"Greening or browning of forests: where is the balance?"

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This essay is about the differing accounts of how well forests, and other types of vegetation, are growing in healthy condition: green or brown, growing well, growing poorly or not at all. It is not directly connected with broad-leaf trees in leaf during summer or wet season compared to the same trees in winter or dry season. Greening and browning can be detected on the ground by foresters but for long there have been methods for wide scale collection of data using satellites that can measure the condition of the leaf cover of croplands and wooded lands. The data from satellites can be analysed to adjust for seasonal variations. The technical complexities of measuring areas of both broad-leaf or needle-leaf forests can also be overcome by using specific criteria to differentiate the data. This data from satellites is ideal for producing maps of large areas of the world, providing overall understanding of what is happening on the ground.

Greening is related to several factors: increased warmth, increased rainfall, and increased concentration of carbon dioxide in the atmosphere. Carbon dioxide is a scarce resource for plants. Many experiments have been done on crop plants and stands of young growing trees to artificially increase the concentration of this gas around a small area of land on which the gas is pumped out from industrial gas cylinders over a time long enough to measure the difference relative to the surrounding vegetation. These are described as Free to Air Carbon dioxide Enrichment experiments. More CO_2 leads to more growth. Browning in contrast can result from a reduction in growth rate of vegetation from many causes: drought, storms, fire, excessive rate of harvesting . . .

Greening or browning of vegetation of all types refers to what can be seen by using satellites to provide photographic images, similar to those on Google Earth website. Also information gathered from satellites can provide detailed data of several types that are directly relevant to vegetation, such as Normalized Difference Vegetation Index, or Leaf-Area-Index. (See Wikipedia articles by those names.) NDVI has been used since the beginning of satellite based studies of geographical trends, so there are long series of data available. LAI is more recent but is more directly related to growth rate of vegetation and thus health of that vegetation. The definition of Leaf-area-index for broad-leaved vegetation is the one-sided leaf area (square metre) per ground area (square

metre); for needle-leaved vegetation it is half the total leaf area per square metre ground area. So this index is a ratio, not a quantity on some linear scale.

The information that can be extracted from these types of data goes beyond the visual images, often like photographs, shown in the papers on this topic. The information is a direct indication of, a proxy, for rate of growth of vegetation. Such growth as an increase in biomass is known technically as Net Primary Production, as mass per unit area per time, typically: tonnes per hectare per year. (See *Trees to store carbon*, this website).

A selection of eight studies of greening and browning are summarised below such that a wide variety of land areas and biomes of the world are included. Many more studies have been made but this is an essay, not a formal review of the large literature on this subject.

A study based on remote sensing leaf-area-index during 2000 to 2018, from five areas of the world reported consistent trends of greening widely over Earth, mostly in the northern hemisphere. By percentage of overall greening in the surveyed areas of these regions showed: Asia at 35%; Europe 32.5%; North America 13.3%; Africa 12.6%; South America 6%; and Australia 0.5%. (Cortes, 2021.)

A report based on data from the system of Normalized Difference Vegetation Index, during 1982 to 2015 revealed a progressive increase of vegetation browning globally in the following regions: boreal forests of Eurasia; Europe; North America; South America; Asia; Australia, and the Congo basin in Africa. The environmental factors that are driving this browning trend are mostly related to climate change. (Liu, 2023]

Another study using data from the leaf-area-index system, during 1981 to 2017 showed that, over globally distributed regions, greening is mostly associated with intensive management of land by farmers and foresters. In contrast, in areas of natural vegetation there are variable patterns of greening and browning in all continents. Greening was also associated with warming of the atmosphere in the northern hemisphere. Browning in tropical regions was more typically associated with large variations and disturbances in patterns of rainfall. The phenomenon of carbon dioxide fertilization producing greening of vegetation was dominant only in temperate forests and grasslands of cooler

climatic regions. This pointed to a lack of any worldwide effect of CO2 fertilization. The overall global trend was identified as a decrease of greening and an increase of browning. The strongest decrease of greening is in the tropical belt of dense vegetation, whilst its strongest increase is sparsely vegetated regions of temperate forests and in cold or arid regions. (Winkler, 2021).

A study using NDVI data from 2000 to 2020 of the state of natural vegetation areas of China showed a balance of 25% of the areas showed increase of greening compared to 11% of those areas with increase of browning. Overall net greening was detected in all the types of natural vegetation in China. This was most conspicuous in regions where regeneration and reforestation programs where conducted. (Yi, 2023.)

In India a study was done using NDVI data from 1981 to 2015 that reveals a widely distributed greening trend over up to 80% in the north western plain region and in Central India. Greening was associated with increase in rainfall and cooler temperatures, specially in the southern peninsula of India. (Parida, 2020).

A study done in sub-Saharan Africa using a combination of many NDVI datasets from 1992 to 2015 revealed the largest changes in land-use occurred mostly in rapidly enlarging areas of croplands. This study was about the ecosystem services (food, timber, and others) that are derived from areas with different vegetation types. This can be related here to trends of greening and browning. The general situation of all vegetation types in this vast region showing little change over 23 years as judged by the continent wide maps provided. In finer detail, the vegetation categories and their increases or decrease in relative area were shown to be as follows, in millions of hectares: cropland up 20M; evergreen forest down 5M; deciduous forest up 6M; shrubland down 20M; desert down 5M. These data indirectly reveal a trend of greening both cropland and deciduous forest totalling 26 million hectares, together with a trend of browning totalling 30 million hectares. (Fenta 2020.)

Another study was done in Africa at smaller scale and finer detail used NDVI data from 2005 to 2018. The region studied was Mount Elgon and its hinterland of well populated East Africa. This is an ancient volcano at the border between southern Uganda and eastern Kenya. The volcanic soils are fertile and this highland region of East Africa is well watered. Going uphill into the

protected region of the forests and montane highlands of Mount Elgon provide strong contrasts of land use and trends of greening and browning. Trends of both greening and browning were detected at multiple scales of area and time. Maps of the greening and browning trends show an intricate patchwork of many small area in these two categories (see images here from Google Earth). Some of this variability can be attributed to increasingly variable patterns of rainfall, in a region that at continental scale is affected by distinct weather patterns of East Africa derived from monsoon winds bearing much moisture from the Indian Ocean. These patterns are less distinct than formerly when patterns of modern agricultural use of these land were established. Here greening and browning trends are difficult to reveal against the background of changes in land-use and climate. (Wanyama, 2020).

Mount Elgon, on border of Uganda westwards, and Kenya eastwards. Central brown area of this inactive volcano has an Afro-alpine vegetation of herbs and tree-like plants. Lower slopes are dense broad-leaf forests in a national park that defines the distinct border. Surrounding areas are farmlands.

The image on next page is at closer scale showing the natural forest, stands of planted forest, and farmland.

In Europe a study using data on leaf-area-index was performed between 2001 to 2015 for the purpose of detecting greening of semi-natural vegetation, in relation to climate changes. Here semi-natural vegetation predominantly is woodland and forest. A strong overall increase in LAI was detected in all the varieties of vegetation of this category. This greening was strongly associated with changes in land-use. The strongest of these was abandonment of agricultural land. This was not confined to areas in Europe that are protected, as in National Parks and other conservation designations; areas of semi-natural vegetation outside such reserves also showed similar greening trends. At the scale of Ireland to the Balkans, and of Norway to northern coastline of Mediterranean Sea, widespread greening was recorded, with isolated patches of browning in southern regions and larger blocks of browning in the north. The United Kingdom shows large blocks of browning mostly in regions of moorlands and uplands that have for many centuries been well stocked with sheep and where both the moorlands and wooded lands have dense populations of deer. (Buitenwerf, 2018)

This information from eight long term studies in a wide range and variety of biomes of the world can be presented from a perspective different from the Argument essay: Are the World's forests really expanding?" That essay was about

land surface area, with examples from the northern boreal region where forests are migrating northward, or the Sahel region of desert lands such as the southern Sahara desert, or western deserts of China where there are major afforestation projects. This is because the comparison, or ratio, of levels of greening and browning, over time, or in a defined area, give information about the general state of heath of forests, grasslands and croplands, rather than simply area of forested land.

I can only suggest an answer based on the studies here, selected to represent a global spread of forests. An important perspective is that the methods used in these studies are similar, most are at global scale and all use historical data from satellites going back decades. Moreover they represent, as the numerous contributing authors, a large range and variety of professional expertise, local knowledge and technical approaches to this question.

It is clear from these studies that both greening and browning are dynamic processes of plant life that vary over time, and are difficult to generalize over global areas. However, pragmatic optimism is more useful than gloom about declining forests. Some are clearly greening and that trend is associated with various types of land use. That is a direct incentive to continue with woodland and forest regeneration and expansion of plantations for timber production. Also here is an incentive for different methods of food crop production. Similarly some of the causes of browning can be reduced by how these vegetation lands are managed. At the smallest scale, optimism encourages people to get out over the weekend and plant more trees.

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