Annex A. Key terms

COST-EFFECTIVE RESTORATION

Interventions are considered cost-effective if the cost of mitigating one tonne of CO2 equivalent is up to USD 100. The threshold of USD 100/tCO2eq was set by using "the middle of the range for carbon prices in 2030 for a 1.5°C pathway, and at the low end of the range in 2050" (Roe et al., 2021, p. 6027).

DEFORESTATION

A tree cover loss event that is: permanent in nature, e.g., when forest is converted to cropland or cleared for development; or when it occurs within humid tropical primary forest boundaries.

FOREST LANDSCAPE INTEGRITY INDEX

The Forest Landscape Integrity Index (FLII) tracks the ecological integrity of forests using data on the intensity and distribution of human pressures known to cause degradation, combined with observed losses in forest connectivity.

FOREST LANDSCAPE RESTORATION (FLR)

The long-term process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscape.

FOREST PROTECTION

A suite of interventions aimed at halting and reversing deforestation by 2030, in line with the Paris Agreement and Glasgow Leaders' Declaration. Forest protection includes reducing deforestation and forest degradation, restoring degraded forestlands, and sustainable management of production forests, with involvement of governments, the private sector, IPs and LCs, and other actors.

FOREST RESTORATION AREA

Area shifting from a non-forest cover state to a forest cover one through afforestation and reforestation activities. The restoration area in this report, therefore, does not include the restoration of degraded forests or interventions in other ecosystems.

GROSS ZERO DEFORESTATION

The Glasgow Leaders' Declaration on Forests and Land Use calls to "… halt and reverse forest loss and land degradation by 2030" but does not specify whether the goal should be to reach gross or net zero by the end of the decade. The 2021-2030 benchmark presented in this year's report for the different indicators uses the "gross zero" interpretation. Indicators tracking a less ambitious "net zero" pathway will be developed in future assessments as data becomes available (e.g., by using the gross forest loss and gain of the upcoming 2025 FAO Forest Resource Assessment).

TREE COVER LOSS

A loss event that may or not be permanent. Non-permanent tree cover loss routinely occurs in the context of logging, fire, or swidden agriculture. Tree cover loss data is often analyzed as a first step to measure deforestation.

Annex B. Methodology

1. Forest loss Indicators

The new FDA's reporting framework (Annex D) analyses forest loss and degradation indicators in two different ways. First, the 2021 data are compared to a 2018-2020 baseline, in order to assess whether there has been a short-term improvement or worsening of any given indicator. The baseline of 2018-20 was chosen to smooth out any single-year anomalies. Second, the 2021 data is benchmarked against a future pathway that delivers the 2030 objectives (e.g., reaching zero deforestation by 2030).

While multiple reduction pathways are in principle possible, for all deforestation, tropical primary forest loss, and forest degradation indicators, a straightforward and transparent linear reduction pathway is established. Each year of the decade (including 2021) requires a 10 percent reduction in loss relative to the baseline to reach zero gross loss by 2030. This is consistent with previous NYDF progress assessments, which also tracked progress against a linear reduction pathway.

The tree cover loss underlying deforestation and tropical primary forest loss was calculated using a >30 percent tree cover density threshold. Improvements in the detection of tree cover loss due to the incorporation of new satellite data and methodology changes between 2011 and 2015 may result in higher estimates of loss in recent years compared to earlier years (Weisse and Potapov 2021) but does not affect the comparison of 2021 data to the 2018-2020 baseline.

Deforestation

Deforestation (ha/yr) is estimated as the part of global tree cover loss (Hansen et al. 2013) that leads to a permanent conversion of forest to a new land use according to a map of the drivers of tree cover loss (Curtis et al., 2018). This includes all tree cover losses that are likely attributed to the production of agricultural commodities and urbanization (Curtis et al., 2018) as well as tree cover loss due to shifting agriculture in humid tropical primary forests (primary forests as mapped by Turubanova et al. 2018). **Table 1** outlines the 30 countries with the highest deforestation in 2021.

Humid tropical primary forest loss

Humid tropical primary forest loss (ha/yr) measures the tree cover loss occurring as of 2001 within humid tropical primary forests, which are defined as mature natural humid tropical forest cover that has not been completely cleared and regrown in recent history (Turubanova et al., 2018). No corresponding map of primary forest is available globally; hence, this indicator is limited to the humid tropics.

Gross GHG emissions from forests

GHG emissions from global deforestation (measured in megatons of carbon dioxide equivalent per year, or $MtCO_2e/yr$) are estimated by combining data on carbon stocks and tree cover loss (Harris et al., 2021, updated with tree cover loss through 2021). Our estimates of gross GHG emissions include aboveground carbon, belowground carbon, deadwood and litter carbon, as well as soil organic carbon. CO_2, CH_4, and N_2O emissions from peat drainage and forest fires are also included. Emissions are attributed to deforestation using Curtis et al. (2018) (updated through 2021) following the same categories used for the global deforestation indicator.

Gross GHG emissions from humid tropical primary forest loss (tCO2e/yr) are estimated by overlaying gross emissions from Harris et al. 2021 with humid tropical primary forest extent in 2001 (Turubanova et al., 2018).

Table 1. Countries with the highest absolute levels of deforestation (in million hectares, Mha) and the relative and absolute change from 2018-2020 baseline to 2021 level

		DEFORESTATION			
		2018-2020 baseline (Mha)	2021 (Mha)	Absolute change from baselne (Mha)	Relative change from baseline
1	**Brazil**	**2.25**	**2.33**	**0.076**	**3%**
2	**Indonesia**	**1.04**	**0.78**	**-0.260**	**-25%**
3	**Bolivia**	**0.50**	**0.53**	**0.030**	**6%**
4	**Democratic Republic of the Congo**	0.48	0.50	0.016	3%
5	**Paraguay**	0.26	0.26	0.003	1%
6	**Malaysia**	0.34	0.26	-0.080	-24%
7	**Lao PDR**	0.24	0.23	-0.015	-6%
8	**Myanmar**	0.18	0.18	0.003	2%
9	**Peru**	0.18	0.17	-0.012	-7%
10	**Colombia**	0.19	0.16	-0.031	-17%
11	**Argentina**	0.13	0.16	0.022	17%
12	**Vietnam**	0.17	0.14	-0.026	-15%
13	**Cambodia**	0.13	0.14	0.009	7%
14	**United States**	0.12	0.10	-0.020	-16%
15	**Cameroon**	0.07	0.089	0.018	25%
16	**Thailand**	0.09	0.087	-0.002	-2%
17	**Mexico**	0.11	0.068	-0.038	-36%
18	**Nicaragua**	0.05	0.064	0.017	37%
19	**Madagascar**	0.08	0.049	-0.027	-35%
20	**Philippines**	0.06	0.045	-0.015	-25%

		DEFORESTATION			
21	**Papua New Guinea**	0.06	0.043	-0.015	-26%
22	**Honduras**	0.04	0.042	0.000	-1%
23	**Venezuela**	0.07	0.031	-0.036	-54%
24	**Liberia**	0.03	0.025	-0.003	-12%
25	**Angola**	0.01	0.024	0.014	131%
26	**Nigeria**	0.03	0.022	-0.003	-10%
27	**Guatemala**	0.04	0.020	-0.019	-48%
28	**Republic of the Congo**	0.03	0.019	-0.008	-30%
29	**Central African Republic**	0.01	0.019	0.008	71%
30	**Canada**	0.01	0.016	0.005	51%

Source: Based on original analysis for this report using data from Hansen et al. 2013, Curtis et al. 2018, and Turubanova et al. 2018.

Degradation

The Forest Landscape Integrity Index (FLII) provides an index of the overall level of degradation (i.e., human modification) for all forests across a continuous scale from the lowest (FLII = 0) the highest (FLII = 10) level of integrity (Grantham et al., 2020) annually from 2017. The Glasgow Leaders' Declaration calls for a halt to land degradation (including forest degradation), implicitly by 2030. Therefore, the 2030 target is set at zero further degradation (i.e., no further loss in FLII). Analogous to other indicators, the pathway to reach this 2030 target reflects a 10 percent decline each year from the baseline rate, which is the average annual loss of FLII units across 2018-2020.[a] The FLII uses proxies for degradation, combining observable pressures within pixels (agriculture, forest cover loss and infrastructure), inferred pressures (e.g., edge effects, overharvest), and losses in forest connectivity in the surrounding landscape to give an aggregate score.

2. Restoration indicators

Rate of forest cover and tree cover gain

[a] Given that many Forest Landscape Restoration pledges exist a less conservative benchmark could be applied (See section Annex C). Future assessments may revise this benchmark upwards as certainty regarding methodological developments allow.

Global data on forest cover and tree cover gain using remote sensing technology are still under development. Recent technological advancements in satellite sensors offer new possibilities for measuring tree height, which improve accuracy for estimating tree gain (and loss) globally. For instance, in late 2021, the University of Maryland and the World Resources Institute (WRI) leveraged data provided by the Global Ecosystem Dynamics Investigation Lidar (GEDI) onboard the International Space Station (ISS) to produce new prototype data on forest cover gain for the period 2000-20.[1]

While these methods have improved understanding of the changing dynamics of global forests, the data they generate does not perfectly align with the indicators employed in this Assessment to measure the rate of forest cover and tree cover gain. The dataset reveals areas where tree cover has increased, but it does not indicate if the gain in tree cover resulted from forest restoration or afforestation versus other factors, such as regeneration after natural disturbances or land abandonment. The data set reports the accumulated gain that occurred between 2000 and 2020 as a single time step. Forthcoming data from University of Maryland and WRI, expected by late 2023, will improve upon this first prototype to include a time series of annual estimates, which will enable a more thorough understanding of the temporal dynamics of tree cover gain. Furthermore, the BIOMASS mission from the European Space Agency (ESA) is expected to start delivering high resolution data on above ground biomass in the first quarter of 2023.

Cost-effective potential for restoration

This assessment indicates how much can be realistically restored between 2020 and 2050, measuring the potential to shift from a non-forest cover state to a forest cover state through afforestation and reforestation activities and through natural forest regrowth. The restoration potential data is available in terms of mitigation potential (measured in $MtCO_2$), the mitigation density (Mt CO_2per hectare (ha)),[2] and the area of forest restoration opportunity (measured in ha).[3] These indicators can be interpreted as a proxy for forest restoration opportunity potential, while keeping in mind the challenges in representing the broad scope of restoration or FLR with any single metric.

Available literature provides estimates of restoration potential both in technical and cost-effective terms.[b] The former refers to the mitigation potential achievable with available technologies, regardless of the cost of implementation. The latter considers the implementation of mitigation activities that are feasible under the price threshold of USD 100/$tCO2_e$[c]. As noted by Roe et al. (2021), the technical potential might not be feasible or desirable due to economic, social, political, or environmental constraints and tradeoffs. Hence, cost-effective potential estimates are considered a more realistic and actionable target for policy,[d] and are the focus of the Forest Declaration Assessment's analysis.

The dataset is based on the cost-effective sectorial estimates from the paper Roe et al. (2021) covering the period 2020 to 2050. Roe et al. (2021) adapted existing mitigation potential estimates from afforestation, reforestation, and natural forest regrowth from two existing papers:

i) Busch et al. (2019):[4]

[b] Interventions are considered cost-effective if the cost of mitigating one tCO_2e is at least USD 100. The threshold of USD 100/tCO2eq was set by using 'the middle of the range for carbon prices in 2030 for a 1.5C pathway, and at the low end of the range in 2050' (Roe et al., 2021, p. 6027).

[c] In simple terms, cost-effective potential can be understood as the amount of mitigation that can be reasonably expected to be unlocked given economic constraints. Following the cost-effective definition outlined by Roe et al. (2021), the threshold of \$100/tCO_2eq was set by using 'the middle of the range for carbon prices in 2030 for a 1.5C pathway, and at the low end of the range in 2050'.

[d] Please see Annex E for further information on the methodology and an in-depth explanation of how conservativeness has been additionally enhanced by applying an algorithm that ensures consistency between various pieces of research.

They “produce spatially disaggregated marginal abatement cost curves for tropical reforestation by simulating the effects of payments for increased CO2 removals on land-cover change in 90 countries” (p. 463). The study defines reforestation as the transition of land from non-forested to forested at 30% tree cover. This definition includes afforestation, although they did not use the term to avoid promoting conversion of native non-forest ecosystems. Busch et al. did not distinguish between anthropogenic versus natural reforestation processes in their data. Other biomes such as deserts and mangroves are excluded from the analysis.

Busch et al. (2019) first model the historical reforestation area (2000 – 2010) as a function of economic and biophysical driver variables. These include agricultural revenues, slope and elevation, distance from the nearest city of more than 750,000 inhabitants, the extent of protected areas, and biome type. Second, they project reforestation area per decade from 2010 to 2050 and convert projections into CO_2 removals in above and below-ground biomass based on the type of biome and whether reforestation is through natural regrowth or forest plantations. Finally, Busch et al. (2019) produce marginal abatement cost curves by applying a per-hectare carbon price effect to the model, which simulates payments for carbon removals.

The analysis accounts for non-linear trends in land-cover change (for instance, the inverted-U-shape relationship between reforestation and deforestation), assumes a 10 percent discount rate and does not include long-lived wood products.

ii) Austin et al. (2020)[5]

They use a Global Timber Model (GTM) to project the mitigation potential of avoided deforestation, forest management activities, increasing harvest rotations, and afforestation/reforestation in response to carbon price signals across 16 regions. Afforestation/reforestation interventions include natural forest regrowth and the establishment of managed timber plantations.

The GTM is a dynamic economic optimization model representing the forestry sector. It determines optimal levels of afforestation/reforestation (together with other interventions) by maximizing net welfare (i.e., producers’ and consumer’s surplus) and assuming future macroeconomic and environmental conditions.

The model differentiates forest types and associated biomes, accessibility to the area and management intensity. Austin et al. (2020) first establishes a baseline scenario representing the extent of future forest and land management, and associated CO_2 fluxes in above- and below-ground biomass and soil carbon, in the absence of carbon price. Second, they develop scenarios under alternative carbon price scenarios and compared these projections to the baseline scenario to estimate net mitigation potential. The model assumes a 5% discount rate.

Roe et al. (2021) averages the cost-effective mitigation potential (with the threshold set to $100/t$CO_2$e) from both papers, when available, or considers the only available estimate when others are missing. These papers are held in highest regard for the provision of reliable mitigation potential estimates since they include spatial opportunity, costs, and are based on well-grounded econometric analyses. Additionally, by averaging the two most updated estimates, Roe et al. (2021) account for the factors considered in the two separate studies, and it is therefore expected to deliver very robust estimates.

Roe et al. (2021) calculates the cost-effective area of opportunity by measuring the land area associated with a given mitigation potential. Thus, the indicator on mitigation density equals the mitigation potential of each country divided by the respective area of opportunity.

The resulting dataset provides one or more indicators of restoration potential for 224 countries. Furthermore, Roe et al. (2021) provides annual estimates for both mitigation potential and area of opportunity, which are multiplied by 30 years to obtain the overall estimate for the period 2020-50. This adjustment allows for comparability between these indicators and the commitments database (see Annex E).

[1] Potapov, P., Hansen, M. C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S., et al. (2022). The Global 2000-2020 Land Cover and Land Use Change Dataset Derived From the Landsat Archive: First Results. *Frontiers in Remote Sensing*, *3*, 856903. https://doi.org/10.3389/frsen.2022.856903.

[2] Roe, S., Streck, C., Beach, R., Busch, J., Chapman, M., Daioglou, V., et al. (2021). Land-based measures to mitigate climate change: Potential and feasibility by country. *Global Change Biology*, *27*(23), 6025–6058. https://doi.org/10.1111/gcb.15873.

[3] World Resources Institute. (2014, May 30). Atlas of Forest and Landscape Restoration Opportunities. https://www.wri.org/data/atlas-forest-and-landscape-restoration-opportunities.

[4] Busch, J., Engelmann, J., Cook-Patton, S. C., Griscom, B. W., Kroeger, T., Possingham, H., et al. (2019). Potential for low-cost carbon dioxide removal through tropical reforestation. *Nature Climate Change*, *9*(6), 463–466. https://doi.org/10.1038/s41558-019-0485-x.

[5] Austin, K. G., Baker, J. S., Sohngen, B. L., Wade, C. M., Daigneault, A., Ohrel, S. B., et al. (2020). The economic costs of planting, preserving, and managing the world's forests to mitigate climate change. *Nature Communications*, *11*(1), 5946. https://doi.org/10.1038/s41467-020-19578-z.