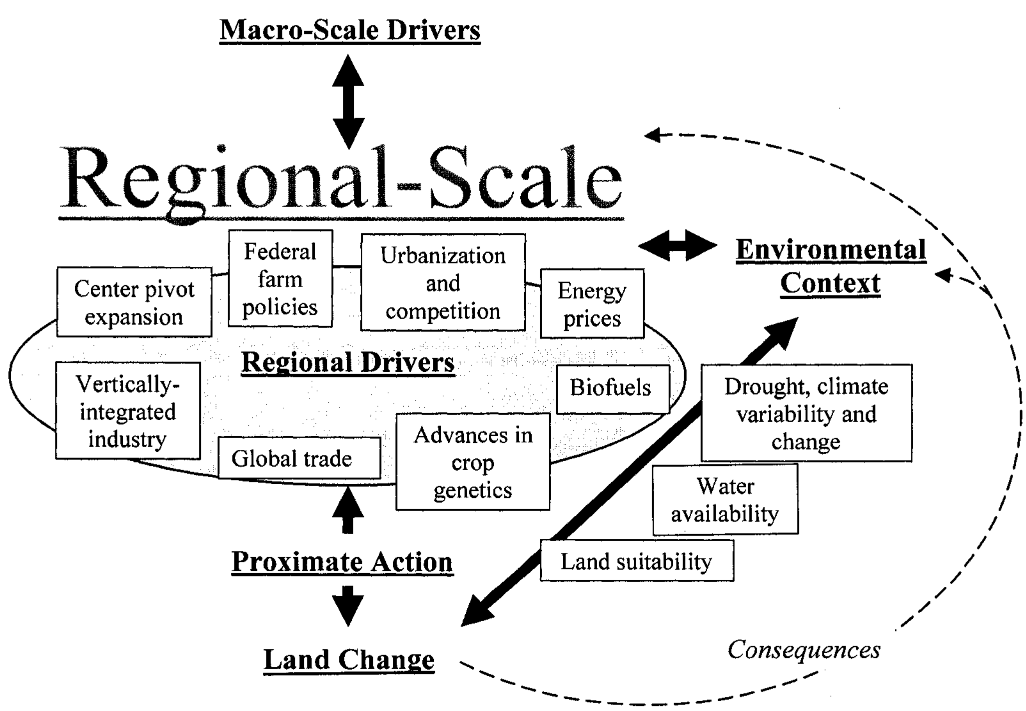

Figure 5.10. A complex of interactive driving forces (white boxes) influence regional land cover change.

Grassland Loss

Between 1973 and 1986, the total area of grassland declined during an expansion of agriculture. Cropland likely expanded in response to increased global demand for wheat and other grains. The growth of international trade and markets caused higher commodity prices that led to increased exports (Coppedge et al. 2001). The price of wheat increased 330% within a five-year period (Skold 1995). Center pivot irrigation also increased across the region during the 1970s, which allowed an expansion of irrigated corn. Some expansion occurred onto areas such as sandy soils and slopes that were previously too difficult to farm using furrow irrigation practices (Lichtenberg 1989). An abundant and relatively inexpensive supply of electricity, natural gas and other fuels was crucial to development of the High Plains Aquifer (Rhodes and Wheeler 1996). The availability of irrigated feed grain was also a factor in the relocation of feedlots and meat packing plants (Harrington and Lu 2002) that may have caused further expansion of cropland.

The rate of grassland loss dropped from 1.5% between 1973 and 1980 to 0.4% between 1980 and 1986. The deceleration in the rate of change occurred during an economic slump, when agricultural land values fell. Economic recession in 1982 led to a slowdown in agriculture that followed a period of crop surplus (Polsky 2004). The deceleration in the rate of land cover change affected the proportion of land cover but did not cause a transition from a mode of grassland loss to one of expansion. Between 1986 and 1992 when the CRP began, the rate of grassland loss to agriculture was an estimated 539 sq k.

In addition to the CRP conversions, the low rate of agricultural expansion was probably also related to the CRP farm policy. Land that would have been abandoned for economic reasons may have been converted to CRP grassland instead.

Population growth and urban development also contributed to grassland loss. The changes were likely localized and relatively small in impact compared to the regional expansion of agricultural land use. Although in the U.S. there have been important changes in exurban environments that impact the density of development beyond the urban edge (Theobald 2001). The land cover estimates indicate that urban conversions were responsible for approximately 1.2% of the total grassland loss. The analysis of population and land use indicates that urban counties lost up to 11% of their agricultural land. The losses were primarily in rangeland and could have been caused by urban expansion. An increasing amount of low-density exurban development may have also contributed. However, there is no direct way to track the outcome of land use changes using the agricultural census or the population census data. In rural counties, the cropland expansion of approximately 10% also indicates grassland loss. It is difficult to know how much of the expansion of rural cropland may be related to "land replacement" processes caused by urban expansion, but the net effect was a loss of grassland.

Agricultural intensification in developing countries may indirectly cause a decline in American agricultural land use and the extent of cropland. Increased production of cattle, soybeans, and other crops in Brazil and Argentina compete with U.S. producers. Recent studies indicate that these countries can produce and export soybeans for between 2 and

12 percent less cost than the U.S. (Schnepf et al. 2006). Global agricultural policies in the form of international trade agreements and the deregulation of agricultural markets led by the World Trade Organization may also stimulate agricultural expansion in developing countries (Mattison and Norris 2005).

Grassland Expansion

Between 1986 and 2000, grassland expanded primarily because of the CRP. The CRP has caused substantial land use changes on the Great Plains as marginal cropland is taken out of production and planted to permanent vegetation cover (Riebsame 1990). Agricultural supports and land conservation efforts, which influence regional land cover, have been a strategy used for decades to help farmers deal with economic fluctuations. Outright abandonment of farmland also occurs. Between 1973 and 1986, when cropland to grassland conversions were less affected by land set-aside programs, the gross rate of grassland expansion was only 2.0%. Based on this low rate of change, the extent of cropland abandonment caused by vacating land uses was also low.

Groundwater depletion has been substantial in the southern part of the ecoregion. Water-level declines of up to 45 m had already occurred by 1980 (McGuire et al 2003). Although the rates of decline have slowed since 1980, the economic impact of having to pump water at greater depths and with lower yields has likely affected patterns of water access in the Western High Plains. The higher rate of cropland conversion to grassland in areas where declines have been greatest suggests that it has an influence on the decision to cultivate.

Grassland Persistence

Grassland cover was more stable on land unsuited to crops and in areas where water access is low. Much of the grassland area is rangeland used for livestock grazing. It is unclear how much the use contributes to grassland stability. Common sense suggests that it plays a role. However, there is a general lack of land use competition in rural areas, as opposed to urban counties, that contributes to grassland persistence. The concentration of population in a few large urban areas, even with the issues of population expansion into surrounding landscapes, causes agricultural loss to urban to be a local issue.

Without a long history of agricultural subsidies and price supports, perhaps many of the low intensity cropland uses would have been abandoned before 1973. This might have caused a greater extent of persistent grassland between 1973 and 2000.

Regional Dynamics of Natural Resource Access and Land Change

There is no doubt that the overall influence of land suitability and climate on the pattern of land cover is great. However, the patterns of land cover change are driven in part by access to surface and groundwater resources. Similar to previous research (Wu et al. 1999), the largest absolute gains of grassland occurred in dryland crop areas as opposed to those areas with ready access to surface and groundwater. Yet, the areas that have the highest amount of historical groundwater decline have a high rate of grassland expansion. The grassland expansion rate in areas of high historical use is nearly as great as those areas without water access, where loss of dryland fallow to the CRP is expected. Approximately 6% of those areas have been converted to grassland, compared with less than 1% in areas that have had only moderate declines in groundwater.

The areas of moderate decline had the highest rate of cyclic change. The conversions from agriculture to grassland and back to agriculture suggest that those areas are more capable of returning to agricultural land use when economic conditions improve.

The simple model of natural resource access shows how the outcome of land use change on land cover is related to historical water access and land quality. The high rate of grassland expansion on arable lands with water access may be a land use response to groundwater depletion. At depths greater than 250ft, the greater depth to groundwater may become more important in the decision to pump groundwater. Energy prices, including a nearly 3-fold increase in natural gas prices, increased throughout much of the study period (DOE 2005). The high rate of grassland loss could indicate agricultural expansion into areas where water declines have been less. These expansions have also occurred onto lands that are otherwise unsuited for cultivation. The current patterns of intensive land use and land cover change are also partly explained by the saturated thickness of the aquifer that remains. There is much variability in aquifer thickness. Some areas still have substantial groundwater, while others have lesser amounts.

The uneven availability of water resources is due in part to temporal variability of intensive uses. The southern High Plains, where groundwater decline is most problematic, had already become an important cotton region by 1930 (Brooks and Emel 2000) and was set to exploit groundwater as it became available. Contemporary intensification occurs where water is still plentiful and soils are good. One of the largest transformations of regional agricultural land use in the Great Plains is the integration of irrigated feed grain production and industrial dairy and livestock production. It has caused specialization and expansion in several regions (Hart and Mayda 1998), including the Western High Plains ecoregion. Despite a global trend towards greater international trade to acquire feed grain (Naylor et al. 2005) there is still a strong link between livestock and feed crop production in the Western High Plains.

Conclusions

Cropland in the western Great Plains is vulnerable to climate change because the region receives precipitation that is marginal for cultivation (Ramankutty et al. 2002). Future loss of access to the High Plains Aquifer, whether from temporary economic conditions exacerbated by water level decline or from declines in water yields because of depletion, also leaves the region vulnerable. Yet, further advances in crop genetics and biofuels development could open new areas to more intensive agricultural land use.

In the future, new driving forces or an expanded influence of current drivers may become important in influencing the rate, pattern and proximate causes of change. New agricultural practices that cause a decrease in the use of fallow, a type of intensification that allows greater production on the same unit of land, could cause a decline in the total area of cropland. It could also cause an expansion of cropland if it makes dryland agriculture more profitable. Based on the Western High Plains analysis, there is substantial fluctuation in the extent and regional pattern of grassland caused by driving forces. Grassland expansion and loss in response to regional driving forces will continue to evolve.

REFERENCES

Anderson, J.F., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey Professional Paper 964, 28p.

Anderson, M.T. and L.H. Woosley, Jr. 2005. Water availability for the western United States: key scientific challenges. U.S. Geological Survey circular 1261.

Ayensu, E., D. van R. Claasen, M. Collins, A. Dearing, L. Fresco, M. Gadgil, H. Gitay, G. Glaser, C. Juma, J. Krebs, R. Lenton, J. Lubchenco, J.A. McNeely, H.A. Mooney, P.Pinstrup-Anderson, M. Ramos, P. Raven, W.V. Reid, C. Samper, J. Sarukham, P. Schei, J.G. Tundisi, R.T. Watson, X. Guanhua, and A.H. Zakri. 1999. International Ecosystem Assessment. Science, 286:685-686.

Brooks, E., J. Emel, B. Jokisch, and P. Robbins. 2001. The Llano Estacado of the US Southern High Plains: environmental transformation and the prospect for sustainability. United Nations University Press.

Burgi, M., A.M. Hersperger, and N. Schneeberger. 2004. Driving forces of landscape change – current and new directions. Landscape Ecology, 19:857-868.

Burgi, M. and A. Schuler. 2003. Driving forces of forest management – an analysis of regeneration practices in the forests of the Swiss Central Plateau during the 19th and 20th century. Forest Ecology and Management, 176:173-183.

Burke, I.C., W.K. Lauenroth, W.J. Parton, and C.V. Cole. 1993. Interactions of land use and ecosystem structure and function: a case study in the central Great Plains. In: Likens, G.E. and P. Groffman (eds), Integrated Regional Models. New York: Chapman and Hall.

Coffin, D.P., W.K. Lauenroth, and I.C. Burke. 1996. Recovery of vegetation in a semiarid grassland 53 years after disturbance. Ecological Applications, 6:538-555.

Coppedge, B.R., D.M. Engle, S.D. Fuhlendorf, R.E. Masters, and M.S. Gregory. 2001. Landscape cover type and pattern dynamics in fragmented southern Great Plains grassland, USA. Landscape Ecology, 16:677-690.

Dennehy, K.F., D.W. Litke, and P.B. McMahon. 2002. The High Plains Aquifer, USA: groundwater development and sustainability. In: Hiscock, K.M., M.O. Rivett, and R.M. Davison (Eds.), Sustainable Groundwater Development. Geological Society, London, Special Publications, 193:99-119.

Department of Energy, United States (DOE), Energy Information Agency. Monthly Energy Review. December 2005, http://www.eia.doe.gov.

Flinn, K.M., M. Vellend, and P.L. Marks. 2005. Environmental causes and consequences of forest clearance and agricultural abandonment in central New York, USA. Journal of Biogeography, 32:439-452.

Gallant, A.L., T.R. Loveland, T.L. Sohl, and D.E. Napton. 2004. Using an ecoregion framework to analyze land-cover and land-use dynamics. Environmental Management, 34:S88-S110.

Garrison, W.L. and D.F. Marble. 1957. The spatial structure of agricultural activities. Annals of the Association of American Geographers, 47:137-144.

Geist, H.J. and E.F. Lambin. 2001. What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. LUCC Report Series No. 4. LUCC International Project Office, http://www.geo.ucl.ac.be/LUCC.

Geist, H.J., W. McConnell, E.F. Lambin, E. Moran, D. Alves, and T. Rudel. 2006. Causes and Trajectories of Land-Use/Cover Change. In: Lambin, E.F. and H.J. Geist (eds), Land-Use and Land-Cover Change: Local Processes and Global Impacts. Berlin: Springer-Verlag.

Hardie, I., P. Parks, P. Gottleib, D. Wear. 2000. Responsiveness of rural and urban land uses to land rent determinants in the U.S. south. Land Economics, 76:659-674.

Harrington, L.M.B., and M. Lu. 2002. Beef feedlots in southwestern Kansas: Local change, perceptions, and the global change context. 2002. Global Environmental Change, 12:273-282.

Hart, J.F. and C. Mayda. 1998. The industrialization of livestock production in the United States. Southeastern Geographer, 38:58-78.

Kromm, D.E. and S.E. White. 1983. Response to groundwater depletion in southwestern Kansas. The Environmental Professional, 5:106-115.

Lambin, E.F. and H. Geist, eds. 2006. Land-Use and Land-Cover Change: Local Processes and Global Impacts. The IGBP Series. Springer-Verlag, Berlin, 222p.

Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X.B. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skanes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, and J.C. Xu. 2001. The causes of land-use and land-cover change: Moving beyond the myths. Global Environmental Change- Human and Policy Dimensions, 11:261-69.

Lichtenberg, E. 1989. Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains. American Journal of Agricultural Economics, 71:187-194.

Loveland, T.R., T.L. Sohl, S.V. Stehman, A.L. Gallant, K.L. Sayler, and D.E. Napton. 2002. A strategy for estimating the rates of recent United States land-cover changes. Photogrammetric Engineering and Remote Sensing, 68:1091-1099.

Matthews, E. 1983. Global vegetation and land-use: new high-resolution databases for climatic studies. Journal of Climate and Applied Meteorology, 22:474-487.

Mattison, E.H.A. and K. Norris. 2005. Bridging the gaps between agricultural policy, land-use and biodiversity. Trends in Ecology and Evolution, 20:610-616.

McGuire, V.L. 2003. Water-level changes in the High Plains Aquifer, Predevelopment to 2001, 1999 to 2000, and 2000 to 2001: U.S. Geological Survey Fact Sheet FS-078-03, 4 p.

McGuire, V.L., M.R. Johnson, R.L. Schieffer, J.S. Stanton, S.K. Sebree, and I.M. Verstraeten. 2003. Water in storage and approaches to groundwater management, High Plains aquifer, 2000. U.S. Geological Survey Circular 1243, 51p.

Natural Resources Conservation Service (NRCS). 2000. National Resources Inventory, 1997. U.S. Department of Commerce, Washington, DC.

Naylor, R., H. Steinfeld, W. Falcon, J. Galloway, V. Smil, E. Bradford, J. Alder, and H. Mooney. 2005. Losing the links between livestock and land. Science, 310:1621-1622.

Nellis, M.D. 1987. Land use adjustments to aquifer depletion in western Kansas. In; C. Cocklin, B. Smit, and T. Johnson, (eds). Demands on Rural Lands: Planning for Resource Use. Boulder, CO: Westview Press, pp.71-83.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers, 77:118-125.

Opie, J. 2001. John Wesley Powell was right; resizing the Ogallala High Plains. In: C. Miller (ed.), Fluid Arguments: Five Centuries of Western Water Conflict. Tuscon: U. of Arizona Press, pp.223-247.

Parton, W.J., M.P. Gutmann, and W.R. Travis. 2003. Sustainability and historical land-use change in the Great Plains: The case of eastern Colorado. Great Plains Research, 13:97-125.

Polsky, C. 2004. Putting space and time in Ricardian climate change impact studies: agriculture in the U.S. Great Plains, 1969-1992. Annals of the Association of American Geographers, 94:549-564.

Qi, S.L., A. Konduris, D.W. Litke, and J. Dupree. 2002. Classification of irrigated land using satellite imagery, the High Plains Aquifer, nominal date 1992. U.S. Geological Survey, Water-Resources Investigations Report 02-4236, Denver, Colorado, pp.31.

Ramankutty, N., J.A. Foley, J. Norman, and K. McSweeney. 2002. The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. Global Ecology & Biogeography, 11:377-392.

Raup, P.M. 1980. Competition for land and the future of American agriculture. In: Batie, S.S. and R.G. Healy (eds), The Future of American Agriculture as a Strategic Resource. Washington D.C., Conservation Foundation, pp.41-77.

Rhodes, S.L. and S.E. Wheeler. 1996. Rural electrification and irrigation in the U.S. High Plains. Journal of Rural Studies, 12:311-317.

Riebsame, W.E. 1990. The United States Great Plains. In: Clark, W. C., B. L. Turner, R. W. Kates, J. Richards, J. T. Mathews, and W. Meyer (eds). The Earth as Transformed by Human Action. Cambridge, UK: Cambridge University Press, pp. 561-575.

Roberts, R.S. and J. Emel. 1992. Uneven development and the tragedy of the commons: competing images for nature-society analysis. Economic Geography, 68:249-271.

Rosa, E.A., R.York, and T. Dietz. 2004. Tracking the Anthropogenic Drivers of Ecological Impacts. Ambio, 33:509-512.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 2004. Great Plains ecosystems: Past, present, and future. Wildlife Society Bulletin, 32:6-15.

Schnepf, R.D., E. Dohlman, and C. Bolling. 2006. Agriculture in Brazil and Argentina: Developments and Prospects for Major Field Crops. Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture, Agriculture and Trade Report, WRS-01-3.

Skold, M. D. 1995. Agricultural systems and technologies of the Great Plains. In: S. R. Johnson and A.Bouzaher (eds), Conservation of Great Plains ecosystems:Current science, future options. Dordrecht: Kluwer Academic Publishers.

Sohl, T.L., A.L. Gallant, and T.R. Loveland. 2004. The characteristics and interpretability of land surface change and implications for project design. Photogrammetric Engineering & Remote Sensing, 70:439-450.

Taylor, J.G. and R.D. Lacewell. 1988. Economic experience and perceptions of US High Plains farmers 1979-1984. Journal of Environmental Management, 26:261-275.

Terrell, B.L., P.N. Johnson, and E. Segarra. 2002. Ogallala aquifer depletion: economic impact on the Texas high plains. Water Policy, 4:33-46.

Theobald, D.M. 2001. Land use dynamics beyond the American urban fringe. Geographical Review, 91:544-564.

Tilman, D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America, 96:5995-6000.

Turner, B. L., and W. B. Meyer. 1991. Land use and land cover in global environmental change: Considerations for study. International Social Science Journal, 43: 669-79.

UNEP. 2005. One Planet Many People: Atlas of Our Changing Environment. Nairobi, Kenya:United Nations Environment Programme, http://grid2.cr.usgs.gov/OnePlanetManyPeople/index.php.

U.S. Department of Agriculture (USDA). 1997. Census of Agriculture, Geographic Area Series, AC97-CD-Vol 1. U.S.D.A. National Agricultural Statistics Service, Washington, D.C.

U.S. Bureau of the Census. 2001. 2000 Census of Population and Housing: Summary File 1 United States. U.S. Bureau of the Census, Washington, D.C.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, and N. Van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources. Photogrammetric Engineering and Remote Sensing, 67:650-662.

Walsh, J. 1980. What to do when the well runs dry. Science, 210:754-756.

Wilson, J.S. and G.H. Lindsey. 2005. Socioeconomic correlates and environmental impacts of urban development in a Central Indiana landscape. Journal of Urban Planning and Development, 131:159-169.

Wu, J., M.D. Nellis, M.D. Ransom, H. Su, and B.C. Rundquist. 1999. Characterizing the relationships between land use and groundwater for Finney County, Kansas. Geographical and Environmental Modelling, 3:203-215.

Wu, J. 2000. Slippage effects of the Conservation Reserve Program. American Journal of Agricultural Economics, 82:979-92.

CHAPTER SIX

SUMMARY OF DISSERTATION RESEARCH

This is a short reflection on the dissertation process and lessons learned while pursuing this degree.

The focus of this dissertation and most of my PhD work has been on understanding land use and land cover change. The process of completing the dissertation was the most challenging part of pursuing the degree. I probably spent most of my time trying to conceptualize the direction of the dissertation research. The research idea and the basic road map for conducting the study were contained in the proposal. However, I needed more time to read, think, and redirect some of the ideas. This may have been the most valuable part of my PhD work. Much of the rest of the time was spent on conducting the research, addressing the science issues and questions that were identified, and writing the findings. The most difficult part of the writing process was to put the results into the three separate papers that are to be submitted to science journals. Although I'm sure that it extended my time in the PhD program, it has been a valuable exercise.

One of the big lessons I learned was to more quickly sharpen and improve the ideas and concepts that are the heart of the research. Keep things as simple as possible. Simplicity is O.K. It is probably better if you can describe the research topic fairly well in one or two sentences. Try to keep the writing straightforward. The next time I take on a research project, I think that I can evolve the topic more quickly into something that is relevant to others.

This PhD means that I can feel comfortable that I understand the research process. This includes everything from conceptualizing the research questions to the effective communication of the results. The research process is not done in a vacuum. There are many other critical thinkers that can instigate new directions and help to develop new perspectives on the research problem. I intend to interact more with other researchers when undertaking my next research study. This PhD means that I have completed enough work, and learned enough about the scientific research process, to engage with other scientists at a relatively high level. The PhD means that I should be able to add to the state of knowledge in my field, and to identify knowledge gaps and try to fill them.

In the course of this research I have identified several ideas for further research. More questions arose during the study then I could answer. I feel like I have gained the research background to look further at those issues. I'll strive to be relevant.

APPENDIX

A much needed focus of land change research is the study of consequences. The field of landscape ecology and the study of patterns and metrics could aid in this focus. While it is beyond the scope of this dissertation, a couple of basic landscape metrics were explored.

METHODS

Metrics of grassland and agricultural patch sizes using Fragstats software (McGarigal et al. 2002) were derived from the 45 sample blocks. The use of land cover samples for analysis of patch trends has been limited, and the impact of the artificial patch edges created by using sample blocks needs more research (Griffith et al. 2003). Here, no adjustments were made for sample edges. Because comparisons are made primarily across time, using the same patch boundaries, some conclusions can be made about how the configuration of the landscape changes in response to grassland expansion and loss.

TRENDS IN THE NUMBER AND SIZE OF LAND COVER PATCHES

The regional expansion and decline of agriculture had an impact on landscape patterns, indicated by changes in land cover patch size and total number of patches. The number of agricultural land cover patches declined slightly prior to the CRP, during an increase in the total area of agriculture, from 306 patches in 1973 to a low of 293 in 1986 (Figure 4.5). The relatively small, 4.2% decline in patch numbers indicates that much of the agricultural expansion may have occurred on land adjacent to other croplands. The number of grassland patches increased from 619 to a high of 684 in 1986. The large proportional increase in grassland patches of 10.5% may indicate an increase in grassland fragmentation caused by cropland expansion. Between 1973 and 1986, the mean patch area of agricultural land cover increased by 7.9%, from 792 to 855 ha, while grassland patches declined by 13.3%, from 322 to 279 ha.

Between 1986 and 1992, patch numbers for agricultural land cover jumped by 18.8%, to 348, and remained steady through 2000. The number of grassland patches declined to 665 during the same period, and rose slightly to 667 in 2000. The total number of grassland patches remained relatively high in 2000, when compared to the 1973 levels (619), despite a 12.9% increase in grassland cover. After 1986, agricultural patch size declined precipitously, by 27.8%, to a low of 617 ha in 2000. Grassland patches increased by 20.8 percent to 337 ha during the same period, a high for all time periods. The declines in grassland patch totals and the increase in mean patch size during this period indicate that CRP and other cropland abandonment may have occurred adjacent to preexisting grassland, causing an aggregation of nearby grassland patches. Conversion to CRP created larger contiguous areas of grassland.

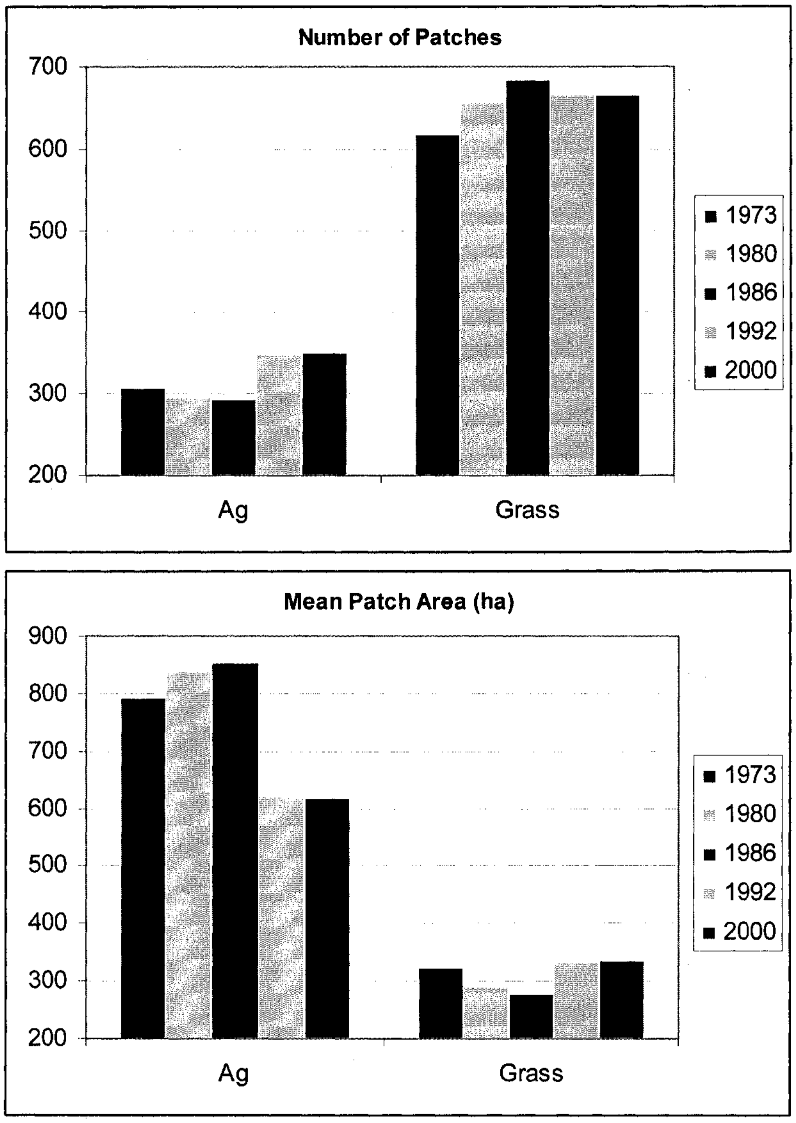

Figure 7.1. Number and mean area (ha) of agriculture and grassland patches.

Overall, there are large differences between patch characteristics for grassland and agriculture. The extent of the two land cover types are similar, particularly in 1992 and 2000 when they only differ by 1.5 percent and 2 percent respectively. Despite the similar extent, grassland averages more than twice the number of patches. Mean patch area of grassland cover is approximately half that of agriculture.

CONCLUSION

Between 1992 and 2000, the large amount of change in the location among CRP lands and cropland did not substantially affect patch size and number. This suggests that without relatively large increases in regional CRP totals, spatial changes in CRP location will not necessarily result in patch-level changes. However, there could be impacts on habitat quality that occur as the more established CRP grasslands are lost.

The ecological implications of these land cover trends include greater amounts of grassland that are potentially available for wildlife habitat. The patterns of grassland change may also have important consequences on the amount and configuration of habitat. Between 1986 and 1992, the increase in grassland patch size and declines in the total number of grassland patches was a reversal of previous trends of increasing grassland fragmentation. The change is a direct result of the response of farmers to public farm policy. The CRP has clearly had an impact in halting the previous acceleration of grassland fragmentation in the region. However, based on the greater number of patches and the much smaller patch size of grasslands in comparison to agricultural land cover, agriculture clearly causes tremendous fragmentation of grassland in the ecoregion.

REFERENCES

Griffith, J.A., S.V. Stehman, and T.R. Loveland. 2003. Landscape trends in Mid-Atlantic and southeastern United States Ecoregions. Environmental Management 32(5):572-588.

McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS spatial pattern analysis program for categorical maps. University of Massachusetts, Amherst, Massachusetts. http://www.umass.edu/landeco/research/fragstats/fragstats.html.