



Reconciling certification and intact forest landscape conservation

Fritz Kleinschroth , Claude Garcia , Jaboury Ghazoul

Received: 28 February 2018 / Revised: 2 May 2018 / Accepted: 14 May 2018 / Published online: 29 May 2018

Abstract In 2014, the Forest Stewardship Council (FSC) added a new criterion to its principles that requires protection of intact forest landscapes (IFLs). An IFL is an extensive area of forest that lacks roads and other signs of human activity as detected through remote sensing. In the Congo basin, our analysis of road networks in formally approved concessionary logging areas revealed greater loss of IFL in certified than in noncertified concessions. In areas of informal (i.e., nonregulated) extraction, road networks are known to be less detectable by remote sensing. Under the current definition of IFL, companies certified under FSC standards are likely to be penalized relative to the noncertified as well as the informal logging sector on account of their planned road networks, despite an otherwise better standard of forest management. This could ultimately undermine certification and its wider adoption, with implications for the future of sustainable forest management.

Keywords Congo Basin · Frontier forests · FSC · Land sharing versus land sparing · Landscape approach · Reduced impact logging

INTACT FOREST LANDSCAPES AND FOREST CERTIFICATION

Forest conservation either aims to protect intact forests by preserving them from human impacts (land sparing), or pursues integrative measures that allow for extensive but sustainable use of forest resources (land sharing) as part of long-term forest management. A challenge is to reconcile these approaches. Forest certification typically stands for land sharing as it promotes responsible forest management, allowing for the integration of timber extraction and forest

conservation in the same forest management unit (Romero et al. 2017). Yet, in 2014, the General Assembly of the Forest Stewardship Council (FSC) adopted a new policy of intact forest landscapes (IFLs) protection that leans toward a land-sparing approach. IFLs are defined as “a seamless mosaic of forest and naturally treeless ecosystems with no remotely detected signs of human activity and a minimum area of 500 km²” (Potapov et al. 2017). The IFL concept has since become part of the definition of ‘high conservation values’ in FSC Principle 9. The so-called Motion 65 requires forest managers to protect the vast majorities of the cores of IFLs (Haurez et al. 2017). This decision has triggered an ongoing process of new FSC standard development (Fig. 1), which has major and controversial implications for certified forest operations in both boreal and tropical regions.

The IFL concept was originally developed for boreal forests where harvesting is done by clearcutting (Yaroshenko et al. 2001). It was then applied to forests globally, including tropical forests where selective logging prevails (Potapov et al. 2017). A default clause in Motion 65 required that by the end of 2016, 80% of overlapping areas between the IFL map (<http://www.intactforests.org/>) and certified concessions had to be set aside from forestry operations. This regulation remains in place until full implementation of IFL policy into national standards (Fig. 1).

The intention of FSC was to use IFL to ensure landscape-scale protection of high conservation areas, but it has become apparent that the IFL definition collides with forestry practices in several regions. Selective industrial logging requires roads to access the harvesting sites, yet the delimitation of IFL is largely based on the identification of roads and other infrastructures from satellite images (Potapov et al. 2008). Even the opening of a temporary logging

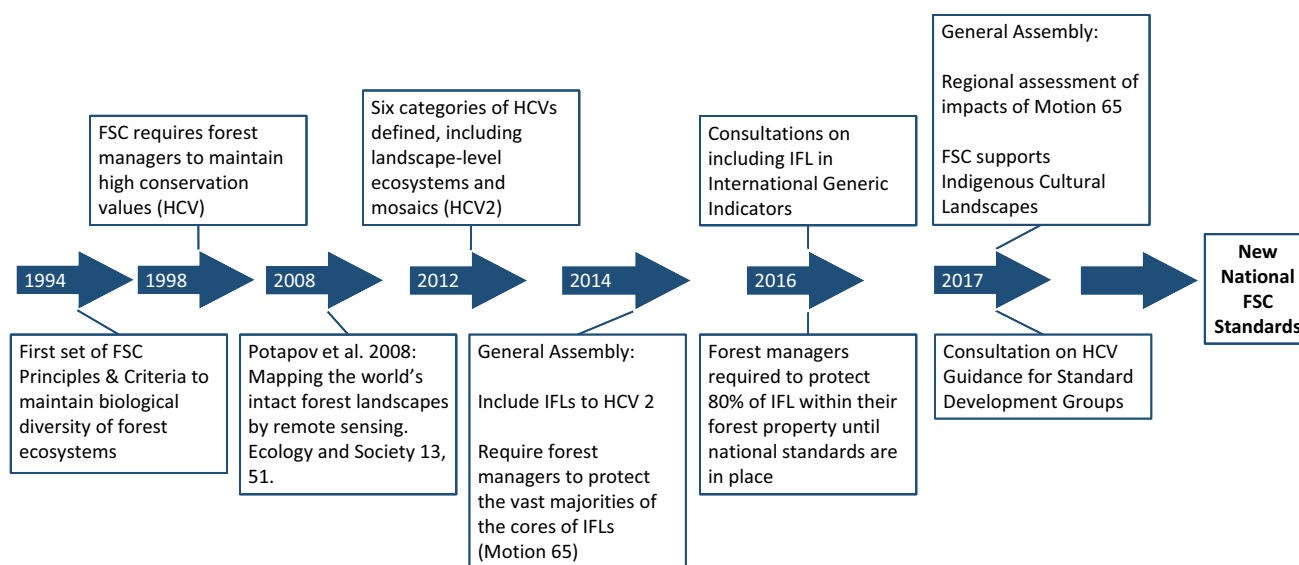


Fig. 1 Timeline of intact forest landscapes policy development in the FSC system (Forest Stewardship Council 2017a; Miettinen et al. 2017; Forest Stewardship Council 2017b)

road means that an area classified as an IFL loses that status permanently. The activities of logging companies are thus not compatible with, or are otherwise severely constrained by, the IFL status if such companies are certified under FSC standards. Although FSC-certified forestry companies already operate under legal boundaries as allocated to them by concession agreements, as well as the voluntary standards stipulated by FSC, the IFL concept introduces a third constraint on operations which is based on a globally determined map of IFL areas derived from remote sensing (Fig. 2). For many FSC-certified companies, this map excludes large parts of their concessions from forestry operations.

HIGHER LOSS OF IFL IN CERTIFIED FORESTS OF THE CONGO BASIN

The forests of the Congo Basin include extensive areas of tropical IFL, as well as many formal and informal logging operations. The formal sector refers to large-scale industrial logging within government allocated concessions. The informal sector comprises unregulated artisanal logging for domestic markets as well as illegal operations. The combination of extensive IFL areas and different logging systems makes the Congo Basin a good case study to explore some of the difficulties in reconciling the IFL concept with forestry operations. Since 2000, new leases of logging concessions in remote areas of the Congo Basin have allowed a rapid expansion of industrial logging activities. This is evidenced by the appearance of extensive new

logging road networks within formerly intact forests (Laporte et al. 2007). We quantified loss of IFL due to road building in a region of the Congo Basin where the majority of certified concessions are located (Fig. 2). We analyzed overlapping areas of designated active forest concessions (WRI and MDDEF 2012; WRI and MINFOR 2012) and IFL defined for the year 2000 (Potapov et al. 2008). Overlapping areas within the study region were similar in size for certified (18 642 km²) and adjacent noncertified (19 177 km²) concessions. We updated two-year interval road layers from Kleinschroth et al. (2017) based on time-series of LANDSAT images between 2000 and 2017 and placed a buffer of 1 km around each road layer. We then calculated the loss of IFL in two-year intervals by extracting the road-buffer from overlapping IFL and concession areas, simulating the methodology of Potapov et al. (2017) as this is the definition used by FSC.

In 10 out of the 12 years (2006–2017) since the first logging concessions were certified (in 2006), absolute loss of IFL was higher in certified than noncertified concessions (Fig. 3), resulting in a higher overall proportion of lost IFL within certified concessions after 2009.

These observations indicate that within the export-oriented industrial sector, certified companies build more roads than noncertified operations. This is presumably because the industry exporting to the European market has better access to capital and expertise to effectively plan and implement logging operations that systematically access large parts of their concessions (Brandt et al. 2014). Nonetheless, in accordance with the responsible forest management adopted by these certified companies, forest

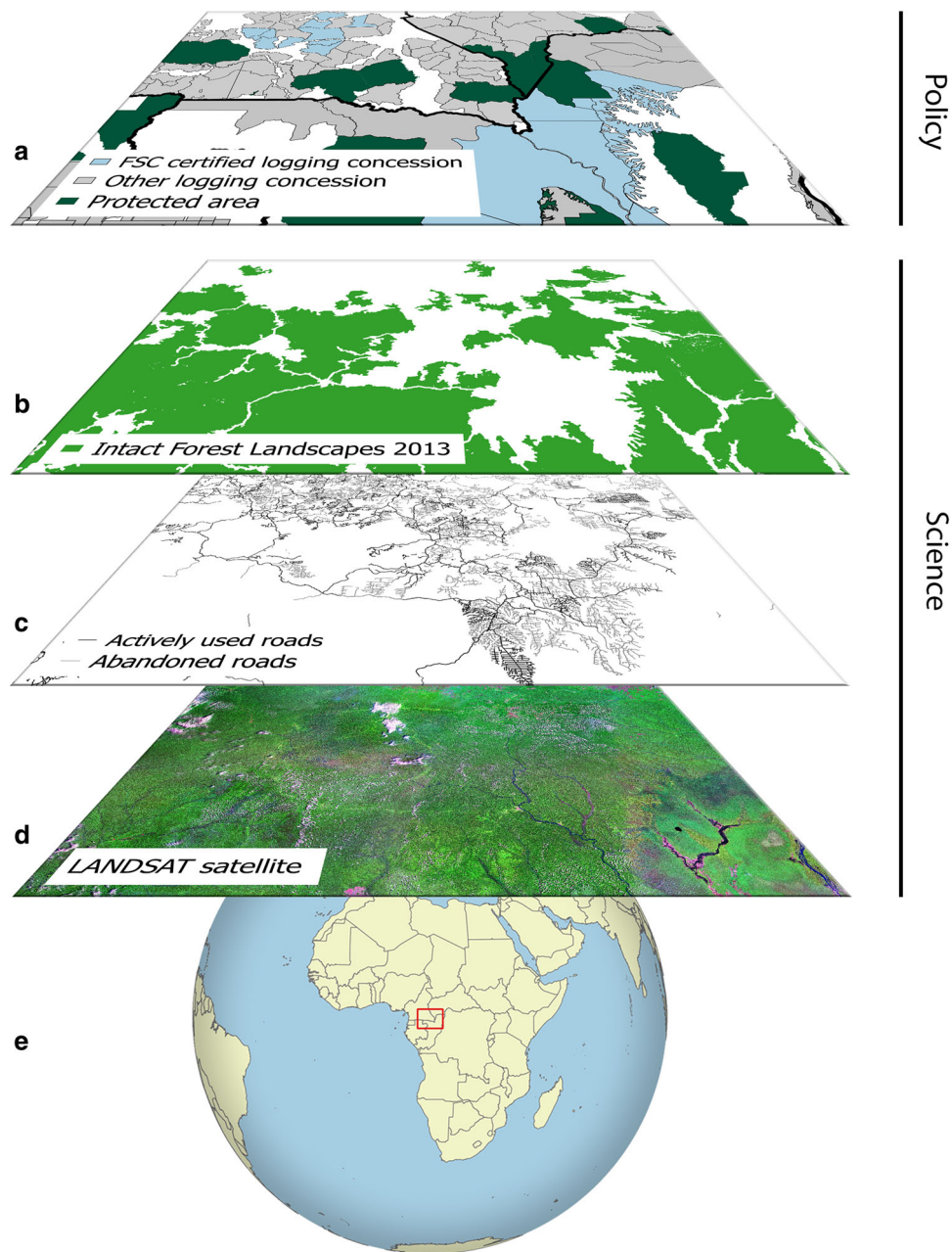


Fig. 2 Overlapping administrative (policy) and descriptive (science) images of a forest landscape in the Congo Basin. **a** Image of forest concessions with and without FSC certification (<http://www.wri.org/tags/forest-atlas>) and protected areas (www.protectedplanet.net) with administrative implications. **b** Image of forest intactness (<http://www.intactforests.org/>) based on the absence of human impacts (such as roads) detected through remote sensing. **c** Descriptive image of road patterns visually detected from Landsat satellite images (Kleinschroth et al. 2017). **d** LANDSAT ETM+ pan mosaics of the forest landscape (Data available from the U.S. Geological Survey). **e** Location of the area shown in (a–d) on a globe with country borders (www.naturalearthdata.com)

impacts are often less severe at any particular location compared to noncertified industrial concessions (Burivalova et al. 2016).

FSC-certified concessions are required to demonstrate sustainability of timber supply, which encourages longer-term investment in the resource (Gullison 2003), and the existing road networks are re-used over multiple rotations

(Kleinschroth et al. 2016c). Noncertified logging companies, on the other hand, often pursue a resource-mining strategy where the most valuable timber resources are rapidly extracted. In the Congo Basin, this strategy is reflected by the quick expansion of extensive but rudimentary road networks after 2000 (Fig. 3). Such extractive “cut-and-run” logging activities were curtailed after 2003

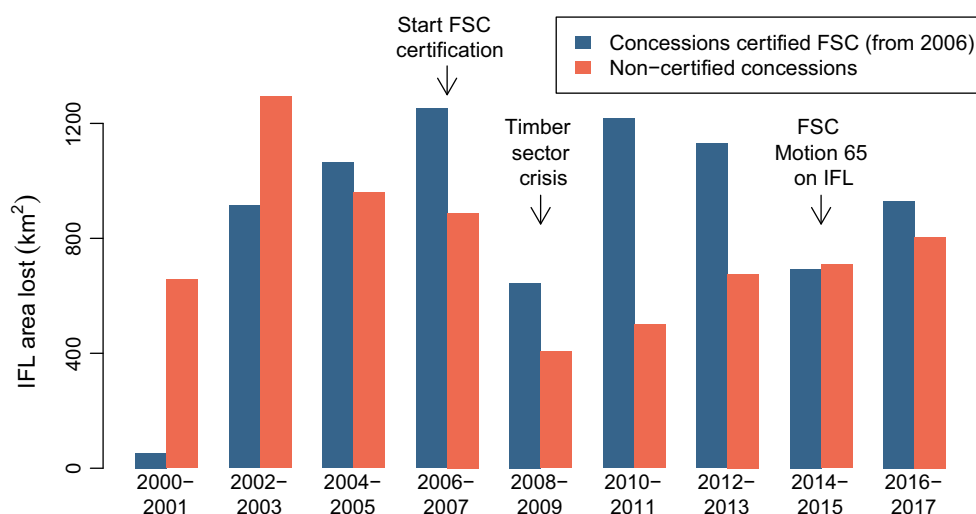


Fig. 3 Loss of intact forest landscapes (IFL) through road building in logging concessions compared between those that have been certified since 2006 and those that were not. Shown is the absolute area lost in each two-year interval. Following the IFL definition (Potapov et al. 2008), any forest within one km of a road is defined to have lost IFL status. Study area as in Fig. 2, updated data from Kleinschroth et al. (2017)

due to resource depletion and changes in forest legislation that required all companies to produce forest management plans, restricting logging to annual allowable cuts (Cerutti et al. 2011). Road building was also greatly reduced by collapsing demand for tropical timber following the 2008–2009 global economic crisis (Fig. 3). FSC certified companies catering for more stable markets were, however, better positioned to resist this timber sector crisis (Karsenty et al. 2010).

INTACTNESS OF IFLS

There are important differences in the detectability of logging by remote sensing. In Central Africa, the volume of extracted timber from informal sources such as artisanal chainsaw milling exceeds the export-oriented industrial sector (Lescuyer et al. 2013). In the Democratic Republic of Congo, an estimated 90% of all logging occurs in the informal sector outside of designated logging concessions (Cerutti and Lescuyer 2014; Lawson 2014). Informal logging operations access the forest in a different way to industrial concessions, mainly by creating narrow, sub-canopy tracks and paths that are mostly invisible to remote-sensing images (Peres et al. 2006). These forests appear “intact” on satellite imagery. In contrast, roads in certified concessions are wide enough to allow well-planned and efficient harvesting over the course of one or two years, after which roads are decommissioned and left to revegetate. These roads remain detectable by remote sensing for up to 20 years after decommissioning (Kleinschroth et al.

2015). The forests that contain them are therefore more readily interpreted as having lost their IFL designation.

An important aspect of certification is the control of post-logging access to forest. The most detrimental impacts of logging roads result from their facilitation of access to forests for hunting and forest clearance (Laurance et al. 2009; Kleinschroth and Healey 2017). Certified concessions ostensibly guarantee strict controls, which should reduce environmentally detrimental post-logging. These measures include gates, patrols and physical closure of roads after harvesting by destroying bridges and emplacement of barriers to make access as difficult as possible (Criterion 1.5, FSC Policy and Standards Unit 2010). These have been shown to have positive effects on great ape and elephant populations (Stokes et al. 2010).

In well-managed concessions, logging road impacts can therefore be transient due to rapid vegetation recovery (Kleinschroth et al. 2016a), while limited post-logging access prevents agricultural encroachment (Cordero-Sancho and Bergen 2018) and helps to maintain populations of great apes and other animal populations by securing their habitats and substantially reducing hunting (Morgan et al. 2017). Certified concessions might have a more extensive and detectable spatial footprint of road networks than other either noncertified concessions or informal operations, but long-term forest quality is more likely to be maintained within certified estates.

Finally, the implications of post-logging conversion are much more severe than those of the operational logging practices themselves (Griscom et al. 2017). As certification incentivises long-term commitment of logging

companies, post-logging re-zoning of land to more transformative land uses such as oil palm plantations is less likely than under unplanned extractive-type logging regimes.

RECONCILING STRATEGIES FOR LANDSCAPE-SCALE CONSERVATION

The construction of easily detectable road networks places certified companies at a comparative disadvantage in terms of the new IFL criterion under the revised FSC guidelines (Haurez et al. 2017). Certified companies are subject to internationally standardized control mechanisms that guarantee transparency and long-term commitment. In these circumstances, the IFL criterion as currently defined seems detrimental to the business model of certified companies as it would prevent their operation in large concession areas on account of the road networks they build, even if such areas would otherwise still remain forested and relatively well protected in the long term. A strict implementation of the existing IFL map risks failure by forcing a conflict between preservation and integration approaches to forest conservation. The latest FSC general assembly in October 2017 responded to this conflict with two new motions that demand regional assessments of the implementation of the IFL policy, comparing environmental, social and economic scenarios (Fig. 1). Another important step is the recognition that many IFLs are also indigenous cultural landscapes. The FSC system is unique in ensuring the rights of indigenous communities, fostering ecosystem stewardship (Smith and Perreault 2017). Any new standards coming out of the IFL policy will have to make sure that they respect the free, prior and informed consent of indigenous peoples.

Intact forest ecosystems are of exceptional value (Watson et al. 2018). The appropriate conservation tool to protect intact forests from human uses would be large protected areas but the FSC system is not the right mechanism to deliver this. The global IFL map was a useful starting point to include land-sparing approaches in the land-sharing-oriented forest certification agenda, but the inherent contradiction between the two approaches needs to be addressed. Certification-based high conservation value policies can only be effective for biodiversity conservation if they take into account more realistic and dynamic models of forest change, including recovery processes. In other words, FSC needs an IFL concept where intactness can be regained following a period of recovery after controlled forestry operations.

Local decision making for the protection of intact and high conservation value forests on the landscape scale requires fine-scale regional maps. Here, remotely sensed

information needs to go hand in hand with field-based species inventories and, for example, carbon-emission-based logging impact baselines (Pearson et al. 2014). Detailed maps would allow for further improvement of certified forest management based on the principles of reduced impact logging (Putz et al. 2012), including set-asides from exploitation and engineering measures to mitigate road-building impacts (Kleinschroth et al. 2016b). Smart road network designs should keep the core of tropical forests free from permanent roads. Building temporary roads under a closed canopy would require higher road engineering efforts due to the wet conditions in tropical forests, but could be a useful step to reduce ecological impacts.

In summary, addressing landscape-scale conservation and management requires resolving agreements between the interests of various stakeholders across areas that are often much larger than the size of a typical concession. IFLs have immense value for conservation, but their scale transcends decision making at local contexts, and their governance creates conflicts among stakeholders with competing, or at least alternative, priorities. Certification is only one of the ways to reconcile divergent interests. The role of the convenor normally falls to governments. If they abrogate this role, other actors like FSC might find themselves bearing the burden of increased responsibilities for environmental, social, and economic outcomes. FSC and FSC certified companies can contribute to IFLs conservation and management, but the definition of local standards that better represent local social, economic and ecological constraints are more likely to be acceptable and implementable, and will moreover allow for more adaptive strategies.

Acknowledgements Fritz Kleinschroth is funded by the DAFNE project of the European Union H2020 programme (Grant Number 690268). Sylvie Gourlet-Fleury, Alain Karsenty, and John R. Healey provided helpful discussion. Diana Franco Gil kindly helped with Fig. 1. The authors thank Peter Ellis and three anonymous reviewers for their useful comments on an earlier version of the manuscript.

REFERENCES

- Brandt, J.S., C. Nolte, J. Steinberg, and A. Agrawal. 2014. Foreign capital, forest change and regulatory compliance in Congo Basin forests. *Environmental Research Letters* 9: 44007. <https://doi.org/10.1088/1748-9326/9/4/044007>.
- Burivalova, Z., F. Hua, L.P. Koh, C. Garcia, and F. Putz. 2016. A critical comparison of conventional, certified, and community management of tropical forests for timber in terms of environmental, economic, and social variables. *Conservation Letters* 10: 4–14. <https://doi.org/10.1111/conl.12244>.
- Cerutti, P.O., and G. Lescuyer. 2014. The domestic market for small-scale chainsaw milling in Cameroon: Present situation, opportunities and challenges. *Occasional Paper*, vol. 61. Bogor: Center for International Forestry Research (CIFOR).

- Cerutti, P.O., L. Tacconi, R. Nasi, and G. Lescuyer. 2011. Legal vs. certified timber: Preliminary impacts of forest certification in Cameroon. *Forest Policy and Economics* 13: 184–190. <https://doi.org/10.1016/j.forpol.2010.11.005>.
- Cordero-Sancho, S., and K.M. Bergen. 2018. Relationships of agricultural land use to an expanded road network within tropical forest landscapes of Cameroon and Republic of the Congo. *Professional Geographer* 70: 60–72. <https://doi.org/10.1080/00330124.2017.1325752>.
- Forest Stewardship Council. 2017a. Advice Note for the interpretation of the default clause of Motion 65. *FSC Directive on FSC Forest Management Evaluations, FSC-DIR-20-007*.
- Forest Stewardship Council. 2017b. International Generic Indicators. *FSC-STD-60-004 V1-1 EN*.
- Griscom, B.W., R.C. Goodman, Z. Burivalova, and F.E. Putz. 2017. Carbon and biodiversity impacts of intensive versus extensive tropical forestry. *Conservation Letters*. <https://doi.org/10.1111/conl.12362>.
- Gullison, R.E. 2003. Does forest certification conserve biodiversity? *Oryx* 37: 153–165. <https://doi.org/10.1017/s0030605303000346>.
- Haurez, B., K. Dainou, C. Vermeulen, F. Kleinschroth, F. Mortier, S. Gourlet-Fleury, and J.-L. Doucet. 2017. A look at Intact Forest Landscapes (IFLs) and their relevance in Central African forest policy. *Forest Policy and Economics* 80: 192–199. <https://doi.org/10.1016/j.forpol.2017.03.021>.
- Karsenty, A., N. Bayol, P. Cerutti, D. Ezzine de Blas, and E. Forni. 2010. The 2008–2009 timber sector crisis in Africa and some lessons for the forest taxation regime. *International Forestry Review* 12: 172–176. <https://doi.org/10.1505/for.12.2.172>.
- Kleinschroth, F., and J.R. Healey. 2017. Impacts of logging roads on tropical forests. *Biotropica* 49: 620–635. <https://doi.org/10.1111/btp.12462>.
- Kleinschroth, F., S. Gourlet-Fleury, P. Sist, F. Mortier, and J.R. Healey. 2015. Legacy of logging roads in the Congo Basin: How persistent are the scars in forest cover? *Ecosphere* 6: 64. <https://doi.org/10.1890/es14-00488.1>.
- Kleinschroth, F., J.R. Healey, P. Sist, F. Mortier, and S. Gourlet-Fleury. 2016a. How persistent are the impacts of logging roads on Central African forest vegetation? *Journal of Applied Ecology* 53: 1127–1137. <https://doi.org/10.1111/1365-2664.12661>.
- Kleinschroth, F., S. Gourlet-Fleury, P. Sist, V. Gond, and J.R. Healey. 2016b. Logging roads in tropical forests: Synthesis of literature written in French and English highlights environmental impact reduction through improved engineering. *Bois et Forêts des Tropiques* 328: 13–26. <https://doi.org/10.19182/bft2016.328.a31299>.
- Kleinschroth, F., J.R. Healey, and S. Gourlet-Fleury. 2016c. Sparing forests in Central Africa: Re-use old logging roads to avoid creating new ones. *Frontiers in Ecology and the Environment* 14: 9–10. <https://doi.org/10.1002/feekleinschroth>.
- Kleinschroth, F., J.R. Healey, S. Gourlet-Fleury, F. Mortier, and R.S. Stoica. 2017. Effects of logging on roadless space in intact forest landscapes of the Congo Basin. *Conservation Biology* 31: 1–24. <https://doi.org/10.1111/cobi.12815>.
- Laporte, N.T., J.A. Stabach, R. Grosch, T.S. Lin, and S.J. Goetz. 2007. Expansion of industrial logging in Central Africa. *Science* 316: 1451. <https://doi.org/10.1126/science.1141057>.
- Laurance, W.F., M. Goosem, and S.G.W. Laurance. 2009. Impacts of roads and linear clearings on tropical forests. *Trends in Ecology & Evolution* 24: 659–669. <https://doi.org/10.1016/j.tree.2009.06.009>.
- Lawson, S. 2014. *Illegal logging in the Democratic Republic of the Congo*. London: Chatham House.
- Lescuyer, G., P.O. Cerutti, and V. Robiglio. 2013. Artisanal chainsaw milling to support decentralized management of timber in Central Africa? An analysis through the theory of access. *Forest Policy and Economics* 32: 68–77. <https://doi.org/10.1016/j.forpol.2013.02.010>.
- Miettinen, P., D. Franco Gil, and M. Karmann. 2017. High conservation values and intact forest landscapes—changes and challenges for certified operation. In *IUFRO 125th Anniversary Congress*, Freiburg.
- Morgan, D., R. Mundry, C. Sanz, C.E. Ayina, S. Strindberg, E. Lonsdorf, and H.S. Kühl. 2017. African apes coexisting with logging: Comparing chimpanzee (*Pan troglodytes troglodytes*) and gorilla (*Gorilla gorilla gorilla*) resource needs and responses to forestry activities. *Biological Conservation* 218: 277–286. <https://doi.org/10.1016/j.biocon.2017.10.026>.
- Pearson, T.R.H., S. Brown, and F.M. Casarim. 2014. Carbon emissions from tropical forest degradation caused by logging. *Environmental Research Letters* 9: 34017. <https://doi.org/10.1088/1748-9326/9/3/034017>.
- Peres, C.A., J. Barlow, and W.F. Laurance. 2006. Detecting anthropogenic disturbance in tropical forests. *Trends in Ecology & Evolution* 21: 227–229. <https://doi.org/10.1016/j.tree.2006.03.007>.
- FSC Policy and Standards Unit. 2010. *FSC forest stewardship standards: structure, content and suggested indicators. FSC-GUI-60-004 (V1-0) EN*. Bonn: Forest Stewardship Council.
- Potapov, P., A. Yaroshenko, S. Turubanova, M. Dubinin, L. Laestadius, C. Thies, D. Aksenov, A. Egorov, et al. 2008. Mapping the world's intact forest landscapes by remote sensing. *Ecology and Society* 13: 51.
- Potapov, P., M.C. Hansen, L. Laestadius, S. Turubanova, A. Yaroshenko, C. Thies, W. Smith, I. Zhuravleva, et al. 2017. The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. *Science Advances* 3: 1–13. <https://doi.org/10.1126/sciadv.1600821>.
- Putz, F.E., P.A. Zuidema, T. Synnott, M. Peña-Claros, M.A. Pinard, D. Sheil, J.K. Vanclay, P. Sist, et al. 2012. Sustaining conservation values in selectively logged tropical forests: The attained and the attainable. *Conservation Letters* 5: 296–303. <https://doi.org/10.1111/j.1755-263x.2012.00242.x>.
- Romero, C., E.O. Sills, M. Guariguata, P.O. Cerutti, G. Lescuyer, and F.E. Putz. 2017. Evaluation of the impacts of Forest Stewardship Council (FSC) certification of natural forest management in the tropics. *International Forestry Review* 19: 1–14. <https://doi.org/10.17528/cifor/004347>.
- Smith, P., and P. Perreault. 2017. *Are all forest certification systems equal? An opinion on indigenous engagement in the Forest Stewardship Council and the Sustainable Forestry Initiative*. Ottawa: National Aboriginal Forestry Association. http://www.nafaforestry.org/pdf/2017/FSCSFICComparisonPaper_Final_28sep2017.pdf.
- Stokes, E.J., S. Strindberg, P.C. Bakabana, P.W. Elkan, F.C. Iyenguet, B. Madzoké, G.A.F. Malanda, B.S. Mowawa, et al. 2010. Monitoring Great Ape and elephant abundance at large spatial scales: Measuring effectiveness of a conservation landscape. *PLoS ONE* 5: e10294. <https://doi.org/10.1371/journal.pone.0010294>.
- Watson, J. E. M., T. Evans, O. Venter, B. Williams, A. Tulloch, C. Stewart, I. Thompson, J. C. Ray, et al. 2018. The exceptional value of intact forest ecosystems. *Nature Ecology & Evolution* 2: 599–610. <https://doi.org/10.1038/s41559-018-0490-x>.
- WRI and MDDEF. 2012. *Atlas forestier interactif du Congo. Version 3.0. Document de Synthèse*. Washington, D.C.: World Resources Institute & République du Congo Ministère de l'économie forestière et du développement durable.
- WRI and MINFOP. 2012. *Interactive forest atlas of Cameroon. Version 3.0. Overview Report*. Washington, D.C.: World Resources Institute & Ministère des Forêts et de la Faune Cameroun.

Yaroshenko, A.Y., P.V. Potapov, and S.A. Turubanova. 2001. *The last intact forest landscapes of Northern European Russia*. Moscow: Greenpeace Russia and Global Forest Watch.

AUTHOR BIOGRAPHIES

Fritz Kleinschroth (✉) is a Postdoc in the Ecosystem Management group at ETH Zurich. He specialises in global landscape-planning issues, working on interdisciplinary nexus approaches for nature conservation and land-use planning. He has a dual-PhD degree in Ecology and Biodiversity from the AgroParisTech, France and in Forestry from Bangor University, UK.

Address: Ecosystem Management, Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, 8092 Zurich, Switzerland.
e-mail: klfritz@ethz.ch

Claude Garcia is a leader of the Forest Management and Development (ForDev) group at ETH Zurich, and a scientist from the Forest and Societies research unit of CIRAD. His research interests include ecosystems, humans, and the norms and institutions the latter develop

to access the former. He develops models and games to understand people's strategies.

Address: Department of Environmental Systems Science, Institute of Terrestrial Ecosystems, ETH Zurich, Universitätstrasse 16, 8092 Zurich, Switzerland.

Address: CIRAD, UPR Forêts et Sociétés, 8092 Zurich, Switzerland.
e-mail: claude.garcia@usys.ethz.ch

Jaboury Ghazoul is a Professor of Ecosystem Management at ETH Zurich, and holder of the Prince Bernhard Chair of International Nature Conservation at Utrecht University. His core expertise is plant reproductive ecology in human-modified landscapes, with a focus on forested landscape mosaics.

Address: Ecosystem Management, Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, 8092 Zurich, Switzerland.

Address: Prince Bernhard Chair of International Nature Conservation, Ecology and Biodiversity, Department of Biology, Utrecht University, Utrecht, The Netherlands.

e-mail: jaboury.ghazoul@env.ethz.ch