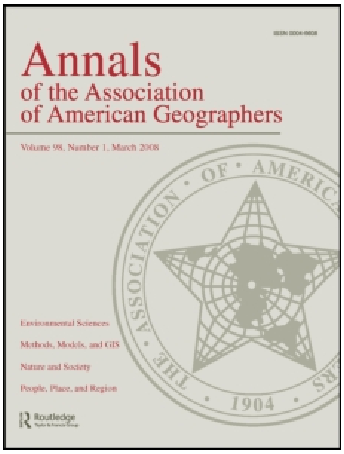

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Satellite Data Methods and Application in the Evaluation of War Outcomes: Abandoned Agricultural Land in Bosnia-Herzegovina After the 1992-1995 Conflict

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Satellite Data Methods and Application in the Evaluation of War Outcomes: Abandoned Agricultural Land in Bosnia-Herzegovina After the 1992–1995 Conflict

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The devastation of wars is most often measured in terms of the number of dead and missing people, but other conflict effects are long-lasting and far-reaching. The 1992–1995 war in Bosnia-Herzegovina resulted in almost 100,000 killed and almost half of the population displaced. This article analyzes the war's effects by evaluating impacts on the postwar agriculture environment from which most Bosnians derive their livelihoods. The war's impacts showed significant geographic variability, with localities near the frontlines and in eastern Bosnia-Herzegovina particularly affected. Thirty-meter Landsat imagery from before, during, and after the war was used to identify abandoned agricultural land in two study areas (northeast and south) within Bosnia-Herzegovina, characterized by different climates, soil, and vegetation. In the image analysis methodology, multiple change detection techniques were tested, and ultimately a supervised classification was chosen. Ground reference data collected during the spring seasons of 2006 and 2007 show the remote sensing methodology is effective in identifying abandoned agricultural land for the northeast study region but not for the southern one. The differential success rates were due primarily to variations in climate and soil conditions between the two regions, but also point to contrasts due to the different nature of the war in the two study regions. The study has important implications for the use of remote sensing data in tracking the course of conflicts and evaluating their long-term impacts. *Key Words: Bosnia-Herzegovina war, environmental outcomes, GPS, ground-referencing methods, Landsat imagery.*

死亡和失踪人数是最常见的战争破坏程度衡量指标，但其它冲突的影响是长期和深远的。1992—1995 年，波斯尼亚和黑塞哥维那的战争造成了近 10 万人死亡和几乎一半的人口流离失所。农业是大多数波斯尼亚人获得生计的主要途径，本文通过评估战后农业环境来分析战争的影响。战争的影响有着显著的地域差异，特别是在前线附近，以及受到影响的波斯尼亚一黑塞哥维那东部地区。利用战争之前，期间和战后的 30 米分辨率的地球资源卫星图像，在波斯尼亚和黑塞哥维那的两个研究区域内（东北部和南部），以确定那些被放弃的农业用地。这两个研究区域各自具有不同的气候、土壤和植被特征。在图像分析方法上，本文测试了多种变化监测方法，最后采用了监督分类方法。地面参考数据采集于 2006 年和 2007 年的春季，研究表明，确认被放弃的农业用地，遥感方法在东北研究区是行之有效的方法，但不适用于南部研究区。成功率的差异主要是由于两个区域之间气候和土壤条件的差异，同时也指出了因发生在这两个研究地区的战争的不同性质而造成的对比。这项研究对使用遥感数据跟踪冲突进程和评估其长期影响具有重要意义。*关键词：波斯尼亚和黑塞哥维那的战争，环境后果，全球定位系统，地面参照方法，地球资源卫星图像。*

Muy a menudo la devastación de las guerras se mide en términos del número de muertos y desaparecidos, pero otros efectos de los conflictos son duraderos y de largo alcance. La guerra de 1992–1995 en Bosnia-Herzegovina resultó en cerca de 100.000 muertes y en el desplazamiento de casi la mitad de la población. Este artículo analiza los efectos de la guerra, evaluando los impactos sobre el entorno de la agricultura en la posguerra, de la cual depende la vida de la mayoría de los bosnios. Los impactos de la guerra exhiben una variabilidad geográfica significativa, notándose particularmente afectadas las localidades cercanas a los frentes de guerra y en la parte oriental de Bosnia-Herzegovina. Se utilizó un conjunto de imágenes Landsat de antes, durante y después de la guerra para identificar la tierra agrícola abandonada en dos áreas de estudio dentro de Bosnia-Herzegovina (nordeste y sur), caracterizadas por tener diferentes climas, suelos y vegetación. En la metodología del análisis de las imágenes se probaron técnicas de detección de cambio múltiple, y en últimas se escogió una clasificación

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supervisada. Los datos de referencia del terreno, recogidos durante las primaveras del 2006 y 2007, muestran que la metodología de percepción remota es efectiva en la identificación de tierra agrícola abandonada en la región de estudio del nordeste, pero no en la del sur. Las tasas diferenciales de éxito se debieron primariamente a variaciones de las condiciones de clima y suelo entre las dos regiones, pero apuntan también a contrastes debido a la diferente naturaleza de la guerra en las dos regiones estudiadas. El estudio tiene importantes implicaciones sobre el uso de datos de percepción remota para hacerle seguimiento al curso de los conflictos y evaluar sus impactos a largo plazo. *Palabras clave: guerra de Bosnia-Herzegovina, efectos ambientales, GPS, métodos de referenciación del terreno, imágenes Landsat.*

There are approximately 110 million mines and other unexploded ordnance (UXO) scattered in sixty-four countries on all continents, remnants of wars from the early twentieth century to the present. Africa alone has 37 million landmines in at least nineteen countries. Angola is by far the most affected zone with 15 million landmines and an amputee population of 70,000, the highest rate in the world. Despite the belated awareness of the toll of landmines due to the 1997 Nobel Peace Prize for the International Campaign to Ban Landmines (ICBL), the removal of mines proceeds at a glacial pace due to the danger, cost ($300 to $1,000 per mine removed), and lack of international agreement on targeting priorities. Efforts to prohibit the future use of mines by militaries have foundered on their low price ($3–$10), easy accessibility, and effectiveness in military campaigns (Mather 2002). In mine-ridden countries such as Mozambique and Angola, which suffered protracted civil wars after independence in 1975, notions of sustainable development are illusory as agriculture, transportation, resource access, and general international investment are hindered (Unruh, Heynen, and Hossler 2003). In Bosnia-Herzegovina (BiH), only about 4 percent of the mines laid over a decade ago have been removed and at present rates of removal, it will take over a century to complete the process. Up to 4,000 km^2 still harbor antipersonnel mines, antitank mines, and UXO (ICBL 2002). In the first nine postwar years, 1,522 people were killed or severely injured by landmine accidents across BiH (United Nations High Commissioner for Refugees 2004).

The War in Bosnia-Herzegovina and the Two Study Areas

Bosnia-Herzegovina is the most mine-afflicted country in Europe, with an estimated 1.3 million people, roughly one third of the population, living in 1,366 mine-affected communities. In 2007, there were more than 12,000 locations requiring clearance (Fitzgerald 2007). About 1 million mines, mostly antipersonnel, still remain in Bosnia-Herzegovina and only about 60 percent of mined areas have been identified (Bolton 2003; Mitchell 2004). As seen in Figure 1, the minefields are found in all regions of the country with a concentration near the war's frontlines, the line of demarcation (Inter-Entity Boundary Line [IEBL]) between the Republika Srpska and the Federation of Bosnia-Herzegovina as agreed in the Dayton Peace Accords in November 1995. Because the region was a strategic narrow strip connecting the two main bodies of Serb-controlled territory during the war, mines are most concentrated in the northern municipality of Brčko.

Although the presence of minefields in all parts of the country is a daily reminder of the war's legacy, the localized distribution of the dead and missing people shows a more uneven distribution. The eastern boundary of the country along the Drina, including the massacre site of Srebrenica and the site of massive ethnic cleansing (Zvornik), shows a disproportionate loss of life (Ó Tuathail and Dahlman 2006). Sarajevo was besieged for almost three years and suffered the single biggest loss of life for any community in the war. Other major regional centers with ethnic divides (Prijedor, Doboj, Mostar, and Foča) also experienced high losses, although every municipality registered dead or missing (Figure 2). The moves of refugees and internally displaced persons (IDPs), mostly due to ethnic cleansing during the war, meant that the mixed communities evident on the map of census data from 1991 in Figure 2 were mostly changed to nearly homogenous communities. The provisions of Annex VII of the Dayton Accords guarantee the safe returns of refugees and IDPs to their former homes, but despite a wave of returns between 1999 and 2004, the process is far from complete and fear of retribution keeps many potential returnees away (Ó Tuathail and O'Loughlin this issue).

The outcomes of wars are multifaceted and include a range of social, economic, political, and environmental consequences from fighting. Consociational political

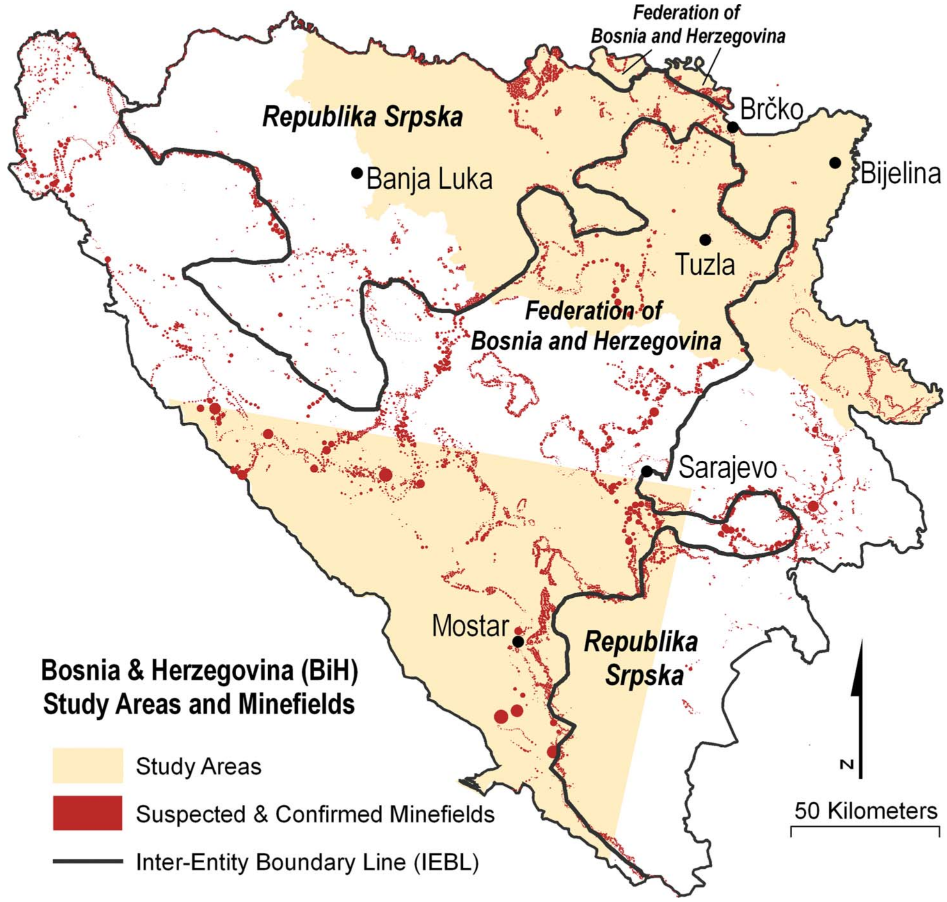

Figure 1. Bosnia-Herzegovina. Location of identified minefields, study regions, and the Inter-Entity Boundary Line established at the Dayton Peace Accords in November 2005.

arrangements can be devised to encourage cross-ethnic reconciliation and shared governance. In BiH, the complicated political arrangements agreed to at Dayton gave a large amount of autonomy to the two entities (Serb and Croat/Bosniak), designed a power-sharing arrangement for the whole country, and allowed local communities a wide range of governmental functions. The arrangement is supported widely by Serbs, moderately by Bosniaks, and weakly by Croats (who did not get their own separate political entity; Ó Tuathail, O'Loughlin, and Djipa 2006).

The war in BiH was marked by a strong international presence, both during the war and in its aftermath. Nearly fifteen years after the ceasefire, the Office of High Representative (OHR) of the United Nations (UN) still remains effectively in charge of the country, the Hague Tribunal on war crimes in the former Yugoslavia continues to prosecute major figures (the latest being that of Radovan Karadžič, former president of the Serb Republic), and thousands of UN peacekeepers remain on patrol. International nongovernmental and governmental agencies operate to identify the bodies of missing persons, to promote grassroots democracy, to settle refugees and displaced persons in their home communities, to rebuild economic infrastructures and promote development, and to raise funds for the identification and removal of the landmines that litter the country. In this article, we extend prior research (Witmer 2008) by comparing the results of a satellite data analysis and field checks from southern and northeast BiH regarding the effects of landmining on agricultural land abandonment in the aftermath of war.[1]

Remote Sensing and the Study of Conflicts

Academic research on war and conflict that examines remote sensing data is still surprisingly limited. Since 1960, satellite reconnaissance has played a significant role in providing information concerning enemy missiles, troop deployments, and military positionings, and the Cold War years saw major technological advancements by American and (later) other military interests (Corson and Palka 2004). Military uses of remote

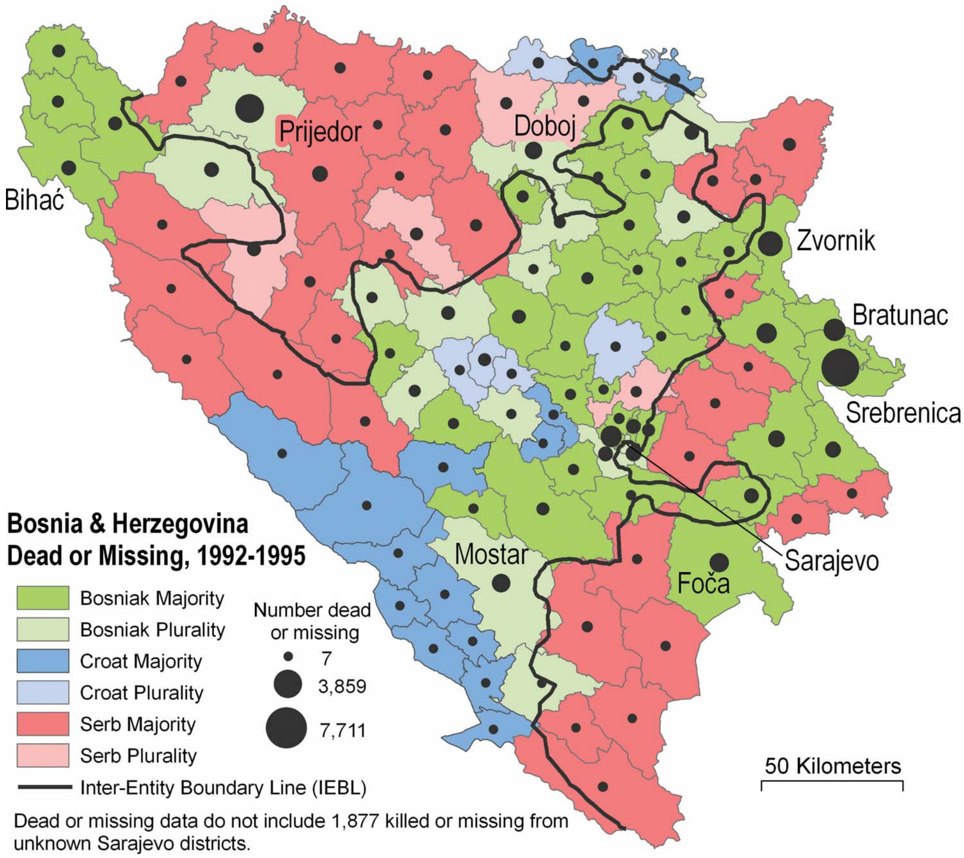

Figure 2. Distribution of deaths by *opština* during the 1992–1995 war and prewar ethnic composition in Bosnia-Herzegovina.

sensing technology are driven by strategic battlefield goals, with little attention given to broader war impacts. The uses of satellite imagery in conflict study tend to concentrate on the immediate impacts of military action, including identification of bomb damage, monitoring of fires and military movements, and mapping minefields.

Public attention was drawn to the use of nonmilitary satellite data during the 1991 Gulf War in Iraq and Kuwait due to extensive interest in the war's environmental consequences spurred by the massive impacts resulting from vehicle movements, hundreds of oil well fires, and numerous oil lakes (Stephens and Matson 1993; El-Baz and Makharita 1994; El-Gamily 2007). Further analyses identified the distribution of burning wells in different oilfields and produced estimates of flow rates and emissions of gaseous pollutants and particulates by incorporating the different spatial and temporal resolutions of AVHRR, Meteosat, Landsat Thematic Mapper (TM), and SPOT data (Husain 1994; Kwarteng 1998; Abuelgasim et al. 1999). The oil trench fires around Baghdad in March 2003 at the start of the second U.S.–Iraq conflict prompted further satellite monitoring using Landsat and IKONOS multispectral imagery (United Nations Environment Programme [UNEP] 2003).

Attention to other conflicts has focused on vegetation changes caused by military actions. The use of herbicides by the United States during the Vietnam War reduced the total mangrove area by one third in South Vietnam (Thu and Populus 2007). In Zimbabwe, a study of land cover changes identified the construction of service roads along minefields, vegetation removal from minefield perimeters, and vegetation regeneration of mined agricultural areas using remotely sensed data (Maathuis 2003). During the 1970s' Sandinista insurgency in Nicaragua, early Landsat MultiSpectral Scanner imagery captured the 45 to 55 percent reduction in agricultural productivity on the plantations (Howes 1979). Isolated areas of abandoned land were visible much later (1986–1996) using Landsat, SPOT, and AVHRR data as long-term results of the Contra war (Smith 1998).

Among the few applications of remote sensing data in conflict study, urban infrastructural and housing impacts of North Atlantic Treaty Organization (NATO) bombings of Yugoslav cities during the 1999 Kosovo war are evident in both Landsat TM (30-m resolution) and Indian Remote Sensing (IRS) 6-m imagery (United Nations Environment Programme and United Nations Centre for Human Settlements 1999). Very fine-resolution imagery is necessary for detecting impacts on the urban built environment. Structural damage from Israeli incursions into Jenin (West Bank) and NATO bombings in Macedonia were documented using IKONOS 1–2-m data (Al-Khudhairy, Caravaggi, and Glada 2005). Repressive actions by the Zimbabwean government resulting in destruction of dwellings were documented using Quickbird imagery (60-cm resolution) from 2002 and 2006 (Lempinen 2006). The U.S. Holocaust Museum's Web site allows visitors to see village destruction in Darfur (Sudan) by putting fine-resolution imagery online via Google Earth (http://www.ushmm.org/googleearth/); when coupled with pictures of destroyed homes identified on the images, viewers can easily see the efforts of Sudanese and paramilitary brutality. Recently, Human Rights Watch highlighted the ethnic cleansing of ethnic Georgian villages in South Ossetia, showing burning and destroyed homes after the August 2008 fighting in WorldView-1 & Formosat-2 satellite imagery (http://unosat.web.cern.ch/unosat/).

Displaced persons fleeing conflict zones often relocate to large refugee camps, where international assistance can more easily be administered and accessed. Remote sensing has been increasingly used to monitor the spatial extent of these camps for more efficient aid management, population estimates, and impacts to adjacent forests (Lodhi, Echavarria, and Keithley 1998; Bjorgo 2000; UN General Assembly Economic and Social Council 2000). Fine-resolution satellite imagery such as IKONOS panchromatic (1 m) and JERS (5–10 m) has been used to count refugee tents to estimate populations at risk (Giada et al. 2003) and locate hidden water sources to site refugee camps for Sudanese in eastern Chad (Bally et al. 2005). Although the UN is the leader in the humanitarian use of satellite data (Bjorgo 2002), little academic research has used the imagery to analyze the effects of war from such a synoptic view. Given the increased availability of mid- to fine-resolution (better than 36 m pixels) satellite imagery since the early 1990s (Stoney 2008), detailed analysis of war effects on the environment (both natural and anthropogenic) is long past due. In this vein, we examine the ability of satellite imagery to provide detailed information that can assist in war recovery by testing the accuracy of an abandoned agricultural land classification in Bosnia-Herzegovina.

The Environmental Context of Bosnia-Herzegovina

Bosnia-Herzegovina covers just over 51,000 km^2. Draping its land cover features (CORINE data from the European Environment Agency) over a shaded relief terrain map in Figure 3 shows the rugged terrain characteristic of BiH's southern and western regions rising to a height of 2,386 m, contrasting with the flat terrain and rolling hills in the northeast. Artificial surfaces are primarily urban and industrial areas but also include mine and dump sites; forests encompass coniferous, broadleafed, and mixed forests; and the agricultural category consists of arable land (irrigated and nonirrigated) and permanent crops. The flatter terrain in northeast BiH has more intensive agricultural land use, whereas the mountains of central BiH remain largely forested. The southern and western regions stand out both in terms of climate and land cover, consisting of poor-quality soil in karst areas supporting only shrubs and grasslands. These differences in land use reflect, in part, differences in soil depth (Figure 4), with southern BiH characterized by very shallow soil (less than 40 cm deep) and most of northeast BiH covered by a moderate soil depth (more than 60 cm deep).

The climate of our southern BiH study region is mediterranean, with temperatures averaging about 2°C in January and 23 to 26°C in July and rainfall between 1,500 and 2,000 mm. By contrast, the northern study region is characterized by a temperate continental climate with January temperatures about 1°C and July temperatures of 20 to 22°C and average rainfall of 800 mm. Despite the relatively abundant precipitation in the south, higher evapotranspiration rates and karst topography result in a higher water deficit or irrigation requirement there (Custovic 2005). The rural population density distribution (not shown but derived from 1991 census data by settlement or village with a buffer used to exclude all settlements within 1 km of the boundaries of urban areas) indicates a northern region from Bihać to Brčko, Tuzla, and Zvornik with higher population densities and corresponds with the higher agricultural productivity expected from the land use map.

Methodology and Ground-Referencing Procedures

Detecting changes to agricultural land use separately for both the northeast and southern study areas from

Figure 3. Land cover of Bosnia-Herzegovina draped over a shaded relief topographic map derived from digital elevation data. Land cover data are from the European Environment Agency (http://dataservice.eea.europa.eu/dataservice/) and elevation data from the Consultative Group on International Agricultural Research (http://srtm.csi.cgiar.org/). These primary land cover data were then overlaid onto topographic relief data collected from the Space Shuttle Radar Topography Mission in 2000. The digital elevation data were captured at a resolution of three arc seconds (nominal 90-m pixel resolution) and projected to UTM zone 33N for processing and display.

satellite imagery requires three steps: obtaining and preprocessing the satellite imagery from before and after the 1992–1995 war, selecting appropriate change detection methods, and conducting an accuracy assessment of the results (Lu et al. 2004). Complete details on the competing change detection methods used for the analysis of the northeast study area can be found in Witmer (2008).

Satellite Imagery and Preprocessing

Based on spatial, spectral, and temporal resolution requirements for this vegetation study, Landsat Thematic Mapper (TM) data were used. The TM sensor records information in the visible wavelengths (blue, green, and red) and near-infrared wavelengths, necessary for measuring vegetation health, which reflects strongly in the near-infrared portion of the spectrum. Because Landsat TM data consist of 30-m pixels with each scene covering 185 × 185 km of the Earth's surface, the northeast study area could be analyzed using two sets of overlapping scenes; one set of scenes was sufficient for the southern study area (see Figure 1). The 30-m pixel size enables us to identify medium to large agricultural fields and to reduce the number of mixed pixels that occurs with coarser imagery (see Figure 5b for an example of this scale; Müller and Munroe [2008] also use these satellite data for studying land abandonment in Albania).

The temporal frequency of the satellite data is dictated by the length and timing of the agricultural growing season and the availability of Landsat scenes. In agricultural land use studies, vegetation phenology is especially important due to the sudden changes in reflectance associated with crop planting and harvesting (Bauer 1985). Because we are detecting revegetation associated with abandoned agricultural land, the imagery should be separated by at least three years (Bauer 1985; Coppin et al. 2004). Landsat images over the previous fifteen years for spring (April, May, June) and summer (July, August, September) were acquired for the years 1990 to 1992 (just before the war) and recent postwar years (2002, 2004, and 2005), to ensure identification of plowed and harvested fields, whether sown with winter or summer

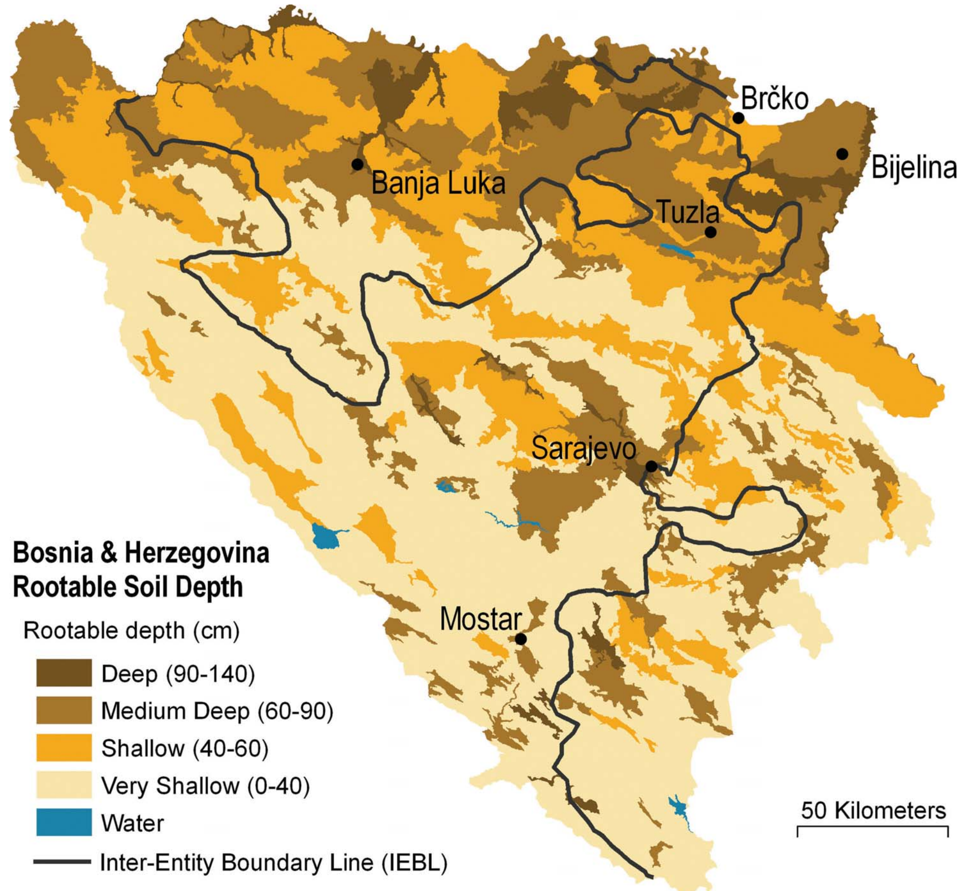

Figure 4. Rootable soil depth for Bosnia-Herzegovina. Data from the Participatory Land Use Development project of the UN Food and Agriculture Organization (http://www.plud.ba/).

crops. The Landsat imagery was acquired from the University of Maryland's Earth Science Data Interface at the Global Land-Cover Facility, Yale University's Center for Earth Observation, the U.S. Geological Survey, and a purchase from Eurimage. All scenes were registered to one of the University of Maryland's Landsat scenes, which have already been ortho-rectified and georegistered as part of their Landsat Geocover project (http://www.landcover.org/portal/geocover/). Co-registering each set of scenes ensures that pixels from different scenes align spatially and that changes detected are due to actual changes in vegetation and not registration errors. Additional processing identified the few pixels contaminated with clouds (mostly over the central BiH mountains) and excluded them from the analysis.

Change Detection Methods

Multiple change detection methods were tested for each study area with the minimum distance supervised classification found to perform best (for details, see Witmer 2008). This method requires the use of training data as input to the classifier. For each study area, thirty to sixty pixels associated with known areas of abandoned agricultural land were identified and used to train the classifier, which then identified all other agricultural pixels that exhibited similar spectral properties associated with abandoned agricultural land. For the northeast study area, the Landsat training pixels were identified using fine-resolution Quickbird imagery (60-cm pixels) available in Google Earth that is sufficient to distinguish the smooth texture of recently plowed, active agricultural land from the rough texture characteristic of shrubs and trees growing on abandoned agricultural land.

Because no fine-resolution imagery was available in southern BiH, fieldwork was conducted to identify areas of both abandoned and active agricultural land. To ensure an even distribution of field data, 200 random points were sampled from the agricultural land covered by the southern set of Landsat scenes. From the collected field data in the south, three areas of abandoned agricultural land (thirty to ninety pixels each)

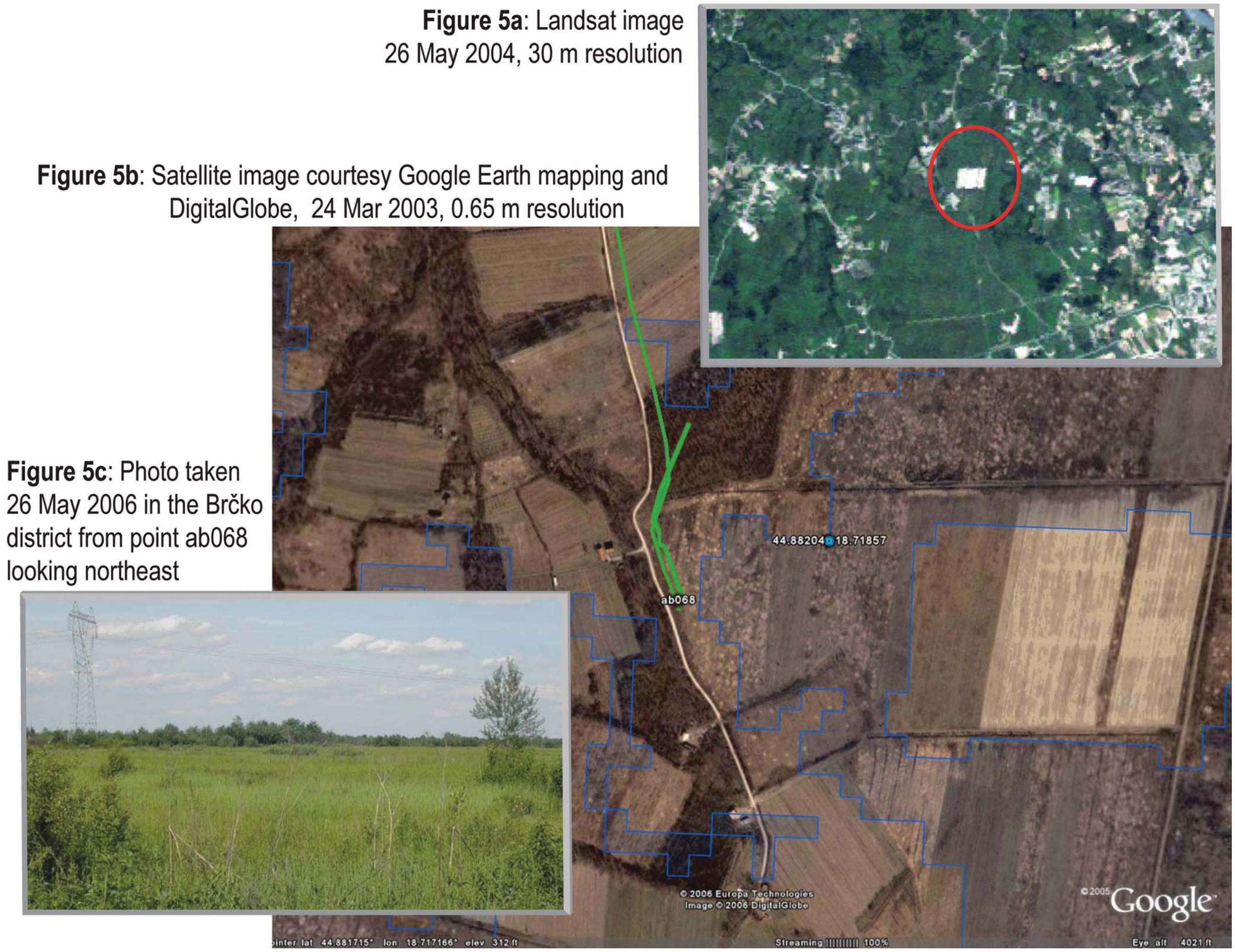

Figure 5. Images of the Brčko district show the general method for collecting ground reference data. Google Earth image, used with permission.

were used to train the classifier and the remainder withheld to conduct an accuracy assessment of the resulting classification.

Ground Reference Data and Accuracy Assessment

A persistent challenge in using satellite imagery is obtaining ground reference data for use in supervised classifications and accuracy assessments (Congalton and Green 1999; Cihlar 2000). Collecting ground reference data is especially problematic when using historical remote sensing data for which firsthand observations are unavailable. For the northeast study area, we chose a postchange detection approach similar to Serneels, Said, and Lambin (2001) and Nordberg and Evertson (2005) where ground reference data are collected after the classification analysis is complete. Following the general guideline of collecting at least fifty samples for each land-cover category (Congalton and Green 1999; Czaplewski 2003), we identified 150 "abandoned land" sites and 100 "active agriculture" sites from the classified imagery using a stratified random sampling approach. Because there is more cultivated land than abandoned land, abandoned land sites were disproportionately sampled to ensure that the smaller category (by area) is not misclassified (Khorram 1999). For the southern study area, observations from five sites (for three contiguous areas) were used to train the classifier and the remaining ninety-two ground observations were used to verify the classification accuracy.

Sample field site coordinates were transferred to a Global Positioning System (GPS) receiver that was then used to locate the points precisely. A detailed roadmap of BiH, a digital road network of paved and farm dirt roads from GISData (Zagreb), and printed Google Earth maps (both Terra Metrics 15 m and Quickbird 60 cm) helped in our navigation to the field sites. For each site visited, the state of the agricultural land was recorded on a field validation form. Because minefields, both confirmed and suspected, still effectively restrict access to much of BiH, only sites visible from paved roads or well-worn farm roads could be visited as part of the fieldwork. Mark Reed, head of the Roehll demining team in the Brčko municipality, indicated that even well-traveled dirt farm roads can contain mines that simply have not detonated due to chance (interview, 26 May 2006). In total, eighty-four field reference points were checked in northeast BiH and ninety-seven field sites were checked in the south. The identification and checking of the classification of sample points is illustrated in Figure 5 for a site in the Brčko region. Figure 5a is one of the Landsat scenes used to detect the abandoned agricultural land. Figure 5b shows Quickbird imagery overlaid with detected abandoned land (blue shaded/outlined), a sampled field site (blue dot with coordinates), and our GPS car track (green) imagery in Google Earth (the field circled in red corresponds to the active field in Figure 5b). The offset green car track and blue abandoned land reflect a georegistration error of the Quickbird imagery. Figure 5c is the photograph taken from point a "ab068" looking northeast toward the sampled field site.

Results

Although the overall land use classification accuracy for both regions is more than 80 percent, this figure hides significant differences between the two regions (Table 1). The producer's accuracy is calculated from the respective column totals in each matrix, the user's accuracy from the row totals, and the total accuracy along the diagonal. Because our aim is to assess the impact of the war (through landmines) on agricultural land, we are most interested in the results as an end user with the individual user's accuracies as the most appropriate measures. For the northeast region, the May 2006 field reference data reveal a user's classification accuracy of abandoned agricultural land of almost 82 percent. In contrast, the May 2007 field reference data for the southern region show a user's accuracy of less than 16 percent. Of the nineteen sites classified as abandoned agricultural land in the south, only three were actually confirmed as abandoned by the field reference data.

The results from Fisher's exact test of independence[2] further highlight the differences in effectiveness of identifying abandoned agricultural land between the study areas. For the northeast, the Fisher's exact test p value is highly significant (the classification is significantly better than random). In contrast, the p value of 0.058 for the southern region indicates that the classification is not significantly different from what could be expected from a random classification (at the 95 percent confidence level).[3]

Multiple reasons explain the differences in classification success. The significant differences in climate and soil conditions mean that vegetation grows much faster and denser in the northeast region than in the south, readily apparent from field observations in both regions. After nearly fifteen years, much of the abandoned land in the northeast was overgrown with dense brush dotted with trees 3 to 5 m tall, whereas abandoned agricultural land in the southern region mostly consisted of short grasses and small bushes with growth inhibited by the

Table 1. Accuracy assessment results for the northeast and southern study areas of Bosnia-Herzegovina

	2006 northeast field data				2007 southern field data		
	AB	NA	Total		AB	NA	Total
Classified data							
AB	49	11	60	AB	3	16	19
NA	2	22	24	NA	2	71	73
Total	51	33	84	Total	5	87	92
	Producer's accuracy		User's accuracy		Producer's accuracy		User's accuracy
	AB = 96.1%		AB = 81.7%		AB = 60.0%		AB = 15.8%
	NA = 66.7%		NA = 91.7%		NA = 81.6%		NA = 97.3%
	Total accuracy = 84.5%				Total accuracy = 80.4%		
	p value = 0.000				p value = 0.058		

Notes: Land cover categories: AB = abandoned; NA = nonabandoned. The reported p value is for Fisher's exact test.

poor soils and rainfall deficit. The shallow soils of southern BiH (Figure 4) were clearly visible along highway roadcuts at not only less than 40 cm deep but often less than 15 cm. This combination of shallow soil, poor soil quality (karst), and limited rainfall explain much of the error in detecting abandoned agricultural land from satellite data in the south.

In addition to these environmental reasons, the nature of the war in the two study areas also affected the ability of the satellite imagery to detect abandoned land. As is evident in Figures 1 and 2, the northeast study area has a much higher density of landmines along the war's frontlines (which shifted frequently) and around major military targets, especially major towns. Many more deaths are reported in the *opštini* in this region as well—and the number of returnees after ethnic cleansing is significantly greater than in the south. In the south, with the exception of the intense fighting for control of Mostar, the fighting was reduced by early demarcation of the zones of control for the respective militias.

Conclusions and Lessons for Other War Zones

Our study was designed to see to what extent a method using satellite imagery for identifying abandoned land due primarily to landmines in one region of Bosnia-Herzegovina could be applied in another region with different terrain, soils, climate, and agricultural profiles. The limitations of the procedure due to the difficulty of detecting slow regrowth in vegetation are evident in the unreliability of the classification. Our study suggests that the procedure that we propose in this article can be extended to other environments with a rich vegetation signal (like northeast Bosnia-Herzegovina) but its use is limited in vegetation-poor regions, like the Sahel. For study areas with relatively rapid vegetation regrowth, moderate-resolution (20–30 m) imagery is sufficient for detecting war-induced abandoned agricultural land. With good knowledge of the climate and soils of a study area, it is possible to study war zones that are still too dangerous for the conduct of research. When available, the use of Quickbird imagery can facilitate detection of land use changes, preferably supplemented with firsthand field data. This is especially important for long-term conflicts (more than five years) where conducting extensive fieldwork is still too risky but sufficient time has passed for land cover changes associated with human abandonment to become visible.

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Notes

1. There is no evidence of widespread abandoned agricultural land before the war began in 1992. Citing Food and Agriculture Organization experts, Bolton (2003) reports that in the Brčko municipality, landmines are the principal cause of agricultural land abandonment.
2. The chi-square test is similar to Fisher's exact test but was not used due to expected values in the error matrix less than five.
3. The error matrix significance was also tested using the kappa (K-hat) measure and associated Z statistic. Results from this measure mirrored those from Fisher's exact test but are not reported because the kappa statistic is designed for multinomial distributions.

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