Note on the JRC Nature paper on harvest, complementing the reply of Ceccherini et al. 2021.

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The JRC paper on harvested forest area (Ceccherini et al. 2020) received many comments. Beyond those published in Nature (Palahí et al. 2021, Wernick et al. 2021), other comments appeared in web pages or blogs. Apart from several fair and constructive criticisms, which were welcome, we found that some comments were either not based on evidence or affected by misunderstandings.

This note complements with additional textual and visual information the rebuttal that we provided in Nature (Ceccherini et al. 2021) to the comments by Palahí et al. 2021 and Wernick et al. 2021. Specifically, here we show and discuss additional figures on: (i) the correct use of the original dataset, based on documentation available in the Global Forest Change (GFC) / Global Forest Watch (GFW) websites; (ii) the comparison of our data with recent country statistics on natural disturbances; and (iii) the comparison of our data with country statistics on harvest.

The **key messages** emerging from our rebuttal and this note are:

1) Based on a new extensive validation exercise carried out for Sweden and Finland, **our original results were partly rectified**: the increase in harvested forest area now appears about one third less steep, i.e. +35% (± 16%) in 2016-2018 vs. 2011-2015 relative to a +54% originally reported for the same periods in Sweden and Finland (see Ceccherini et al. 2021). All evidence indicates that w**e made a correct use of the information available from the GFC dataset** (see section 1) and that **the change in results is entirely due to the undocumented change in algorithm occurred in 2015** in the GFC dataset. The first documentation of this inconsistency is in Palahí et al. 2021, and the first attempt to quantify its impact is in our reply. It is unfortunate that the inconsistency of the GFC dataset for the year 2015 was undocumented, but it is positive that it is now recognized. This helped us to make a preliminary assessment of the impact on our results, and hopefully will help others to avoid similar problems when using the same dataset. Given the huge importance and the widespread use of the GFC dataset, any transparent reprocessing that will make it temporally more consistency will be welcomed.
2) Although **our approach to estimate the impact of natural disturbance** on harvested forest areas is crude, available evidence indicates that it **correctly captures the trend** (see section 2).
3) **Our method essentially captures clear-cuts, due to the limited spatial resolution of the Landsat pixel** (30x30m), and not smaller-scale forestry activities such as thinning and selective loggings, which represent a large share of total harvest in many EU countries. As it can be evinced from the main figure in the original paper (but unfortunately not adequately highlighted in the original abstract), the biomass corresponding to the harvested clear-cut areas observed in our study is less than 50% of the total harvested biomass reported in country statistics at EU level. The above indicates that **the "perceived" contradiction between our results and country statistics is largely due to misunderstandings and incorrect comparisons** (see section 3). Our results should be interpreted as a warning on a recent increase in clear-cuts observed by satellites, not necessarily as a criticism to country statistics.

Beyond the results, our study was the first one showing a high-resolution map and temporal evolution of clear-cut harvest in Europe. In this sense, we believe that our study represents an important step forward in combining Earth observation and big data analytics for *complementing* country statistics in the monitoring of forest resources.

On the correct use of the GFC dataset

The comment by Palahí et al. 2021 starts noting an inconsistency in the Global Forest Change (GFC) time series, and in particular a "*major enhancement"* of the detection algorithm in 2015. It notes that "*the Global Forest Watch (GFW) website warns about these inconsistencies and advises against using the GFC product for temporal trend analyses*" and then concludes that "*The abrupt* changes [in Ceccherini et al. 2020] *are largely an artefact stemming from incorrect use of the GFC data time-series".* The alleged "*incorrect use of GFC data*" appears a key criticism by Palahí et al.

Our rebuttal already explained that the change of algorithm in 2015 was totally undocumented: the websites by GFC[1] and GFW[2] include warnings on combining two time series, 2001-2010 and 2011-2019 (and this was clearly acknowledged in Ceccherini et al. 2020), but do not include any warning against trend analyses after 2012.

Here we provide further textual and visual evidence that, in recent years, the GFC time series has been extensively used in the scientific literature to assess the impact of forestry activities as in our paper.

Specifically, below we report four recent examples where the GFC dataset was tested. In these cases, abrupt increases in forest cover loss were shown between 2015 and 2016 (as in our study) without being discussed as the result of potential inconsistencies in the time series.

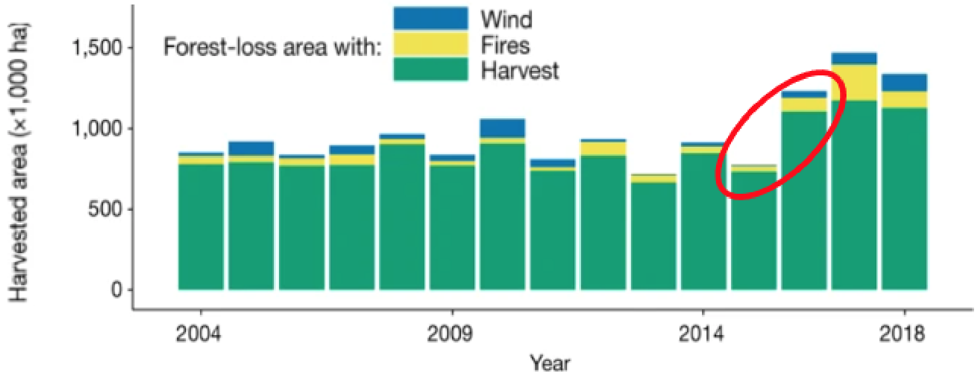
- Rossi et al. (2019), assessing forest harvesting in Norway, concluded that "*Overall, [GFC] proved to be a useful dataset for the purpose of assessing harvesting activity under the given conditions.*" An marked increase in harvest is shown in 2016 (their figure 12), but it is not discussed as a possible inconsistency in the dataset.
- Galiatsatos (2020), testing the GFC dataset in Guyana, concluded that "*when suitably calibrated for percentage tree cover, the Global Forest Change datasets give a good first approximation of forest loss (and, probably, gains)*." The authors also note that "*in countries with large areas of forest cover and low levels of deforestation, these data should not be relied upon to provide a precise annual loss/gain or rate of change estimate for audit purposes without using independent high-quality reference data*" – however, this latter recommendation seems to refer to the fact that deforestation requires estimating both forest cover losses (more certain) and gains (more uncertain). Our paper focused on forest cover loss only. Furthermore, Galiatsatos et al. (2020) show an abrupt increase in harvest in 2016 (their figure 7), but it is not discussed as the result of a possible inconsistency in the dataset.
- Shimizu et al. (2020), in Japan, concluded that "*the Global Forest Change map can be used to detect larger forest disturbances, but it should be used cautiously because of the substantial commission error for small-scale disturbances*". In particular, the authors indicate that GFC shows good accuracies for forest disturbances larger than 3 ha. In this regard, it should be noted that disturbances > 3 ha represent about two thirds of the harvested forest area detected by Ceccherini et al. (2020) (Extended Data Fig. 5). Shimizu et al. (2020) show an abrupt increase in harvest in 2016 (their figure 5), but it is not discussed as a possible inconsistency in the dataset.

Furthermore, in the Figure below we compare the results from our original paper (Fig. 1a) with a paper in a high-level journal (Harris et al. 2021, Fig. 1b), which fully relies on map-based area estimates from the GFC dataset. Also in this case, a clear discontinuity in gross emissions emerges between 2015 and 2016 (red oval), and it is not specifically discussed. It should be noted that Harris et al. 2021 does not specifically focus on trends, and that Fig. 1b is in their Extended data. Therefore, the noted inconsistency in the GFC dataset does not directly affects the general findings of their paper.

[1] http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.7.html
[2] https://data.globalforestwatch.org/

Nevertheless, it is also worth noting that Harris et al. 2021 (which includes the developers of the GFC are co-authors) mentions that "*one algorithm covers 2011–2019*" and that "*Gross emissions can be estimated annually*"; these are key methodological assumptions we followed in our paper when producing and discussing the results, but also those aspects flagged by Palahi et al. as "incorrect" use of the dataset.

(a) Estimates of harvested forest area in the EU, from the original JRC study



(b) Global forest-related emissions associated to stand-replacement disturbances (Harris et al. 2021).

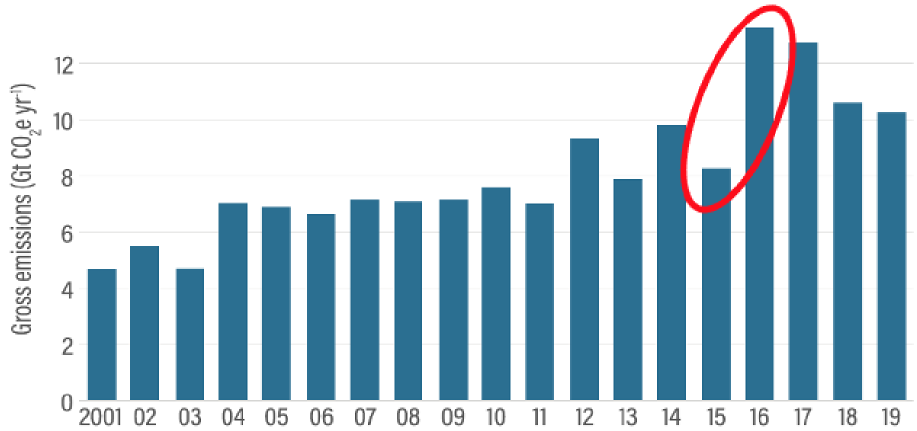


Figure 1. (**a**) estimates of harvested forest area in the EU, from the original JRC study (Ceccherini et al. 2020), compared to (**b**) gross forest-related emissions associated to stand-replacement disturbances (natural and anthropogenic) observable in Landsat imagery, 2001–2019 (Harris et al. 2021, Extended data fig. 9). Both studies use the GFC dataset and show similar discontinuities in the time series between 2015 and 2016 (red ovals). See the respective references for details.

The current problems in the time series inconsistency of the GFC datasets after 2015 further highlights the opportunity to establish a GFC-like annual forest assessment product based on the use of Copernicus Sentinel-1 and Sentinel-2 imagery. This will have the combined advantage of offering higher spatial resolution (10 m pixel spacing) and temporal resolution than Landsat time series. Combining the continuous use of dense time series of Sentinel-1 with multiple viewing configurations and dual polarized backscattering and coherence, which is not affected by atmospheric conditions, and intermittent Sentinel-2 spectral time series should lead to an improvement in precision of loss estimates of at least a factor 9. A re-engineered European GFC products can be fully generated on current Copernicus DIAS infrastructure, and eventually expanded to a global version.

1. Comparing our data with recent country statistics on natural disturbances

Our estimates of harvested biomass due to natural disturbances (due to windthrows and insects) are lower than the absolute values of salvage logging statistics that recently became available for 14 European countries (see Camia et al. 2021), but show the same recent increasing trend (Fig. 2). Since our method detects anomalies in forest cover losses (in other words major events but not the "background" level of natural disturbances), somehow lower values from those reported by countries are expected, because the latter include all natural disturbances. However, for the purpose of our study, detecting the trend was more important. Furthermore, it is important to note that the magnitude of the recent rise in natural disturbance events varies significantly between countries, with central Europe (Germany, Austria, Czechia, Poland, etc.) showing a large pulse of bark beetle infestations. On the other hand, comparing time series of harvest statistics from salvage logging with remote sensing retrievals should be made with caution because of possible lags (e.g., salvage logging may take a few years after the disturbance takes place) and uncertainty on the fraction of timber that is collected after the disturbance.

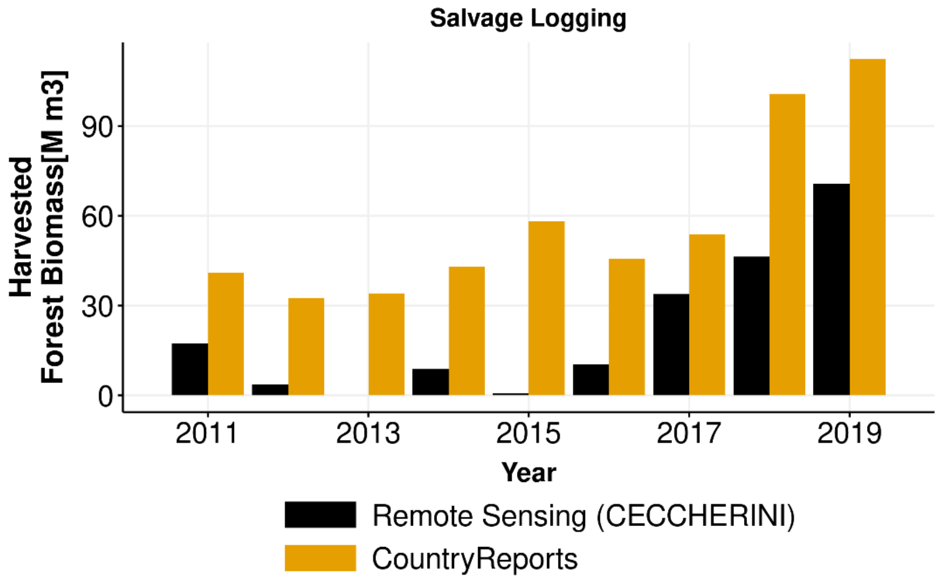


Figure 2. Time series of forest biomass loss associated with "salvage logging" from our original study CECCHERINI (in black) and country reports (in yellow) for 14 European countries (based on Camia et al. 2021). Salvage loggings dataset has been collected in 14 EU Member States by searching national datasets and/or consulting with national experts. Through the Standing Forestry Committee under the EC, the following Member States validated and acknowledged data on salvage loggings and/or provided additional information: Austria, Bulgaria, Croatia, Czechia, Estonia, France, Finland, Germany, Hungary, Lithuania, Poland, Slovakia, Slovenia and Sweden. It is important to note that the time series where annual data on salvage loggings are available varies among Member States.

2. Comparing our data with country statistics on harvest

Fig. 3a below is the main figure in the original paper (Ceccherini et al. 2020), showing an estimated increase in harvested biomass by 69% in 2016-2018 relative to 2011-2015.

Most of the criticisms received apparently assumed that our study estimated total harvest, even if in the paper it was reported several times that our estimates were mostly related to clear-cuts. Translated into numbers, this assumption is illustrated in Fig. 3b, i.e., the "perceived" starting point was the current level of total harvest reported in countries statistics (about 470 Mm^3/y, based on FAOSTAT). This led some criticism to suggest that our results were "impossible" because a harvest removal of 790 Mm^3/y (470 Mm^3/y + 69% increase) is probably beyond the harvesting capacity in the EU. Fig. 3b, however, compares "apples with elephants": *tonnes of clear-cut fellings overbark* (our study) vs. *m^3 of total removals underbark* (country statistics).

In other words, these criticisms overlooked the unit of harvested biomass in the y-axis (x100000 t) of Fig. 3a (red oval). By converting this amount of biomass into m^3 – as first approximation this can be done simply by multiplying by 2 (see [3])– anyone could obtain a harvest estimate in m^3 associated to our study and compare it with country statistics. This estimate is illustrated as red solid line in Fig. 3c. An "apple-with-apple" comparison with country statistics, however, requires some further step. The biomass estimated in our study, as it can be clearly evinced in the methods of Ceccherini et al. 2020, corresponds to fellings over bark (o.b.), i.e. harvest removals o.b. plus residues. Country statistics (grey line in Fig. 3b) are generally expressed as removals under bark (u.b.) and thus need to be converted into fellings o.b. (solid black line in Fig. 3c). This already indicates that, when a like-with-like comparison is done, our results are well below country statistics as shown in Fig 3c.

In addition, direct comparison is further complicated by the fact that wood removal statistics in EU underestimate wood uses by up to 20% (Camia et al. 2021). The blue lines in Fig. 3c include the 2020 updates from countries and consider a range on min/max values based on official statistics on wood use (data available till 2015 from the JRC Bioenergy report, Camia et al. 2021, and here extrapolated proportionally to the official harvest removals statistics until 2018). When these more realistic estimates of total wood harvest are applied, our estimates are in the order of 40-60% of country statistics (depending on the year, Fig. 3c). If the adjustment of the results associated to the new validation exercise (Ceccherini et al. 2021) is extrapolated at EU level, then the increase in harvest after 2015 would be reduced compared to the original estimate (orange line, Fig. 3c). With this additional approximate correction, our estimates become about 40-50% of country statistics (orange line *vs*. blue lines in Fig. 3c).

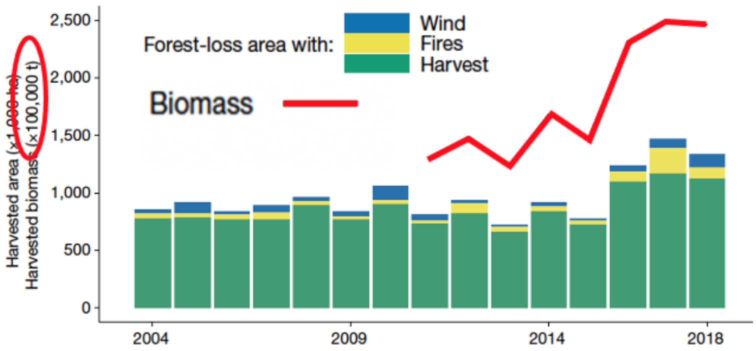
Although the above demonstrates that our results are fully "possible", why is our estimated harvest so low compared to country statistics?

The answer is that our study essentially focuses on clear-cuts. Small-scale forest activities such as thinning and selective logging, which are the predominant form of harvest in many countries, are not included in our study. While we regret that this information was missing in the abstract of the original paper (because considered too "technical" for most readers of Nature) - and this may have contributed to the misunderstanding - it is explained at least five times in the main text[4].

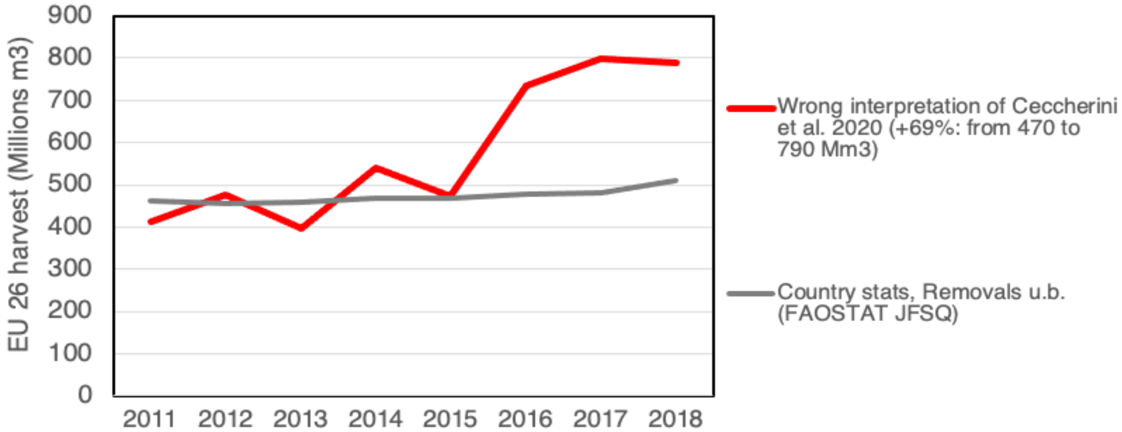
[3] Assuming an average wood density close to 0.5 tonnes/m^3, based on table 4.14 of the IPCC 2006 Guidelines for National GHG inventories.

[4] From Ceccherini et al. 2020: "*We note that the GFC dataset is sensitive to clear-cuts instead of the actual wood harvest, which can be complemented by thinning operations that may not be seen by the satellite*". "*Our approach has limitations in the detection of small-scale silvicultural practices*". "*Although the GFC does not require full clear-cuts to detect forest-cover loss, it is not able to reliably capture partial removal of trees caused by forest thinning and selective logging*". "*Most changes occurring below the canopy cannot be detected by optical instruments, potentially leading further to an underestimation of actual harvested wood". "Small-scale silvicultural practices such as thinning or selective logging—which are relevant in some EU countries—could therefore not be fully detected*".

(a) Estimates of harvested area and biomass in Ceccherini et al. 2020



(b) Incorrect comparison between the "perceived" harvest in Ceccherini et al. 2020 and country statistics



(c) Correct comparison between the observed clear-cut harvest in Ceccherini et al. 2020 and country statistics

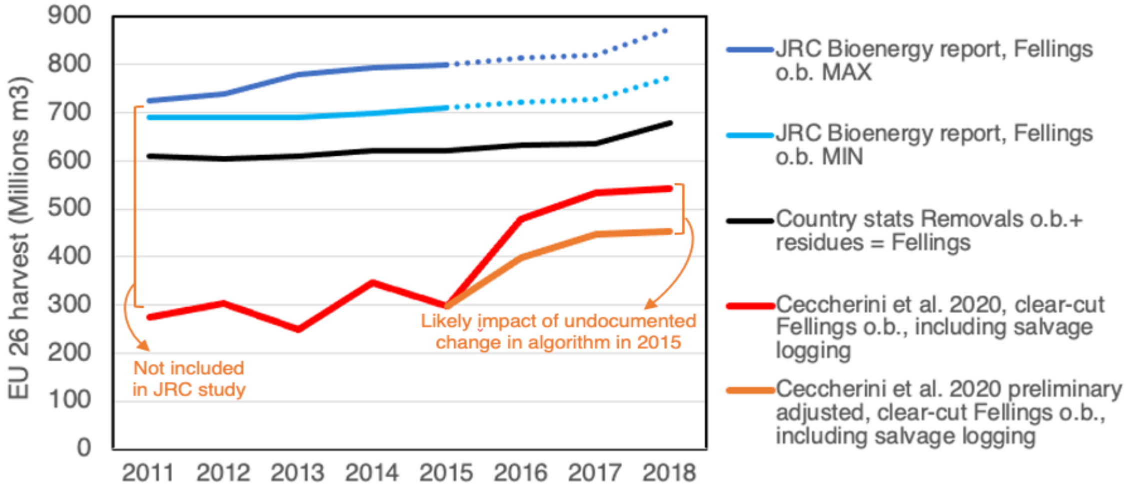


Figure 3. (a) Estimates of harvested area and biomass as originally reported by Ceccherini et al. 2020; **(b)** results from Ceccherini et al. 2020 as wrongly "perceived" by many critics, compared to country statistics on total harvest (FAOSTAT); **(c)** correct like-with-like comparison between results from Ceccherini et al. 2020 on clear-cut felling and country statistics on total fellings, including a preliminary adjustment of Ceccherini et al. 2020 due to the undocumented change in algorithm in 2015 (this correction reduces the increases in harvest in 2016-2018 vs. 2011-2015 by about one third, based on an extensive validation exercise performed for Sweden and Finland illustrated by Ceccherini et al. 2021, and here extrapolated to the entire EU). The fellings from Ceccherini et al. 2020 were obtained simply multiplying the values of biomass (Fig 3a) by 2. The JRC Bioenergy report (Camia et al. 2021) includes 2020 updates of country statistics and considers a min-max based on the statistics on wood use; the original data are till 2015, which here we extrapolated till 2018 (dotted blue lines). See text for details.

In addition, country-specific statistics or modelled estimates of the share of clear-cuts (or final fellings) on total harvest are provided in original supplementary information table[5]. By combining the information from that table with the harvest statistics from countries, it can be estimated that approximately 45-50% of total EU total harvest comes from clear-cuts. While this number should be seen as an approximation because it is affected by many uncertainties, it is worth noting that it is the same order of magnitude of our independently-estimated clear-cut harvest (Fig 3c).

According to our analysis, the increase in clear-cut harvest can be only partly explained by the increase in salvage logging (when expressed as fellings o.b., equal to about 9 Mm^3/y on average during 2011-2015 and 45 Mm^3/y during 2016-2018, see section 2).

Overall, the above indicates that the "perceived" contradiction between our results and country statistics is largely due to misunderstandings and incorrect comparisons. Our results should be interpreted as a warning on a recent increase in clear-cuts observed by satellites – with potential consequences on biodiversity and climate change –, and not necessarily as a criticism to country statistics. Instead, the methodology presented in our paper provides a means to use remote sensing products to complement country statistics, especially in the timely analysis of recent changes that in many cases are reported by the National Forest Inventory statistics only few years later. Once the context and the numbers of our study are understood correctly, we welcome any independent study further checking and improving our results.

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[5] https://static-content.springer.com/esm/art%3A10.1038%2Fs41586-020-2438-y/MediaObjects/41586_2020_2438_MOESM1_ESM.pdf

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