Returning forests analyzed with the forest identity

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Amid widespread reports of deforestation, some nations have nevertheless experienced transitions from deforestation to reforestation. In a causal relationship, the Forest Identity relates the carbon sequestered in forests to the changing variables of national or regional forest area, growing stock density per area, biomass per growing stock volume, and carbon concentration in the biomass. It quantifies the sources of change of a nation's forests. The Identity also logically relates the quantitative impact on forest expanse of shifting timber harvest to regions and plantations where density grows faster. Among 50 nations with extensive forests reported in the Food and Agriculture Organization's comprehensive Global Forest Resources Assessment 2005, no nation where annual per capita gross domestic product exceeded $4,600 had a negative rate of growing stock change. Using the Forest Identity and national data from the Assessment report, a single synoptic chart arrays the 50 nations with coordinates of the rates of change of basic variables, reveals both clusters of nations and outliers, and suggests trends in returning forests and their attributes. The Forest Identity also could serve as a tool for setting forest goals and illuminating how national policies accelerate or retard the forest transitions that are diffusing among nations.

forest area | forest carbon | sustainable forestry | timber resources | woody biomass

Are prospects for global forests deteriorating or improving? Amid widespread reports of deforestation, some reports provide clues that suggest a reversal of the overall forest decline in many regions. The turning point from net deforestation to net reforestation is defined as the forest transition (1). During the past two centuries, Europe has experienced forest transitions. Since 19th century transitions in the U.S. (2), the forests of industrial and urbanized Massachusetts, Pennsylvania, Ohio, and Illinois have expanded by more than half (3).

Area, density, biomass, and carbon confer valued attributes on forests (Table 1). Forest area harbors biodiversity, beautifies landscape, and bestows solitude. Forest area also anchors soil, slows erosion, and tempers stream flow. The density of growing stock, which is the volume per area of timber large enough to harvest profitably, furnishes lumber and paper. The tons of forest biomass per volume of growing stock energize ecosystems and can fuel economies. According to its carbon concentration, the forest biomass withholds carbon dioxide that would add to greenhouse gas in the atmosphere.

In this paper, we develop a simple equation, the Forest Identity, to understand forest transition and prospects. The Forest Identity separates the variables of changing area, density, biomass per volume, and carbon concentration that drive the changing attributes in a variety of regions. The Global Forest Resources Assessment 2005 (FRA2005) by the United Nations Food and Agriculture Organization (FAO) (4) provides timely data to animate the Forest Identity. We begin with histories of transitions from shrinking to expanding forests and the diffusion of transitions. We then build the attributes of area, density, biomass, and carbon into the Forest Identity. Using FRA2005 data, we apply the Identity to understand the recent changes in the forests of seven exemplary developing and developed nations. Next, we use it to analyze the impact of forest industry and international trade on forest changes. We then use the Identity and FRA2005 to relate forest changes to gross domestic product (GDP) and plot a concluding synoptic chart of changing forests in 50 nations. A relationship between biomass per growing stock volume and density plus assumed steady carbon concentration then turns the chart into a display of the global variety of changing expanse, growing stock, biomass, and carbon. The synoptic chart suggests four categories of nations and clarifies the prospects for transitions from deteriorating to improving forest variables and their combinations in the attributes of forest area, growing stock, biomass, and sequestered carbon.

Table 1. Attributes of forests and variables that cause them

Symbol		Dimensions
	Attribute	
A	Area	ha
V	Volume of growing stock	m^3
M	Biomass	tons
Q	Carbon	tons
	Variable	
A	Area	ha
D	Density	m^3/ha
B	Allometric biomass ratio	tons/m^3
C	Carbon concentration	tons/ton

Results

Transitions Worldwide. As a reference case, France offers especially well documented forests together with contextual data (1). The French forest transition around 1830 was followed by a reforestation that accelerated after 1960 (Fig. 1). Forest area expanded by one-third from 1830 to 1960, whereas total French population nevertheless grew, although slowly, from ≈32 to 42 million. Then, although total population burgeoned to 61 million from 1960 to 2005, forest area expanded more than one-quarter.

A diffusion of forest transitions between 1810 and 1930 can be surmised from the lowlands of Denmark to the mountains of Switzerland and the highlands of Scotland and on to Russia (Table 2). Changing borders make calculations more difficult for Germany. Germany illustrates a transition in density or growing stock sharper than in area. Although the German forest area nearly doubled after the Middle Ages (7), it scarcely increased between 1988 and 2002. On the other hand, German growing stock increased rapidly to an average of 320 m^3/hectare (ha) (4).

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Abbreviations: FRA2005, Global Forest Resources Assessment 2005; FAO, United Nations Food and Agriculture Organization; GDP, gross domestic product; ha, hectare.

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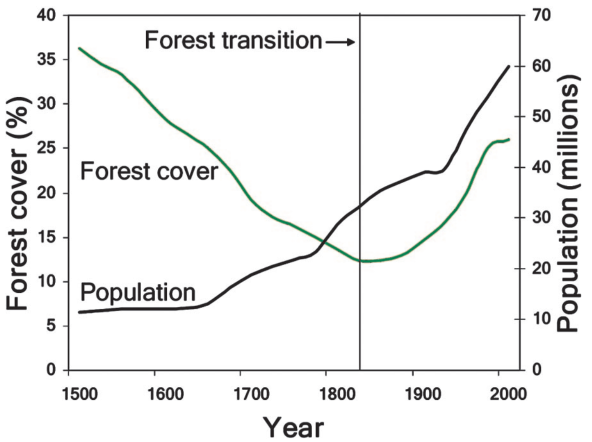

Fig. 1. Trends in modern French forest area and population. The vertical bar marks a forest transition (source, ref. 1).

The transcontinental span of the U.S. permits mapping of the spread or diffusion of transitions in 48 States (Fig. 2). Before 1800, European settlers cleared a comparatively modest area. The number of settlers then increased and expanded farming by clearing forests. In the 60 years from 1850 to 1910, American farmers cleared ≈77 million ha, more forest than the total cleared in the previous 250 years of settlement (8). Although the total area of American forests changed modestly after 1920, regional transitions occurred in more and more states, diffusing transitions across the nation and continent.

In Connecticut, where the first U.S. transition occurred, forests expanded from 29% of the state in 1860 to 60% in 2002 (9). Subsequent reports of forest areas in states (3) show a diffusion of forest transition generally west and south. Deforestation and then reforestation look like spatially diffusing innovations as analyzed by Swedish geographer Torsten Haegerstrand (10). New implements, techniques, and behaviors cause reappraisal of every scrap of territory and new areal distributions of activity (11).

In tropical developing El Salvador, a survey that encompassed secondary growth, pasture successions, living fences, tenure demarcations, urban forests, and orchards revealed that land with >25% tree cover expanded from 72% to 93% between 1992 and 2001 (12). Forests are recovering in Puerto Rico and the Dominican Republic, next to deforested Haiti (13).

Forest transitions are also occurring across several countries in Asia but later than in Europe and North America. FRA2005 data suggest that a forest transition has recently occurred in Asia; the continent lost 792 kha of forest between 1990 and 2000, but it gained 1,003 kha between 2000 and 2005 (4). For example, in China, where forest expansion began in the late 1970s, national-scale reforestation and afforestation significantly increased forest area from 96,000 kha in the late 1970s to 143,000 kha in the early 2000s. The forests of populous China are sequestering carbon (14, 15). A forest transition has taken place in Japan since World War II. Its total living biomass stock has increased from 1.5 Pg carbon (1 Pg = 10^{15} g) in 1947 to 2.9 Pg in 2000 (16), although the forest area increased only a little from 22.2 to 23.7 Mha.

In two developing nations with tropical forests, the Indian forest area has slowly expanded since ≈1990 (17), whereas in Vietnam, the turnaround from the same date has been more clearly defined, averaging ≈2% per year (4).

Table 2. In six European nations, approximate years of transition from shrinking to expanding forest areas, the minimum areas at transition, and the forest areas in 2005 (5–7)

	Approximate year of transition	Forest extent at time of transition, % of national area	Forest extent, 2005, % of national area
Denmark	1810s	4	11
France	1830s	14	28
Portugal	Pre-1870s	7	40
Switzerland	1860s	18	30
Scotland	1920s	5	17
European Russia	1930s	28	39

The Forest Identity. The attributes of area, growing stock, accumulated biomass, and sequestered carbon impart importance to forest transitions (Table 1). The attributes need to be defined and placed in a causal relationship to basic rates of change that can be combined to fit different interests and users. Forest area (A) interests people from those who value biodiversity to those who collect water. The volume (V) of living trees larger than a minimum diameter, i.e., the growing stock that interests foresters, is identical to A multiplied by its density (D) of growing stock:

$$V \text{ m}^3 = A \text{ ha} \times D \text{ m}^3/\text{ha}$$

$$\ln(V) = \ln(A) + \ln(D)$$

$$\text{d} \ln(V)/\text{dt} = \text{d} \ln(A)/\text{dt} + \text{d} \ln(D)/\text{dt}.$$

In the analysis that follows, the annual rates of change of the logarithms of A and D were estimated by dividing the FRA2005 changes from 1990 to 2005 by the 15-year span. Percentage changes closely approximate the rates of change of logarithms actually encountered.

Letting lowercase letters be annual percentage changes leads to an identity for national change in volume $v = a + d$.

This identity combines the variables of forest landscape area and the density of stock per area into the changing attribute of growing stock volume.

Ecologists appreciate the food energy in biomass, and engineers value the fuel energy in it. Calculating the attribute of aboveground biomass (M) in living trees requires an additional variable (B):

$$M \text{ tons of biomass} = A \times D \times B,$$

where B is tons of biomass/m^3 of growing stock.

Because foliage and branches comprise less, and trunks and growing stock more of a tree as it grows, the ratio (B) frequently declines from 3 tons to 1 ton per m^3 as trees grow (18). The ratio B declines ≈3% when D increases 10%. Because the specific gravity of growing stock is ≈0.5 (19), a B of 1 indicates the growing stock holds half the above-ground biomass. Including roots and dead organic matter would, of course, require a higher B, but we concern ourselves with above-ground biomass. In annual percentage changes, $m = a + d + b$.

The threat of climate change from increasing carbon dioxide in the atmosphere has encouraged an interest in the carbon sequestered in forests. The quantity may be sufficient for forests to be the missing carbon sink in the budgeting of carbon emission and its addition to the atmosphere (20). Estimating the attribute of carbon (Q) sequestered above ground in the forest requires the C ton carbon per ton of biomass, which ranges from 0.48 to 0.53 (19). The Forest Identity is the final integration of the four variables, illustrated by FRA2005 values for the U.S.:

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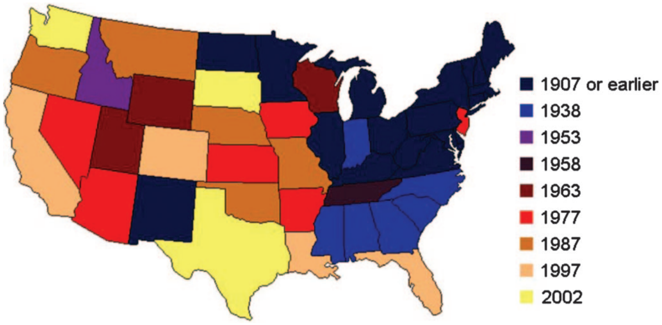

Fig. 2. Forest transitions in the U.S. Dark to light colors indicating the spread of forest transitions from the Northeast, where minimum areas were reported in 1907. The colors indicate the date when the minimum forest area was reported (source, ref. 3).

$$Q = A \times D \times B \times C \text{ ton of carbon/ton of biomass}$$

$$15{,}826 \text{ million tons} =$$

$$303{,}089 \text{ kha} \times 116 \text{ m}^3/\text{ha} \times 0.9 \text{ ton/m}^3 \times 0.5 \text{ ton/ton}.$$

If a and d changed as FRA2005 reports for 1990–2005, if B falls 3% for each 10% rise of D, and if C is constant, the carbon sequestered in U.S. trees increased 0.45% per year:

$$q = a + d + b + c$$

$$0.45\%/\text{year} = 0.10 + 0.49 - 0.14 + 0.$$

The identities for v, m, and q that link three different combinations of the rates a, d, b, and c plus a itself provide the rates of change of attributes from habitat to sequestered carbon.

Assume, as seems likely, that b is $-0.3 \times d$, and that the c carbon per ton of dry biomass changes negligibly. Then the changes of sequestered carbon can be calculated from the FRA2005 changes of a and d. Seven nations illustrate the variety of changes during 1990–2005 (Fig. 3). Indonesia demonstrates how a 2% shrinkage of area a plus a rapid 4% per year fall in density d of growing stock cut growing stock fully 6%. Because the ratio b increases as density falls, however, biomass m and carbon q fell more slowly than growing stock v. Shrinking area mainly lowered the Brazilian biomass. Although expanding area dominated the increase of biomass in India and China, and growing density dominated the increase in Japan and the U.S., increasing area and density both increased French biomass.

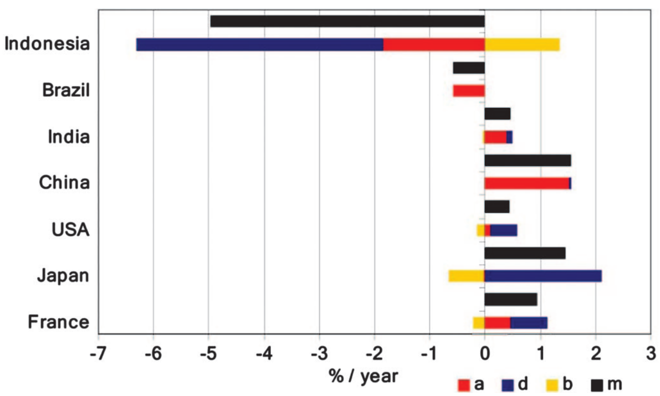

Fig. 3. Depicted during 1990–2005 in each of seven countries are the rate of change of total above-ground biomass (*m*) (upper bars) and (lower bars), the contributions of changing area (*a*), growing stock density (*d*), and biomass (*b*) per volume of growing stock that summed to change (*m*) (source, ref. 4).

Extending analyses of the Forest Identity over longer periods shows the dominance of a or d can persist, characterizing a nation and perhaps a strategy or policy. In China, from 1949 to 2005, a generally expanding a countered a frequently declining d to increase the attribute v at an average 0.2% per year (4, 16). In Japan, a generally increasing d added to a scarcely changing a to produce an average increase v of 1.6% per year (4, 16). The Forest Identity clarifies and quantifies the terms of forest change and debate.

Industrial Harvest, Trade, and Leakage. How closely does the impact on forests match the scale of timber harvest? Divergent national harvests vs. national changes in growing stock answer, "Not much." The U.S. gained growing stock during 1990–2005 while harvesting much round wood and some fuel. China did likewise. On the other hand, Indonesia and Brazil lost much growing stock without harvesting as much timber as either the U.S. or China (4).

Deforestation implies that people both clear forests and convert the land to another use. Where part of a forest is cut down but replanted, or where the forest grows back on its own within a relatively short time, there is no change in area A, and therefore, no deforestation (4). If, over area A, the density D is cut in one portion of A as it grows in another, timber harvest can, of course, be sustained. It is not forest industries themselves but rather a high density of population in combination with poverty that tends to drive deforestation (21).

The annual procurement of $\approx$1,600 million m^3 of industrial round wood extracts about a half percent of the total of nearly 400,000 million m^3 of growing stock in global forests (4). Developed temperate countries produce $\approx$70% of industrial round wood, with Brazil, China, and India accounting for another 15%. North America is both the world's major producer and exporter of industrial wood, producing 38% of the world's production. Comprising 19% of the value of primary forest products in 2000, international trade has sufficient weight to affect spatial patterns of harvests. Including harvested firewood would likely lower the percentage of products exported. Because the low energy content of firewood makes its distant transportation impractical, its inclusion would likely add more to the numerator than the divisor and thus lower the export percentage. Nevertheless, in some cases, trade can export the impact of one nation's timber consumption to another nation that harvests the timber (22, 23).

Tropical timbers are mainly produced and consumed within the tropical world. Temperate developed countries import modest amounts of African and South American timber. The Southeast Asia–Pacific region is the only large producer and exporter of tropical wood, with much flowing from Malaysia and Indonesia to the other Asian countries, including Japan and China, and also to the U.S. and Europe. These are instances of exported impact or leakage of one nation's timber consumption to another's forests.

Logically, and other things being equal, trade from warmer, moister climates, where trees grow fast, to cooler or drier ones, where they grow slowly, decreases the global forest area harvested. For example, trade between U.S. regions encourages shifting round wood production to the South, where trees grow faster than in the North. From 1976 to 2001, harvest in the South rose 1.6% per year, much faster than the slow 0.3% per year rise in the North (3). The shift toward harvest in a region where density increases about twice as fast slowed the expansion of area to replace the growing stock by 17% or 3,100 kha. (See analysis in supporting information, which is published on the PNAS web site.)

Similarly, exports from fast-growing plantations decrease the global forest area harvested. Production plantations are being established in South America, Africa, Asia, and the southern U.S. As they are planted, plantations enable the introduction of improved trees, whether the trees are improved by classic or new methods (24). Already 33% of the world's industrial wood comes

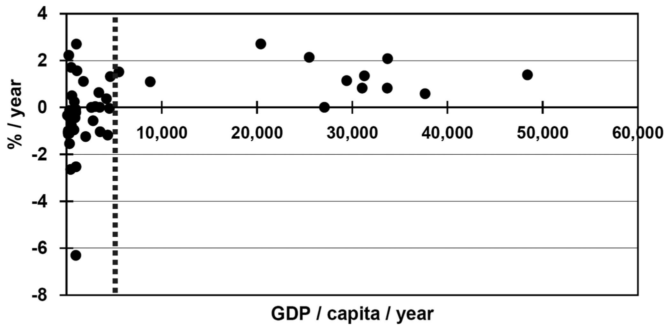

Fig. 4. The average annual change $a + d$ of growing stock in nations plotted as a function of their GDP per capita. The vertical line marks \$4,600. The change in growing stock was measured during 1990–2005 and the GDP in U.S. dollars in 2003. The vertical axis expresses the rate of growing stock change. The nations depicted are those with the most growing stock reported in 2005, except French Guiana and Myanmar, for which GDP was lacking. Canada reported identical forest area and no change in growing stock from 1990 to 2005 (4, 34).

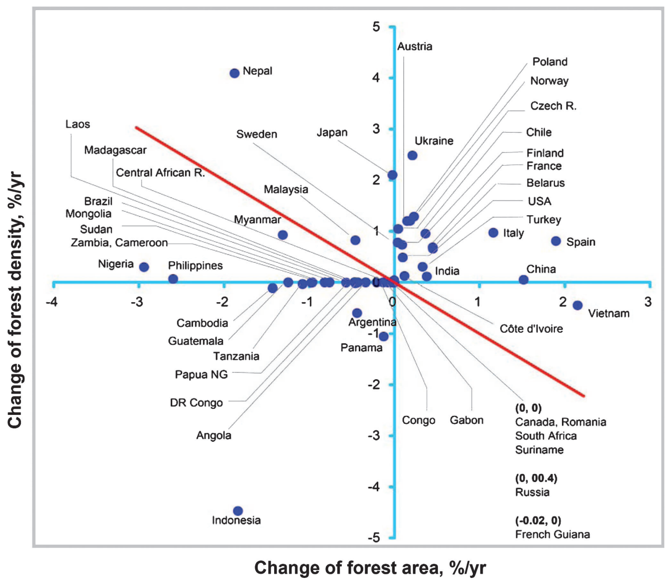

Fig. 5. A synoptic chart of changing forests during 1990–2005 in the 50 nations with the most growing stock reported in 2005. On the chart, the horizontal axis or longitude is the relative change of forest area (a), and the vertical axis or latitude is the relative change of growing stock density (d). Volume (v) was positive in nations above the diagonal line, $a = -d$, because growing stock was increasing.

from plantations (25). Expansion of plantations is expected to lower the percentage of wood production volume from natural forests from the present 67% to 50% by 2025 and 25% of production by 2050 (26). Consider the entire decrease from 67% to 25% natural production and the 33% to 75% increase of plantation production that caused it. Logically, lowering the volume harvested from natural forests from 67% to 25% will shrink the natural area to match their production from 80% down to 40% of the total area to match all production. (See analysis in supporting information). Thus, plantations and the trade to make them effective reduce the impact of industrial pressures on natural forests, which may be rich in soil carbon and biodiversity.

Discussion

If humanity causes an environmental impact, the impact is reasonably hypothesized to increase with the human activity measured by GDP. If the impact increases with GDP at low incomes but then decreases at higher incomes, the result is said to follow an environmental Kuznets curve (27, 28). The growing stock in a sample of 50 nations did not change regularly with GDP at low levels of GDP per capita, but with one exception, the growing stock grew from 1990 to 2005 in the nations with more than approximately \$4,600 GDP per capita (Fig. 4). In the exception, Canada improbably reported identical area and growing stock in 1990 and 2005. Evidently, the tendency of nations to work toward higher GDP and measures such as good governance that raise GDP do not uniformly shrink forests.

A chart with coordinates of changing area a and density d displays a synoptic view of the performance of the many nations with adequate data (Fig. 5). Shrinking forest area and, especially, declining density make Indonesia an outlier on the chart. The expansion of forest areas in China, India, Italy, Spain, and Vietnam locates these five nations of diverse climate and wealth on the right side of the chart. The annual 2–4% increase of the density of Japanese, Nepalese, and Ukrainian forests locates these diverse nations high on the synoptic chart.

The causal relationships in the Forest Identity support the interpretation of Fig. 5 and its coordinates of the basic rates a and d in terms of the valued attributes of the forest. One measure of interest for all nations is whether their growing stock or volume (v) is increasing. The diagonal line in Fig. 5 represents $a = -d$, and in those nations above the line, $v = a + d$ is positive. The horizontal and vertical distances between a national data point and the diagonal line equal one another and equal the national change in volume v. Eight of the nine nations mentioned in the preceding paragraph lie above the diagonal line, indicating increasing growing stock. The Identity and its chart show that Japan and Nepal increased their stock by compensating for shrinking area with growing density. Vietnam increased its stock by compensating for a declining density by expanding its forest area.

Other attributes of interest are the changes in tons of biomass and sequestered carbon. If $b = -0.3 \times d$, nations with increasing and decreasing biomass (m) could be separated on Fig. 5 by a diagonal line representing $m = a + d + b = a + (1 - 0.3)\, d = 0$. If the carbon concentration of biomass changes negligibly, the diagonal line for $m = 0$ is also the line for carbon $q = 0$. Because Vietnam increased its volume by expanding forest area faster than density fell, the distance from $m = 0$ on the chart exceeds the distance from $v = 0$, reflecting a faster increase of biomass and sequestered carbon than volume and probably a faster increase of young trees rather than growth of older ones. In the opposite way, a nation like Nepal that countered its shrinking forest area with increasing density, the distance from $v = 0$ on the chart exceeds the distance from $m = 0$, reflecting a faster increase of volume than biomass and carbon. Among the 50 nations plotted on the synoptic chart, however, none fell between the line for $v = 0$ drawn on Fig. 5 and lines for $m = 0$ and $q = 0$ that might be drawn. That is, none of the 50 nations accumulated biomass or carbon without also increasing their volume of growing stock.

At the same time that Fig. 5 opens a synoptic view of forest changes, it also exposes shortcomings in data that should encourage improved measurement. Consider, for example, the line of nations along the equator of $d = 0$ whose forests apparently shrank without changing density. Although the unchanging densities may be real, they may also be an artifact of the estimation of national growing stock from area alone.

A synoptic chart of biomass or carbon rather than growing stock would need adjustment for any b not equal to $-0.3 \times d$. Despite qualifications, the message about prospects from the synoptic chart of a and d comes from the goodly number of nations, some after transitions, that have improved their forests amid deforestation in other nations. According to the attribute most valued, transitions could be defined on the chart as positive change in area (a) or as greater distances above the lines for zero of volume (v), biomass (m), or carbon (q).

The distribution of points in Fig. 5 suggests four groups of countries, which illustrate causes of deforestation and restoration. In the first, exemplified by China and India, conversion of land to forest expanded the area. Because new forests were young, the trees on the converted land added growing stock per area slowly.

In the second group, exemplified by Europe and the U.S., volume per area increased, although forest area expanded slowly. In this group, one can suggest, forest protection allowed volume per area to grow, while preservation of farming retarded forest expansion. The determinants of forest transitions in Europe included agriculture, silviculture, timber imports, energy technology, economic development accompanied by a rural exodus, and government policies. Governments intervened with legislation, road networks, forest services, nature conservation, education, expertise, and policies on afforestation. With improved transport and new technologies, agriculture intensified and concentrated on fertile areas, accentuating the abandonment of marginal land. Migration to urban–industrial centers depleted rural populations. Fossil fuels replaced wood, and declining rural populations used less fuel wood.

In the U.S., agricultural development in the Midwest and rail transportation played special roles. In parts of the South, forests reclaimed land where cotton and tobacco fields were abandoned before and during the Great Depression of the 1930s and then again in the postwar boom of the 1950s. Disturbance, whether by farming, wildfire, pests, or logging, was not forever fatal.

In the third group of nations in Fig. 5, the slowly changing area and volume per area hint that a forest transition is near. Accounts today of lessening deforestation in some parts of the world resembled the change of deforestation in Europe in the 19th century. Subsequently, European deforestation halted and gave way to expansion, in area and density, that has been sustained over many decades. Logically, transitions in nations with extensive forests, like China and possibly Russia or Canada, have the greatest absolute effect. The transition in India is encouraging for other tropical developing nations.

In the fourth group of nations evident in Fig. 5, forests suffered. In Indonesia, both area and volume per area shrank, and in Nigeria and the Philippines area shrank.

What forces that brought transitions to the first two groups of nations might bring transitions to the other two? In most cases, combinations of factors were responsible, including agricultural and wider socioeconomic factors as well as increasingly effective enforcement of forest laws. Growth in off-land employment and migration to urban areas reduced pressures on the forest by rural populations. Rising crop yield has spared and may well continue to spare land for forests (29). Rising timber yield, for example, in plantations helps meet timber demand with fewer disturbances to natural forests as reasoned above. A dramatic example of a steep forest transition is South Korea, where the national total biomass stock increased >4-fold from 1973 to 2000 (30).

Of course, changes in the demand for lumber, pulp, and fuel as well as food will heavily determine future land use and cover. Fortunately for forests, the consumption of timber products has lagged behind population and income (31). In the U S., as early as 1987, the demand for newsprint switched from a steady and steep annual rise to a decline, which reduced the consumption from the peak of 12 million tons in 1987 to 10 million tons in 2004 (32). Replacement of fuel wood by fossil fuel has spared forests, a sparing that increasing use of biomass fuel would reverse.

Conclusion

Forests combine the area that harbors biodiversity and insulates people with the density of timber per ha to grow product for construction and fuel. Forests also combine area and density with the third variable of biomass per timber volume to grow the biomass that energizes ecosystems and economies. And adding the fourth variable of carbon concentration, they sequester carbon per ton of biomass. Decomposing the rates of changing timber volume into the sum of two components, the rates of changing biomass into the sum of three components, and the rates of changing carbon sequestration into the sum of four components serves a purpose. It can, for example, quantitatively estimate the impacts on the forest area harvested by trade between regions of fast and slow tree growth and by plantations. Decomposition in the Forest Identity allows the display of the components and their sums on a single chart. It exposes the forces that could switch forests from subtractions to additions of timber and biomass and switch them from producing to reducing the greenhouse gas, carbon dioxide.

Use of the Forest Identity may also improve prediction of future forests and clarify changes needed to achieve prescribed forest goals. Although this report has used the Identity to identify historical trends, the Identity could create scenarios by foreseeing reasonable rates of change for each of the four variables, nation by nation and region by region. Assembling the proper variables in a causal relationship leads to estimates of the attributes of changing hectares of forest, m^3 of growing stock, tons of biomass, or tons of carbon. Alternatively, the likelihood of any desired change in an attribute, such as sequestered carbon, could be tested by inquiring whether reasonable rates of change of the driving variables assembled in the causal relationship match the anticipated change of the attribute.

Recent assessments suggest that forest transitions of the kind experienced in Europe and the U.S. during recent centuries are now spreading to some other parts of the world. Deforestation does continue in about half of the 50 nations with most forest. However, 36% of the 50 increased forest area and 44% increased biomass. Without depopulation or impoverishment, increasing numbers of countries are now experiencing transitions in forest area and density. Although complacency would be misplaced, insights provided by FRA2005 and the Forest Identity provide grounds for optimism about the prospects for returning forests.

Materials and Methods

Addressing the difficulties of taking measurements in the field in diverse nations, the FRA2005 (4) is the most comprehensive assessment of global forest resources to date. It covers 229 countries and territories in 1990, 2000, and 2005. National governments and specialists, including 172 national teams, provided the voluminous data. FRA2005, compiled in 2003–2005, is the latest in the FAO's series of assessments of world forests at intervals of 5–10 years since 1946. Mather (33) examined the evolution, challenges, and remaining difficulties of the global assessments. Importantly for this paper, FRA2005 adjusted 1990 values for comparison with 2005 values, and the analyses here calculate average percentage rates of change during the 15-year span of 1990–2005. Other surveys and scholarly histories of national forests that expand the 15-year span of FRA2005 are cited above. Because the method of the Forest Identity is both new and essential to the analysis, it is developed in the text.

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