Effectiveness of protected areas in the Western Caucasus before and after the transition to post-socialism

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Effectiveness of protected areas in the Western Caucasus before and after the transition to post-socialism

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ABSTRACT

Economic and social transition periods can have strong negative effects for the environment and for wildlife. The collapse of the Soviet Union in 1991 provides a striking example of social turmoil and transition to a new society. It is unclear, however, how humans affected the environment in the course of the collapse, and if institutions designed to safeguard the environment continued to fulfill their intended role. Our goal was to assess the impact of the collapse of the Soviet Union on forest canopy removal rates in protected areas, and how these rates varied by protected area status and over time. We monitored forest canopy removal within and outside of protected areas using a 1985–2010 time series of Landsat satellite images from the Western Caucasus. On average, we found surprisingly low annual forest canopy removal rates of only 0.03%. The highest canopy removal inside of protected areas of all types occurred after 2000. Among the protected areas, we found the highest canopy removal rates within Sochi National Park, attributable to construction for the Olympic Games and in spite of the Park's protected status. Overall, it is encouraging that forest canopy removal rates in protected areas in the Western Caucasus are far lower than in other Russian regions. Because many local endemic plant and animal species are found in the Caucasus region, clear cuts are prohibited, and this regulation appears to be effective. However, forest canopy removal within protected areas caused by major social and political events such as the Olympic Games is of concern.

1. Introduction

Protected area effectiveness and human disturbance inside of nature reserves are important environmental issues affecting wildlife (Bruner et al., 2001; Hocking et al., 2000). Unfortunately, the establishment of a protected area per se is not enough to safeguard biodiversity. Without proper enforcement, protected areas can become 'paper parks' that do not contribute to nature conservation (Bruner et al., 2001). This is why it is important to measure protected area effectiveness (Joppa and Pfaff, 2011; Knorn et al., 2012). The rate of removal of the forest canopy is commonly used as a proxy for protected area effectiveness (Andam et al., 2008; DeFries and Hansen, 2005; Joppa and Pfaff, 2011; Knorn et al., 2012; Mas, 2005; Naughton-Treves et al., 2011). Here, we estimated forest canopy removal rate within and outside of protected areas to assess effectiveness of protected areas.

Protected areas may be especially vulnerable when the economy declines; as people's income plummets, they rely more on natural resources, such as bushmeat (Bragina et al., 2015; Brashares et al., 2004; Wilkie and Godoy, 2014). A striking example of a major economic downturn was the collapse of the Soviet Union in 1991 and the subsequent transition to post-socialism, which resulted in increased poverty (Dudwick et al., 2003), abandonment of agriculture (Ioffe and Nefedova, 2004), and the decline of livestock populations (Kolesnikov, 2003). As a result of economic issues, conservation funding plummeted, and conservation institutions were weakened (Brandt, 1992; Wells and Williams, 1998). At least some regions experienced increased pressure on natural resources, for example due to illegal logging as a source of income (Vandergert and Newell, 2003; Lebedev, 2001). While official forest statistics show a decrease in forest logging after the collapse, considerable

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forest canopy removal, much of which may be due to illegal logging, was found in Russia and other post-soviet countries (Wendland et al., 2015; Baumann et al., 2012; Kuemmerle et al., 2009).

In Russia, protected area status likely affects the vulnerability to illegal natural resource extraction. As a rule, in a strict nature reserve (IUCN category I) only staff can enter the protected area without special permission. Unlike strict nature reserves, the management policies of national parks allow visiting tourists though commercial activity is prohibited, including logging, but rangers patrol the territory as well as in strict nature reserves. The regulations of other protected areas (IUCN categories III–IV) restrict commercial logging as well, while allowing low-level extractive use, for example cattle grazing (Federal Law of Russian Federation on Nature Reserves, 2014). The collapse of the former Soviet Union appears to have been associated with different levels of forest canopy removal, depending on protected area status. For example, in European Russia, two long-established strict nature reserves remained effective and provided forest protection in spite of the changing institutional and economic situation (Sieber et al., 2013). However establishment of some national parks after the breakdown of the Soviet Union had little to no effect on lowering forest canopy removal within their borders (Wendland et al., 2015). These differences in effectiveness associated with protected area status, as well as regional differences in forest types, forest use, and markets for timber, raise the question of how effective protected areas in other parts of Russia were before and after the collapse.

Due to its unique geological history, the Western Caucasus is home to many endemic species (Akatov et al., 1990) and a large part of it is protected, albeit with varying levels of protection (Dubinin et al., 2005). Our study area included several protected areas of IUCN categories I–IV in Russia and three protected areas in IUCN category I in Abkhazia. While forest logging is prohibited or restricted in all of these categories of protected areas (Federal Law of Russian Federation on Nature Reserves, 2014), levels of enforcement most likely varied in the past, and some illegal logging has been documented in protected areas of the Western Caucasus (Plotnikov, 2010). We wondered if patterns of forest canopy removal in the Western Caucasus followed patterns documented in other parts of Russia.

Our study spanned three periods: the last five years of socialism (1985–1990), the period of transition to post-socialism (1991–1999), and the decade after 2000, because we expected rates of forest canopy removal to vary before and after the collapse. There are many factors that might have affected forest canopy disturbance rates. Increased poverty, weakened regulation, and the war in Abkhazia in 1992–1993 might all have increased forest logging in the region, as was the case in the Russian Far East and Siberia (Vandergert and Newell, 2003). Such logging may have also occurred within protected areas because the transition period brought huge turmoil to post-Soviet countries, including the erosion of the nature protection infrastructure and reduced law enforcement (Henry and Douhovnikoff, 2008; Williams, 1996). On the other hand, the timber industry underwent a difficult period during the transition, and forest harvesting declined in European Russia (Potapov et al., 2011), suggesting that there was less demand for timber.

Another potential cause of forest canopy removal in the Western Caucasus was the preparation for the 2014 Olympic Games in Sochi. The construction of infrastructure for the Olympics substantially modified the landscape through clearing land for construction of buildings, roads, and trails (WWF Russia, 2014), with some events taking place inside Sochi National Park. Construction within national parks is restricted by Russian Federal Law. However, a special amendment to the Law was added in 2006 allowing for the construction for 'recreational activities' within national parks (Federal Law of Russian Federation on Nature Reserves, 2014). This amendment provided a legislative base for the development of Olympic infrastructure, and this is why we were interested in analyzing the amount forest canopy removal related to the Olympic Games.

The goal of our study was to estimate the effectiveness of the Western Caucasus protected areas during 1985–2010 in terms of safeguarding forests within them from forest canopy removal. In particular, our aims were to (1) compare the forest canopy removal rate before the collapse of the Soviet Union, right after it, and in the later post-Soviet period, (2) estimate forest canopy removal rates within and outside of protected areas of different IUCN categories, and (3) estimate forest canopy removal associated with the 2014 Olympic Games.

2. Methods

2.1. Study area

Our study area in the Western Caucasus includes three regions of Russia: Krasnodar Krai, Adygea Republic, and Karachaevo-Cherkessiya Republic of Russia and the disputed territory of Abkhazia. The study area encompasses two Landsat footprints totaling about 67,400 km^2 (Fig. 1) and includes mountains in the south and plains in the north. Our study area is located on the border of temperate and subtropical zones, and elevation causes strong altitudinal zonation. Elevation varies from about 0 to 3346 m. Plains include arable agricultural land and pastures; mountainous areas includes forests (coniferous, deciduous, and mixed forests), alpine, nival, and snow zones. Lowlands have semi-dry climate in the north and warm and wet climate in the south of the study area with mean temperatures above freezing in January. Mountainous areas have snow cover for 4–6 months. Precipitation levels vary from 400 mm/year in the lowlands to up to 3700 mm/year in the mountains. The elevation of timberline is 2200–2500 m, and the snowline is at 3200–3500 m (Akatov et al., 1990).

Typical woody plant species are oriental beech (*Fagus orientalis*), whose range is restricted to the shore of the Black Sea, Nordmann fir (*Abies nordmanniana*), Caucasian spruce (*Picea orientalis*), European yew (*Taxus baccata*), Georgian box (*Buxus colchica*), Caucasian rhododendron (*Rhododendron caucasicum*), Caucasian wingnut (*Pterocarya fraxinifolia*), and sweet chestnut (*Castanea sativa*, Cherepanov, 1995). Animal species include Caucasian tur (*Capra caucasica*), the Caucasian subspecies of Eurasian lynx (*Lynx lynx dinniki*), wildcat (*Felis silvestris caucasica*), chamois (*Rupicapra rupicapra caucasica*), red deer (*Cervus elaphus maral*), Eurasian badger (*Meles meles caucasicus*), European mink (*Mustela lutreola turovi*), European otter (*Lutra lutra meridionalis*), as well as Bearded vulture (*Gypaetus barbatus*), Griffon vulture (*Gyps fulvus*), and Egyptian vulture (*Neophron percnopterus*). The Caucasus Mountains are also where mountain bison (*Bison mountainous*), a hybrid of European bison subspecies *Bison bonasus caucasicus* and *Bison bonasus bonasus*, and American bison (Bison bison), were reintroduced after Caucasian bison (*Bison bonasus caucasicus*) were extirpated at the beginning of the 20th century (Akatov et al., 1990).

2.2. Protected areas

We analyzed forest canopy removal within 15 protected areas. Five protected areas were in IUCN categories I, one in category II, one in category III, and eight in category IV. Protected areas in IUCN category I are strict nature reserves, economic use is not permitted, and the area is closed to the public. Protected areas in IUCN category II prohibit economic development and hunting, but allow

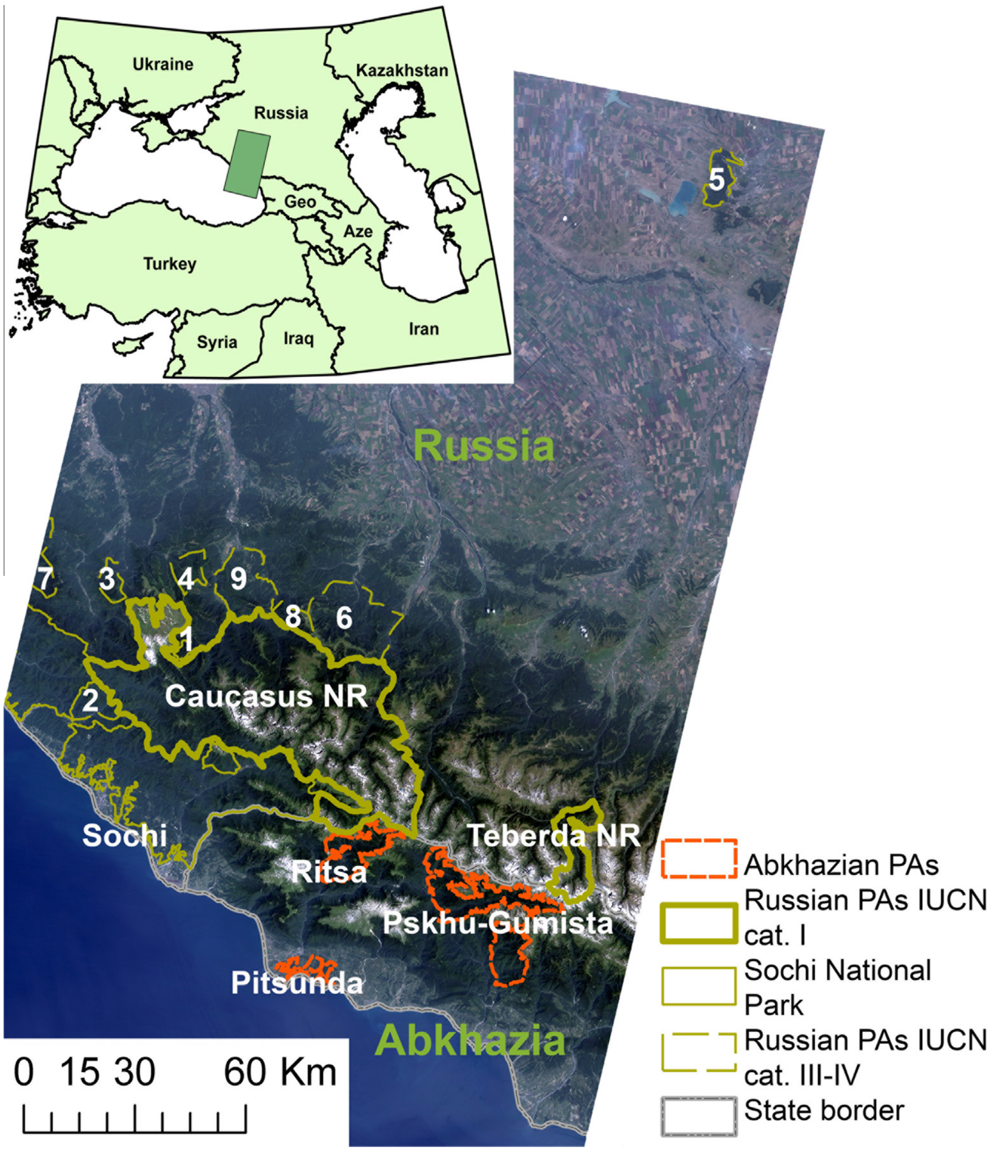

Fig. 1. Study area with Russian and Abkhazian protected areas. 1 – the nature monument 'Buiny Ridge', 2 – Sochi sanctuary, 3 – sanctuary 'Chernogor'e', 4 – sanctuary 'Kamyshanova polyana', 5 – sanctuary 'Russkiy les', 6 – Psebaiskiy hunting sanctuary, 7 – Tuapsinskiy sanctuary, 8 – Turinyi sanctuary, 9 – Dahovskiy sanctuary.

certain economic activities inside them, such as ecotourism. In protected areas in categories III–IV, forest logging is either prohibited or restricted, but protection levels are generally lower (Federal Law of Russian Federation on Nature Reserves, 2014; Law of Republic of Abkhazia on environmental protection, 2010).

Strict nature reserves (IUCN category I) included two in Russia and three in Abkhazia (Fig. 1). The Russian reserves were the Caucasus Federal Biosphere Nature Reserve (founded in 1924; 2775 km^2) and the western part of Teberda Federal Biosphere Nature Reserve (1936; 189 km^2). The Abkhazian reserves were Pitsunda-Miussera nature reserve (1966; 38 km^2), Ritsa nature reserve (1930; 164 km^2), and Pskhu-Gumista nature reserve (1941; 388 km^2). IUCN category II included only Sochi National Park (founded in 1983; 2033 km^2). The nature monument 'Buiny Ridge' (1990; 18 km^2) was in IUCN category III. Protected areas in IUCN category IV were Sochi sanctuary ('zakaznik' in Russian, founded in 1993; 152 km^2), sanctuaries 'Chernogor'e' (1986; 54 km^2), 'Kamyshanova polyana' (1987; 69 km^2), 'Russkiy les' (1977; 87 km^2), Psebaiskiy hunting sanctuary (1971; 380 km^2), Tuapsinskiy sanctuary (1986; 170 km^2), Turinyi sanctuary (the area held its protected status in 1993–1998; 56 km^2), Dahovskiy sanctuary (the area acquired its protected status in 1963–2002; 222 km^2). Several of the protected areas are part of the UNESCO World Heritage Site 'Western Caucasus' (UNESCO, 1999), but this does not confer additional protective status.

We acquired protected area boundaries from the World Database on Protected Areas (protectedplanet.net), which is based on the Digital Map of Protected Areas of the Russian Federation (FSI 'VNII prirody' Minprirody of the Russian Federation, Protected Areas Laboratory, 1999–2001; www.RINPRO.RU). For protected areas in IUCN categories III–IV, we used OpenStreetMap data (http://beryllium.gis-lab.info/project/osmshp/).

2.3. Satellite images

Our study area was covered by two Landsat footprints (path: 173; rows: 29 and 30; 30 m resolution), for which we acquired imagery from the archives of the United States Geological Survey. We chose cloud-free (<10%) images acquired during the growing season (May–September) to classify land cover classes. We acquired images from four time steps: (1) before the collapse of the Soviet Union (01 August 1985), (2) the point immediately at the start of the transition period a change point (1990), ten year later (15 July 1999 and 06 September 2001) and twenty years later (6 August 2010). We did not use the thermal bands in our analysis, and we excluded clouds and cloud shadows through on-screen digitizing.

2.4. Land use and forest canopy removal mapping

In a first step, we classified the 1985 image into five land cover classes to increase the accuracy of our subsequent forest canopy removal mapping: (1) agriculture, i.e., arable fields; (2) forests, including deciduous, coniferous and mixed forest; (3) grasslands and meadows, including alpine meadows; (4) urban areas, including buildings, roads, etc.; (5) 'other', including water, bare soil, rock, glaciers. For each class, we manually collected 2000–20,000 training pixels based on the Landsat imagery and, where available, Google™ Earth high-resolution imagery. The number of training pixels per class depended on our assumptions about the spectral complexity of the respective classes. For example, we collected the most pixels of agriculture and grassland to provide reliable discrimination of these classes as they can easily be confused (e.g., 27% of random grassland points, which we collected for accuracy assessment, were classified as agriculture). For the classification, we used imageRF, which is an IDL-based tool that implements Random Forests (Breiman, 2001) for the classification of satellite images (Waske et al., 2012).

Based on the 1985 land cover map, we selected the area covered by forest for subsequent mapping of forest canopy removal. For each year, we created forest canopy removal index maps (Healey et al., 2005). The forest canopy removal index is a linear transformation of normalized tasseled cap indices (i.e., brightness, greenness, and wetness). We calculated the forest canopy removal index as a $DI = nBr - (nGr + nWet)$ where nBr, nGr, and nWet is normalized brightness, greenness, and wetness, respectively. When the forest canopy is disturbed, brightness increases due to soil exposition, while greenness and wetness decline. Forest canopy removal thus exhibit relatively higher disturbance index values compared to undisturbed forest (Healey et al., 2005). We subtracted the forest canopy removal index map for 1985 from that for 1990, the index map for 1990 from that for 1999, and the index map for 2001 from that for 2010. This resulted in three maps of forest canopy removal index differences with 30-m resolution, for which we determined thresholds to separate disturbances from unchanged forest. As disturbance index values can vary for the same area depending on atmospheric or phenological differences (Healey et al., 2005), we determined a separate threshold for each map. For 1990–1985, a threshold value of 0.35 provided the best separation of 'forest canopy removal' and 'other'. For 1990–1999, most disturbed forest pixels had values >6.8 and for the 2001–2010 map, the threshold was 0.1. Using these thresholds, we mapped forest canopy removal as a land cover class.

We combined the three forest canopy removal maps, and the map of other land uses, into one change map displaying forest canopy removal for our entire study period. Our final map thus had eight classes: stable forest, forest canopy removal in 1985–1990, forest canopy removal in 1990–1999, forest canopy removal in 2001–2010, agriculture, grassland, urban area, and other. If a pixel was disturbed several times, we only considered it as disturbed in the first time period. In total, repeated disturbance was <1% of all disturbed area in all three time periods.

In our initial results, varying phenology among images from different years caused some false-positive forest canopy removal at timberline. Since the elevation of timber line in the study area is 2200–2500 m (Akatov et al., 1990), we decided to maintain a conservative estimation of forest canopy removal rates and did not analyze area above 2300 m to avoid false-positive results.

2.5. Accuracy assessment

We generated a standard error matrix to estimate the accuracy of our map. We sampled 100 random points from each class, and assigned the true value for each of them manually based on visual interpretation of the Landsat images. Whenever possible, we verified Landsat interpretation of the points with Google Earth images, thus ensuring that our accuracy data was of higher quality than our classification (Olofsson et al., 2014). To make sure that Landsat and Google Earth provide consistent results, we compared two interpretations of 50 random points. Only 3 points out of 50 (6%) were assigned differently. Then, we calculated user's and producer's accuracy for each class, as well as the overall accuracy of our map, while correcting for possible sampling bias (Olofsson et al., 2013). Producer's accuracy refers to the land use class' area on the ground which was classified as that class and user's accuracy is how much of classified as a certain class area was actually that class (Olofsson et al., 2013).

2.6. Comparing forest canopy removal inside and outside of protected areas

The non-random placement of protected areas, for example in remote locations that do not have much conversion pressure, complicates the estimation of protected area effectiveness (Joppa and Pfaff, 2009, 2010). For this reason, we used a statistical technique known as 'matching' to create a sample of protected and not-protected pixels equally distanced from settlements, roads, and other possible factors affecting the likelihood of forest canopy removal, see our covariate list below (Andam et al., 2008; Joppa and Pfaff, 2010). With this new sample we can estimate the effect of protection on forest cover without bias from the placement of protected areas influencing the result. As we were interested in the effect of protected area status, we categorized protected areas into four groups according to their IUCN categories: (1) Caucasus and Teberda strict nature reserves, (2) the three Abkhazian nature reserves (Pitsunda-Miussera, Ritsa, and Pskhu-Gumista), (3) Sochi National Park (IUCN category II), and (4) other protected areas altogether (IUCN categories III–IV). We also estimated the effect of all protected areas combined (i.e., categories I–IV, Abkhazian and Russian) and all Russian protected areas (i.e., categories I–IV above) to analyze trans-boundary variability of forest canopy removal. Below, 'treatment' means one of these protected area groups.

We randomly sampled 1% of forested pixels from each group of protected areas based on forest cover in the 1985 imagery. We maintained a 300-m minimum distance between random points to reduce spatial correlation, which reduced our final sample of forested pixels to slightly less than 1%. For control group, we sampled four times the number of forested pixels from outside as from inside protected areas. Our final sample consisted of 3453 forested pixels from Russian strict nature reserves, 1238 from Abkhazian nature reserves, 3756 from Sochi National Park, 2099 from the other protected areas, and 22,938 from outside of protected areas.

To match pixels from inside and outside of protected areas we used propensity score matching. In propensity score matching, a propensity score is estimated for each pixel. Conceptually, a propensity score is the probability that a pixel will receive the treatment (i.e., protected area status) based on measured covariates, for example, distance to roads and elevation (Guo and Fraser, 2010). The propensity score is estimated using a binary regression model, because each pixel can be located either inside or outside of a protected area.

Once the propensity score was estimated, we matched control observations (those not in protected status) to treatment observations with similar scores. We matched propensity scores using nearest neighbor 1-to-1 matching without replacement. To ensure good matches, we restricted the maximum distance between propensity score values to one-fourth of the standard deviation of the estimated propensity scores (Guo and Fraser, 2010).

The next step was to estimate the effect of protected areas on forest canopy removal using this matched sample of protected and not-protected pixels. As control observations never exactly equal the treatment observation, matches in our resulting samples were never precise. For this reason, we further controlled for differences in covariates by subjecting the matched sample to regression analysis. Specifically, we performed logistic regression on the matched sample of treatment and control observations where disturbed/not-disturbed was our response variable, and protected/not-protected pixels and the covariates listed below were independent variables. The logistic regression resulted in a set of marginal effects. Marginal effects represent the predicted rate by which forest canopy removal would change if an observation switched from being unprotected to protected. In other words, the marginal effect is the percent of forest canopy removal reduced by protected area status. For example if 3.4% of protected area is disturbed and 3.6% of non-protected area is disturbed, there is a marginal effect of 0.2% (Guo and Fraser, 2010). There were a number of available covariates in our study area which potentially could affect the likelihood of logging, including: distance to the nearest road, settlement, building(s), river and railway station; distance to the city of Sochi, the largest city in the study area; distance to the Black Sea; slope and elevation. However, several of these variables were correlated, and we removed one of each pair of variables that had a correlation coefficient greater than 0.5 to avoid multicollinearity issues in the propensity score regression or in the regression of protected areas on forest canopy removal. For this reason, we controlled for three covariates in our regression models that are most commonly considered in estimating factors causing forest loss: distance to nearest road, distance to Sochi, and slope.

3. Results

3.1. Land use mapping

Our map had an overall accuracy of 87.5% while average user's accuracy was 61.3% and producer's accuracy was 88.1% (Table 1). Total adjusted (see Methods: Accuracy assessment) forested area was 17,486 km^2 which was 28.3% of the study area. Agriculture amounted to 17,286 km^2 or 28.0% of the area; grasslands made up 6619 km^2 or 10.7%, urban area, cities and roads made up 485 km^2 or 0.8%, and the rest was class 'other' and included glaciers, water bodies etc., which occupied 19,944 km^2 or 32.2%, mainly the large area of the Black Sea. Thus, forest area comprised approximately one third, or 36%, of the terrestrial area. Forests were mainly centered in the mountainous areas of the south, covering the slopes of the Greater Caucasus Range, and along the Kuban and Laba rivers in the north. Most of the north of our study area was covered by agriculture and grassland. Alpine meadows covered large areas above timberline of the Greater Caucasus Range.

Total forest canopy removal in 1985–2010 amounted to 95.8 km^2, i.e., only 0.6% of the forested area. Average annual forest canopy removal was 4.2 km^2 or 0.03%. The adjusted canopy removal areas in the different time periods were even smaller (Table 2), and translated to annual rates of 1.4 km^2 in 1985–1990, 0.8 km^2 in 1990–1999, and 2.4 km^2 in 2001–2010 across our study area. In the following, we provide un-adjusted area estimates when reporting canopy removal rates within and outside of the protected areas and for each protected area. The reason for this is that would have had to have accuracy estimates for each protected area to do the adjustment, which was not feasible given the lack of canopy removals in several of them.

Table 1
Area-adjusted accuracy of land use and forest canopy removal (FCR) classes.

	Producer's accuracy (%)	User's accuracy (%)	Adjusted area	±CI (km^2)	±CI (%)
Stable forest	90.7	95.0	17,486	1231	7%
FCR, 1985–1990	66.1	27.0	7	2	35.1
FCR, 1990–1999	100.0	16.0	7	3	46%
FCR, 2001–2010	100.0	57.0	22	4	17%
Agriculture	86.1	81.0	17,286	1605	9%
Grassland	72.0	62.0	6619	1338	20%
Urban	99.5	52.0	485	93	19%
Others	90.7	95.0	19,944	994	5%
Average	88.1	61.3			
Overall accuracy	87.5				

3.2. Forest canopy removal before and after the collapse of the Soviet Union

Annual forest canopy removal was 3.4 km^2/year from 1985 to 1990, 4.5 km^2/year in the 1990s, and 4.2 km^2/year in the 2000s, or 0.02, 0.03, and 0.03%, respectively. Thus, the rate of forest canopy removal was low throughout the entire study period, but in post-Soviet time and during the 2000s the forest canopy removal rate was higher than in 1985–1990. In protected areas, the average forest canopy removal rate was less than 0.08% per year in 1985–1990. In the 1990s, the average forest canopy removal rates declined for all categories of protected areas (Table 2). In the 2000s, Abkhazian protected areas and Russian protected areas of categories I as well as III–IV witnessed an increase in forest canopy removal rate to approximately the level of 1985–1990s. Sochi National Park experienced an even larger rate of forest canopy removal during the 2000s of 0.38% (Table 2).

The majority of forest canopy removal in Sochi National Park in 2000s was due to construction associated with the Olympic Games in 2014. Total forest canopy removal in Sochi National Park in 2000s was 7.4 km^2. Most of it, 6 km^2 or 81%, was related to the Olympic sites (Fig. 2). By comparison, the same area lost only 0.05 km^2 in 1985–1990 and 0.27 km^2 in 1990–1999.

3.3. Effectiveness of protected areas

All protected areas together contained 670.9 km^2 of forest in 1985. Total forest canopy removal in all protected areas in 1985–2010 was 16.1 km^2. To find annual forest canopy removal, we divided 16.1 by 23 years, i.e. five year of 1985–1990, nine years of 1990–1999, and nine years of 2001–2010. Thus we found very low annual rates of 0.7 km^2, or 0.1% on average, in protected areas.

Table 2
Forest canopy removal rate in protected areas before and after the collapse of the socialism and in the last decade.

Category of PA	Rate of forest canopy removal			
	1985–1990	1990–1999	2001–2010	Total, 1985–2010
Russian strict nature reserves	0.79 km^2/ 0.06%	0.70 km^2/ 0.03%	3.63 km^2/ 0.16%	5.12 km^2/ 2.06%
Abkhazian strict nature reserves	0.04 km^2/ 0.01%	0.03 km^2/ 0.00%	0.11 km^2/ 0.02%	0.18 km^2/ 0.24%
Sochi National Park	0.84 km^2/ 0.08%	1.11 km^2/ 0.06%	7.37 km^2/ 0.38%	9.32 km^2/ 4.30%
Russian protected areas of IUCN cat. III–IV	0.50 km^2/ 0.08%	0.27 km^2/ 0.02%	0.74 km^2/ 0.06%	1.51 km^2/ 1.16%

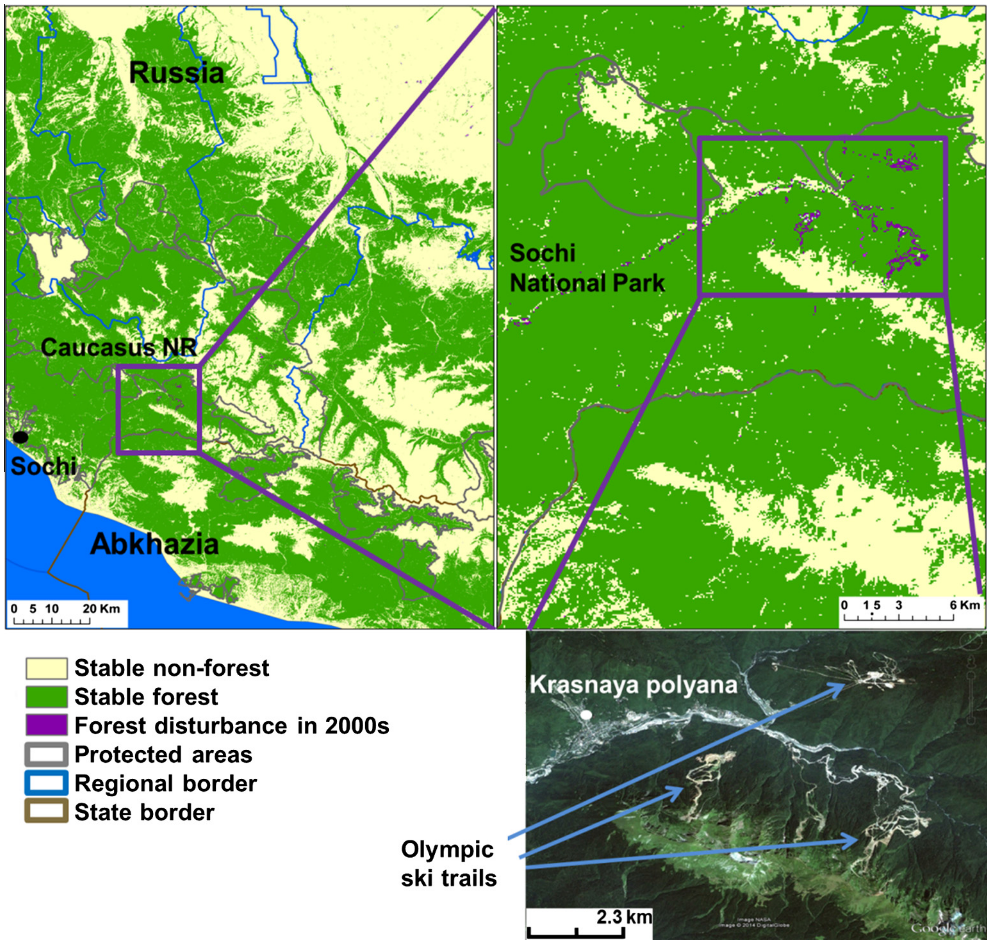

Fig. 2. Forest canopy removal in Sochi National Park around the site of the 2014 Olympic Games. Upper images show forest canopy removal in Sochi National Park, lower right image is Google™ Earth high-resolution image of the area.

At the same time, this rate was higher than the average forest canopy removal rate of 0.03% in the study area (see above).

In general, Abkhazian strict nature reserves had less forest canopy removal than Russian strict nature reserves, and also less than other Russian protected areas. Indeed, Abkhazian strict nature reserves had the lowest rate among all protected areas and lost only 0.2% of forested canopy area in 1985–2010 compared to 2.1% in Russian strict protected areas (Table 2). The annual forest canopy removal rate was 0.01% in Abkhazian strict nature reserves compared to 0.09% in Russian strict nature reserves.

Among protected areas of all categories in both countries, we observed the highest rate of forest canopy removal in Sochi National Park: 9.3 km^2 or 4.3% in 1985–2010 (Table 2). Russian protected areas of IUCN category III–IV lost 1.5 km^2 or 1.2%. The annual forest canopy removal rate was 0.19% in Sochi National Park and 1.2% in Russian protected areas of IUCN categories III–IV.

When we analyzed the effect of protected area status on forest canopy removal rates using propensity score matching, we found few statistically significant differences (Table 3). Qualitatively the results were promising because the negative sign on the marginal effects indicated that protected areas reduced the likelihood of forest canopy removal relative to similar control observations. However, the magnitude of these effects was small and subsequently, only a few protected areas and time periods were statistically significant at even a 90% confidence level. Only when all protected areas were compared to areas outside of protected areas (last row, Table 3), did protected areas reduce forest canopy removal by about 0.1% compared to unprotected areas in the years 1985–1990 and the 1990s, but not in the 2000s. To put this in context, in 1985–1990 canopy removal outside of protected areas was on average 0.12% and in 1990–1999 0.22%. Thus, if all of these areas had been protected, the forest canopy removal rates would have been 0.02% in 1985–1990 and 0.12% in the 1990s, according to our estimated treatment effect. The lack of statistical significance in the 2000s might be due to increased forest canopy removal rates within protected areas, as indicated by the remote sensing analysis. While we did not conduct formal tests of spatial autocorrelation, if any correlation remained it would likely

Table 3
Estimates of protected area impact on forest canopy removal using propensity score matching and logistic regression.

	Year		
	1985–1990 (%)	1990–1999(%)	2001–2010(%)
Russian strict nature reserves ($N = 4778$)	−0.07	−0.10	−0.24*
Abkhazian strict nature reserves ($N = 2368$)	−0.08	−0.09	−0.07
Sochi National Park ($N = 7512$)	−0.09	−0.06	−0.28
Russian protected areas of IUCN cat. III–IV ($N = 4198$)	−0.14*	−0.05	−0.05
All Russian protected areas ($N = 6068$)	−0.04	−0.01	−0.11
All protected areas ($N = 8158$)	−0.10*	−0.10*	−0.07

* 90% significance level.

increase the standard error estimates, further reducing the likelihood of a statistically significant finding.

3.4. Forest canopy removal connected with Olympic Games of 2014

Many events of the 2014 Olympic Games were held within Sochi National Park close to the city of Krasnaya Polyana. Olympic construction started after 2007 when the city of Sochi was chosen to host the Games, which means that forest canopy removal connected with this construction falls in the third period of our study, the 2000s. Forest canopy removal within this area was 5.66 km^2, which was 77% of all forest canopy removal in Sochi National Park during the 2000s.

4. Discussion

How institutional and socioeconomic shocks affect protected area effectiveness is not well understood, particularly in the case of the Soviet Union collapse. We analyzed forest canopy removal inside and around protected areas in the Western Caucasus from 1985 to 2010. We found that forest canopy removal rates in this area were overall extremely low. These low rates were a surprising finding, because they were much lower than in other regions of Russia and other post-Soviet states (Griffiths et al., 2012; Kuemmerle et al., 2007; Baumann et al., 2012). For example, forest canopy removal in Ryazan oblast and Mordovia Republic was 0.15–0.45%/year (Sieber et al., 2013). Similarly, across European Russia the gross forest loss in 2000–2005 was 1.5% i.e. 0.3% of annual forest loss (Potapov et al., 2011), which is ten times more that we found. Forests of the Western Caucasus include economically valuable timber species. Especially, Nordmann fir is a dominant coniferous species, and timber from Nordmann fir is highly prized (Eroğlu et al., 2009; IUCN, 2014). Starting in the 1930s, our study area underwent substantial logging (Plotnikov, 2010). However, our results indicate that clear cut rates were very low in recent decades. We suggest that there are several possible factors in play here. First, the biogeographical history of the region has resulted in high endemism (Akatov et al., 1990), and many plant and animal species are included in the Red List of Russia. Russian legislation prohibits removal of Red Listed species' habitat, which makes logging illegal in most of the Western Caucasus (Federal Law of Russian Federation on Protection of Environment, 2014). Second, mountainous terrain of the Western Caucasus can make logging complicated. Third, mapping at ten-year intervals, which we did, can result in instances where forest canopy removal may be missed if it occurs at the beginning of an interval (Masek et al., 2008). Hence, this may result in discrepancies when compared with results obtained by mapping at annual intervals (Sieber et al., 2013; Griffiths et al., 2012) or five-year intervals (Baumann et al., 2012; Potapov et al., 2011). However, all these studies report annual canopy removal rates that are at least 5 times higher than our rates (Sieber et al., 2013: 0.15–0.45%/year versus 0.03%/year, this study), which is hard to explain solely due to missing removals at the beginning of a period.

We want to stress, however, that our analysis is a conservative estimate of forest canopy removal. Our satellite image analysis captured only stand-replacing forest canopy removal such as clearcuts. The mapping of selective logging, which is also employed in our study area (Plotnikov, 2010), was beyond the scope of our study. It is possible that selective logging is the dominant harvest practice because the cost of timber transportation in this region is very high, and loggers may cut only the most valuable trees to maximize profits. Forest certification by outside organizations such as The Forest Stewardship Council has not been conducted in Western Caucasus so far, and the fact that there are no restrictions on timber place of origin encourages opportunistic logging (Plotnikov, 2010). Also, we did not separate natural versus human forest canopy removal in the study area. To approximate how much forest canopy removal in our study area was natural versus human-caused, we visually inspected 46 random points classified as forest canopy removal. Among these points, 18 were caused by natural, and 28 (61%) by anthropogenic disturbance. Interestingly, the most common type of natural land use change was the shifting location of river beds, and resulting erosion and tree fall. We found no evidence of insect outbreak or wildfire among these 46 points.

The forest canopy removal rates were overall very low, and stayed low after the collapse of the Soviet Union in 1991. These results differed from other data on timber harvesting in Russia including official volumes of harvested timber declined in 1990s (Filiptchouk et al., 2001; Peterson et al., 2009; Potapov et al., 2011) and the same was found in estimates of forest canopy disturbance based on remote sensing (Sieber et al., 2013). During the same time, i.e., the 1990s, only few other regions had an increasing harvest trend (Lebedev, 2001; Vandergert and Newell, 2003). We suggest that the increase in forest canopy disturbance in the Western Caucasus was probably related to the decline in the enforcement of environmental regulations in post-Soviet time (Simeone, 2013). We also suggest that forest canopy disturbance rates in the Western Caucasus were overall so low that the general decline of the timber industry in the 1990s did not affect the harvesting rates that we detected in the Caucasus. Also, from a methodological point of view, it is less likely that we underestimated canopy disturbance in 1985–1990, when we used a five year interval, than in 1990s–2010, when our mapping interval was 10 years (Masek et al., 2008). In general, it should be noted that forest canopy disturbance was low in all three time periods, making comparisons difficult.

We did not find significant differences in forest canopy removal rates inside and outside protected areas of any protection category. The overall lack of significance in the matching analysis – indicating no difference in forest canopy removal between observations within and outside of protected areas – is likely a result of the overall low forest canopy removal rates in our study area. In many protected area categories and years the canopy removal rate was 0% for both treatment and control groups. Given that the removal rate of both protected and non-protected forest was so low (on average only 0.03% annually), there was little data for matching comparisons. Such low removal rates within protected areas and outside of protected areas that share similar observable characteristics make it hard to infer whether protected areas would be effective at preventing canopy removal if logging pressure increases.

In spite of these low average forest canopy removal rates, we did find some removals inside of protected forests. We expected forest canopy removal rate to vary depending on the level of protection. In the strict nature reserves only staff can visit a protected area without special permission, which should limit numbers of illegal loggers as well as number of ignition and wildfires. The management policies of national parks allow tourism, but prohibit commercial development, including logging. The regulations of other protected areas (IUCN categories III–IV) restrict logging as well, but sometimes allow some other land uses, such as cattle grazing (Federal Law of Russian Federation on Nature Reserves, 2014). This is why we expected to find the highest forest canopy removal rates in the least protected areas of IUCN categories III–IV. Interestingly, among all protected area we analyzed, we found the least forest canopy removal in Abkhazia, which contains three IUCN category I PAs (0.24% for the entire study period). We had anticipated that the chaos during and following Abkhazian war in the early 1990s might have been associated with illegal logging, but perhaps the economic decline after the Abkhazian war at the beginning of 1990s limited timber harvesting. All categories of Russian protected areas lost more forest than Abkhazian ones. According to Russian and Abkhazian legislation, development is prohibited within strict nature reserves, and this includes logging and construction. However, we did find 16.1 km^2 of forest canopy removal within Abkhazian protected areas. This is in line with reports of illegal logging in the study area. For example, logging of Nordmann Fir was reported within UNESCO World Heritage Site 'Western Caucasus' in 2005–2009 (Plotnikov, 2010) and extensive forest logging was reported within Sochi National Park in the 1980s (Akatov et al., 1990).

In spite of the low overall forest canopy disturbance rate, we found some hotspots with relatively intensive canopy removal in the latter years of our study. The most important of these hotspots was due to construction of infrastructure for the Olympic Games within Sochi National Park. Among all protected areas and time periods, the site of the Olympic Games had the highest annual canopy disturbance rate in spite of its status as a national park. Furthermore, our findings are based on a Landsat image from 2010, which is before the Olympic construction was finished. Hence, our estimation is conservative, and the actual area affected by forest canopy removal is likely larger. This result is in line with other studies of forest canopy removal in the Western Caucasus (e.g., Hansen et al., 2013) which also show that Olympic construction near the city of Sochi was the biggest source of forest canopy disturbance in the area.

In summary, we found that forest canopy removal rates in the Western Caucasus before and after the collapse of the Soviet Union were surprisingly low, especially when compared with other Russian regions. Largely because of these low removal rates, we did not find a statistically significant effect of protected areas on forest removals. We also found that the Olympic Games had a negative effect on forest integrity. Given the high number of endemic species, and the high value of Western Caucasus protected areas for conservation, further efforts are necessary to meet the intended goal of protected areas in this region, i.e., to eliminate or severely restrict anthropogenic forest canopy removal. However it is encouraging to see that the collapse of socialism did not result in widespread logging in the Western Caucasus.

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