BIOSPHERIC PRODUCTIVITY IN AFRICA

Is it positive or negative, and how it is responding to the "twin evils" of anthropogenic CO_2 emissions and global warming?

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Nearly three decades ago, Idso (1986) published a small item in *Nature* that advanced the idea that the aerial fertilization effect of the CO_2 that is liberated by the burning of coal, gas and oil was destined to dramatically enhance the productivity of Earth's vegetation. In fact, in a book he had published four years *earlier* (Idso, 1982), he had predicted that "CO_2 effects on both the managed and unmanaged biosphere will be overwhelmingly positive," if not "mind-boggling." And in a monograph based on a lecture he gave a few years later (Idso, 1995), he said that "we appear to be experiencing the initial stages of what could truly be called a *rebirth of the biosphere*, the beginnings of a biological rejuvenation that is without precedent in all of human history." Consequently, and in light of the fact that such a worldview is the exact *opposite* of the apocalyptic vision promoted by climate alarmists, it is instructive to see what others have discovered and published about the matter; and in this summary we report such information for the continent of Africa.

Beginning with a 2002 *New Scientist* article[1] by Fred Pearce entitled "Africa's deserts are in 'spectacular' retreat," evidence is presented of vegetation reclaiming great tracts of barren land across the entire southern edge of the Sahara. According to the author, "the southern Saharan desert is in retreat, making farming viable again in what were some of the most arid parts of Africa." In addition, he states that "Burkina Faso, one of the West African countries devastated by drought and advancing deserts 20 years ago, is growing so much greener that families who fled to wetter coastal regions are starting to go home."

Vegetation is ousting sand across a swathe of land stretching from Mauritania on the shores of the Atlantic to Eritrea 6000 kilometers away on the Red Sea coast.

What is more, besides being widespread in space, the greening was widespread in time, having been happening since at least the mid-1980s.

And the good news was not confined to Burkina Faso. "Vegetation," according to Pearce, "is ousting sand across a swathe of land stretching from Mauritania on the shores of the Atlantic to Eritrea 6000 kilometers away on the Red Sea coast." What is more, besides being widespread in space, the greening was widespread in time, having been happening since at least the mid-1980s.

[1] http://www.co2science.org/articles/V5/N45/EDIT.php.

Are such findings unique? Not in the least. In our Editorial of 15 Mar 1999, we had already reported that in a study of a series of satellite images of the Central and Western Sahel that were taken from 1980 to 1995, Nicholson et al. (1998) could find no evidence of any overall expansion of deserts and no drop in the rainfall use efficiency of native vegetation.

It has further been observed in a satellite study of the entire Sahel from 1982 to 1990 (Prince et al., 1998) that a steady rise in rainfall use efficiency has been detected, suggesting that plant productivity and coverage of the desert had actually increased during this period.

Quoting Chris Reij of the Free University of Amsterdam, Pearce wrote that "aerial photographs taken in June show 'quite spectacular regeneration of vegetation' in northern Burkina Faso." The data indicated the presence of more trees for firewood and more grassland for livestock. In addition, a survey that Reij was collating showed, according to Pearce, "a 70 percent increase in yields of local cereals such as sorghum and millet in one province in recent years." Also studying the area was Kjeld Rasmussen of the University of Copenhagen, who reported that since the 1980s there had been a "steady reduction in bare ground" with "vegetation cover, including bushes and trees, on the increase on the dunes."

Pearce also reported on the work of a team of geographers from Britain, Sweden and Denmark that had spent much of the prior summer analyzing archived satellite images of the Sahel. Citing Andrew Warren of University College London as a source of information on this study, he said the results showed "that 'vegetation seems to have increased significantly' in the past 15 years, with major regrowth in southern Mauritania, northern Burkina Faso, north-western Niger, central Chad, much of Sudan and parts of Eritrea."

But are such findings unique? Not in the least. In our Editorial of 15 Mar 1999[2], we had already reported that in a study of a series of satellite images of the Central and Western Sahel that were taken from 1980 to 1995, Nicholson *et al.* (1998)[3] could find no evidence of any overall expansion of deserts and no drop in the rainfall use efficiency of native vegetation. And it has further been observed in a satellite study of the *entire* Sahel from 1982 to 1990 (Prince *et al*., 1998) that a steady *rise* in rainfall use efficiency has been detected, suggesting that plant productivity and coverage of the desert had actually *increased* during this period.

[2] http://www.co2science.org/articles/V2/N6/EDIT.php.
[3] http://www.co2science.org/articles/V2/N6/EDIT.php.

That the greening phenomenon has continued apace is further borne out by the study of Eklundh and Olsson (2003), who analyzed Normalized Difference Vegetation Index (NDVI) data obtained from the U.S. National Oceanic and Atmospheric Administration's satellite-borne Advanced Very High Resolution Radiometer whenever it passed over the African Sahel for the period 1982-2000. As they describe their findings, "strong positive change in NDVI occurred in about 22% of the area, and weak positive change in 60% of the area," while "weak negative change occurred in 17% of the area, and strong negative change in 0.6% of the area." In addition, they report that "integrated NDVI has increased by about 80% in the areas with strong positive change," while in areas with weak negative change, "integrated NDVI has decreased on average by 13%." The primary story told by these data, therefore, is one of strong positive trends in NDVI for large areas of the African Sahel over the last two decades of the 20th century; and Eklundh and Olsson conclude that the "increased vegetation, as suggested by the observed NDVI trend, could be part of the proposed tropical sink of carbon."

In the years that have followed, many more scientists have confirmed the recent stunning increase in African vegetation. In 2005, Africa was featured in a special issue of the *Journal of Arid Environments*[4] entitled "The 'Greening' of the Sahel." Therein, Anyamba and Tucker (2005) described their development of an NDVI history of the region for the period 1981-2003. Comparing this history with the precipitation history of the Sahel developed by Nicholson (2005), they found that "the persistence and spatial coherence of drought conditions during the 1980s is well represented by the NDVI anomaly patterns and corresponds with the documented rainfall anomalies across the region during this time period." In addition, they report that "the prevalence of greener than normal conditions during the 1990s to 2003 follows a similar increase in rainfall over the region during the last decade."

The Journal of Arid Environments, Olsson et al. (2005) also report finding "a consistent trend of increasing vegetation greenness in much of the region," which they describe as "remarkable." And they say that increasing rainfall over the last few years "is certainly one reason" for the greening phenomenon.

However, they find that the increase in rainfall "does not fully explain" the increase in greenness.

In another analysis of NDVI and rainfall data in the same issue of the *Journal of Arid Environments*, Olsson *et al*. (2005) also report finding "a consistent trend of increasing vegetation greenness in much of the region," which they describe as "remarkable." And they say that increasing rainfall over the last few years "is certainly one reason" for the greening phenomenon. However, they find that the increase in rainfall "does not fully explain" the increase in greenness.

4 http://www.co2science.org/articles/V9/N2/EDIT.php.

For one thing, the three Swedish scientists note that "only eight out of 40 rainfall observations showed a statistically significant increase between 1982-1990 and 1991-1999." In addition, they report that "further analysis of this relationship does not indicate an overall relationship between rainfall increase and vegetation trend." So what else could be driving the increase in greenness?

As for the major cause of the increased growth, Ichii *et al.* favored carbon dioxide, reporting that "CO_2 fertilization effects strongly increased recent NPP [net primary productivity] trends in regional totals."

Olsson *et al*. suggest that "another potential explanation could be improved land management, which has been shown to cause similar changes in vegetation response elsewhere (Runnstrom, 2003)." However, in more detailed analyses of Burkina Faso and Mali, where production of millet rose by 55% and 35%, respectively, since 1980, they could find "no clear relationship" between agricultural productivity and NDVI, which argues against the land management explanation.

A third speculation of Olsson *et al*. is that the greening of the Sahel could be caused by increasing rural-to-urban migration. In this scenario, widespread increases in vegetation occur as a result of "reduced area under cultivation," due to a shortage of rural laborers, and/or "increasing inputs on cropland," such as seeds, machinery and fertilizers made possible by an increase in money sent home to rural households by family members working in cities. However, Olsson *et al*. note that "more empirical research is needed to verify this [hypothesis]." And in response to this call for additional research, many scientists answered in the months and years that followed.

In a model-based study, Ichii *et al*. (2005)[5] "simulated and analyzed 1982-1999 Amazonian, African, and Asian carbon fluxes using the Biome-BGC prognostic carbon cycle model driven by National Centers for Environmental Prediction reanalysis daily climate data," after which they "calculated trends in gross primary productivity (GPP) and net primary productivity (NPP)." In doing so, solar radiation variability was found to be the primary factor responsible for interannual *variations* in GPP, followed by temperature and precipitation variability. In terms of GPP *trends*, the authors report that "recent changes in atmospheric CO_2 and climate promoted terrestrial GPP increases with a significant linear trend in all three tropical regions." In the African region, for which we are most interested in terms of the present discussion, the rate of GPP increase was about 0.3 PgC $year^{-1}$ per decade. As for the major cause of the increased growth, Ichii *et al*. favored carbon dioxide, reporting that "CO_2 fertilization effects strongly increased recent NPP trends in regional totals."

In another study published that same year, Herrmann *et al*. (2005)[6] investigated the "temporal and spatial patterns of vegetation greenness and rainfall variability in the African Sahel and

[5] http://www.co2science.org/articles/V8/N50/B2.php.
[6] http://www.co2science.org/articles/V9/N23/B1.php.

their interrelationships based on analyses of Normalized Difference Vegetation Index (NDVI) time series for the period 1982-2003 and gridded satellite rainfall estimates." Based on their analysis, the three researchers determined that "the overall trend in monthly maximum NDVI [was] positive over a large portion of the Sahel region, reaching up to 50% increase in the average NDVI in parts of Mali, Mauritania and Chad." In addition, they found that "rainfall emerges as the dominant causative factor in the dynamics of vegetation greenness in the Sahel at an 8 km spatial resolution," but that "the presence of spatially coherent and significant long-term trends in the residuals suggests that there might be another, weaker, causative factor," which is also suggested by the fact that the "recovery of vegetation greenness [was] beyond what would be expected from the recovery of rainfall conditions alone."

In a discussion of their findings, Herrmann *et al*. state that their study "confirms previous regional-scale findings for the period 1982-1999 by Eklundh and Olsson (2003) and Olsson *et al*. (2005), who observed widespread positive trends of both time-integrated NDVI and NDVI amplitudes, and Anyamba and Tucker (2005), who [observed] increases in growing season NDVI across most parts of the region." In concluding, they thus say that "a greening of the Sahel expressed in positive trends in NDVI indicates a net increase in biomass production during the period 1982-2003, which challenges the notion of irreversible desertification in the Sahel."

A greening of the Sahel expressed in positive trends in NDVI indicates a net increase in biomass production during the period 1982-2003, which challenges the notion of irreversible desertification in the Sahel.

Writing as background for their work on the subject, Midgley and Seydack (2006)[7] note that "present and predicted future impacts of global environmental change on intact forests are both alarming and contentious," and that "some local models have predicted the *demise* [italics added] of South Africa's only significant extent of indigenous forest, the Knysna forest, by 2050," as reported by Midgley *et al*. (2001). In a study designed to see how bad things had become by the end of the 20th century, the pair of authors measured and analyzed the growth of all trees greater than 10 cm in diameter at breast height in 108 0.04-ha plots distributed throughout an unharvested nature reserve within the Knysna forest over the period 1991-2001.

Following a protocol that provided what they say is "probably an under-estimate," the two researchers determined that "net basal area and aboveground biomass increased over the 10-year study period by 2% and there was a 1.2% increase in stem numbers, distributed almost equally amongst all size-classes." Yet, because of the particular nature of the Knysna forest, Midgley and Seydack say that "over relatively short periods such as our decade, the aboveground biomass of this forest is more sensitive to negative/stressful conditions that would increase mortality, than to factors which may increase growth." Nevertheless, and *in spite of this*, they found that "biomass increased." And because "precipitation over the period

7 http://www.co2science.org/articles/V10/N4/B1.php.

1991-2001 was some 5% less than the long-term average," they concluded that the observed increase in growth rate "may have been the effect of the increase in global atmospheric carbon dioxide."

In a contemporaneous study, Seaquist *et al*. (2006)[8] provided important new details about the "greening up" of the African Sahel. Using a satellite data-driven light-use efficiency model to assess changes in absolute amounts of net primary production (NPP), expressed as carbon content, and its inter-annual variability in the African Sahel for the period 1982-1999, Seaquist *et al*. report that an extensive, albeit discontinuous, east-west band of NPP increase (>10 g C m^{-2} $year^{-1}$) was identified. The band extended up to about 17°N, and included several hotspots (>20 g C m^{-2} $year^{-1}$) in central Senegal, south-western Mali, southern Chad, southern Sudan, as well as the Ivory Coast and southern Benin. For the Sahel in its entirety, the researchers determined that the mean rate of change per pixel was 8.4 g C m^{-2} $year^{-1}$, which yields a total mean rate of change of 51.0 Mt C $year^{-1}$ and an absolute net gain in NPP over the entire 18-year period of 918.0 Mt C. In addition, they report that "this increase is associated with a decrease in the inter-annual variability of NPP for the 1990s compared to the 1980s," such that "overall, the increase in NPP through time appears to be associated with an increase in the stability of this ecosystem," with the changes in carbon capture and increase in stability being driven primarily by rainfall "followed by atmospheric CO_2."

As for what the driving force is that seems to have breathed new life into old trees, taxon-specific analyses of African inventory and other data suggest that widespread changes in resource availability, such as increasing atmospheric carbon dioxide concentrations, may be the cause of the increase in carbon stocks, as some theory and models predict.

Focusing more on carbon sequestration, Lewis *et al.* (2009)[9] documented changes in aboveground carbon storage in "79 permanent sample plots spanning 40 years (1968-2007), located in closed-canopy moist forest, spanning West, Central and Eastern Africa," based on data obtained from more than 70,000 individual trees spread across ten countries. Their work revealed that "aboveground carbon storage in live trees increased by 0.63 Mg C ha^{-1} $year^{-1}$ between 1968 and 2007," and that "extrapolation to unmeasured forest components (live roots, small trees, necromass) and scaling to the continent implies a total increase in carbon storage in African tropical forest trees of 0.34 Pg C $year^{-1}$."

In discussing their results, the 33 researchers who conducted the study say the observed changes in carbon storage "are similar to those reported for Amazonian forests per unit area,

8 http://www.co2science.org/articles/V10/N19/B1.php.
9 http://www.co2science.org/articles/V12/N26/EDIT.php.

providing evidence that increasing carbon storage in old-growth forests is a pan-tropical phenomenon," and they report that "combining all standardized inventory data from this study and from tropical America and Asia together yields a comparable figure of 0.49 Mg C ha^{-1} $year^{-1}$," which equates to "a carbon sink of 1.3 Pg C $year^{-1}$ across all tropical forests during recent decades," which can account for roughly *half* of the so-called *missing carbon sink*, which has been long sought but never found (but is now, perhaps, half-found).

As for what the driving force is that seems to have breathed new life into old trees, Lewis *et al*. write in the concluding sentence of the abstract of their paper that "taxon-specific analyses of African inventory and other data suggest that widespread changes in resource availability, such as *increasing atmospheric carbon dioxide concentrations* [italics added], may be the cause of the increase in carbon stocks, as some theory (Lloyd and Farquhar, 1996) and models (Friedlingstein *et al*., 2006; Stephens *et al*., 2007; Ciais *et al*., 2008) predict."

Primarily in response to the ongoing rise in the air's CO_2 content, it would appear from the results of this study that the African continent is significantly greening up, and that it has recently been doing so at a significantly enhanced rate.

Returning once again to a model-based study, Ciais *et al*. (2009)[10] modeled the terrestrial carbon balance of Africa over the past century (1901-2002) using a spatially-resolved process-based vegetation model (ORCHIDEE), which is forced by changing climate, human-induced changes in land use, and a parameterization of natural fires. This work revealed that the African net terrestrial carbon (C) balance increased from a net CO_2 source to the atmosphere of 0.14 Pg C per year in the 1980s to a net sink of 0.15 Pg C per year in the 1990s." In addition, they say that the land use flux due to deforestation was "a source of 0.13 Pg C per year," and that "this implies that climatic trends (mainly increasing precipitation) and CO_2 increase (the fertilization effect), are causing a sink of 0.28 Pg C per year which offsets the land-use source."

In further discussing their findings, the five researchers indicate that "the trend of gross primary production is closely matching the trend in satellite observed NDVI," or Normalized Difference Vegetation Index; and they write that their simulated trend in gross primary production "is also consistent with an increased vegetation activity over [the] Sahel reported by Eklundh and Olsson (2003) and Olsson *et al*. (2005)," while at the continental-scale the gross primary production trend can be largely (70%) explained by the CO_2 fertilization effect. Primarily in response to the ongoing rise in the air's CO_2 content, therefore, it would appear from the results of this study that the African continent is significantly "greening up," and that it has recently been doing so at a significantly enhanced rate.

[10] http://www.co2science.org/articles/V13/N2/B1.php.

In an attempt to overcome shortcomings, the two scientists developed a new vegetation model -- the adaptive dynamic global vegetation model (aDGVM).

Forward simulations to the year 2100 with this impressive model suggest that grasslands will spread into the Sahara and into the horn of Africa. In addition, it is predicted that 34.6% of today's grasslands are transformed into savannas, and 45.3% of today's savannas are transformed into deciduous woodlands. Thus, the CO_2- and warming-induced greening of the earth phenomenon, which has been manifest throughout the entire world over the past few decades, seems destined to continue throughout the entire 21st century in Africa.

One year later, Doherty *et al.* (2010)[11] modeled future changes in land biogeochemistry and biogeography in the region bounded by 12.5°N, 12.5°S, 25°E and 42.5°E, representing most of East Africa (Kenya, Tanzania, Uganda, Rwanda, Burundi, Ethiopia, and Somalia), as well as portions of Central Africa (the Democratic Republic of Congo and Southern Sudan). This they did using eighteen future climate projections derived from nine general circulation models that figured prominently in the IPCC's Fourth Assessment Report, employing the projections as input to the Lund-Potsdam-Jena dynamic global vegetation model that simulates changes in vegetation and ecosystem carbon cycling under future climate conditions, based on what they describe as "a coupled photosynthesis-hydrological scheme [that] computes gross primary productivity, plant respiration, and evapotranspiration on a daily time step based on the current climate, atmospheric CO_2 concentration, vegetation structure and phenological state, and soil water content."

As a result of this effort, Doherty *et al*. report that "all simulations showed future increases in tropical woody vegetation over the region at the expense of grasslands," noting that "regional increases in net primary productivity (18-36%) and total carbon storage (3-13%) by 2080-2099 compared with the present-day were common to all simulations," and that "seven out of nine simulations continued to show an annual net land carbon sink in the final decades of the 21st century because vegetation biomass continued to increase." In light of these findings, the researchers write that "overall, our model results suggest that East Africa, a populous and economically poor region, is likely to experience some ecosystem service benefits through increased precipitation, river runoff and fresh water availability," and they state that "resulting enhancements in net primary productivity may lead to improved crop yields in some

[11] http://www.co2science.org/articles/V13/N19/B1.php.

areas." What is more, they specifically state that their results "stand in partial contradiction of other studies that suggest possible negative consequences for agriculture, biodiversity and other ecosystem services caused by temperature increases."

With respect to the continent as a whole, Scheiter and Higgins (2009)[12] write that "recent IPCC projections suggest that Africa will be subject to particularly severe changes in atmospheric conditions" in the years and decades ahead, and that these changes could have equally severe repercussions for its flora and fauna. However, they say that how the continent's "grassland-savanna-forest complex will respond to these changes has rarely been investigated," and that "most studies on global carbon cycles use vegetation models that do not adequately account for the complexity of the interactions that shape the distribution of tropical grasslands, savannas and forests."

In an attempt to overcome these shortcomings, the two scientists developed a new vegetation model -- the *adaptive dynamic global vegetation model* (aDGVM) -- that employs established sub-models for photosynthesis, respiration, canopy scaling, competition for water, competition for light, reproduction and mortality, and which additionally contains the novel elements of dynamic carbon allocation and phenology functions, as well as a fire model that estimates fire intensity as a function of fuel biomass, fuel moisture and wind speed, and which simulates topkill (stem mortality) as a function of individual tree size and fire intensity, all of which phenomena are related to the individual plant's physiological state and the environmental conditions surrounding it.

Forward simulations to the year 2100 with this impressive model suggest, in the words of the two researchers, that "grasslands will spread into the Sahara and into the horn of Africa, such that the total area covered by deserts or bare soil decreases by 5.7%." In addition, they say "it is predicted that 34.6% of today's grasslands are transformed into savannas," and that "45.3% of today's savannas are transformed into deciduous woodlands." As a result, they indicate that "the total biomass stored in each of the biomes increases, with high relative changes in grasslands and savannas (by 256% and 241%, respectively)" and with a 102% increase in tree biomass. Thus, the CO_2- and warming-induced *greening of the earth* phenomenon, which has been manifest throughout the entire world over the past few decades, seems destined to continue throughout the entire 21st century in Africa.

Finally, Heubes *et al*. (2011)[13] modeled the future spatial distribution of desert, grassland, savanna, deciduous and evergreen forest in West Africa using six bioclimatic models. None of these models, however, took any account of the photosynthetic-enhancing and transpiration-reducing effects of projected increases in atmospheric CO_2 concentration, being based *solely* on the *climatic* projections of 17 general circulation models of the atmosphere for emissions scenario A2a, as described in the Fourth Assessment Report of the IPCC (2007), which projections were downscaled to 0.1 degree of latitude and longitude as described by Ramirez and Jarvis (2008). So what did their work reveal?

[12] http://www.co2science.org/articles/V12/N46/B2.php.
[13] http://www.co2science.org/articles/V15/N21/C3.php.

The six scientists report finding "a climate-driven greening trend," with "northward spread of grassland into the Sahara and the replacement of savannas by deciduous forest," which results they say "are concordant with results from Cramer *et al*. (2001), Scholze *et al*. (2006) and Scheiter and Higgins (2009)," although they add that the latter investigators "attributed the greening to increased CO_2 levels." Further to this point, they state that the models they used "indicate that climatic change alone can yield this pattern," where "the expected 'greening' of the Sahara is primarily driven by increasing precipitation," as they note has also been suggested by Hickler *et al*. (2005).

Using satellite images that reflect the region's current vegetation state, Heubes *et al*. additionally modeled "real" as opposed to "potential" vegetation, which enabled them to "clearly show," as they describe it, "effects of human activity negatively affecting tree cover, as also demonstrated by other case studies, e.g. in Senegal (Vincke *et al*., 2010) and Mali (Ruelland *et al*., 2010). More specifically, they report that in West Africa, "agricultural expansion, sometimes facilitated by other human activities such as wood extraction, has been identified as major drivers of forest loss and degradation," citing Norris *et al*. (2010).

In further describing their findings, "considering climate change alone," in the words of Heubes *et al*., "the model results of potential vegetation (biomes) show a 'greening' trend by 2050." However, they say that "the modeled effects of human impact suggest future forest degradation." Hence, it can readily be appreciated that the *additional* impetus for greening that is provided by the ongoing rise in the air's CO_2 content may well spell the difference between *better* days or *sadder* days for the biomes of West Africa and the welfare of the region's growing human population in the years and decades ahead.

Clearly, the ongoing rise in the air's CO_2 concentration and its *anti-transpiration effect* (which improves plant water-use efficiency) are enhancing the vegetative productivity of Africa. And, it is important to note that the observed African greening over the past quarter-century is occurring in spite of what the world's climate alarmists claim has been a period of *unprecedented increases* in the "twin evils" of anthropogenic CO_2 emissions and global warming.

Clearly, the ongoing rise in the air's CO_2 concentration and its *anti-transpiration effect* (which improves plant water-use efficiency) are enhancing the vegetative productivity of Africa. And, it is important to note that the observed African greening over the past quarter-century is occurring in spite of what the world's climate alarmists claim has been a period of *unprecedented increases* in the "twin evils" of anthropogenic CO_2 emissions and global warming.

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