An ecosystem context for global gross forest cover loss estimates

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Fundamental questions remain about the contributions of forests to the global carbon cycle and how these are affected by natural and anthropogenic drivers. Deforestation, the human-induced conversion of forests to non-forest land, currently accounts for an estimated 12% of anthropogenic carbon emissions (1). The future response of forests to global climate change could result in substantial positive or negative feedback to the carbon cycle, and this forest feedback will in turn affect the mitigation efforts required to reach stabilization targets for atmospheric CO_2 concentrations (2, 3). Accurate quantification of land-use change involving forests (afforestation, deforestation), natural disturbances (fire, insects), and forest management (harvesting, fire suppression) is a prerequisite to estimating the net contribution of forests to the global carbon balance. However, globally consistent data on these processes are difficult and costly to obtain. Hansen et al. (4) address one of these issues with a synthesis of data from several continental-scale studies into a globally consistent estimate of gross forest cover loss (GFCL), defined by the authors as any "conversion of forest cover to non-forest cover."

The authors first use coarse spatial resolution imagery from the Moderate Resolution Imaging Spectroradiometer to depict forest cover change globally by stratum. They estimate GFCL as the reduction in forest cover between 2000 and 2005 by sampling 541 randomly selected 18.5 × 18.5-km blocks extracted from Landsat-7 Enhanced Thematic Mapper Plus imagery. The difference in forest cover indicates a global average GFCL rate of 3.1% over 5 yr or 0.6% yr^{-1} relative to the forest area in 2000.

Although these new global statistics provide great value because of their globally consistent definitions and methodology, the estimates must be placed into context to assess their implications. GFCL provides important but incomplete information to infer knowledge about the carbon cycle or the sustainability of human actions: important because it provides an objective (sample-based) estimate of GFCL; incomplete because it does not inform about net changes, the cause of the changes, or the likely successional trajectories that will follow cover loss.

GFCL statistics do not inform about rates of forest recovery and net changes.

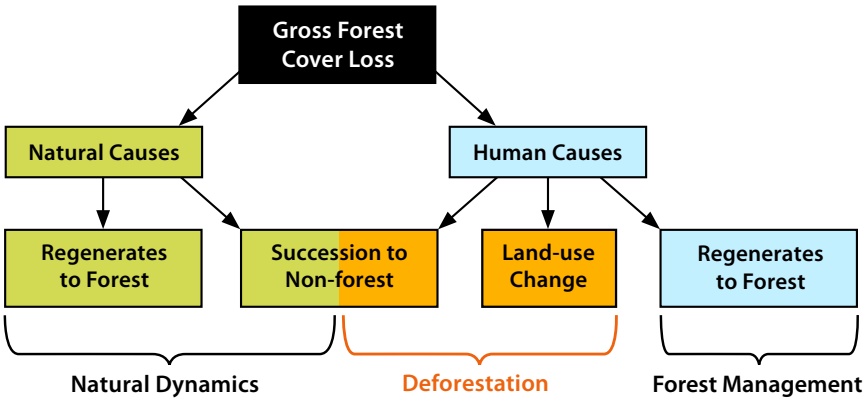

Fig. 1. GFCL results from natural (fire, insects) and human (harvesting, land clearing) causes. The proportion of area that regenerates back to forests differs greatly between regions and by cause of disturbance. The background rates of natural disturbances, the cause of disturbances, and the rates of recovery provide the ecological context for GFCL statistics.

Therefore, comparing regional or national GFCL statistics without ecological context can lead to misunderstanding. Just as it is impossible to judge the financial performance of a corporation by reviewing only the expense side of the ledger, knowledge about the health of forests, net forest area changes, and carbon balances cannot be inferred from GFCL alone. For example, although Hansen et al. (4) report an annual GFCL of 560,000 ha yr^{-1} for China, overall forest area has been increasing because large-scale afforestation efforts have resulted in net increases in forest area in China (5, 6).

The rapid and large changes in surface reflectance properties resulting from GFCL are relatively easy to detect with remote sensing. In contrast, the slower successional processes of forest regrowth are much harder to quantify using remote sensing techniques (7). This is particularly true in the circumpolar boreal forests where regeneration is slow compared with most other regions of the world, and reflectance change associated with forest growth over a 5-yr period is small.

Forest cover loss can be due to natural (wildfire, insects, windthrow) or human causes (harvesting, land clearing, fire), and the affected area can either regenerate back to forest or not (Fig. 1). For most regions, GFCL statistics presented by Hansen et al. (4) do not attribute causes, yet understanding the cause of forest cover loss can be an important step toward estimating the likelihood and rate of forest recovery. It will also aid in developing baselines to assess whether an observed value of GFCL should be a cause for concern. For example, boreal forests with a natural 150-yr forest fire return interval (8) (and assuming no other types of disturbances) will experience an annual average GFCL of 0.67%. However, if all of the burned area regenerates naturally, net forest area loss will be zero. Similarly, two forest estates under sustainable management, with 25-yr (e.g., southeast United States) and 100-yr (e.g., boreal forests) harvest rotation periods would experience annual GFCL rates of 4.0% and 1.0%, respectively, because that proportion of the area is harvested annually. But if the forests successfully regenerate after harvest, then net forest cover loss is zero.

Natural forest disturbances in most tropical systems are based on gap dynamics (9, 10), driven by the loss of single or small groups of trees. The resulting subtle forest cover changes are more difficult to detect by remote sensing than large-scale disturbances (11, 12). The natural GFCL (in the absence of human impacts) observed from remote sensing in such gap-dynamics forests is near zero.

Obtaining estimates of GFCL, therefore, is only the first important step in a more complex inquiry. It will be

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necessary to build on this information and derive estimates of the proportions of GFCL attributed to human and natural causes, and for each of these the proportion of area that does not regenerate back to forest. Large regional differences in the drivers of GFCL and regeneration contribute to difficulties in interpreting regional (or national) estimates of GFCL. Understanding the drivers of GFCL is also a prerequisite to developing effective policy responses.

The experience with Canada's National Forest Carbon Monitoring, Accounting and Reporting System (13), designed to quantify and report changes in Canada's managed forest carbon stocks, was that it is relatively easy to detect forest cover loss but much more difficult to quantify the area that is deforested. Attributing an observed cover change to "human-induced conversion of forest to non-forest" requires additional spatially referenced information on land-use change or repeated postdisturbance observations to confirm that forest is not growing back.

For the 5-yr period 2000–2004, Canada reported roughly 20,000 km^2 yr^{-1} of disturbances that resulted in forest cover loss, including clearcut harvesting, wildfire, and severe and moderate-to-severe areas of mountain pine beetle impacts in the managed forest (2.3 million km^2) (14). This translates into an annual rate of GFCL of approximately 0.9%, slightly below the annual GFCL rate of 1% reported by Hansen et al. for Canada's total forest area (3.05 million km^2). Of these 20,000 km^2 yr^{-1} of GFCL, only approximately 485 km^2 yr^{-1} (2.5% of observed GFCL) were deforestation. Nearly all of the area of forest cover loss due to fire, insects, or harvesting will return to forest. Notwithstanding ecological succession and legal requirements to regenerate harvested areas, a small (and at present poorly quantified) proportion of the area with forest cover loss may not regenerate back to forest and contribute to net forest area losses.

Carbon balances cannot be inferred from GFCL alone.

Hansen et al. (4) demonstrate that a globally consistent, sample-based estimate of GFCL can be developed, along with statistical estimates of uncertainty. This is an important achievement: during the international climate change negotiations of recent years, much time was invested debating the tradeoffs between comprehensive wall-to-wall mapping of forest cover change and sample-based approaches like the one successfully implemented here. With more time and resources, the sampling intensity can be increased and the time between remote sensing images decreased to obtain estimates with greater spatial and temporal resolution. The opening of the Landsat archive by the United States Geological Survey (15) reduces costs and encourages time-series analyses to quantify disturbance and recovery (7, 16).

Understanding, quantifying, and monitoring changes in rates of forest disturbance and forest recovery are necessary activities to estimate forests' contribution to the global carbon cycle. The global synthesis by Hansen et al. (4) has laid an important foundation toward this goal, but sustained national and global efforts to monitor forests and forest changes will be required to fully quantify forest contributions to the global carbon cycle. Moreover, additional efforts have to be aimed at quantifying changes that are not readily observed through remote sensing, such as increased rates of within-stand tree mortality (17), changes in growth rates (18), and responses of dead organic matter and soil carbon pools to global change (19). Further advances in remote sensing of forest characteristics and dynamics, support of globally coordinated efforts to track forest carbon, and models with which to synthesize large quantities of data will be required to advance scientific understanding and to support policy aimed at reducing emissions from deforestation and degradation.

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