Deforestation, then reforestation

A chapter in: *Trees of the people,* by Alan R. Walker
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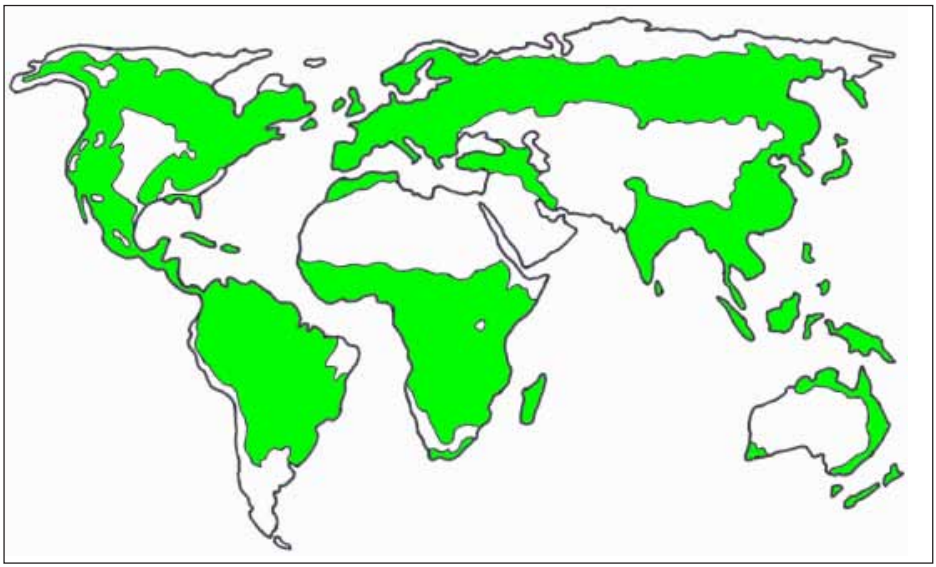
We have been cutting down trees ever since we invented stone axes. We compounded that change in the lives of forests, woodlands and trees by using fire to alter the structure of woodlands. Our most fundamental impact on the lives of trees was our transition away from relying on hunting and gathering for food. We cultivated the land, we invented farming, agriculture. This change was slow, diffuse and variable in its impact on woodlands compared to the impact of axes and fire, nevertheless far more extensive in space and over time. These three technologies first impacted woodlands in a way that would, much later, come to be called deforestation.



Forests and woodlands of the world (compacted). Green = 8 biomes: taiga; temperate broadleaf forest; subtropical evergreen forest; Mediterranean vegetation; monsoon forests and mosaics; tree savanna; dry forest and woodland savanna; tropical rainforest. Information from Wikipedia: *Biome*.

The human activity of cutting down trees is hard dangerous work done with a purpose. That purpose of tree-fellers is not a process, or a state of nature, called deforestation. Purposes of tree-fellers include provision of fuel-wood and timber and to create space on which to plant food-crops. The purpose of farming is what has led to deforestation of greater extent than felling for timber without any replacement of the trees. We changed the way we live fundamentally by our development of widespread agriculture in a self-reinforcing way. More food and better food allowed our children to survive better – our numbers grew and we cut down more trees. So it continues.

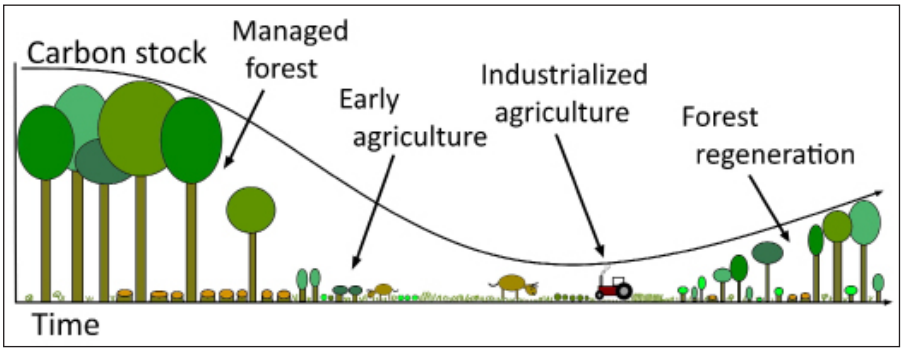
Settlement of indigenous people in Amazon basin region of Brazil, with a swidden or slash-and-burn crop on the far ground. Credit: Wikimedia, Miranda Gleilson

This change in the character of lands of the world capable of supporting growth of trees started as the farming method usually called slash-and-burn. A less pejorative term is swidden farming, from swidden being the cleared area for planting food crops. The evidence we have of how we developed our social cultures and methods of obtaining food points to our early habitat as open landscapes of tree savannas with sufficient access to water and with trees sufficient as fuel-wood and for tools and shelter. The grasses of the savanna provided food for our livestock animals. We are a restless mobile species. We tamed the ancestors of goats, sheep and cattle into livestock that need much grass as food and so need frequently to move onto fresh pastures. For these early people forests could have been places to enter only for foraging and hunting, but not to

live within: too dark and tangled. Until, that is, our growing success as a species led to greater pressure on the resources of the savannas. The need for more space, more land, on which to grow food crops could have been the incentive to develop the slash-and-burn method of expanding farming into forests and woodlands. The small patches that were cleared by cutting the trees and burning the slash, the cut branches and stumps, became swiddens where food crops were planted. The wood ash fertilized the soil and the burn had removed small weed plants that might compete with the crops. The removal of canopy trees brought more sunlight onto the crops and if there was sufficient rain to support a forest there would be growth of a sufficient crop of food plants. After several years a combination of declining fertility of the soil, and increasing impact of weeds required a new swidden to be created. The previous swidden was left as a fallow, for the surrounding trees gradually to regenerate its tree cover.

Swidden farming in Bolivia. Credit: Wikimedia, Neil Palmer.

This farming method continues in remoter areas. As we invented new techniques for growing better breeds of plants and specific tools for preparing the ground, we improved our nutrition by quality and quantity. As our health and reproductive capacity improved we were able to give birth and raise more children in good health. As our populations grew locally within the forested lands the cycles of swiddens reached an intensity of use of the land that there was insufficient regeneration of the slow-growing trees. Deforestation started early, continues now, and goes faster using chain-saws and logging trucks.



Pattern through time of a forest transition; over of period of many centuries or measured by only decades.

After another long stretch of our history foresters and botanists came to understand that this trend of reduction of forest cover, when examined at large enough scales of space and time, does not lead inexorably to total deforestation. In some regions the pressure on the wooded lands lessens. Techniques of agriculture, new machines and fuels, better fertilizers, all helped to lessen the pressure on woodlands. More food, as crops of improved strains and breeds of plants and livestock, could be produced on smaller areas of land. The pressure on woodlands decreased. The foresters saw a transition in the landscape as deforestation lessened and more trees regenerated naturally or were planted on land that recently had been farmed. Details of this transition are revealed by comparing old maps and formal written records of land-use and ownership with what we now see on the land. Now we view the state of the land of entire regions of the world with the convenience of our computers linked to a global mapping service. With the right access to current data from high-definition cameras mounted on satellites it is possible to see, or robotically count, individual trees. Often analysis of the data indicates more trees on Earth than previously recognized. It is too early to tell how all these trees compare with continuing deforestation. The time will come when a balance sheet of numbers of trees in natural forests being felled against numbers of trees of any sort growing anywhere, including commercial plantations, can be completed using accurate data. Hopefully we will not have to wait too long. This chapter describes the main trends

of this forest transition. It is bound to be a long haul, a difficult path to create, but there are increasingly good reasons for optimism about more trees on the land.

The focus here is on trees rather than forests. Observations of areas of land with trees provide data as either hectares of land bearing trees in dense or sparse numbers per unit area; or counts of individual trees where the canopy is not continuous. The information needed to understand what is currently happening in the areas of Earth that naturally carry trees is the number of individual trees per hectare or per square kilometre. For much of this vast area of Earth the words forest and deforestation give the wrong emphasis. The iconic tropical rain forests of the world are large and almost overwhelming in their grandeur: they deserve the attention given to them. Meanwhile the smaller, less impressive trees of the much larger areas of the world capable of supporting trees, the hotter, drier or colder regions, must be included in any assessment of loss versus gain of numbers of trees at global scale.

Congo River basin forest. Credit: Wikimedia, Abel Kavanagh.

Social origins of deforestation.

Farming by slash & burn has a bad reputation amongst people who live in modern towns and cities. A primitive practice that destroys pristine nature or is it a means of growing food for subsistence of a small group of people in a remote areas? It works well at low intensity, sufficient for

natural regeneration of the swidden areas left as fallow land. The bad reputation of this form of agriculture may derive from prejudices of people of European origin who colonized regions of North and South America, and Africa. They asked the wrong question: why do these people use such a crude method of growing food? It works for them as long as there is sufficient forest for a long rotation time between the clear-cuts for adequate regeneration. The same constraint applies to modern forestry in regions where it is the original natural forest that is being managed as a renewable resource: clear-cut followed by natural regeneration. The problem for the people who still rely on slash-and-burn for their subsistence is that they are unlikely to have any formal rights of use of the forest land, they have limited access to modern tools and fuels, and as their populations grow despite these constraints they come into direct competition with other groups of people using the forest in the same way.

Deforestation in the Congo River basin. Credit: Google Earth.

Such competition does not necessarily lead to a zero-sum conflict, a winner-takes-all situation. Lands that would a long time ago have been forested and with people using slash-and-burn farming have been transformed into well populated and productive farmland, as long as there is

sufficiently fertile soil and rainfall. An example is the Green Belt Movement of East Africa. This revolution, conceived and organized by local foresters and agriculturalists, works onward from the social traditions of slash-and-burn methods to adapt to a widely organized land-use by subsistence farmers growing crops of maize and beans, and often rearing several cows of improved breed to provide milk for their family or for sale locally. The farmers plant trees more than relying on natural regeneration. They will often plant alien trees such as species of *Eucalyptus* that grow rapidly, producing fuel-wood and timber.

Tree savanna in the Sahel; Burkina Faso. Credit: Google Earth.

The Green Belt Movement has similarities of intent with the Great Green Wall plan for the Sahel region, just south of the Saharan desert. Here there have been fears expressed, since the 1950s, by people from other lands, that the Saharan sands are advancing southward in a trend of either overgrazing by livestock, overuse of the trees of the Sahel, or climate change, or all three. This project is for a stretch of land where new trees are being planted, fifteen kilometres wide, stretching from Senegal to Djibouti. There is a possibility that this plan owes more to a general concern about environmental threats dating from the 1950s than to accurate counts of trees per unit area within the Sahel. Nevertheless the plan was formalized internationally by 2007. Eighteen million hectares had been planted by 2023. Now there are methods that can be used to monitor what is happening on the ground in the Sahel and similar regions using data collected from satellites as trees per square kilometre. If such counts

continue long enough a trend, up or down of tree number or vegetation cover, will become clearer. What is already clear are examples of where communities of local people in this region, despite its dry climate and current political instabilities, are making better use of the ability of existing tree growth to provide fuel, construction timber, and shelter. In the long term it will be the people of the Sahel who will nurture the seedlings and care for a regenerating resource of trees.

Miombo woodland in Zambia. Credit: Google Earth.
Right: Miombo woodland in Malawi. Credit: Wikimedia, Geoff Gallice

Another example of the way slash-and-burn farming has been transformed into a sustainable system of land-use is that known locally as chitemene, in the woodlands of southern Africa. These woodlands form a band, about one thousand kilometres wide, from Angola across to Mozambique, of a type called miombo. These trees, typically *Brachystegia* and *Julbernardia* genera, are small or irregular in form but they usually coppice well and so can be managed to provide renewing supplies of wood for manufacture of charcoal as cooking fuel. This chitemene forestry is organized at local collective level and manages clear-cut harvest as small-scale areas with a rotation timing for natural regeneration. At a casual glance, on a long boring drive through miombo woodland, the clear-cuts might prompt the observer's dismay at what looks like deforestation. To the people living there this forestry method can be a sustainable land management system with its origin in the methods of swidden or slash-and-burn farming.

Politics of deforestation.

Deforestation has been an interest for me ever since I learnt about an organization called the Forestry Commission, with one of their research centres close to where I lived in England. Trees grow well here – fertile soils, mild wet climate, although a limited flora after the geological event of this land becoming cut off from the migrating forests of mainland Europe. After that geological time Britain became about 60 percent forested, the rest being upland moorlands and lowland grasslands, according to evidence from pollen analysis. This Commission was established in 1919 in response to the strategic risks of being deforested: the woodland cover was already down to about 4 percent. Now it is 13 percent and rising steadily, mostly as conifer plantations together with more hardwood plantations and many woodland restoration projects using mixtures of native species. This is a forest transition in rapid action.

Conifer plantation in Britain on former upland sheep pasture; farm now operates on the lower fertile pastures. Credit: Google Earth.

For Britain as a former imperialist country it is easy to find here examples of the behaviours of colonialist settlers, and similarly from other European countries. Conspicuous in this history is how blind these settlers were to the methods of the indigenous peoples of the colonized lands. Blind to how they managed their trees and forests. Early in this imperial time the people of the invaded lands were almost invisible to

the colonists, they were few in number and wary of these strange new people who arrived in boats from across the seas. The indigenous people had been there for many thousands of years, using woodlands as a natural resource with a prodigious ability to self-regenerate, but also easy to damage by careless use. Lighting fires to drive deer toward hunters, or to stimulate regrowth of fresh grass for livestock grazing, could spread and deforest large areas. To the early colonists these seemingly empty, unused, lands were there for the taking. They were *terra nullius* as the prevalent legal doctrine of the time claimed, land belonging to nobody – a practical concept to justify theft of other people's land for profitable business.

Nature tourism in USA: Yosemite of the 1870s, and, right, forests near Mount Rainier in 1914. Credit: Wikimedia, Asahel Curtis.

These forests were also seen by some of the colonists, more educated and wealthy, as sharply contrasting with to their deforested homelands. These forests were seen as pristine, virgin, primary, old-growth, in character. They were the true forests, not to be exploited but revered and protected as preserves of nature. So along with pragmatic colonial land-grabbers there were other colonists, of other means, free to develop deeply romantic feelings about these forests. They wished the forests to remain the way they seemed to be for the colonists: pristine and empty of people. National parks were established and nature tourism flourished in these

new countries. These perceptions about forests remain with us. They are popular in television programs and books. Depictions of these wild-looking forests are contrasted with images of active deforestation: brutal machines like alien robots demolish ancient trees to make way for endless fields of soya-bean or for grazing cattle. This is real and continuing, at colossal scale, but rarely if ever are all the other wooded lands of the world featured in these accounts of deforestation. In this way a particular narrative about deforestation developed a long time ago and continues. Forests and woodlands are deeply attractive to many people with the resources and leisure to enjoy their beauty: they are a good thing. Thus to cut down trees to gain agricultural land and timber is a bad thing. In contrast to this narrative one way of understanding deforestation as a human activity is as the counterpart of the production of food and timber. Deforestation / farming: two sides of a coin.

Cattle ranch, southern Argentina, with remains of original woodland; central black dots are cattle. Credit: Google Earth.

The loss of nature caused by deforestation is to be mourned, equal in mourning for the loss of nature caused by farming. We mourn because we are sentient, but, being part of nature, we people also need to eat. As do the wolves of the forest eat moose and moose eat trees and grass. It is our pragmatism that puts food on the table. Claims often made that loss of nature, of reductions of number and distributions of species of wild plants and animals caused by deforestation and farming, are a danger to

the long term welfare of life on Earth are vague and disconnected from the obvious vigour of livings things to arise, reproduce and spread. In the long term nature will continue to thrive; in a shorter term our imperative is to live within what we know are the ecological boundaries of this planet Earth.

Tree savanna in Tanzania. Credit: Wikimedia.

The Amazon basin forest is huge, has a unique flora and fauna, and deserves all the protection it can get. But compare the map on page 26 of South America showing a computerized mapping of satellite data to show potential land where planting for reforestation can be promoted. These enormous regions are already wooded, easily seen with a global mapping service on the internet. Similarly in Africa where the grassy plains of parts of East and Southern Africa are well publicized with their scenic vistas and big animals. But the wildlife of miombo woodlands is discrete and there are few distant vistas. The boreal conifer forests start in Alaska, traverse Canada and start again in Norway thence round the globe to Beringia, close to Alaska. Trees can be all dully similar, but here it is their number that count, not their ability to interest us. Their number is counted by the billion, but are all the isolated small trees of the drier lands of the world being counted? Whatever, trees are the dominant life-form by biomass, by value as habitat to other life-forms, by value to us as fuel and construction timber, to soak up our waste carbon dioxide, or simply a place to go for a contemplative walk. Humanity

could not have developed the way it did without access to trees. More of them are needed even with many billions, or maybe several trillions, of them already growing.

Conifer forests and fire in Blue Mountains of Oregon. Credit: Google Earth.

Colonial era foresters also failed to understand, in two well described cases, what they saw as forested land; by Langston, 1995, about Oregon State, USA, and in the wet coastal forests of West Africa by Fairhead, 1998. The Oregon Trail, followed by many early settlers moving from eastern USA toward newer opportunities westward, took several routes. One of these wound through the deep valleys of a mountainous area those settlers named Blue Mountains, after the tone of montane conifer forests. At first glance these forests seemed empty, unused by people. There were many different groups of indigenous peoples who regularly traveled through this landscape and stopped to hunt in it and gather resources. But the foresters amongst the settlers saw this land as a huge resource of good timber for immediate use to build houses, then for businesses to extract the standing timber for sale as construction lumber to local markets and markets in neighbouring states. The settler foresters, used to and trained in, the forests of New England and elsewhere in the east, misunderstood what they saw on the Blue Mountains. The soils of this land are volcanic in origin. They are rich in mineral nutrients that plants need. Trees thrive on these soils, but only where the alignments

of the mountains cause sufficient rain to fall from winds recently blown over the Pacific Ocean. These are anomalous forests: fertile soil but insufficient rain and at severe risk of fire during hot dry seasons. To the settlers the forest fires were more likely to be blamed on the indigenous peoples who also used the forests and sometimes set fires for hunting purposes, rather than understanding the particular dryland ecological adaptations of these forests.

Coastal forest of West Africa, here close to Accra, Ghana. Credit: Google Earth.

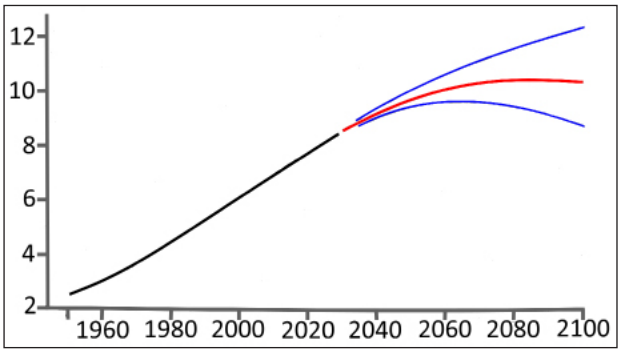
The hot wet forests of coastal West Africa, from Sierra Leone to western Nigeria, were all affected by varieties of imperial colonization. These usually involved managerial attempts to modernize the economy. Forestry was seen as a key asset by people in awe of the commercial value of tall hard-wood trees. However, the Europeans failed to see the forest for the trees. These forests are naturally dense, very humid, and in those days with little more access than by footpaths and small-scale tracks for local trading. The foresters had little or no means to survey from aircraft. Most limiting of all was the colonial attitude of the foresters. They were dismissive of local forms of organization and use of these forests. Also in those days of the early 1900s they based their ideas about ecology of plants on a recent theory that claimed forests developed as a succession of phases always leading to a stable state called the climax. To the minds of the colonial foresters in West Africa what they saw of the forests had been in a stable climax condition, virgin and pristine, until disturbed and partially deforested by slash-and-burn farming and primitive forestry for wood to manufacture charcoal. Some other research ecologists

never accepted this theory of climax vegetation because they saw in forests that individual species of tree constituting a thing called a forest, all lived according to how well they competed with trees of other species by their specific abilities to grow and reproduce. This understanding now prevails and little use is made of the climax forest concept – the stress is on the dynamism of trees that make up a vegetation form called forest.

The result of this misunderstanding of forest ecology was possibly more narrative of deforestation. Trees were being felled to make way for farmland but the extent of forest clearance and its long-term impact became exaggerated in the formal reports by these colonial foresters. Colonial imperialism was a method for exploiting new frontiers of natural resources, either renewable or by direct extraction with little concern for regeneration. These lands, new to the imperialists, were usually seen as there for the taking without reference to the indigenous people or any traditional or legal rights to the land.

Forest transitions.
Farmland versus woodland is the central theme of this story: the relationships that need to be known for any analysis of the dynamics of deforestation over reforestation. There are many of us people in the world and feeding ourselves is an imperative stronger even than reproducing ourselves. A forester turned plant breeder called Norman Borlaug is now credited as the founding father of the Green Revolution. He researched the breeding of better varieties of rice, of wheat, and other species. These combined with synthesis of ample quantities of nitrogenous fertilizer and availability of synthetic herbicides led rapidly to far greater productivity of existing farmland areas. More rice per hectare of paddy field, more wheat . . . This reinforced the pre-existing trend in Borlaug's own country, the USA, for mechanization of farming to have led away from the deforested lands of eastern America, with its numerous small farms on overcrowded, hilly land to the open, flat and thinly wooded lands to the west. The forests of New England spontaneously and rapidly regenerated. Similarly, an economist from Denmark, Ester Boserup, became famous for ideas complementing those of Norman Borlaug. But Boserup

directly related increase in the human population to our intensification of farming. For hungry people necessity becomes the mother of invention.



World population of people, recent past and predicted to 2100. Black = 1950 to 2022; red = median prediction; blue = 95% prediction level. Redrawn from Wikipedia.

Norman Borlaug was a plant breeder motivated to find better ways to feed the many new people populating our world and Ester Boserup wrote as a socialist demographer keen to prove that Malthusian doom about overpopulation is misguided. Now demographers calculate that current trends and behaviours around the business of making babies relative to the number of people dying, mostly of old-age, is likely to start a trend of leveling off during the next fifty years. Our population may be in absolute decline by about 2100. The pressure on farmland will diminish thereafter. A few countries are already in this phase, Japan is one example. The rate of abandonment of marginal farmland, the mountainsides and the dry lands, will increase and trees will repopulate these areas, by planting or spontaneously.

Britain, also Ireland, has become, since the 1920s, a field experiment in reforestation by plantation. Various conifer species, all exotic to these islands, have dominated this transition. There are also plantations of beech and oak to provide local supplies of hardwood timber for manufacture of furniture and specialist parts of building construction. Reforestation here is a general motive, and now there is urgent need to sequester, to store, carbon out of the atmosphere and into wood. There it remains for the typical forty years from planting a sapling conifer to its time for harvest and then can remain for another fifty years, or much more, as

the beams, rafters, panel boarding, floor boards, used in building new houses and similar. Add to that the efforts of private, often volunteer led, reforesting using native broad-leaf species, planted as nursery grown seedlings onto land formerly used as upland sheep pastures. This style of reforestation is often promoted through the ideals of nature conservation, of rewilding, to good effect for fundraising and volunteer labour. Woodland restoration is a more utilitarian term that includes all the new trees growing on public land in towns and cities and in private gardens. To reiterate, the best criterion for this forest transition is not hectares of forest: it is trees per hectare of land that is most informative. Any kind of tree, any place, even the trees planted alongside the motorways and autoroutes. It would be counter-productive to be too fussy about what to plant in a private garden in a city, or to discount plantation conifers because they are not botanically a native species.

Natural regenerating woodland, Basilicata region, Italy. Credit: Google Earth

Trade and economy.

Wood is the natural resource that enabled the earliest humans to become like us. To gain the skills to use fire to cook their food was a fundamental change in how our ancestors lived and thrived. Many people still use fuel-wood for cooking – they have little or nor alternative. The rest of us use mainly fossil fuels for cooking, derived long ago from trees and other plants. These sources of external energy, over and above what we gain

from food, are the basis of humanity's system of trade and economy. This system is fundamentally similar, of the same category, as the ecological flows of energy and materials that occur in a forest, on a prairie, or in lake. Plants convert energy of sunlight into their structures of cellulose and wood. Herbivores obtain material and energy from plants, and carnivores eat herbivores. All of the science of ecology derives from these fundamentals of the flow of energy.

As human societies became denser and more complex, with money instead of barter, with claimed rights to land or to harvesting rights, with moral systems of restraint and fair sharing, the people needed access to land on which to grow crops or on which trees naturally grow. How to share that access was the crucial problem to be solved. Trees grow slowly and fertile land is often scarce. The search for easy-to-harvest resources such as forests (cheap in terms of exchange of money) is never ending and leads directly to over-exploitation and conflict. In this context of deforestation the fundamental character of trees and timber, in contrast to fossil fuels, is that they are a renewable resource, if we are careful. The system of trade and economy that now prevails worldwide is bewilderingly complex but operates as a dynamic balance between extraction of resources of energy and materials, either with renewal of the resource or without renewal. Some resources are fundamentally non-renewable to us: copper ore is becoming scarce whilst this metal is greatly in demand for the transitions to renewable electrical energy.

For renewable resources, use or misuse of woodlands is a starkly simple case. An example of this economy is how international trade in felled wood as timber for building ships operated during the 1690s to 1740s (lumber in USA, where timber is standing trees). This lucrative trade was intensely competitive. England needed a large merchant navy for its imperial expansion and trading, along with a large navy of warships to enforce the aims of merchants, to project their political power across the oceans. English shipyards had already depleted their local sources of hardwood timber for building hulls of these ships and there never were adequate supplies of stem-wood of conifers, tall and straight, for

ship masts. Importing mast timber, such as Norway spruce, from Scandinavian countries became risky as competition from other trading or imperialist ambitions became intense. However, as the colonization of North America developed rapidly, the American region that became New England could supply hardwood lumber for hulls and soft-wood stems for masts. American foresters felled large areas of the forests of New England to meet this demand coming from across the Atlantic. The resource of wood as standing forest seemed to be endless and empty of owners, thus free for the taking. The resource was cheap and easy. Or at least it seemed so whilst being felled without any restraint or effort to allow regeneration. Moreover, the felling of the trees opened up space on which to grow food crops. The deforestation of New England proceeded far faster than the deforestation of Old England during that early phase of colonization of America by settlers from Europe.

Commercial nursery growing tree seedlings of many species; one of 8 polytunnel sheds.

Natural resources rarely if ever are free gifts from nature. Such resources need supplementation from the resources of human labour and care and attention as part of our system of trade and economics. Now we describe this care system as ecosystem services. The economic reality of that term is that we often provide much of the services that enable the woodlands and plantations to grow and regenerate to meet our needs. There is no contradiction here since we humans are part of nature. Natural regeneration of woodlands can be rapid and effective but there is increasing demand for stocks of seedlings, raised in commercial nurseries, to plant new woodlands using volunteer or paid labour. The volunteer work

requires donation of funds. Regeneration forests managed as resources for timber and carbon uptake need to make a monetary profit within the system of trade and economy such that the owners of the forest can stay in business, with the forest felled for sale and cleared land being replanted with stock from a nursery. Running a tree nursery needs much labour to collect seed and tend delicate seedlings, and capital for the shelters and seedling trays. In the case where regeneration of a commercial forest or amenity woodland is to be natural rather than by replanting then the crucial guideline is the maximum sustainable yield. Exploiting the resource beyond that line leads directly to deforestation.

Land use and land rights.
Forests that are managed for, or have been planted as, an ecosystem service ought to have formal land-rights. This applies even when the trees grow on land occupied by the original, indigenous, people. The concept of natural resource needs to embody the concepts of rights of use, rights of harvest, and duty of care of the forest and its capacity to regenerate. Authors of a study of nine countries of South East Asia revealed that without a system of formal land-rights there was no sign of any forest transition (Youn, 2017). If forests are taken into public ownership, as being owned by the state government, there is also likely to be no forest transition. Similarly, in the absence of a system of formal land-rights in a particular country, allowing ownership of potential forest land, there will be no incentive to create or manage a forest on that land. And with ineffective trading systems in timber and wood products there will be little or no forest transition.

Cultural traditions and norms based on historical precedents can inhibit forest transitions. This can happen in countries where land rights and tenure systems are less well established than traditional rights. Also continuing economic, social or recreational use of land often precludes forestry. Examples occur in European countries where ownership of large areas of land had been established before the legal system was sufficiently well developed for such ownership to be fully documented within the modern legal system. People who have inherited these lands are likely to

defend vigorously the traditional uses for farming, sport hunting, conservation of open landscapes, or just passive accumulation of monetary asset value. Such landholdings may be sold for large profit to new owners with personal motives that are incompatible with forestry.

Managed broad-leaf woods in the arable landscape of central France; deforestation ceased here long ago. Credit: Google Earth.

In countries where land rights, tenure and legal systems are poorly established then there is a campaigning case to be made for litigation to enhance use of forests to reduce climate heating. In other words campaigns are made for planting trees to soak up carbon dioxide from the atmosphere. Campaigns are now conducted at national and international courts on the basis that increasing forest cover is a proven means of reducing climate heating. Latin America is a region active with such campaigns. Another example is development of the concept of legal rights to be conferred on the natural world, the world of forests, of rivers and seas and the plants and animals amongst them. Known as Rights of Nature, these are being developed by campaigners with the help of lawyers. There may come to be victories for these campaigns in the courts of some countries.

Displacement of land use.
Information and claims about extent and effect of schemes for forest regeneration lead in some cases to incorrect or even false accounting. This is because increased area of land for new forests is made available at the direct expense of land that is potentially of use for farming. The outlook for a world-wide forest transition is likely to be less optimistic than at first sight from the examples of replanting schemes to create new forests, combined with natural regeneration on land no longer used for farming.

Net reforestation, as a positive balance between rates of deforestation and forest regeneration, at the global level, needs to account for what is known as the tendency for displacement of economic activity from countries with intensive economies to countries with less intensive economies. The economic connection goes typically from a long industrialized country in Europe or North America to a recently industrializing country in Africa or Central and South America. Land of relatively low productive potential in Europe formerly used for growing crops of livestock or plant food can be abandoned if the economy of that country is robust enough to import much food from other countries. In those other countries there develops a strong incentive to cut down forests and convert them into farmland growing foodstuffs for export to the countries with intensive economies.

Agricultural crop-land in forested Chaco region of Paraguay. Credit: Wikimedia, Peer V.

Examples of this are the deforestations within the area of the Amazon basin forest for the widespread production of soya beans as both a crop

to export and as foodstuff for cattle reared on the deforested land and destined for export as beef. Importing countries are found widespread in North America, Europe and the industrialized countries of South East Asia. Many of the importing countries have undergone substantial forest transitions, but to focus environmental publicity on these examples of regeneration of forests can easily give a false impression of the state of the world's forests.

The same type of displacement of deforestation occurs through the international trade in timber or lumber. A country in Europe that industrialized early and has developed an economic ability to import cheap timber from countries far away cannot correctly claim for itself a net regeneration of forests when most of its timber for construction and fuel-wood is imported. Again, when the environmental benefits of growing trees are expressed as mitigating climate change, the accounting context is global, not national. Furthermore, claims that there is ample land available for reforestation for the main purpose of carbon sequestration need to be treated with caution. This is likely to be another and large scale example of displacement of land-use. Who owns this land and what do they intend to do with it? This is a question insufficiently asked by researchers working in the richer countries – a lack of attention to what people far away and in different cultures want from their natural resources.

Forest ecology.
At global scale the long-ago history of woodlands provides the mystery of how a desert as vast and dry as the Sahara was once tree savanna, inhabited by various peoples who made an adequate living there, to judge by many archaeological remains. The Sahara was then green because of astronomical factors causing long-term climatic change (see Chapter: *Forest migrated to survive ice-ages*). This is the type of climate change that periodically caused ice-sheets to develop then retreat over the lands of the northern hemisphere. The Saharan and Arabian deserts are close to and in stark contrast to the rain forests of the Amazon and Congo River basins. Both forests straddle the equator, 10°North to 10°South, whilst the Sahara is entirely north of the equator, 10°North to 30°North. Cli-

mate changes long ago turned that land into a desert. At the time-scale of these astronomical changes the Sahara's latitude is currently too high for sufficient rainfall in the current global climate system. Deforestations followed by transitions to regenerating forests will always a natural phenomenon caused by astronomical forces, and in addition a phenomenon now caused by our activities of food and timber production.

Bush fire of dry grass in Northern Territory, Australia. Credit: Wikimedia,Thomas Schoch.

The type of vegetation mixture known simply as savanna covers about twenty percent of Earth's land surface and comprises a mix of grasses and trees, with some shrubs, that vary from savanna woodland where trees form a thin canopy through to grass savanna where trees are few and widely separated. Over a large scale, forest merges into savanna woodland whilst grass savanna merges into semi-desert. Savannas are distinct from prairies and steppes. The former develop in all-year warm to hot climates with distinctly seasonal rainfall. The latter develop in climates with a distinct cold-season and more variable seasonal distribution of rainfall.

The plant life-forms, tree and grass, have a competitive relationship. A closed canopy of trees will capture so much light energy that grasses cannot grow in the shade. Tree seedlings dispersed away from their parent trees into areas of tall grass will similarly be deprived of sufficient light, nutrients and water, to thrive. Furthermore, fires that start from lightning strike, or are set by people for hunting or farming reasons, burn rapidly across the surface of dry grass and consume tree seedlings. The grass will grow again as soon as there is rainfall because most of it survives. This is enabled by their growing point, their meristem, being

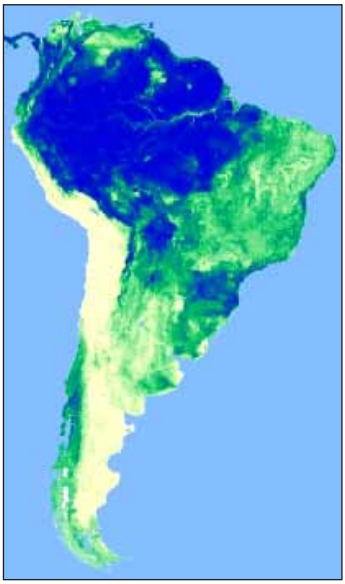
just above their roots. For the trees in contrast the main meristem for upward growth is at the tip of the main stem. The many herbivores that inhabit savannas are similarly a greater threat to the reproduction of trees than to reproduction of grasses. One bite at the tip of tree seedling is likely to kill it – not so for a clump of grass.

There are various sources of evidence, historical and from current practice, that savannas are often a type of vegetation much influenced by people, long ago and currently. Fires are set to burn off old above-ground grass to encourage growth of new grass, timed in anticipation of the distinct rainy season. Modern sheep or cattle ranching businesses will clear large areas of trees from savanna to increase the grass available to the livestock. Savanna trees have limited use as construction timber: the trunks have never had to grow tall and straight in competition with close neighbours because there is never sufficient water to support tree growth into forest form.

Care is needed about what lands are suitable for new plantations that are on areas not on formerly forested. Planting trees on grassland is termed afforestation: contrasting with reforestation. It needs care because the trees may fail in competition with grasses, or should be prevented because the grasslands are more important as either natural grazing lands or used as such by local people herding livestock sustainably. Afforestation of grasslands that are either currently or potentially ecologically best for grass as feed for livestock or suitable for large scale production of food crops needs to be re-evaluated where such lands, as in Brazil south of the forested regions, this is happening.

Measuring deforestation.
There are several methods for estimating how much forests are changing by area on the ground as hectares or square kilometers of forest, or as individual trees on the ground per unit area. The original method, and still used by such organizations as the Food and Agriculture Organization of the United Nations, is to ask local foresters to assess the state of forests in a wide range of countries. These are formal, national, forest inventories.

Forest here includes also other wooded land: the two types defined together as land covered by trees higher than 5 metres and forming canopy cover of at least 5% of the area. However, there is likely to be considerable under reporting of the trees within the extensive areas of the world covered in tree savanna. These trees are of low commercial importance, and the land these trees stand on is mostly of commercial value for low intensity ranching of cattle and sheep. The other approach, typically taken by forest scientists working in universities and similar institutions, is to measure the forests remotely. Formerly done by aerial survey, now by gathering data from satellites.



Forested land of South America, as indicated by software model of potential for reforestation, on the light green areas. From: Bastin, 2019.

An example of the FAO information is from Keenan, 2015. A table of rates of change of area of natural forest, and of planted forest, for four climatic domains of the world is on next page. These rates are summarized here as the means of four assessments from 1990 through to 2015. Clearly there has been over this 25 year recent period a decline in most areas of natural forest, whilst in the same period planted forests in all of these climate domains have increased. Note that 'Planted forests' include plantations of usually one species of tree intended for production of timber and also rubber extraction, and planted areas of trees for nature

conservation and similar objectives. It does not include plantings for palm-oil and similar agricultural products.

Net rates of change of forest and other wooded land from 1990 to 2015

Natural forests

Boreal / polar	-0.87
Temperate	+0.76
Sub-tropical	-1.01
Tropical	-8.49
Total	-9.10

Total decline in area: 3961 million hectares to 3999 Mha

Planted forests

Boreal /Polar	+1.11
Temperate	+1.99
Sub-tropical	+0.28
Tropical	+1.12
Total	+4.67

Total increase in area: 168 million hectares to 278 Mha

Counting areas of forest in regions of the world might seem an appropriate method to assess deforestation. These areas can be huge and also often appear from above as a dense mass of undulating lumps in shades of green: the closed canopy forests. But there are larger areas of the world with many trees per area that do not fit the popular understanding of forest. In these areas each tree is now visible from above using modern methods and can be counted robotically. Focus on the word forest is a distraction here. For accurate estimates of deforestation and reforestation it is necessary to count trees, per unit area. With dense canopy forest the average number of trees per hectare can be estimated by ground survey and then related to the mapped area of forest.

When the first satellites were launched with the purpose of detecting the state of vegetation on land, during the 1970s, there was enthusiasm for using the data to measure the areas occupied by different types of

vegetation, and their seasonal variations in greenness. Areas forested could then be assessed for the likely number of trees they carried, based on forestry knowledge of typical tree numbers per area of typical forests. The technique is called normalized difference vegetation index. It continues in use, but the engineers who make these machines have now provided much greater sensitivity and availability of this type of data. This is not the place to go into the technical details. Here it is the results in the hands of foresters and botanists that are important: individual trees can be counted automatically over large areas. As the photographs here show, internet services such as Google Earth and Bing Maps provide photographs from space, freely on your computer, that show individual trees, particularly in the tree savanna lands of the world. But try counting them by the hectare!

People counting trees need to know what species they are counting and what is their stature and condition. They often want to know what the people in the same lands are doing with these trees. Always there has been the need for researchers to survey as much as possible, by careful sampling methods, as they see them on the ground. Ground-truthing is hard but essential work to achieve plausible information against which to cross check information from a satellite. In addition, researchers often search for historical accounts, as written documents and maps going back several hundreds of years, or from asking the local people going back several decades. Historical data from satellites of the state of the world's forests is now available going back to the 1980s as archived digital data, made readily available to researchers.

Forest expansion.
Tropical rain forests are a major sink for carbon by taking up carbon dioxide from the atmosphere directly into individual trees. Reduction in area of forest will reduce this carbon storage and works against humanity's collective efforts to mitigate climate heating. Despite the large areas of the world where deforestation continues and reforestation does not compensate, the global balance of both tree number and their enhanced ability to store carbon demonstrates an upward trend. This goes toward

both more trees and their greater ability to store carbon. The irony of this effect, known as carbon dioxide fertilization, is bitter. When I was attending college classes in botany, carbon dioxide fertilization was described as good news because for plants carbon dioxide is a scarce resource. This was also the first time we heard about impending climate heating, but in those days higher temperature was just another factor that could increase agricultural productivity.

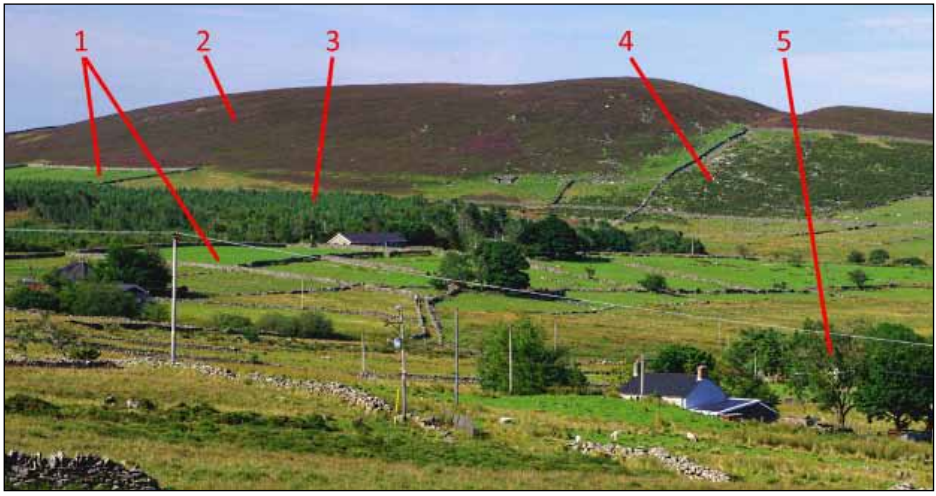
Mixture of farming and forestry on the hilly terrain near Kunming city, China. Credit: Google Earth.

The effect of this fertilization of forest trees by higher concentrations of CO_2 is known as greening. This is detected in forests when the leaf area index, as a quantitative measure of the area / amount of vegetation that can take up carbon, indicates more photosynthesis, more growth, and more biomass. (See Chapter: *Leaves*.) Note that browning is a term for a decrease in leaf area index, but this is not always a direct opposite of the greening mechanism. Browning of forest leaves may indicate some other cause of poor photosynthesis and growth: pollution, drought, insect infestation, infection with fungi, bacteria . . .

Climate heating as a result of increased concentration of CO_2 in atmosphere has the effect of increasing the rate at which trees take up this CO_2. The plants grow faster if the air temperature is slightly higher. These two factors, more supply of nutrient plus more heat for metabolism, produce distinct increase in net growth. This growth is known as net primary production (here measured as grams or tonnes of carbon fixed into the plant by photosynthesis minus the carbon lost by respiration, per unit of time). This is a phenomenon that can be measured experimentally in large-scale, open-air, experiments called free air carbon dioxide enrichment (Norby, 2005). Sufficient numbers of these experiments have been done to prove that this effect is far more than theoretical. It happens on a wide scale and net primary production has been estimated to have increased by 6% from 1982 to 1999 (Nemani, 2003). This study also showed the largest increase in this productivity to be in tropical forests, with the Amazon basin forests accounting for 42% of the global increase. It is difficult to answer how much this effect should be celebrated, deplored, or accepted as another example of anthropogenic causation. The crucial thing for us, along with reversing deforestation, is that we meet the targets and legal obligations for reduction of carbon dioxide in the atmosphere. More recent studies corroborate this trend of greening. A massive collection and collation of remote sensing data showed a persistent increase of forest and woodland greening at a global level, covering an area of from 25% to 50% of the global vegetated area, compared to an area of less than 4% of vegetated areas showing decrease in forest uptake of carbon (Zhu, 2016).

Forest greening leads to increase in the size of trees and other plants, they grow taller and wider so their volume increases, the weight of this enlarged volume increases; that is the biomass of the individual trees increases by the kilogram of all their structural components. This is usually abbreviated to just carbon as shorthand for all the physical stuff that makes up the tree, its weight or mass. An example of this increased level of tree growth is from a study in the Amazon basin forest, where the measured biomass of trees of 10cm or greater of diameter at breast height was approximately 0.62 tonnes of carbon per hectare (Phillips,

2008). So forest greening could also be described as forest expansion, but this is not an increase in the number of trees in a forest, or the number of hectares or square kilometres that the forest covers.



Landscape of small-scale forest transition in Europe on upland livestock farms. 1: Improved pastures. 2: Heather moor, formerly for sport shooting. 3: Commercial conifer plantation in second rotation. 4: Upland pasture invaded by gorse. 5. Broad-leaf trees thrive here. Livestock farming here is now subsidized within a regime requiring 10% of a farm's land to be planted with broad-leaf trees. Trees already smother abandoned farm buildings, as shown below.

Referring back to the table of rates of change of forested areas of the world, of natural forests and of plantations, reveals that measurable forest transition is occurring in the temperate forests, and only that cat-

egory. For the four categories of plantation forests all of them are clearly acting as a major component of forest transitions, throughout the world's forested regions. Other studies using different techniques and approaches about expanding forests have shown an upward trend for the global balance of number of trees, and the ability of trees to soak up carbon dioxide from the atmosphere. A study using a combination of information from satellites about existing forested areas of the world according to the usual definitions of forest and woodland and information from the same source that includes all the drier regions as tree savanna, has claimed there is room for an extra 0.9 billion hectares of land in which number of trees could be increased (Bastin, 2019). Such proposals need to be evaluated or acted on with the precaution that such planting of trees is not another displacement of land use.

Volunteers planting hazel tree seedlings to add to birches planted 20 years ago in a woodland regeneration site on former upland sheep pasture.

An example of a study done about the state of forests and forestry of India about turn of this century found that afforestation was at a rate of 1.55 million hectares per year, compared to the deforestation rate of 0.272 million hectares per year. This was predicted to lead, over the next

decade to an additional 315 million tonnes of forest carbon, with the majority of that from the sustainable forestry sector and the rest from the commercial timber sector (Ravindranath, 2001). Other studies have tended to provide confirmation of this increasing trend of greening at a global level. However, there is at least one recorded exception to this trend: the Amazon basin forest which has shown a long-term decreasing trend of the rate at which it can take up carbon (Brienen, 2015). This is the rate per unit area per year, so is not related to the decreased area of this forest, or at least not directly related. Possibly there is some large-scale climatic influence at work here. Droughts may be one of them and another cause may be that higher temperatures accelerate the life-cycles of trees so that they die young and without accumulating as much carbon as older trees.

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