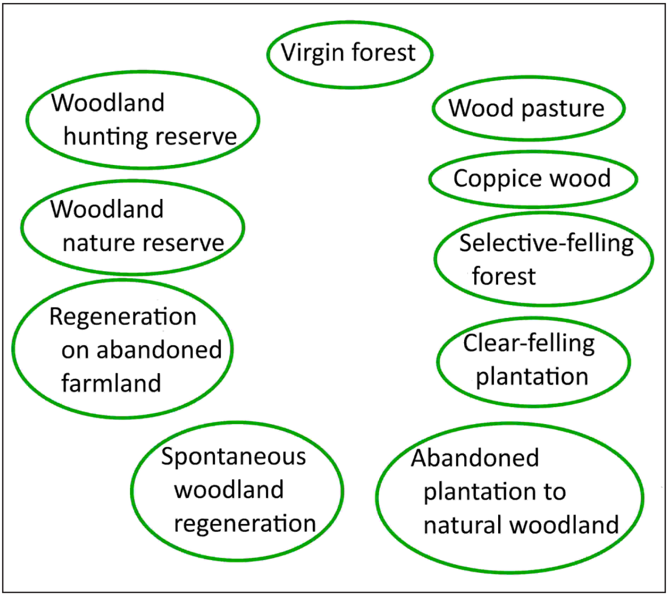
Regeneration woodlands

A chapter in: *Trees of the People,* by Alan R. Walker
www.alanrwalker.com

At the margin of a large industrial city was a massive steelworks. Making steel is a competitive business needing huge financial flows. This steelworks eventually became unprofitable as the costs of raw materials, energy and labour rose in the face of competition. Demolition workers cleared the machinery and buildings, leaving a bare wasteland of concrete, tarmac and contaminated soil. Nearby are suburban housing estates of modern layout, with patches of public woods and rows of street trees. Seeds blew on the wind, were carried within birds, and some settled on the patches of habitable ground amongst this post-industrial dereliction. Twenty years later birch and rowan seedlings had regenerated a young woodland of patches amongst the grass and herbs already pushing up through decaying tarmac. Now the entire site has a regeneration plan for recreational and communal facilities, also for large areas with accessible woods.

The vitality and vigour of all vegetation sometimes astonishes us with our perspectives of domesticated countryside and town life. We forget how small herbs push up, we fail to see how rapidly empty grounds are colonized by plants randomly dispersed over them and able to find a minimum of space and nutrients to establish themselves.

Left: small area of site of former steel works 20 years after it was demolished. Right: nearby housing area with amenity woods as source of seed onto the derelict land. Credits: Bing Maps.



Virgin forest is the origin of two categories of woodland: *natural* at left, and *crop* at right, as a few examples here.

Regeneration defined.

"*Regenerate*: verb, 1. to undergo or cause to undergo moral, spiritual or physical renewal or invigoration. 2. to form or to be formed again; come or bring into existence once again. 3. . . ." (Collins English Dictionary.) A new wood can appear on disused agricultural land as seeds are blown or carried by birds and mammals. Chapter 'Wooden buildings' described how a field at an agricultural research station was deliberately left, fenced but untended since 1883. Now it closely resembles woods nearby. The photograph here on page 4 shows previous pasture on a rocky hillside, abandoned for rearing sheep about thirty years ago, that is regenerating spontaneously, first as scrub then a new wood. Thousands of years ago a natural woodland would have grown here.

Of contrasting origin, the broad-leaf woodland shown on page 15 was planted by hand with seedlings grown in a nursery, all protected by vole- or deer-guards and a perimeter livestock fence. After several decades of maturing it looks convincingly natural, despite the small stature of the trees, contrasting strongly with the previous use of the land as sheep pasture.

Regenerate is easy to define, in contrast to *nature* and *natural* and *wild:* words often used in contrary meanings. Also my dictionary provides several definitions for these three words. All separate the worlds of live organisms from the world of humans and our technology, as if we are not part of nature. This ancient concept contrasts with the facts of human evolution and our immense impact on life on Earth through power of our technology. We are dependent on nature for food, even on a spacecraft, and because we can predict by abstract thought far into the future, we bear responsibilities toward the wellbeing of nature.

Woodland path in a nature reserve of Sessile Oaks, *Quercus petraea*, most of it on very steep rocky ground accessible only to feral goats.

Definitions of natural woodland have used examples from regions of the world so remote that humans have never used them: *virgin forest*. There is no need to travel that far once you agree with the concept that we are part of nature. For the purposes of this book there are *natural woods and forests* and there are areas of trees that we plant and manage closely to provide a *crop*. Wheat in a farmer's field provides a crop for conversion into flour then bread. Trees in a plantation of conifers provide a crop of timber, of lumber, and a store of carbon. So *natural woodland* can be a flexible concept that includes a wide range of woodlands ranging from virgin forest in remote boreal or mountain tundra regions, to forests long ago used as hunting reserves and now more likely to be nature reserves. An area of land formerly used for crops of wheat or flocks of sheep but now abandoned will soon be colonized by scrub bushes and trees followed by natural woodland. But note: Scots pine, *Pinus sylvestris*, is classed as *native* to a few parts of Scotland, elsewhere in Britain it is classed as *alien*; Sitka spruce, *Picea sitchensis*, from Alaska, classed in Britain as alien, has become fully *naturalized* and spreads widely.

The problem with words is that they can only be defined by the use of other words, and so on, and so on . . .

Former sheep pasture, abandoned ~30 years ago, now undergoing spontaneous regeneration as scrub then woodland.

Historical forests.

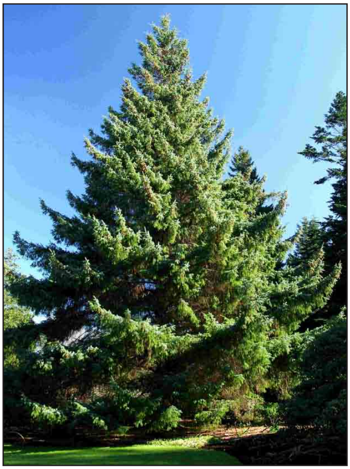
Our ancestors used trees and woodlands as crucial components of their cultural and technological development. In chapter 'History' I described how early peoples of the northern hemisphere occupied new lands that became habitable as ice-sheets and glaciers retreated. Population density of these various peoples was sparse, so their impact on the woodlands was slight and temporary as they felled trees to construct shelter and as they burnt fuelwood for cooking. During the last phase of the Stone Age, the Neolithic times about 12,000 to 2,000 years before present, people living in areas remote from centres of early agricultural civilization were able to live in stable equilibrium with their land. The natural regeneration rate of trees through coppicing of some species and prompt establishment of seedlings in recent fallow areas was sufficient for use by sparse numbers of people and their livestock. These former landscapes of woods, forests, savanna, prairie and steppe became humanized as the people equipped themselves with tools: axes, knives, spears, needles and controlled fire. Meanwhile the woodlands kept much of their original natural character and vegetational dynamics: their ability to grow, change with the climate and regenerate naturally.

Natural stands of broad-leaf trees on the island and within the river gorge on hillside beyond.

Our populations expanded as productivity from developing agricultural crops increased and as people cleared much woodland. People managed the forests that remained as sources of fuel, timber, forage for pigs and cattle, and as hunting reserves. These woods survived through these centuries within agricultural landscapes because people had many uses for them. People developed varied techniques for making use of woodland resources alongside techniques for regenerating the trees. They developed silviculture as a technology. Coppice woods were maintained from generation to generation of both trees and people as the ability of broad-leaf species like hazel, oak and ash to regenerate from the original root-stock became widely managed for small timber.

Plantation forestry developed, alongside coppice silviculture, to exploit broad-leaf species well suited as large timber for construction of buildings and ships. The techniques of planting and managing conifer trees for timber became well developed and supplied a booming export trade in softwood timber for building. For sailing ships built of oak there was great demand for tall, straight and strong masts from spruce and fir trees.

A young specimen of Sitka spruce, *Picea sitchensis*, thriving in natural form as an isolated tree in a botanic garden located a continent and an ocean away from its endemic origin. Natural shape shown here, when not confined to a plantation crop.



Botanists, as professional plant hunters, found sponsors keen to expand their options for commercial forestry and amenity planting on their private estates. They explored globally then returned home with seeds of such great variety of species of exotic species that a mania for tree planting developed amongst people rich enough to buy and cultivate these exotic novelties. Production forestry developed alongside this recreational tree planting, leading to the development of plantation forestry based on a small group of conifer species that happened to be well adapted also to their new habitats. Spruces, firs and larches were experimented with, sometimes leading to the seemingly bizarre situation of species such as Sitka spruce now thriving in greater number than in their original endemic place and range, reproductively naturalized and spreading by seed to become treated as weeds.

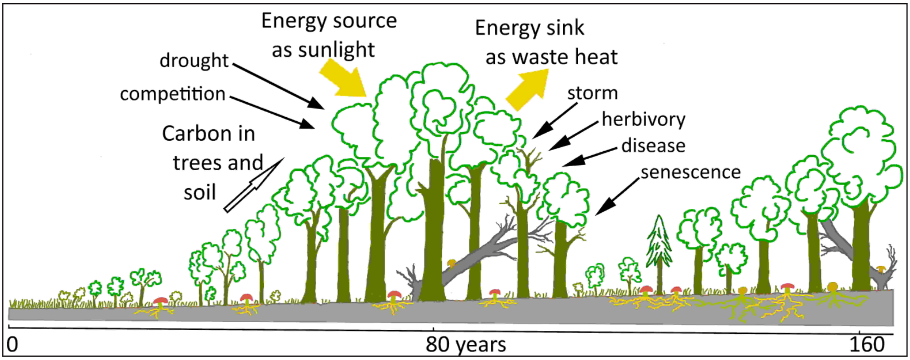
In our times there is now much gloomy news about clear felling of natural forests for timber; about clearing of tropical rainforests for livestock and arable crops. However, there is increasing evidence to be optimistic that woodlands globally are regenerating as natural woodlands and as plantation crops faster than they are declining.

One factor in favour of regeneration is the large areas of former agricultural land, now abandoned, in Europe and beyond for one example. A study published in 2023 assessed a plan by the European Union for planting of three billion trees by 2030, for the main purpose of carbon storage. At first sight this seems an impossible aim: where can all these trees be planted? The researchers found that the trees would require a total land area of between 0.81 and 1.37 million hectares within the land area of the European Union. During the last 24 years expansion of the forest area here was 2.44 million hectares. So the new plan for expansion is actually lower than historic reforesting rates. Furthermore the area of abandoned agricultural land currently available is sufficient for 7.2 billion trees. But care is needed in a context wider than this group of countries. The authors emphasized that such massive tree planting should not be done at a level that reduces agricultural production in the EU, with substitution by imports of food, thereby merely displacing the problem of greenhouse gas emission from Europe to elsewhere in the world.

This potential adverse effect of reforestation is not the only one. Large areas of dark green forest have a negative albedo effect of forests: that is they absorb much heat energy from sunlight thus increasing global warming. Forestry business consumes resources and energy: operating huge tree nurseries, planting each tree manually, fencing the forest, thinning and finally harvesting the timber and preparing the ground for a further planting. Natural regeneration of woodlands seems to cost nothing but all other methods for tree regenerations have many and varied costs.

Ecology of woodland development.

Forests have dynamic characteristics of growth, death, decay and regrowth. These changes over time can be understood best by means of long term observations of how land currently without trees becomes land with stands of trees expanding into woodland by natural spread and germination of seed. The time-scale is by the decade and century.

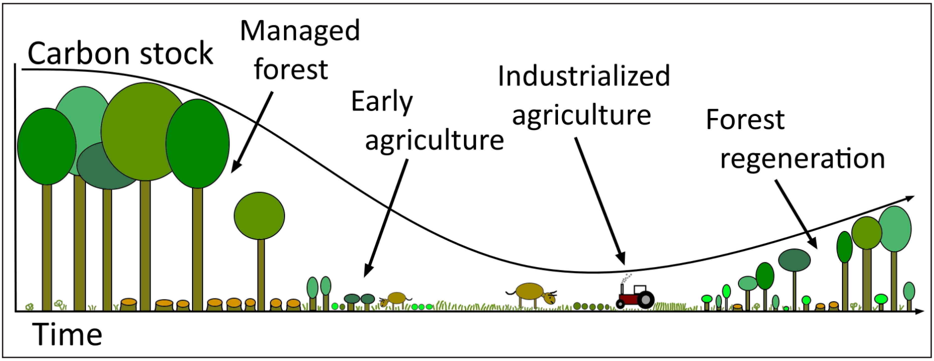


Forest dynamics, starting from initiation on grassland.

Initiation of the stand involves herbs, bushes and young saplings of trees; all have adequate light and nutrients. A phase of stem exclusion follows when the tree stems, crowns and roots start to mature fully. This leads to competition between trees for light, water and nutrients. When the canopy closes smaller trees will not thrive and seedlings will fail to establish. Meanwhile herbs and bushes diminish in the area they cover. Eventually a phase of understorey re-initiation begins when competition for resources lessens as some mature trees die but remain standing as snags, and the number of trees diseased or thrown down by storm increases. Gaps are created providing space and sunlight. Forest fires are usually rarer than storms but have the same effect. The wood or forest reaches a renewed stage of old-growth or maturity in which a greater variety of species of trees and other plants is likely to develop, along with a denser network of mycorrhizal fungi, soil animals and microbes.

This late phase rarely if ever seems to come to a stable end point of a succession of growth phases. The more woodlands are studied for many decades, the more researchers find a slow dynamic that is complex, variable and difficult to predict. Individual trees of each species have evolved as survivors because of their inherent vigour to germinate, mature and reproduce themselves. They reproduce whilst competing for space, light and nutrients. There lies the dynamism of woods and forests. As an assemblage of populations of different species, the forest renews at a slow pace that is overall resistant to wide fluctuations caused by external influences. The forest changes – thereby it persists.

Because of this variability of numbers with time it is difficult to formulate an ideal of what a deliberately regenerated wood or forest should consist of as part of a management plan. It seems that only the broad outlines of the desired mature woodland can be predicted from knowledge of what the land currently supports well and what it formerly supported long ago in natural conditions.



Forest transition from natural, to crops, to natural, over many centuries.

Pragmatism is one approach: make a well informed guess of what to plant then see what works. Thereafter accept that some level of management will probably be needed. Moreover, studies of the dynamics of newly established regeneration woods shows that they go through similar vegetation development patterns to those described for long established woods with the usual slow transitions as described above. A new wood becomes similar to nearby woods with histories going back hundreds of years.

Savanna woodlands.

The terms wood, forest, and woodlands can easily limit the perspective of those of us who live where the climate and original natural tree populations were dense enough to form a canopy. One reason why the extent of tree cover globally can be underestimated is the perception that savanna is mostly open ground with only sparse trees clustered around patches of wet fertile ground; the land shown in television programmes featuring lions chasing antelope. At the arboreal side of the spectrum defining savanna rather than the prairie side, there are vast areas of the Americas, Africa and elsewhere with vigorous growth of trees but not densely enough to form a predominantly closed canopy.

An area of Burkina Faso, south of the Sahara desert. Farmland to the left, treed savanna as a Forest Reserve to the right. Credit: Google Earh.

The Sahel region where the Sahara Desert abruptly meets the wet zone of Central Africa and the start of the Congo rain forest is a good place to see this. During recent decades many people have planned to halt the advance of the sandy desert southward by planting trees. If you use a satellite imaging website to scan at one kilometre altitude, 12^{o} latitude north, along a transect coast to coast, you will see semi-desert to treed savanna where the individual trees are visible if you zoom down to one hundred metres. Agricultural land is clear as angular field boundaries of sparse pasture and croplands. Amongst these are well defined blocks of greenery as areas of protected forest. These are varieties of forest reserve. Few of them are national parks in the sense of nature reserves for the benefit of wild animals and tourists. They are reserved and guarded to maintain a traditional and continuing management system that includes fuelwood, coppice wood for timber and charcoal, and wood-pasture for livestock forage. Regeneration is by a combination of natural seeding and planting seeds and seedlings. Burkina Faso and Ethiopia are particularly clear examples to view north of the equator.

At the same latitude south of the equator, Zambia shows this pattern clearly with its highly characteristic woodland type, miombo, comprising trees of genera *Brachystegia*, *Jubernalia*, *Isoberlinia* and similar. Here the belt of treed savanna between 5º and 20º south and where the annual rainfall is between 1500mm to 750mm, seems endless: ocean to ocean across the continent. Miombo species respond well to coppicing and high rates of wood extraction are possible sustainably as long as the system is well guarded. Land-rights and tenure of farmland and access to the products of such forestry are an issue of central importance here. Few of these treed areas are for amenity and competition for their resources can be severe.

Miombo woodland in southern Africa. Credit: Wikimedia.

Regeneration by silviculture.
Where tree planters start to regenerate a wood on open ground by use of some proportion of natural re-seeding or of seedlings from a nursery, there are various silvicultural options. Some generic examples show the range. Within a woodland that is becoming moribund – slowly dying

through heavy grazing by livestock or deer – fencing can be erected as exclosures. To exclude deer a fence at least two metres high is needed. On many sites voles and rabbits are likely to be the worse threat to small seedlings and various tubular guards around each seedling will be needed. As soon as the saplings have trunks thick enough to resist the teeth of small mammals the guards need to be removed and, currently, disposed to landfill. Experimental biodegradable guards are becoming available. If sufficient tree planters or machinery are available then the ground herbage can be partially cleared, and the top layer of soil screefed, scarified, to reduce competition against naturally spread seed or planted seedlings. The best spacing for planted seedlings for wood of broad-leaf species starts at one per 2 x 2 metre square, giving a theoretical total of 2500 seedlings per hectare, through to a 4 x 4 metre square (625 per hectare). This is greatly flexible depending on soil type, drainage, local climate, also spacing needs to allow for a patchwork of new plantings to create open glades by the time the trees mature.

Fencing to exclude deer from a regeneration site on moorland formerly used for sheep grazing. Planted 35 years before this photograph.

Increasingly the perspective of what climatic conditions will prevail by the time a new woodland matures eighty years later is important. Planters need to plan for resilience against changes affecting the physiology of the trees. They can select tree species with robust reproductive capacity that will promote continued natural regeneration under harsher conditions of heat and drought. In the context of regeneration in an already hot dry climate the tree planters should anticipate increased frequency of forest fires. They can use the small scale topography of the land to act as natural fire breaks such as ravines, river banks or rocky areas where no planting is done.

In Ireland and Britain the Sitka spruce population is spreading widely on its small wind-borne seeds. Maybe in eighty years time we will have adapted our thinking to no longer treat these adaptable trees as weeds because we need to concentrate on more regeneration work?

Tubes with stakes to protect amenity planting close to a city.

Woodlands recently created adjacent to existing woodland grow faster, taller and have higher structural diversity than their isolated counterparts. This can speed up the benefits of woodland regeneration. So for tree planters a simple approach to selecting species of tree to plant is to observe what currently grows best in existing small woods and hedgerows. If a large lake is nearby there may be islands, or on hilly ground there will be steep ravines: such areas are likely to have always been without grazing pressure from livestock or deer. Such refugia, safe places, of natural vegetation guide of species that will work for a regeneration scheme.

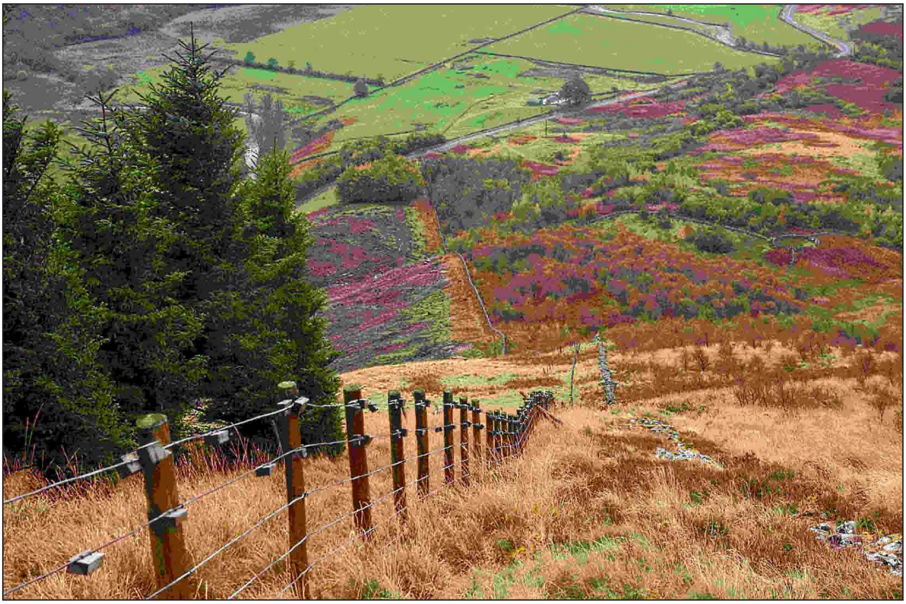
Vole guard as plastic spirals around birch seedlings within a fenced regeneration plot.

Who owns the land?

When people plan woodland regeneration, as new plantings on land that may be abandoned farmland, problems are likely. Who owns the land and what future purposes for it may they have in mind? What have regulators specified for land-use, specially rules based on ecological or cultural heritage? Who will provide funds to purchase the land and new trees? However, these regulatory systems and requirements may not be the barrier they appear at first sight. Grants and concessions may be available to fulfil wider environmental objectives of governments and other authorities. The possibility may exist of selling in advance the carbon credits calculated from anticipated storage of tonnes of carbon in trees (‘Wooden buildings’). A woodland provides multiple benefits that can be promoted for grants and support of local people and authorities.

Many woods or woodlots within agricultural land remain intact and healthy for centuries because people own and maintain them as hunting grounds. The social culture and norms of hunting birds and deer provides the skills for stalking and culling deer that usually become a serious problem for regenerating woodlands. Furthermore, researchers in Europe have shown that a wide landscape dominated by intensive agricultural land but with many small woods can be as good for variety of plant species as are similar areas of trees growing as large blocks.

People find it difficult to find a balance between workaday pragmatism and motivating idealism, but plans for regeneration projects need to see far into the future. For woodland regenerators with plans lasting at least the life span of the trees they plant, flexible plans are likely to work better than attempting to regenerate a woodland that matches a concept of what may have been there a thousand years ago. The botanical terms *ancient* and *old-growth* originated with precise meanings but now often evoke ideals about things old and gnarly. Regenerating woods needs trial, error and acceptance that the trees have their own dynamics.



Land uses and ownership: a regeneration project at right on former sheep pasture; sheep farming continues on the lower more fertile ground; the conifer plantation at left was being harvested and replanted. The new stock-fence follows the line of the original stone wall.

Living with herbivores as allies and threats.

When people lived in sparse populations with insignificant impact on woodlands, natural conditions within woodlands included populations of herbivores at low density, from deer to mice to beetles, from elephants to antelope to termites. The grazing and browsing of these animals influenced the composition and numbers of many populations of plant species. Trees are particularly susceptible to this grazing pressure. One bite at the growing tip containing the apical meristem can kill a needle-leaf sapling, and a few branches nibbled will severely damage a broadleaf sapling. Meanwhile the grasses respond to their tops being eaten by continuing to grow vigorously from meristems at the level where their roots start. When grasses, herbs and bushes grow to their full capacity they often overshadow tree seedlings from light and compete strongly for nutrients.

Populations of deer and antelope worldwide were, long ago, generally low because of hunting by large predators. Now, amongst the domesticated landscapes of the world, this balance between tree growth and herbivore nutrition is upset. Herbivores become a central problem for foresters and their plantations, and for people regenerating woodlands. If herbivore control is too strong then a potential regenerated natural wood will lack grazing pressure and the seedlings struggle reach the sunlight.

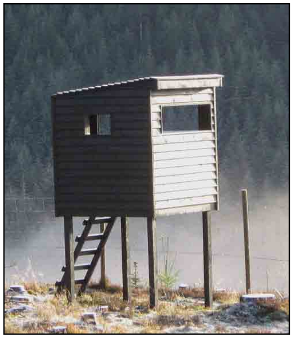
Elk (*Cervus canadensis*) in Rocky Mountain National Park, USA.

Fencing – great lengths at large cost of purchase and maintenance – is the common solution for plantations of timber trees. Foresters grow plantations at maximum feasible density and once the canopy closes the forest loses most ground-level plants. To regenerate woodland surrounded by a fence people plant at lower density and in patches. However, the ground layer of grass, herbs, bushes and ferns acts as a competitive barrier to natural germination and establishment of seedlings. Thus paying for a fence, its maintenance and eventual replacement becomes both a major cost and an impediment to regeneration woodlands

Planters can use domestic animals for grazing management where the pressure can be calibrated to balance with regeneration. Cattle are useful for this because they graze grass coarsely, they cause little damage to tree seedlings and their weight on big hooves tramples down areas of ferns and bushes. Horses or ponies are easier to handle than cattle and they need to eat far more grass per animal per day than cattle or sheep (which have multiple stomachs for efficient digestion).

Cattle for applying grazing pressure to a nature reserve for regeneration of Scots pine, *Pinus sylvestris* - the foreground saplings.

Some countries have dense populations of deer because of a combination of few or no natural predators, and land owners who maintain numerous deer for private or commercial sport hunting. Estimates of how many deer per area of land are too many for tree growth, without use of fenced exclosures, vary depending on species of deer, type of woodlands and their species composition. For a large area of northern USA researchers found fewer than 5.8 to more than 17.4 white-tailed deer (*Odocoileus virginianus*) per square kilometre, depending on character of the habitats. The researchers concluded that any more of these deer than 5.8/km^2 will have a detrimental impact on development of tree seedlings and also have complex impacts on the ecology of understorey plants.



Deer control by shooting is often done from a high-seat facing open ground; some more comfortable than others.

The changes in woodland composition and character over time need to be measured by the decade at least. Long term studies are difficult to sustain and finance but those that have been completed in savanna lands of Africa for example, reveal perspectives important for woodland management in general. Elephants eat trees: they delicately pick up seeds from the ground with their trunks and they push down entire trees to browse on. African savanna elephants (*Loxodonta africana*) however are much more likely to be a publicized cause for concern for the managers of national reserves. These iconic herbivores range over wide areas according to season and episodic fluctuations between drought and wetness. Their destructive effect on attractive and well loved groves of tall fever-trees (*Vachellia xanthophloea*) in Amboseli National Park, Kenya, was demonstrated by a twenty year experiment using fenced exclosures. Now these trees are protected within a patchwork of fenced exclosures. This seems incongruous in a nature reserve but preferable to one solution that some conservationists seriously considered, or vigorously opposed: a cull of many of the elephants that had formed a large population in this reserve.

The history of such savanna lands and the people who have lived in them for millennia provides a fresh perspective. A pair of researchers working in a region of Kenya near the Amboseli and the Tsavo national parks, gathered oral evidence of farmers from six ethnic groups. The people of this treed savanna, traversed by the Tsavo River, had long ago learnt to live with elephants and many other species of large wild animals, alongside their own livestock and fields of food crops. Not an easy compromise for them as a way of making a living, but an alternative policy for large areas of land here had been imposed by the administrative power of the former colonial government. This policy was for national parks, originally with a strong element of sport hunting, but later for wildlife conservation and tourism.

Hunting trophies on a farmhouse in agro-forestry area of France. Hunting culture here is well developed.

Now, under pressure of both human population density and social attitudes, this policy of land management becomes increasingly problematic. One option is a mix of methods aimed at sustainability. These include small private game reserves, often with the wild animals provided with fodder supplements and some veterinary care. Local people need to monitor and regulate the resources of livestock grazing, and fuelwood gathering or coppicing at a level where local knowledge is fully effective. Income from tourism may be maintained once an adequate proportion goes direct to the local people, of whom some can act as guides, wardens, anti-poaching specialists, and hunters for culling herbivores and predators when necessary. A crucial mechanism for this is new or improved legal provision of land rights and land tenure, together with rights of access to land held by government agencies. This is a growing trend, heading away from the old model of national parks that originated from a combination of hunting and conservation priorities but then became reliant for funds on tourism by visitors from countries far away.

Cleansing the air of pollutants.

The leaves of trees are adapted for the crucial work of taking in carbon dioxide from the surrounding air and letting out oxygen and water vapour (see 'Photosynthesis'). These gases and vapour pass in and out through pores (stomata) in the outer layer of leaves and the flows are regulated so that both photosynthesis to capture carbon, and transpiration to pull up water from the roots, work together. Most of the surface of each leaf has an outermost layer of cells specialized to protect the leaf from dehydration and to deter herbivorous animals. Waxes, hairs, and various complex chemicals, typically terpenes, combine to defend each leaf (see 'Herbivore').

London Planes, *Platanus x hispanica*, thriving in London despite all the tarmac and repeated heavy pruning. During summer they will provide benefits of living greenery, shade, and removal of some of the pollutants from road vehicles.

Some of the terpenes are volatile: the pleasant aroma of a conifer forest in summer is from terpene molecules such as limonene and isoprene. Summertime pollen released from conifer trees forms clouds like smoke from a fire, contributing to the pollen-count broadcast on weather forecasts to inform those of us allergic to pollen.

Trees also absorb or remove, or otherwise cleanse pollutants from the air that we breath: including toxic gases such as sulphur dioxide and ozone together with the microscopic particles of dust and smoke that make the sky hazy and choke our breathing. Trees are well promoted to provide us with this amenity of cleaner air, specially in towns and cities where most air pollution is from road transports and industries.

Within this topic there are seeming contradictions and confusions. These include technical difficulties of obtaining empirical data by direct examination of stands of trees and their leaves.. It is gained by chemical analysis of specific compounds, or by processing leaves to extract, sieve and count minute particles. Such data is incorporated in computerized models of these cleansing effects but this can lead to mismatch between what the model predicts and what the leaves on trees of that particular wood are actually doing.

Sometimes this removal of pollutants is expressed simply as tonnes per year of a gas or of dust particles but greater specificity is needed. (A tonne carbon dioxide fills, at sea level, a balloon of about 11 metres diameter.) An example from of trees removing pollutants in the city of Strasbourg in France follows; from Selmi *et al.* 2016. This is a busy port-city on the river Rhine, also with suburbs of two-storey houses on gardens with trees, and with several large dense woods of broad-leaf species such as European beech, ash and chestnut. Data for analysis by computer model (*i-Tree*) were of the species and woodland structure of stands of trees, not individual trees or leaves.

> *Pollutants removed as grams per square metre of tree cover per year:*
> Total pollutant removal was 5.89 grams, comprising:
> Carbon monoxide: 0.08g
> Nitrogen dioxide: 0.92g
> Ozone: 3.73g
> Particulate matter, diameter 10 micrometres: 0.79g
> Particulate matter, diameter 2.5 micrometres: 0.30g
> Sulphur dioxide: 0.07g

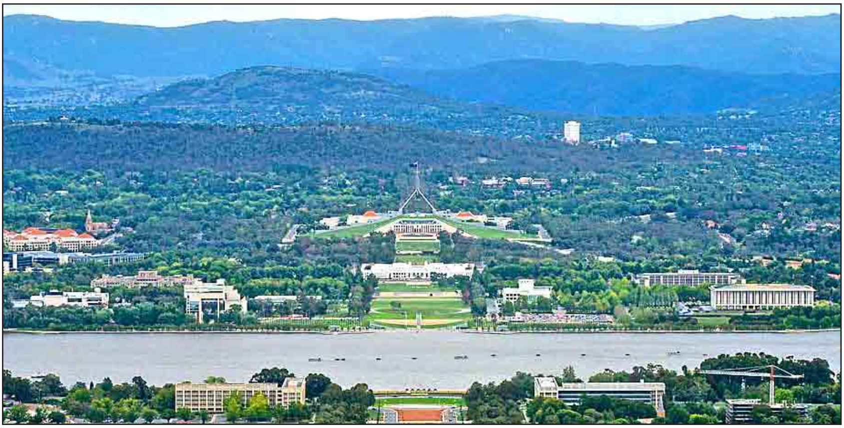
The total removal as above, 5.89g/m^2/year, was similar to results using the same research method from cities in USA, ranging from 6.2g to 23.1g. But the residents and public health authorities of Strasbourg really want to know is by how much all these trees – an estimated 588,000 of them – have removed of the total in the air over that city. The calculations gave 88.23 tonnes per year of pollutants removed by trees, which seems a lot but was approximately 0.5% of the total pollutants estimated to be in the city's atmosphere. The dominant method for controlling these pollutants remains actions at their source by combination of technical improvements, legislation that sets limits on allowable emissions from factories, vehicles, heating of houses using coal or wood, and for individual responsibility.

Nevertheless, improvements to tree cover in towns and cities that include ability to absorb pollutants is best incorporated as one of the many and varied benefits of these trees. Surely there is sufficient of scope for silvicultural work to be more effective through knowledge about how trees do absorb or de-toxify pollutants from the atmosphere.

Conifer trees remove more particulate pollutants that broad-leaf trees. Of trees in general those with complex leaf structures, such as ash or firs are better at capturing and holding particulate pollutants than species with simpler leaf structure. Deposition of particles occurs at the leaf surface, probably by interaction with the wax layer of the epidermis cells of the leaf. Thus leaves with rough or hairy surfaces are more effective.
The pollutant gases in the table above, carbon monoxide, nitrogen dioxide, and ozone will enter the inner cells of the leaf through the stomata pores of both needle-leaf and broad-leaf trees. Here these molecules encounter high intensities of enzyme activity of photosynthesis, respiration, and construction of the complex compounds for tree growth that will be distributed in the phloem tubes of the tree. The pollutants are rapidly transformed, metabolized, hence the relatively high proportions of these gaseous pollutants removed in the table above.

Multipurpose woodlands.
One of the fundamental resources to be extracted from woodlands in many low-income countries is wood as fuelwood and for charcoal and small scale timber for on-farm use (see 'Fuelwood'). The example of miombo woodlands in the savannas of southern Africa is again useful. Many of the tree species here are naturally good for coppicing as an evolved adaptation to damage. The trees regenerate vegetatively from sprouts and shoots from cut stumps of coppiced or pollarded trees. People using these woodlands employ methods long established for sustainable provision of wood products. Rotations at 30 to 50 years of demarcated harvest areas are the basis of a resilient culture for forest management.

These woodlands also include areas of food crop farming which are little different in principle from what has been practised in high-income countries of Europe for example. Agro-forestry was mentioned and illustrated in chapter 'Carbon' in the context of storing carbon. The practice of wood-pasture here, with pollarded or otherwise protected trees, is ancient and now rare in Europe, but it continues elsewhere. These varied systems demonstrate there is nothing incompatible between livestock at low density and the health of trees within woodlands. Land managed for agro-forestry can also provide recreational access, particularly in upland areas where the intensity of management systems is lower and distant views are more frequent than in the fertile lowlands. People's wish for recreational use may seem trivial in the contexts of fuelwood and subsistence farming. However, with towns and cities near to attractive wooded countryside economists may calculate that recreation generates the highest financial flows per area of land when compared to both upland livestock farming and commercial forestry. The example used here is the entire country of Wales. The economists who produced this analysis of costs and benefits came to many counter-intuitive conclusions. Nevertheless they demonstrated the high value of recreational benefits of forests with easy access and facilities at short distance from large urban areas.



Canberra, Australia. Credit: Wikimedia.

A clear example of the importance of trees and woods for the enjoyment of people, and their health, widen this perspective. Australia has a federal constitution with the national capital established separately from the six states on a small area of low agricultural value. Livestock farmers had cleared nearly all the original trees by the early 1800s but when Canberra was established formally in 1913 the federal government started extensive planting of trees for amenity. See above for how green it is now.

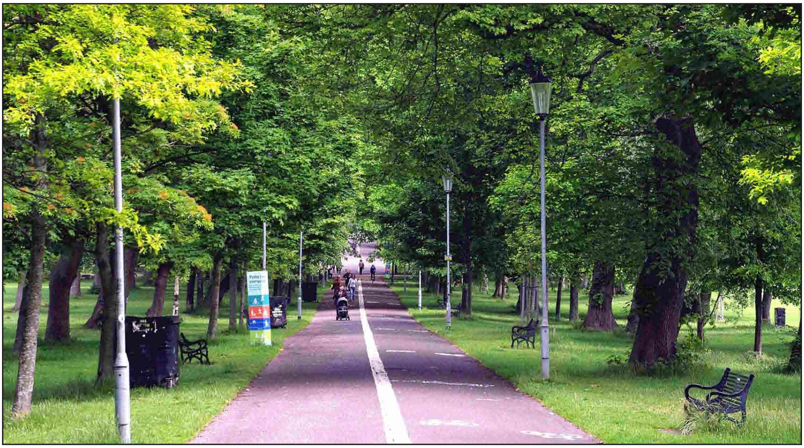
Economists use a concept of this type of resource: *public goods*. This is a type of wealth not as money in the bank, nor does it contribute directly to a country's gross domestic product. The price in dollars of a thing is only what you need to pay to possess it, whilst the value of the thing, a camera for example, can be stored wealth of useful information or happy memories you can share. Public goods are wealth as both systems and things that can be shared: clean air, libraries, street lighting. The classic example of a public good is from the people and organizations of a maritime nation who build lighthouses around their coast: any and all mariners can benefit from the service whilst no mariner is excluded from using the service.

These are the calculations of *ecosystem services*: a term that sits uncomfortably amongst the aesthetics of woodland planting as too mercenary for some tastes, or just incomprehensibly mathematical. The concept of ecosystem service is about biological, living, resources that are useful to people. Insects pollinating crops of fruit or vegetables are from the farmer's point of view an ecosystem service. Mercenary or altruistic notwithstanding, if volunteers running a small-scale project to regenerate a woodland can obtain funds in direct exchange for the monetary value of the carbon these trees will store then ecosystem services demand attention.

In addition the volunteer labour can be given a monetary value if that helps to generate funds for a project. Economists use a notional value of an hour or day of unpaid volunteer work as some minor fraction of the typical pay for similar work in the commercial sector. The significance of this is that volunteer labour not only creates wealth as amenity, timber, carbon storage and so on, but that this wealth is a resource with substantial ability to spontaneously regenerate. This will increase the sum of resources of living things that benefit people.

Privately owned urban trees in a wealthy area of a city provide the public goods of pollution reduction and beauty.

Such resources are often described by the concept of *natural resources*, or *natural capital*. In other words the worldwide stocks of rock, soil, air, water, sunlight, and living things. *Capital* as a technical term used by economists means any resource which enables the production of more resources. For people planting trees, their benefit is similar to their benefit from public goods because the trees spontaneously produce more resources as timber, shade, recreation, and habitat for many other living things. Many of these benefits can be public despite the usual situation where the land where the regenerated woodland stands is privately owned.



Public goods: commuting route for walkers and cyclists to city centre; open space for ball games; peaceful fresh air; park benches under big trees.

The benefits of amenity trees in towns and cities are many and varied: when walking below the canopy of an old-growth forest, or in the shade of rows of pollarded of street trees our spirits are lifted. Psychological depression has a large cost to a country's health services, but access to open green space and the simple sight of things living, large, green and permanent, calms our nerves.

Access to amenity is like access to jobs, fair pay, adequate housing: some people have more than others. This is particularly stark when the quality of urban environments varies along social and racial patterns, the sort of urban zoning so common in large cities worldwide. Studies to measure disparities in wealth measured by either money or access to resources or similar use a calculation that gives a *Gini coefficien*t. For example a study of the distribution of street trees in the vast city Lagos, capital of Nigeria, gave a Gini coefficient of 0.81, indicating severe inequality. (Gini coefficient measures the inequality among the values of a frequency distribution, such as level of income. The coefficient goes from 0 representing perfect equality, to 1 representing total inequality.) The photograph on page 25 of privately owned urban street trees was taken within four kilometres of an area in the same city where the only trees were saplings newly planted by the city corporation as part of an urban housing regeneration scheme.

Recently there has been great increase in activity for woodland regeneration. There is something about trees that resonates with deep sensitivities and emotions of people. Could this relate somehow to our long cultural past? Trees were vital to the origin of human social culture and methods to survive in environments that could be harsh. Trees continued to be vital to the development of human civilization and technology as it grew in villages and small towns that were closely integrated with the surrounding tree flora. These trees germinated, grew, reproduced and died at an almost imperceptible pace against the pace of the people amongst them. Trees were not just continuing physical landmarks – could they have been, and continue to be, useful friends and emotional allies?

References and notes.

(Many articles are accessible as abstract or full text using search engines such as Google Scholar, an institutional login, or a pay-wall.)

Historical perspective and definitions.

Birks, H.J.B., Deacon, J. & Peglar, S.M., 1975. Pollen maps for the British Isles 5000 years ago. Proceedings of the Royal Society of London, Series B, 189: 87-105.

Challenger, M., 2022. *How to be an animal: what it means to be human.* Canongate Books, Edinburgh, ISBN: 9781786895752, [Biological and sociological argument for humans being part of nature.]

Denevan, W.M., 1992. The pristine myth: the landscape of the Americas in 1492. Annals of the Association of American Geographers, 82: 369-385.

House, S. & Dingwall, C., 2003. A nation of planters: introducing the new trees, 1650 - 1900. In: *People and Woods in Scotland: a history*. Smout, T.C. (editor), Edinburgh University Press, Scotland, ISBN: 0748617019.

Peterken, G., 2023. *Trees and Woodlands*. Bloomsbury Publishing Plc., London, ISBN: 9781472987013. [Chapter 5 for definition of natural woodland.]

Stroh, P.A., *et al.*, 2023. *Plant Atlas 2023: mapping changes in the distribution of the British and Irish flora*. Botanical Society of Britain and Ireland; Princeton University Press, Durham & Oxford, ISBN: 9780691247595. [Maps of Scots pine and Sitka spruce on pages 88 and 92: https://plantatlas2020.org]

Wilson, P., 2020. *A-Z of Tree Terms: a companion to British arboriculture.* Ethelburga House, Kent, England, ISBN: 9780957178427. [More than a glossary – detailed explanations of many aspects of arboriculture.]

Natural regeneration and silviculture.

Angelsen, A. & Kaimowitz, D., 2001 (Editors). *Agricultural Technologies and Tropical Deforestation*. CABI Publishing, Wallingford, UK. ISBN: 0851994512. [See: A.Mather, pages 35-52, *The Transition from Deforestation to Reforestation in Europe*.]

Chidumayo, E.N., 2013. Forest degradation and recovery in a miombo woodland landscape in Zambia: 22 years of observations on permanent sample plots. Forest Ecology and Management, 291: 154-161.

Edlin, H.L., 1970. *Collins Guide to Tree Planting & Cultivation*. Collins, London, ISBN: 0002191598 [This remains simplest and most practical guide to methods in Britain and elswhere; second-hand copies available.]

Harmer, R., Kerr, G. & Thompson. R., 2010. *Managing Native Broadleaf Woodland*. Forest Research, Edinburgh, ISBN: 9781839150067. [Much practical information, a handbook written by foresters; see chapter 6: Regeneration]

Hirons, A.D. & Thomas, P.A., 2018. *Applied Tree Biology*. John Wiley & Sons Ltd, USA, ISBN: 9781118296400. [Ch. 5 for silviculture methods.]

Ky-Dembele, C., *et al.*, 2007. The relative importance of different regeneration mechanisms in a selectively cut savanna-woodland in Burkina Faso, West Africa. Forest Ecology and Management, 243: 28-38. [Managed harvesting of wood products in national reserves at margins of Sahel.]

Nagendra, H. 2007. Drivers of reforestation in human-dominated forests. Proceedings of the National Academy of Sciences of the United States of America, 104: 15218-15223. [Study of 55 forest sites in Nepal on social and land-tenure influences on regeneration.]

Redmond, M.D., *et al.*, 2018. Woodland resilience to regional drought: dominant controls on tree regeneration following overstorey mortality. Journal of Ecology, 106: 625-639. [The need to anticipate future increases in risk of fire and drought when replanting.]

Starr, C., 2013. *Woodland Management: a practical guide*. The Crowood Press, England, ISBN: 9781847976178. [Silvicultural methods for regenerating woodlands.]

Syampungani, S., Geldhuys, C.J. & Chirwa, P.W., 2015. Regeneration dynamics of miombo woodland in response to different anthropogenic disturbances: forest characterisation for sustainable management. Agroforestry Systems, 90: 563-576.

Land management.

Ashmole, P. & Ashmole, M. (editors), 2020. *A Journey in Landscape Restoration: Carrifran wildwood and beyond*. Whittles Publishing Ltd., Scotland, ISBN: 9881849954723. [Examples of actions to gain support, funds and permissions for establishing a natural woodland on old pasture land.]

Fuentes-Montemayor, E., *et al.*, 2022. The long-term development of temperate woodland creation sites: from tree saplings to mature woodlands. Forestry, 95: 28-37.

Continued

Honnay, O., Hermy, M. & Coppin, P., 1999. Effects of area, age and diversity of forest patches in Belgium on plant species richness, and implications for conservation and reforestation. Biological Conservation, 89: 73-84. [Many small woods can be as good for nature as a few large woods of same total area.]

Hughes, S. *et al*., 2023. New woodlands created adjacent to existing woodlands grow faster, taller and have higher structural diversity than isolated counterparts. Restoration Ecology, 31: e138892023.

Doggart, N., *et al.,* 2023. Agricultural fallows are the main driver of natural forest regeneration in Tanzania. Environmental Research Letters, 18: 054008

Herbivores.

Hester, A.J., Mitchell, F.J.G. & Kirby, K.J., 1996. Effects of season and intensity of sheep grazing on tree regeneration in a British upland woodland. Forest Ecology and Management 88: 99-106. [Low level of grazing pressure necessary for long term health of woodlands.]

Pepper, S., Barbour, A. & Glass, J., 2020. *The Management of Wild Deer in Scotland: deer working group report*. Scottish Government, Edinburgh, ISBN: 9781838605253 [Distribution maps and population estimates for red, roe, Sika and fallow deer; also information on legal constraints for killing deer, and management targets for culling.]

Putman, R., Apollonia, M. & Andersen, R. (editors). 2011. *Ungulate management in Europe: problems and practices*. Cambridge University Press, England, ISBN: 9780521760591.

Russell, M.B., *et al*., 2017. Interactions between white-tailed deer density and the composition of forest understories in the northern United States. Forest Ecology and Management, 384: 26-33. [Comprehensive study of impact of white tailed deer on mixed forests found deer at more than 5.8/km^2 are detrimental to tree growth.]

Van Uytvanck, J., *et al*., 2010. Woodland regeneration on grazed former arable land: a question of tolerance, defence or protection? Journal for Nature Conservation, 18: 206-214. [Utility of cattle and similar for managed grazing

pressure.]
Western, D., & Maitumo, D., 2004. Woodland loss and restoration in a savanna park: a 20-year experiment. African Journal of Ecology, 42: 111-121. [Fencing to deter elephants in Amboseli National Park, Kenya, from eating trees.]

Pollution mitigation.

Brack, C.L., 2002. Pollution mitigation and carbon sequestration by an urban forest. Environmental Pollution, 116: S195-S200. [Reforestation of site of Canberra city.]

Beckett, K.P., Freer-Smith, P.H. & Taylor, G., 2000. Effective tree species for local air quality management. Arboricultural Journal, 26: 12-19. [Details of empirical methods for measuring mitigation of pollution.]

i-Tree model: https://www.itreetools.org/about

Freer-Smith, P.H., Beckett, K.P. & Taylor, G., 2005. Deposition velocities to *Sorbus aria, Acer campestre, Populus deltoides* × *trichocarpa* 'Beaupré', *Pinus nigra* and × *Cupressocyparis leylandii* for coarse, fine and ultra-fine particles in the urban environment. Environmental Pollution, 133:157-167. [Evidence that conifers take up more more pollutants than broad-leaf trees.]

Hiatt, M.H., 1998. Bioconcentration factors for volatile organic compounds in vegetation. Analytical Chemistry, 70: 851-856. [Detailed description of methods.]

Nemitz E., *et al*., 2020. Potential and limitation of air pollution mitigation by vegetation and uncertainties of deposition-based evaluations. Philosophical Transactions of the Royal Society A. 378: 20190320

Nguyen, T.B., *et al*., 2015. Rapid deposition of oxidized biogenic compounds to a temperate forest. Proceedings of the National Academy of Science, 112: e312. [Details of how terpenes and similar move between air and leaves.]

Selmi, W., *et al*., 2016. Air pollution removal by trees in public green spaces in Strasbourg city, France. Urban Forestry & Urban Greening, 17: 192-201.

Setala, H., *et al*., 2013. Does urban vegetation mitigate air pollution in northern conditions? Environmental Pollution, 138:104-112. [By a small amount.]

Multipurpose woodlands

Bateman, I.J., 2009. Bringing the real world into economic analyses of land use value: incorporating spatial complexity. Land Use Policy, 26S: S30-S42. [Economic valuation of conifer plantations in context of upland sheep farming and recreational access from large urban areas.]

Bateman, I.J. *et al*., 2022; A review of planting principles to identify the right place for the right tree for 'net zero plus' woodlands: applying a place-based natural capital framework for sustainable, efficient and equitable (SEE) decisions. People and Nature, 5: 271-301.

Lee, H., *et al*., 2023. Three billion new trees in the EU's biodiversity strategy: low ambition, but better environmental outcomes? Environmental Research Letters, 18: 034020.

Dasgupta, P., 2012. *The Economics of Biodiversity: the Dasgupta review*. Crown Office, London, ISBN: 9781911680291. [492 pages, serves as a textbook of ecological economics with explanations of natural capital, ecosystem services, etc. Free pdf online – search term: *Dasgupta review*]

Downie, M., 2011. *Conservation Refugees: the hundred year conflict between global conservation and native people*. MIT Press, USA, ISBN: 978-0-262-01261-4. [Material on the legal doctrine of *terra nullius* and proposition that conventional management of national parks should be replaced with social use of multi-purpose landscapes.]

Fynn, R., *et al*., 2016 Strategic management of livestock to improve biodiversity conservation in African savannahs: a conceptual basis for wildlife - livestock coexistence. Journal of Applied Ecology, 53: 388-397. [Integration of livestock with wildlife for sustainable future of savanna.]

Continued

Kamau, P.N. & Sluyter, A., 2017. Challenges of elephant conservation: insights from oral histories of colonialism and landscape in Tsavo, Kenya. Geographical Review, pgs:1-22. [Evidence supporting potential change of national park policy toward locally controlled multi-purpose savanna.]

Nepal, S.K., 2002. Involving indigenous peoples in protected area management: Comparative perspectives from Nepal, Thailand, and China. Environmental Management, 30: 748-763 [Nature reserves should balance needs of tourism with traditional practices of farmers.]

Walker, L.R. & del Moral, R., 2003. *Primary succession and ecosystem rehabilitation*. Cambridge University Press, England, ISBN 0521800765. [Ch 8 for modern ecological theory applied to regeneration.]

Social justice.

Adeyemi, O & Shackleton C. M., 2023; Street tree abundance, composition, and (mal)distribution in Lagos Metropolis, Nigeria. Trees Forests and People, 15: 100740.

Burghart, K.T., 2022. Current street tree communities reflect race-based housing policy and modern attempts to remedy environmental injustice. Ecology, 104: e3881.

Foster A. I., Dunham, M. & Bukowska, A., 2022 An environmental justice analysis of urban tree canopy distribution and change. Journal of Urban Affairs, DOI: 10.1080/07352166.2022.2083514.