Global forest alteration, from space

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A novel approach examines evidence of alteration to establish intact forests.

Assessing forest degradation at the regional and global scales is difficult for various reasons. Degradation is a complex concept that is difficult to define. As such, and in addition, it is difficult, and expensive, to measure. What little information is available is often inadequate, lacking in detail, richness and consistency, particularly across jurisdictional boundaries. Non-productive aspects such as biodiversity tend to be particularly poorly described.

Satellite observations provide a promising approach to gathering information. The availability and technical quality of satellite images are improving steadily, while the price is decreasing. Satellite imagery makes it possible to assess large, and even inaccessible, landscapes at a low cost, relatively rapidly. Moreover, suitable historical satellite images (Landsat) dating back to approximately 1980 are available in public archives, making it possible to assess change over time.

This article describes the result of an attempt to use satellite images to assess forest degradation. The method described was originally developed to map intact forest landscapes, or IFLs (Yaroshenko, Potapov and Turubanova, 2001; Aksenov *et al*., 2002; Lee *et al*., 2002; Strittholt *et al*., 2006; Potapov *et al*., 2008). It is therefore referred to as the *IFL Method*. The method and its definitions were designed specifically to work with satellite imagery and are therefore different from what would be used for ground-based observations. The results are replicable and consistent in

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A forest landscape is dominated by forests but may include naturally occurring treeless areas such as these wetlands in the northern European part of the Russian Federation. The IFL Method identifies visible changes in a forest landscape resulting from human influence

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both time and space – that is, for a country, a continent, or the world, at the same point in time.

DEFINING FOREST ALTERATION

The concept of a *forest landscape*, as it is used here, is a mosaic of naturally interspersed land cover types. A forest landscape is dominated by forests but may also include naturally occurring treeless areas, such as small lakes, wetlands, rivers and rocky outcroppings.

Forest degradation is an ambiguous concept. One person's degradation may be another person's improvement; it all depends on one's perspective. For the purposes of this article, the more neutral term *forest alteration* is used. *Forest alteration* is used here to indicate a visible change in a forest landscape resulting from human influence.

THE IFL METHOD

The IFL Method consists of two mutually dependent components: the method itself and a set of definitions and criteria. Well-defined criteria are used to prove that an area is not intact (see Box). These rules have been designed to be globally applicable and easily replicable, allowing for repeated assessments over time as well as independent verification.

The assessment logic has three major characteristics:

The landscape is classified as being either altered or not altered (intact). Although the IFL Method can be adapted to assess different types and degrees of alteration, this article takes a very simple view on alteration: a landscape is either intact, or it is altered.

An IFL is an unbroken expanse of natural ecosystems that shows no signs of significant human activity and is large enough to maintain all native biodiversity, including viable populations of wide-ranging species. In this assessment, an intact area had to be at least 50 000 hectares (ha) in size to be considered an IFL.

Criteria

A. Alteration

Portions of the study area with evidence of *significant* human-caused alteration are considered disturbed and not eligible for inclusion in an IFL. Such evidence includes:

1. Settlements (including a buffer zone of 1 km);
2. Infrastructure used for transportation between settlements or for industrial development of natural resources. Evidence would include roads (except unpaved trails), railways, navigable waterways (including seashore), pipelines and power transmission lines (including, in all cases, a buffer zone of 1 km on either side);
3. Agriculture and forest plantations;
4. Industrial activities during the past 30–70 years, such as logging, mining, oil and gas exploration and extraction, peat extraction;
5. Areas affected by stand-replacing wildfires during the past 30–70 years, if they are located in the vicinity of infrastructure or developed areas.

Human influence that either took place in the distant past or is of low intensity is considered *insignificant*. Portions with such "background" influence remain eligible for inclusion in an IFL. Sources of background influence might include diffuse grazing by domestic animals, low-intensity selective logging, and hunting.

B. Fragmentation

Portions of the study area that remain eligible for inclusion in an IFL are then assessed for fragmentation. Portions considered otherwise eligible, but that are too small, or too narrow, are eliminated. An IFL must satisfy the following criteria:

1. Larger than 50 000 ha;
2. At least 10 km wide at the broadest place (measured as a diameter of the largest circle that can be fitted inside the patch);
3. At least 2 km wide in narrow parts connecting wider patches, and in appendages.

Two types of criteria are being used. Two types of criteria are used to separate intact and non-intact forest landscapes: (A) alteration, and (B) fragmentation. These criteria are used in sequence to determine if an area qualifies to be considered an IFL.

First, the level of alteration is assessed. Altered parts of the study area are rejected as being ineligible for inclusion in IFLs. Remaining parts are then assessed for their degree of fragmentation. Again, parts determined to be ineligible are rejected.

The landscape is considered intact until proven otherwise. The assessment logic works much as a court process. The initial assumption is that the entire area of study is "innocent", i.e. intact/not altered. The method then seeks to prove that areas are "guilty" by finding evidence of alteration. Once all altered areas have been eliminated, only intact areas remain. The logic is that it is easier to spot evidence of alteration and fragmentation than to prove their absence.

APPLYING THE IFL METHOD

The IFL Method was used to assess the ecological integrity of the world's *forest landscape zone*. The forest landscape zone is different from what FAO calls the *forest zone* in that it includes treeless areas that occur naturally within the broader ecosystem that we call a forest landscape. Assessments of these two types of areas are, therefore, not comparable.

The boundary of the forest landscape zone was defined using a global tree canopy cover dataset – part of the Vegetation Continuous Fields MODIS 500 m product (VCF) (Hansen *et al.*, 2003). Forest was defined as an area with a tree canopy cover greater than 20 percent in the year 2000. Forest patches smaller than 4 km^2 were excluded. Forest landscape fragments smaller than 500 km^2 were not considered in the analysis.

The forest landscape zone was assessed in two steps. First, a preliminary fragmentation analysis was carried out for countries for which Geographic Information System (GIS) datasets for transportation infrastructure and settlements were available at a scale of 1:500 000, or finer. Areas in the vicinity of roads, pipelines, power lines and settlements were eliminated from the area of study, fragmenting the forest landscape zone into a mosaic. The goal was to identify landscape fragments free from major elements of infrastructure and greater than 50 000 ha in size. Areas that did not qualify were eliminated from further consideration, while other areas were retained as candidates for IFL.

Proportion of forest landscape zone that has been altered, by forest type

Forest type	Total area *(Mha)*	Altered area *(Mha)*	Proportion altered *(%)*	Intact area *(Mha)*	Proportion intact *(%)*
Closed forests	2 748.4	1 901.3	69.2	847.1	30.8
Open forests and woodlands	1 377.6	1 108.0	80.4	269.6	19.6
Naturally treeless areas	1 461.5	1 265.3	86.6	196.2	13.4
Forest landscape zone total	5 587.6	4 274.7	76.5	1 312.9	23.5

The second step was to use high spatial resolution Landsat TM (global coverage representing an average date of 1990) (Tucker, Grant and Dykstra, 2004) and ETM+ (global coverage representing an average date of 2000) imagery to assess all remaining potential IFL areas systematically for alteration and to draw precise boundaries for each IFL.

The image analysis was conducted through expert-based visual interpretation, using GIS overlays with additional thematic and topographic map layers.

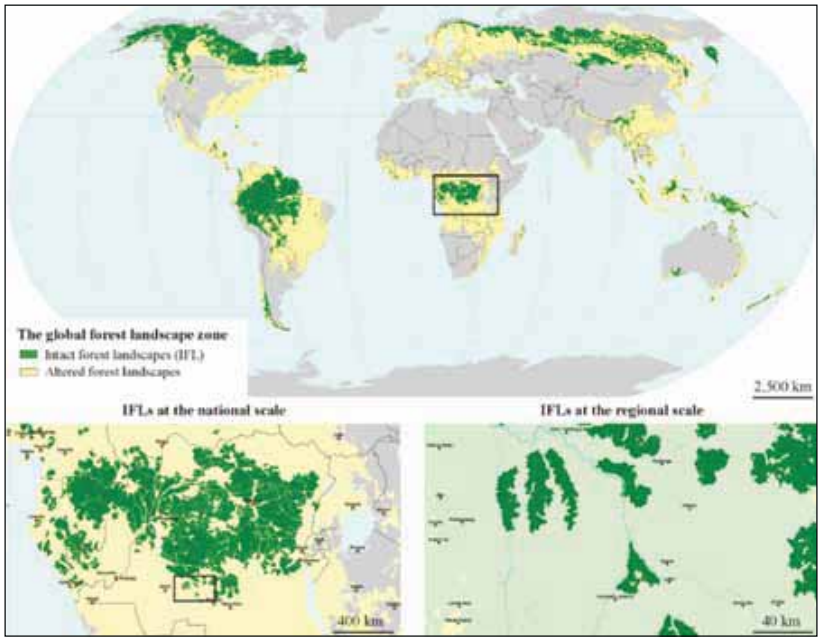
A GLOBAL ASSESSMENT OF FOREST ALTERATION

The current extent of the world's forest landscape zone, as defined above, is 5 587.6 million ha (Mha), or 37.3 percent of the Earth's total land surface. This area can be divided into three major forest ecosystem types, based on tree canopy cover (Hansen *et al.*, 2003):

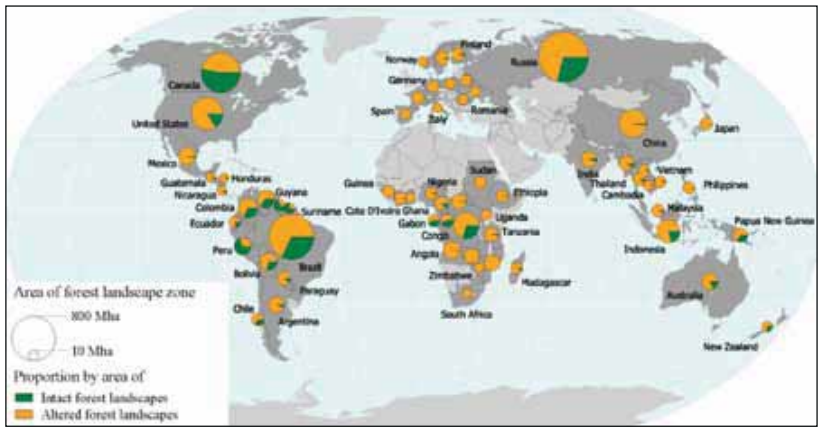
1. *Closed forests* with a tree canopy cover greater than 40 percent (49.2 percent of the forest landscape zone);
2. *Open forests and woodlands* with a tree canopy cover of 20–40 percent (24.7 percent of the forest landscape zone); and
3. *Naturally treeless areas* with a tree canopy cover below 20 percent, e.g. savannahs, grasslands, wetlands, agriculture areas, mountain ecosystems, lakes (26.1 percent of the forest landscape zone).

IFLs represent 23.5 percent of the forest landscape zone (1 312.9 Mha). The balance is affected by development or fragmentation (Figure 1). In the context of the IFL Method, this part is considered altered. The extent of alteration differs among closed, open and non-forest ecosystems (Table).

Approximately two-thirds (69.2 percent) of the world's closed forests are non-intact. There are more remaining IFLs in the boreal and subtundra zones of the north than there are in the south; a long history of human activity has transformed the original woodlands and savannah-type ecosystems of the tropics and the temperate forest–steppes into croplands, pastures, or pyrogenic shrubland or grassland communities.



1
The world's intact and altered forest landscapes. The IFL Method produces maps that are relevant for planning and monitoring at the global, national and regional scales. The regional-scale map shows non-intact forests in light green and treeless areas in yellow



2
Forest alteration, expressed as the proportion of altered landscapes within the forest landscape zone of selected countries. Countries included in the analysis are shown in dark gray (62 countries total)

COUNTRY-LEVEL BASELINE

A country-level assessment was conducted that was limited to countries with at least 10 million ha of area in the forest landscape zone (Figure 2). Of these 62 countries, the forest has been almost entirely altered, i.e. less than 1 percent of the forest landscape zone remains as IFL, in 19. This group consists of European countries other than Finland, the Russian Federation and Sweden, and African countries outside the Congo Basin. Major levels of alteration, i.e. the proportion of remaining IFLs is between 1 and 10 percent of the forest landscape zone, are seen in a group of 21 countries. This group includes African countries on the edge of the humid tropical forest biome, Central American countries, countries in Southeast Asia, and Northern Europe. China and India also belong to this group. The remaining 22 countries have an IFL proportion that is greater than 10 percent of the total forest landscape zone. Only five of them, however, have an IFL proportion greater than 50 percent: Canada, French Guiana, Guyana, Peru and Suriname.

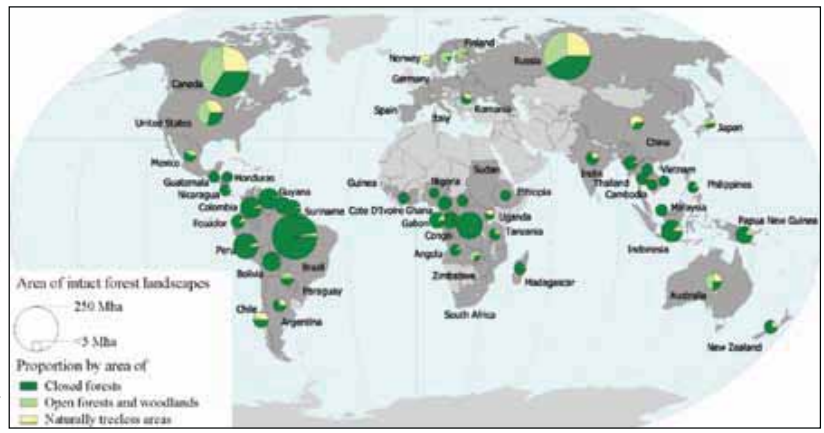
Two different groups of countries emerge when the composition of the IFLs is examined in terms of closed, open and non-forest ecosystems (see Figure 3). The first group is made up of developed countries in which there is industrial forest management. In these countries, the densest and most productive forests have been altered by management or converted to plantations. Where the natural tree canopy density is low and forests are, therefore, less attractive, in terms of forest management, most areas remain intact. Examples are mountainous regions, wetlands and the northern part of the boreal zone.

A different pattern prevails in the second group. In these areas, accessible forests have been cleared for agriculture or grazing, while inaccessible tracts of dense forests remain largely intact.

The least altered dense forests are found among the countries of Central Africa, in Latin America and in Papua New Guinea. The large proportion of dense forests within the IFLs of these countries makes them important repositories of carbon, and their alteration would lead to significant carbon emissions.

ASSESSMENT OF THE IFL METHOD

The IFL Method has many advantages for assessments of large areas. It is suitable for all countries and continents. It is inexpensive to apply, and it can be applied quickly. Its data needs are fulfilled by satellite imagery, which is available in the public domain for free or at a low, and diminishing, cost. It is rigorously defined and lends itself to independent replication and verification. It is also suitable for monitoring – through replication at different points in time in order to measure change. It can be adapted and refined, for example to assess smaller landscapes. Remote and otherwise inaccessible landscapes can be assessed. The result is consistent across the entire area of study (for



3
Intact forest landscapes in selected countries and their composition, by forest type. Countries included in the analysis are shown in dark gray (62 countries total)

example, a country, or the world), and results can, therefore, be compared. Results are spatially explicit, in that they take the form of a map that is detailed enough to underpin decisions about conservation priorities and measures. Statistical information can easily be derived from the map. The method is tested and ready to use.

The resolution, and quality, of the maps has been judged sufficient for them to be used as a tool to support wood procurement and forest management in the boreal forest. For example, in Canada and the Russian Federation, and in the standard for controlled wood, the Forest Stewardship Council (FSC) is using maps produced by the IFL Method (Aksenov *et al*., 2002; Lee *et al*., 2002) as a proxy for large landscape-level forests, a type of forest considered by FSC to have a high conservation value (FSC Canada, 2004; FSC Russia, 2008; FSC, 2006).

The IFL Method can also be used to monitor how forest alteration expands over time. Monitoring simply involves applying the method at a different point in time than that of the baseline study and comparing results. Examples of regional monitoring in the northwestern part of the Russian Federation and Central Africa are given in FAO (2009).

There are also limitations. Skills in GIS and interpretation of remotely sensed data are required. It is suitable only for large areas (province, country, region, the world). Its consistency makes it insensitive to variations among nations in the understanding of "intactness" and "alteration". For example, in interpreting burned areas, would the cause of a fire factor in – such that they be might considered intact, if the burning is the result of natural fires, or altered, if it is the result of human-caused fires? Should the smallest allowed size of an IFL be differentiated with regard to biome (e.g. boreal vs. tropical forests) or natural disturbance regime (e.g. fire dynamics vs. gap dynamics)?

The IFL Method is biased towards overestimating the area of IFLs. This is because of its "innocent until proven guilty" logic. Human influence that is difficult to detect in satellite imagery, such as selective logging, small-scale slash-and-burn agricultural practices, and hunting (for example, poaching in Central Africa), may be overlooked, causing an altered area to be mapped as an IFL. The accuracy of the result will depend on the quality and spatial resolution of the satellite imagery.

A significant limitation of the method, as it was used for this study, is its binary nature. Landscape is classified as being either intact or altered. Neither type nor degree of alteration is differentiated. However, the method can be modified to suit different purposes. It can be made more sensitive to different types of alteration by defining additional and less strict categories, e.g. in terms of patch size and alteration within patches. It could include smaller patches as fragments of intactness to make the method more suitable for assessment of small landscapes (Lee, Gysbers and Stanojevic, 2006; Mollicone *et al*., 2007).

The method is capable of generating useful results without adding field verification when it is applied by experienced analysts who have expert knowledge of the landscape they are assessing and who have access to Landsat TM/ETM+ images. In particular instances, field verification will improve the accuracy of the method. For example, verification could be applied in cases in which the satellite imagery is poor or in which human influence is difficult to detect, e.g. because the influence is diffuse rather than distinct, or because it is invisible from space because it is on a small scale or occurs under the canopy. There is a certain degree of subjectivity in determining IFL boundaries across transition zones from intact to disturbed areas, especially within non-forest territories, savannahs, woodlands and mountain areas. Resources for fieldwork should be focused on verifying the interpretation at important points in which there is a lack of clarity, rather than on a random or systematic sampling.

CONCLUSIONS

The IFL Method provides a cost-effective way to assess the degree of human influence across a large forest landscape, be it a country, or the world. The method is designed to use satellites as the main source of data, reducing cost and enhancing speed. Targeted ground verification of selected spots helps increase accuracy. The result is a map that shows the precise location and boundaries of intact forest landscapes, i.e. the remaining patches of un-altered land in the forest landscape zone, with sufficient accuracy to guide wood procurement, at least in the boreal forest. This map provides a guide for policy-making and priority-setting, as well as a baseline for monitoring change by recurrent application of the IFL Method to intact forest landscapes. The distinction between intact and non-intact forests used here is consistent with experience from satellite-based deforestation measurements and can be used to provide important background data for accounting of carbon loss from forest alteration.

The method can be refined to be more sensitive to the intensity or type of alteration without changing its logic or data requirements, thus enabling it to measure degrees of alteration.

The method will benefit from improvements in the quality and price of, and access to, satellite images. The effect of such improvements will be particularly strong in the humid tropics, where persistent cloudiness makes it difficult to acquire images.

The usefulness of the method can be expanded through at least three types of measures:

- *Capacity-building*. An analyst using the IFL Method must have two areas of expertise: interpretation of satellite images and GIS, and forest

ecology and management. This combination of skills is rare, particularly in developing countries. Concerted training efforts can certainly help in this regard.

- *Transparency and review of results*. The results of the IFL Method are relatively easy to communicate and understand because they can be articulated on maps. These maps need to be reviewed by regional and local experts, as well as by relevant stakeholders. As such, the logistical challenges for a rigorous, paper-based review process are many, particularly for a regional or global assessment. It is possible to let reviewers access maps and provide feedback via the Internet. Development of a Web-based platform for transparency and review is, therefore, needed.
- *Funding for development and application*. The IFL Method has been developed thanks to financial contributions from corporations and foundations in the private sector. Government engagement in the further development and application of the method would be extremely beneficial.

In the case of the present study, the authors envision that the global IFL map will be periodically updated and improved to reflect further alteration. The continual improvement of satellite-borne sensors and analytical techniques will gradually reduce the necessary effort. A continuous external review process has been organized on a dedicated Web site (www.intactforests.org), which allows users to view the IFL map against a background of satellite imagery. ◆

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