War and Agriculture:
Three Decades of Agricultural Land Use and Land Cover Change in Iraq

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ABSTRACT

The main objective of this dissertation was to assess whether cultivated area in Iraq, as estimated using satellite remote sensing, changed during and as a result of war and sanctions. The first study used MODIS NDVI data during OIF and the end of UN sanctions to study changes in cultivated area for Iraq as a whole and to identify spatial patterns. The results revealed significant changes in cultivated area for Iraq as a whole, with cultivated area decreasing over 35,000 ha per year. Regionally, there was little change in cultivated area in northern governorates in the Kurdish Autonomous Region, significant decreases in governorates in central Iraq, and initial increases in governorates containing the southern marshlands followed by decreases related to drought. The second study used Landsat images converted to NDVI to study changes in cultivated area in central Iraq for four periods of conflict, and relates those changes to effects on food security. The results indicated that cultivated area changed little between the Iran-Iraq War (1980 to 1988) and the Gulf War (1990 to 1991), increased by 20 percent (from 1.72 to 2.04 Mha) during the period of United Nations sanctions (1990 to 2003), and dropped to below pre-sanction levels (1.40 Mha) during Operation Iraqi Freedom (2003 to 2011). Finally, the third study builds on findings from the second study to address patterns of agricultural land abandonment in central Iraq. The largest areas of abandoned land were those cultivated during the Late Sanctions period (2000-2003). Further, the results indicate that proximity to surface water and roads are strong indicators of continuity of agricultural land use, and that abandoned lands are positioned in peripheral regions more distant from surface water and the transportation grid. We also found that surface soil salinity is increasing in the cultivated lands of central Iraq, regardless of whether it was cultivated during every period or during only a single period. The overall findings indicate that the UN sanctions had the greatest impact on cultivated area, which increased during sanctions, when food imports all but ceased, and then decreased after sanctions ended and food imports resumed.

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I thank my wife and children for their love and understanding when my time seemed all-consumed, and for bearing with me when frustration reigned. Looking back, the times you tore me away from my research were the most joyful and fulfilling of the last three years.

I thank the United States Air Force Academy and the Air Force Institute of Technology for sponsoring me for this degree. I look forward to taking what I have learned here to my next assignment in continuing service to my country.

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Chapter 1: Introduction

Research Context and Justification

Conflict and geopolitical forces are important drivers of land use and land cover change, and agricultural regions can be the most susceptible to those changes (de Beurs and Henebry 2008). However, the effects of war on agriculture go far beyond where bombs explode or where tanks travel. Young men conscripted or drafted into military service are no longer present to tend fields. Fuel burned to power military vehicles is no longer available to power tractors. Money spent by states to build military equipment and compounds cannot also be spent to repair roads and irrigation systems. War and instability affect a nation's ability to organize manpower and manage other resources such as money and land.

My goal for this research was to better understand effects of conflict on agricultural land use and land cover in Iraq, which has a long history of both conflict and agriculture. The oldest farming community yet discovered was found in Iraq and dates to 9000 BC (Spencer 2007). The world's first cities probably began in Mesopotamia, the lands near the Tigris and Euphrates Rivers (Tripp 2007). As for conflict, the three culturally distinct population centers of Mosul, Baghdad, and Basrah were combined into one administrative boundary by the Ottoman Empire during the late 1800s and early 1900s, probably with the intent of creating a divided nation—those three populations couldn't fight the Empire if they were too busy fighting each other (Tripp 2007). Tension still exists between these regions within Iraq.

Within the last three decades, Iraq has been embroiled in almost continuous conflict, including the Iran-Iraq War (1980 to 1988), the Gulf War (1990 to 1991), economic warfare in the form of comprehensive sanctions (1990 to 2003), and Operation Iraqi Freedom (OIF) (2003 to 2011). These four conflicts were fought in distinctly different ways. The Iran-Iraq War resembled World War I and WWII, with trench warfare, tank battles, and chemical weapon attacks, but limited aerial campaigns. In stark contrast to the previous conflict, the Gulf War demonstrated a more modern style of warfare, which included precision bombing, rapid ground mobility, but relatively little force-on-force combat. Then, the comprehensive sanctions enforced by the United Nations Security Council represented a form of economic warfare. Most recently, Iraq experienced the long-term occupation and reconstruction of OIF, after an initial invasion similar to the modern style of warfare of the Gulf War. Given the different types of warfare Iraq has experienced, it seems reasonable to expect that these periods of conflict would also have different effects on agricultural land use and land cover. Similarly, given the different cultural and environmental features within Iraq, it seems just as reasonable to expect that changes vary spatially.

The climate and geography of Iraq limits agriculture. The land cover of Iraq is mostly barren or sparsely vegetated (69.2 percent), open shrublands (20.0 percent), croplands (5.9 percent), grasslands (2.6 percent), water (0.9 percent), and urban or built-up (0.7 percent) (NASA LP DAAC 2010). Other classes combined make up less than one percent of land cover. Approximately 78 percent of Iraq's 43.7 million ha (Mha) surface area is not viable for agriculture due to the harsh climate and poor soils; the remaining 9.5 Mha are described as supporting agricultural activities (Schnepf 2004; UNFAO 2012). Over half of that area is used for seasonal grazing or orchards for tree crops such as dates, figs, etc. As of the early 2000s, Iraqi agricultural statistics indicated that 3.5 to 4 Mha were under cultivation annually (Schnepf 2004). Rain-fed agriculture is possible in Iraq's north, but irrigated agriculture is prevalent in the fertile valleys of the Tigris and Euphrates Rivers (Spencer 2007). There is little agricultural activity in the western desert regions (Ahmad 2002). Most of Iraq's climate is dry and extremely hot with short, cool winters, with the exception of the northern mountain regions which have cold winters and temperate summers (Spencer 2007). Precipitation is low, as low as 100 mm annually for central and western regions, and rare during the summer months, except in the mountainous north where precipitation can exceed 1100 mm annually (NCDC 2010). Droughts are natural hazards that form a normal part of the climate in this region, although a part that is not entirely predictable (Liu 2007). The primary limiting factors are high summer temperatures, water availability, and soil salinity.

Despite a long history of agriculture, in recent decades Iraq has become dependent on imported food. With the development of the oil industry in the 1930s, Iraq's population moved from the farms to the cities, reducing the indigenous agricultural labor force. Starting in the 1960s, rapid population growth, along with limited arable land and stagnant agricultural productivity, increased dependence on food imports (Schnepf 2004). Food demand outpaced food production over the years creating a growing reliance on food imports. However, there still remains potential to increase domestic production by adding additional agricultural inputs (intensification), incorporating more land for cultivation (extensification), reclaiming sodic soils through better drainage, planting salt-tolerant crop species, and through other means. Thus, Iraq presents a unique environment to study changes in agricultural land use and land cover as an effect of conflict.

The current security situation in Iraq makes a nationwide field study of agricultural changes impractical. Further, official Iraqi government statistics have proven unreliable (USDA FAS 2008). International statistics reported for Iraq for harvested area, production, and yield are often unofficial, semi-official, or estimated figures, or have been imputed from other sources to account for non-reported or missing data (UN FAO 2012). Because of the scale and scope of my hypothesis, I decided that remotely sensed data would provide the most reliable, comprehensive information. Satellite image analysis has proven to be effective for analysis of land use/land cover change within the agricultural sector, especially where reliable census data are unavailable (Dannenberg and Kuemmerle 2010). Analyzing land use patterns using satellite images can provide a spatial dimension that census-based studies often lack (Evans et al. 2002; Kuemmerle et al. 2008). Plus, freely available long-term image time series have proven effective for monitoring land cover changes caused by instability (de Beurs and Henebry 2004). In this dissertation research, I used Moderate Resolution Imaging Spectroradiometer (MODIS) normalized difference vegetation index (NDVI) data and Landsat images converted to NDVI to study changes in cultivated area in Iraq from 1984 to 2011 as effects of conflict and geopolitical forces. I should note here that this research could not have been accomplished without the free availability of MODIS and Landsat data given the size of the study area and the number of images and scenes required for compositing as part of the methods.

Dissertation Components, Attribution, and Research Objectives

This dissertation is composed of three manuscript chapters prepared for submission to peer-reviewed academic journals. The three manuscripts progress in scale of the area studied, while continuing with the overall dissertation theme of the effects of conflict on agricultural land use and land cover in terms of cultivated area. The first manuscript, Chapter 2, studies the entire country of Iraq during the end of UN sanctions and OIF. I co-authored the manuscript with Dr. James Campbell (chair) and Dr. Carl Zipper (committee member), and submitted it to the Annals of the Association of American Geographers. Chapter 2 pursues three research questions: (1) Did total cultivated area in Iraq change significantly between 2001 and 2011? (2) Were changes in cultivated area equally distributed or were there noticeable spatial patterns? And (3) How were changes in cultivated area distributed across cropping seasons? The second manuscript, Chapter 3, studies an area in central Iraq that contains approximately half of the country's croplands during four periods of conflict from 1984 to 2011. I co-authored the manuscript with Dr. James Campbell (chair) and Dr. Randy Wynne (committee member), and submitted it for a special issue of Photogrammetric Engineering and Remote Sensing, where it was accepted for publication in August 2012. Chapter 3 objectives were to: (1) determine if the effects of three decades of war have impacted Iraq's cultivated land in central Iraq, (2) determine where the most noticeable changes occurred, and (3) examine impacts those changes had on food security and water use in Iraq. Finally, the third manuscript, Chapter 4, builds on the findings from Chapter 3 to identify abandoned agricultural lands in central Iraq. I co-authored the manuscript with Dr. James Campbell (chair) and submitted it to the Journal of Land Use Science. The objectives were to (1) identify abandoned agricultural lands, (2) determine which period of conflict resulted in the largest area of abandoned lands, and (3) quantify agricultural land use and abandonment as related to proximity to surface water sources, accessibility, and salinity. Together these three manuscripts present a comprehensive study of the effects of conflict on agricultural land use and land cover in Iraq.

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Chapter 2: Spatio-Temporal Patterns of Cropland Land Cover Change in Iraq during Operation Iraqi Freedom and the End of Sanctions

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Abstract

Iraq has experienced significant geopolitical change related to Operation Iraqi Freedom (OIF) (2003 to 2011). Conflict and sociopolitical forces are important drivers of land use/land cover change, and agricultural regions can be the most susceptible to those types of changes. However, there is little remote sensing research about OIF's effects on agricultural land use/land cover. Our objectives were to (1) determine if cultivated area in Iraq changed significantly between 2001 and 2011, (2) identify patterns for cultivated area change, and (3) identify seasonal differences in cultivated area. We created multi-temporal features of MODIS NDVI data for years 2001 to 2011 and used decision tree analysis to set thresholds to distinguish between cultivated and not cultivated lands. Validation with higher resolution imagery showed 92 to 96 percent overall classification accuracies. We regressed cultivated area (ha) on time (2001, 2002, 2003,…) and years with drought influence (yes, no). The results revealed significant changes in cultivated area for Iraq as a whole, with cultivated area decreasing over 35,000 ha per year. Regionally, there was little change in cultivated area in northern governorates in the Kurdish Autonomous Region, significant decreases in governorates in central Iraq, and initial increases in governorates containing the southern marshlands followed by decreases related to drought. Seasonally, Iraq had significant decreases in cultivated area for winter crops and lands cultivated for both winter and summer crops. The greatest changes occurred in central Iraq for lands cultivated during both winter and summer seasons, possibly related to increasing wheat imports.

Keywords: land use, NDVI, MODIS, cultivation, food imports

Introduction

In the last decade, Iraq has experienced significant geopolitical events including war and military occupation from 2003 to 2011 (hereon referred to as Operation Iraqi Freedom (OIF)), the end of an oppressive regime followed by numerous transitional governments, the end of United Nations (UN) economic sanctions, and the resumption of food imports. Indeed, the United States-led invasion of Iraq in 2003 was the catalyst for all of these changes. With the end of OIF in 2011, we deemed it appropriate to investigate how cropland use and land cover has changed.

Though OIF began in 2003, some of the reasons for the war and why it could have had noticeable effects on agricultural land use date back decades. With the development of the oil industry in the 1930s, Iraq’s population moved from the farms to the cities, reducing the indigenous agricultural labor force. Starting in the 1960s, rapid population growth, along with limited arable land and stagnant agricultural productivity, increased dependence on food imports (Schnepf 2004). Food demand outpaced food production over the years creating a growing dependence on food imports. For example, wheat imports, Iraq’s major staple and its largest food import by percentage of tonnes imported, increased from 414 thousand tonnes in 1961 to 1.8 million tonnes in 1979 (UN FAO 2012a).

In 1979, Saddam Hussein took power as President of the Republic of Iraq. Early in Hussein’s reign, his government attempted to return control of Iraq’s agricultural sector to non-government entities and investment after years of failing government policies (Springborg 1986). Shortly after taking power, Hussein invaded Iraq’s eastern neighbor Iran, citing numerous border disputes, though most historians believe that his true motive was to establish Iraq as the dominant power in the region following the Iranian Revolution (Tripp 2007). The Iran-Iraq War lasted from September 1980 to August 1988, with both countries suffering military invasions from the other. Iraq's reliance on food imports continued to grow (Schnepf 2003). Wheat imports rose from 1.8 million tonnes prior to the war to 3.3 million tonnes in the 1989, the year after the Iran-Iraq War ended (UN FAO 2012a). The economic impact of the Iran-Iraq War was significant, resulting in delays on repayment of foreign loans, defaults to foreign contractors, and postponement of development projects (Spencer 2007). Iraq's enormous debt following the Iran-Iraq War is often cited as one of the reasons for its invasion of Kuwait in 1990 (Tripp 2007).

On August 2, 1990, Iraq invaded its southern neighbor Kuwait, and just four days later, the UN Security Council adopted Resolution 661 imposing comprehensive sanctions against Iraq (Russett et al. 2006). These sanctions failed to compel Hussein to withdraw his troops from Kuwait as he became determined to survive them just as he had survived the Iran-Iraq War (Freedman and Karsh 1995; Haass 1997). His defiance prompted the UN Security Council to authorize military force to remove Iraqi forces from Kuwait. The Gulf War's actual military conflict, from invasion to cease fire, was brief (January to February 1991), and executed by a multinational force led by the United States (US) to expel Iraq from Kuwait. Within a few short weeks, Iraq suffered extensive damage and destruction of its economic infrastructure (Tripp 2007). The coalition forces encountered little resistance, but stopped short of deposing Hussein and his regime.

After he was expelled from Kuwait, Hussein continued to defy UN demands, resulting in continued and even stricter sanctions. Foreign companies were prohibited from investing directly in Iraq. Oil exports were cut off, affecting revenues needed to purchase food and agricultural inputs. Agricultural products considered "dual-use", such as fertilizers, agricultural machinery, pesticides, chemicals, and parts that could have been used to repair damaged water-purification systems, were banned (Weiss et al. 1997). Although food imports were not banned, most countries that had been exporting food to Iraq ceased doing so. Wheat imports dropped to the lowest levels recorded, only 300 thousand tonnes (UN FAO 2012a). In the absence of food imports, upon which the country had become dependent, there was growing pressure for Iraqis to increase domestic agricultural production. The Hussein regime became more heavily involved with agricultural production, creating incentives for farmers to expand crop area and punishments, including death, for farmers who failed to deliver their quotas to state collection centers (Schnepf 2003). Under the Oil-for-Food Program (OFFP) some food imports resumed, and between 2000 and 2002 nearly 80 percent of cereals consumed came from imported grain (Schnepf 2004). Wheat imports increased to new single-year highs, as high as 3.2 million tonnes in 2000; however, Hussein's policies for increased production remained (Schnepf 2004; UN FAO 2012a). Despite their ineffectiveness and the civilian casualties attributed to the sanctions, they were renewed every six months until May 2003.

By 2003, the country's agricultural sector continued to suffer from the effects of prior wars, sanctions, and political instability. Iraq's irrigation infrastructure had deteriorated and was barely functioning, prime cropland suffered from widespread salinization, and soil fertility had been badly depleted from overexploitation (Schnepf 2003). The US led another military invasion into Iraq in 2003, and the Hussein regime fell quickly. After that campaign, the US and other countries conducted sustainment and stability operations in Iraq in an effort to establish political stability and to rebuild. Food imports resumed almost immediately, and many aid organizations have been investing in Iraq's agricultural sector (USAID 2006). With the fall of the Hussein regime in 2003, aid organizations augmented the rationing system put in place by the Hussein regime with imported food, but such policies have discouraged local production and distribution since local farmers could not compete with subsidized food imports (Foote et al. 2004).

Food security is essential to the sustenance and survival of any nation, whether it be from domestic production, food imports, or both. Domestic production requires the utilization of land. Therefore, it is reasonable to expect that as geopolitical forces affected Iraq's ability to import food and essential agricultural inputs, those forces would also affect cropland utilization. We conducted research to determine if and how such effects may have occurred. Given that Iraq is a nation with differing cultural and environmental features, it was reasonable to expect that changes would vary spatially. We also sought to identify seasonal changes related to crop type. For example, it is estimated that 70 to 85 percent of Iraq's cultivated land is used to grow cereals, such as winter wheat (Schnepf 2003). Wheat and wheat flour are also Iraq's largest food imports (UN FAO 2012a). Therefore, we reasoned that as wheat imports increased the amount of land cultivated for winter wheat may have decreased. Because wheat is produced primarily as a winter crop in northern and central Iraq, that would also suggest that the amount of land cultivated with winter crops would decrease over time, and that these seasonal changes should also vary spatially.

Because of the scale and scope of our hypothesis, we decided that remotely sensed data would provide the best information. Conflict and sociopolitical forces are important drivers of land use and land cover change, and agricultural regions are the most susceptible to those types of changes (de Beurs and Henebry 2008). The current security situation in Iraq makes a nationwide field study of agricultural changes impractical. Further, official Iraqi government statistics have proven unreliable (USDA FAS 2008). International statistics reported for Iraq for harvested area, production, and yield are often unofficial, semi-official, or estimated figures, or have been imputed from other sources to account for non-reported or missing data (UN FAO 2012b). Satellite image analysis has proven to be effective for analysis of land use/land cover change within the agricultural sector, especially where reliable census data are unavailable (Dannenberg and Kuemmerle 2010). Analyzing land use patterns using satellite images includes a spatial dimension that census-based studies often lack (Evans et al. 2002; Kuemmerle et al. 2008). Plus, freely available long-term image time series have proven effective for monitoring land cover changes caused by instability (de Beurs and Henebry 2004).

We used the Moderate Resolution Imaging Spectroradiometer (MODIS) normalized difference vegetation index (NDVI) data to answer the following questions:

1. Did total cultivated area in Iraq change significantly between 2001 and 2011?
2. Were changes in cultivated area equally distributed or were there noticeable spatial patterns?
3. How were changes in cultivated area distributed across cropping seasons?

Materials and Methods

Study Area

The land cover of Iraq is mostly barren or sparsely vegetated (69.2 percent), open shrublands (20.0 percent), croplands (5.9 percent), grasslands (2.6 percent), water (0.9 percent), and urban or built-up (0.7 percent) (NASA LP DAAC 2010). Other classes combined make up less than one percent of land cover. Approximately 78 percent of Iraq’s 43.7 million ha (Mha) surface area is not viable for agricultural use due to the harsh climate and poor soils; the remaining 9.5 Mha are described as supporting agricultural activities (Schnepf 2004; UNFAO 2012). Over half of that area is used for seasonal grazing or orchards for tree crops, such as dates, figs, etc. As of the early 2000s, Iraqi agricultural statistics indicated that 3.5 to 4 Mha were under cultivation annually (Schnepf 2004). Rain-fed agriculture is possible in Iraq's north, but irrigated agriculture is prevalent in the fertile valleys of the Tigris and Euphrates Rivers (Spencer 2007). There is little agricultural activity in the western desert regions (Ahmad 2002). Cereal production, primarily wheat and barley, occupies about 70 to 85 percent of Iraq's cultivated land (Schnepf 2003). Rain-fed wheat and barley, grown over the winter months, comprise from one-third to half of the total production; most of that occurs in the northern provinces (PECAD 2003; Schnepf 2003). Additional grain production occurs on irrigated lands in central and southern Iraq as both winter and summer crops (Schnepf 2003).

Most of Iraq's climate is dry and extremely hot with short, cool winters, with the exception of the northern mountain regions which have cold winters and temperate summers (Spencer 2007). Precipitation is low, as low as 100 mm annually for central and western regions, and rare during the summer months, except in the mountainous north where precipitation can exceed 1100 mm annually (NCDC 2010). Droughts are a natural hazard that are a normal part of the climate in this region, though not entirely predictable (Liu 2007).

Iraq has low crop yields by international standards. Many factors are involved. Farmers rely on low quality, farm-saved seed because seed improvement programs have repeatedly broken down over the last three decades (USAID 2006). Rainfed crop yields depend on the amount of precipitation received during the growing season, so droughts affect the northern regions more so than the central and southern regions (Schnepf 2003). In central and southern Iraq, irrigated agriculture predominates, and the primary limiting factors are high summer temperatures, water availability, and soil salinity (Schnepf 2004). The high soil salinity was caused by years of improper irrigation and poor drainage (USAID 2006).

Data

We used MODIS NDVI data for our analysis (NASA LP DAAC 2012). NDVI is calculated as the ratio of the difference between near infrared and red radiances divided by the sum of the near infrared and red radiances (de Beurs and Henebry 2004). NDVI is highly correlated with measures typically associated with plant health and productivity, such as vegetation density and cover, green leaf biomass, leaf area index, chlorophyll content, and crop condition (Lenney et al. 1996). Time series of MODIS NDVI data have been repeatedly demonstrated to be effective for quantifying vegetation and measuring vegetation dynamics (Zhang et al. 2003; de Beurs and Henebry 2008; Jacquin et al. 2010; Pittman et al. 2010; Sakamoto et al. 2010; Shao et al. 2010). To avoid cloud covered scenes, the MODIS daily acquisitions are converted into sixteen-day composites for a total of twenty-three composites per year. Compositing improves data quality and reduces data volumes by selecting cloud-free observations for each pixel within the given time interval (Pittman et al. 2010).

We evaluated years 2001 to 2011, allowing us to include two years of pre-OIF data while sanctions were still in place, though some food was being imported under the Oil-for-Food Program, and several years of data following the end of sanctions in May 2003. We downloaded the data from the Oak Ridge National Laboratory Distributed Active Archive Center. These data are free and undergo a standard processing procedure to surface reflectance (Vermote et al. 1997). The spatial resolution of the MODIS NDVI data (250 m) limits its ability to resolve smaller field sizes, but it can indicate cropland presence over large areas (Pittman et al. 2010). The MODIS NDVI composites have been shown to be capable of detecting human-driven land cover changes (Jacquin et al. 2010).

To validate our results with higher resolution imagery, we downloaded Landsat Global Land Survey (GLS) for 2000, 2005, and 2010 (USGS and NASA 2011). The GLS collection is a carefully coordinated collection of high resolution imagery (30 m) for global modeling. Use of these three periods of images allowed us to identify where croplands existed before and during our study period.

We chose to limit our analysis to areas identified as croplands by the MODIS Land Cover Products (LCP) for years 2001 to 2009 (NASA LP DAAC 2010). The LCP provides a land cover map (500 m resolution) derived from observations spanning a year's input of MODIS Terra and Aqua data. The LCP uses the International Geosphere-Biosphere Programme (IGBP) classification scheme, which includes eleven natural vegetation classes, three developed and mosaic land classes, and three non-vegetated land classes. The IGBP defines croplands as lands covered with temporary crops followed by harvest and a bare soil period for both single and multiple cropping systems (Strahler et al. 1999).

To minimize misclassifications in the mountainous north, we incorporated a digital elevation model in our analysis. We downloaded a digital elevation model (DEM) via the USGS's Earth Explorer. This DEM is the result of a collaborative effort between the U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA) to provide a notably enhanced global elevation model named Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) (USGS and NGA 2011). The GMTED2010 incorporates the current best available global elevation data. We used mean elevation from the 7.5-arc-second (approximately 250 m) spatial resolution raster.

Data Analysis

We combined the cropland land cover class from the LCPs for all years 2001 to 2009 to calculate the maximum extent of croplands in Iraq for those years. The combined area was 4.6 Mha. Next, we visually inspected those areas and masked pixels that could not be visually confirmed as croplands with the GLS imagery, giving particular attention to those areas marked as marshlands (Munro and Touron 1997; CIMI 2010) or lands used for grazing (Schnepf 2004) since those regions might have the highest potential for misclassification. In the mountainous north, we calculated the slopes for visually identifiable croplands and found them all to have slopes less than 10 degrees; therefore we masked areas with slopes greater than that value. In the end, our cropland mask included 3.9 Mha of land in Iraq (Figure 2.1), which agrees with estimates that 3.5 to 4.0 Mha of land is cultivated each year (Schnepf 2004).

For classification, we used decision tree analysis. Decision tree analysis is one of the most common methods of cropland classification and has been used with both Landsat and MODIS NDVI data (Beltrán and Belmonte 2001; Wardlow et al. 2006; Budreski et al. 2007; Shao et al. 2010). The first step was to create random points and visually inspect them in GLS imagery to identify those points that were coincident with croplands occupying the same area as a single MODIS NDVI pixel. The first 100 points that could be visually confirmed as representing cropland pixels were used for training data. We followed the same steps to find 100 points that would represent areas not cultivated. Next, we combined all 23 16-day NDVI composites for each year (2001 to 2011) into five rasters: maximum NDVI per pixel, minimum, mean, range, and sum. We extracted these raster values to our training data points for all years for a total of 11,000 point values. These point values were used in a decision tree analysis to determine which variables and what thresholds would be used for classification. We used CART

6.0 with leave-one-out cross-validation with the Gini decision rule. Results showed that maximum NDVI alone could separate "cultivated" and "not cultivated" classes with a threshold of 3575 (NDVI maximum of 0.3575). Overall classification accuracy was 93.8 percent for test pixels. Pixels with a cell value greater than 3575 were reclassified as cultivated and all others as not cultivated.

We converted the reclassified rasters to polygon shapefiles to reduce storage requirements. This also made possible the ability to split pixels along boundaries. We chose to use governorate (or province) political boundaries as our unit of analysis for three reasons: (1) Iraq's Ministry of Agriculture has historically managed agricultural activities through assistant directors at the governorate (or provincial) level (Abi-Ghanem et al. 2009); (2) official government statistics on land use, area, and number of holdings are aggregated to the governorate level (COSIT 2001); and (3) differences in cultural and environmental features can be easily separated by governorates.

To determine if changes over time were significant, we calculated cultivated area in hectares for each year, and then performed regression analysis with cultivated area (ha) as the response variable and time (2001, 2002, 2003…) and years with drought conditions (Yes or No) forming the explanatory factors. Inclusion of drought influence in the regression analysis was necessary to account for outliers related to drought years. The 2008/2009 drought was described as one of the worst droughts ever recorded in Iraq, so severe that farmers were reported to have delayed or foregone planting operations (USDA FAS 2008), which would have affected our results. However, drought effects on agriculture production vary spatially, with rainfed agriculture in the north being more affected than irrigated agriculture throughout the rest of the country (Schnepf 2004). Use of regression, as opposed to other time-series techniques, was appropriate for this analysis because of its ability to incorporate additional explanatory factors and interactions, like drought years, and because of the limited data (only eleven years) for the time-series. We tested for the presence of positive autocorrelation in our regression model errors using the Durbin-Watson statistical test for independence (Montgomery et al. 2008). The null hypothesis was that the slope of the regression line was equal to or near zero; the alternate hypothesis was that the slope of the regression line was not equal to or near zero. Slope represents the change in hectares per year as reported by the regression analysis. We defined a slope as “near zero” if it was between -100 and 100 ha per year.

To identify the amount of cropland area cultivated for winter and/or summer crops we separated dates of imagery for winter and summer crops and repeated our methods and calculated the sum of non-overlapping areas, as defined by Thenkabail et al. (2009). Winter crops, such as winter wheat and barley, are typically planted between September and November and harvested between May and June; irrigated summer crops, such as corn, millet, sorghum, rice, and sesame, are typically planted between April and May and harvested in August and September (Schnepf 2004). We divided the 23 16-day MODIS NDVI composites for each year into two groups—winter (Julian calendar days 001 to 129) and summer (days 145 to 272). We excluded late fall data because they would have included the early-growth period of a crop like winter wheat that has two growth stages: one from planting to vernalization late in one calendar year, and another from greenup to harvest early in the next calendar year (Huang and Linlin 2009).

Validation

We validated our classification methods by creating 200 random points (100 per class) for each year from 2001 to 2011 and visually inspected the higher resolution GLS imagery to determine if pixels had been properly classified as cultivated or not cultivated. This validation method had its limitations. While we were able to determine if a point was in what appeared to be cropland, it was impossible to tell if there was an actual crop growing there each year. However, the validation could confirm if our methods had classified a pixel as cultivated when it was in fact open dessert, open shrubland, urban, water, etc. Hence, we choose to be as conservative as possible during validation. For example, if our methods classified a 250 m pixel as not cultivated but the same 250 m area appeared to be cropland in higher resolution GLS imagery, then we defaulted to labeling that validation point as cultivated since it could have been cultivated during that year. Likewise, if our methods classified a 250 m pixel as cultivated but in higher resolution imagery the same area did not appear to be cropland, then we labeled the point as not cultivated. A two-by-two contingency table was created for each year to assess overall accuracy. Overall accuracies for each year ranged between 92 to 96 percent. We should reiterate that the spatial resolution of the MODIS NDVI data (250 m) limits its ability to resolve smaller field sizes, and it is possible that our results are biased towards larger parcels, representing only larger scale agricultural enterprises and excluding small fields used in more subsistence-level activity.

Results and Discussion

Spatial Changes

For Iraq as a whole, cultivated area ranged between 2.46 and 3.55 Mha for all years, and between 3.03 and 3.55 Mha for non-drought years (Figure 2.2). Regression analysis results were statistically significant ($p < 0.001$), explaining 92 percent of the total variation in cultivated area. The slope was negative (slope = -35,037), indicating a decrease in cultivated area over time. Fifteen of the eighteen governorates had significant relationships ($p < 0.05$), and r^2 ranged between 0.658 and 0.998 (Table 2.1). However, obvious patterns based on regression analysis slope existed (Figure 2.3).

In the north, three governorates had slopes near zero (slope = -76 to 14), indicating little change in cultivated area over time (Figure 2.3). All three of these governorates—Arbil, As Sulaymaniyah, and Dahuk—are associated with rainfed agriculture and are in the Kurdish-controlled regions of northern Iraq (Schnepf 2004). The Kurdish Autonomous Region (KAR) was established and recognized as an autonomous region by the Iraqi government in the early 1970s after years of heavy fighting with Kurdish rebels, and therefore, has a different history of war and agriculture than the majority of Iraq (Tripp 2007). As a result, the region was largely isolated from the sociopolitical factors that drove changes in cropland use in the majority of Iraq. For example, during the Iran-Iraq War (1980 to 1988), some factions of Kurds received support from Iran and conducted raids against Iraqi forces in northern Iraq. When the war ended, Iraqi forces executed a brutal, genocidal campaign against the Kurds which destroyed over 4000 Kurdish villages and killed as many as 182,000 Kurds, including 5000 killed in the cyanide gas attack on the town of Halabja in 1988 (Spencer 2007). Survivors were transferred to government-controlled resettlement camps, agriculture was destroyed, and much of the croplands were declared prohibited territory (Tripp 2007). Following the Gulf War in 1991, Kurdish uprisings in the north were again brutally suppressed, but this time the US and the UN established a no-fly zone in the north that stopped Iraqi military operations in that region. Hundreds of thousands of Kurdish refugees returned to the region (Spencer 2007). The region has been largely autonomous since, and therefore may not have experienced the forcible increases in cultivated area during the sanctions as did central Iraq. In fact, official government statistics on agricultural production and harvested area did not include Kurdish-controlled governorates—Arbil, As Sulaymaniyah, and Dahuk—after 1991 (Foote et al. 2004), and were excluded as recently as 2007 because of their autonomy (USDA FAS 2008).

Twelve of the eighteen governorates had statistically significant regression results with negative slopes greater than -100 (slope = -6123 to -143), indicating decreasing cultivated area over time (Figure 2.3). These twelve were all associated with irrigated agriculture in central Iraq (Schnepf 2004). In the absence of food imports during sanctions, Iraqis were forced to increase domestic agricultural production. *Intensification*—an increase in productivity from increased inputs to land already under cultivation (Wood et al. 2004)—was not possible due to the bans on imports of dual-use fertilizers, pesticides, etc. As an alternative, the Hussein regime pursued *extensification*—the horizontal expansion of agriculture into previously uncultivated lands (Elnagheeb and Bromley 1994; Schnepf 2004). However, because of Kurdish autonomy in much of the north, extensification was most effective in central Iraq. In separate research of irrigated agriculture in central Iraq (Gibson et al., in press), we used Landsat TM and ETM+ imagery from 1984 to 2011 to identify changes in cultivated area in central Iraq as related to four different periods of conflict; the results indicated that cultivated area changed little between the Iran-Iraq War and the Gulf War, increased during the period of U.N. sanctions, and decreased during OIF. Once the Hussein regime was removed from power and the sanctions ended, abundant imported foods replaced the food rationing systems and strict production controls, lowering demand for domestic production which was unable to compete with subsidized food imports, thus resulting in less cultivated area (Foote et al. 2004; Gibson et al., in press). Additionally, a recent USAID report (2004) stated that 75 percent of Iraq's irrigated area is saline, and as much as 20 to 30 percent is no longer farmed because of salinity aggravated by poor management.

Three governorates did not have statistically significant results according to our regression analysis ($p > 0.05$): Al Basrah, Dhi Qar, and Maysan (Figure 2.3). Also, the Durbin-Watson test for independence revealed these three governorates had significant autocorrelation. These three governorates contain the Iraqi Marshlands. The Iraqi Marshlands are the largest wetland ecosystem in the Middle East (CIMI 2010). Traditional cultivation there used the silt-rich flood waters to grow rice, and the year-to-year variation in flood levels determined the extent of cultivation (Munro and Touron 1997). However, upstream dam construction and drainage operations since the 1970s have caused significant damage (CIMI 2010). While some projects may have been designed to contain water, others, like the "Third River" project completed in 1993, were intended to divert water from the marshes (Munro and Touron 1997). The Hussein regime claimed these projects were an effort to increase arable land; however, a more likely interpretation is that the projects completed in the 1990s were yet another form of persecution against Shia inhabitants of the marshes who had already endured economic blockades and repeated bombardments by the Iraqi Army for their support of coalition forces during the Gulf War (Tripp 2007). Within a decade, 90 to 95 percent of the vast marshes were dry and uninhabited (Spencer 2007). Following the initial military invasion in 2003, local residents tore down and destroyed many of the levees, dams, and channels retaining and/or diverting water, resulting in uncontrolled releases that partially restored some of the former marshlands (Richardson and Hussain 2006). By March 2004, almost 20 percent of the marsh was reflooded (Richardson et al. 2005). The 2008/2009 drought and reduced flow from Iran reduced the size of the marsh almost to 2003 levels, but by 2011 the marshland area had recovered to 45 percent (CIMI 2010; UN 2011).

To determine if it would be prudent to study change in groups of larger areas for the remainder of our analysis, we repeated the regression analysis using the same variables but this time using our own digitized boundaries separating Iraq into three distinct regions: the KAR in the north, central Iraq, and the southern marshlands (Figure 2.4). We created these boundaries based on other published maps, elevation and slope, precipitation patterns, land cover, and interpretation of GLS imagery. Dividing Iraq in such a way allowed us to explain broad patterns and regional trends. Statistical analysis revealed that the KAR had a slightly negative regression slope ($p < 0.0001$, $r^2 = 0.997$, slope = -451); however, relative to the slope for the central Iraq group, we interpret this slope to indicate little change over time (Figure 2.5). The central Iraq group had highly negative regression slope ($p < 0.001$, $r^2 = 0.925$, slope = -34,782), indicating large decreases in cultivated area over time. The results for the southern marshlands were not significant.

Seasonal Changes

To determine if changes over time were significant for seasonal crops, we repeated the regression analysis by calculating cultivated area in hectares for winter and summer cropping seasons, and then performed regression analysis with cultivated area (ha) as the response variable and time (2001, 2002, 2003…) and years with drought conditions (Yes or No) forming the explanatory factors. Regression analysis revealed significant declines over time for croplands cultivated only for winter crops ($p < 0.05$, $r^2 = 0.711$, slope = -6984) and croplands used for both winter and summer crops ($p < 0.05$, $r^2 = 0.727$, slope = -36,640) (Figure 2.6). Croplands cultivated only for summer crops did not exhibit significant change. This seems to indicate that less land is being cultivated for winter cereals, which is the major staple in Iraq (Schnepf 2004). Simultaneously, wheat and wheat flour imports, Iraq's largest food import, increased from 1.8 million tonnes in 2003, when OIF started and food imports resumed, to 3.8 million tonnes in 2009, the most recent data available (UN FAO 2012a). In fact, analysis of UN FAO data (2012a) revealed that wheat and flour of wheat imports have reached new highs in recent years. During the Iran-Iraq War (1980 to 1988) the mean for those two imports was 2.6 million tonnes. The mean decreased to only 1.0 million tonnes during early sanctions (1990 to 1996), but increased during the Oil-for-Food Program (1997 to 2002) to 2.4 million tonnes. During OIF (2003 to 2009) the mean for wheat and flour of wheat imports was 3.7 million tonnes. Imports of barley, Iraq's other major winter cereal crop, are relatively small, between zero and 429 tonnes, and have not changed significantly over time (UN FAO 2012a). Therefore, it would appear that the change in cultivated area is due primarily to loss of wheat lands related to increased wheat imports.

Regionally, there were noticeable differences in the amount of land cultivated for winter crops, summer crops, or both winter and summer crops (Figure 2.7). In the KAR, cultivation was primarily for winter crops—0.9 to 1.0 Mha of croplands were cultivated for winter crops only, less than 0.02 Mha for summer crops, and between 0.1 and 0.2 Mha for both winter and summer crops (non-drought years). Regression analysis yielded significant results only for winter crops, with a slightly negative slope indicating little decrease over time ($p < 0.001$, $r^2 = 0.973$, slope =

-333). This result indicated very little change over time, as the cultivated land loss over the analysis period totaled less than one percent of the cropland base.

In central Iraq, the amount of land dedicated to winter crops and winter and summer crops were more similar, with 0.8 to 1.2 Mha of croplands cultivated for winter crops only, and 0.6 to 1.1 Mha for both winter and summer crops (non-drought years) (Figure 2.7). Irrigation in central Iraq allows farmers to cultivate lands more than once per year, as opposed to the north which relies more on winter precipitation. The amount of land dedicated to only summer crops was also higher in central Iraq, as high as 0.09 Mha, again attributable to irrigation. Regression analysis only had significant results for areas cultivated for both winter and summer crops, with a negative slope indicating a substantial decrease over time ($p < 0.005$, $r^2 = 0.827$, slope = -38,795). That negative slope represents a 20 percent decrease over the study period. This may be the result of farmers shifting land use from winter and summer crops to a single season, but if that were the case Figure 2.7 should show an increase in either winter or summer crops while winter and summer crops decreased. Thus, we believe the results indicate farmers shifted from winter and summer crops to winter only, but cultivated less area for winter crops in total.

The significant decreases in cultivated area in central Iraq, especially for lands cultivated during both winter and summer, may have been influenced by high soil salinity caused by years of overexploitation and poor management. In central Iraq, most cultivation occurs within close proximity to water sources (rivers, canals, etc.) for irrigation that has traditionally been limited to the timely flooding of fields (Schnepf 2004). Approximately 63 percent of the water for Iraq's irrigated land is gravity fed from rivers and channels, 36 percent is pumped from rivers and channels, and only 1 percent is from ground water (USAID 2007). Prior to the Hussein regime, the Iraqi government maintained the nation's irrigation canal system. During the Iran-Iraq War, government resources were diverted to the war effort and away from nonmilitary infrastructure. After the Iran-Iraq War, Iraq's enormous debt prevented reinvestment into the neglected irrigation infrastructure, which may have seemed an unnecessary expense with the growing dependence on food imports purchased with oil revenues. With the implementation of comprehensive sanctions immediately following Iraq's invasion of Kuwait in 1990, parts that could have been used to repair the country's ailing irrigation system were banned. After neglecting these systems for years and then overexploiting the land to increase production during the sanctions, there was widespread water logging and salinization that significantly reduced productivity (Schnepf 2004).

The quality of water for irrigation has also come into question. Decreased flow of the Euphrates River entering Iraq has caused salinity to reach levels that limit the water's usefulness for agriculture (Rahi and Halihan 2010). This combined with upstream farmers in Iraq using too much water inefficiently increases salinity to a level that makes return flow unsuitable for re-use without dilution. A recent USAID report (2004) stated that 75 percent of Iraq's irrigated area is saline, and as much as 20 to 30 percent is no longer farmed because of salinity. The greatest environmental threats facing Iraq are soil salinization and desertification, both of which can be aggravated by increased agricultural use followed by abandonment (Williams 1999; Haktanir et al. 2002). Once severe salinization has occurred the rehabilitation process can take several years, but the degree of salinity can be improved by plant selection, tillage practices, and soil management (Schnepf 2004). Assuming that the problem of salinity is greater in summer months when evaporation is at its highest, it would make sense that farmers would shift those lands to winter only cropping when irrigation waters are likely less saline.

Much less land was cultivated in the southern marshland region (Figure 2.7). Between 0.07 and 0.12 Mha for winter crops and less than 0.03 Mha for summer crops. However, the amount of land cultivated for both winter and summer crops varied greatly, from about 0.04 Mha before reflooding to as high as 0.17 Mha in 2006. Following the 2008/2009 drought, these values stayed below 0.06 Mha. This apparent increase in cultivated area following the partial restoration of marshlands may actually be the return of natural wetland vegetation which is difficult to distinguish from traditional marsh cultivation. Regression analysis only had significant results for areas cultivated for winter crops, with a negative slope indicating decreases over time ($p < 0.001$, $r^2 = 0.890$, slope = -3787).

Conclusions

It appears that OIF and the end of UN sanctions had a significant impact on cultivated cropland area in Iraq, with total cultivated area decreasing over time. Changes were not uniform across time or space. The cropland cultivated area changed little in three governorates in northern Iraq which have been under Kurdish control and generally autonomous since the Gulf War of 1991. The majority of Iraq, twelve governorates located in the nation's central region, experienced significant decreases in cultivated area from 2001 to 2011. We believe the reduction to be a result of reduced domestic production demand once the Hussein regime was removed from power and food imports resumed and reached new highs. Three governorates containing the Iraqi marshlands saw increases in cultivated area initially following the initial OIF invasion in 2003 as marshes were reflooded, but then decreased during the drought of 2008 and 2009. Croplands used for both winter and summer cultivation had significant decreases in cultivated area over time, with most of this change occurring in central Iraq. Cereals, such as winter wheat, represent 70 to 85 percent of Iraq's cultivated area, and changes in the amount of land dedicated to their cultivation may be related to increasing wheat and wheat flour imports.

Agriculture, now the second largest economic sector, is still Iraq's largest employer and can be effective for promoting stability through private sector development, poverty reduction, and food security (USAID 2006). As the political situation stabilizes, it will become increasingly important to monitor changes in land cover and assess agriculture performance and growth. A baseline study is critical to monitor current conditions and assess future changes. Even though agriculture is such a vital component of Iraq's economy, there is limited information available on how it has been affected by OIF and sociopolitical forces. Because the security situation in Iraq still faces some challenges, a remote sensing approach to studying land cover change was adopted. Our research presents strategies for monitoring such changes and provides an important baseline overview for this area.

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Tables

Table 2.1 Results of regression analysis with cultivated area (ha) as the dependent variable and time (2001, 2002, 2003,…) and drought influence (Yes, No) as the independent variables. Governorates with significant p-values (< 0.05) are in bold. Governorates are arranged from north to south, west to east.

Governorate	***p-value***	***r^2***	***r^2 adjusted***	***slope***
Dahuk	0.0001	0.9936	0.9908	-56
Arbil	0.0001	0.9980	0.9971	-73
As Sulaymaniyah	0.0001	0.9964	0.9949	14
Ninawa	0.0004	0.9150	0.8786	-5863
Salah ad Din	0.0007	0.9021	0.8601	-4548
At Ta'mim	0.0002	0.9274	0.8962	-2000
Al Anbar	0.0003	0.9185	0.8835	-3380
Baghdad	0.0113	0.7758	0.6798	-352
Diyala	0.0004	0.9267	0.8809	-6123
Karbala	0.0014	0.8779	0.8256	-853
Babil	0.0153	0.7546	0.6495	-3723
Wasit	0.0014	0.8778	0.8254	-4723
An Najaf	0.0468	0.6577	0.5110	-143
Al Qadisiyah	0.0227	0.6618	0.5168	-2528
Al Muthanna	0.0081	0.7965	0.7093	-676
Dhi Qar	0.8687	0.0918	-0.2974	1399
Maysan	0.3712	0.3434	0.0620	-1150
Al Basrah	0.6065	0.2184	-0.1166	-725

Figures

Figure 2.1. Map of Iraqi croplands.

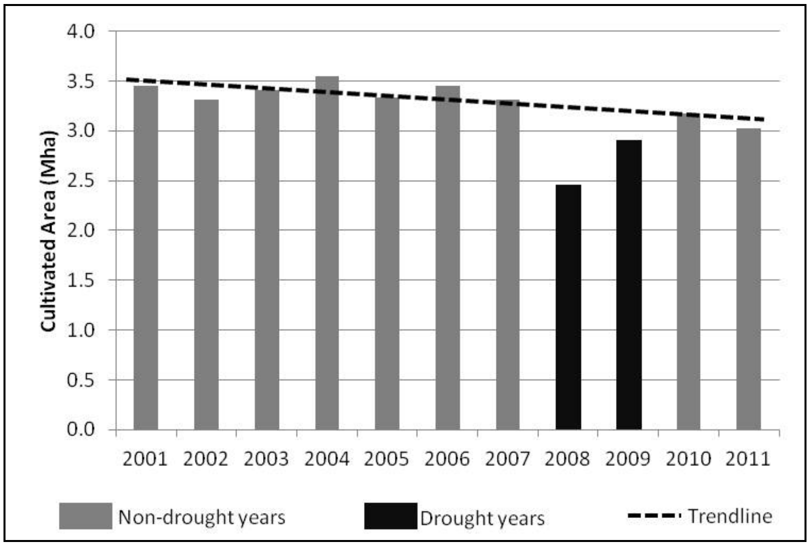
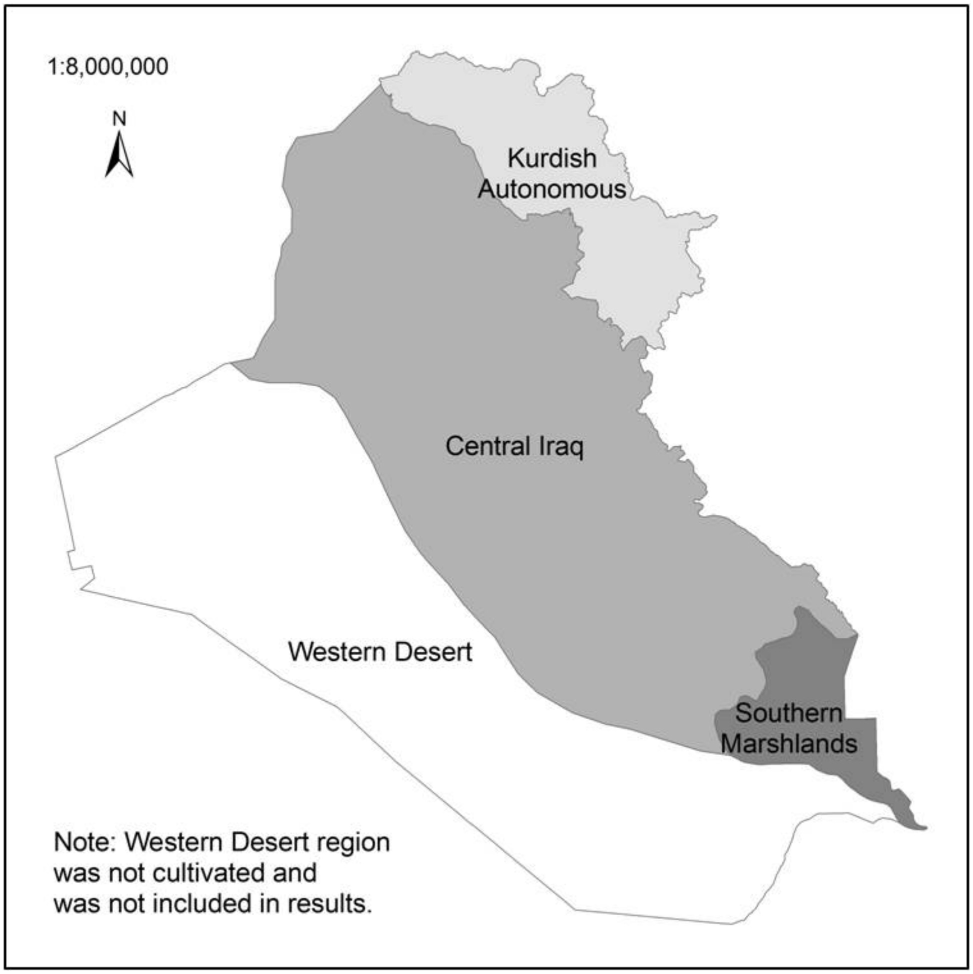


Figure 2.2. Total cultivated area in Iraq for each year from 2001 to 2011 with trendline representing negative regression analysis slope (slope = -35,037 ha/year).

Figure 2.3. Map of Iraqi governorates distinguished by regression analysis slope.



Note: Western Desert region
was not cultivated and
was not included in results.

Figure 2.4. Map of regions used in this study.

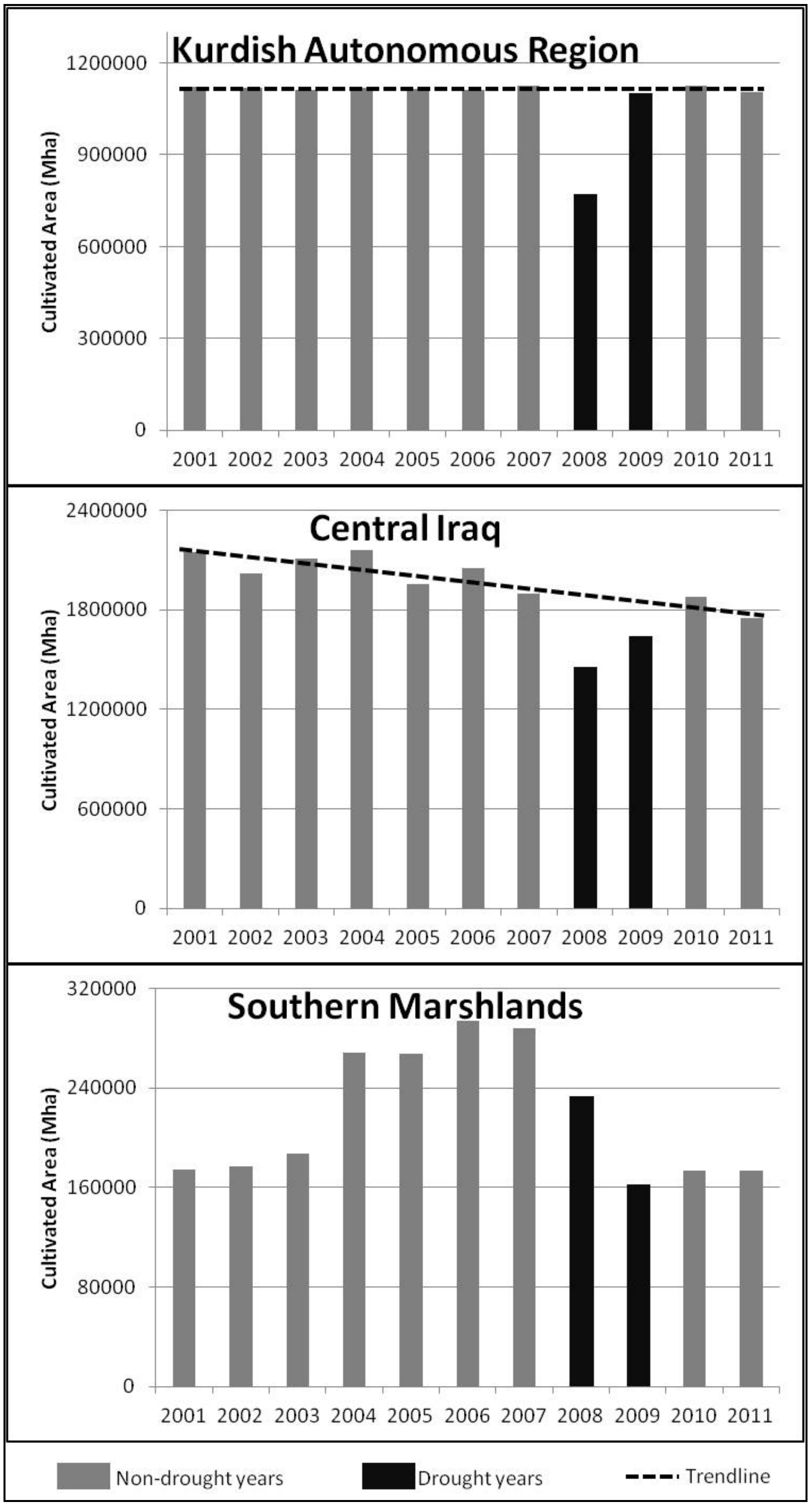


Figure 2.5. Total cultivated area by region for each year from 2001 to 2011 with trendline representing regression analysis slope. KAR: slope = -451 ha/year. Central Iraq: slope = -34,782 ha/year. Southern marshlands: Not significant.

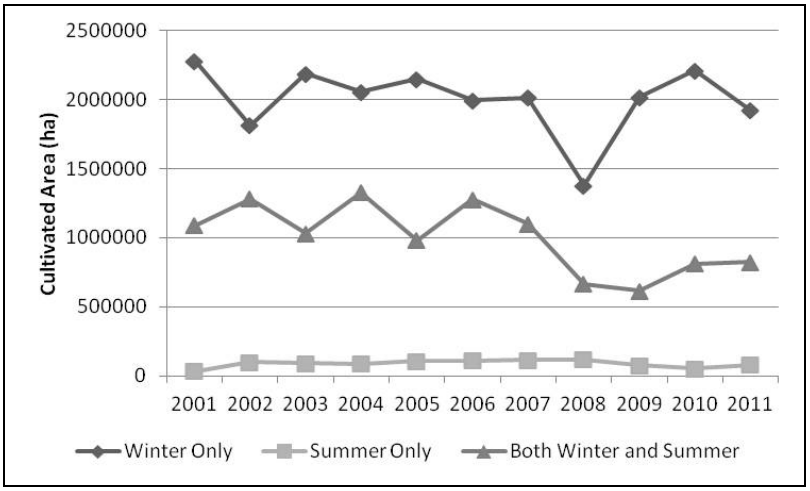


Figure 2.6. Total cultivated area in Iraq for winter crops and summer crops over time. Winter crops only: slope = -6984 ha/year. Both winter and summer crops: slope = -36,640 ha/year. Summer crops only: Not significant.

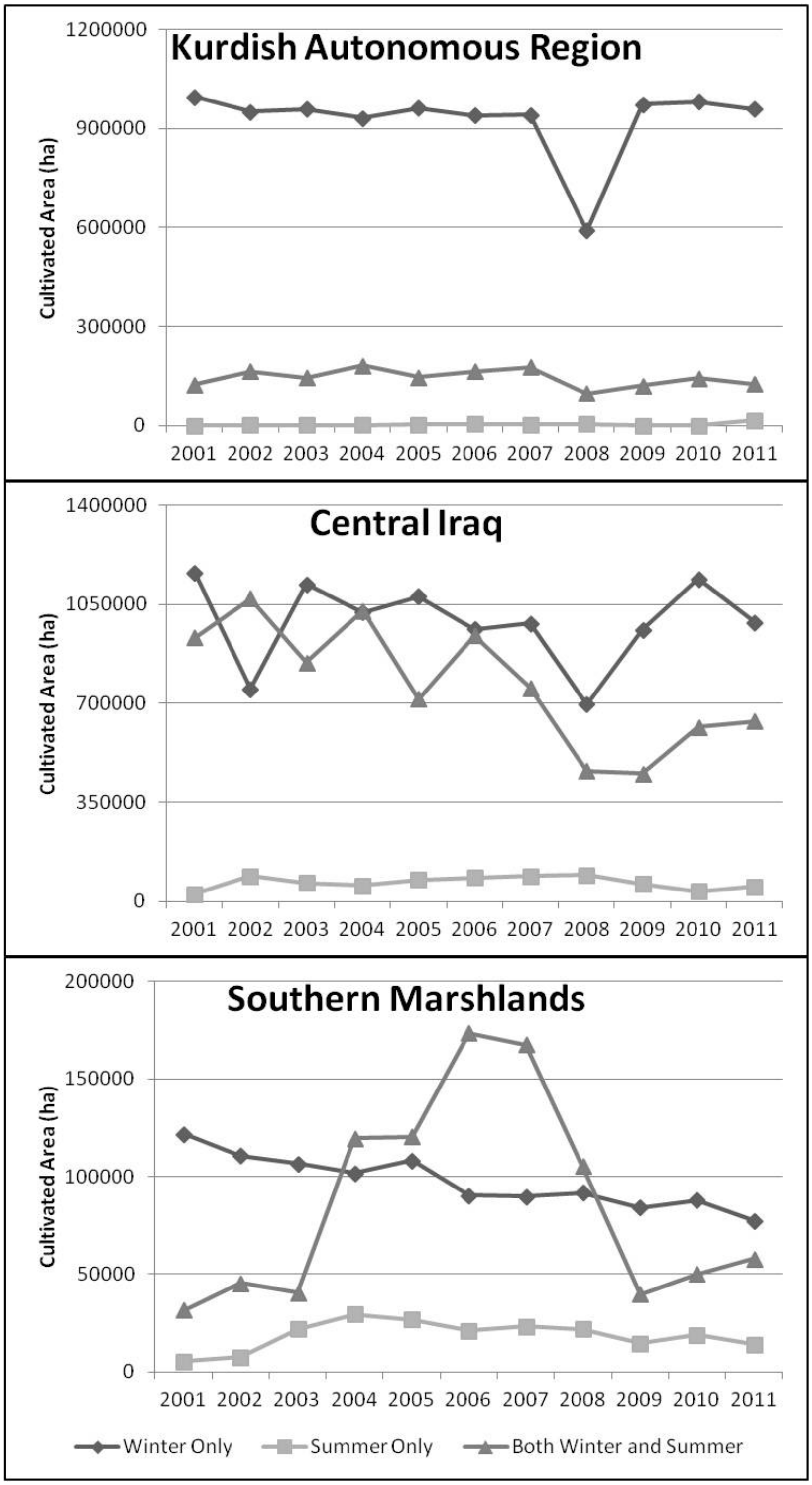


Figure 2.7. Total cultivated area in Iraq by region for winter crops and summer crops over time. The greatest slope was for areas cultivated for both winter and summer crops in central Iraq (slope = -38,795 ha/year).

Chapter 3: Three Decades of War and Food Insecurity in Iraq

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Abstract

Iraq has suffered more than three decades of near-continuous war and instability, affecting its food security. Our objectives were to assess whether cultivated area in central Iraq, as estimated using Landsat TM and ETM+ imagery, changed during and as a result of three decades of war and sanctions, and to determine which period of conflict experienced the greatest change. We created multi-temporal features of maximum normalized difference vegetation index (NDVI) per pixel and used decision tree analysis to classify pixels with high maximum NDVI as cultivated. Validation with higher resolution imagery showed a 94 percent overall classification accuracy and a kappa statistic of 0.88. The results indicated that cultivated area changed little between the Iran-Iraq War (1980 to 1988) and the Gulf War (1990 to 1991), increased by 20 percent (from 1.72 to 2.04 Mha) during the period of United Nations sanctions (1990 to 2003), and dropped to below pre-sanction levels during Operation Iraqi Freedom (2003 to 2011).

Keywords: land use, Landsat, NDVI, cultivation, sanctions

Introduction

The effects of war on food security have long been recognized. For example, in the 1930s, Japan experienced a growth in population but stagnant domestic food production and limited natural resources, leading to military expansion and invasion into Manchuria and Mongolia. Those invasions and other acts eventually led to war with the United States and the Allies in World War II (WWII) and to a serious crisis in food security for large populations in Asia (Yasuba 1996). During WWII in Europe, an effective Allied blockade compelled Germany into the Molotov-Ribbentrop Pact with the Soviet Union, also known as the Treaty of Non-Aggression between Germany and the Soviet Union, in which the Soviet Union agreed to provide Germany with soybeans and vegetables (The Economist 2011). Following WWII, the Geneva Conventions of 1949 provided guidelines for ensuring basic subsistence rights of civilian populations during periods of armed conflict. Stewart (1993) studied 16 wars in developing countries during the 1970s and 1980s and found that per capita food production declined in all but two of the countries involved. More recently, Messer (2011) stated that at least 14 countries in sub-Saharan Africa alone have suffered from severe food insecurity due to conflict or damage from past wars.

Just as no country is identical to another, not all wars are the same. Doocy et al. (2011) stated that the recent Iraq conflict resulted in the largest displacement in the Middle East in recent history and has strained food security and humanitarian assistance in Jordan and Syria. In the Democratic Republic of Congo and the Darfur region of western Sudan, theft and destruction of crop fields is an accepted strategy of denying enemies important food resources in contested regions (Mkandawire and Aguda 2009). In Sri Lanka, hundreds of thousands of people abandoned up to 70 percent of agricultural land in the war zone in 2008 and 2009, leading to a sharp increase in food insecurity (Kingsolver et al. 2010). White (2005) linked the 1998 to 2000 border war between Ethiopia and Eritrea with their long-term food insecurity. Lopez (2010) found that socioeconomic inequality, political corruption, and a culture of violence in Columbia is responsible for armed conflict that has plagued the nation for decades and has led to acute food insecurity for those internally displaced. During the Soviet war in Afghanistan, the Soviet Army mined orchards near Qandahar, instigating widespread abandonment (de Beurs and Henebry 2008). Upon return, many farmers found the cost of reclaiming those areas for food production too costly and instead cultivated opium poppies, a practice that survived instability under the Taliban and the US war in Afghanistan (Chouvy 2011).

Food shortages during war may result from a wide variety of causes including destruction of crops and fields, dislocation of populations, asset-stripping of tools and seed stocks, foreign-exchange fluctuations, transportation risks, and increased disease (Messer 1998). In some cases, food security can become an issue of food sovereignty. For example, Koc et al. (2007) stated that Iraq has been undergoing coercive integration into the global economy since the US-led invasion in 2003.

Inextricably linked to food security is water use, which can also be stressed by war and conflict. One of the main impacts of war on water is the availability of safe, clean water and sanitation to civilians in conflict zones, since disease can lead to higher mortality rates than does military action (Allouche 2011). Baban (1997) identified areas for potential conflict over water resources, citing upstream countries like Syria, Turkey, Libya, and Ethiopia that planned to divert water from rivers and aquifers to fill reservoirs and irrigation systems in an effort to increase agricultural production. Conflicts over water are typically local in extent and often in water-short nations that depend on food imports; however, water can also be the source of conflict as increases in irrigation capacity often ignore distributional issues (Allouche 2011).

From a remote sensing perspective, war and institutional changes are important drivers of land use and land cover change, and agricultural regions are the most susceptible to those types of changes. De Beurs and Henebry's (2004) analysis of Advanced Very High Resolution Radiometer (AVHRR) data from 1985 to 1988 and from 1995 to 1999 found that the disestablishment of the Soviet agricultural sector led to widespread de-intensification of agriculture in Kazakhstan of great enough significance to affect land surface phenology throughout much of the country. They also found socio-economic turbulence over twenty years affected land surface phenology in Afghanistan's agricultural regions (de Beurs and Henebry 2008) using AVHRR data from 1982 to 1988 and 1995 to 2000 and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery for 2001 and 2003. Forkuor and Cofie (2011) used Landsat Multispectral Scanner System (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) imagery to link increased urbanization with agricultural land loss in Freetown, Sierra Leone with the decade-long civil war. Witmer and O'Loughlin (2009) used Landsat TM imagery to identify abandoned agricultural land in Bosnia-Herzegovinia before, during, and after the war there. Suthakar and Bui (2008) found that between 1984 and 2004 there was a remarkable decrease in agricultural land use in the Faffna Peninsula of Sri Lanka caused by large scale population migrations from war-torn areas, with the use of Landsat TM and the Indian Remote Sensing satellite system. De Vos et al. (2008) used Landsat TM satellite imagery to validate reports of the Turkish army burning forests, agricultural fields and villages as a strategy against uprisings in Turkish Kurdistan. Beaumont (1996) applied Landsat MSS imagery to compare agricultural land use and changes in irrigation practices in Syria before and after the construction of several irrigation projects in Turkey. Zaitchik et al. (2002) conducted similar research using Landsat TM imagery and concluded that changes in water diversion and extraction have changed the distribution of human settlement in the landscape of the Khabour River basin more than droughts that force migration or famine induced by war.

Iraq has a long history of agriculture and war, with the last thirty years almost continuously in conflict (Table 3.1). Iraq's history is unique in that it has experienced many different types of warfare over the last three decades, from the World War I and WWII style of warfare of the Iran-Iraq War which included tank battles, chemical weapon attacks, and limited aerial campaigns; to the more modern style of warfare of the Gulf War and the initial campaign of Operation Iraqi Freedom (OIF) which included precision bombing, rapid ground mobility, but relatively little force-on-force combat; to economic warfare in the form of comprehensive United Nations (UN) sanctions; to the long-term occupation and reconstruction of OIF, post invasion (Gibson and Campbell 2011). During these conflicts, Iraq's landscapes were observed by civil satellite remote sensing systems. However, we found little published research applying remote sensing to assess the long-term effects of war on Iraq's agricultural land cover.

We sought to determine if the effects of three decades of war have impacted Iraq's cultivated land, specifically in central Iraq, as observed by Landsat TM and ETM+ imagery. Satellite image analysis has proven to be effective for analysis of land use/land cover change within the agricultural sector, especially where reliable census data are unavailable (Dannenberg and Kuemmerle 2010). Analyzing land use patterns using satellite images includes a spatial dimension that census-based studies often lack (Evans et al. 2002; Kuemmerle et al. 2008). Plus, freely available long-term image time series have proven effective for monitoring land cover changes caused by conflict and war (de Beurs and Henebry 2008). Our second goal was to identify which periods of conflict experienced the greatest changes in cultivated area. Due to the dates of available data, we could only include a few years of some conflicts, split other conflicts, and combine still others. The resulting periods studied were the Iran-Iraq War (1984-1988), the Gulf War and Early Sanctions (1990-1993), Late Sanctions (2000-2003), and OIF (2008-2011). The gaps in years between these four periods allow time for changes to occur, thus making changes more obvious. Other goals were to determine where the most noticeable changes occurred, and to examine what impacts those changes had on food security and water use in Iraq.

Materials and Methods

Study Area

Three Landsat scenes were chosen for this research (WRS path 168, row 037; path 168, row 038; and path 169, row 037). The study area includes the city of Baghdad and adjacent regions mostly to its east, west, and south (Figure 3.1). According to the MODIS Land Cover Product (NASA LP DAAC 2010), the area is mostly barren or sparsely vegetated (64 percent), open shrublands (16 percent), croplands (15 percent), water (3 percent), and urban and built-up (2 percent). Other land cover classes make up less than one percent of land cover. We chose these three scenes because they have little natural vegetation that could be confused with cultivated land (Schnepf 2004). Therefore, changes in cultivated area should be quite obvious. Also, irrigated agriculture in central Iraq is far less affected by drought than rain-fed agriculture in the north (USDA FAS 2008), reducing the possibility of effects related to lower-than-normal precipitation being attributed to conflict and instability.

Approximately 78 percent of Iraq's 43.7 million ha (Mha) surface area is not viable for agricultural use due to the harsh climate and poor soils; the remaining 9.5 Mha support agricultural activities (Schnepf 2004). Over half of that area is used for seasonal grazing or orchards for tree crops like dates, figs, etc. Only about 3.5 to 4 Mha is under cultivation annually. Rain-fed agriculture is possible in Iraq's north, but irrigated agriculture is prevalent in the fertile valleys of the Tigris and Euphrates Rivers. There is little agricultural activity in the western desert regions (Ahmad 2002). Cereal production constitutes about 70 to 85 percent of Iraq's cultivated land, two-thirds of which occurs in the irrigated zones of central Iraq (Schnepf 2003). Winter crops, such as winter wheat and barley, are typically planted between September and November and harvested between May and June; irrigated summer crops, such as corn, millet, sorghum, rice, and sesame, are typically planted between April and May and harvested in August and September (Schnepf 2004).

Most of Iraq's climate is dry and extremely hot with short, cool winters (Spencer 2007). Precipitation is low, less than 250 mm annually for most of Iraq and less than 100 mm annually for the majority of our study area, where irrigation is necessary year-round (USAID 2007). Precipitation is rare during the summer months, except in the cooler north (NCDC 2010). Over 90 percent of Iraq's precipitation occurs between November and April (Schnepf 2004). Between May and October, high temperatures and dry winds lead to high evaporation rates (Mahdi 2000).

Iraq has low crop yields by international standards. Farmers rely on low-quality, farm-saved seed because seed improvement programs have repeatedly broken down over the last three decades (USAID 2006). The primary limiting factors are high summer temperatures, water availability, and soil salinity (Schnepf 2004). The high soil salinity was caused by years of improper irrigation and poor drainage (USAID 2006).

Data Selection and Processing

We chose to use the Landsat family of sensors because it has imagery dating back to the early 1970s, has maintained a consistent suite of calibrated sensors, and is freely available. The TM and ETM+ have suitable spatial resolution (30 m) for our analysis and have been used for decades in this type of research. However, the temporal resolution of Landsat did pose some challenges. Cloud-free scenes were not uniformly available throughout the year. There were several years in the mid-1990s in which not a single TM image of central Iraq was available. Also, after the ETM+ scan-line-corrector (SLC) malfunction of Landsat 7 in 2003, portions of scenes are not useable for this study. All of these factors combined to make a season-to-season or year-to-year study impractical. Therefore, we created multi-temporal features to account for years when fields were left fallow, experienced early or late green-ups or harvests, suffered from drought conditions, etc.

To determine which dates of imagery would be most appropriate for our methods, we studied the phenology of the scenes using ten years of MODIS NDVI data (2001 through 2010). This multistep process created one thousand random points within the three scenes, subsequently reduced to only those points that could be positively identified as agricultural fields in higher resolution imagery. We ensured that the points were in fields of large enough size to encompass an entire MODIS NDVI pixel (250 m). Next, we extracted MODIS NDVI values for 300 of those points for all 230 16-day composites between 2001 and 2010. The values were entered into a spreadsheet that was used to create phenological charts like the one shown in Figure 3.2.

Based on the curves, we decided images acquired between February 2nd and April 5th would be identified as recording days when winter cereal crops would be “green”, and images dated between June 10th and August 12th would record days when summer crops would be “green.” The low NDVI during summer months in the phenological charts may be an effect of our point locations or that summer crops are planted further apart than cereal crops, creating mixed pixels with both vegetation and barren land. What appears to be a second, though less distinct “green” period in the fall is most likely the early-growth period of a crop like winter wheat that has two growth stages: one from planting to vernalization and another from greenup to harvest (Huang and Linlin 2009). Excessive cloud cover during these days prevented inclusion in this study. Table 3.2 lists dates of imagery used for each period.

We downloaded the Landsat imagery using the Global Visualization Viewer (courtesy of the U.S. Geological Survey). These images were preprocessed using the Level 1 Product Generation System and received Level 1T Standard Terrain Correction, which provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a digital elevation model for topographic accuracy. The vast majority of the images had reported cloud cover estimates of less than 10 percent, the highest estimate was 20 percent, and all were inspected to ensure that the location of cloud cover would not obscure cultivated areas. We also inspected for blowing sand and haze and found no indication of any in our study area. Because our methods employ compositing, the effects of unnoticed, light haze in a single scene should be mitigated. We used the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) to correct each image to directional surface reflectance (Masek et al. 2006). In this process Landsat digital numbers are calibrated to at-sensor radiance and atmospherically corrected to surface reflectance using 6S (Vermote et al. 1997). The version of LEDAPS we used also included an improved cloud mask algorithm that can mask pixels that were cloud covered or shadowed by clouds.

Analysis

After the images were processed and converted to NDVI, they were grouped into periods. Within groups, we created a mosaic raster layer that contained the maximum NDVI value for each pixel. Along with the 300 points in positively identified cultivated areas used to create the phenological charts discussed earlier, we also created 300 random points in what could be positively identified as areas not cultivated (barren, sparsely vegetated, water, urban, etc.) and extracted MODIS NDVI values as before. These 600 points had values for maximum, minimum and range of NDVI values per pixel and were used in a decision tree analysis to determine which variables and what thresholds would be used for classification. Decision tree analysis is one of the most common methods of cropland classification and has been used with both Landsat and MODIS NDVI data (Beltrán and Belmonte 2001; Budreski et al. 2007; Shao et al. 2010; Wardlow et al. 2006). We used CART 6.0 with leave-one out cross-validation with the Gini decision rule. Classification accuracy was 100 percent for test pixels. The decision tree results showed that maximum NDVI alone could separate cultivated and not cultivated classes with a threshold of 0.3078. We rounded this up to 0.31 for our threshold and classified pixels with greater than a 0.31 NDVI maximum as cultivated and all others as not cultivated.

In addition to investigating the timing of changes, we were also interested in where changes had occurred. To accomplish this task we reclassified the rasters for each period with unique values for cultivated pixels, and then added the rasters together. The resulting raster allowed us to identify which pixels were cultivated during any single period, or during multiple periods.

Validation

For validation, we created random points and then visually confirmed whether or not their collocated pixels were classified correctly with the use of higher resolution imagery. For this process, we used Quickbird panchromatic images at 0.62 m resolution acquired between May 2002 and June 2003. This validation method had its limitations. First, we did not have access to high resolution imagery prior to the advent of civil satellite remote sensing systems like Quickbird. This means that we were not able to validate our results for the periods of the Iran-Iraq War, Gulf War and Early Sanctions, and were limited to only validating the results of our classification for the period of Late Sanctions. However, we believe that conclusions of this limited validation extend in space and time because our methods (acquisition dates of imagery linked to phenology, LEDAPS preprocessing, use of NDVI, etc.) were consistent for all periods.

A second limitation was that while we were able to determine if a point was in what appeared to be an agricultural field at the time the images were acquired, it was impossible to tell if there was an actual crop growing in the field. However, the validation could confirm if our methods had classified a pixel as cultivated when it was in fact barren, open shrubland, urban, water, etc. Hence, we choose to be as conservative as possible during validation. For example, if our methods classified a 30 m pixel as not cultivated but the same 30 m area appeared to be an agricultural field in higher resolution imagery, then we defaulted to labeling that validation point as cultivated since it could have been cultivated during that year. Likewise, if our methods classified a 30 m pixel as cultivated but in higher resolution imagery the same area did not appear to be an agricultural field, then we labeled the point as not cultivated. This conservative approach may have artificially lowered the overall accuracy.

We created 50 random points per category for our sample size, as suggested by Congalton and Green (2009) as a general guideline. We compiled our results in an error matrix and calculated overall accuracy according to Campbell and Wynne (2011). Forty-eight of our 50 random points for the "cultivated" class were positively identified as being in agricultural fields. We also created 50 random points for the "not cultivated" class, but opted not to use the higher resolution imagery to validate all of these points due to time and cost constraints, and because most could be positively identified as being barren, water, or urban in the Landsat imagery. Forty-six out of the 50 "not cultivated" pixels were correctly classified. The overall accuracy of our classification was 94 percent, and Kappa was 0.88.

As further validation, we compared our results for a single governorate in Iraq with official statistics for Iraq for the year 2001. Our study area completely contained only two governorates: Baghdad and Babil. Because Baghdad governorate is relatively small and mostly urbanized, we selected Babil to validate our methods. According to the Central Organization for Statistics and Information Technology in Iraq (COSIT 2001), Babil had approximately 429,210 ha of permanent cropland in 2001. We created a subset of our results for the Late Sanctions period (2000 to 2003) for only the governorate of Babil, and our cultivated area was 439,287 ha, within 2 percent of the COSIT area. Therefore, we are confident that our methods were successful in identifying croplands that were cultivated during the period.

Results and Discussion

Changes in Cultivated Area

First, we compared cultivated area for only the three periods that did not use Landsat 7 SLC-off images: the Iran-Iraq War, the Gulf War and Early Sanctions, and Late Sanctions

(Figure 3.3). Our results showed that little change occurred between the Iran-Iraq War and the Gulf War, 1.69 and 1.72 Mha respectively. Cultivated area increased by approximately 20 percent from Early Sanctions to Late Sanctions, to over 2.04 Mha. Cultivated area in Iraq is estimated to be between 3.5 and 4 Mha annually, and our study area includes about half of Iraq's cropland land cover class according to the MODIS LCP, which would mean cultivated area should be approximately 1.75 to 2 Mha. Our results are within that range. To identify the amount of cultivated area that was double-cropped we separated dates of imagery for winter and summer crops and repeated our methods and calculated the sum of non-overlapping areas (Thenkabail et al. 2009). We found little change in single-cropped and double-cropped cultivated area between the Iran-Iraq War and the Gulf War and Early Sanctions, followed by noticeable changes during the sanctions: (1) increase from 0.96 to 1.33 Mha for winter crops, (2) decrease from 0.24 to 0.07 Mha for summer crops, and (3) increase from 0.52 to 0.65 Mha for areas double-cropped (Figure 3.4). This may indicate that lands previously used in production of traditional summer crops exclusively were increasingly being used for winter cereal crops instead.

To include the period of OIF, we applied the Landsat 7 SLC-off gap masks to all periods for comparison. The gap masks hid 43 to 44 percent of the cultivated area for the prior periods, showing consistency in the amount of information hidden by the gaps. Again, the results showed little change prior to sanctions, 0.96 Mha during the Iran-Iraq War period and 0.96 Mha during the Gulf War and Early Sanctions period, an increase of approximately 20 percent to 1.17 Mha during the Late Sanctions period, followed by a large drop to 0.79 Mha during OIF. By assuming this value is 43 to 44 percent lower than it could be because of the gaps in the combination of SLC-off images, we estimate that the actual cultivated area for the OIF period could be as high as 1.4 Mha. That constitutes an approximately 30 percent decrease in cultivated area from the period of Late Sanctions to OIF. Using this same principle to adjust OIF values, it appears that summer and double-cropped areas returned to near pre-sanction levels while winter crops experienced the greatest changes since the end of sanctions, decreasing from 1.32 to 0.68 Mha.

Conflict and Food Security in Iraq

With the development of the oil industry in the 1930s, Iraq's population moved from the farms to the cities, reducing the indigenous agricultural labor force. Starting in the 1960s, rapid population growth, along with limited arable land and stagnant agricultural productivity, increased dependence on food imports (Schnepf 2004). Food demand outpaced food production over the years creating a growing dependence on food imports. Iraq's agricultural potential and dependence on food imports, plus its history of political turmoil, made its agricultural sector particularly susceptible to geopolitical stressors like war and sanctions.

In 1979, Saddam Hussein took power as President of the Republic of Iraq. Early in Hussein's reign, his government attempted to return control of Iraq's agricultural sector to private control and investment after years of failing government policies (Springborg 1986). Shortly after taking power, Hussein invaded Iraq's eastern neighbor Iran, citing numerous border disputes, though most historians believe that his true motive was to establish Iraq as the dominant power in the region following the Iranian Revolution (Tripp 2007). The Iran-Iraq War lasted from September 1980 to August 1988, with both countries suffering military invasions from the other. Iraq's harvested area and production expanded during the 1980s for most crops, despite the diversion of labor and resources towards the war effort; however, Iraq's reliance on food imports also continued to grow, mostly from the US (Schnepf 2003). The economic impact of the Iran-Iraq War was significant, resulting in delays on repayment of foreign loans, defaults to foreign contractors, and postponement of development projects (Spencer 2007).

Iraq's enormous debt following the Iran-Iraq War is often cited as one of the reasons for its invasion of Kuwait in August of 1990 (Tripp 2007). Not much is written about Iraq's agriculture during the time between the end of the Iran-Iraq War and Iraq's invasion of Kuwait, but it appears that during this interval harvested area did not differ significantly from that between 1980 and 1988 (UN FAO 2010; USDA FAS 2010), perhaps indicating that similar agricultural practices and policies existed. In August 1990, the UN Security Council adopted Resolution 661 imposing comprehensive sanctions against Iraq (Russett et al. 2006). These sanctions failed to compel Hussein to withdraw from Kuwait as he became determined to survive them, much as he had survived the Iran-Iraq War (Freedman and Karsh 1995; Haass 1997).

The Gulf War's actual military conflict, from invasion to cease fire, was brief (January to February 1991), and executed by a multinational force authorized by the UN and led by the US to expel Iraq from Kuwait. The military engagement began with an aerial bombing campaign designed to attack Iraq's leadership, key production, infrastructure, population, and fielded military forces, in that order (Reynolds 1995). Within a few short weeks, Iraq suffered extensive damage and destruction of its economic infrastructure, more so than during all eight years of its war with Iran (Tripp 2007). The bombing destroyed electrical grids, roads and bridges, sewage and water-purification systems, oil refineries, factories and other industries (Spencer 2007). Schnepf (2003) reported anecdotal evidence that Iraq's irrigation infrastructure suffered significant damage. A limited ground campaign followed the aerial bombardment, encountering little resistance, but stopped short of deposing Hussein and his regime.

After he was expelled from Kuwait, Hussein continued to defy UN demands, resulting in continued and even stricter sanctions. The aim of economic sanctions is to coerce target states and their political leaders to change their contested policies by making defiance of international norms more costly than cooperation (Werthes and Bosold 2005). In the case of Iraq, foreign companies were prohibited from investing directly in Iraq. Oil exports were cut off, affecting revenues needed to purchase food and agricultural inputs. Agricultural products considered "dual-use", such as fertilizers, agricultural machinery, pesticides, chemicals, and parts that could have been used to repair damaged water-purification systems, were banned (Weiss et al. 1997). Although food imports were not banned, most countries that had been exporting food to Iraq ceased doing so. In the absence of food imports, upon which the country had become dependent, there was growing pressure for Iraqis to increase domestic agricultural production. *Intensification*—an increase in productivity from increased inputs to land already under cultivation (Wood et al. 2004)—was not possible due to the bans on imports of dual-use fertilizers, pesticides, etc. The only alternative was *extensification*—the horizontal expansion of agriculture into previously uncultivated lands (Elnagheeb and Bromley 1994). The Hussein regime became more heavily involved with agricultural production, creating incentives for farmers to expand crop area and punishments, including death, for farmers who failed to deliver their quotas to state collection centers (Schnepf 2003).

Iraq was confronted with inadequate internal food production after years of reliance on external food supplies purchased with oil revenues (Messer 1998). In response, Hussein created a food rationing system that eventually distributed food rations to virtually everyone in the country through local food stores or bakeries (Foote et al. 2004). But such measures were not sufficient to support basic needs. Food rations only provided about 1300 calories per person per day, about

40 percent less than World Health Organization recommendations (UN 2003). The Iraqi people suffered terribly—the monthly death toll from malnutrition-related illnesses averaged 5750 by the mid-1990s (Spencer 2007). Reports estimated that more than 500,000 Iraqi children died in the first five years that the sanctions were imposed (Messer 1998). Some have described the severity of the sanctions as genocidal in nature (Simons 1999). The sanctions themselves were a greater danger to food security than armed conflict.

Hussein initially refused the Oil-for-Food Program (OFFP) resolution in 1991, but in 1996 he agreed to its terms. With the implementation of the OFFP, monthly caloric intake increased and childhood malnutrition rates dropped, but were still well below pre-sanction levels (Foote et al. 2004). Between 2000 and 2002, nearly 80 percent of all cereals consumed in Iraq came from imported grains (Schnepf 2004), yet during this same time cereals were still the main crops, averaging 75 percent of Iraq's harvested area (UN FAO 2010). Despite their ineffectiveness and the civilian casualties attributed to the sanctions, they were renewed every six months until after the US invasion of Iraq in 2003.

By 2003, the country's agricultural sector remained plagued by the effects of prior wars, sanctions, and political instability. Iraq's irrigation infrastructure was barely functioning, prime cropland suffered from widespread salinization, and soil fertility had been badly depleted from overexploitation (Schnepf 2003). The opening aerial bombardment campaign of OIF in March of 2003 greatly resembled the initial air campaign of the Gulf War, but with greater precision and close coordination with a near-simultaneous ground invasion. The Hussein regime fell quickly. Since that initial campaign, the US has led other countries in sustainment and stability operations in Iraq in an effort to increase political stability while rebuilding continues. Food imports resumed almost immediately, and many aid organizations have been investing in Iraq's agricultural sector (USAID 2006). With the fall of the Hussein regime in 2003, aid organizations have augmented the rationing system put in place by the Hussein regime with imported food, but such policies have discouraged local production and distribution since local farmers could not compete with subsidized food imports (Foote et al. 2004). Despite Iraq's strong agricultural heritage, decades of war, sanctions, and political instability have left the country unable to provide for its domestic market.

Spatial Changes and Water Use

By reclassifying the rasters for each period with unique values and combining them, we were able to identify pixels cultivated during a single period or during multiple periods (Figures 3.5 and 3.6). We also converted pixels classified as cultivated during the Iran-Iraq War, Gulf War and Early Sanctions, and Late Sanctions into polygons and conducted a nearest neighbor analysis to better understand the dispersion of agriculture during these periods. We excluded the period of OIF because the Landsat 7 SLC-off gaps would have biased the results. The results provided the average distance from each feature to its nearest neighboring feature. Observed mean distances (OMD) were 169.6 m, 164.8 m, and 195.0 m for the Iran-Iraq War, the Gulf War and Early Sanctions, and Late Sanctions periods, respectively. The larger OMD for the Late Sanctions period means that cultivated area was more dispersed than it was during previous periods, possibly indicating that farmers cultivated land further away from previously used lands. In central Iraq, this effect poses some challenges since agriculture there is predominantly irrigated and most cultivation occurs within close proximity to water sources (rivers, canals, etc.) for irrigation that has traditionally been limited to the timely flooding of fields (Schnepf 2004). Approximately 63 percent of the water for Iraq's irrigated land is gravity fed from rivers and channels, 36 percent is pumped from rivers and channels, and only 1 percent is from ground water (USAID 2007).

Prior to the Hussein regime, the Iraqi government maintained the nation's irrigation canal system. During the Iran-Iraq War, government resources were diverted to the war effort and away from nonmilitary infrastructure. After the Iran-Iraq War, Iraq's enormous debt prevented reinvestment into the neglected irrigation infrastructure, which may have seemed an unnecessary expense with the growing dependence on food imports purchased with oil revenues. With the implementation of comprehensive sanctions immediately following Iraq's invasion of Kuwait in 1990, parts that could have been used to repair the country's ailing irrigation system were banned. After neglecting these systems for years and then overexploiting the land to increase production during the sanctions, there was widespread water logging and salinization that significantly reduced productivity (Schnepf 2004). Under OFFP, Iraq was able to purchase over 2,000 pressurized irrigation systems, including center pivots, but there was no training on their installation and operation, and many were never distributed (USAID 2007).

Center pivot irrigation, in the simplest of terms, is a sprinkler system that rotates about a central pivot. They can be large structures of pipe, supported by trusses, mounted on wheels, with several sprinklers that irrigate the crops from overhead. Water, typically derived from groundwater sources, is pumped to the sprinklers from the center pivot point, resulting in circular crop patterns. Use of center pivot irrigation is a logical strategy for an extensification program because, relative to flood irrigation, it can be applied economically to uneven terrain and areas distant from floodplains. In a false color image acquired for March 7, 1991, we were only able to visually locate two circles indicative of center pivot irrigation. In a March 8, 2003 image we found 277, and in a February 10, 2011 image we found 422.

Despite the increased use of center pivot irrigation, the vast majority of Iraq's irrigation is still gravity fed. It is estimated that this method currently wastes over 60 percent of water in Iraq due to uneven fields (USAID 2007). For efficient use of water in the gravity surface method of irrigation, fields must be as level as possible so that moisture content is constant throughout the field. Level fields could achieve higher efficiencies than center pivot systems, and laser leveling techniques could reach efficiencies comparable to trickle irrigation systems (USAID 2004).

The quality of water for irrigation has also come into question. Decreased flow of the Euphrates River entering Iraq has caused salinity to reach levels that limit the water's usefulness for agriculture (Rahi and Halihan 2010). This combined with upstream farmers in Iraq using too much water inefficiently increases salinity to a level that makes return flow unsuitable for re-use without dilution. A recent USAID report (2004) stated that 75 percent of Iraq's irrigated area is saline, and as much as 20 to 30 percent is no longer farmed because of salinity. The greatest environmental threats facing Iraq are soil salinization and desertification, both of which can be aggravated by increased agricultural use and abandonment (Williams 1999, Haktanir et al. 2002). Once severe salinization has occurred the rehabilitation process can take several years, but the agricultural cropping system's tolerance to salinity can be improved by plant selection, tillage practices, and soil management (Schnepf 2004).

Conclusions

Our research focus was to study food security in Iraq during four conflicts (Iran-Iraq War from 1980 to 1988, Gulf War from 1990 to 1991, UN Sanctions from 1990 to 2003, OIF from 2003 to 2011) using time-series analysis to identify changes in agricultural land use. We used Landsat TM and ETM+ imagery to create multi-temporal NDVI data to quantify and compare cultivated area as an effect of war. Key steps were the explicit application of land surface phenology in data selection and decision tree analysis to set thresholds for classification. Overall accuracy was 94 percent and Kappa was 0.88.

We found that little change occurred between the Iran-Iraq War and the Gulf War, 1.69 and 1.72 Mha respectively, and then cultivated area increased by approximately 20 percent from Early Sanctions to Late Sanctions to over 2.04 Mha. We estimate that cultivated area decreased by approximately 30 percent to an estimated 1.4 Mha during OIF, which coincides with the end of the sanctions. We were also able to calculate area that was single-cropped or double-cropped and found that winter crops, such as winter wheat and barley, experienced the greatest changes, with little change occurring between the Iran-Iraq War and the Gulf War and Early Sanctions periods (1.03 and 0.96 Mha), to over a 30 percent increase during sanctions (1.33 Mha), followed by an approximately 50 percent decrease after sanctions during OIF (0.68 Mha). The main cause for the increase in cultivated area during the period of UN sanctions was the Hussein regimes' policy of extensification when food imports ceased and domestic intensification was not possible due to the bans on dual-use items like fertilizers, pesticides, etc. When the sanctions ended, agricultural lands with high salinity and other subprime lands were abandoned.

The impact of sanctions on food security cannot be understated in the case of Iraq. Decades of war, political instability, and mismanagement of agricultural lands, combined with increasing population, had left Iraq dependent on food imports. Despite that dependence, the target of the UN sanctions, the Hussein regime, was able to withstand comprehensive sanctions for years while the Iraqi people starved. The quick return to pre-sanction levels of cultivated area during OIF indicates a return to dependence on food imports even as the country moves towards political independence.

Before the development of the oil industry, agriculture was Iraq’s primary economic sector. Now the second largest economic sector, agriculture is still the country’s largest employer and can be effective for promoting stability through private sector development, poverty reduction, and food security (USAID 2006). As the political situation in Iraq stabilizes, it will become increasingly important to monitor changes in land cover and assess agriculture performance and growth. Our research presents strategies for monitoring such changes and provides an important baseline overview for this area.

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Tables

Table 3.1. Periods of Conflict in Iraq since 1980

Conflict	Dates
Iran-Iraq War	September 1980 to August 1988
Gulf War	August 1990 to February 1991
UN Sanctions	August 1990 to May 2003
OIF	March 2003 to December 2011

Table 3.2. Dates and Landsat Satellite (#) of Imagery Used in Study

Period	Scene 168/037	Scene 168/038	Scene 169/037
Iran-Iraq War	June 24, 1984 (5)	June 24, 1984 (5)	June 15, 1984 (5)
	March 7, 1985 (5)	March 7, 1985 (5)	March 30, 1985 (5)
	June 14, 1986 (5)	June 14, 1986 (5)	June 21, 1986 (5)
	March 23, 1988 (4)	March 23, 1988 (4)	March 30, 1988 (4)
Gulf War and Early Sanctions	June 25, 1990 (5)	June 25, 1990 (5)	July 10, 1990 (4)
	March 8, 1991 (5)	March 8, 1991 (5)	March 7, 1991 (4)
	July 24, 1992 (4)	August 9, 1992 (4)	July 31, 1992 (4)
	February 17, 1993 (4)	February 17, 1993 (4)	February 24, 1993 (4)
Late Sanctions	June 28, 2000 (7)	June 28, 2000 (7)	June 27, 2000 (5)
	March 11, 2001 (7)	March 11, 2001 (7)	March 18, 2001 (7)
	August 5, 2002 (7)	August 5, 2002 (7)	July 11, 2002 (7)
	March 1, 2003 (7)	March 1, 2003 (7)	March 8, 2003 (7)
OIF	March 14, 2008 (7)	March 14, 2008 (7)	March 5, 2008 (7)
	June 21, 2009 (7)	June 21, 2009 (7)	June 28, 2009 (7)
	June 24, 2010 (7)	June 24, 2010 (7)	July 1, 2010 (7)
	February 19, 2011 (7)	February 19, 2011 (7)	February 10, 2011 (7)

Figures

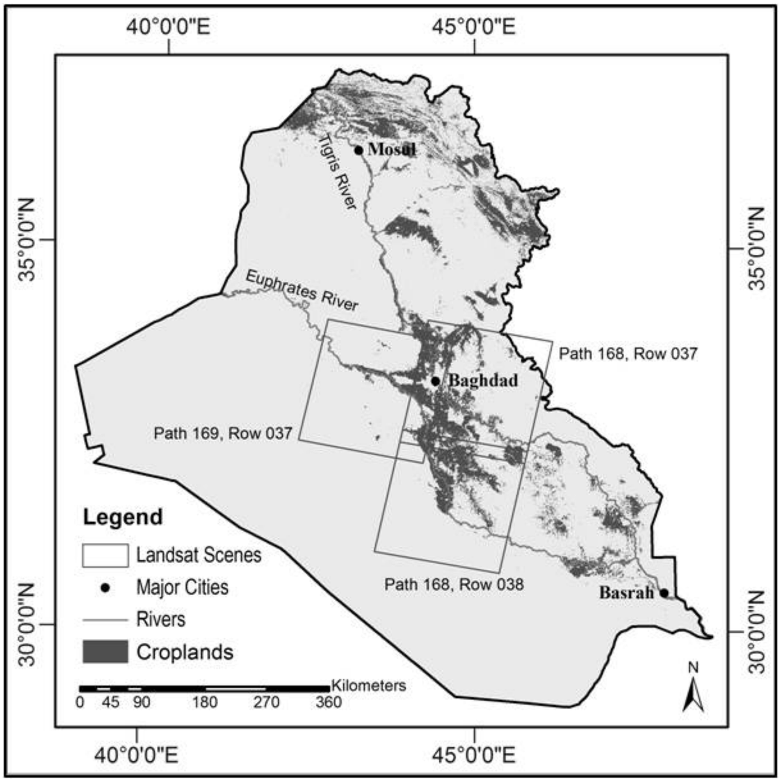

Figure 3.1. Locations of Landsat scenes used in this study.

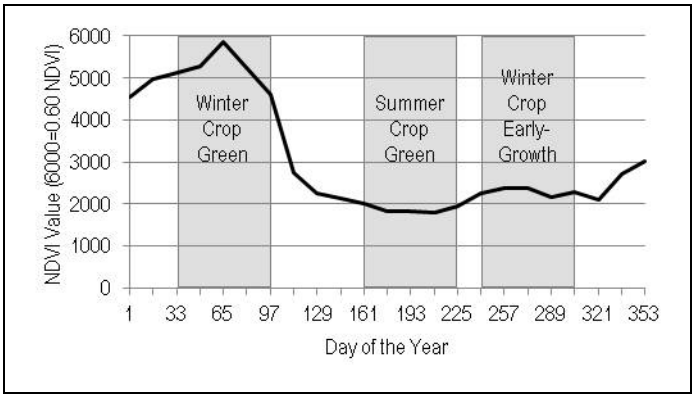

Figure 3.2. Example of the phenological curves used to select dates of imagery. This curve represents the average 2001 MODIS NDVI values for 300 random points. Similar curves were created for all years from 2001 to 2010, and the bars highlight the best days of all years for imagery to classify winter and summer crops.

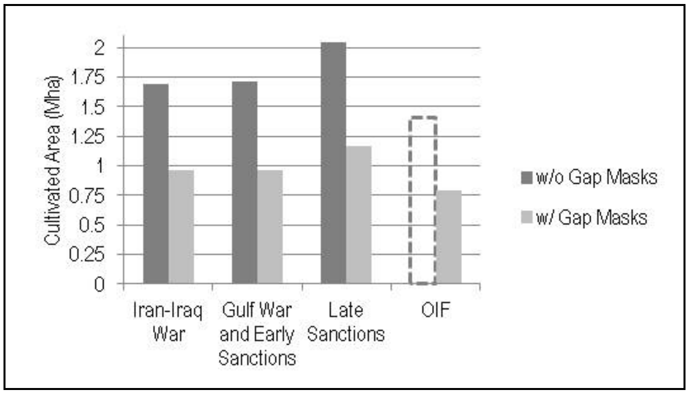

Figure 3.3. Total cultivated area in hectares per period. Gap masks were applied to all periods to allow fair comparison with OIF period which included Landsat 7 SLC-off imagery. The dashed bar outline represents an estimate for cultivated area during the OIF period, assuming consistency in the amount of area concealed by SLC-off gaps.

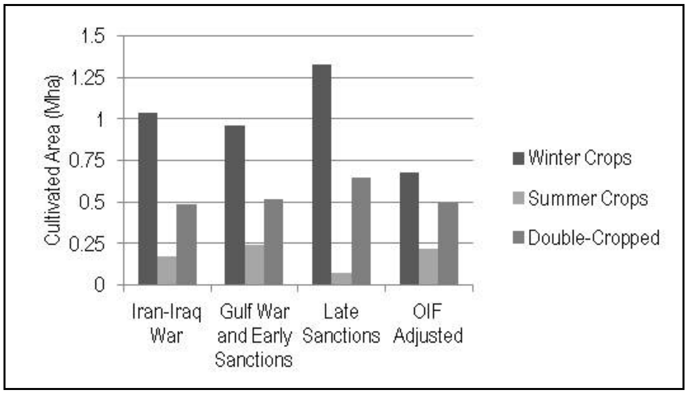

Figure 3.4. Total cultivated area in hectares per period by use. OIF values were adjusted to account for gaps in Landsat 7 SLC-off imagery.

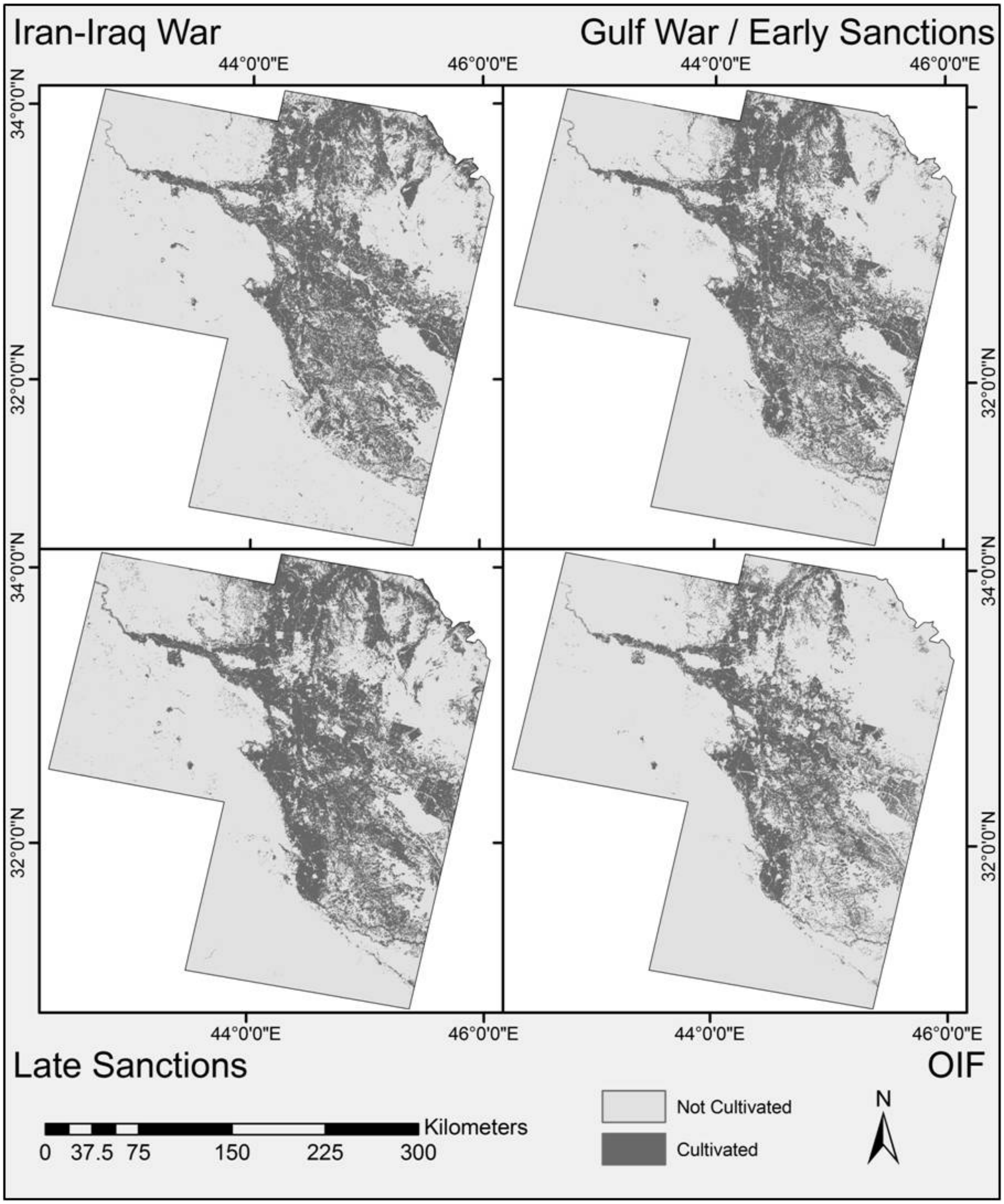

Figure 3.5. Classification results of entire study area for all four periods. The pale appearance of the OIF period is caused by gaps in Landsat 7 SLC-off images.

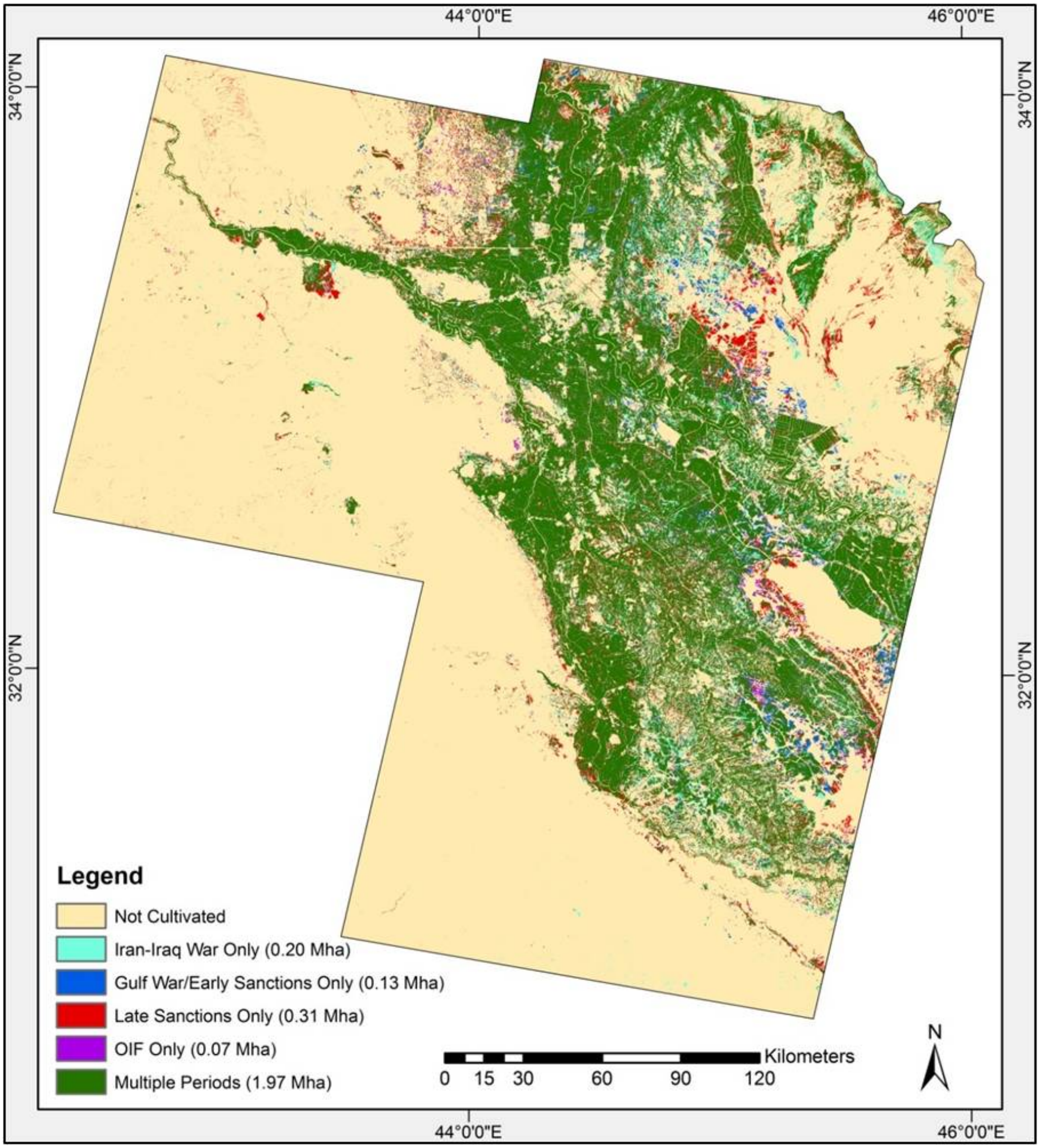

Figure 3.6. Classification results of entire study area for all four periods combined with different colors highlighting land used during single or multiple periods. Gaps in Landsat 7 SLC-off images used for the OIF period cause this color figure to be somewhat incomplete for that period.

Chapter 4: Drivers of Agricultural Land Abandonment in Iraq during War, Sanctions, and Instability

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Abstract

Abandonment of agricultural lands forms a world-wide problem with both social and environmental consequences. Iraq's agricultural system, having experienced shocks from decades of conflict, forms an instructional case study of historical and spatial characteristics of land abandonment. We studied land abandonment in central Iraq during four conflicts (Iran-Iraq War from 1980 to 1988, Gulf War from 1990 to 1991, UN Sanctions from 1990 to 2003, and Operation Iraqi Freedom from 2003 to 2011) using time-series analysis to identify changes in agricultural land use. We used Landsat TM and ETM+ imagery to create multi-temporal normalized difference vegetation index (NDVI) data to quantify and compare cultivated area as an effect of war. Key steps were the explicit application of land surface phenology in data selection and decision tree analysis to set thresholds for classification. Overall classification accuracy was 94 percent and Kappa was 0.88. We combined rasters for different periods to identify when lands were cultivated and subsequently abandoned. The largest areas of abandoned land were those cultivated during the Late Sanctions period (2000-2003). We analyzed relationships between land use and land abandonment patterns and three drivers of abandonment: availability of surface water, accessibility of roads, and salinity as indicated with the normalized difference salinity index (NDSI). The results indicate that proximity to surface water and roads are strong indicators of continuity of agricultural land use, and that abandoned lands are positioned in peripheral regions more distant from surface water and the transportation grid. We also found that surface soil salinity is increasing in the cultivated lands of central Iraq, regardless of whether it was cultivated during every period or during only a single period.

Keywords: land use, Landsat, NDVI, cultivation, extensification

Introduction

Environmental and socio-economic changes have led to increased levels of land abandonment globally (Cramer et al. 2007). For example, the collapse of the Soviet Union in the early 1990s caused abandonment of up to 20 million hectares (Mha) of agricultural land within its former boundaries (Vuichard et al. 2008). Land mismanagement can lead to degradation that undermines food production and political stability (Fadhil 2009). In Somalia, which has been affected by drought and political instability for years, farmers have cultivated pastoral lands in an attempt to maximize food security while giving little attention to the threat of soil loss (Omuto and Vargas 2009). In Syria, increasing political influence on the location and use of irrigation projects during the 1990s encouraged farmers to move out of floodplains and onto soils that suffer from loss of aggregate structure when wetted, thereby increasing wind erosion (Zaitchik et al. 2002). In Iraq, opportunistic barley cultivation and subsequent abandonment in the semi-desert region has contributed to desertification (Jaradat 2003). Additionally, Iraq has been identified as a hotspot for land degradation caused by conflict (Scherr and Yadav 1995).

Conflict and institutional changes are important drivers of land use and land cover change, and agricultural regions are among the most susceptible to those changes. De Beurs and Henebry's (2004) analysis of Advanced Very High Resolution Radiometer (AVHRR) data from 1985 to 1988 and from 1995 to 1999 found that disestablishment of the Soviet agricultural sector led to widespread de-intensification of agriculture in Kazakhstan of great enough significance to affect land surface phenology throughout much of the country. They also found socio-economic turbulence over twenty years affected land surface phenology in Afghanistan's agricultural regions (de Beurs and Henebry 2008) using AVHRR data from 1982 to 1988 and 1995 to 2000 and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery for 2001 and 2003.

Forkuor and Cofie (2011) used Landsat Multispectral Scanner System (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper Plus (ETM+) imagery to link increased urbanization with agricultural land loss in Freetown, Sierra Leone with the decade-long civil war. Witmer and O'Loughlin (2009) used Landsat TM imagery to identify abandoned agricultural land in Bosnia-Herzegovinia before, during, and after the 1992 to 1995 war there. Suthakar and Bui (2008), using Landsat TM and the Indian Remote Sensing satellite system, found that between 1984 and 2004 there was a remarkable decrease in agricultural land use in the Faffna Peninsula of Sri Lanka caused by broad scale population migrations from war-torn areas. De Vos et al. (2008) used Landsat TM satellite imagery to validate reports of the burning of forests, agricultural fields and villages by the Turkish army as a strategy to suppress uprisings in Turkish Kurdistan, leading to widespread abandonment of agricultural lands. Remote sensing technologies will continue to be an important resource for observing land use changes in current and future conflict regions.

In previous research, we used civil satellite remote sensing systems to compare the effects of four different types of conflicts on cultivated area in central Iraq (Gibson et al., in press). Although these conflicts were almost continuous, with little time separating episodes which sometimes merged with one another, the styles of warfare were distinct. For example, the Iran-Iraq War from September 1980 to August 1988 used tactics and strategies similar to World War I and World War II with trench warfare, tank battles, and chemical weapon attacks, but limited aerial campaigns. In 1990, the Gulf War officially began when Iraq invaded Kuwait, although the actual military conflict with coalition forces was brief, lasting only a few days from January to February 1991, characterized by precision bombing, rapid ground mobility, and relatively little force-on-force combat. Then, from August 1990 to May 2003, economic warfare in the form of comprehensive United Nations (UN) sanctions disrupted supply chains and market systems. And, most recently, the long-term occupation and reconstruction of Operation Iraqi Freedom (OIF), from March 2003 to December 2011, which initially resembled the modern style of warfare used in the Gulf War, transformed into a counter-insurgency operation. The results revealed little change in cultivated area between Iran-Iraq War and the Gulf War and early sanctions, then a 20 percent increase in cultivated area during sanctions, followed by a 30 percent decrease during OIF. We concluded that prior to sanctions, Iraq had become dependent on food imports purchased with oil revenues, and that during sanctions Iraqis were forced to expand their cultivated area in an effort to increase domestic food production. After sanctions, food imports resumed and cultivated area declined significantly.

In this paper, building on our previous research, we sought to identify patterns of agricultural land use and land abandonment in central Iraq during conflicts. Benayas et al. (2007) reviewed causes and consequences of agricultural land abandonment and identified three major types of drivers: ecological, socio-economic, and land mismanagement. Ecological drivers include factors such as elevation, slope, aspect, soil fertility, water availability, etc. Socio-economic drivers include market incentives, migration, technology, tenure systems, accessibility, etc. Land mismanagement that leads to abandonment typically can derive from over-exploitation and use of unadapted land. Our objectives were to assess agricultural land use in central Iraq, defining the three drivers of abandonment in the following manner:

1. Ecological drivers—proximity to water sources, given that agriculture in central Iraq is almost exclusively irrigated.
2. Socio-economic drivers—accessibility as indicated by proximity to roads.
3. Land mismanagement—soil degradation in the form of increasing salinity.

Remote sensing technologies provide one of the most economical, robust, and comprehensive resources for examining agricultural changes over time. Satellite image analysis has proven to be effective for analysis of land use/land cover change within the agricultural sector, especially where reliable census data are unavailable (Dannenberg and Kuemmerle 2010). Analyzing land use patterns using satellite images includes a spatial dimension that census-based studies often lack (Evans et al. 2002; Kuemmerle et al. 2008). Plus, freely available long-term image time series have proven effective for monitoring land cover changes caused by conflict and war (de Beurs and Henebry 2008). Due to the dates of available data, we could only include a few years of some conflicts, split other conflicts, and combine still others. The resulting periods studied were the Iran-Iraq War (1984 to 1988), the Gulf War and Early Sanctions (1990 to 1993), Late Sanctions (2000 to 2003), and OIF (2008 to 2011). The gaps in years between these four periods allow time for changes to occur, thus making changes more obvious.

Materials and Methods

Study Area

Three Landsat scenes were chosen for this research (WRS path 168, row 037; path 168, row 038; and path 169, row 037). Because they include Iraq's principal agricultural regions, this study area includes the city of Baghdad and adjacent regions mostly to its east, west, and south (Figure 4.1). According to the MODIS Land Cover Product (NASA LP DAAC 2010), the area is mostly barren or sparsely vegetated (64 percent), open shrublands (16 percent), croplands (15 percent), water (3 percent), and urban and built-up (2 percent). Other land cover classes make up less than one percent of land cover. The area covered by the three scenes has little natural vegetation that could be confused with cultivated land (Schnepf 2004). Therefore, changes in cultivated area should be quite obvious. Also, irrigated agriculture in central Iraq is far less affected by drought than rain-fed agriculture in the north (USDA FAS 2008), reducing the possibility of effects related to lower-than-normal precipitation being attributed to conflict.

Approximately 78 percent of Iraq's 43.7 million ha (Mha) surface area is not viable for agricultural use due to the harsh climate and poor soils; the remaining 9.5 Mha support agricultural activities (Schnepf 2004). Over half of that area is used for seasonal grazing or orchards for tree crops such as dates, figs, etc. Only about 3.5 to 4 Mha is under cultivation annually. Rain-fed agriculture is possible in Iraq's north, but irrigated agriculture is prevalent in the fertile valleys of the Tigris and Euphrates Rivers. There is little agricultural activity in the western desert regions (Ahmad 2002). Cereal production constitutes about 70 to 85 percent of Iraq's cultivated land, two-thirds of which occurs in the irrigated zones of central Iraq (Schnepf 2003).

Most of Iraq's climate is dry and extremely hot with short, cool winters (Spencer 2007). Precipitation is low, less than 250 mm annually for most of Iraq and less than 100 mm annually for the majority of our study area, where irrigation is necessary year-round (USAID 2007). Precipitation is rare during the summer months, except in the cooler north (NCDC 2010). Over 90 percent of Iraq's precipitation occurs between November and April (Schnepf 2004). Between May and October, high temperatures and dry winds lead to high evaporation rates (Mahdi 2000).

Iraq has low crop yields by international standards. Farmers rely on low-quality, farm-saved seed because seed improvement programs negotiated with other nations have repeatedly broken down over the last three decades (USAID 2006). Primary limiting factors in central Iraq are high summer temperatures, water availability, and soil salinity (Schnepf 2004). High soil salinity has been caused by years of improper irrigation and poor drainage (USAID 2006).

Data Selection and Processing

We chose to use the Landsat family of sensors because it has imagery dating back to the early 1970s, has maintained a consistent suite of calibrated sensors, and is freely available. The TM and ETM+ have spatial resolution (30 m) suitable for our analysis and have been used for decades for agricultural analysis. However, the temporal resolution of Landsat did pose some challenges for our study. Cloud-free scenes were not uniformly available throughout the year. There were several years in the mid-1990s in which not a single TM image of central Iraq was available. Portions of Landsat 7 ETM+ images are not useable due to the scan-line-corrector (SLC) malfunction in 2003. Also, comparing a single image from one year with a single image from another year does not account for years when fields were left fallow, experienced early or late green-ups or harvests, suffered from drought conditions, etc. Therefore, we created multi-temporal features by compositing several images to represent agricultural land use during separate periods of conflict.

To determine those dates of imagery that would be most appropriate for our methods, we studied the phenology of scenes using ten years of MODIS NDVI data (2001 through 2010). This multistep process created one thousand random points within the three scenes, subsequently reduced to only those points that could be positively identified as agricultural fields using higher resolution imagery. We ensured that the points were in fields large enough to encompass an entire MODIS NDVI pixel (250 m). Next, we extracted MODIS NDVI values for 300 of those points for all 230 16-day composites between 2001 and 2010. These values were entered into a spreadsheet that was used to create phenological charts like the one shown in Figure 4.2. These charts guided our selection of Landsat images to represent dates most significant for the Iraqi agricultural calendar.

Based on the curves, we decided images acquired between February 2nd and April 5th would be effective as recording days when winter cereal crops would be "green", and images dated between June 10th and August 12th would record days when summer crops would be "green." The low NDVI during summer months in the phenological charts may be a consequence of our point locations, or that summer crops are planted further apart than cereal crops, creating mixed pixels with both vegetation and barren land. What appears to be a second, though less distinct "green" period in the fall is most likely the early-growth period of a crop like winter wheat that has two growth stages: one from planting to vernalization and another from greenup to harvest (Huang and Linlin 2009). Seasonal cloud cover during the fall prevented inclusion of such crops in this study. Table 4.1 lists dates of imagery used for each period.

We downloaded the Landsat imagery using the Global Visualization Viewer (courtesy of the U.S. Geological Survey). These images were preprocessed using the Level 1 Product Generation System and received Level 1T Standard Terrain Correction, which provides systematic radiometric and geometric accuracy by incorporating ground control points by employing a digital elevation model for topographic accuracy. The vast majority of the images had reported cloud cover estimates of less than 10 percent—the highest estimate was 20 percent, and all were inspected to ensure that the cloud cover and shadows would not obscure cultivated areas. Our inspection of imagery revealed no indications of haze or blowing sand in the study area. Because our methods employ compositing, the effects of unnoticed, light haze in a single scene should be mitigated. We used the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) to correct each image to directional surface reflectance (Masek et al. 2006). In this process Landsat digital numbers are calibrated to at-sensor radiance and atmospherically corrected to surface reflectance using 6S (Vermote et al. 1997). The version of LEDAPS we used also included an improved cloud mask algorithm that can mask pixels that were cloud covered or shadowed by clouds.

Analysis

After the images were processed, they were converted to NDVI using the formula:

Equation 1.

$$NDVI = \frac{Near\ Infrared\ Reflectance \quad Red\ Reflectance}{Near\ Infrared\ Reflectance + Red\ Reflectance}$$

NDVI is highly correlated with measures typically associated with plant health and productivity, such as vegetation density and cover, green leaf biomass, leaf area index, chlorophyll content, and crop condition (Lenney et al. 1996).

Next, the data were grouped into periods corresponding to individual conflicts. Within groups, we created a mosaic raster layer that contained the maximum NDVI value for each pixel. Along with the 300 points in positively identified cultivated areas used to create the phenological charts discussed earlier, we also created 300 random points in what could be positively identified as areas not cultivated (barren, sparsely vegetated, water, urban, etc.) and extracted MODIS NDVI values as before. These 600 points (encompassing cultivated and uncultivated areas) had values for maximum, minimum and range of NDVI values per pixel. These pixels were then available for a decision tree analysis to determine which variables and what thresholds would be used for classification. Decision tree analysis is one of the most effective methods of cropland classification and has been used with both Landsat and MODIS NDVI data (Beltrán and Belmonte 2001; Budreski et al. 2007; Shao et al. 2010; Wardlow et al. 2006). We used CART 6.0 with leave-one out cross-validation with the Gini decision rule. Classification accuracy was

100 percent for test pixels. The decision tree results showed that maximum NDVI alone could separate cultivated and not cultivated classes with a threshold of 0.3078. We rounded this up to 0.31 for the threshold and classified pixels with greater than a 0.31 NDVI maximum as cultivated and all others as not cultivated.

Because we were interested in identifying where land was most frequently used or abandoned, we reclassified the rasters for each period with unique values for cultivated pixels, and then added the rasters together. The resulting raster allowed us to identify which pixels were cultivated during any single period, or during multiple periods.

Digitized roads and water bodies were provided by the Map Services Center of the Office of the Director of National Intelligence (ODNI). No measures of accuracy were provided for these data, or dates for when the data was digitized, but our visual inspection of the streets' line and water bodies' line and polygon layers overlaid with GLS imagery proved them to be highly accurate and suitable for our analysis. To determine the average distance of cultivated areas from water and road features, we created rasters with pixels containing values for distance from those features. We also created a 1 km buffer around the features to calculate the percent of cultivated area within 1 km of surface water or roads for each period.

To determine changes in salinity over time, we used Landsat images acquired during summer months between 1984 and 2010 when agricultural land use would be near its lowest and evaporation near its highest. After the images were processed, they were converted to the normalized difference salinity index (NDSI) using the formula:

Equation 2.
$$NDSI = \frac{Red\ Reflectance - Near\ Infrared\ Reflectance}{Red\ Reflectance + Near\ Infrared\ Reflectance}$$

NDSI has been found effective for predicting salinity and sodicity (Aldakheel et al. 2005; Odeh and Onus 2008). Khan et al. (2001) found that NDSI could identify different salt classes based on the dry surface crust. Bannari et al. (2008) found that NDSI had one of the highest correlation coefficients with electrical conductivity when compared to other salinity indices. NDSI takes advantage of the substantially higher red reflectance for salt-affected areas (Khan et al. 2001). Being the inverse of NDVI, vegetated areas should have a lower NDSI than non-vegetated areas (Setia et al. 2011).

Validation

For validation, we created random points and then visually confirmed whether or not their collocated pixels were in what appeared to be croplands using higher resolution imagery. For this process, we used Quickbird panchromatic images at 0.62 m resolution acquired between May 2002 and June 2003. This validation method had its limitations. First, we did not have access to high-resolution imagery collected prior to the advent of civil satellite remote sensing systems like Quickbird, so we were not able to validate results for the Iran-Iraq War, Gulf War and Early Sanctions, and were limited to validating results of our classification for the Late Sanctions. However, we believe that conclusions of this limited validation extend in space and time because our methods (acquisition dates of imagery linked to phenology, LEDAPS preprocessing, use of NDVI, etc.) were consistent for all periods.

A second limitation was that, although while we were able to determine if a validation point matched to an agricultural field at the time the images were acquired, it was impossible to tell if there was an actual crop growing in the field. Nonetheless, the validation could confirm if our methods had classified a pixel as cultivated when it was in fact barren, open shrubland, urban, water, etc. Hence, we chose to be as conservative as possible during validation. For example, if our methods classified a 30 m pixel as not cultivated but the same 30 m area appeared to be an agricultural field in higher resolution imagery, then we defaulted to labeling that validation point as cultivated since it could have been cultivated during that year. Likewise, if our methods classified a 30 m pixel as cultivated but in higher resolution imagery the same area did not appear to be an agricultural field, then we labeled the point as not cultivated. This conservative approach may have artificially lowered the overall accuracy.

For accuracy assessment, we created 50 random points per category for the sample size, as suggested by Congalton and Green (2009) as a general guideline. We compiled the results in an error matrix and calculated overall accuracy according to Campbell and Wynne (2011). Forty-eight of the 50 random points for the "cultivated" class were positively identified as agricultural fields. We also created 50 random points for the "not cultivated" pixels, but opted to not use the higher resolution imagery to validate all of these points due to time and cost constraints, and because most could be positively identified as being barren, water, or urban in the Landsat imagery. Forty-six out of the 50 "not cultivated" pixels were correctly classified. The overall accuracy of our classification was 94 percent, and Kappa was 0.88.

As further validation, we compared the results with records for a single governorate in Iraq with official agricultural statistics for Iraq for the year 2001. The study area completely contained only two governorates: Baghdad and Babil. Because Baghdad governorate is relatively small and mostly urbanized, we selected Babil to validate our methods. According to the Central Organization for Statistics and Information Technology in Iraq (COSIT 2001), Babil had approximately 429,210 ha of permanent cropland in 2001. We created a subset of the results for the Late Sanctions period (2000 to 2003) for only the governorate of Babil, and our cultivated area was 439,287 ha, within 2 percent of the COSIT area. Therefore, we are confident that our methods were successful in identifying croplands that were cultivated during the period.

Results and Discussion

Cultivated Area by Period

Figure 4.3 shows that cultivated area changed little between the Iran-Iraq War and the Gulf War, 1.69 and 1.72 Mha respectively. Cultivated area increased by approximately 20 percent from Early Sanctions to Late Sanctions, to over 2.04 Mha. Correcting for the gaps in the combination of SLC-off images, we estimate that the actual cultivated area for the OIF period could be as high as 1.4 Mha. That constitutes an approximately 30 percent decrease in cultivated area from the period of Late Sanctions to OIF.

To better understand how cultivated area could expand and contract so greatly, one must understand the role of the Iraqi government in property rights and their use. Agricultural land ownership has undergone several changes over the last few decades. In the 1930s, after gaining independence from Britain, the Iraqi monarchy passed laws granting land ownership to tribal leaders and village chiefs, establishing what would later become a system of absentee land ownership with large plots of land cultivated by indentured sharecroppers (Schnepf 2004). In 1958, the ruling monarchy was overthrown by the Iraqi army, and the new socialist government enacted reforms that redistributed agricultural lands to individuals (Mahdi 2000). However, the redistribution process was slow, resulting in the government owning large proportions of arable land (Schnepf 2004). After the Ba'ath Party gained power in 1968, the government transitioned to state-owned farms and collective ownership (USAID 2005). In 1979, Saddam Hussein took power as President of the Republic of Iraq. Early in Hussein's reign, his government attempted to return control of Iraq's agricultural sector to non-government entities and investment after years of failing government policies (Springborg 1986). Those initiatives were never fully realized due to a shift in government priorities to the war with Iran from 1980 to 1988. Less than two years after the Iran-Iraq War ended, Iraq invaded Kuwait in August 1990, resulting in comprehensive UN sanctions and a halt to food imports. In the absence of food imports, upon which the country had become dependent, there was growing pressure for Iraqis to increase domestic agricultural production. The Hussein regime became more heavily involved with agricultural production, creating incentives for farmers to expand crop area and punishments, including death, for farmers who failed to deliver their quotas to state collection centers (Schnepf 2003). After the US-led invasion of Iraq in 2003, the Hussein regime fell and the sanctions were lifted. As of 2005, the land administration system was still centralized at the federal level, and much of Iraq's agricultural land was still either state-owned or collectively-owned (USAID 2005).

Patterns of Land Abandonment

To determine which period resulted in the largest areas of agricultural land abandonment we reclassified the rasters for each period and combined them, allowing identification of pixels used during single periods, during multiple periods, or never used. We could also determine which combinations of periods these areas had been cultivated. The resulting raster distinguished 15 different combinations identifying when areas were cultivated, however, we combined these to only distinguish two groups and four subgroups:

1) Used during multiple periods

2) Used during only one period

a) Iran-Iraq War

b) Gulf War and Early Sanctions

c) Late Sanctions

d) OIF

Figure 4.3 shows the amount of cultivated area for each period and also distinguishes between areas that were used during multiple periods and areas that were used only during a single period. It is important to realize that expansion can occur alongside extensive farmland abandonment (Benayas et al. 2007). For example, 0.20 Mha of agricultural lands were cultivated during the Iran-Iraq War period that were not cultivated again during any of the following three periods. During the Gulf War and Early Sanctions period, 0.14 Mha were cultivated that were not cultivated during the previous Iran-Iraq War period, nor during the following two periods. And during the Late Sanctions period, 0.31 Mha were cultivated that were not cultivated during the previous two periods, nor during the OIF period. We consider these areas to have been abandoned because they were used only during their respective periods. Not enough time has elapsed since OIF ended to identify those agricultural lands abandoned since the end of that conflict. Figure 4.4 shows where the cultivated areas identified by our methods exist spatially.

From Figure 4.4 we can identify two patterns of land abandonment: 1) small fields/projects that appear to be contained within the broader irrigation structure, and 2) large projects that are clearly peripheral to the broader irrigation structure. The smaller projects appear to be immediately adjacent to previously cultivated lands used during multiple periods. Use of these adjacent lands would seem to be a logical strategy for extensification by simply extending irrigated lands to adjacent areas to minimize investment in new irrigation infrastructure. The larger projects would have required much greater investment to expand the existing irrigation system or by construction of new systems of channels and related irrigation structures. Given the state of agricultural land ownership during the sanctions, when many of these new projects appeared, it seems reasonable to assume they were governmental enterprises or, at minimum, influenced by the central government. Small projects that simply expand existing fields are difficult to represent in the graphic because they are often only one or two pixels in width around previously existing fields, however, the larger projects are easy to distinguish. For example, Figure 4.5 shows an example of a large extensification project established during sanctions.

We converted the rasters representing abandoned lands for each period into polygon shapefiles to better identify groups of pixels. Table 4.2 contains common statistics representing the distribution of the data for each period. We found that the vast majority of abandoned areas were very small, often the size of a single pixel (900 m^2 or 0.09 ha). However, many of these single pixels formed a diagonal chain around the edges of larger fields, so may in fact represent larger parcels. The means were similar for all periods; however, the Late Sanctions period had a noticeably larger standard deviation. We also counted the number of polygons larger than 1 ha and larger than 1 km^2, representing large extensification projects that were quickly abandoned. The Late Sanctions period had 43,710 polygons greater than 1 ha, while the Iran-Iraq War and the Gulf War and Early Sanctions periods only had 29,384 and 19,230, respectively. The OIF period had far fewer polygons greater than 1 ha, 8974, but this low number is most likely an effect of the gaps in the SLC-off images. When we compared periods with polygons greater than 1 km^2 (100 ha) we found that the Late Sanctions period had 146 polygons representing very large extensification projects, while the Iran-Iraq War and the Gulf War and Early Sanctions periods had only 73 and 53, respectively. Again, the OIF period had far fewer, only 11.

Ecological Driver: Water Availability

We measured proximity to water features two ways: (1) percent of total cultivated area for each period within 1 km of a water feature, and (2) mean distances of pixels classified as cultivated for each period from water features. The results indicate that 49 percent of lands used during multiple periods are within 1 km of water features (Figure 4.6). Only 35 percent to 39 percent of lands cultivated only for a single period are within 1 km of water features, meaning that lands used only during a single period tend to be positioned farther from surface water sources. The report of mean distances confirm that conclusion, with the mean distance for lands cultivated during multiple periods being 1779 m, and then increasing over time from the Iran-Iraq War to OIF from 1987 m to 2815 m, respectively. This result suggests that that amount of land within 1 km of water features is limited, and cultivated lands further than 1 km from surface water are more likely to be abandoned.

Cultivating lands far from water sources poses challenges in central Iraq. Agriculture in central Iraq is predominantly irrigated by flood irrigation (Schnepf 2004), so most cultivation occurs in close proximity to water sources (rivers, canals, etc.). Approximately 63 percent of the water for Iraq's irrigated land is gravity fed from rivers and channels, 36 percent is pumped from rivers and channels, and only 1 percent is from groundwater (USAID 2007).

It is noteworthy that irrigation systems established at the scales employed in this region of Iraq inherently depend upon centralized design and administration (Wittfogel 1957; Worster 1992), so most of these projects, by their size and scope, reflect strategic policy decisions defined by national authority. Prior to the Hussein regime, the Iraqi government maintained the nation's irrigation canal system. During the Iran-Iraq War, government resources were diverted to the war effort and away from civil infrastructure. After the Iran-Iraq War, Iraq's enormous debt prevented reinvestment into the neglected irrigation infrastructure, which may have seemed an unnecessary expense with the growing dependence on food imports purchased with oil revenues. With the implementation of comprehensive sanctions immediately following Iraq's invasion of Kuwait in 1990, import of parts that could have been used to repair the country's ailing irrigation system were banned. After neglecting these systems for years and then overexploitating the land to increase production during the sanctions, there was widespread saturation and salinization that significantly reduced productivity (Schnepf 2004).

As for abandoned land and proximity to water, one area stood out where an increasing numbers of small fields are used for a short period and then abandoned while more small fields appear nearby (Figure 4.7). The average proximity to water features for all pixels classified as cultivated within the entire study area was 1.9 km, but for pixels in this area it was 7.4 km. The circular shape of these fields is indicative of center-pivot irrigation. Under OFFP, Iraq was able to purchase over 2,000 pressurized irrigation systems, including center pivots (USAID 2007). Center pivot irrigation, in the simplest of terms, is a sprinkler system that rotates about a central pivot. They can be large structures of pipe, supported by trusses, mounted on wheels, with several sprinklers that irrigate the crops from overhead. Water, typically derived from groundwater sources, is pumped to the sprinklers from the center pivot point, resulting in circular crop patterns, as viewed from above.

Use of center pivot irrigation is a logical strategy for an extensification program because, relative to flood irrigation, it can be applied economically to uneven terrain and areas distant from floodplains. In a false color image acquired for March 7, 1991, we were able to visually locate only two circles indicative of center pivot irrigation. However, in a March 8, 2003 image we found 277, and in a February 10, 2011 image we found 422. These fields do not appear to have been in constant use. According to our classification map (Figure 4.4) the few center-pivot fields classified as cultivated during the Gulf War and Early Sanctions period were not cultivated in later periods, and the majority of those cultivated during the Late Sanctions period were not used during the OIF period. This may indicate either that the soils in these areas are only suitable for cultivation for a few years, that groundwater sources are limited, or that the center-pivot systems are in need of repair and maintenance. Given the increasing number of center-pivot fields cultivated during the OIF period, adoption of this technology appears to be a growing trend and may spread to other parts of the study area and within Iraq.

Socio-Economic Driver: Accessibility

A robust transportation infrastructure is essential for support of any agriculture system, both to supply the agricultural enterprise with equipment, labor, and chemicals, and to ship produce to market. We measured proximity to roads two ways: (1) percent of total cultivated area for each period within 1 km of a road, and (2) mean distance of pixels classified as cultivated for each period from roads. Results indicate that over three-fourths of lands used during multiple periods are within 1 km of roads (Figure 4.8). Only 53 percent to 59 percent of lands cultivated only for a single period are within 1 km of a road, meaning that lands used only during a single period tend to be less accessible. The mean distances confirm that conclusion, with the mean distance for lands cultivated during multiple periods being 808 m, and more than double that for lands cultivated during only a single period, with mean distances ranging from 1488 m to 1899 m. These results suggest that agricultural land within 1 km of roads is preferred and used repeatedly, whereas areas further from roads are only used for a few years at a time.

The importance of road networks and the need for improvements for the transportation of agricultural commodities in Iraq has been long recognized. Research in the 1950s and 1960s described the majority of roads in Iraq as dirt, of poor construction, and poorly maintained (Adams 1963; Powers 1954; Yudelman 1958). Adams (1963) stated that inadequate roads limited farmers to the use of donkeys and other animals to transport farm products, underscoring the need for greater investment. Iraq's transportation infrastructure improved during the 1970s, though the new construction and upgrades of the road system may have been motivated by military reasons (Edirisinghe 2004). During the Iran-Iraq War (1980 to 1988) money that could have been used to improve the transportation infrastructure in Iraq was diverted to the war effort; following the war, Iraq's tremendous debt prevented such investment (Amirahmadi 1990). After Iraq's invasion of Kuwait in 1990, the US led a military effort to remove Iraqi military forces from Kuwait and to weaken Iraq's military threat in the region. The Gulf War's actual military conflict, from invasion to cease fire, was brief (January to February 1991), and began with an aerial bombing campaign designed to attack Iraq's leadership, key production, infrastructure, population, and fielded military forces, in that order (Reynolds 1995). Within a few short weeks, Iraq suffered extensive damage and destruction of its economic infrastructure, more so than during all eight years of its war with Iran (Tripp 2007). Bombing destroyed or severely damaged much of Iraq's transportation infrastructure, including roads and bridges (Spencer 2007). Comprehensive UN sanctions against Iraq from 1990 to 2003 prevented the country from reinvesting in its transportation infrastructure. By 2003, Iraq's road networks were still in poor condition and in need of major repairs and improvements.

After the initial military operations of OIF in 2003, many organizations have been investing in Iraq, but no amount of investment will induce subsistence farmers to grow cash crops unless there are roads to reach the market (Al Rashid 2007). Labor-intensive works projects to repair rural roads essential to transport goods to market would make local agriculture more competitive with food imports (Yousif 2006). In some parts of Iraq, the US Army Corps of Engineers have worked with local Iraqi agencies to upgrade unpaved roads to allow for easier transport of crops to silos (OSIGIR 2006).

We found that abandoned areas furthest from roads were mostly wadiis. A wadi can be defined as a dry valley with seasonal, rainfall-dependent surface runoff (Portnov and Safriel 2004), but water within the wadiis has been used in irrigation (Abdulla et al. 2002; Costa 1983). In some cases, earthen dams can be built across a wadi to create reservoirs for later use (Hachum and Mohammad 2007). Even though more sophisticated and reliable methods of irrigation are prevalent outside of the wadiis, run-off agriculture is still used as a complementary source of income (Costa 1983). Wadiis have been cultivated for centuries throughout the Middle East to grow wheat and other grains and cereals, dates and other tree crops, beans, alfalfa, clover, etc. (Abu-Gharbieh 1987; Costa 1983; Davies 1957; Hammouri and El-Naqa 2007; Portnov and Safriel 2004). We acknowledge we cannot validate whether or not all pixels classified as cultivated within wadiis are indeed cultivated, but with Landsat and higher-resolution images we were able to identify many areas within wadiis that appear to have a patchwork of straight line patterns that we believe to be evidence of cultivation during some years (Figure 4.9).

Land Mismanagement Driver: Surface Soil Salinity

We used summer images converted to NDSI to compare changes in salinity over time. We did not have field measurements of saline and sodic soils to set thresholds to classify areas as having low salinity, high salinity, etc. Therefore, we shall only note trends in changes of NDSI.

Figure 4.10 shows the results of our analysis. We divided cultivated area for each period into groups: those cultivated during every period and those cultivated during only single periods.

The results show that lands used only during a single period had higher NDSI values than lands used during multiple periods. This is most likely an effect of these areas being less capable of supporting dense vegetation, even when cultivated, which may also explain why they were used only during a single period. Also, parcel size, parcel shape, and radiometric and spectral contrast with surrounding parcels can all contribute to the problem of mixed pixels. Mixed pixels occur as resolution elements fall on the boundaries between landscape parcels (Campbell and Wynne 2011). Areas that were cultivated during only a single period had lower NDSI values during years when they were cultivated than years when they were not. As the inverse of NDVI, vegetated areas should have a lower NDSI than non-vegetated areas (Setia et al. 2011). Areas that were cultivated during multiple periods had increasing NDSI values over time, indicating increasing salinity.

Two interesting trends in the NDSI results for areas cultivated during only a single period exist. First, the NDSI lows for each period increase over time (Figure 4.10). Specifically, the NDSI low for the Gulf War and Early Sanctions period is greater than the NDSI low for the Iran-Iraq War period, and the low for the Late Sanctions period is greater than the lows for the previous two periods. Second, NDSI highs increase over time after an area has been abandoned. For example, areas that were cultivated during the Iran-Iraq War period have greater and greater NDSI values each year after being abandoned. The Gulf War and Early Sanctions period demonstrated a similar trend.

Areas that were cultivated during every period also had increasing NDSI values over time, indicating increasing salinity. This could be the result of overexploiting prime lands that depend on water that was previously used for irrigation and returned to its source, only to be reused downstream. For example, decreased flow of the Euphrates River entering Iraq has caused salinity to reach levels that limit the water's usefulness for agriculture (Rahi and Halihan 2010). This effect combined with upstream farmers in Iraq using too much water inefficiently increases salinity to a level that makes return flow unsuitable for re-use without dilution. A recent USAID report (2004) states that 75 percent of Iraq's irrigated area is saline, and as much as 20 to 30 percent is no longer farmed because of salinity.

The single largest area of abandoned land in the study area also had some of the highest NDSI values (Figure 4.11). This area was classified as cultivated for the Late Sanctions period only. Visual inspection of Landsat imagery revealed that the area was barren between 1984 and 1993, widely cultivated between 1998 and 2003, and used less and less between 2004 and 2011 (no imagery is available from 1994 to 1997). Also, in World View color images dated June 27, 2011, there appear to be large expanses of dissolved solids to the north of these fields. Though central Iraq is relatively flat, evaluation of the Shuttle Radar Topography Mission and Advanced Spaceborne Thermal Emission and Reflection Radiometer digital elevation models revealed that this particular area does decrease in elevation from south to north from as high as 33 m to as low as 19 m. Given the slope and aspect, it seems reasonable that runoff would accumulate and evaporate in the northern ends of these fields and leave evidence of overexploitation in the form of salt deposits.

The vast majority of Iraq's irrigation is still gravity fed. It is estimated that this method currently wastes over 60 percent of water in Iraq due to uneven fields (USAID 2007). The greatest environmental threats facing Iraq are soil salinization and desertification, both of which can be aggravated by increased agricultural use and abandonment (Haktanir et al. 2002; Williams

1999). Once severe salinization has occurred the rehabilitation process can take several years, but the agricultural cropping system's tolerance to salinity can be improved by plant selection, tillage practices, and soil management (Schnepf 2004).

Conclusions

Our research focus was to study land abandonment in central Iraq during four conflicts (Iran-Iraq War from 1980 to 1988, Gulf War from 1990 to 1991, UN Sanctions from 1990 to 2003, OIF from 2003 to 2011) using time-series analysis to identify changes in agricultural land use. We used Landsat TM and ETM+ imagery to create multi-temporal NDVI data to quantify and compare cultivated area as an effect of war. Key steps were the explicit application of land surface phenology in data selection and decision tree analysis to set thresholds for classification. Overall accuracy was 94 percent and Kappa was 0.88.

We found that some 0.20 Mha were abandoned after the Iran-Iraq War and 0.14 after the Gulf War. Cultivated area expanded by approximately 20 percent during the sanctions, with 0.31 Mha being cultivated for the first time and then abandoned. The main cause for the increase in cultivated area during the period of UN sanctions was the Hussein regimes' policy of extensification when food imports ceased and domestic intensification was not possible due to bans on dual-use items such as fertilizers, pesticides, etc. When the sanctions ended, agricultural lands with high salinity and other subprime lands were abandoned. We estimate that cultivated area decreased by approximately 30 percent during OIF, which coincides with the end of the sanctions, with less than 0.07 Mha being cultivated for the first time. These areas warrant continued observation due to the potential for later abandonment.

We analyzed land use and abandonment patterns related to three drivers of abandonment: availability of water, accessibility of roads, and salinity as indicated by NDSI. The results indicate that lands used most often are ones in close proximity to surface water features and roads, and that lands further from these two are more likely to be abandoned. We also found that salinity is increasing in the cultivated lands of central Iraq, regardless of whether it was cultivated during every period or during only a single period. However, the largest areas of abandoned land were those cultivated during the Late Sanctions period.

Before the development of the oil industry, agriculture was Iraq's primary economic sector. Now, as Iraq's second largest economic sector, agriculture is still the country's largest employer and can be effective for promoting stability through private sector development, poverty reduction, and food security (USAID 2006). As the political situation in Iraq stabilizes, it will become increasingly important to monitor changes in agricultural land use/land cover and land abandonment. Our research presents strategies for monitoring such changes and provides an important baseline overview for this area.

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Tables

Table 4.1. Dates and Landsat Satellite (#) of Imagery Used in Study

Period	Scene 168/037	Scene 168/038	Scene 169/037
Iran-Iraq War	June 24, 1984 (5) March 7, 1985 (5) June 14, 1986 (5) March 23, 1988 (4)	June 24, 1984 (5) March 7, 1985 (5) June 14, 1986 (5) March 23, 1988 (4)	June 15, 1984 (5) March 30, 1985 (5) June 21, 1986 (5) March 30, 1988 (4)
Gulf War and Early Sanctions	June 25, 1990 (5) March 8, 1991 (5) July 24, 1992 (4) February 17, 1993 (4)	June 25, 1990 (5) March 8, 1991 (5) August 9, 1992 (4) February 17, 1993 (4)	July 10, 1990 (4) March 7, 1991 (4) July 31, 1992 (4) February 24, 1993 (4)
Late Sanctions	June 28, 2000 (7) March 11, 2001 (7) August 5, 2002 (7) March 1, 2003 (7)	June 28, 2000 (7) March 11, 2001 (7) August 5, 2002 (7) March 1, 2003 (7)	June 27, 2000 (5) March 18, 2001 (7) July 11, 2002 (7) March 8, 2003 (7)
OIF	March 14, 2008 (7) June 21, 2009 (7) June 24, 2010 (7) February 19, 2011 (7)	March 14, 2008 (7) June 21, 2009 (7) June 24, 2010 (7) February 19, 2011 (7)	March 5, 2008 (7) June 28, 2009 (7) July 1, 2010 (7) February 10, 2011 (7)

Table 4.2. Statistics for Polygon Shapefiles Representing Abandoned Land Area (ha)

	Iran-Iraq War	Gulf War and Early Sanctions	Late Sanctions	OIF
Mean	5021	4392	5078	4029
Median	900	900	900	900
Mode	900	900	900	900
Minimum	900	900	900	900
Maximum	4,131,900	8,375,400	17,556,300	14,663,700
Standard Dev.	32,394	39,972	52,351	41,837
Area > 1 ha	29,384	19,230	43,710	8974
Area > 1 km²	73	53	146	11

Figures

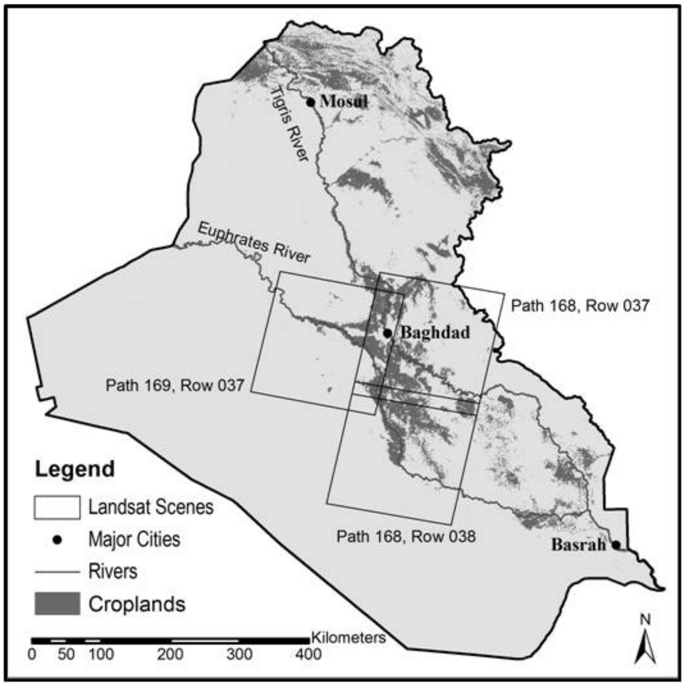

Figure 4.1. Locations of Landsat scenes used in this study.

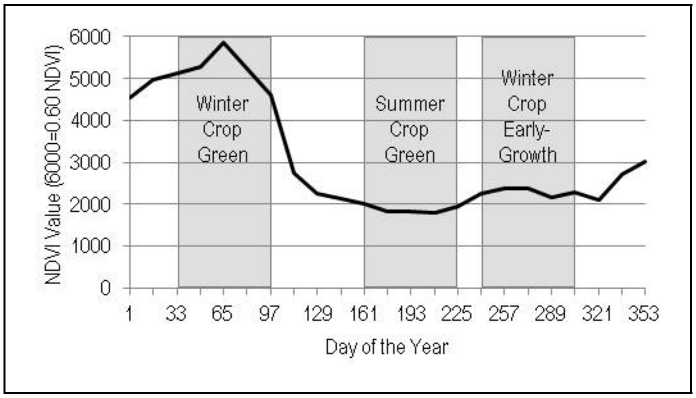

Figure 4.2. Example of the phenological curves used to select dates of imagery. This curve represents the average 2001 MODIS NDVI values for 300 random points. Similar curves were created for all years from 2001 to 2010, and the bars highlight the best days of all years for imagery to classify winter and summer crops.

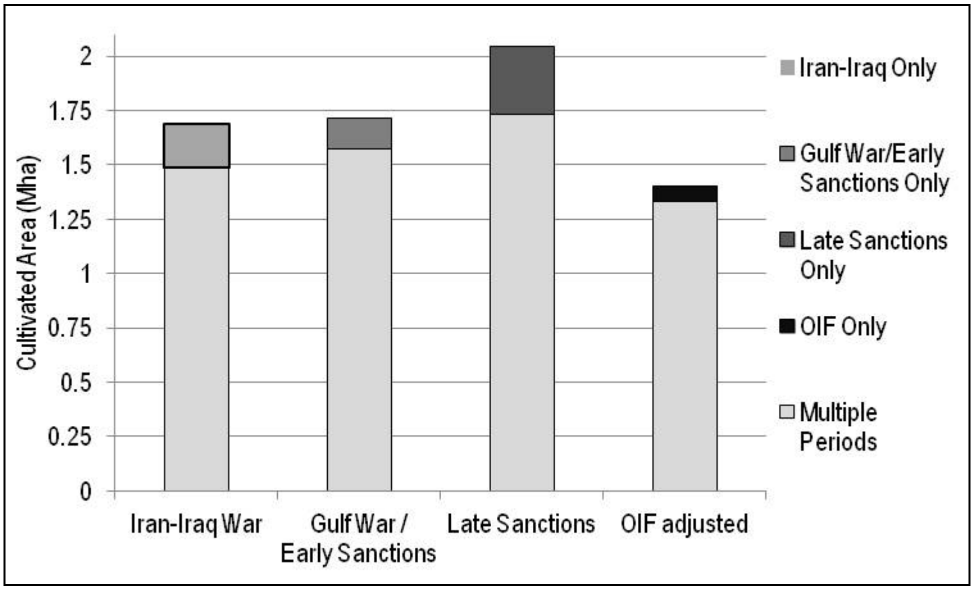

Figure 4.3. Total cultivated area in hectares per period. The bar for cultivated area during the OIF period was adjusted to account for area concealed by SLC-off gaps.

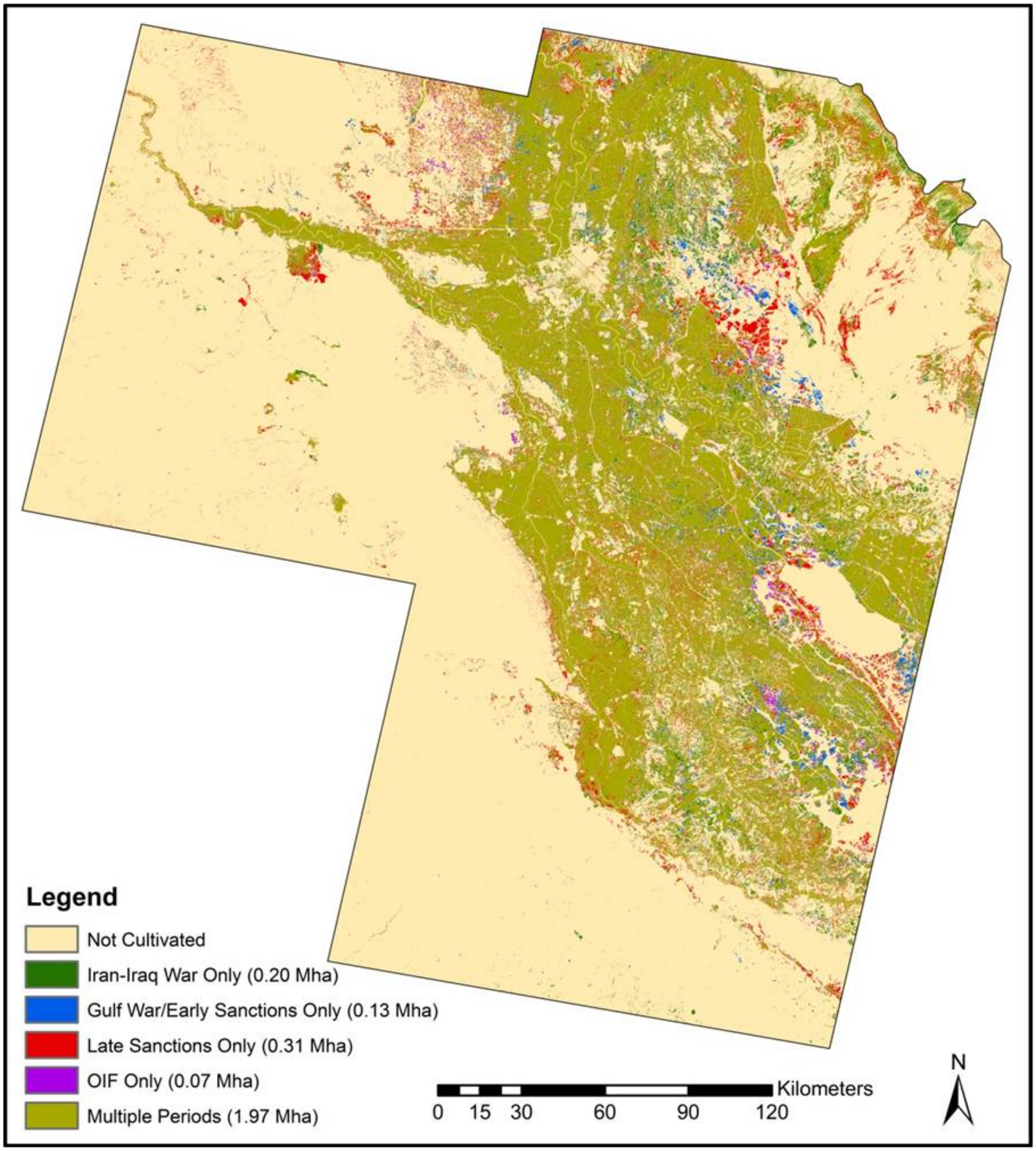

Figure 4.4. Classification results of entire study area for all four periods combined with different colors highlighting land used during single or multiple periods. Gaps in Landsat 7 SLC-off images used for the OIF period cause this figure to be somewhat incomplete for that period.

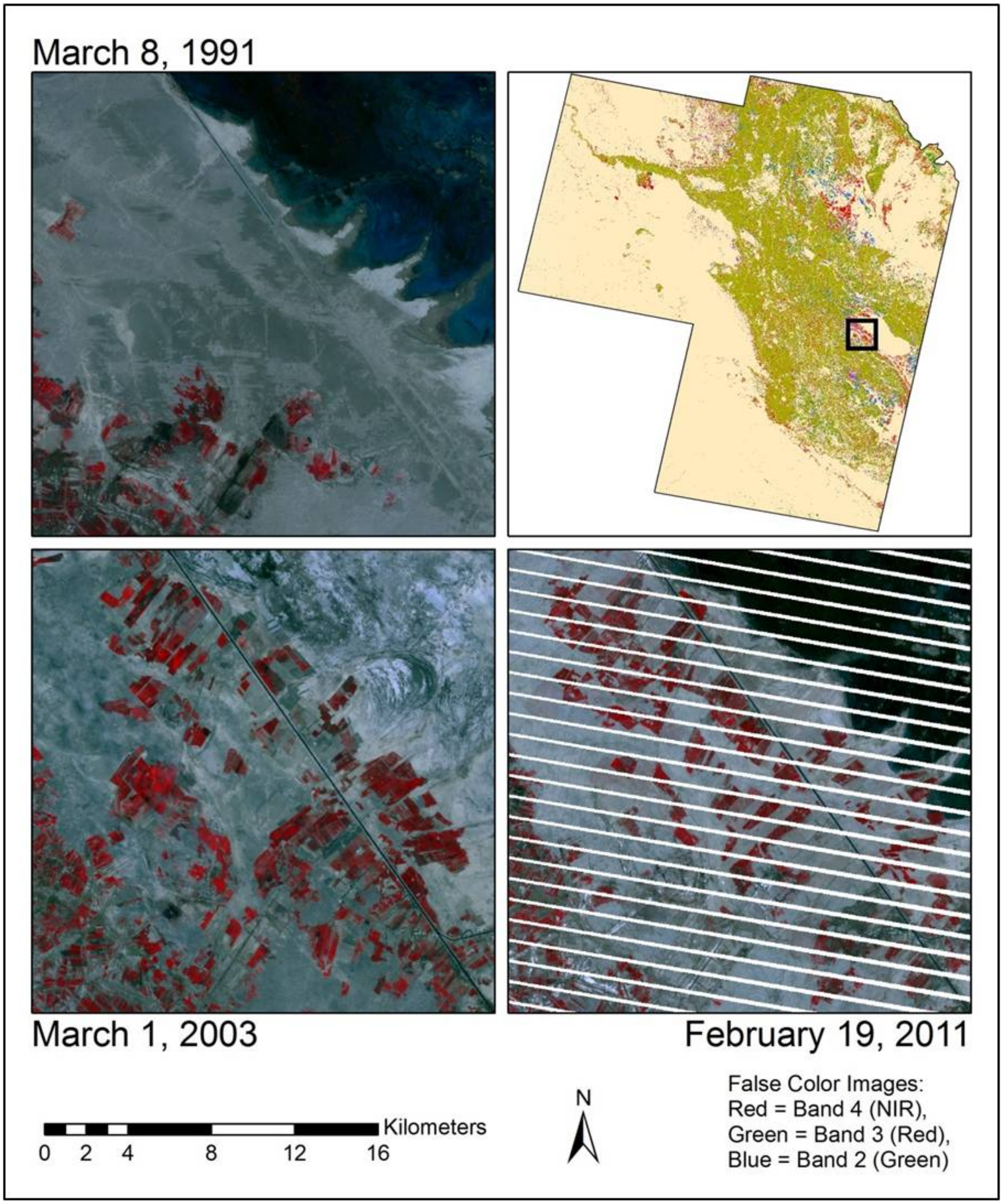

Figure 4.5. Example of large agricultural extensification projects in central Iraq during UN sanctions. The black box in the upper right graphic depicts the location of the three false color images. The image in the upper left is from March 1991, when sanctions had only been in place for a few months. The image in the lower left is from March 2003, shortly before sanctions

ended, and shows an example of large extensification projects undertaken during sanctions. The image in the lower right shows the same area almost eight years after sanctions ended (Landsat 7 SLC-off). The dark region in the northeast quadrant of the images varies because of fluctuating water levels in an impoundment.

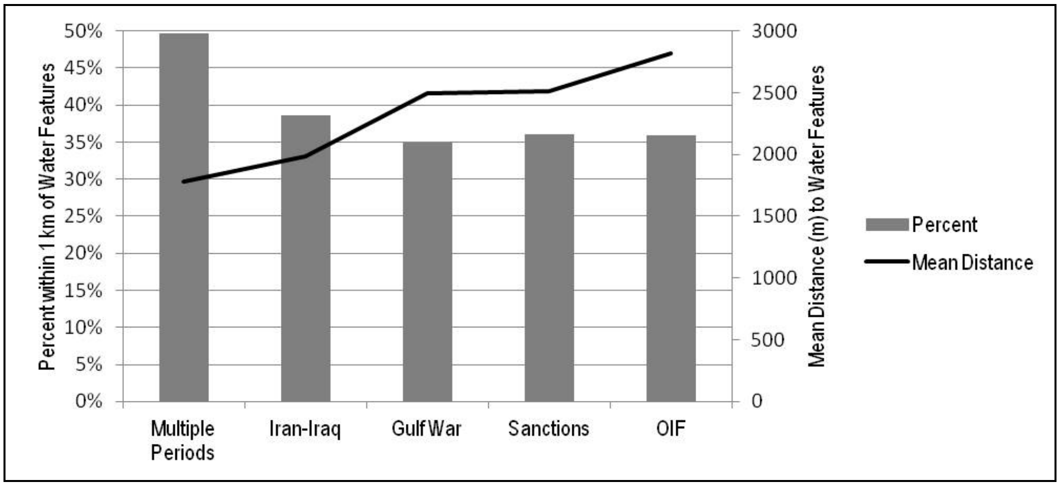

Figure 4.6. Percent of cultivated area within 1 km of water features and mean distance for all pixels classified as cultivated from nearest water feature by period. This graph infers that agricultural lands cultivated during only a single period, and subsequently abandoned, tend to be further from surface water sources.

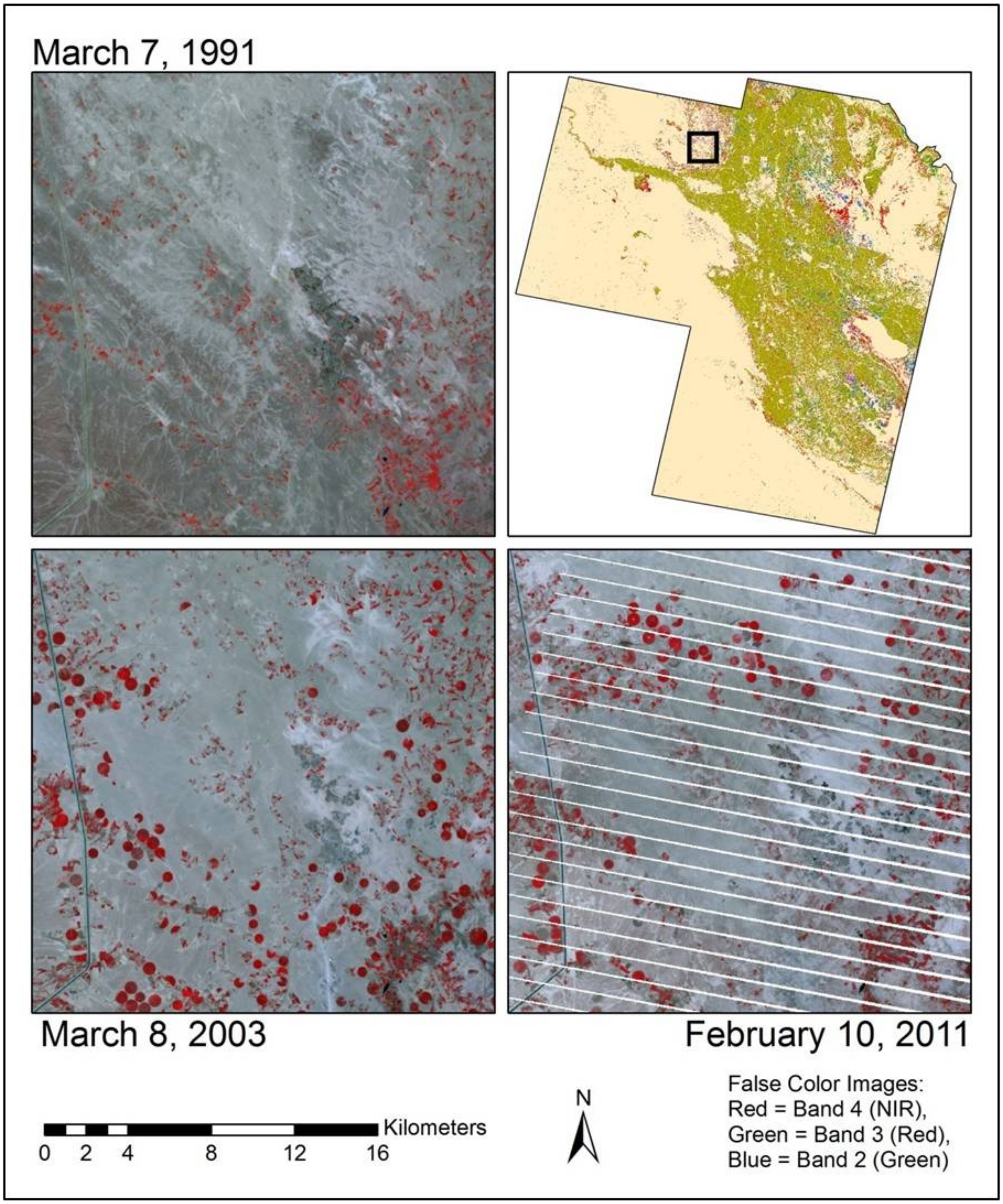

Figure 4.7. Example of adoption of center-pivot irrigation in central Iraq during sanctions and continuing afterwards. The black box in the upper right graphic depicts the location of the three false color images. The image in the upper left is from March 1991, when sanctions had only been in place for a few months. The image in the lower left is from March 2003, shortly before

sanctions ended, and shows an example of numerous center-pivot irrigation projects undertaken during sanctions. The image in the lower right shows the same area almost eight years after sanctions ended (Landsat 7 SLC-off), with different center-pivot fields.

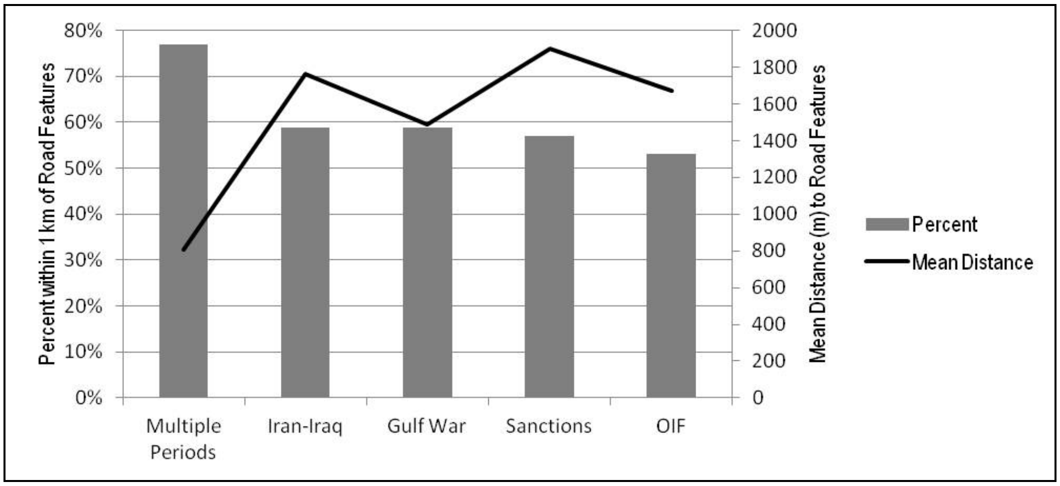

Figure 4.8. Percent of cultivated area within 1 km of road features and mean distance for all pixels classified as cultivated from nearest road feature by period. This graph infers that agricultural lands cultivated during only a single period, and subsequently abandoned, tend to be further from the transportation grid.

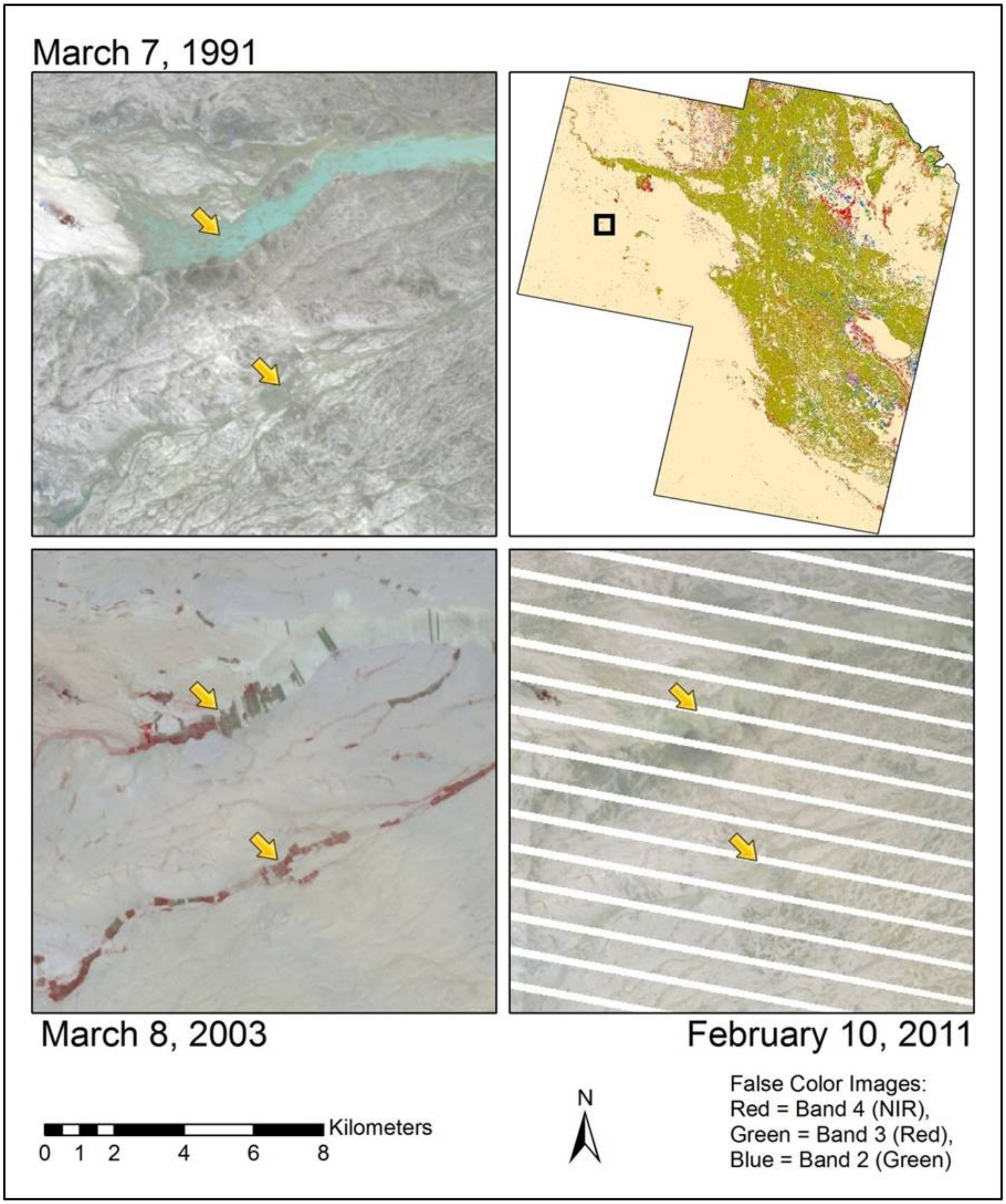

Figure 4.9. Example of wadiis cultivated in central Iraq during sanctions. The black box in the upper right graphic depicts the location of the three false color images. The image in the upper left is from March 1991, when sanctions had only been in place for a few months. The image in the lower left is from March 2003, shortly before sanctions ended, and shows an example of

wadi cultivation undertaken during sanctions. The image in the lower right shows the same wadi almost eight years after sanctions ended (Landsat 7 SLC-off), and it appears to no longer be used for cultivation. Yellow arrows were added for reference.

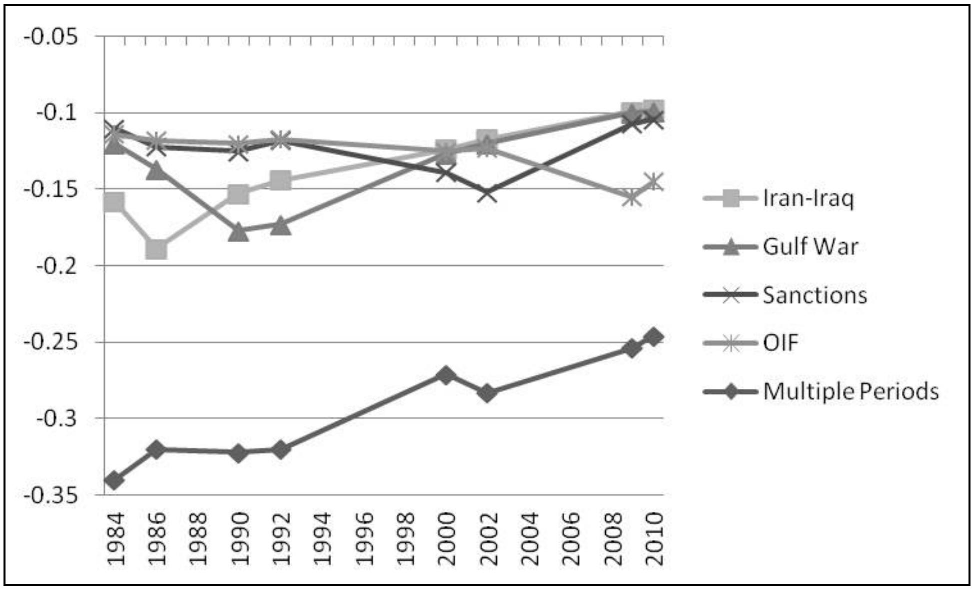

Figure 4.10. Mean NDSI values for all pixels for a given period. There appears to be increasing surface soil salinity in lands that were abandoned after only being used during a single period. Lands that have been cultivated for multiple periods also appear to have increasing surface soil salinity.

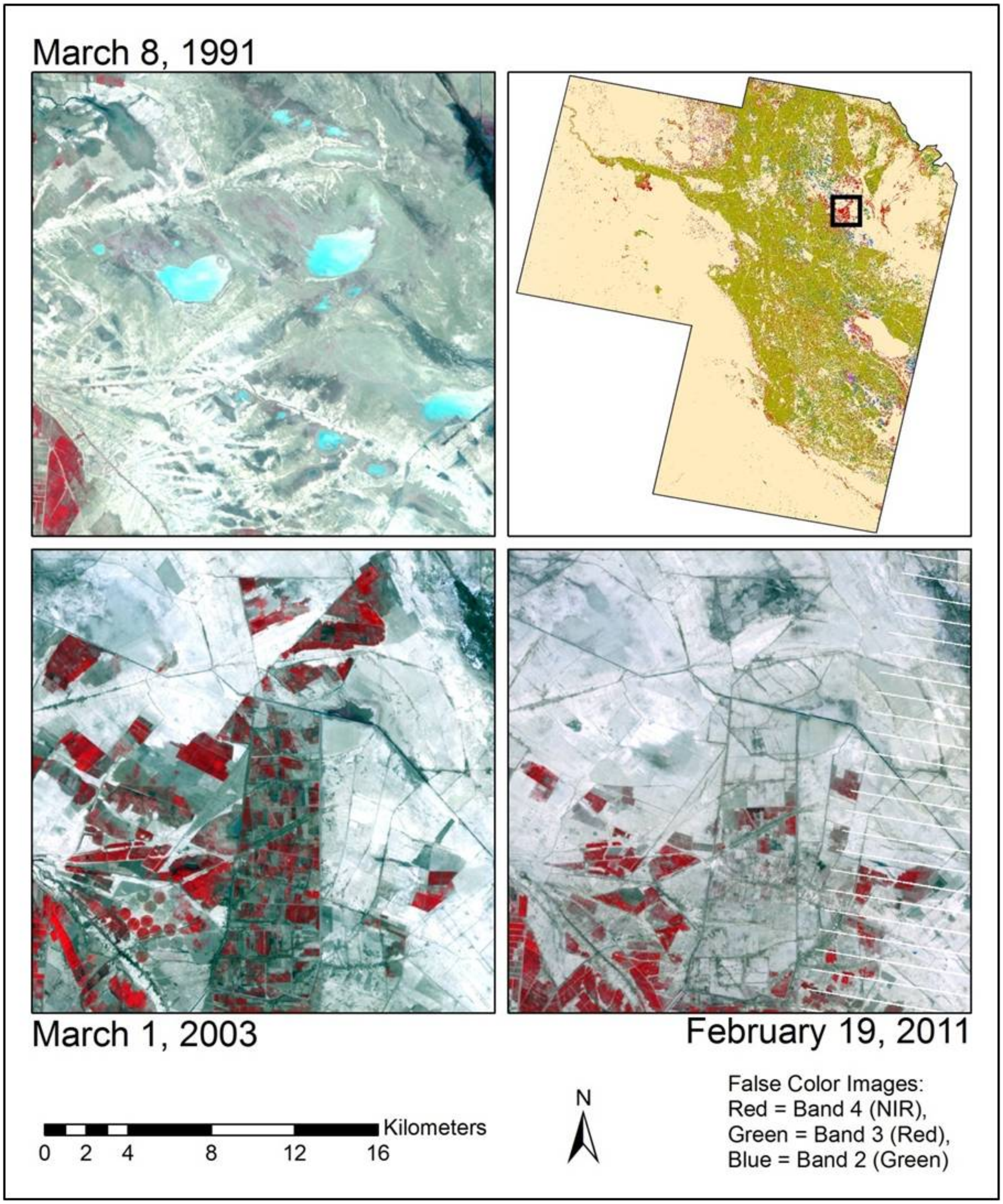

Figure 4.11. Example of large areas of abandoned agricultural land in central Iraq. The black box in the upper right graphic depicts the location of the three false color images. The image in the upper left is from March 1991, when sanctions had only been in place for a few months. The image in the lower left is from March 2003, shortly before sanctions ended, and shows an

example of large extensification projects undertaken during sanctions. The image in the lower right shows the same area almost eight years after sanctions ended (Landsat 7 SLC-off), with many of the fields no longer in use. The area may have been abandoned due to high soil salinity.

Chapter 5: Conclusion

Summary of Findings

The results of my research presented in Chapter 2 reveal that Operation Iraqi Freedom (OIF) and the end of UN sanctions had significant impacts on cultivated cropland area in Iraq, with total cultivated area decreasing over time. Changes were not uniform across time or space. In northern Iraq, which has been under Kurdish control and generally autonomous since the Gulf War of 1991, the cropland cultivated area changed little within its three governorates. The majority of Iraq, twelve governorates located in the nation's central region, experienced significant decreases in cultivated area from 2001 to 2011. I believe these reductions to be a result of reduced demand for domestic production once the Hussein regime was removed from power and food imports resumed to reach new highs. The three governorates containing Iraq's marshlands saw increases in cultivated area initially following the initial OIF invasion in 2003 as marshes were reflooded, but then decreased during the drought of 2008 and 2009. Croplands used for both winter and summer cultivation had significant decreases in cultivated area over time, with most of this change occurring in central Iraq. Cereals, like winter wheat, represent 70 to 85 percent of Iraq's cultivated area, and decreases in the amount of land dedicated to their cultivation may be related to increasing wheat and wheat flour imports.

The research presented in Chapter 3 found that little change occurred between the Iran-Iraq War and the Gulf War, 1.69 and 1.72 Mha respectively, but then cultivated area increased by approximately 20 percent from Early Sanctions to Late Sanctions, to over 2.04 Mha. I estimate that cultivated area decreased by approximately 30 percent to an estimated 1.4 Mha during OIF, which coincides with the end of the sanctions. I was also able to identify areas that were single-cropped or double-cropped and found that winter crops, such as winter wheat and barley, experienced the greatest changes, with little change occurring between the Iran-Iraq War and the Gulf War and Early Sanctions periods (1.03 and 0.96 Mha), to over a 30 percent increase during sanctions (1.33 Mha), followed by an approximately 50 percent decrease after sanctions during OIF (0.68 Mha). The main cause for the increase in cultivated area during the period of UN sanctions was the Hussein regimes' policy of extensification when food imports ceased and domestic intensification was not possible due to bans on dual-use items like fertilizers, pesticides, etc. When sanctions ended, agricultural lands with high salinity and other subprime lands were abandoned. The impact of sanctions on food security cannot be understated in the case of Iraq. Decades of war, political instability, and mismanagement of agricultural lands, combined with increasing population, had left Iraq dependent on food imports. Despite that dependence, the target of the UN sanctions, the Hussein regime, was able to withstand comprehensive sanctions for years while the Iraqi people starved. The quick return to pre-sanction levels of cultivated area during OIF indicates a return to dependence on food imports even as the country moves towards political independence.

In Chapter 4, I found that some 0.20 Mha were abandoned after the Iran-Iraq War and 0.14 after the Gulf War. Cultivated area expanded by approximately 20 percent during the sanctions, with 0.31 Mha being cultivated for the first time and then abandoned. The main cause for the increase in cultivated area during the period of UN sanctions was the Hussein regimes' policy of extensification when food imports ceased and domestic intensification was not possible due to the bans on dual-use items like fertilizers, pesticides, etc. When the sanctions ended, agricultural lands with high salinity and other subprime lands were abandoned. I estimate that cultivated area decreased by approximately 30 percent during OIF, which coincides with the end of the sanctions, with less than 0.07 Mha being cultivated for the first time. These areas warrant continued observation due to the potential for later abandonment. Additionally, I analyzed land use and abandonment patterns related to three drivers of abandonment: availability of water, accessibility of roads, and salinity as indicated by NDSI. The results indicate that lands used most often are ones in close proximity to surface water features and roads, and that lands positioned further from these two features are more likely to be abandoned. I also found that salinity is increasing in the cultivated lands of central Iraq, regardless of whether it was cultivated during every period or during only a single period. However, the largest areas of abandoned land were those cultivated during the Late Sanctions period.

Contributions and Further Work

My dissertation research makes several contributions to the scientific community and to policy makers. For example, understanding the cultural and environmental differences within a country allows one a better understanding of what impacts war and sanctions will have on a nation’s ability to feed its own people and how that ability contributes to land use. In the case of Iraq, the Kurdish Autonomous Region in the north, where rainfed agriculture is possible and the centralized government has had little influence in recent years, sanctions and political instability appear to have had little effect. In contrast, in central Iraq, where cultivation is only possible with a state-maintained irrigation infrastructure and a central government is able to exert its influence through favoritism, coercion, and other means, the government’s response to war, sanctions, and political instability had enormous effects on agricultural land use through extensification, expansive irrigation projects, and, in recent years, land abandonment. In the current geopolitical environment, when stricter international sanctions are being proposed for other Middle Eastern countries like Syria and Iran for their oppression of their populace and the pursuit of nuclear weapons, respectively, one should consider cultural and environmental difference within those countries to understand asymmetric effects. Questions to be asked include: Are these nations dependent on food imports? Do they have the ability to expand their agricultural base? Where will agriculture expand and how might that affect long-term land cover? What are the likely environmental consequences of their agricultural policies? Studies building upon my research can now begin to address potential effects on agricultural land use and land cover change in Syria and Iran.

This research contributes to the field of remote sensing by providing a robust example of how easily-accessed, freely-available data can be used to study large areas over decades. It demonstrates the value of sequential imagery, specifically the Landsat TM and ETM+ archive, to document agricultural land use change at temporal and spatial detail sufficient to monitor trends and changes in cultivation and production. As I first stated in the Introduction chapter of this dissertation, I would not have been able to complete this research without the free availability of MODIS and Landsat data. Many regions of the world, especially those experiencing armed conflict, or recovering from conflict, lack the institutions to conduct systematic census of agriculture, or inventories of agricultural resources to support efficient administration and planning.

Land cover change research often incorporates only a few images, comparing one point in time to another point in time, but the availability of Landsat images now allows for inclusion of dozens or even hundreds of images over multiple decades to create multi-temporal composites. Further, recent acquisitions are available to the public within days, allowing researchers to incorporate very recent images. However, the temporal resolution of Landsat did pose some challenges for my research. Cloud-free scenes were not uniformly available throughout the year. There were several years in the mid-1990s in which not a single TM image of central Iraq was available. Portions of Landsat 7 images are not useable due to the scan-line-corrector (SLC) malfunction in 2003. Jensen (2002) identified data continuity as a key issue necessary for sustaining progress in the field of remote sensing. With the deteriorating condition of the Landsat 5 TM and Landsat 7 ETM+ instruments, and the Landsat Data Continuity Mission (LDCM) not scheduled to launch until January 2013, coverage gaps are now occurring (Campbell and Salomonson 2010). In the case of Iraq, the absence of available Landsat images during several years in the mid-1990s limited my ability to identify changes related to the Oil-for-Food Program, a part of UN sanctions. Given the deterioration of the current Landsat systems in operation, one might predict a similar data gaps for Syria and Iran should a similar study be attempted in a few years.

I see the potential for further work related to my dissertation to include a period post-OIF, after the Iraqi government has had time to solidify. Keys to analysis of future changes will be if and how the government decides to handle land ownership reform and whether or not oil revenues will be used to improve ailing irrigation systems and transportation grid. Also, will Iraq's central government implement a national strategy to address its dependence on food imports and take necessary steps to adopt practices that will improve the poor soil conditions of its limited arable land caused by years of overexploitation? Such decisions would go far in ensuring future food security and independence. From a remote sensing perspective, future work might also benefit from *data fusion*—the use of techniques that combine data from multiple sources to achieve greater accuracy and information (Campbell and Salomonson 2010)—to mitigate gaps in MODIS and Landsat data.

In conclusion, agriculture—now the second largest economic sector—is still Iraq's largest employer and can be effective for promoting stability through private sector development, poverty reduction, and food security (USAID 2006). As the political situation stabilizes, it will become increasingly important to monitor changes in land cover and assess agriculture performance and growth. A baseline study is critical to monitor current conditions and assess future changes. Even though agriculture is such a vital component of Iraq's economy, there is limited information available on how it has been affected by OIF and sociopolitical forces. Because the security situation in Iraq still faces some challenges, a remote sensing approach to studying land cover change was adopted. My research presents strategies for monitoring such changes and provides an important baseline overview for this area.

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