Are the world's forests really expanding?

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The short answer is yes, but let me try to convince you using information from foresters and botanists, that the world's forests are thriving better than often portrayed in newsprint and television. Photosynthesis is the best phenomenon to start with, at the heart of how forests and woodlands can expand in several fundamental ways. This amazing biochemical engine takes in carbon dioxide from air then strips out the carbon to incorporate that element into the bulk of leaves, branches, stem and roots. The roots absorb water then photosynthesis splits molecules of H_2O such that its hydrogen goes mostly to combine with carbon and overall oxygen is excreted as a waste gas to the atmosphere. Usually there is sufficient water and sunlight for these reactions but carbon dioxide is always in short supply. From the perspective of plant growth CO_2 has become a trace nutrient. Plants evolved in ancient atmospheres rich in this gas and now retain the ability to respond to higher concentrations of it with greater growth. That is measured in grams or tonnes (1 million grams = 1 tonne = 1Mg) as increased structural material, mainly cellulose and lignin, the biomass of the plant. Doubling the CO_2 concentration in a greenhouse full of tomato vines doubles the rate of photosynthesis of the plants. Horticulturalists often use bottles of this industrial gas. Stands of trees grown experimentally in a setup called Free-Air Carbon dioxide Enrichment will increase by mass per unit area, at double the rate of the control stands without this enrichment. This type of increase in plant growth, natural or artificial, is called CO_2 fertilization.

More CO_2 aggravates the greenhouse effect and since 1900 the world's atmosphere heated overall by over 1.0°C. This varies with latitude: northern zones have heated more than those south of the equator. Speed of chemical reactions increase as the surrounding temperature rises, including photosynthesis, thus potentially accelerating the rate of growth of plants. Not in a direct or linear way though, because of interactions with limiting nutrients such as nitrogen and also supply of water. Nevertheless, length of season for plant growth expands with warmer climates. Sites where this has been studied over large areas using data from satellites to produce maps, together with direct observation of trees at ground level, reveal green leaf for longer each year. Researchers call this *greening*, for deciduous broad-leaf trees at least: leaf-bud starts earlier and leaf-fall starts later. This seasonal (phenological) expansion leads directly to greater growth, as tonnes of woody biomass per hectare of forest. Usually this is expressed, for consistency in publications, as mass of carbon rather than wood (weight for weight, fully dry wood comprises about half carbon).

Foresters with an interest in history – encouraged by the longevity of their subjects – and who work in regions with old maps and administrative documents, know how forest landscapes change. They may see a sequence from dense natural forest to cropland and pastureland with isolated stands of trees, then back again to dense forest after the farmlands have been abandoned. The forest remnants expand over wider areas of land and come to resemble approximately the original forest. National parks, nature reserves, patches of farmland set-aside, are places where regeneration of trees either happens naturally or is encouraged by people. Forestry agencies are now motivated by subsidy and legislation from national governments to plant more forests specifically to remove carbon from the air and store it as standing trees, as dead wood in soil, and as construction timber, lumber. The subsidy is usually related to obligations of governments to international treaties for mitigating climate heating.

There are three mechanisms of expansion of forests. Both CO_2 fertilization and forest greening increase tonnes of woody biomass within a forest, and forest regeneration increases the area of land covered by trees. But life is complicated and examples here will show the variability within what appears to be a general trend. The growth of a forest may decrease over time.

In eastern Canada researchers measured tree-rings (dendrology technique) to assess growth rate from 1950 to 2007 at nine sites in a transect from James Bay to Nova Scotia, covering nine degrees of latitude and four vegetation zones. They recorded a decline in the growth of needle-leaf and broad-leaf species. They proposed that water stress induced by heating of the atmosphere was the main cause.

During a study in the Amazon basin at 321 sites researchers assessed individual trees by measuring stem diameter and height to calculate biomass per hectare per year. They found this growth rate declined moderately.

In the Congo basin researchers using satellite imagery and ground level sensors recorded more browning of the canopy than its greening. They concluded this was probably due to a decline in the moisture level of the forest, induced by the combination of short but severe droughts and changes in the structure of the upper canopy.

Such examples of decline in forest biomass, or of *browning* of vegetation, contrast with studies using various methods that show increase in forest biomass or growing season. South of Annapolis in eastern USA there is a forest owned by the Smithsonian Institution. Formerly this area was farmland but by now the naturally regenerated trees have been closely investigated during many decades. When the scientists plotted data about the stem dimensions of trees collected over 22 years at 55 plots within the forest, as biomass per hectare, the graph revealed an upwardly curving line. The tree's growth rate had accelerated: its average for these broad-leaf trees was equivalent to 1.7 tonnes of carbon per hectare per year (1.7MgC /ha/yr, or 1.7MgC $ha^{-1}yr^{-1}$). At this site since 1900 the yearly average temperature rose by 2.4°C, the growing season lengthened by 41 days, and since 1970 the concentration of CO_2 increased by 50 parts per million.

A contrast of scale was a study of natural forest at ten sites across South America, Africa and Asia. Researchers measured two million trees by diameter, height and density of wood to calculate biomass. At seven sites trees increased biomass whilst at three sites their growth declined. Average accumulation of carbon at all sites was 0.24MgC / ha/yr.

A similar study concentrated on six countries of the Amazon basin, spanning the dry south east to the wet north west. The team measured six hundred trees for ten years each to estimate the cross-sectional area occupied by the tree stems. The growth rate trees accelerated during the study and average across the Amazon basin was 0.62MgC /ha/yr. The researchers attributed this accelerating growth to CO_2 fertilization.

Some areas of vegetation are browning at a global scale. Researchers have shown a long term decline of biological activity that is most clearly seen from space as reduced leaf cover over the nineteen years worth of suitable data. The researchers attributed this decline to warmer air leading to dehydration stress on the plants. This browning trend almost balanced a greening trend that collaborating researchers in the same study detected in other regions. However, this study included all types of vegetation and the general statement the researchers made was that greening had been greater than browning for forests, shrublands, savanna, grasslands and croplands.

Results from this type of study using satellite imagery vary greatly because of the different techniques for data from space and the many types of mathematical models used to analyse the raw data. Workers on another study of this type found a persistent increase of growing season, as greening, over 25% to 50% of the world's vegetated area, whilst 4% of this area showed a decrease of growing season as browning. The study included all vegetation types but conspicuously greening forest areas included the Amazon and Congo basins whilst areas of browning to a similar degree were in some parts of the wide northern boreal zone.

Our world has suffered huge loss of forest over large areas: we cut down and use trees. Centuries ago in many countries of Europe dense wide forests were cleared, leaving small fragments, during agricultural development whilst trees were rapidly felled for construction timber and domestic and industrial fuel. Scientists of the Food and Agriculture Organisation of the United Nations perform regular assessments of global forest resources, as areas covered by trees, by using a combination of satellite imagery and inventories of national forestry agencies. Their latest assessment of changes by area from 1990 to 2015 show globally for all forests, natural and planted, there has been a loss of 3.1%. This comprises a loss of 6% for natural forest at a total of 240 million hectares but a gain for planted forest of 40% at a total of 110 million hectares. Despite this loss of natural forest the current data show increased areas in the temperate biome, also increased areas of planted forest in the boreal, temperate, sub-tropical and tropical biomes.

New England in the eastern USA was where the pattern of agricultural development replacing dense cover of mixed forest became conspicuous by the early 1800s. Now in Massachusetts, at Harvard Forest, researchers have followed the phenomenon of forest expansion by area through historical records of land use and categories of vegetation. When farmers modernized using powerful machines and artificial fertilizers most of them found it profitable to move westward to exploit lands more suitable for this revolution. Gradually on the remaining abandoned farmlands stands of trees spread their seed and regenerated forests. If now you view the area, using satellite images online, the few remaining farms are conspicuous amongst a wide and dense canopy dominated by deciduous broad-leaf species. This transformation developed on fertile and well watered land.

In ecological contrast is an entire administrative district of southern Italy: Basilicata with its one million hectares and two Mediterranean Sea coastlines. A team studied this entire area using satellite data covering twenty six years and they checked this against visual checks on the ground at eighty random sites. They found that the woodlands of Basilicata had expanded in area by 70,154 hectares, an increase on the original areas covered by trees of 19.7%. Furthermore, this expansion of tree cover is at the southern end of the Apennine mountain chain, characterised by infertile and unstable soils all prone to drought and excessive heat. Each patch of trees remaining on high land acted as a refuge (refugium) from which seeds dispersed out onto land that was becoming less used for intensive agriculture.

Landscape conservationists now call this type of regeneration natural rewilding but a similar landscape can be created by planting and tending seedlings. There are many areas of the world where the ecological potential for people actively to restore tree cover in various ways appears greater than commonly understood. This has been mapped using satellite data and mathematical models (global map of forest cover available online, see References).

The economic, social and political context is clearly crucial for these examples of forest expansion and regeneration to become commonplace. This is complex and difficult: it involves people and the social friction that inevitable follows from their differences of interest and power.

Evidence has been published of the effect that horticultural or incidental CO_2 fertilization has on crops: decrease of vital nutrients in food for people, such as zinc, iron and protein. Tropical and subtropical forests, those huge carbon stores or sinks, are inhabited by people with land-rights that are usually traditional, undocumented or non-existent. Such rights are often deliberately ignored by outsiders seeking profitable timber or new croplands. The formalization and enforcement of land-rights, and payment for ecosystem services delivered by indigenous people, remains vitally important for any worldwide trend of forest expansion. The irony of forests expanding because of direct effects of increasing CO_2 and heat on plant growth is bitter. Nevertheless, forests also expand because we cultivate and plant trees, we make space and protections for them, we seek better ways of managing fires, and we fight against deforestation.

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