OCCASIONAL PAPER

# Agriculture and deforestation in the Democratic Republic of the Congo

## A synthesis of the current state of knowledge

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CIFOR

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# 1 Introduction

After Brazil, the Democratic Republic of the Congo (DRC) is home to the largest contiguous expanse of tropical forest in the world. Most researchers agree that deforestation in the DRC has been relatively low in the past particularly when compared to the rates in other tropical countries. However, researchers and international agencies have expressed increasing concern that this rate is likely to accelerate if new policies are not adopted. Many of those concerned about future deforestation argue that the primary driver is shifting cultivation and that if nothing is done to change the practice, it will cause even more forest loss in the near future. This report reviews the evidence in support of these claims. In the first section, we summarize and compare the results of the most recent remote sensing-based studies on the rate of change in forest cover and try to explain why and how they differ. We then survey both the peer-reviewed and gray literature on the relationship between agriculture and deforestation in the DRC, with particular attention to the role of shifting cultivation. Finally, we integrate the insights from both the remote sensing studies and the broader literature to arrive at a general picture of the current state of the forest in the DRC and the risks for its future.

# 2 Estimating deforestation rates

## A review of the remote sensing evidence

Very few satellite remote sensing-based estimates of deforestation in the DRC were undertaken before the year 2000. This has changed dramatically in the last few years; between 2008 and 2014 at least 10 studies have been completed that attempt to estimate the overall rate of deforestation in the DRC. Unfortunately, these studies use different methods, different types of imagery and different definitions of deforestation — making comparison difficult. Thus, there is no definitive estimate on either the extent of forest cover in the DRC or the rate of deforestation. The methods used by the relevant studies can be divided into those that take a sampling approach and those which use wall-to-wall imagery.

### 2.1 Sampling approach

In studies that use a sampling approach, only a small fraction of the area of interest is actually analyzed with satellite data (from less than 1% to 13% in the reviewed studies), and the results are statistically extrapolated regionally. Most approaches use a fixed grid sampling framework, taking samples at latitude/longitude intersection points — typically at half degree intersections. A number use stratified random sampling, based on some other measure of deforestation (such as coarse resolution imagery), to optimally sample forest loss, which is not an evenly distributed spatial process. At the sample points, data is typically extracted from 10–20 km square boxes (this would be 1/80–1/325 the area of a full Landsat scene), and the data within that box is then carefully classified to determine forest cover.

In the grid sampling approach, sample sites are located at regular intersections of the latitude/longitude grid. This is the approach taken by the Food and Agriculture Organization of the United Nations (FAO) Remote Sensing Survey (RSS) 2010 (Lindquist et al. 2012), and the several related studies by Duveiller et al. (2008), Ernst et al. (2010a, 2010b, 2013) and Mayaux et al. (2013). The Congo Basin Forest Partnership State of the Forest (SOF) reports for 2008 and 2010 use this method; SOF 2008 (Atyi et al. 2009) uses the findings of Duveiller et al. (2008) for its forest change numbers, and SOF 2010 (de Wasseige et al. 2012), the results from Ernst et al. (2010a). The FAO-RSS analysis of the African tropics was conducted by the Joint Research Centre (JRC) team, and so largely follows the methods described in Mayaux et al. (2013) and Raši et al. (2011).

A key difference between studies is how they define and report 'deforestation'. For Mayaux et al. (2013), deforestation refers to "the conversion of tree cover and half of the tree cover mosaic into one of the other land-cover classes," where they define 'tree cover' as 70% or higher canopy coverage, and 'tree cover mosaic' as areas with canopy coverage of 30%–70%. Ernst et al. (2013) use the same full tree cover class (>70%), but define mosaic land-cover classes slightly differently, with high (40%–70% tree cover) and low (10%–40% cover) classes. Their deforestation metric is the full sum of all conversions from tree cover (>70%), mosaic high (40%–70% cover), and mosaic low (10%–40% cover) — notably different from Mayaux et al. (2013). Duveiller et al. (2008) use 10 classes: dense forest, degraded forest, long fallow and secondary forest, forest–agriculture mosaic, agriculture and short fallow, bare soil and urban area, non-forest vegetation, forest–savannah mosaic, water bodies and no data. Deforestation is defined as the transition from either dense or degraded forest to any other class. Unlike the other studies, class definitions do not depend on specific cover percentages, but rather are left up to the interpreter.

Table 1 (Panel A) summarizes the results from the principal studies that use a sampling approach.

Three of these report gross deforestation numbers for the 1990–2000 epoch, but Ernst et al. (2013) and Hansen et al. (2010) report numbers for 2000–2005, and only Mayaux et al. (2013) report numbers for 2000–2010. Ernst et al. (2013) and Duveiller et al. (2008) additionally report a suite of numbers relating to degradation, recovery and net effects, that Mayaux et al. (2013) do not. Furthermore, Mayaux et al. (2013) only report numbers for 'Central Africa', which includes all Congo Basin countries. Thus, the numbers are not strictly comparable simply on that basis (let alone 'deforestation' nomenclature).

For the 1990–2000 epoch, Duveiller et al. (2008) report the highest net deforestation rates (0.20%/year), with Mayaux et al. (2013) reporting 0.16%/year, and Ernst et al. (2013) 0.11%/year. Given that Mayaux et al. (2013) include non-DRC Central Africa, and due to the differing definitions of deforestation, it is difficult to determine if these numbers are meaningfully different. The DRC has been reported to have the highest rate of deforestation in the Congo Basin (Zhuravleva et al. 2013) so including the other Congo Basin countries would tend to bring down the rate. It is surprising, however, that it would do so by such a large amount, considering that the DRC's forests comprise around two-thirds of the Congo Basin forest area.

In the post-2000 period, Ernst et al. (2013) report a substantial increase in the deforestation rate in 2000–2005, doubling to 0.22%/year, whereas Mayaux et al. (2013) report a dramatic decrease in the rate to 0.10%, but for 2000–2010. Although those epochs are not identical, the large discrepancy in reported rates makes it very difficult to get a clear picture of not only the rate of deforestation but, more fundamentally, whether it has been increasing or decreasing.

Hansen et al. (2008) use a stratified sampling approach in their study focused on the humid tropics, and their follow up study in 2010 extended the analysis to global forest cover. They use Moderate-Resolution Imaging Spectroradiometer (MODIS) to provide the stratification for a selection of sample blocks measuring 18.5 km per side. Both studies only examine the 2000–2005 period, and only use seven sample blocks from the DRC (five within the humid forest zone). They report a deforestation rate of 0.6% per year — substantially higher than the other remote sensing-based estimates. It is likely that their low overall sampling density (0.22%) may be contributing to this high rate; extrapolating the statistics from five 18.5 km$^2$ sample plots in the DRC's humid forests may simply be insufficient for such a large area, even with well-calibrated MODIS as reference. A subsequent study undertaken by the same lead author using a wall-to-wall approach finds substantially lower estimates, as discussed below (Hansen et al. 2013).

## 2.2 Wall-to-wall approaches

A change in US policy in 2008, giving free access to all archived Landsat imagery, enabled several groups of researchers to develop methodologies to estimate deforestation using wall-to-wall imagery. Two products — Forêts d'Afrique Centrale Evaluées par Télédétection (FACET) (OSFAC 2010; Potapov et al. 2012) and Global Forest Change (GFC) (Hansen et al. 2013) — follow similar methodologies, with GFC essentially expanding FACET from a 5-year analysis to an annual one, and from a focus on Central Africa to global forest cover. In the GFC, Hansen et al. (2013) analyzed over 650,000 Landsat images using Google Cloud infrastructure. Both use MODIS data to normalize the large quantities of Landsat imagery (8881 images for FACET and over 650,000 for GFC globally). Another group of researchers has taken a slightly different approach in the Global Forest Cover Change (GFCC) project (Sexton et al. 2013), using Landsat imagery to rescale a global MODIS product in order to get results at 30 m resolution.[1]

Both FACET and GFC use decision tree classifiers to determine land-cover classes. For FACET, the classifiers are used to directly determine forest and non-forest — and within forest, whether the forest is primary (>60% tree cover), secondary (>60% tree cover, regrowing forests), or woodland (30%–60% tree cover). Training data for these classes appears to be largely manually collected. For GFC, the classifiers are used to determine the percentages of tree cover, forest loss and forest gain, at each yearly epoch. Training data for loss and gain were collected manually, and for percentage tree cover were derived from MODIS Vegetation Continuous Fields (VCF) and a similar Landsat product (Hansen et al. 2011).

1 http://landcover.org/research/portal/gfcc

**Table 1. Deforestation rates from selected studies**

Panel A. Sampling approaches

| | | | | Reported deforestation rates (%) | | | |
|---|---|---|---|---|---|---|---|
| **Study** | **Extent** | **Sampling sites** | **Classes** | **1990–2000** | **2000–2005** | **2005–2010** | **2000–2010** |
| Duveiller et al. (2008) | DRC | 267 | Gross deforestation | 0.25 (0.06) | | | |
| | | | Gross reforestation | 0.05 (0.01) | | | |
| | | | Net deforestation | 0.2 | | | |
| | | | Gross degradation | 0.19 (0.04) | | | |
| | | | Gross recovery | 0.07 (0.03) | | | |
| | | | Net degradation | 0.12 | | | |
| Ernst et al. (2013) | DRC | 334 (1990–2000), 242 (2000–2005) | Gross deforestation | 0.15 (0.02) | 0.32 (0.05) | | |
| | | | Gross reforestation | 0.04 (0.01) | 0.10 (0.03) | | |
| | | | Net deforestation | 0.11 | 0.22 | | |
| | | | Gross degradation | 0.07 (0.01) | 0.16 (0.03) | | |
| | | | Gross regeneration | 0.02 (0.00) | 0.04 (0.02) | | |
| | | | Net degradation | 0.06 | 0.12 | | |
| Mayaux et al. (2013) | Central Africa | 173 | Gross deforestation | 0.19 | | | 0.11 |
| | | | Net deforestation | 0.16 | | | 0.10 |
| Hansen et al. (2010) | DRC | 7 | Gross forest cover loss | | 0.60 | | |

Panel B. Wall-to-wall approaches

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Hansen et al. (2013) GFC | DRC | | Total loss | | | | 0.22 |
| | | | Total gain | | | | 0.07 |
| | | | Loss >50% cover | | | | 0.27 |
| | | | Loss >75% cover | | | | 0.28 |
| Potapov et al. (2012) FACET | DRC | | Gross loss | | 0.22 | 0.25 | 0.23 |
| | | | Primary forest cover loss | | 0.07 | 0.13 | 0.10 |
| | | | Secondary forest loss | | 1.28 | 1.11 | 1.16 |
| | | | Primary and secondary loss combined | | 0.22 | 0.27 | 0.26 |

DRC = Democratic Republic of the Congo
FACET = Forêts d'Afrique Centrale Evaluées par Télédétection
GFC = Global Forest Change

Note: All numbers are given as annual rates with confidence intervals in parentheses, quoted directly from the given papers, or computed from tables.

The GFCC project takes a rather different approach. Instead of analyzing huge quantities of Landsat data, it relies instead on the fidelity of the MODIS VCF product, and change estimates derived from it. Its key innovation is in rescaling the 250 m VCF product to Landsat resolution (30 m) at the epochs of interest (2000 and 2005), using various ancillary data (notably, a MODIS-based crop mask), and innovative methods. The GFCC project has not yet released its final change data, nor published details on what its categories refer to and how they are computed, and thus is not reported here. Results for FACET and GFC are summarized in Table 1 (Panel B).

FACET uses the following categories for forest and change: (i) primary forest = mature forest with >60% canopy cover; (ii) secondary forest = regrowing forest with >60% canopy cover; and (iii) woodlands are areas with tree cover of >30% but <60%. Deforestation is defined as conversion from a forested state (>30% tree cover) to a non-forested state (<30% tree cover), and is differentiated between woodland, secondary and primary forests, based on the classification at the start of the relevant epoch. GFC provides tree cover loss results based on tree cover categories, using 2000 as the base year (0%–25%, 26%–50%, 51%–75%, 76%–100%), as well as changes in area for each category of tree cover.

The total loss figures for Hansen et al. (2013) and Potapov et al. (2012) appear to be quite close, but they are measuring slightly different things — Hansen's loss is for all classes of tree cover, while Potapov's is only for 'forest' (defined as a minimum of 30% tree cover). The rest of the figures cannot be directly compared either, but since Potapov's primary and secondary forest classes include all areas with tree cover >60%, it is somewhere between Hansen's >50% and >75% classes. Thus, we can see that the rates are quite similar. Also, we can see from Potapov's figures that the bulk of forest loss is taking place in secondary forests. While primary forest loss accelerated between the two periods, it was still only about one-tenth the amount of secondary forest loss.

## 2.3 Comparing the two approaches

It is quite difficult to compare the two approaches directly since very few of the estimates overlap in time coverage. The Mayaux et al. (2013) estimate for 2000–2010 is less than half that of both estimates using the wall-to-wall approach, but the estimate of Mayaux et al. is for the wider Central Africa region, while the others are for the DRC alone. Hansen et al. (2010) obtain an estimate of 0.60% from a sampling approach for 2000–2005, which is almost three times higher than the Potapov et al. (2012) estimate of 0.22% for the same period. The estimate of 0.60%, however, was an outlier among all of the estimates regardless of approach and was based on a very limited number of observations.

Each approach offers different strengths and weaknesses, making selection of any one as closest to 'truth' somewhat difficult. For an accurate representation of what is going on only in the DRC, and only for the 2000–2010 period, the FACET estimates may be most useful, because they distinguish primary from secondary forest. An assessment of this product by one of the authors, using high-resolution imagery at a number of sites, found FACET's primary/secondary forest distinction to be generally quite robust.

Mayaux et al. (2013) offer the additional classes of degradation, regeneration and reforestation — distinctions that a human analyst can make, but are far more problematic (at this point) for automated tools to discern. If those provide useful distinctions, and the 1990–2000–2005 time period is sufficient, then Mayaux et al. (2013) (or the related studies) may be preferred.

For global comparisons, the GFC product is difficult to beat, as it covers all global forest cover, thus allowing comparisons between regions. Another consideration is future repeatability. As production of the GFC product must necessarily be largely automated, future updates may likely be provided. Updating the FAO-RSS or FACET products, by contrast, would likely take substantially more labor and thus not be practical on any frequent basis. If GFC updates are regularly provided, it will be possible to track trends more carefully over time, and even on a yearly basis, with good confidence that the relative changes are meaningful.

## 2.4 Province-level estimates

In order to better understand the differences in datasets, as well as to get a better understanding of where current deforestation is taking place, it is

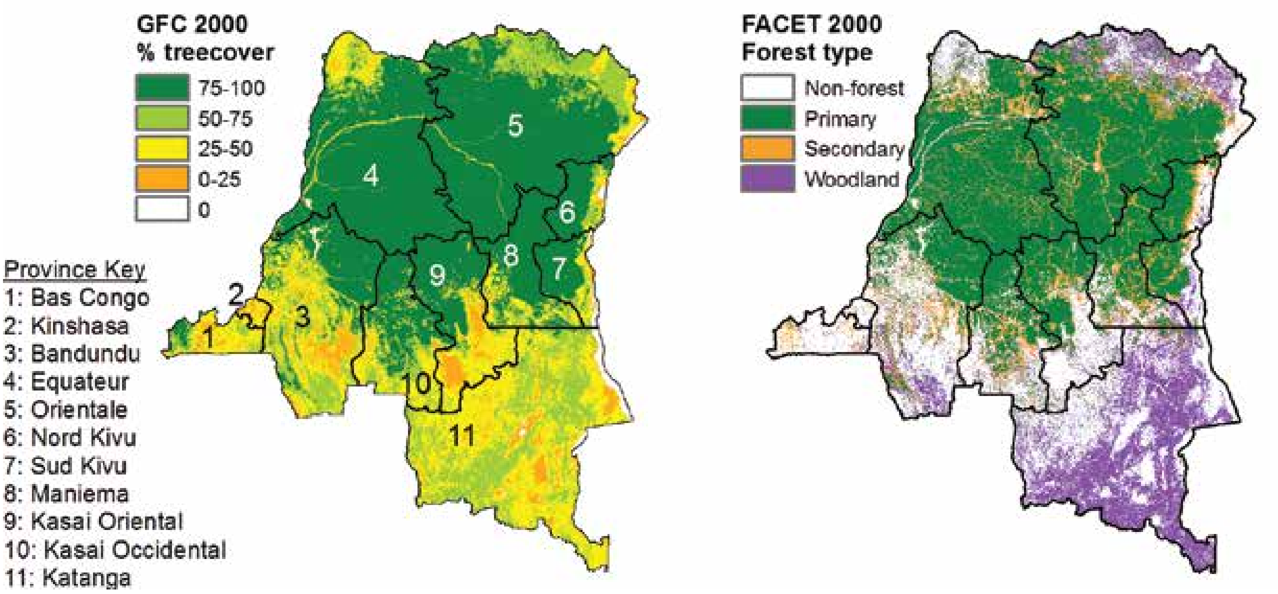


**Figure 1. Forest Cover in 2000**

useful to compare estimates at the province level. We used both the GFC and FACET datasets to calculate province level summaries of loss rates. To do so, it was first necessary to determine year 2000 forest cover, so that rates of change could be calculated. For FACET, this is straightforward, because the FACET dataset provides a simple year 2000 layer showing primary, secondary and woodland forest. GFC, however, provides a year 2000 forest cover percentage (for each ~30 m pixel), leaving it for the user to decide what percentage of forest cover may be deemed 'forest'. Figure 1 shows year 2000 forest cover according to FACET classes and according to the GFC percentage of forest cover.

Overall, FACET 'primary forest' shows good similarity to the GFC category >75%, suggesting a cut-off between 50% and 75% for GFC would most closely replicate FACET. However, GFC shows much more forest in thinly forested areas (<50%) where in many cases FACET shows non-forest. In the country-level results available in the online supplementary materials for Hansen et al. (2013), the authors present change for four categories of forest cover: <25%, 25%–50%, 50%–75% and 75%–100%, but their final column is based on a threshold of 50% tree cover, seeming to imply that it is their first choice as a definition of forest, or the best choice given the limitations of the analysis. Thus in Table 2, we compare the forest amount per province for 2000 between FACET (combining all three classes of forest — woodland, secondary and primary) and GFC using both the >50% and >75% categories as alternative definitions of 'forest'.

It is clear that the very definition of 'forest' here has strong implications for the estimates of forest cover, both within and across the datasets. Comparing the FACET dataset with GFC 50, the FACET dataset shows much less 'forest' than the GFC (except for Katanga); compared with the GFC 75 category, however, FACET shows significantly more forest across all provinces, with some differences strikingly high. Note that the differences between FACET and GFC are among the highest in the two provinces with the least tree cover (which also happen to be the provinces with the smallest area) – Kinshasa and Bas-Congo. The differences are also quite striking for Katanga province, where the GFC estimates decline dramatically when the threshold changes from 50% to 75%, indicating that this province has a large area in the 50%–75% tree cover range.

Next, we calculated forest loss for both datasets at the province level using the same definitions for forest described in Table 2. For GFC, loss pixels were only counted if the year 2000 forest cover estimate was over 50% (for FACET, this was not a concern because the year 2000 forest cover was categorical). Table 3 shows the province-level deforestation rates for both datasets for the periods 2000–2005 and 2006–2010, and the rate of change between the two periods.

**Table 2. Province-level comparison of forest area in 2000 between FACET and GFC**

| Province | Total area ($km^2$) | GFC 50 | | GFC 75 | | FACET | | % Change from FACET | |
|---|---|---|---|---|---|---|---|---|---|
| | | Area ($km^2$) | %[a] | Area ($km^2$) | %[a] | Area ($km^2$) | %[a] | GFC 50[b] | GFC 75[b] |
| Kinshasa | 10,684 | 1,248 | 12% | 95 | 1% | 934 | 9% | 34% | –90% |
| Bas-Congo | 53,953 | 19,138 | 35% | 6,223 | 12% | 12,172 | 23% | 57% | –49% |
| Nord-Kivu | 59,946 | 51,423 | 86% | 44,173 | 74% | 45,781 | 76% | 12% | –4% |
| Sud-Kivu | 63,968 | 48,736 | 76% | 40,773 | 64% | 44,045 | 69% | 11% | –7% |
| Maniema | 128,000 | 104,820 | 82% | 92,352 | 72% | 99,755 | 78% | 5% | –7% |
| Kasai-Occidental | 153,166 | 107,202 | 70% | 77,060 | 50% | 95,546 | 62% | 12% | –19% |
| Kasai-Oriental | 169,203 | 100,746 | 60% | 85,475 | 51% | 97,680 | 58% | 3% | –12% |
| Bandundu | 296,639 | 178,415 | 60% | 110,956 | 37% | 158,709 | 54% | 12% | –30% |
| Équateur | 404,198 | 367,258 | 91% | 345,276 | 85% | 353,186 | 87% | 4% | –2% |
| Katanga | 487,922 | 210,299 | 43% | 6,530 | 1% | 256,814 | 53% | –18% | –97% |
| Oriental | 500,132 | 454,959 | 91% | 389,442 | 78% | 427,343 | 85% | 6% | –9% |
| Total | 2,327,811 | 1,644,243 | 71% | 1,198,354 | 51% | 1,591,964 | 68% | 3% | –25% |

FACET = Forêts d'Afrique Centrale Evaluées par Télédétection
GFC = Global Forest Change
a Percentage of province area covered by that forest category
b Relative increase in forest area between FACET and GFC 50 and GFC 75

**Table 3. Deforestation rates by province for 2000–2005 and 2006–2010**

| Province | FACET loss rates, %/year | | GFC 50 loss rates, %/year | | FACET rate change | GFC rate change |
|---|---|---|---|---|---|---|
| | 2000–2005 | 2006–2010 | 2000–2005 | 2006–2010 | | |
| Kinshasa | 2.44 | 2.85 | 1.56 | 1.53 | 17% | –2% |
| Bas-Congo | 0.81 | 0.97 | 0.43 | 0.50 | 19% | 16% |
| Sud-Kivu | 0.42 | 0.44 | 0.37 | 0.38 | 3% | 3% |
| Nord-Kivu | 0.30 | 0.38 | 0.26 | 0.33 | 25% | 26% |
| Kasai-Occidental | 0.55 | 0.77 | 0.27 | 0.44 | 40% | 64% |
| Kasai-Oriental | 0.31 | 0.51 | 0.33 | 0.35 | 64% | 7% |
| Maniema | 0.36 | 0.38 | 0.47 | 0.65 | 6% | 40% |
| Bandundu | 0.31 | 0.38 | 0.25 | 0.30 | 22% | 19% |
| Katanga | 0.25 | 0.32 | 0.23 | 0.27 | 27% | 18% |
| Équateur | 0.18 | 0.31 | 0.17 | 0.29 | 71% | 71% |
| Oriental | 0.21 | 0.25 | 0.20 | 0.23 | 18% | 19% |
| All | 0.27 | 0.36 | 0.24 | 0.32 | 32% | 31% |

Note: This table illustrates provincial forest loss rates, when using (a) FACET as the year 2000 forest cover basis, and (b) GFC year 2000 forest cover >50%. The final column shows the percentage increase of the loss rate between the 2000–2005 and 2006–2010 epochs. Provinces are ordered by Forest Area 2000.

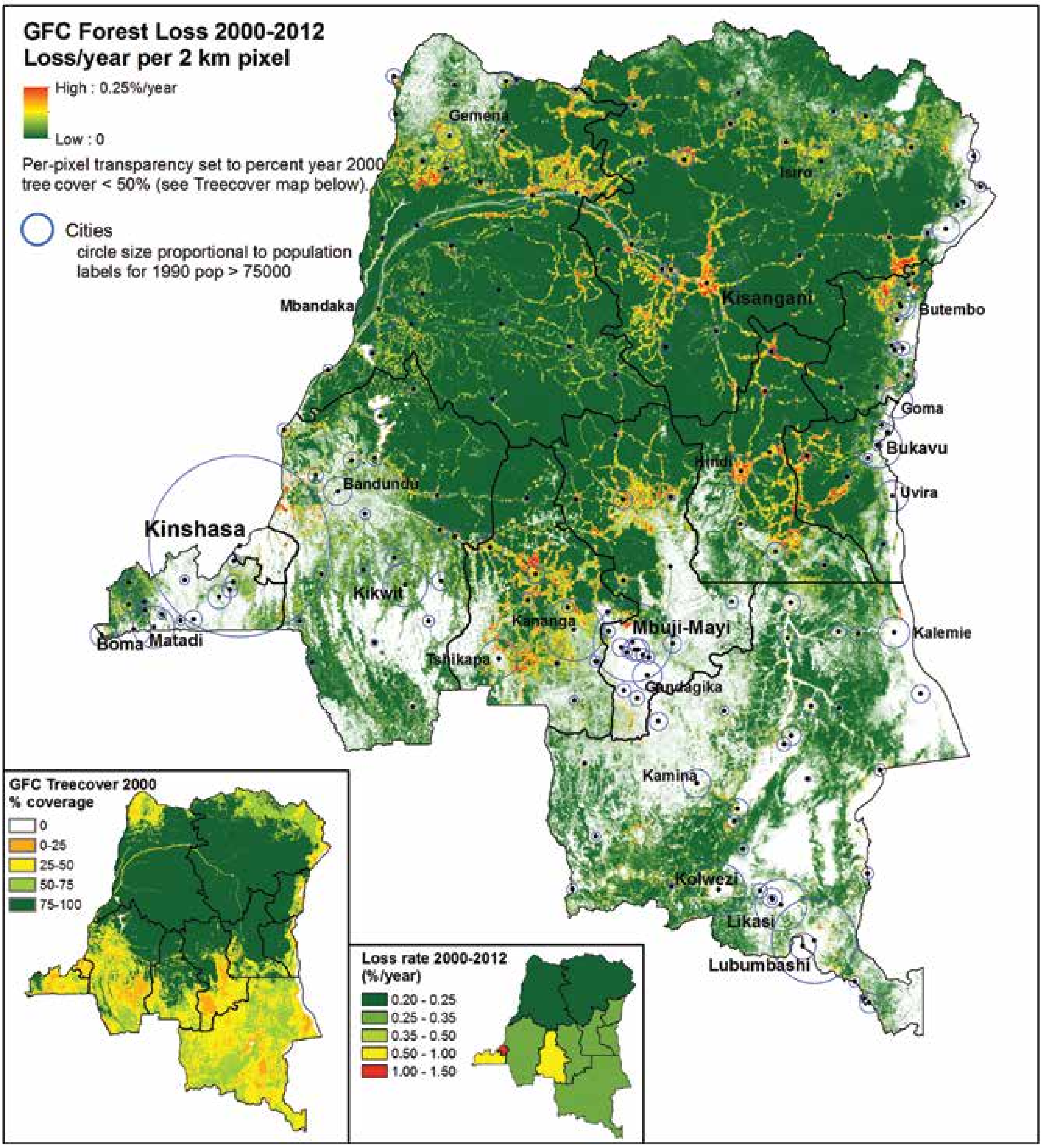


**Figure 2. GFC forest loss 2000–2012**

Note: Loss is aggregated to 2-km pixels to enhance display, and converted to a yearly loss rate for comparability between periods. To counteract the effect of low loss rates for pixels with low year 2000 forest cover appearing dark green, and thus implying (with this color scale) dense forest, per-pixel transparency was set to the inverse proportion of year 2000 forest cover. For year 2000 forest cover, we aggregated pixels from GFC with forest cover >50% (displayed in lower left inset). Thus, a 2-km pixel with year 2000 forest cover of 25% will display significantly faded, at 75% transparent. Provincial loss rates are mapped in the inset map.

On average, the FACET dataset shows higher rates of deforestation (13% higher for both epochs). There are large differences in forest loss estimates between the two datasets for some provinces. The most dramatic differences again are for the two least forested provinces of Kinshasa and Bas-Congo. There are also substantial differences in certain provinces for rates of change between the two epochs. One dramatic difference is the case of Kinshasa where FACET shows an increase in deforestation by 17% and GFC shows a decline in the deforestation rate by 2%. In the case of Kasai-Oriental, the rate of increase is more than five times higher in FACET compared to GFC. In all cases, except for Kinshasa province in the GFC case, the rate of loss appears to be increasing between epochs, by about 30% (but with a wide range from 3% to 70%). The rates of change for the two provinces with the largest forest areas — Équateur and Orientale — are relatively low, but are accelerating.

Figure 2 is a map of forest loss showing the provinces and major cities and towns, using the GFC dataset summarized to 2-km pixels to accentuate change. The size of the circles around the towns and cities indicates population size. There seem to be several hotspots around Kisangani in the center, south of Gemena in the north, around Butembo in the eastern DRC, and around Kananga and Kindi. Thus it appears that the majority of deforestation is taking place around medium-sized cities. And most of these hotspots, with the exception of Kisangani, are at the forest fringe and not at its center. Kisangani is unique in that its location on the Congo River makes it an important port and transport hub.

## 2.5 Global context

Since the study by Hansen et al. (2013) is global in scope, we can obtain a sense of the larger global deforestation context by comparing loss figures for the DRC with those from other tropical forested countries. Table 4 presents both the annual tree cover loss and the annual loss for tree cover higher than 50% for the five most forested tropical countries.

**Table 4. Annual tree cover loss rates for the five most forested tropical countries (2000–2012)**

| Country[a] | Annual total loss rate | Annual loss rate for tree cover >50% |
|---|---|---|
| Brazil | 0.36% | 0.53% |
| Indonesia | 0.70% | 0.83% |
| Democratic Republic of the Congo | 0.22% | 0.27% |
| Malaysia | 1.20% | 1.34% |
| Paraguay | 0.80% | 1.43% |

a Presented in order of size of forested area
Source: Based on Hansen et al. (2013)

The first column shows the rate of all annual tree loss, while the second shows the rate of tree loss in areas where tree cover in 2000 was identified as being at least 50%, and so corresponds more closely to tree loss in forested areas (note that >50% tree cover has no relationship to forest status as primary or secondary). The DRC had both the lowest annual tree loss rate, compared to the five most forested tropical countries, and the lowest rate of tree loss in forested areas. The comparison for the forested areas is the most dramatic, with the DRC showing about half the rate of deforestation of Brazil, a third of the rate in Indonesia, and about a fifth of the rates in Malaysia and Paraguay.

Thus the deforestation rate in the DRC is relatively low compared to other tropical countries, using Hansen et al.'s (2013) global estimates. Although the precise estimates of forest loss for the DRC differ depending on the definition of forest used, the methods used to calculate it and the approach taken for the analysis, the overall picture is of some forest loss, particularly of secondary forests and in peri-urban areas and the densely populated eastern DRC. In the next section, we review the literature, assessing the role of agriculture and shifting cultivation as the main driver of current and future deforestation.

# 3 Literature review

## Agriculture and deforestation in the DRC

We used both Web of Knowledge and Google Scholar to search for articles from January–March 2014. We carried out a targeted search using the following combination of key words "deforestation and agriculture and Democratic Republic of Congo," and then more general searches using only "deforestation and Democratic Republic of Congo" and "agriculture and democratic Republic of Congo." All articles that were related to agriculture in the DRC that had any discussion of deforestation were reviewed, as were articles that were related to deforestation in the DRC and had any discussion of agriculture. The papers reviewed from Google Scholar were those that appeared up to the end of the tenth page of the search. The searches were conducted in both English and French by a researcher fluent in both languages.

We found a total of 44 papers that met our initial criteria: 16 from Web of Science and 28 from Google Scholar, which after a review of titles appeared to discuss the issues of agriculture and deforestation in the DRC. Next, we classified the papers based on whether they made a specific claim about the relationship between agriculture and deforestation (or forest degradation) in the DRC; 15 met these criteria. Each of these papers was then classified based on (i) its specific claim about agriculture and deforestation, (ii) its evidence in support of that claim, (iii) the area or region for which it made the claim, (iv) whether it made a claim about the role of shifting cultivation in deforestation, and (v) its evidence in support of that claim. The results are summarized in Table 5.

**Table 5. Relevant papers, claims and evidence**

| Authors | Claim about agriculture | Evidence | Study area | Shifting cultivation | Evidence |
|---|---|---|---|---|---|
| Akkermans et al. (2013) | Forest clearing for agriculture is the principal driver of deforestation. | None | Kisangani | | |
| Aquino and Guay (2013) | | | DRC | Slash and burn agriculture and biomass production are two of the most important drivers of deforestation. | None |
| Atyi and Bayol (2008) | The principal cause of deforestation is subsistence agriculture. | None | DRC | | |
| Bamba et al. (2008) | Unsustainable agricultural practices lead to degraded soils and changed land cover. | Creation of transition matrix of land classes for an area and analysis of land cover classes 1960–2005 | Bas-Congo province | The traditional system of natural regeneration no longer functions in Bas-Congo. | Much of the secondary forest in 1960 was fallow and fields in 2005. |

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**Table 5.** Continued

| Authors | Claim about agriculture | Evidence | Study area | Shifting cultivation | Evidence |
|---|---|---|---|---|---|
| Bamba et al. (2010) | Population density is associated with higher deforestation in part through agriculture. | Quantifying association between forest fragmentation and population density around Kisangani using a Landsat image from 2001 | Orientale Province near Kisangani | | |
| Desclée et al. (2006) | Agriculture led to forest degradation around Virunga National Park. | Remote sensing imagery | Area around Virunga National Park (Kivu-Nord province) | Shifting cultivation is not practiced in the area; forest degradation is the result of permanent cultivation. | |
| Dupain et al. (2008) | | | Area around Maringa-Lopori-Wamba Landscape | Slash and burn agriculture and charcoal production are causing deforestation. | None |
| Ernst et al. (2013) | Population density and small-scale agriculture are closely linked to deforestation. | None: "the lack of reliable spatial data prevents any rigorous conclusion for two variables: fuelwood and agriculture." (p.1177) | DRC | Future population increase will make shifting cultivation unsustainable. | None |
| Iloweka (2004) | Poverty and a shortage of arable land result in shortened fallow periods, resulting in soil degradation. | None | Bas-Congo province | Deforestation is caused by shortening fallows. | None |
| Kissinger (2011) | Agriculture is the primary driver of deforestation and forest degradation. | Cited REDD+ Readiness Plan | DRC | | |
| Mayaux et al. (2013) | The combination of agriculture and population growth is a prominent cause of deforestation. | Statistical relationship between proportion of an area in cropland and deforestation | Central Africa landscape | | |

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**Table 5.** Continued

| Authors | Claim about agriculture | Evidence | Study area | Shifting cultivation | Evidence |
|---|---|---|---|---|---|
| Megevand et al. (2013) | Infrastructure will likely improve, which will increase agricultural productivity, which will increase deforestation if no ameliorative policies are adopted. | None | Congo Basin | Shifting cultivation in the forest zone may become unsustainable because of population growth. | The most densely populated areas of the DRC already have a population density too high for sufficient fallows. |
| Potapov et al. (2012) | | | DRC | Local slash and burn agriculture is the predominant deforestation driver. | The average patch size in imagery corresponds to slash and burn sized plots. |
| Zhang et al. (2002) | | | Central Africa | Shifting cultivation remains the main determinant of deforestation in Central Africa. | None (assumed relationships for simulation model) |
| Zhuravleva et al. (2013) | The main driver of forest loss and fragmentation was agricultural expansion. | Visual inspection of remote sensing images | DRC | | |

DRC = Democratic Republic of the Congo

Overall, the consensus from the literature is that small-scale agriculture, mostly in the form of shifting cultivation, is the major contributor to deforestation in the DRC. Shifting cultivation is an agricultural management strategy that involves the clearing of land and then cultivating and fallowing it in a cyclical fashion (Thrupp et al. 1997). It is the dominant form of agriculture in the DRC. Shifting cultivation is believed to be problematic for those concerned about deforestation for two distinct reasons. First, where land with forests is available, farmers may clear these forests to create agricultural fields. Since forests are cleared, this is viewed by many as 'deforestation'. However, if these patches are small and fallow periods are relatively long, then fields will tend to regenerate to forest once more, although the structure and diversity of such forest will be dependent on fallow length, size of patch and surrounding vegetation, among other things. There will likely be differences in species composition and some losses in biodiversity, but these are less than in almost any other anthropogenic system. (Finegan and Nasi 2004; Makana and Thomas 2006). This type of farming tends to happen in areas with relatively low population density and where there is abundant and available land. The second claim often made against shifting cultivation is that because of increasing population pressures and a shortage of available land, fallow periods become too short to allow soils to regenerate sufficient fertility leading to land degradation (Mertz 2002; Ickowitz 2006). This issue tends to be a problem in peri-urban areas and areas with a relatively high population density.

Few of the studies provided sufficient evidence to support the claim that agriculture is the main driver of deforestation in the DRC; however, the little evidence that is presented, along with the overwhelming consensus and lack of other main drivers suggest this is a credible conclusion. Charcoal production and mining are also mentioned as contributors to forest loss, but agriculture seems to be the prime driver. It should be noted that the impacts of agriculture and charcoal production appear to be relatively confined to peri-urban areas, areas along the Congo River up to Kinshasa, Bas-Congo province and the eastern DRC. Although several papers mention shifting cultivation specifically as the main culprit in causing deforestation, only one provides some evidence in support of the claim and it is specific to a heavily populated area in Bas-Congo province (Bamba et al. 2010) where the concern was that high population density was resulting in shorter fallow periods.

Many of the papers reviewed were case studies that were relevant to particular areas. This includes Iloweka (2004) and Bamba et al. (2008) for Bas-Congo, Akkermans et al. (2013) and Bamba et al. (2010) for the area surrounding Kisangani, Dupain et al. (2008) for the area around Maringa-Lopori-Wamba Landscape, and Desclée et al. (2006) for the area around Virunga National Park. Four out of five of these case studies are in densely populated areas, which are not representative of the country. Only five studies were focused on the DRC as a whole and three were for the Congo Basin/Central Africa region.

In the context of the DRC, it seems misleading to claim that shifting cultivation is the cause of deforestation since it is not shifting cultivation per se, but rather agriculture practiced in areas with a relative high density of population surrounding large towns and cities. More intensive agriculture might moderately decrease deforestation in areas with high population densities, but it is by no means certain that it would. Both Phelps et al. (2013) and Hourticq et al. (2013), using two different models, show that an increase in productivity as a result of intensification can lead to an increase in deforestation in the context of the DRC (or the Congo Basin for Hourticq et al. 2013). This is because productivity growth increases the profitability of agriculture and thus increases the value of agricultural land, making land clearing a more attractive activity. In addition, many attempts at promoting intensification in sub-Saharan Africa have failed because many of the recommendations tend to be labor intensive (Byrelee and Heisey 1996; Moser and Barrett 2003; Mafongoya 2006; Long et al. 2009). In many communities, labor is a binding constraint, particularly for women, who play an essential role in agriculture in the Congo Basin.

Several of the studies reviewed claim that deforestation is likely to accelerate in the future; some are concerned about the impacts of future shifting cultivation as population grows (Zhang et al. 2002; Ernst et al. 2013), while others focus on the potential impacts of global investment in industrial plantations, timber and mineral extraction (Hourticq et al. 2013). Several papers cite a dramatic prediction that population growth will result in an almost total loss of the DRC's primary forest by 2050 at the hands of shifting cultivators. This prediction, cited by Hourticq et al. (2013), Ernst et al. (2013) and Tollens (2010), is based on a simulation model developed by Zhang et al. (2002). This model assumes that shifting cultivators farm a plot of cleared land for 2 years and then leave it fallow for 15 years. Based on these (and other) assumptions and the projected population growth for the DRC, they arrive at the conclusion that only 6% of the DRC's forests would remain by 2050. However, the assumptions of a 2-year cropping cycle and a 15-year fallow period that are used to arrive at this conclusion are quite unrealistic. Based on the existing historical record, actual (as opposed to 'ideal') fallow periods for communities in the DRC, during periods of much lower population density, have rarely been that high. Table 6 presents reported cultivation and fallow periods for the Congo Basin from various historical sources.

A fallow period of 15 years does not seem to have been the norm in the DRC even in 1907. Predictions based on simulation models, which must assume homogenous and atypical behavior are useful perhaps to emphasize a point, but should by no means be taken as realistic projections.

Even if intensification policies are appropriately designed to reduce (or at least not increase) labor pressure, a prerequisite for sustainable intensification is an improvement in the country's

**Table 6. Historic cropping and fallow periods for the Congo Basin**

| Location | Crops | Crop cycle in years | Fallow period in years | Original source |
|---|---|---|---|---|
| Central Congo | Rice, maize, cassava | 2–3 | 10–15 | Livens (1949) |
| Yombe, DRC | Beans, cassava, plantains | 5 | 6–7 | Van Overbergh (1907) |
| Seke-Banza, DRC | Beans, maize | 1 | 3 | Van Overbergh (1907) |
| Lake Leopold II region, DRC | Cassava, bananas, plantains | 2–3 | 6–7 | Maes (1913–1914) |
| Lake Bangweulu, DRC and Zambia | Cassava | 1–2 | 2–3 | Trapnell (1946) |
| Lukamba, DRC | Cassava, maize | "short" | 5–9 | Drachoussoff (1947) |
| Kuba, Central Africa | Maize, beans, cassava, peanuts | 2½ | 7 | Jan Vansina (1953, 1956) |

DRC = Democratic Republic of the Congo
Source: Table modified from Ickowitz (2006)

transportation infrastructure. The DRC has one of the worst transportation infrastructures in the world; among African countries, only Chad's road transport quality index is lower (Buys et al. 2006). In order for farmers to be able to get access to inputs such as fertilizer and improved seed and tuber varieties to enable intensified agriculture, they need better access to markets. However, better roads and greater market integration will also make deforestation at the hands of large-scale investors more of a real threat. Improvements in transportation and market access will make the DRC more attractive to global investors in oil palm, rubber, timber and commercial agriculture. This is not necessarily bad, but it certainly increases the risk of deforestation. It is these global forces that have been proven in the rest of the world to dramatically accelerate deforestation (Rudel 2013). It is perhaps in large part because of the poor state of the DRC's infrastructure (as well as conflict) that it has not had much global investment in industrial plantations and timber concessions, and therefore has a relatively low rate of forest loss.

Improving the DRC's infrastructure is, however, imperative for reducing poverty and bringing other essential services, such as health care and education, to its widely dispersed population. The DRC has the second lowest Human Development Index ranking in the world (only Niger is ranked lower) with over 87% of its population living on less than $1.25 a day.[2] It is unlikely that this vast population of poor people will see dramatic improvements in their well-being without improvements in the country's infrastructure. This improved infrastructure will likely result in increased deforestation. This should be expected and managed. Instead of trying to prevent all future deforestation, the focus should be on its management to try to minimize biodiversity and carbon losses and maximize livelihood benefits for local communities.

2 To view the Human Development Index visit http://hdr.undp.org

# 4 Conclusions

While there is some variation in the recent deforestation estimates for the DRC, depending on definitions, methods and approaches, it is clear that deforestation is taking place, albeit at a slower rate than in the rest of the tropics. This deforestation is concentrated in Kinshasa and Bas-Congo provinces, in the eastern DRC and around medium-sized cities along the Congo River. Rates of primary forest loss appear to be very low, but are accelerating.

Agriculture appears to be the main driver of deforestation and its impact will likely increase as the population of the DRC grows. While some researchers argue that this presents a real threat to the future of the DRC's forests, there is a lack of strong evidence to show the magnitude of this threat. If the impact continues to be felt in the same peri-urban areas where it is currently taking place, the two largely deforested provinces, and the eastern DRC, overall deforestation may not be very extensive. While the local impacts may be real, there is a strong possibility that both the biodiversity and carbon impacts of such deforestation will be limited.

Policies and projects that promote agricultural intensification in the relatively densely populated areas of the DRC need to address labor constraints carefully if they are to be successful. In addition, promoters should be aware that such policies may not actually reduce deforestation since they can make agricultural land more valuable, and rely on improvements in infrastructure, which will also make investment attractive to other actors. In our view, if such policies can successfully reduce poverty, they are a worthy investment in a country with a population as poor as that of the DRC, even if they do not reduce deforestation in these areas. Such policies, however, are not likely to be successful or suitable for the vast areas of the DRC that have a low population density and where many of its primary forests are located.

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Deforestation in the Democratic Republic of the Congo (DRC) is significantly lower than in other heavily forested tropical countries. However, there is increasing concern that this rate is likely to accelerate. Many of those concerned about future deforestation argue that shifting cultivation is the primary driver and that if nothing is done to change the practice, it will cause even more forest loss. This study reviews the evidence in support of these claims. In the first section, we compare the results of the most recent remote sensing-based studies on the rate of change in forest cover and try to explain why and how they differ. We then review the literature on the relationship between agriculture and deforestation in the DRC, with particular attention to the role of shifting cultivation. Finally, we integrate the insights from both the remote sensing studies and the broader literature to arrive at a general picture of the current state of the forest in the DRC and the risks for its future. Overall, we find that while there is substantial variation in the recent deforestation estimates for the DRC depending on definitions, methods and approaches, some deforestation is taking place — albeit at a slower rate than in the rest of the tropics. This deforestation is concentrated in Kinshasa and Bas-Congo provinces, in the eastern DRC and around medium-sized cities along the Congo River. Agriculture appears to be the main driver of deforestation and its impact will likely increase as the country's population grows. While some researchers argue that this presents a real threat to the future of the DRC's forests, there is a lack of strong evidence to show the magnitude of this threat. If the impact continues to be felt mainly in the areas where it is currently taking place, the overall ensuing deforestation may not be very extensive. While the local impacts may be real, given the vast size of the DRC and the location of its large tracts of forests, there is a strong possibility that the overall biodiversity and carbon impacts of such deforestation will be limited.

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