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Patterns in recent disturbances to peat forests in the Cuvette Centrale, Africa, and their key drivers

Karimon Nesha,[1]* Martin Herold,[1,2] Johannes Reiche,[1] Robert Masolele,[1] Kristell Hergoualc'h,[3,4] Erin Swails,[3] Daniel Murdiyarso[5] and Corneille E. N. Ewango[6]

Key Messages

- Peat forest disturbances (PFDs) affected about 30,294 ha within the Cuvette Centrale during 2019–2021, spanning the Democratic Republic of the Congo (DRC) and the Republic of the Congo (ROC). Most PFDs (91%) took place in north-west DRC, especially in the Sud-Ubangi district and along the Congo River. They occurred mostly during the first six months of each year, especially between February and May. Over three-quarters of disturbances took place outside forest concessions, indicating that peat was being exploited illegally.
- Smallholder agriculture was the leading cause of the disturbances. About 90% of PFDs took place within 1 km of the edges and 99% within 3 km of the edges, leaving the core of the forests relatively untouched. Smallholders may be drawn to the edges because they are more accessible for agricultural drainage. Indeed, disturbances occurred more frequently around roads and rivers.

Summary

The Cuvette Centrale in the Congo Basin, spanning the Republic of the Congo (ROC) and the Democratic Republic of the Congo (DRC), is home to the world's largest tropical peatlands. Despite their important role in storing carbon, these forests have been insufficiently studied. This brief assesses recent peat forest disturbances (PFDs), including from human activities such as draining peat for agriculture and natural causes such as flood. In addition to examining spatial and temporal patterns during 2019–2021 in the Cuvette Centrale, we provide an assessment of the direct drivers of PFDs through visual interpretation of Planet and Sentinel 2A data. In so doing, the study identifies a vital need to develop sound strategies to conserve peat forest in the area. Such strategies could become the foundation for national-level policies to protect peatlands in line with the Brazzaville Declaration and the Paris Agreement. In addition, our findings on direct drivers could set a baseline for machine learning models, enabling them to automate visual interpretation and scale up assessment across the region.

This infobrief summarizes the key findings from Karimon Nesha et al. (2024) Environ. Res. Lett. 19 104031, https://iopscience.iop.org/article/10.1088/1748-9326/ad6679.

Introduction

Peatlands are critical ecosystems, acting as significant carbon sinks and playing a vital role in regulating the global climate. The Cuvette Centrale in the Central Congo Basin in Africa is home to the most important stores of tropical peat in the world (Dargie et al. 2017; Crezee et al. 2022). These peatlands, which span the Republic of the Congo (ROC) and the Democratic Republic of the Congo (DRC), store 28.7–30.8 petagrams of carbon (29% of all tropical peat carbon stock).

1 Wageningen University and Research (*Corresponding author: karimon.nesha@wur.nl; karimonnesha@gmail.com)
2 Germany Helmholtz GeoResearch Center Potsdam (GFZ)
3 CIFOR-ICRAF
4 CIRAD
5 IPB University
6 Université de Kisangani

These peatlands are covered by swamp forests, mostly palm trees and hardwood-dominated vegetation (Dargieet al. 2017; Gumbricht et al. 2017a).

Given the significance of the immense carbon stocks within the peat and vegetation in these ecosystems, the ROC, DRC, and Indonesia signed the Brazzaville Declaration in 2018. The Declaration, which commits parties to the protection and sustainable management of tropical peatlands, aligns with broader international efforts such as the Paris Agreement and the UN-Reducing Emissions from Deforestation and Forest Degradation (UN-REDD) programme.

Despite their importance, the peat forests of the Cuvette Centrale remain understudied and are increasingly threatened by human activities. Previous studies have identified general threats to these peatlands, such as land-use changes and climate change (Dargie et al. 2019). These threats could get worse if they are not addressed, resulting in irreparable damage to vital ecosystems. Understanding the drivers of PFDs is thus crucial to develop appropriate responses both nationally and internationally. To that end, Earth observation data sources can play a pivotal role to monitor PFDs and identify drivers of change.

This study systematically analyses recent PFDs and their direct drivers in the Cuvette Centrale across the DRC and ROC during 2019–2021. The analysis primarily uses Radar for Detecting Deforestation (RADD alerts) (Reiche et al. 2021), two recently drawn peatland maps (Gumbricht et al. 2017b; Crezee et al. 2022), and high-resolution imagery from Norway's International Climate and Forests Initiative (NICFI) Planet and Sentinel-2A.

By filling in knowledge gaps, the research aims to support better strategies to conserve and restore peatland both national and internationally in alignment with the Paris Agreement and Brazzaville Declaration.

Specifically, the study looks at spatial and temporal patterns of PFDs; examines the impact of accessibility and protection status on the location of disturbances; and identifies the direct drivers of PFDs and how they vary in time and space.

Data and methods

Data sources

An overview of the data and methodological framework employed in this study is shown in figure 1.

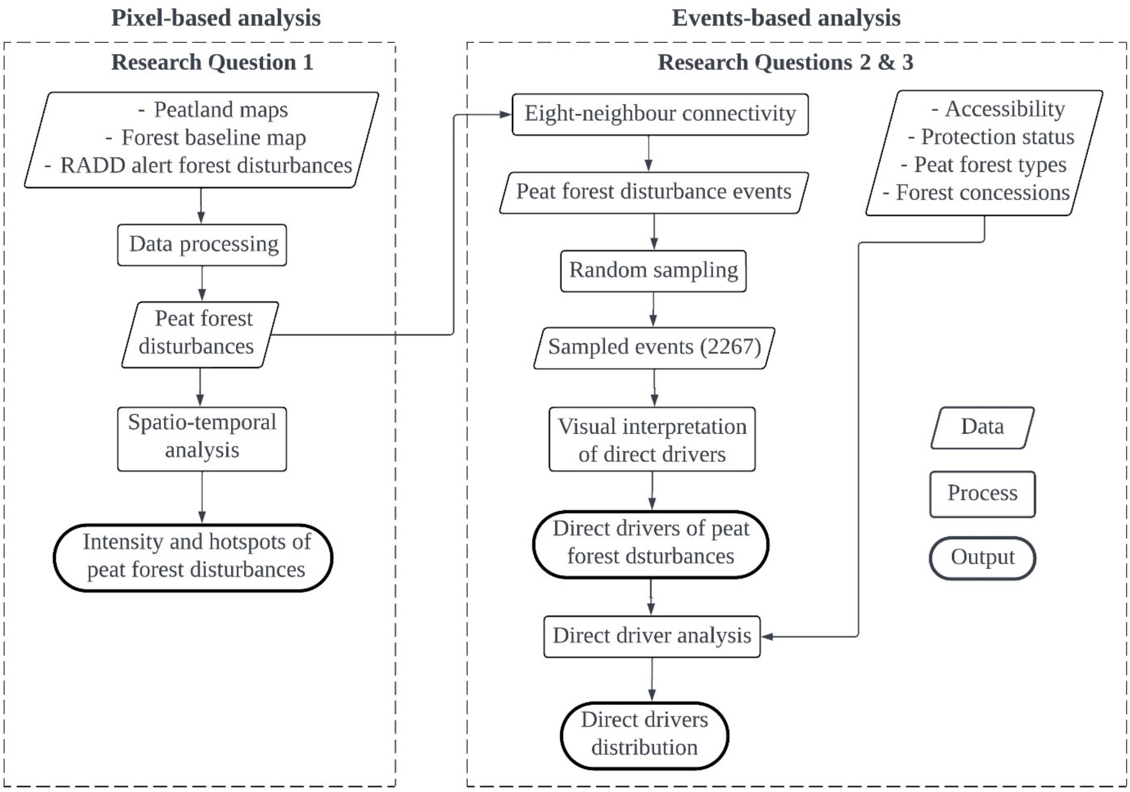

Figure 1. Major datasets and processes supporting analysis of peat forest disturbances and their direct drivers in Cuvette Centrale, 2019–2021

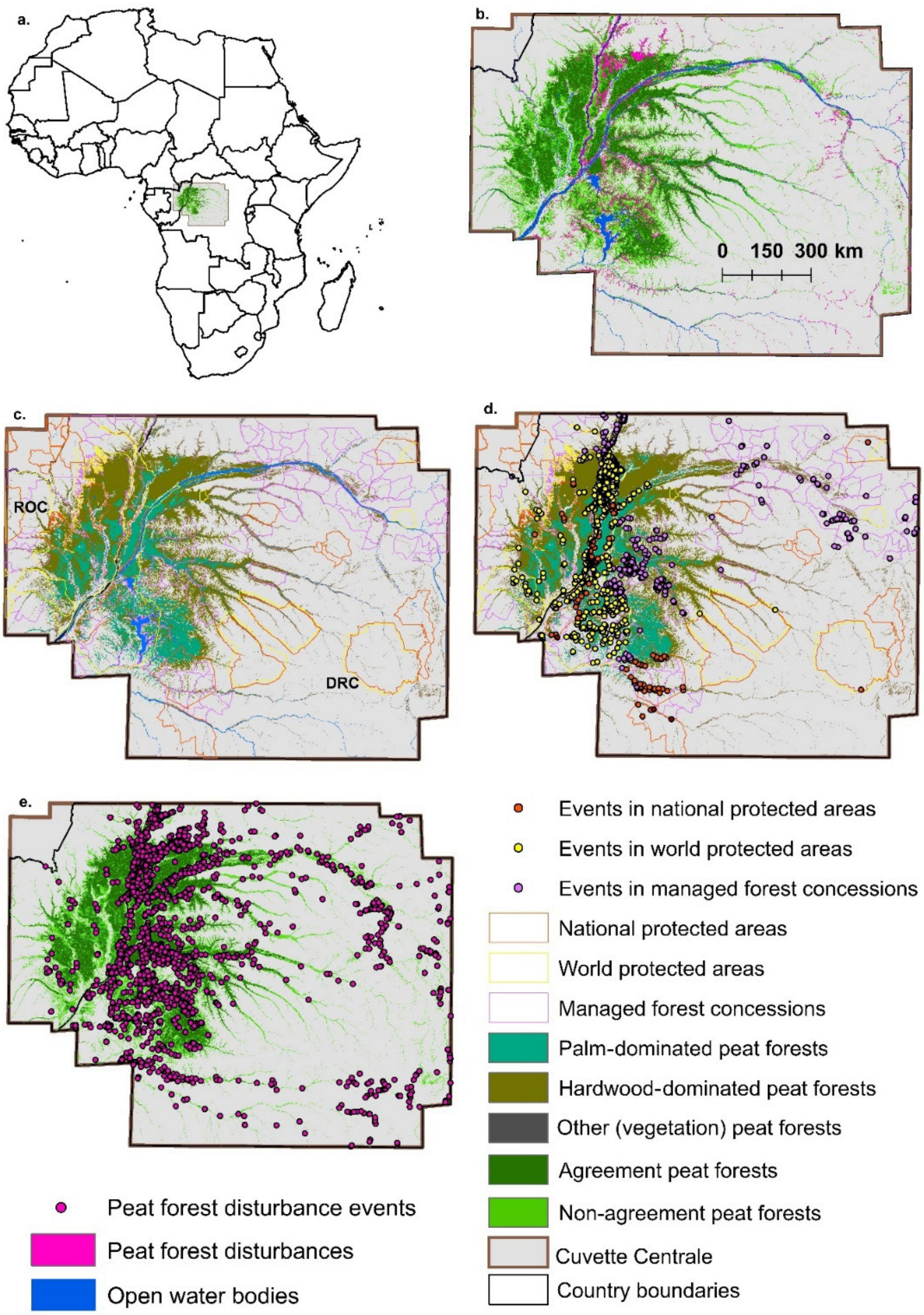

Figure 2. Distribution of peat forest disturbances

Note: a) Study area in the Cuvette Centrale, Africa. b) PFDs (combined peat forests that segregate agreement and non-agreement peat forest areas). c) Distribution of hardwood, palm-dominated, and other peat forests (collectively representing the combined peat forests) overlayed with protected areas (both national and international) and managed forest concessions. d) Distribution of the sampled PFD events intersecting national and world protected areas, and managed forest concessions. Sampled PFD events are shown visually on the map; we analysed all disturbances. Peat forests are shown according to vegetation types. e) Distribution of randomly sampled 2,267 disturbance events to analyse direct drivers of PFDs.

We integrated two remote sensing (RS) - based peat maps – Gumbricht (231 m) and Crezee (50 m) (Figure 2a and b) (Gumbricht et al. 2017; Crezee et al. 2022). We then combined this combined peat map with a third set of data – a forest baseline mask in Africa (10 m) for 2018 (Turubanova et al. 2018) to generate a combined peat forest map (Figure 2b). Figure 1 provides an overview of the datasets and methodology of this study.

We used the RADD alert system, a Sentinel-1-based dataset, from 2019 onwards to identify PFDs. The system provides near-real-time information on forest disturbances in primary humid tropical forests (Reiche et al. 2021). This system defines forest disturbance as the complete or partial removal of tree cover within a 10 m Sentinel-1 pixel. The alert contains "Alert confidence" and "Date" when the disturbance was first detected. We masked out PFDs from the RADD data using the combined peat forest map in the Cuvette Centrale (Figure 2b).

Photo by Kristell Hergoualc'h/CIFOR

Photo by Kristell Hergoualc'h/CIFOR

Analytical framework

We quantified the relative intensity of disturbances per unit area (1 km x 1 km grid cell) as the ratio of PFD pixels (10 m) to peat forest pixels (10 m) in each grid cell to assess the spatial distribution of PFDs. Further, we analysed the temporal pattern of PFDs each month, aggregated per year, to assess both intra-annual and interannual patterns over the period. We identified areas with more than 10% disturbances each month, aggregated annually, as temporal hotspots. We also analysed the distribution of disturbances within and outside forest concessions, and national and world protected areas (Figure 2c and d). Additionally, we identified the proximity of disturbances to the edges of peat forests.

Drawing on the framework of proximate causes elaborated by Geist and Lambin (2002), we identified five direct drivers of forest disturbances: smallholder agriculture, small-scale logging, floods, roads, and settlements (Table 1). Drivers that did not fit into one of these categories were labelled 'unidentified'.

We employed random sampling on the PFD pixels aggregated as events. We grouped the distinct spatially connected disturbance pixels into one single object that we defined as a PFD event. Around 4% of total events (61,779) were selected at random, leading to 2,267 events (Figure 2e). Using high-resolution satellite images (4.77 m Planet and 10 m Sentinel-2A) as a visual guide, we interpreted post-disturbance land use per event to identify direct drivers (Figure 6). We applied distinct criteria for each driver class to assign a specific driver; these are visible on the images following disturbances (Table 1).

Table 1. Class description and criteria of direct drivers of peat forest disturbances in the Cuvette Centrale based on Planet and/or Sentinel-2 imagery

Driver class	Description
Smallholder agriculture	• Regrowth of vegetation in sample events within one year • At least one complete/partial harvesting at the sample events within two years of vegetation regrowth • Texture smooth and comparable with adjoining crop fields, i.e., similar vegetation patterns followed in the adjoining crop fields in events with no visible harvesting vegetation • Large events with multiple croplands (Figure 3) • Usually next to crop fields over large areas • No adjoining crop fields (i.e., an individual/isolated event), new disturbances close by within a year • Small events usually expanding from an existing crop field (Figure 4) • Usually close to settlements/roads/river networks • Usually non-mechanized clearing of croplands (Figure 4)
Small-scale logging	• No clearing of vegetation within a year of post-disturbance regrowth and tree canopy clearly visible in one to two years • No vegetation regrowth and a bare patch for more than a year • Usually small to medium events
Flood (Figure 5)	• Event occurrence during June–December 2019 • Located along the rivers • No adjoining crop fields • No cropping pattern in the sample events
Roads	• Linear canopy visible for more than three months after opening • Usually part of existing road networks • Usually connected with disturbances/settlements
Settlements	• Houses and their roofs clearly visible • Appear bright on the image • Usually, several houses co-located
Unidentified	• Events outside perimeters of the above-mentioned classes • Significant spatial mismatch of the RADD alert events due to shifting in Planet images • Events not recognizable due to unclear/cloudy Planet and/or Sentinel-2 images

Note: See Nesha et al. (2024).

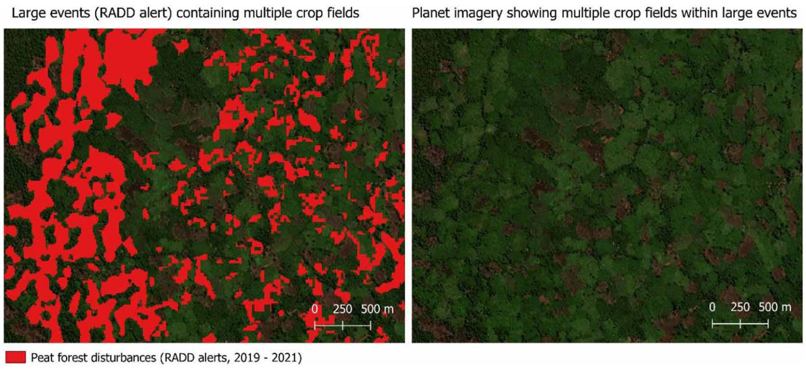

Figure 3. Large events containing multiple croplands, distinguishable by separate crop fields, cropping periods and patterns within the events.

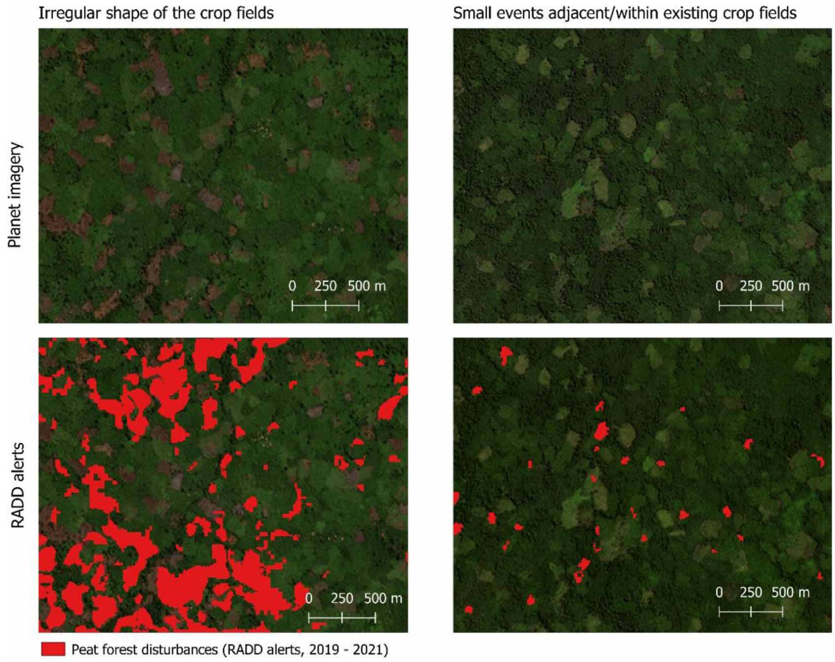

Figure 4. Small events usually expanding from an existing crop field (right column Figures), and non-mechanized clearing of croplands (left column Figures). Small events are typically adjacent to existing crop fields, illustrating the expansion of agricultural land into nearby peat forest areas. We identified non-mechanized clearing of croplands by noting the irregular shapes of crop fields and the absence of machinery in their vicinity during the observed period.

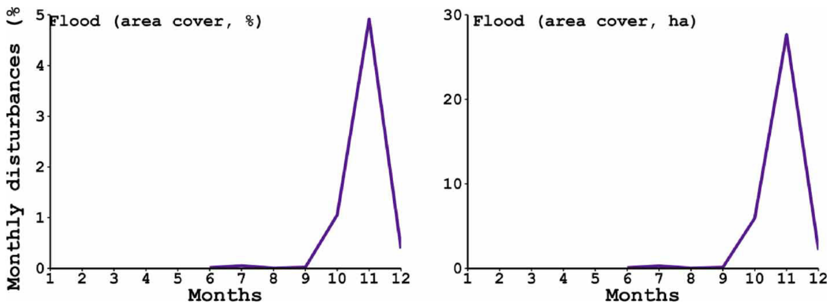

Figure 5. Distribution of flood events, mainly along the Congo River in the Cuvette Centrale, showing higher proportion of forest disturbances since October in the year 2019. We incorporated flood events exclusively for the year 2019 due to the well-documented major flooding event that year (Gou et al 2022), which we confidently identified using the RADD alert product. While flash floods were reported in 2020 and 2021, we excluded them due to limitations in identifying them using the RADD product.

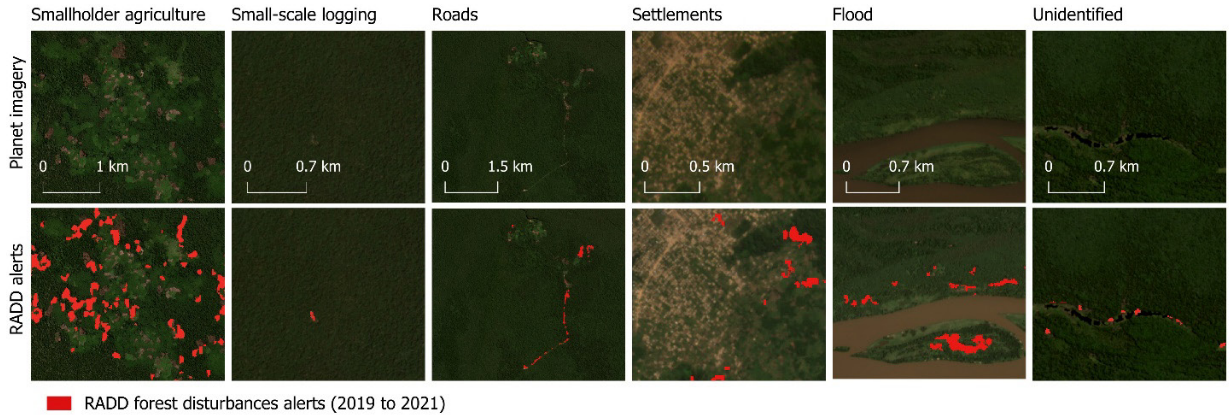

Figure 6. Example Planet images relating to direct drivers of PFDs in the Cuvette Central with disturbances detected from RADD alerts (2019–2021)

Note: We identified direct drivers following disturbances visualized on the 4.8 m spatial resolution Planet and 10 m resolution Sentinel-2 imagery. For each disturbance event, we examined 24 monthly images in the subsequent two years from both Planet and Sentinel-2. Consequently, if an event occurred later in 2021, we analysed the subsequent monthly images from both Planet and Sentinel-2 over 2022 and 2023. Although not all images were free of clouds, the available time series of clear monthly images over two years was sufficient to confidently identify a driver to a disturbance event.

Findings

Most peat forest disturbances take place in the first half of the year

Disturbances occurred within an area of 30,294 ha in the peat forests of the Cuvette Centrale during 2019–2021. The vast majority (around 91%) were concentrated in the DRC. A substantial portion of spatial hotspots took place in the north-west, especially in Sud-Ubangi district. PFDs in most affected areas were of medium intensity, ranging from 2% to 20% over 21,049 ha (Figure 9a). Spatial hotspots were relatively unusual, covering an area of 2,831 ha.

There was a consistent interannual pattern to the temporal distribution of PFDs, which occurred mostly in the first half of each year (62% in 2019, 69% in 2020, and 78% in 2021) (Figure 7a). This seasonal trend began in January, with temporal hotspots appearing between February and May. There was no intra-annual trend except in 2019, which had extensive disturbances (20%) in November and December.

Most disturbances took place outside forest concessions and on the peat edges

More than three-quarters of disturbances (about 77%) occurred outside managed forest concession areas (Figure 2d). About 40% took place within protected areas. They occurred predominantly on the edges of peat forests, leaving core regions relatively untouched (Figure 8). About 90% occurred within 1 km of the forest edges, with 99% within 3 km. In addition, 76% of disturbances took place within 5 km of rivers or roads, with about 94% occurring within 10 km.

Smallholders were the leading driver of peat forest disturbances

Smallholder agriculture was the leading driver of PFDs in both countries, representing 89% of 2,267 sampled events in the DRC and 77% in the ROC, representing overall more than 88% of events in Cuvette Centrale. Logging was the next most prevalent driver in Cuvette Centrale at around 7% (Figure 9b–6d; Table 2). Logging events made up 18% of disturbance areas in the ROC, nearly triple the percentage identified in the DRC. Most flood events (98%) occurred along the Congo River, where all small settlements were located near rivers and water channels in the DRC. About three-quarters of road events were found in the ROC.

Most drivers occurred between January and June each year (Figure 7b), a trend primarily linked to smallholder agriculture (Figure 7b.1). Logging events, though less prominent, were also concentrated in the first six months of the year (Figure 4b.2). Flood events were concentrated from October to December in 2019. No clear seasonal pattern was observed for other events (Figure 4b.3).

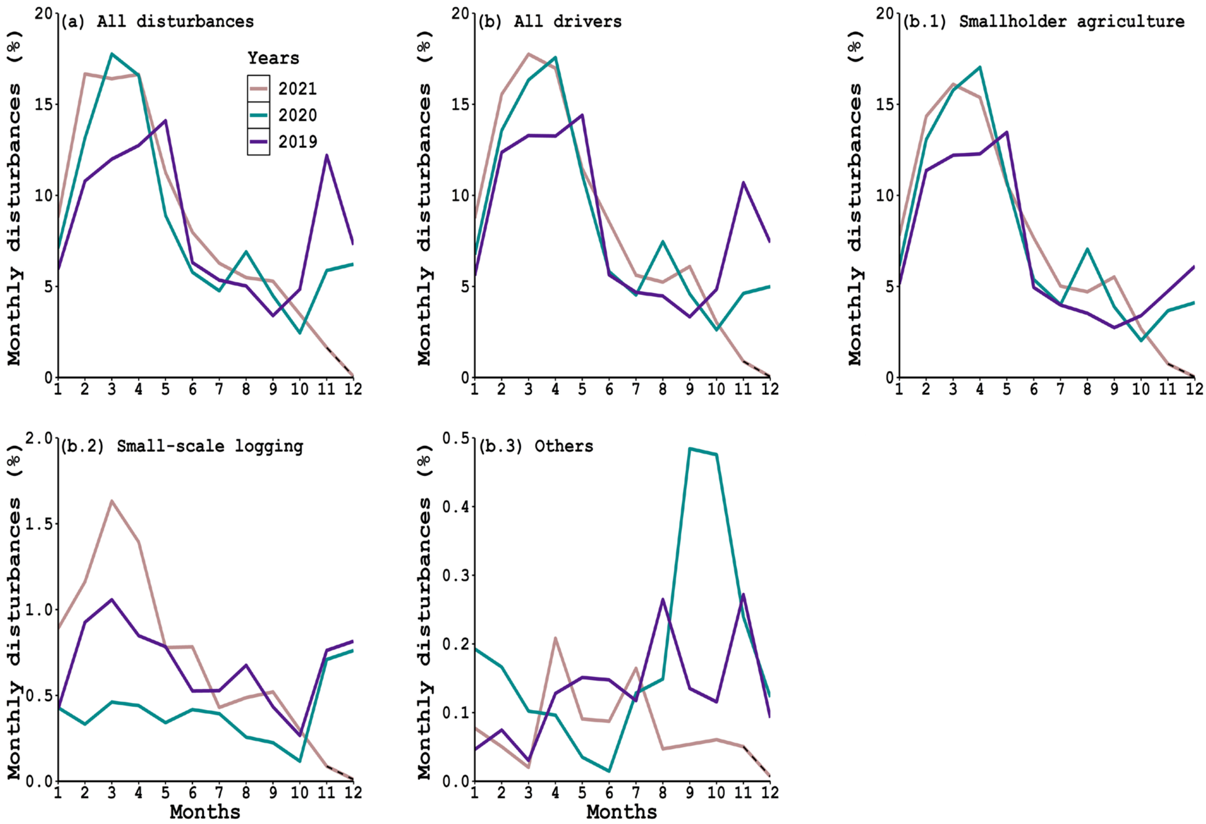

Figure 7. Temporal distribution of disturbances in the Cuvette Centrale

Note: The distribution of disturbances (in percentage on the y-axis) is depicted month-wise aggregated by year from 2019 to 2021 (x-axis). Lines for November and December 2021 are black dashes to indicate lack of high confidence data for these months. a) Temporal distribution of all disturbances. b) Temporal distribution of all drivers. b.1) agriculture; b.2) logging; b.3) other events, respectively. Other events include roads, settlements, and unidentified. We calculated the monthly percentage of disturbances (y-axis) based on the total sum of all drivers per year, segregated by months on the x-axis. Figure parts b.2 to b.3 have much lower scales, with logging and other factors making up only a small fraction of disturbances compared with agriculture in Figure b.1.

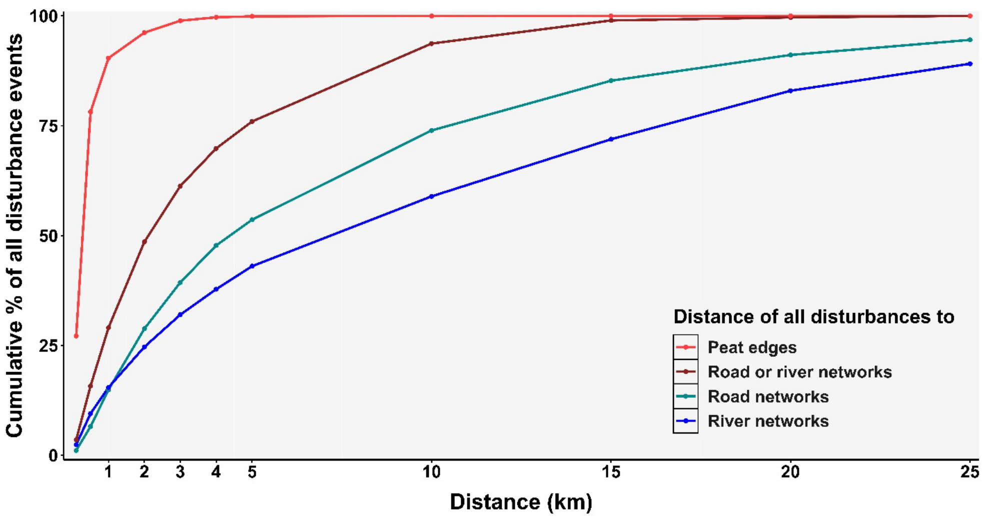

Figure 8. Distribution of all disturbances by protection status and accessibility in the Cuvette Centrale, 2019–2021

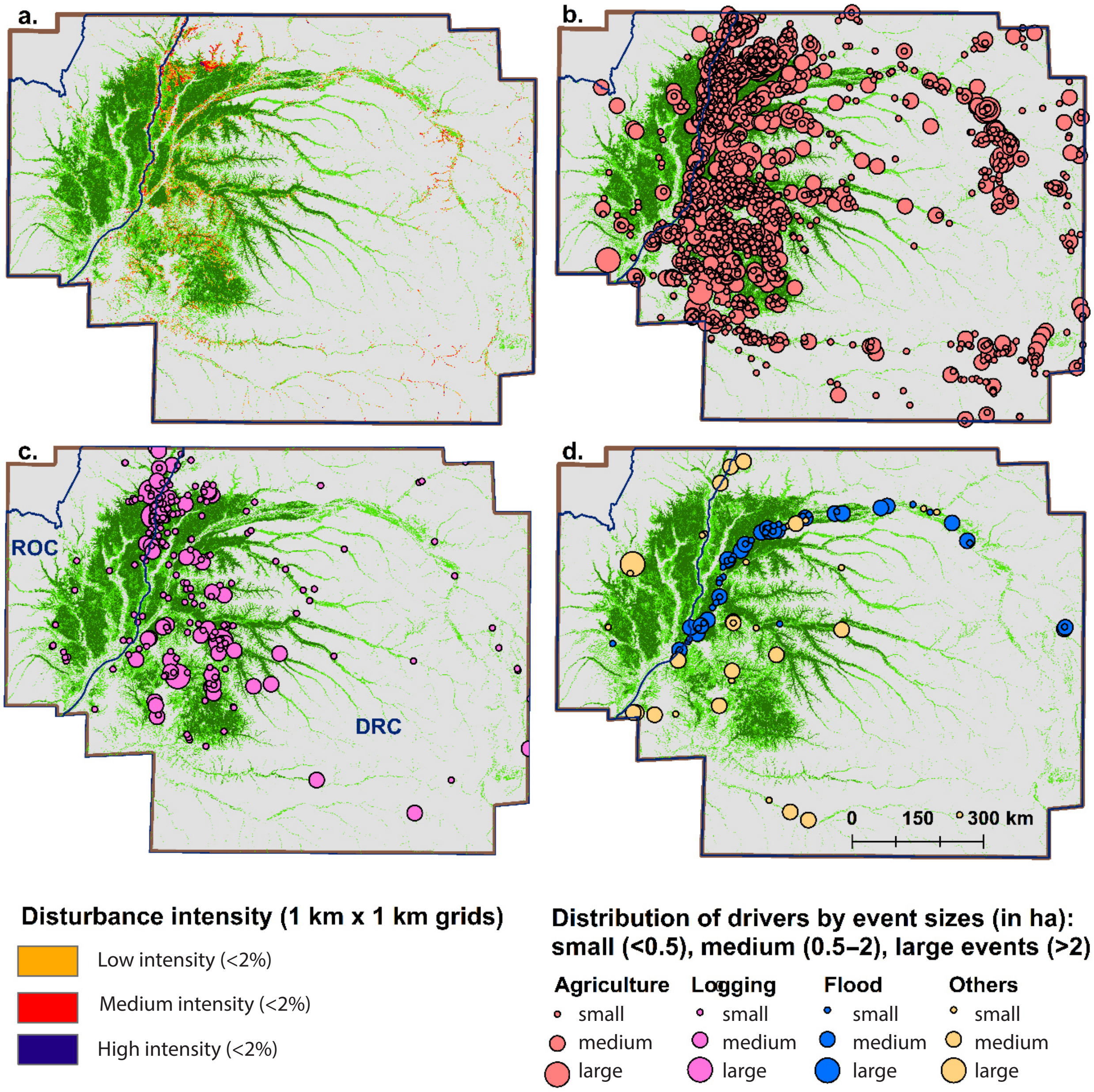

Figure 9. Disturbance intensity and distribution of drivers by event sizes

Note: a) Distribution of intensity of the disturbances in Cuvette Centrale in a 1 km x 1 km grid cell. Distribution of direct drivers of the PFDs: b) smallholder agriculture, c) logging, d) flood, and others (roads, settlements, and unidentified). Drivers are shown by the size of events: small (< 0.5 ha), medium (0.5 to 2 ha), and large (> 2 ha) events.

Table 2. Distribution of drivers of peat forest disturbances in the Cuvette Centrale by countries, DRC, and ROC, 2019–2021

Drivers	ROC				DRC			
	Number of events	Events area (ha)	Area (%) relative to events in ROC	Area (%) relative to events in Cuvette Centrale	Number of events	Events area (ha)	Area (%) relative to events in DRC	Area (%) relative to events in Cuvette Centrale
Agriculture	142	80.7	77.0	6.7	1791	979.6	89.1	81.4
Logging	49	18.5	17.6	1.5	177	68.8	6.3	5.7
Flood	5	0.7	0.7	0.1	69	36.5	3.3	3.0
Roads	3	1.4	1.4	0.1	1	0.6	0.1	0.1
Settlements	0	0.0	0.0	0.0	12	4.3	0.4	0.4
Unidentified	3	3.5	3.3	0.3	16	9.4	0.9	0.8
Total		104.7	100.0	8.7		1099.2	100.0	91.3

Conclusions

Our study provides a pioneering analysis of PFDs and their direct drivers in the Cuvette Centrale; our findings revealed 30,294 ha of PFDs from 2019 to 2021. While this is less than a 1% loss of peat forest area over the period, the impact of disturbances may become worse over time if left unaddressed. Significantly, the DRC incurred about 91% of total disturbances, underscoring the need for more effective policy at both national and international levels to curb loss of peat forests in the country.

Disturbances were overwhelmingly seasonal, largely occurring in the first six months of each year from 2019 to 2021. Smallholder agriculture was responsible for 88% of PFDs, with peaks in the first half of each year. Still, three years may not be long enough to identify interannual patterns over the long term. Consequently, more research with extended datasets is needed to assess whether these trends hold up over time.

More than three-quarters of disturbances (about 76%) took place within 5 km of river or road networks, underscoring their role in making peat forests more accessible. Nearly 90% took place within 1 km of peat edges and 99% were within 3 km. This indicates that PFDs left core peat regions relatively unscathed. About 77% of PFDs took place outside managed forest concessions, with a large proportion (40%) extending into protected areas. If these issues are not addressed, PFDs could intensify in the years ahead, leading to a substantial expansion of their cumulative impact over time.

Smallholder agriculture was a leading driver of PFDs in both the ROC (~77%) and the DRC (~89%). In the ROC, logging events were also an important cause of disturbances (18%). Agricultural disturbances tend to cluster, while logging activities are more spread out, often occurring alongside agriculture. Logging may also be the first step towards tropical forest degradation, which might lead to widespread forest clearing. Further research using longer time series is essential to validate these patterns in the Cuvette Centrale peat forests.

Our findings could provide a baseline for automating visual interpretation with machine learning, enabling the generation of a time series record of PFD drivers in Cuvette Centrale. Moreover, using these technologies, the findings could help scale up analysis across the entire region. Future research should integrate ground data with RS observations to identify specific crops and validate RS-based findings. In addition, identifying underlying factors that contribute to PFDs will lay a solid foundation for informed policy.

Recommendations

- Take actions at the national level to meet peatland protection commitments outlined in the Brazzaville Declaration and the Paris Agreement.
- Target both agriculture and logging to mitigate loss of peat forests in the ROC, while focusing on smallholder agriculture in the DRC.
- Expand international collaboration with the ROC and DRC to meet the peatland protection committments.

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References

Crezee B, Dargie GC, Ewango CEN, Mitchard ETA, Emba BO, Kanyama TJ, Bola P, Ndjango J-BN, Girkin NT, Bocko YE, et al. 2022. Mapping peat thickness and carbon stocks of the central Congo Basin using field data. *Nature Geoscience* 2022:1–6. https://doi.org/10.1038/s41561-022-00966-7

Dargie G C, Lawson I T, Rayden T J, Miles L, Mitchard E T A, Page S E, Bocko Y E, Ifo S A and Lewis S L 2019 Congo Basin peatlands: threats and conservation priorities Mitig. Adapt. Strateg. Glob. Change 24 669–86

Dargie GC, Lewis SL, Lawson IT, Mitchard ETA, Page SE, Bocko YE, Ifo SA. 2017. Age, extent and carbon storage of the central Congo Basin peatland complex. *Nature* 542(7639):86–90. https://doi.org/10.1038/NATURE21048

Geist HJ and Lambin EF. 2002. Proximate causes and underlying driving forces of tropical deforestation. *BioScience* 52(2):143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:pcaudf]2.0.co;2

Gou Y, Balling J, De Sy V, Herold M, De Keersmaecker W, Slagter B, Mullissa A, Shang X, Reiche J. 2022 Intra-annual relationship between precipitation and forest disturbance in the African rainforest Environ. Res. Lett. 17 044044

Gumbricht T, Román-Cuesta RM, Verchot L, Herold M, Wittmann F, Householder E, Herold N, Murdiyarso D. 2017a. An expert system model for mapping tropical wetlands and peatlands reveals South America as the largest contributor. *Global Change Biology* 23(9):3581–3599. https://doi.org/10.1111/GCB.13689

Gumbricht T, Román-Cuesta RM, Verchot LV, Herold Md, Wittmann F, Householder E, Herold N, Murdiyarso D. 2017b. Tropical and Subtropical Wetlands Distribution version 2 (V3 ed.). Center for International Forestry Research (CIFOR). https://doi.org/10.17528/CIFOR/DATA.00058

Nesha K, Herold M, Reiche J, Masolele R, Hergoualc'h K, Swails E, Murdiyarso D, Ewango CEN. 2024. An assessment of recent peat forest disturbances and their drivers in the Cuvette Centrale, Africa. *Environmental Research Letters* 19(10):104031. https://iopscience.iop.org/article/10.1088/1748-9326/ad6679

Reiche J, Mullissa A, Slagter B, Gou Y, Tsendbazar NE, Odongo-Braun C, Vollrath A, Weisse MJ, Stolle F, Pickens A, et al. 2021. Forest disturbance alerts for the Congo Basin using Sentinel-1. *Environmental Research Letters* 16(2):024005. https://doi.org/10.1088/1748-9326/ABD0A8

Turubanova S, Potapov PV, Tyukavina A, Hansen MC. 2018. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. *Environmental Research Letters* 13(7):074028. https://doi.org/10.1088/1748-9d326/aacd1c

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