Title: The importance of capturing management in forest restoration targets

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Abstract:

The restoration of tree cover has been placed at the top of international policy agendas, yet often the ‘type’ of restored forests can be widely different, with consequences for biodiversity and livelihoods. We used a map of forest management types to assess the extent of managed forests in recent tree cover gains globally. We call on policy makers to differentiate forest management as a distinct element of reforestation targets.

Main text:

The restoration of forests is a critical component in reversing biodiversity decline [1] and mitigating the impacts of climate change, although some recent estimates on the mitigation potential of forest restoration have been overestimated [2]. In addition, despite costs associated with tree planting, actively restoring forests has the potential to create net benefits of up to $9 trillion USD through job creation and Nature’s Contributions to People (NCPs) associated with forests [3]. It is, therefore, not surprising that targets and pledges for the reforestation of degraded lands have been placed high in the agenda of multilateral policies, such as the EU Biodiversity Strategy or the Bonn Challenge. Depending on the definitions of forest-cover gain, some also include mosaic landscapes with tree cover of different purposes, including agroforestry and plantations. Not all gains in forest cover, however, are of equal benefit to biodiversity and NCPs, and earlier studies have indicated that newly planted trees that are part of commercially used timber and fruit plantations dominate in many regions [4,5]. The value that such managed tree plantations provide for biodiversity is often lower compared to restored natural forests [6,7], and they may also be less efficient for carbon sequestration depending on harvest cycles and the fate of the wood product [4]. In contrast, the natural regeneration of forests, assisted or spontaneous, can be of lower cost and provide enhanced benefits for carbon and biodiversity [8]. Since 2000, when plantation forests represented around 5% of global forests, plantations have expanded at a global annual rate of 1.8%, which is expected to continue until 2050 [9]. The largest expansions in the future will take place in Asia and Latin

America, with plantations in South America predicted to more than double by 2050 [9]. These developments call for better global monitoring and quantitative reporting of both natural and managed forest cover gain separately.

Here, we combine three of the longest running time series of remotely-sensed forest-cover change with a global layer of forest management for the year 2015[10] to determine which type of management is predominant for regrown trees (see supplementary information Table 1) and where it occurred. We used different global forest-cover datasets to account for differences in definition and approaches, and based on an ensemble average of cumulative forest cover gain, we find that approximately 88.8 million ha (± 42.9 SD) of natural trees have regrown and 26.2 million ha (± 12.2 SD), or ~22%, of trees have been anthropogenically planted between 2000 and 2015 (**Figure 1a-b**). Further, of those areas with regained forest cover, human managed forests make up approximately 33% (range 17-52%) in countries that have made forest restoration pledges (SI Figure 2). However, events of forest cover change are rare, and when validated independently we find the accuracy of detection (evaluated by F1 score) can be relatively low (SI Table 3), ranking from 0.15 (ESA CCI) to 0.54 (Hansen et al.). This shows that there is considerable uncertainty among estimates of forest cover gain by the different datasets.

The majority of forest-cover gain until 2015 has regenerated naturally; however, there are several regions where either re- or afforestation through planting trees is predominant (**Figure 1a**). We find that gains of managed trees occurred in areas with the highest conservation value (4-17% across datasets, i.e., locations identified in Jung et al. 2021 as areas that maximize conserving biodiversity globally), although most forest-cover gain occurred in other land not considered to be in the top 30% of the most valuable global areas for biodiversity conservation (**Figure 2a**). However, this may contribute to enhancing connectivity among landscapes. Although trees are commonly planted on previously forested or degraded land, in many instances countries have replaced land that was previously covered by natural regenerating forests with plantations. For instance, the overall increase in forest cover in the south of China has largely been driven by an expansion of monoculture tree plantations such as eucalyptus and rubber (**Fig. 1a**), often on land previously covered by natural forest cover [11]. Given that in many countries natural forest loss is ongoing and often exceeds restoration commitments [12], the replacement of natural forest with timber plantations challenges the interpretation of reported restoration success.

Countries across the world have pledged to restore millions of ha of forest (range 0.009 to 21 million ha) as part of the Bonn Challenge, from a total of 150 million ha by 2020 up to 350 million ha of forest globally by 2030. Indeed, some of these commitments seem enormous, encompassing more than 10% of the land area of some countries, and will be challenging to reach without a transformation of the food system [12] or the utilisation of forests for economic exploitation. We found that forest-cover gain within landscapes of medium intensity food production had a larger expansion of managed trees (range 9-26%) than any gains in intense or non-food producing areas (**Figure 2b**), also indicating that natural and managed forest cover gains are not taking place in the most “degraded” landscapes, e.g. those where intense agriculture is dominating production. These results highlight that an open discussion and independent monitoring of restored forests is timely, if restoration is to benefit biodiversity and climate mitigation.

We acknowledge that our estimates of forest management are already six years out of date. Yet, to our knowledge, there are no newer global spatially-explicit estimates of forest management or other remotely-sensed forest-cover gain data temporally overlapping with such layers. For instance, the most widely used remote sensing data on forest-cover change has effectively stopped providing further annual updates on forest cover gains since 2012 [13]. More recent time series of global land cover promise improved consistency [14], but they have limited temporal availability of less than a decade. We also note that our estimates of forest-cover gain per management type are at coarse scale and rather conservative, making it likely that many smaller areas with natural regrowth, managed plantations and small-scale restoration actions might have been missed. This is also exemplified by the comparably lower precision of detecting forest gain in some of the coarser grained datasets (SI Table 3), and the general uncertainty in forest cover change estimates is likely to propagate to analyses such as this one. More highly resolved and more recent maps of forest management are a much needed resource to better capture outcomes of reforestation efforts. Until then, our results provide some first coarse global quantitative approximations, independent of national statistics, that highlight the extent to which natural and managed forests are established.

If we are to make this decade one of meaningful restoration of forests, and reverse biodiversity loss while not jeopardizing food security, we urge the remote-sensing community, sustainability scientists and policy makers to focus not only on forest loss, but also keep track on where and what type of forest is being restored, and how persistent it is according to remote sensing data. Although planting managed instead of natural forests as part of initiatives such as the Trillion Trees (https://trilliontrees.org) or the Bonn Challenge achieves the specified targets, it also might result in perverse outcomes for biodiversity, climate mitigation and people's livelihoods, for example by promoting afforestation on grassland biomes or expulsion of people managing forests, and jeopardising the achievement of equitable and transformative restoration targets. An additional challenge of many afforestation projects is that, unless there is some form of commercial exploitation or positive synergy with local human livelihoods [5,15], the planted trees might not be cost efficient and fail to reach maturity, while with natural regeneration only the initial opportunity costs of planting are to be accounted for [8].

Moving forward, we make three recommendations. First, new remote sensing data at national and global level should be developed and continually updated to track forest gain and management type. Platforms such as Global Forest Watch or Restor could provide the necessary infrastructure to provide a snapshot of information on annual forest gain, further differentiated by management type. Second, gains in tree cover should – given that much of the world's tree cover gains occur in food production landscapes - also be evaluated in the broader landscape and socio-economic context to avoid perverse outcomes affecting progress on other SDGs related to poverty, inequality, and peace and justice [15]. Here, a new integrated approach to forest restoration and landscape planning should be considered that considers the nexus of biodiversity, food production and people's livelihoods as a whole system, rather than as individual sectors. Third, more work and infrastructure for the attribution and validation of detected forest-cover gain events, including evaluating long-term forest persistence, are direly needed. Financial incentives for meeting forest restoration pledges should ideally be evaluated not only in terms of total initial area planted, but also using concrete measures that provide context on the nature of reforestation, address forest management in terms of use, and consider long-term evaluation of progress. This would enhance transparency, comparability and accountability among pledging countries.

Restoring forests is one of many potential strategies that can help to mitigate the effects of climate change, halt further biodiversity loss and support sustainable development across scales. Yet, despite the biophysical potential of natural and planted forest restoration measures, long-term success and impacts will critically depend on how new forests are managed, and how tradeoffs with other land uses are resolved. Here, remote sensing data can play a critical role in this decade of restoration to better evaluate what is restored and where.

Methods

We make use of a global forest management layer (FML) developed for the year 2015 at 100m [10], created through a global remote-sensing based classification with good overall accuracy (>82%). The FML follows the FAO definition of 'Forest' as land spanning more than 0.5 hectares with trees higher than five meters and a canopy cover greater than ten percent [16].We create a global mask that remapped the six classes of the FML to either natural or managed forests broadly following FAO definitions: naturally regenerating forest includes close-to-nature active and passive regenerating trees, forest areas with nearby disturbances such as roads, and those where it is impossible to distinguish between planted and naturally regenerated trees; managed forest, considered as any trees established through deliberate seeding and/or planting either for timber or food production within productive landscapes. Detailed information on the definitions and remapping can be found in the Supplementary information Table 1.

The mask of the two different types of forest management was then intersected with the currently best available estimates of remotely-sensed forest-cover gain covering the period prior to 2015. Definitions and thematic resolutions of forest cover maps differ between different products [17] (see also supplementary information Table 1, SI Figure 1), which is why we relied on multiple rather than any single forest-cover change data. Specifically we used remotely-sensed time series data prior to 2015 from Hansen et al., the most recent MODIS land cover data (v.6) and layers from the European Space Agency Climate Change Initiative (ESA CCI) [13,18,19]. From each map we selected only those grid cells where a gain in forest cover (closed or open forest) took place since the start of monitoring and aggregated (mean) all maps from their original resolution (range 30m to 500m) to a 1km consensus grain to minimise disagreements in spatial and thematic resolution between the different data. We then extracted per dataset the amount of area (in m^2) contained within each individual 1km dataset and natural or managed forest zone (see above). Further details on data pre-processing can be found in the supplementary information. Both the forest management layer and each of the different forest-cover gain estimates were then intersected at 1km, and we extracted and then summarised annual estimates of forest-cover gain up until 2015 for both natural and managed forest types (see also SI Figure 2). We then conducted an independent validation of the forest cover gain estimates of the three datasets through the use of Geo-Wiki, a tool for visual interpretation of high resolution satellite imagery and time series (SI Figure 3). A total of 1000 validation points at 1km were generated in a randomly stratified manner and assessed whether there was any forest cover gain and of what type the forest type was. Accuracy statistics were calculated for each dataset and are reported in detail in SI Table 3.

We also collated publicly available data on country pledges from the Bonn Challenge (https://www.bonnchallenge.org/pledges), which is a global effort to restore forests on 150 million hectares of degraded and deforested land by 2020 and 350 million by 2030. In addition, we made use of recently made available data on areas of global conservation value for species, as well as data from a global assessment of the distribution and intensity of food producing landscapes (see also SI Table 2). Use of the former can help to identify where forest restoration could contribute to buffering and connecting areas with the 30% highest potential biodiversity value, while the latter layer indicates the broad level of agricultural production intensity (low, medium, high) where forest restoration took place. Using the masks for each management type at an aggregated 1km resolution, we summarised forest-cover gain over time globally and for individual countries. To assess visually the dominant type of forest management (Figure

1a), we aggregated forest-cover gain estimates across all data at 10km resolution. We stress that these estimates are necessarily coarse, at global scale, ignore tree cover persistence and lack detailed knowledge of on-the-ground restoration implementations. Nevertheless these are currently best-available global remote sensing estimates independent of national statistics. All data were pre-processed on the Google Earth Engine platform [20] while figures were created in R. Additional information on datasets considered can be found in the supplementary materials.

Data availability

All land-cover data are publicly available through Google Earth Engine (see code availability). The global forest management layer has been released as part of Lesiv et al. [10]**.** The validation data created as part of this work are made available as a separate data file on a GitHub repository (https://github.com/Martin-Jung/FML_ForestGain) with the methods described in the supplementary information.

Code availability

The Google Earth Engine script used to extract the information has been made available in supplementary materials. All other scripts are made available on a GitHub repository (https://github.com/Martin-Jung/FML_ForestGain).

Acknowledgement

The authors acknowledge funding from Norway's International Climate and Forest Initiative (NICFI). We furthermore thank Martina Dürauer, Ivelina Georgieva and Maria Shchepashchenko for their assistance through Geo-Wiki.

Author contribution statement

MJ conceived the idea, led on the analysis and drafted the manuscript, ML contributed data and edited the manuscript, EWT, DS, LS and SF conceived the idea and contributed to the drafting of the manuscript.

Competing Interest statement

The authors declare no competing interests.

Figures

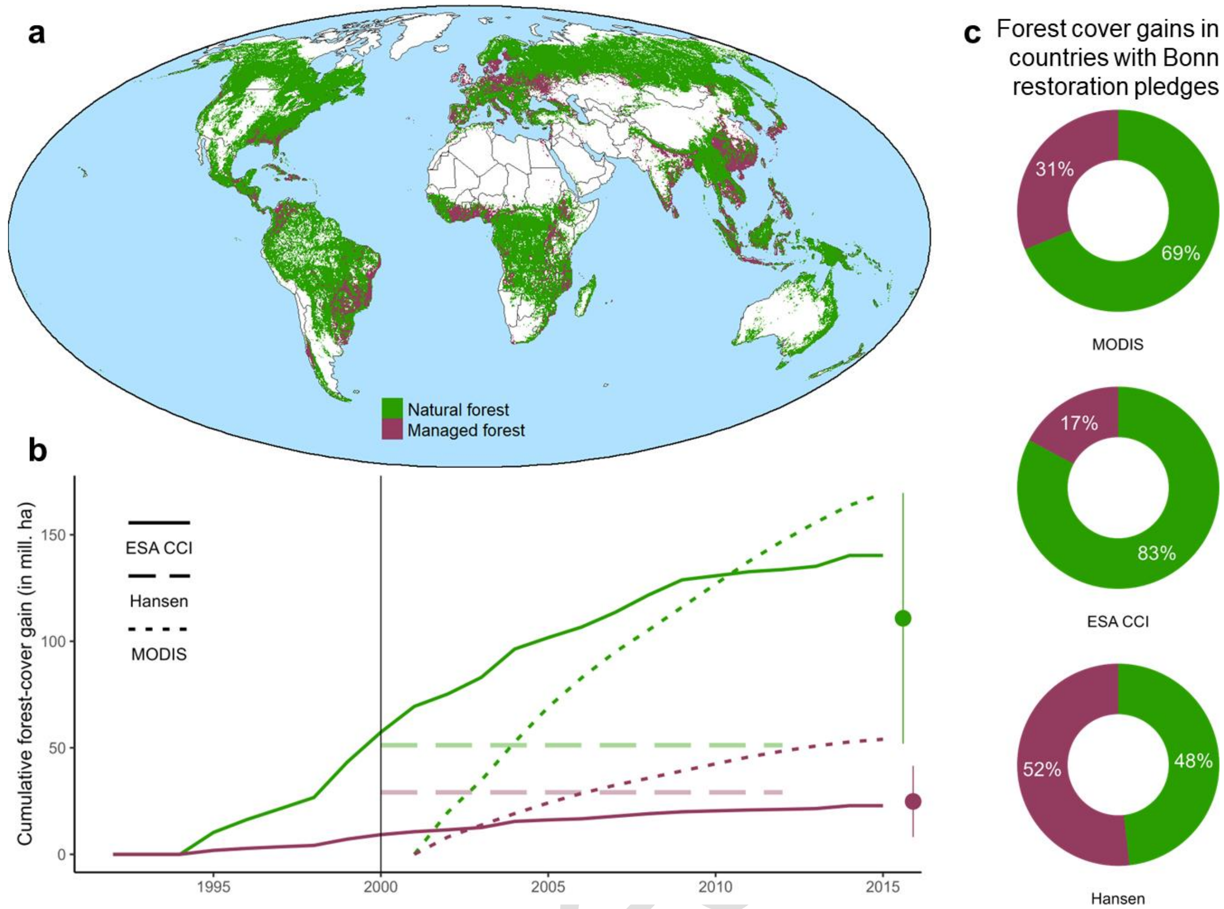

***Figure 1 Areas with forest gain globally and across three different remote sensing datasets** (**a**) Areas with any forest cover gain from 1992 (respectively 2000 for ESA CCI and MODIS, as indicated by the vertical line in panel **b**) up until 2015 shaded by forest management type (aggregated consensus for visualisation, thus forest area might appear overrepresented). (**b**) Cumulative forest cover gain (units 10^6 ha) across three forest cover data sources. Colours indicate tree cover gain in natural (green) or managed forests (violet). The overall arithmetic mean and standard deviation of forest-cover gain for each management type across the three datasets are shown on the right (df = 3). (**c**) Proportion of forest-cover gain per forest management type in countries with existing restoration pledges (see SI Figure 2 in supplementary information, also for comparison with countries without pledge), colours as in panel **a**.*

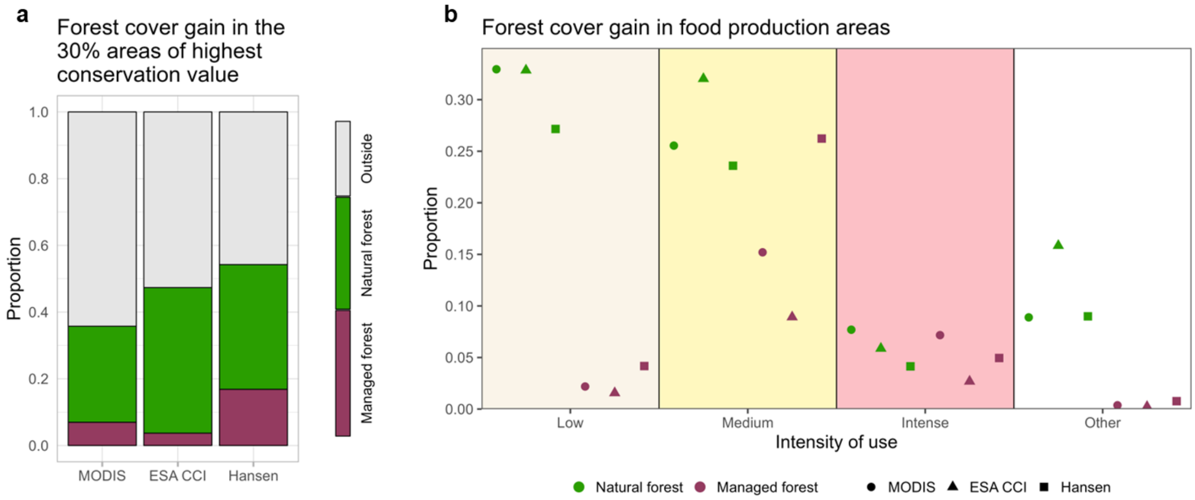

***Figure 2 Forest cover gain occurs in high conservation value and low to medium intensive food production areas** Proportion of forest cover gain per forest management type in areas considered to be (a) of high conservation value and for (b) various levels of intensity of food production (low, medium, intense and other). Colours of bars (a)*

and points (b) indicate the type of forest management. Details on the respective layers can be found in methods and supplementary information.

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