The ecology of peace: preparing Colombia for new political and planetary climates

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Colombia, one of the world's most species-rich nations, is currently undergoing a profound social transition: the end of a decades-long conflict with the Revolutionary Armed Forces of Colombia, known as FARC. The peace agreement process will likely transform the country's physical and socioeconomic landscapes at a time when humans are altering Earth's atmosphere and climate in unprecedented ways. We discuss ways in which these transformative events will act in combination to shape the ecological and environmental future of Colombia. We also highlight the risks of creating perverse development incentives in these critical times, along with the potential benefits – for the country and the world – if Colombia can navigate through the peace process in a way that protects its own environment and ecosystems.

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After more than five consecutive decades of social, political, and armed conflict, the government of Colombia has signed a peace agreement with the largest rebel group, the Fuerzas Armadas Revolucionarias de Colombia (which recently became the political party Fuerza Alternativa Revolucionaria del Común), or FARC. The resolution of this conflict has many ecological, environmental, and socioeconomic implications (Panel 1). In the aftermath of conflicts elsewhere, rural development has intensified, accelerating land transformation and other environmental changes (Le Billon 2000; Baptiste *et al.* 2017). In today's Colombia, these socioenvironmental transformations will occur alongside a variety of ongoing global environmental changes. This socioenvironmental upheaval, which is happening in one of Earth's most important biodiversity hotspots (Myers *et al.* 2000), creates challenges and opportunities for national, regional, and local governments; environmental managers; academia; and society in general. The decisions made at this crucial time will likely affect the lives of both present and future generations of Colombians, and will have ecological, climatic, and biogeochemical consequences with global implications.

We examine how current efforts to achieve peace in Colombia and ongoing changes in global climate will shape the ecological character of this biodiversity hotspot. We highlight challenges for environmental research and policy, and discuss how management decisions made within Colombia could have global consequences.

In a nutshell:

- The resolution of armed conflicts can accelerate land transformation, especially deforestation
- Here, we analyze the possible environmental consequences of the peace agreement between the Colombian government and FARC, the former guerrilla group
- This peace agreement, in combination with climate change, will likely shape the ecological and environmental future of Colombia
- Colombian biodiversity faces risks due to more rapid land transformation and a warming climate
- To prevent or mitigate ecological and environmental degradation, the Colombian government should prioritize rural development in non-forested areas, strengthen environmental research, and engage scientists in decision-making processes

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Colombia's sociopolitical climate

Colombia's population has quadrupled over the past century, and as of 2015 was close to 49 million people (Figure 1; WebFigure 1d). Historically, about 65% of the Colombian population has been concentrated in the Andean and Caribbean regions of the Magdalena–Cauca river basin (Etter *et al.* 2006).

The ongoing conflict in Colombia has lasted for more than 50 years (Álvarez 2003; Baptiste *et al.* 2017) and has directly affected more than 8 million victims, including 220,000 who

Panel 1. Conflict, resolution, and deforestation

In recent decades, 80% of armed conflicts have occurred in biodiversity hotspots, especially in regions with extensive tropical forests (Álvarez 2003; FAO 2005). Countries with low GDP and high inequality generally have a higher probability of armed conflict (FAO 2005), as do countries dependent on the export of primary commodities (Collier and Hoeffler 2002). Some resources have been linked to the initiation of conflicts, whereas others are more likely to lengthen the duration of pre-existing wars. But the association with onset of civil war is not always robust (reviewed in Ross 2004). Remote and inaccessible forests offer not only convenient hiding places for rebels (Figure 4) but also cover for illegal activities such as natural resource extraction and drug production (Donovan *et al.* 2007), both of which can provide funding for rebels and organized crime alike. Moreover, a weak central government and the feeling of abandonment in populations settled in these remote regions facilitate the establishment and strengthening of armed groups (Donovan *et al.* 2007). A number of researchers have examined how warfare impacts the environment (eg Ordway 2015; Gaynor *et al.* 2016). Both periods of warfare and subsequent peace can increase the severity of forest conversion, but their impacts are context-dependent; some studies have demonstrated that both can either drive deforestation or favor forest recovery (reviewed in Ordway 2015). This context-dependence stems in part from the variety of events within armed conflicts; these events have been classified into military tactics, supporting military activities, changing institutional dynamics, movement of people, and altered economies and livelihoods (Gaynor *et al.* 2016). Each of these events consists of several pathways that can have either positive or negative impacts on the environment (Gaynor *et al.* 2016). When the conflict is over, forests have often been disregarded and left unattended, with governmental and international agencies focused on the many other issues that arise with the end of war (Le Billon 2000; but see Beevers 2016). In several cases, especially in developing countries, forests provide the government with a new source of income that can support post-conflict activities and provide a home for demobilized soldiers and displaced populations that want to return to rural areas (FAO 2005; Ordway 2015). The history of post-conflict periods around the world has shown the importance of including an environmental and forestry management strategy in the peace agreement agenda (Nichols *et al.* 2016). Protection of forests from potential problems that come with the resolution of conflict needs to begin before the end of the war (FAO 2005; Clerici *et al.* 2016).

were killed (Registro Único de Víctimas; http://rni.unidadvictimas.gov.co). In November 2016, FARC, the largest group involved in the conflict, signed a peace agreement with the national government (www.altocomisionadoparalapaz.gov.co). Implementation of the agreement began in 2017. A few months afterward, the second largest group involved in the conflict – the self-proclaimed National Liberation Army, or ELN – entered into negotiations with the Colombian government. Illegal activities by other groups, including drug-trafficking organizations and paramilitary groups, continue.

The presence and activities of FARC were concentrated in rural and forested regions of the country (Figure 1), potentially benefiting forests. As conflict drove a massive migration of people from rural to urban areas (UNHCR 2016), forests regrew on abandoned farmlands, increasing forest cover (Sánchez-Cuervo *et al.* 2012). The spatial correlation between

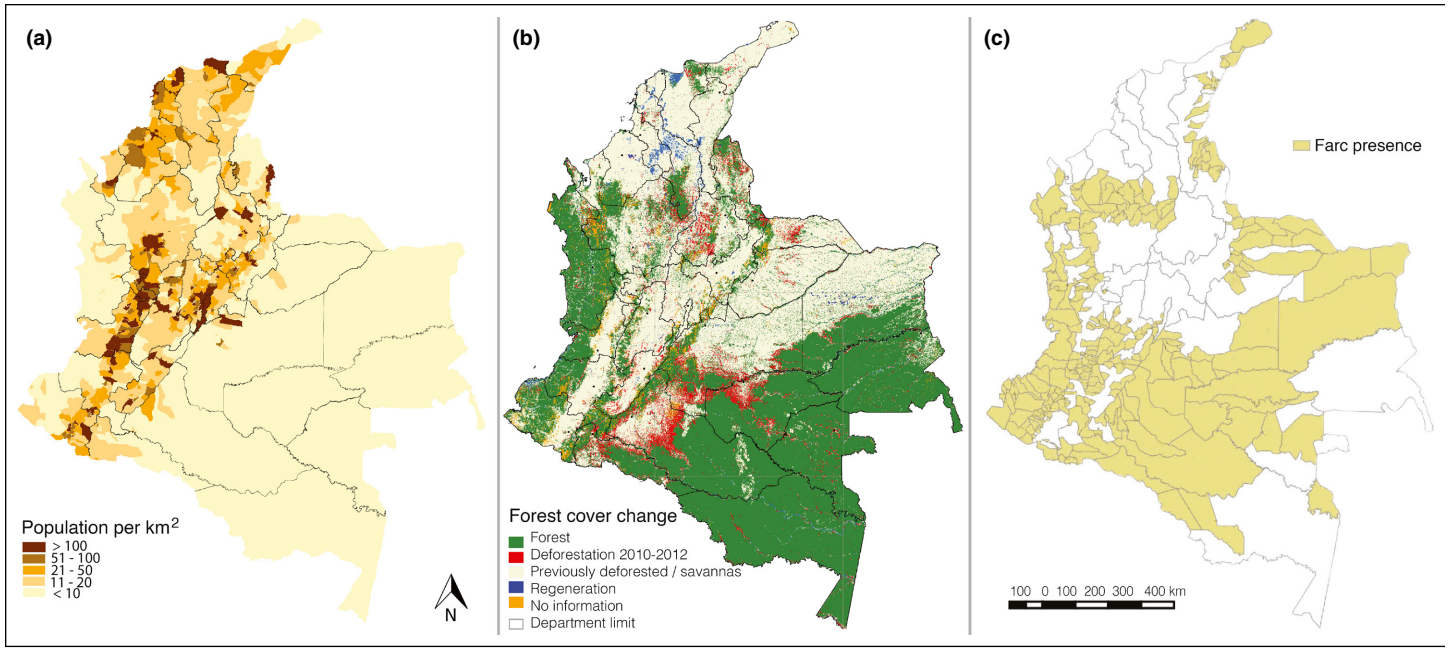

Figure 1. Maps of Colombia's (a) population density (2005), (b) forest cover (2010–2012), and (c) FARC presence (2014). Modified from: (a) Departamento Administrativo Nacional de Estadística (DANE; https://geoportal.dane.gov.co/atlasestadisticocOld); (b) Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM; www.ideam.gov.co/web/siac/catalogo-de-mapas); and (c) Fundación Paz y Reconciliación 2016 (www.pares.com.co/paz-y-posconflicto/gruposarmadosilegales/farc/los-mapas-del-conflicto).

forested areas and FARC presence also suggests that the armed conflict may have unintentionally contributed to the conservation of large forested areas (Figure 1). However, FARC also inhabited environmentally degraded territories, including those affected by illicit crops and illegal mining. Under the new sociopolitical conditions, the forested areas previously occupied by FARC may become targets for investment by national and international corporations interested in expanding their agricultural and mining activities (Clerici *et al.* 2016). After the resolution of long conflicts, countries tend to prioritize social and economic factors, and environmental considerations are often disregarded (Panel 1). In Colombia, deforestation increased by 44% during the year the peace agreement was signed (IDEAM 2016). This deforestation will likely accelerate unless the Colombian government aggressively enforces the country's environmental laws, makes efforts to replace illegal economies with sustainable livelihoods, and promotes a socially inclusive environmental governance of the territories previously affected by the conflict (Panel 1). The drive for rapid economic growth in rural areas poses major challenges to the conservation of ecosystems and biodiversity.

A new biophysical climate in Colombia

In the coming decades, Colombia is projected to become warmer, and water-insecure regions such as the northern coast are projected to become drier (Figure 2). By mid-century, mean temperatures across Colombia are forecast to increase by as much as 3–4°C under a no-mitigation scenario (RCP8.5; IPCC 2013) or by 1–1.5°C under an ambitious mitigation scenario (RCP2.6; Figure 2). Over the same period, annual precipitation is projected to decline in several regions of the country, including the Amazon (Figure 2). Together, warming and altered precipitation patterns will likely suppress productivity and reduce the country's capacity to sequester greenhouse gases (GHGs) (Figure 3; a more detailed description of Colombia's current and future biophysical climate can be found in WebPanel 1).

Adapting to Colombia's changing political and biophysical climates

Five factors can strongly influence the ecological and socioeconomic future of Colombia and other societies recovering from conflict: the environmental context, migration of vulnerable populations, the effectiveness of environmental policy instruments, the availability of scientific support for decision makers, and the approach to incentivizing rural development. We discuss each of these below.

Land-use transformation (deforestation), emissions, ecosystem services, and biodiversity

The disarming of FARC in the wake of the peace agreement could unintentionally accelerate deforestation in Colombia.

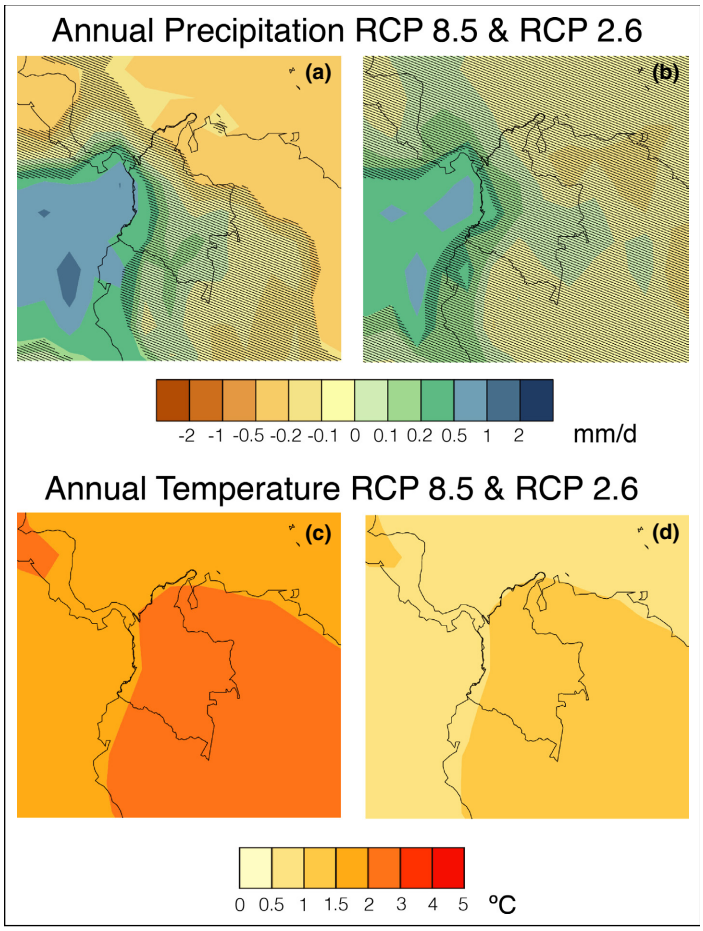

Figure 2. Projections of mean annual precipitation (a, b) and temperature (c, d) for Colombia under RCP8.5 (a, c) and RCP2.6 (b, d) from the AR5 IPCC (2013) Jan–Dec CMIP5 subset. Simulations represent mean values for the period 2081–2100 minus mean values for the period 1986–2005. Hatched areas in panels (a) and (b) represent areas where the signal was smaller than one standard deviation of natural variability. All figures were made based on the IPCC Fifth Assessment Report Climate Change Atlas using the Climate Explorer Tool (https://climexp.knmi.nl/plot_atlas_form.py). For RCP2.6, the mean across models is smaller than one standard deviation of natural variability.

Tropical regions account for 58% of recent net global forest loss (Ferretti-Gallon and Busch 2014), with most of this deforestation occurring in humid tropical forests (Kim *et al.* 2015). Colombia's tropical forest covers circa 460,000 km^2 (Figure 1). Between the years 1500 and 2000, national deforestation rates rose from an estimated 100 km^2 yr^{-1} to more than 2300 km^2 yr^{-1} (Etter *et al.* 2008), second only to Brazil among all Latin American countries (Kim *et al.* 2015). In the Colombian Andes, deforestation had removed 80% of the natural vegetation by the year 2000 (Etter *et al.* 2008), although some regrowth has been documented (Sánchez-Cuervo *et al.* 2012).

With market forces incentivizing resource extraction, many ecologically diverse tropical forests have been transformed into ecologically simplified rangelands and crop areas. Cattle grazing is now the most widespread land use in the Colombian Andes

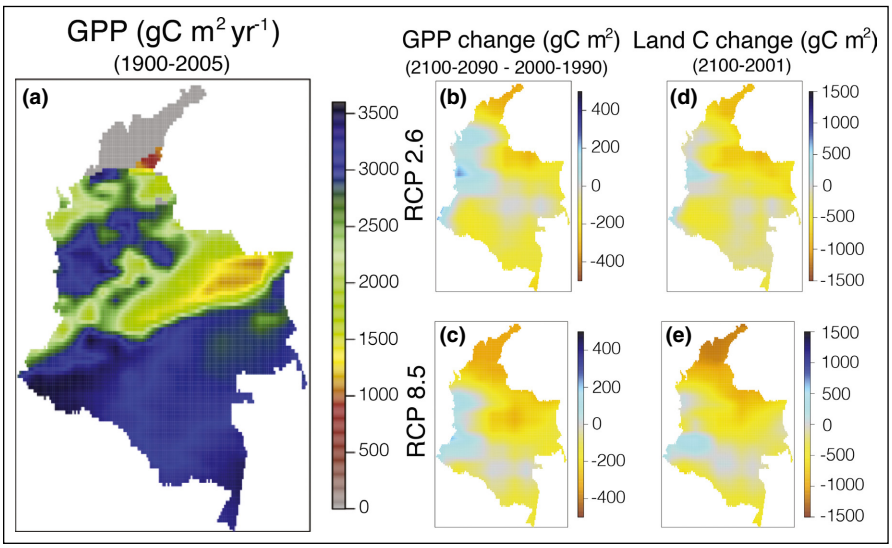

Figure 3. Maps of Colombia's (a) mean annual Gross Primary Productivity (GPP) between 1990 and 2005 from Moderate Resolution Imaging Spectroradiometer (MODIS) v17f satellite-derived estimates (Running *et al.* 2004), and (b–e) future changes in GPP and land C storage as projected by an ensemble of 9 CMIP5 models for two IPCC Representative Concentration Pathways, RCP2.6 (top row) and RCP8.5 (bottom row). Positive values represent increases over the 21st century.

(Etter *et al.* 2008). Both cattle grazing and mining (including illegal mining exacerbated by the armed conflict) have contributed to deforestation and land degradation. Mining has become important to the Colombian economy (Restrepo *et al.* 2015); its contribution to the country's gross domestic product (GDP) has grown by an order of magnitude over the past 20 years (Restrepo *et al.* 2015). With the resolution of conflict, illegal mining activities (previously supported by FARC) may decline and legal mining may increase, especially in the Andean region (WebFigure 2). Erosion from forest clearing and associated activities, such as mining and cattle grazing, has already degraded about 40% of the Colombian territory (WebFigure 3; IDEAM–MADS 2014), and rates of deforestation and soil erosion could further increase now that the conflict has ended.

To further complicate matters, large-scale forest loss can reduce precipitation and river flows over continental regions such as tropical South America (Coe *et al.* 2009; Lawrence and Vandecar 2015; Spracklen and Garcia-Carreras 2015). Understanding the strength of this link is a challenge for scientists, but is important for Colombian policy makers, who need to consider water supply when making decisions about the roughly 30% of the country that is covered by forests. Climate change is expected to further alter water availability through effects on precipitation, including intensification of El Niño events (WebFigure 1c; see also Cai *et al.* 2014), and through the depletion of tropical glaciers (WebFigure 1b; see also Ceballos and Tobón 2007).

In addition to affecting hydrology, accelerated degradation of natural ecosystems in a post-conflict Colombia would have major biogeochemical consequences. Ecosystem disturbance and land-cover change (especially deforestation) are already the largest sources of GHG emissions in Colombia (UNFCCC 2015). Deforestation leads to soil carbon (C) losses (eg via soil erosion; Lal 2003) and reduces the capacity of ecosystems to sequester C (via plant growth; Brienen *et al.* 2015); changes in climate are likely to intensify these effects.

The peace process and the disarming of FARC could impact Colombia's biodiversity in unexpected ways. If the peace agreement enhances access to forest resources, deforestation rates and habitat fragmentation could spike (Clerici *et al.* 2016). As natural habitat is fragmented or lost, species will face elevated risks of population decline and extinction. Concurrent with habitat loss and extinctions, ecosystems will be increasingly affected by climate change. In the Colombian Andes, for instance, many species are endemic or restricted to small geographic ranges (Duque *et al.* 2015), and as climatic conditions change, many species will be forced to shift their ranges to higher elevations (Duque *et al.* 2015). The ability of species to migrate will be hindered by the degradation, fragmentation, and loss of natural habitats. Moreover, climate change and deforestation are not the only threats facing Colombia's biodiversity. Introduction of invasive species and pests, pollution, hunting, and altered fire regimes are all examples of disruptive anthropogenic forces that increase the risks of species loss (Peres *et al.* 2010).

When increased ecological vulnerability associated with ecosystem degradation is combined with higher social vulnerability in natural/rural areas of the country, the ability of ecosystems to provide services to society is potentially highly threatened due to reductions in or loss of ecological integrity (Berrouet *et al.* 2018). This is particularly relevant when the effects of global change overlap with major social transformations. Therefore, integrated assessments of social and ecological vulnerability to global change could help to identify land-use policies and biodiversity conservation strategies that can boost the production and distribution of ecosystem services during the implementation of the peace agreement.

Migration of vulnerable populations

The combination of new political and biophysical climates will likely alter the population dynamics of Colombia's people, with particularly dramatic impacts on victims and vulnerable populations, and potentially contrasting effects on the environment. Forced displacement in Colombia soared because of the internal conflict (Ibáñez and Vélez 2008). The new political climate may substantially reduce conflict-driven migration, or even reverse the process (eg allow people to return to rural areas), whereas the changing biophysical climate will potentially produce climate migrants (eg people who leave water-insecure regions). A decline in forced displacement could reduce pressure on biodiversity

in urban areas while at the same time increasing pressure in rural areas, likely exacerbating deforestation.

Gender inequality increased during the armed conflict with FARC (Salcedo 2013), a typical effect of this type of internal conflict (Jansen 2006). Among the victims, African-descendant, indigenous, and poor rural communities in general have been widely recognized as highly vulnerable populations, along with women and children (Mazurana and Carlson 2006; Alzate 2008). Because the armed conflict was concentrated primarily in rural areas in which government presence is weak, the threat of violence to these populations will likely decline in its aftermath. New opportunities for vulnerable populations will depend on the implementation of effective governance in regions where FARC formerly had a strong influence, as well as on the participation of these communities in the implementation of the peace agreement (ie giving communities a strong voice in decision-making processes).

Current and future environmental policy instruments

Colombia's plan to mitigate its impact on climate and to adapt to climate change is largely summarized in a set of ongoing policy instruments, including the Colombian Low Carbon Development Strategy (CLCDS), the National Strategy for Reducing Emissions from Deforestation and Forest Degradation (ENREDD+), the National Adaptation Plan to Climate Change (PNACC), and the Colombian Intended Nationally Determined Contribution (iNDC). Colombia's biodiversity commitments largely relate to the UN Convention on Biological Diversity (CBD). The country's most important climate-related targets include zero net deforestation in the Amazon by 2020, and a 20% reduction in GHG emissions below business-as-usual projections by 2030 (iNDC; see current emissions in WebFigure 1f). The potential for widespread, rapid, land-cover changes in post-conflict Colombia raises questions about how best to manage and maintain the nation's commitments to biodiversity preservation and climate-change mitigation and/or adaptation. The effectiveness of these policies will likely depend on the ways in which rural areas that were previously affected by conflict are developed, managed, and/or conserved in the future (see section below: Rural development: the key?).

Informing policy with science

The efficacy of environmental policies and regulations cannot be assessed without extensive environmental monitoring. In tropical regions, such monitoring has historically been sparse and underfunded. To gain a better understanding of how major stressors, including global change and national post-conflict recovery, are affecting the functioning of tropical ecosystems, policy makers must invest in more intensive monitoring efforts (Sierra *et al.* 2017).

One particular challenge for monitoring ecosystem processes in Colombia is that many areas (eg those that are poorly developed because of intense and prolonged conflict) are logistically difficult to access. Remote-sensing approaches may be useful for monitoring ecosystem responses to changes in climate and land use/land cover in those areas. However, because the capabilities of remote sensing are limited (eg unable to measure belowground processes), thorough monitoring will also require long-term field measurements. Plans to establish a monitoring system that integrates remote sensing with in situ measurements are currently under development (Sierra *et al.* 2017), but the implementation of such a system may be too slow to record present-day environmental transformations.

Scientists should also engage with policy makers and other interested parties so that environmental monitoring is relevant to decision-making needs, and so that decisions are based on the best available scientific evidence. Although effective engagement can be challenging, a promising approach in this regard is the research for development ("R4D") framework, which proposes that scientific research should not only be communicated but also designed with the active participation of relevant stakeholders (Laws *et al.* 2013). In Colombia, this would involve victims of the conflict, affected communities, the national government, and even former FARC rebels.

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Figure 4. Images from before the peace agreement of (a) a group of FARC rebels returning to their base camp, and (b) a rebel at a camouflaged FARC encampment.

Rural development: the key?

Some of the main principles of the peace agreement are related to land management and rural development (first chapter, www.altocomisionadoparalapaz.gov.co). The implementation of this part of the agreement will strongly influence the future biophysical and sociopolitical climates of Colombia. Rural development implies a series of trade-offs; for instance, the process is likely to increase economic opportunities for people in rural areas, thereby reducing the pressure on urban areas from rural displacement (which increased because of the armed conflict). At the same time, these opportunities may exacerbate pressure on rural forests. To protect Colombian forests and the valuable services they provide, one policy option would be to prioritize rural development in non-forested regions, which already cover half of Colombia (Figure 1). Such targeted development would complement the approach recently advanced by Baptiste *et al.* (2017), who suggested providing incentives to grow, manage, and protect forests. At the same time, local land-use planning and in situ work programs could be used to connect and designate new protected areas within the already fragmented (and at-risk) strategic natural areas. Such conservation initiatives and activities could be promoted through participatory approaches. Involving area residents in the planning would provide insights about local perceptions, land-use practices, and adaptive capacities that could increase the likelihood of local acceptance, and thus successful implementation, of these initiatives. Moreover, such efforts could improve the quality of life in rural areas by providing opportunities for new generations and encouraging social and gender equality.

Conclusions

Modern Colombia is currently experiencing two almost inevitable transformations: intensification of natural resource use and land-cover change in areas previously influenced by FARC, and climate change. These changes represent major challenges but also an opportunity for generations of Colombians that have only lived in a time of war. Wisely and effectively regulating deforestation in the face of political pressures to accelerate development will present a dilemma for some politicians, but an unregulated or poorly regulated intensification of natural resource use would magnify the pressure that climate change will place on the country's ecosystems, with consequences for biodiversity, ecosystem services, and the well-being of the Colombian people.

At the same time, however, Colombia has also been given a momentous opportunity. If the Colombian people (1) take advantage of increased access to technology for monitoring climate, ecosystem processes, and various natural resource uses; (2) base their decisions on scientifically sound evidence; (3) effectively implement climate policies such as those from the iNDC; (4) prioritize efforts to help vulnerable populations displaced by conflict or climate; and (5) protect natural resources (eg forests, soils, biodiversity) that paradoxically are at increasing risk in these more peaceful times and that provide valuable products and ecosystem services, this transition from conflict to peace could not only improve the quality of life of millions of people in a sustainable way but would also serve as a historic example of how a society can end a war without endangering its own environment and ecosystems.

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Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1950/suppinfo

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