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Land-use change in the Caucasus during and after the Nagorno-Karabakh conflict

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Abstract Socioeconomic shocks can shape future land-use trajectories. Armed conflicts are an extreme form of a socioeconomic shock, but our understanding of how armed conflicts affect land-use change is limited. Our goal was to assess land-use changes related to the 1991–1994 Nagorno-Karabakh conflict between Armenia and Azerbaijan in the Caucasus region. We classified multi-temporal Landsat imagery, mapped land-use changes during and after the conflict, and applied matching statistics to isolate the effect of the conflict from other potential drivers of land change. In our study area, local land-use changes were dominated by high farmland abandonment rates of more than 60 % in the conflict zone. Concomitantly, we found a substantial displacement of agricultural activities into nearby Azerbaijani territory (>30 % of all abandoned land in the conflict zone was offset by new agricultural areas on Azerbaijani territory), likely as a consequence of refugee migrations. After the armed conflict ceased, only 17 % of the abandoned fields were re-cultivated, indicating that the land-use system may have transformed profoundly. Our results showed that an armed conflict can have substantial impact on land use. Spatially, our results indicated that armed conflicts may cause lasting land-use change in areas distant from the actual battlegrounds, representing an example of a distant linkage in land systems, in our case caused by refugee movements. Temporally, armed conflicts appear to be able to cause a transition of the land-use system into a new state, akin to other drastic socioeconomic shocks.

Keywords Land-use change · Landsat · Coarsened exact matching · Local and displaced land-use change · Warfare · Armed conflicts

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Introduction

Socioeconomic shocks can cause land-use systems to undergo periods of rapid and drastic changes (Liu et al. 2007; Scheffer 2010), and shape land systems' future trajectories (Dearing et al. 2010). In general, land-use changes are caused by either slow drivers of change (e.g., demographic changes or industrialization) or fast drivers [e.g., revolutions, economic crisis, or technological breakthroughs such as the development of transgenic soybeans or the Haber–Bosch process (Aide and Grau 2004; Rudel et al. 2005; Lambin and Geist 2006)]. These drivers sometimes also interact with each other. For example, industrialization is commonly considered a slow driver of change but the technological breakthrough of the

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development of the Haber–Bosch process and the subsequent adoption of synthetic fertilizer during industrialization occurred quickly.

The impact of fast drivers on land systems can be dramatic and result in both increasing and decreasing land-use intensity. For example, agricultural land-use intensity increased substantially in Argentina following the development of transgenic soybean variants (Gasparri et al. 2013). Contrary, the breakdown of the Soviet Union (Baumann et al. 2011; Prishchepov et al. 2013) and the nuclear accident of Chernobyl (Hostert et al. 2011) both lead to widespread farmland abandonment and decreasing land-use intensity. In general though, much remains to be learned about the effect of fast drivers on land systems, for example whether certain rapid and drastic socioeconomic changes cause similar dynamic pattern of land-use change (e.g., Petschel-Held et al. 1999; Vaclavik et al. 2013; Niedertscheider et al. 2014).

Particularly, drastic socioeconomic shocks are armed conflicts and warfare, which have numerous consequences for people's lives and livelihoods (Brunborg and Urdal 2005; Buhaug et al. 2006; Hoddie and Smith 2009). Armed conflicts also affect the environment potentially for decades and centuries (El-Baz 1992), but such effects can be complex and with regard to land use may require examining different spatial and temporal dimensions.

In terms of spatial dimensions, the most immediate land-use changes typically occur within the actual combat zone (hereafter: "local effects"). Local effects are directly related to the conflict and can result in either increasing or decreasing pressure on land use, for example in the form of illegal logging, mining, and poaching due to a lack of enforcement by local authorities (Dudley et al. 2002; Alvarez 2003; Stevens et al. 2011). Even more extreme, forests may be lost over large areas, for example when defoliating agents are used, as in the Vietnam war (Westing 1975). However, land-use activities can also decrease in combat zones when people are engaged in fighting or are forced to flee, causing high rates of farmland abandonment (Suthakar and Bui 2008; Witmer 2008; Witmer and O'Loughlin 2009), the destruction of settlements (Hanson et al. 2008, 2009; Dyer and Jones 2010), or declining logging (Gorsevski et al. 2012).

The effects of armed conflicts on land use are by no means only local though and can affect land systems far away from the combat zone. For example, abandonment rates are generally lower at larger distances from the combat zone (Witmer 2008). Conversely, land-use activities afar from the combat zone may rise due to refugees (Stevens et al. 2011). Refugees fleeing from battlegrounds often move far within their country or even across international borders (Ware 2005; Sanchez-Cuervo and Aide 2013). As refugees move, so does their need for natural resources. Depending on the population density and

economic activity, this may lead to increasing land-use pressure at the destination (Hugo 1996). Potential land-use changes can be diverse, including forest disturbance for building resource extraction and heating (Gorsevski et al. 2012, 2013), forest clearing for agricultural land use (Alix-Garcia et al. 2013), and urban growth (Maystadt and Verwimp 2009; Alix-Garcia and Saah 2010). As such, the distant effects of conflict on land use show similarities to the phenomenon of urban–rural teleconnections (Global Land Project 2012; Seto et al. 2012), which determine linkages between urban populations and the hinterland of cities. However, our understanding of such linkages in relation to conflict is limited.

In terms of the temporal dimension, it is unclear whether land-use changes caused by an armed conflict persist during a post-conflict period. In other words, does a conflict represent a socioeconomic shock event from which a land system eventually recovers into its pre-conflict state, or does the land system transition into a new state (Scheffer et al. 2009; Scheffer 2010)? If refugees return after fighting ends (Ware 2005), then it is likely that the land system recovers, farmlands are re-cultivated, and forest resources use resumes. However, there can also be situations when a return is unlikely. For example, territorial boundaries may still be disputed after fighting ends (Johnson 2012), raising questions about land ownership, making it difficult to invest in agriculture, and thus leaving abandoned fields unmanaged. Likewise, land-use pressure can remain low when demand for certain agricultural products dwindles, like the case of date palm devastation in Iraq in the 1990s illustrates (El-Juhany 2010). More drastically, antipersonnel mines, which are unfortunately often used in conflicts (Andersson et al. 1995; Jeffrey 1996; Pearn 2003), and unexploded ordinance, may remain in the combat zone for years (International Campaign to Ban Landmines 2012), severely restricting land use. Finally, de-militarized zones between war-participating countries, as in the case of the Korean demilitarized zone (Higuchi et al. 1996; Kim 1997; John et al. 2003) or the establishment of military bases like Guantanamo Bay (Santos et al. 2006; Witmer and Lowney 2007), may prohibit land use and shift land systems toward trajectories of rewilding (Martin and Szuter 1999; Machlis and Hanson 2008; Machlis et al. 2011).

Isolating the effects of conflicts from other drivers is challenging though. For example, farmland abandonment might not be solely triggered by conflict, but rather be a consequence of broad-scale socioeconomic, demographic, and institutional change, such as the breakdown of the former Soviet Union (Müller et al. 2009; Prishchepov et al. 2012a, b; Alcantara et al. 2013), or reflect general land-use patterns that occur elsewhere, too (Grau et al. 2004; Gellrich et al. 2007). Not accounting for such influences might bias the assessments of the effect of conflicts (Andam et al.

2008; Joppa and Pfaff 2009), and it may be necessary to use quasi-experimental approaches (Alix-Garcia et al. 2012) to identify the effect of warfare on land-use change.

Here, we assessed the effects of an armed conflict on land use for the case of the Nagorno-Karabakh conflict. The conflict between Armenia and Azerbaijan over the former autonomous oblast Nagorno-Karabakh arose following Gorbachev's policy of opening Soviet rule and turned into a full-scale war in 1991, during which approximately 1 million people migrated to escape the violence. At the same time, the former Soviet Union underwent strong socioeconomic and political changes that triggered widespread farmland abandonment (Alcantara et al. 2013) and regionally high rates of forest disturbance as a consequence of changes in forest legislation and illegal logging (Wendland et al. 2011; Baumann et al. 2012). The Nagorno-Karabakh conflict therefore offers a unique opportunity to assess conflict-related land-use changes in the larger context of a major nonviolent socioeconomic shock. Specifically, we were interested in three research questions:

1. What were the local effects of the armed conflict on land-use change in the Nagorno-Karabakh region and how far did these effects extend around the conflict zone?
2. What were the land-use displacement effects of the conflict?
3. How did land-use changes during the post-conflict period differ from those during conflict?

Methods

Study area and the Nagorno-Karabakh conflict

Our study area was the Nagorno-Karabakh region including parts of the war-faring countries Armenia and Azerbaijan. The area is located in the southern Caucasus (Fig. 1) and has an elevation profile ranging from <50 m up to almost 3,600 m. Dominant soil types in the region are chernozems and phaeozems (Yigini et al. 2013). The climate in our study region varies substantially and is mostly determined by the mountain range of the Southern Caucasus. Precipitation varies between 300 mm and 4100 mm per year, and the temperature amplitude throughout the year is high, indicating a highly continental climate (Sylvén et al. 2009).

Armenia and Azerbaijan were both part of the Soviet Union and declared their independence in 1991. Thereafter, land reforms restructured land ownership entirely. Both countries distributed formerly collectivized land to rural residents. In Armenia, the allocation strategy exclusively involved the distribution of physical land plots. In Azerbaijan, the distribution was additionally done through entitlement shares (i.e., in the form of paper certificates), though only for a minor proportion of the agricultural land (Lerman et al. 2004). Thus, whereas agriculture during Soviet times was characterized by large farms and large fields, most agricultural areas today are owned by family farms, and field sizes are small [on average 1.9 ha in Armenia, and 2.8 ha in Azerbaijan (Giovarelli and Bledsoe 2001)].

Before the war, the region was dominated by intensive crop production and less intensive livestock grazing. Dominant crops in Armenia are wheat and barley (Curtis 1995). In the Azerbaijani agricultural sector, grapes, cotton, and tobacco are the most important cash crops, accompanied by a larger focus on livestock and dairy products than in Armenia (FAOSTAT 2014). During the last 15 years, agriculture became less economically important for both countries, though the overall production of agricultural products increased in both countries between 1992 and 2011 (FAOSTAT 2014).

The Nagorno-Karabakh region, i.e., the land that Armenia and Azerbaijan fought over, is at least partly a relic of Stalin's "divide-and-rule" policy. Stalin intentionally placed large ethnic majorities (i.e., Azerbaijani people) inside regions containing a different ethnicity (i.e., Karabakh Armenians, Derouen and Heo 2007) to ensure cooperation with the Soviet leadership. This intentional displacement of ethnic majorities paved the road toward a conflicting situation for several reasons: first, there was a significant difference in the standard of living between the Armenian and Azerbaijani population in Nagorno-Karabakh, reflected, e.g., in the substantially lower life expectancy and the lower level of consumer goods produced per person for the Azerbaijani population. Second, the region was, and still is, characterized by stark national cultural and linguistic differences, as during Soviet times territorial autonomy never aimed at cultural integration of the different ethnicities. Third, the stark ethno-demographic differences in that region due to the arbitrary placement of Azerbaijani into territory surrounded by Karabakh Armenians (Yamskov 1991) led to a situation characterized by tensions between ethnicities. During Soviet times, these tensions were suppressed by Moscow (Derouen and Heo 2007), but rose when Mikhail Gorbachev launched his policy of perestroika and glasnost. The relaxation of the authoritarian Soviet rule thus resulted in various outbreaks of conflicts that had previously been suppressed, and the Nagorno-Karabakh conflict was among the first (Cornell 1999, 2002).

The start of the full-scale war was September 25, 1991 (Gleditsch et al. 2002; Derouen and Heo 2007). The war, which ultimately was an ethnic conflict, led to about 30,000 deaths and nearly 1 million refugees mainly Azerbaijani
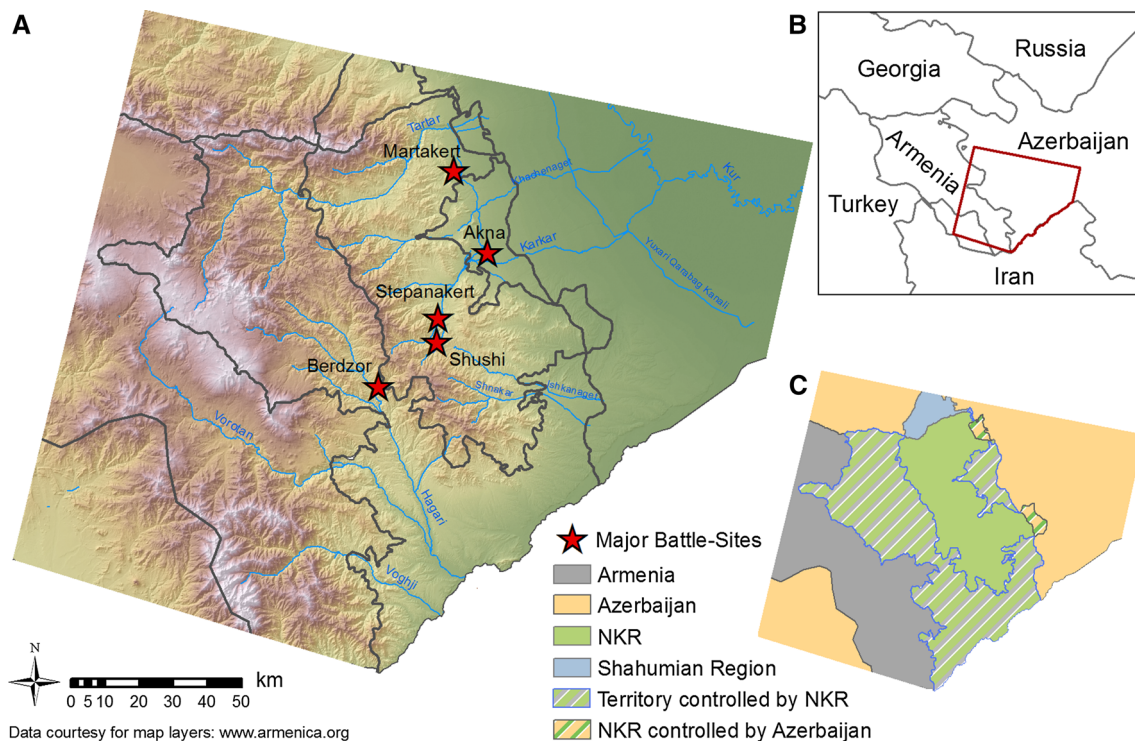
Fig. 1 Overview over the study area including the major clashes of the conflict (**a**), the greater geographical location of our study area (**b**), and the current administrative deviation of the study area (**c**)

people (Gleditsch et al. 2002; Mooradian and Druckman 1999). A cease-fire was instituted in 1994, but peace negotiations still continue, and so do animosities and deliberations between the primary actors in that war (Derouen and Heo 2007). Today, Nagorno-Karabakh is de facto a presidential republic, but its status remains officially unrecognized by the international community, including Azerbaijan and Armenia, and its territorial boundaries are under dispute (Fig. 1c). However, since the cease-fire, Nagorno-Karabakh has established a functioning government including a prime minister and executive ministers, and built a modern, well-equipped army that is considered to be one of the most capable among all post-Soviet armed forces in the region, and is financially supported by Armenia (Derouen and Heo 2007, SIPRI 2012).

Satellite-based mapping of land-use change

We used Landsat imagery to assess land-use changes because Landsat data are available since 1985, and their spectral and spatial resolution is well suited to map land use (Irons et al. 2012; Wulder et al. 2012). We selected the images for our analysis based on (a) seasonal coverage [two images per year from different seasons are necessary to map farmland abandonment (Baumann et al. 2011; Prishchepov et al. 2012a, b)] and (b) cloud cover.

Table 1 Image acquisition dates for Landsat imagery, used in the study

| | Landsat footprint (path/row) | | | |
	168/032	169/032	169/033	168/033
1987	1987-09-21	1987-06-24	1986-07-23	1987-07-19
	1987-09-05	1987-09-28	1986-09-09	1987-09-05
2000	2000-07-22	1999-10-07	2001-06-06	2000-07-22
	2000-09-08	2000-07-29	2002-09-29	2000-08-23
2010	2010-08-03	2010-08-10	2010-07-09	2010-08-03
	2010-09-04	2011-07-28	2010-08-10	2010-09-04

Subsequently, we selected three time points (1987, 2000, and 2010) for our analysis and focused on two time steps: 1987–2000, which captured the land-cover changes following the war between 1991 and 1994; and 2000–2010, which captured post-conflict land-use changes (Table 1). While we would have preferred analyzing images with acquisition dates closer to the start and end of the main conflict, and in the form of a dense time series in the postwar period to better understand what happened to the war-affected lands, the limited image availability was restricting in this regard. We converted images into surface reflectance values using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS, Masek et al.

2008) and masked out clouds and cloud shadows using Fmask (Zhu and Woodcock 2012).

First, we assessed the pre-war land use in our study region. The land-use classes of interest were water, managed agricultural land, unmanaged vegetation, non-vegetated areas, and forest. For each of these classes, we collected training data by visually interpreting the Landsat imagery and confirming each point's land-use attribution whenever possible with high-resolution imagery in Google Earth. We used the training data to classify our Landsat imagery using a nonparametric random forests classifier (Waske et al. 2012). After the classification, we applied a majority filter to remove single pixels, which likely represent misclassifications. We digitized settlements manually based on the Landsat imagery.

Second, we mapped land-use changes between 1987 and 2000. We quantified (a) forest disturbance, (b) farmland abandonment, (c) new agricultural land, and (d) abandoned settlements. For the first three classes, we manually collected training data by interpreting the Landsat imagery of both time points (i.e., 1987 and 2000), confirmed these data where plausible in Google Earth, and classified all images for a given time step using random forests. We only assessed land-cover changes in areas that have been assigned to the associated class in 1987 (e.g., farmland abandonment was only possible in areas previously classified as managed agricultural land). To detect abandoned villages and cities, we manually checked each village in Google Earth high-resolution imagery and labeled a village as abandoned when only ruins were visible (Fig. 2). In addition, we checked our Landsat imagery for new settlements to see whether refugee movements during the conflict led to the establishment of new settlements.

We assessed changes in land use between 2000 and 2010 in the same way as changes between 1987 and 2000. However, unlike during the first period, we did not find any agricultural abandonment and as such excluded this class from the classification between 2000 and 2010. Further, for the period 2000–2010, we did not find any abandoned settlements as in 1987–2000, but several new settlements that were built between 2000 and 2010. We did find examples of re-cultivation of previously abandoned farmland though. Thus, the land-cover change classes we assessed between 2000 and 2010 were (a) forest disturbance, (b) new agricultural land, (c) re-cultivation of abandoned farmland, and (d) new settlements.

After the classification, we assembled a final change map consisting of (a) the land-cover classes for each time step and (b) the settlement layer with a label for each settlement class (i.e., persistent settlements 1987–2010, abandoned settlements 1987–2000, new settlements 2000–2010). By embedding the settlement layer into the final change map in the form of a mask, we avoided potential confusion between settlement areas and other land-cover classes, which could have been a problem in case of destroyed settlements. Using this final change map, we then assessed local and displaced land-use changes during the war and postwar period.

We assessed the accuracy of our change map using a random sample of 50 points for each class. We manually inspected each of the points by interpreting the Landsat images from both time points and, where available, Google Earth imagery (Baumann et al. 2012). Based on this, we calculated the error matrix, derived the overall classification accuracy, the kappa statistics, and user's and producer's accuracies (Congalton 1991; Foody 2002), which we corrected for potential sampling bias (Card 1982; Olofsson et al. 2013).

Assessing the effects of the Nagorno-Karabakh conflict on land use

Local effects and their spatial extent

To assess the extent of local effects of the Nagorno-Karabakh conflict on land use, we calculated land-use change rates with increasing distance to the major fighting zone, which we defined as the locations of major clashes of the conflict (Derouen and Heo 2007, Fig. 1). While skirmishes were more widespread within our study area, we focused on the major combats because they provided a spatially exact location. We calculated 50 rings of 2-km width around the major clashes (overall 100 km around the major clashes), sampled 10,000 points in each ring, and extracted for each of the points the land-cover information based on our classifications.

To measure the effect of the conflict on land use, we had to pay careful attention to other drivers that potentially influenced rates and patterns of the observed land-use change. Specifically, during the first period (i.e., 1987–2000), our study region underwent substantial socioeconomic changes following the dissolution of the Soviet Union that, for example, in Russia (Prishchepov et al. 2013; Alcantara et al. 2013), resulted in similar land-use changes to those observed in our study area (i.e., farmland abandonment). We used matching algorithms to reduce the potential impact of a non-random occurrence of an event. For example, farmland abandonment is most likely in areas that are least profitable for farming (Gellrich et al. 2007; Rey-Benayas et al. 2007; Müller et al. 2009; Baumann et al. 2011; Prishchepov et al. 2013), which are often areas of limited accessibility or limited market access. If the spatial patterns of areas that are marginal for farming are correlated to the spatial patterns of conflict, potentially biased conclusions about the effect of conflict on abandonment may arise. Matching statistics can be used
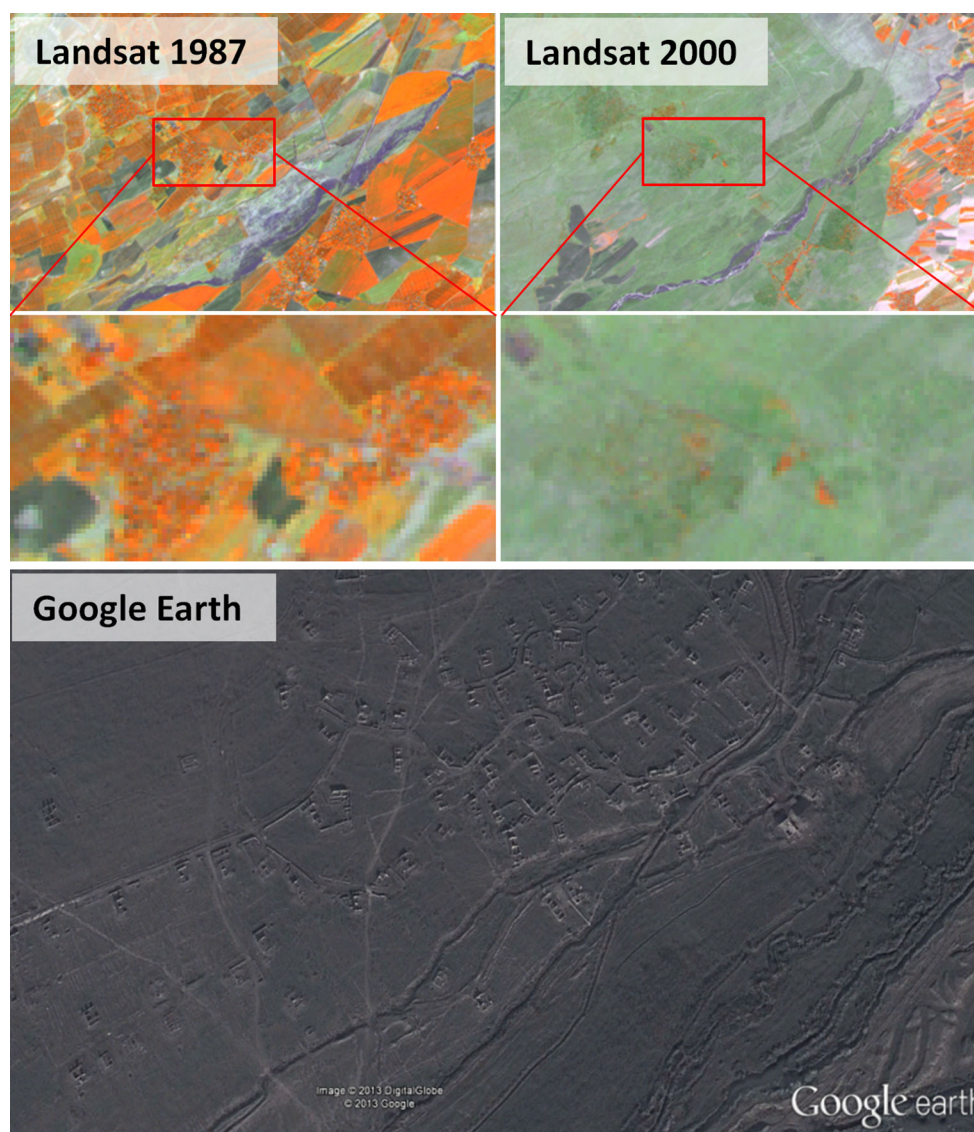
Fig. 2 Example of a settlement being destroyed between 1987 and 2000. The *left and the center image* shows Landsat TM imagery in band combination 4–5–3, *the image on the right* shows the Google Earth high-resolution image of the same settlement

to reduce the risk of biased estimates by finding observations in the treatment group (i.e., active farmland in 1987 where conflicts occurred in the early 1990s) and the control group (i.e., active farmland in 1987 away from conflict sites), whose covariants are as similar as possible and thus without the conflict would be equally likely to be abandoned.

We used Coarsened Exact Matching (CEM) as matching algorithm (Iacus et al. 2012), and we choose elevation, slope, distance to cities, and distance to roads as covariates (Gellrich et al. 2007; Baumann et al. 2011; Prishchepov et al. 2013) to find matching observations across our 50 rings around the conflict zone. CEM is effective in finding a high number of exact matches in the treatment and

control group when covariates are present in continuous values. For example, continuous covariates in a dataset often substantially reduce the number of matches because two observations are unlikely to have identical values on a continuous scale (Iacus et al. 2012). The underlying idea from CEM is to temporally coarsen each covariate into groups by building strata before the actual matching process based on histogram distributions (i.e., for covariates comprised of continuous values) or categories (i.e., for covariates comprised of categorical values). Within each of the strata, CEM then tries to find exact matches between the treatment and the control group and merges the matched data of the strata into the matched dataset (Blackwell et al. 2009). Thus, by pre-coarsening the data, the CEM

offers the advantage of exact matches while still retaining a sufficient large and balanced sample. Iacus et al. (2009, 2012) provide a more comprehensive explanation on CEM.

Once we found matching observations in each of our 50 rings around the conflict zone, we assessed for each ring our land-change classes of interest. We fitted a local polynomial regression (Cleveland 1979; Cleveland and Devlin 1988) to derive a trend for each land-cover class in relation to the distance to the major battle zone. We then determined at which distance to the main conflict zone a certain trend ended (e.g., decreasing farmland abandonment rates with increasing distance to the conflict zone). To do this, we calculated the slope of each point in the regression function and defined the trend-ending point as the distance to the conflict where the slope was zero.

Distant effects

To examine the distant effects of the Nagorno-Karabakh conflict, we analyzed land-cover changes in the following administrative units: (1) Armenia (29,489 km^2), (2) Azerbaijan (152,510 km^2), (3) Nagorno-Karabakh (NKR, 4,169 km^2), and (4) territories controlled by NKR (7,387 km^2) and (5) NKR controlled by Azerbaijan (incl. Shahumian Region, 831 km^2, Fig. 1).

We first sampled 10,000 points in each region and chose Nagorno-Karabakh (NKR) as the control region because here the fighting was most severe during the conflict. We then selected matching observations in NKR and the other remaining administrative units and compared the change rates relative to NKR in a treatment/control matching procedure. We calculated for each of the administrative regions the rates of change for (a) farmland abandonment, (b) new cultivated lands 1987–2000, and (c) forest disturbance 1987–2000. Additionally, we assessed the proportion of abandoned settlements in each of the five regions.

Differences between the conflict and post-conflict period

To assess differences in land-use changes between our two time periods (i.e., 1987–2000 vs. 2000–2010), we analyzed the three land-use changes: (a) new agricultural land 2000–2010, (b) re-cultivation of agricultural fields that had been abandoned during the conflict (hereafter: "re-cultivation"), and (c) forest disturbance 2000–2010. To do so, we combined the analysis schemes of the previous two sections. Specifically, for our three land-change classes, we analyzed the rates of change within each buffer zone, as well as across the territorial distribution of our study region. Again, we selected matching observations prior to the statistical analysis between the treatment and control groups.

Results

Our classifications showed that land-use change, both during and after the conflict, was generally not very widespread. Only 4.9 % of the analyzed area changed from 1987 to 2010. Across the entire study area, forest disturbance was the least common change process with disturbance rates of 0.2 % between 1987 and 2000, and 0.01 % between 2000 and 2010. Farmland abandonment occurred only during the first time periods. Of all the areas farmed in 1987, >9 % were abandoned by 2000 (557 km^2) and 16.75 % (93.5 km^2) of these areas were re-cultivated by 2010. New agricultural land (i.e., agricultural land that was not in agricultural use in 1987) was the most widespread change class, representing 53 % of all areas that changed (almost 750 km^2). Across our entire study area, we identified 140 cities or settlements that were destroyed during the conflict (25 % of all settlements in 1987). The classification accuracy of our change map from the Landsat images was high, with an overall map accuracy of 80 % and a kappa value of 0.80. User's and producer's accuracies were higher for the stable classes than for the change classes (Table 2).

While land-use change for the entire study area was relatively minor, the local land-use effects of the conflict in the conflict period (1987–2000) were profound. Out of the 140 destroyed cities or settlements, 62 were within 20 km of the major battlegrounds, equaling ~45 %. Abandonment was highest in areas close to the conflict zone, reaching rates of over 60 % (Fig. 3), and forest disturbance rates were marginal (<0.01 %). The high local rates of farmland abandonment were also visible at the administrative level. Abandonment rates were highest in the contested areas: NKR (29 %), areas that are under NKR control (31 %), and areas controlled by Azerbaijan (30 %, Fig. 4b). In contrast, farmland abandonment in Armenia and Azerbaijan was rare (both ~2.5 %). These results were persistent through the matched comparison with NKR as the control region. Farmland abandonment rates here were four times higher than in Azerbaijan (Table 3).

With increasing distance to the battlegrounds, abandonment rates decreased gradually up to a distance of 35 km, and new agricultural land and forest disturbance became more common. Agricultural expansion rates were highest at about 75 km distance to the conflict zones (18 %, Fig. 3). Most of these new agricultural areas were located on Azerbaijani territory (almost 95 % of all new agricultural land, Fig. 4d). Forest disturbance rates were generally low, but in some places reached almost 20 %. Overall, with increasing distance to the battlegrounds, forest disturbance rates increased continuously (Fig. 3). New agricultural areas were most widespread at a distance of 75 km away from the major battlegrounds.

Table 2 Classification accuracies of the Landsat classification

	PA (%)	UA (%)	O (%)	C (%)
Unvegetated areas	75.17	82.00	24.83	18.00
Constant forest	82.00	92.00	18.00	8.00
Managed agricultural land	81.79	70.00	18.21	30.00
Unmanaged vegetation	86.32	82.00	13.68	18.00
Water	100.00	82.00	0.00	18.00
Forest disturbance 1987–2000	3.14	82.00	96.98	18.00
Forest disturbance 2000–2010	100.00	80.00	0.00	20.00
Agricultural abandonment 1987–2000	78.15	72.00	21.85	28.00
New agricultural land 1987–2000	11.34	66.00	88.66	34.00
New agricultural land 2000–2010	99.40	54.00	0.60	46.00
Managed → abandoned → managed agriculture 1987–2000–2010	25.24	70.00	74.76	30.00
Overall accuracy	80.01			
Kappa statistics	0.8001			

Presented are the overall classification accuracy, the kappa statistics for the overall classification. For each class, user's and producer's accuracies (UA, PA) are shown as well as errors of omission and commission (O, C)

Fig. 3 Rates of the land-cover change classes relative to the distance to the major clashes of the conflict. The *top row* represents land-cover changes during the first period of analysis (1987–2000), the *bottom row* the land-cover changes during the second period of analysis (2000–2010). The *black line* represents the local polynomial regression of land-cover changes with increasing distance to the major battle grounds. The *gray area* is the error estimate
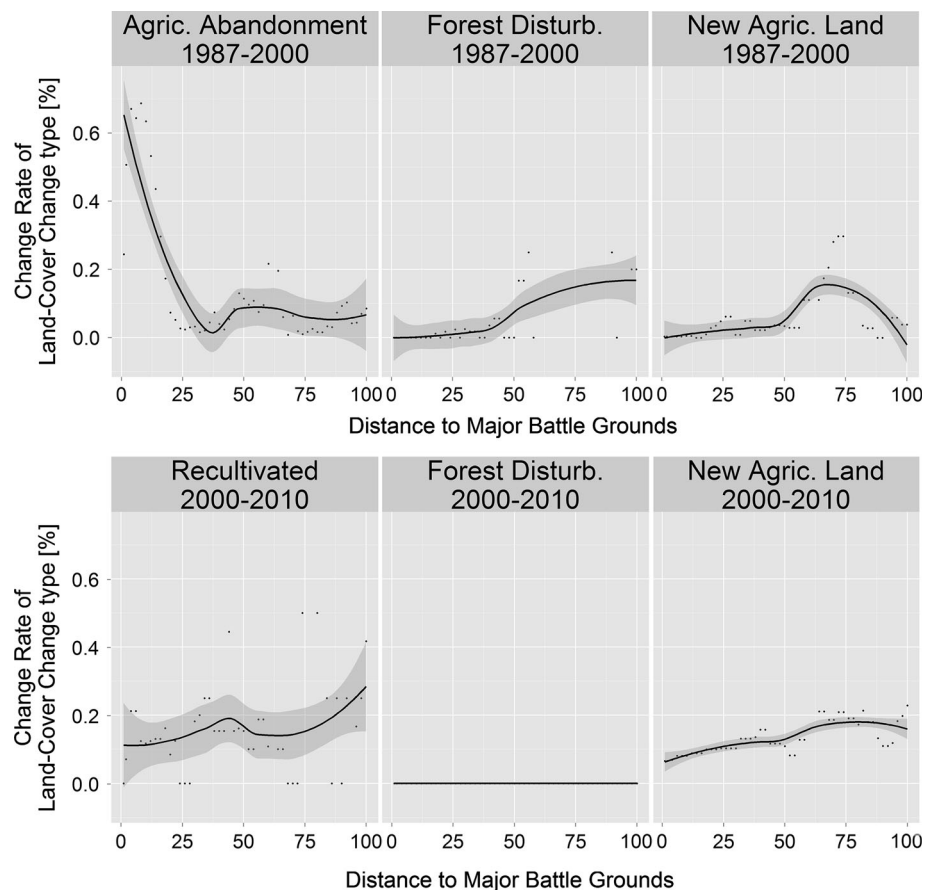
Compared to the period of the armed conflict (1987–2000), land-use changes were quite different after the conflict (2000–2010). Local effects during the postwar period were dominated by the re-cultivation of previously abandoned agricultural land as well as the expansion of agriculture into areas that had not been farmed in 1987. We did not find any agricultural abandonment after the conflict. Overall, 16.75 % of all areas that had been abandoned during the conflict were again used for agriculture by 2010. The re-cultivation rate (i.e., the area under agricultural use in 2010 relative to the areas that had been abandoned during the conflict period) was highest at larger distance to
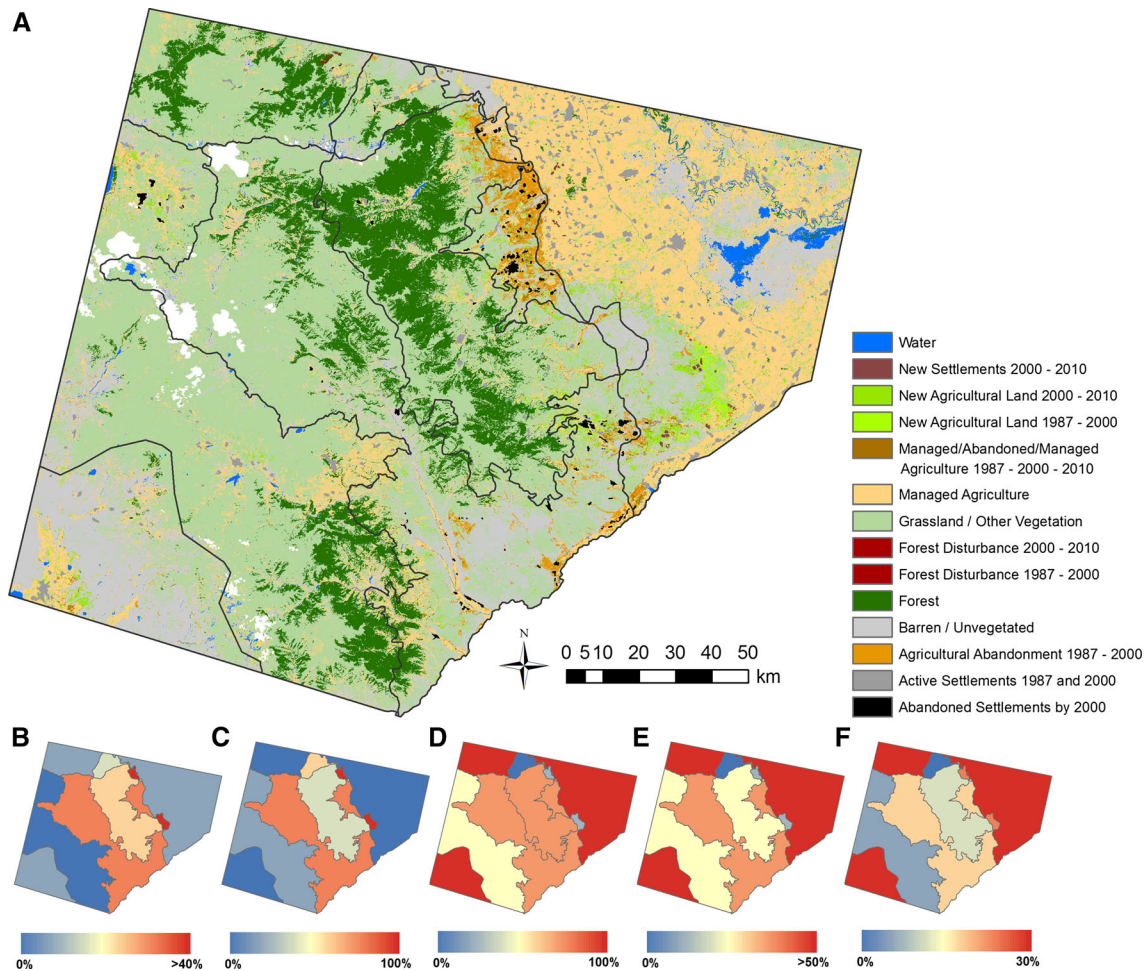
Fig. 4 Land-cover classification from multi-temporal Landsat images that includes all mapped changes across both analyzed time periods (**a**). The bottom row represents land-use changes summarized at the administrative level: % Agricultural abandonment 1987–2000 (**b**), % abandoned settlements (**c**), new agricultural areas per administrative region relative to all new agricultural fields in our study area for the periods 1987–2000 (**d**) and 2000–2010 (**e**), and re-cultivated agricultural areas per administrative region relative to all re-cultivated fields (**f**)

the former battlegrounds, reaching levels of >20 % (Fig. 3). The largest area of re-cultivated land occurred on NKR territory or territory under NKR control (47 and 13.5 %, respectively). The largest area of new agricultural land was located in Azerbaijan (57 % of all new agricultural fields), and we also observed all new settlements (a total of 30) on Azerbaijani territory or territory under Azerbaijani control. Forest disturbance rates were marginal (<0.01 %) (Table 4).

Discussion

Socioeconomic shocks can cause rapid changes in land use and can strongly influence land-use trajectories, possibly triggering a land system transition into a new state. Armed conflicts are an extreme form of a socioeconomic shock,

but our understanding of the implications of armed conflicts on land use is limited. Here, we analyzed land-use changes related to the Nagorno-Karabakh conflict both during the conflict and in the decade after using Landsat data. The Nagorno-Karabakh conflict between 1992 and 1994 was a bloody conflict with heavy military action and led to the forced migration of more than 1 million people. Our results suggest that this conflict resulted in four major land-use change trends.

First, we found high rates of farmland abandonment in the immediate battle zone, but abandonment rates rapidly decreased away from this zone. Similar patterns have occurred during other conflicts, including in Bosnia-Herzegovina (Witmer 2008; Witmer and O'Loughlin 2009). People leave the fighting grounds to protect their lives or are being forced to leave. The lack of security, the missing workforce, and limited access to agricultural markets all

Table 3 Results of the regional matching analysis

	Treatment			
	Armenia	Azerbaijan	Territory controlled by AZ	Territory controlled by NKR
Farmland abandonment 1987–2000 (%)	2.15 versus 2.63	44.60 versus 11.89	18.18 versus 18.75	34.19 versus 41.78
Forest disturbance 1987–2000 (%)	0.11 versus 0.00	0.05 versus 1.82	0.00 versus 0.00	0.08 versus 0.00
Forest disturbance 2000–2010 (%)	0.00 versus 0.00	0.00 versus 0.00	0.00 versus 0.00	0.00 versus 0.00
New agric. Land 1987–2000 (% newly used land of land available for cultivation)	0.04 versus 0.00	0. 14 versus 0. 22	0.00 versus 0.00	0.16 versus 0.38
New agric. Land 2000–2010 (% newly used land of land available for cultivation)	0.00 versus 1.09	0. 23 versus 5.05	0 versus 3.95	0. 04 versus 3.90
Re-cultivation of abandoned lands 2000–2010 (%)	0.00 versus 0.00	7.17 versus 7.69	0.00 versus 0.00	7.56 versus 14.61

The numbers represent the rates of land-cover change between the treatment and the control group, which here represents the territory of Nagorno-Karabakh (NKR)

contribute to a decline in agricultural activities and farmland abandonment. We suggest that this causal chain was also present in the case of Nagorno-Karabakh conflict where Azerbaijani were forced to leave the NKR (Gleditsch et al. 2002) and the surrounding areas that were controlled by Karabakh Armenians. In terms of abandonment though, the effects of the armed conflict were fairly local.

Second, we found a substantial amount of agricultural expansion during the time of the conflict, largely on Azerbaijani territory bordering the NKR. We suggest that the mechanism behind this land-use change is the same as for the farmland abandonment. A large proportion of the migrants were Azerbaijani, who migrated to Azerbaijan (www.envsec.org, 2004), where they were allowed to settle. While the majority of the migrants moved further east toward Baku, by 2008 about 15 % of them were located in regions close to the border (i.e., in the regions of Fizuli, Beylagan, and Agjabadi, IDMC 2008). Because of the rare situation in Azerbaijan that refugees (or internally displaced persons (IDPs)) enjoy the same rights as other citizens and do not experience any discernible discrimination (UNHCR 2009), it was likely comparatively easy for them to seek employment in the agricultural sector or to benefit otherwise from Azerbaijan's land reform during the mid-1990s, when former collective land was parceled and distributed to families (Croissant 1998; Giovarelli and Bledsoe 2001; Lerman and Sedik 2010). This can explain the overall increase in agricultural areas and subsequent increasing agricultural activities on Azerbaijani territory afar from the conflict itself, a trend similar to what has been observed in Tanzania where refugee inflows from Burundi and Tanzania during the mid-1990s yielded net economic benefits, partly through increased agricultural activities (Maystadt and Verwimp 2009). While the area of new farmland was not as large as that of abandoned farmlands, we suggest that this spatial shift of cultivated land was a direct consequence of the armed conflict. Areas that were not directly connected to the conflict zone underwent a land-use transition as a consequence of a distant socioeconomic shock. Thus, our results suggest that the conflict caused a displacement of land use from the conflict zone to nearby Azerbaijani territory, with the translocation of refugees being the mechanism leading to these displacement effects. As refugees likely maintain some ties, cultural and economically, to their homeland, conflicts and refugee migrations thus appear to foster distal linkages in land systems between the origin and receiving regions, potentially with important feedback mechanisms (e.g., remittances, Lambin and Meyfroidt 2011; Meyfroidt et al. 2010; Seto et al. 2012).

The third major finding of our analysis was that much of the land-use change that occurred during the war did not revert back after the war ended. Specifically, while we found that some new agricultural area and some re-cultivated fields occurred in the prior conflict zone, agricultural expansion on Azerbaijani territory was the dominant land-use change after the war. We suggest that this is a consequence of several factors. First, many areas are still under dispute. Although the fights ended almost 20 years ago, and there is now both a government and an army in the NKR, the overall conflict still remains unsolved and the NKR territory remains un-recognized by Armenia, Azerbaijan, and the international community (Gleditsch et al. 2002). As a result, potential investors in the agricultural sector might be hesitant, and this is one likely reason why wide areas still remain un-cultivated. Second, large areas are still contaminated with land mines (International Campaign to Ban Landmines 2012), making it impossible to farm. Third, the lack of workers due to the outmigration to Azerbaijan might have decreased the ability to use agricultural land. Arguably, none of these developments will revert over the coming years as the broader ethnic conflict still remains unsolved with numerous violent

Table 4 Output of the matching process for the regional analysis

Comparison	Matching covariate	Un-matched			Matched			
		Mean treated	Mean control	Mean diff.	Mean treated	Mean control	Mean diff.	% Balance improvement
NKR versus Armenia	Elevation (m)	2,154.24	1,132.84	−1,021.40	1,219.35	1,189.41	−29.94	97.07
	Slope (%)	27.20	24.80	−2.41	24.31	24.53	0.22	90.76
	pH soil	7.11	7.10	−0.01	7.10	7.10	0.00	100.00
	Dist. to road (m)	5,429.59	3,859.38	−1,570.21	2,380.27	2,479.08	98.81	93.71
	Dist. to settlement (m)	9,765.24	4,850.71	−4,914.53	4,139.37	4,116.21	−23.16	99.53
NKR versus Azerbaijan	Elevation (m)	716.76	1,132.84	416.08	1,156.56	1,148.63	−7.93	98.10
	Slope (%)	11.09	24.80	13.71	19.84	20.10	0.26	98.11
	pH soil	7.58	7.10	−0.48	7.10	7.10	0.00	100.00
	Dist. to road (m)	18,274.16	3,859.38	−14,414.79	4,579.52	4,150.84	−428.68	97.03
	Dist. to settlement (m)	5,774.84	4,850.71	−924.13	4,517.88	4,573.92	56.04	93.94
NKR versus NKR controlled by AZ (incl. Shahumian region)	Elevation (m)	1,453.68	1,132.84	−320.83	1,466.49	1,490.73	24.24	92.45
	Slope (%)	24.70	24.80	0.09	24.47	24.20	−0.27	−190.19
	pH soil	7.10	7.10	0.00	7.10	7.10	0.00	0.00
	Dist. to road (m)	16,611.18	3,859.38	−12,751.81	10,466.75	10,090.20	−376.55	97.05
	Dist. to settlement (m)	4,835.07	4,850.71	15.64	5,657.48	5,693.14	35.65	−127.91
NKR versus Territory controlled by NKR	Elevation (m)	1,369.18	1,132.84	−236.34	979.37	991.07	11.70	95.05
	Slope (%)	20.71	24.80	4.09	20.50	20.83		91.85
	pH soil	7.11	7.10	−0.01	7.10	7.10	0.33	100.00
	Dist. to road (m)	6,428.92	3,859.38	−2,569.54	3,162.67	3,136.39	−26.28	98.98
	Dist. to settlement (m)	9,177.94	4,850.71	−4,327.23	4,420.20	4,359.97	−60.23	98.61

"NKR" refers to the territory of Nagorno-Karabakh, which serves as the control group in the analysis

outbreaks every year despite the instituted cease-fire from 1994. Thus, it is unclear whether the land systems on both sides of the political borders will eventually revert back into pre-war conditions, with the possibility that the war may have caused a permanent shift in land systems in our study area.

Lastly, compared to other regions in the former socialist Bloc, our results suggest much less pronounced land-use change in our study area. The collapse of the Soviet Union and the subsequent economic and political transition triggered more widespread land-use change in other areas, including farmland abandonment (Baumann et al. 2011; Hostert et al. 2011; Alcantara et al. 2013) at rates of 50 % and larger, as well as substantial changes in logging rates (Kuemmerle et al. 2009; Baumann et al. 2012). Contrarily, in our study, farmland abandonment was only high locally but for the study area as a whole rather low and forest disturbance was rare. In both countries (i.e., Armenia and Azerbaijan), this is partly attributable to the fast redistribution of farmland to the people (Curtis 1995; Lerman 2009), and in the case of Azerbaijan additionally to the expansion of irrigation (Lerman 2009). In terms of the

conflict, the relative land system stability of large areas in our study might thus suggest that armed conflicts should be considered a more regional-to-local socioeconomic shock, with strong, but spatially restricted effects on land use.

Overall, our study shows that armed conflict can have substantial effects on land use, but these effects are localized in the conflict zone, and in areas where refugees settle. Refugees can cause displacement effects that trigger land-use changes far away from the actual combat zone and in areas that otherwise might not have changed. Armed conflicts and socioeconomic shocks in general may thus represent mechanisms that may establish distal linkages in land systems. Our results also show that armed conflict can cause land systems to transition into new, possibly stable states, similar to other drastic socioeconomic shocks. Much remains to be learned though about the relationship of armed conflicts and land use. For example, in our study, most of the observed changes were limited to changes in agricultural change, whereas the main land-use changes observed in other studies were related to logging and deforestation. Thus, for a deeper understanding of the relationship between land use and conflict, we recommend

an integrative assessment of different land-use changes. Likewise, our study represents a conflict that turned into a full-scale war, but other forms of violent conflicts such as civil unrests (Gorsevski et al. 2013) might affect land systems differently. Lastly, our study did not shed light on the influence of the conflict on the underlying drivers of land change, which themselves might influence land systems elsewhere. For example, violent conflict in one country might affect the demand for goods it receives through trade with a second country, potentially affecting the land system of the trade partner. Likewise, conflict may affect other underlying drivers of land change such as demographics, institutions (e.g., land ownership), and technology diffusion (e.g., the adoption of new technology and cropping systems), all of which may have far-ranging and potentially lagged effects on land change (Angelsen and Kaimowoitz 1999; Geist and Lambin 2004; Zoomers 2010). In sum, armed conflicts have severe consequences for people's lives and livelihoods. Here, we show that full-scale wars affect land systems locally, but also establish distal linkages dependent on the sociopolitical situation in our study area. Because armed conflicts are unfortunately widespread, understanding the relationship between conflict and land use and the outcome of conflict for sustainability should be a research priority and requires interdisciplinary efforts of natural and social scientists.

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