Forests migrated to survive ice-ages

A chapter in: *Trees of the people*, by Alan R. Walker

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Many thousands of years ago the northern lands of Earth slowly emerged from under vast sheets of ice. For millennia these lands had been covered by ice three to four kilometres thick. Ice advanced southward year by year until it reached regions where today cities such as Chicago, London, Moscow now stand. Ice accumulated because the Earth's winter seasons fluctuate: colder, warmer, and colder again during immensely long cycles of variation in our orbit on Earth around the Sun. As the ice advanced it pushed over the land: crushing, freezing, and obliterating all life before it. Only mountains survived and even they were ground lower and smoother. Then, as the winters became milder again and ice melted, the land left behind was desolated: bare rock, boulders, gravel, and sand as lifeless as the Moon.

Tundra in Svalbard. Credit: Wikimedia, A.Weith.

But many living things thrive on empty spaces: there are fewer other organisms to compete with. First to migrate into the empty lands were bacteria, then lichens, mosses, herbs, and grasses. Eventually trees migrated north and thrived again in the lands they had occupied previously. After grasslands and forests established, herbivorous animals walked in, trampling the land and eating tree seedlings. These animals maintained enough open space for more grass to grow. Predators moved into the newly vegetated lands: lions and wolves seeking the large herds of deer and bison. The top predator, humans working in bands and equipped with spears, set fire to forests that were encroaching onto their grassland hunting grounds. After the fire passed over, clearing the ground of leaf litter, fresh grass developed next season, encouraging more herbivores into range of the hunters. The people collected wood for their cooking fires, their shelters, and to manufacture more spears.

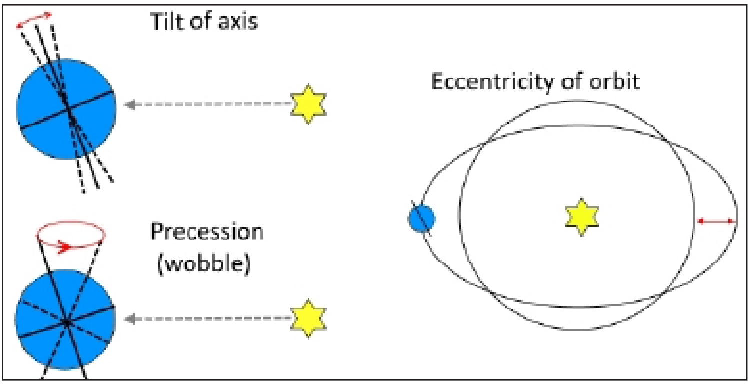
As the centuries and millennia passed the people replaced their stone knives and axes for ones made of bronze, and then iron. They felled trees for large timbers to build weatherproof houses or seaworthy boats. They nurtured the cut stumps of certain species of tree to regrow as multiple stems of suitable size for more timber. They converted areas of grassland into croplands, and put out their newly domesticated livestock to graze and browse in the forest. In these ways forests lost their primeval character wherever they were in reach of humans. Nevertheless, humans needed the trees for their survival in those early days. Now we humans might seem able to live independently of trees and forests, but would that be wise?

Tundra in Siberia. Credit: Wikimedia.

Ice advances over the forests.

The time when these latest ice-sheets were thickest and widest, the Last Glacial Maximum, was about twenty thousand years ago. Colossal astronomical forces create these slow cycles of cold and warmth as Earth changes its position relative to our Sun, over times measured by the millennium. The astronomer Milutin Milanković published in 1920 a book to explain these cycles. His theory was supported well by astronomical evidence, and so these changes are now called Milankovitch Cycles.

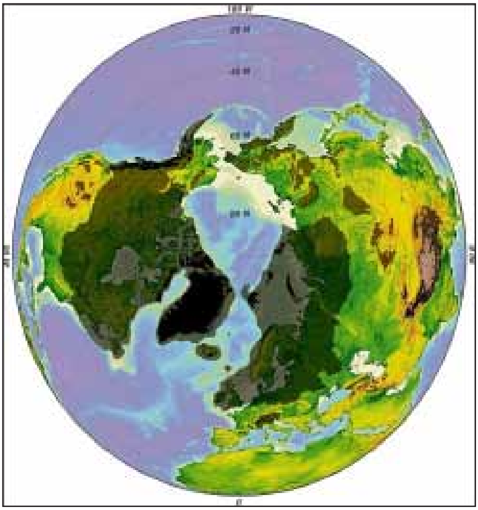
There are three main oscillations of Earth's position relative to the Sun. Axis of Earth though the poles tilts from 22.1° off the vertical at a right-angle with the Sun to a maximum tilt of 24.5° at the opposite phase of this tilting cycle, which lasts 41,000 years. A small difference but when tilt is closer to vertical, north and south polar regions receive little light from the sun (less insolation) during winter seasons. Snow accumulates, compacts, and consolidates into ice. Furthermore, this effect of tilting is compounded by two more cycles. The Earth's orbit around the sun slowly changes from an ellipse that is nearly circular to an ellipse that is more oval (or eccentric). When we are at the far end of an oval orbit insolation from the sun is less intense. Also, Earth slowly wobbles on its spinning axis (a precession) because our planet is not a perfect sphere. When one of these wobbles adds to the effects of axis tilt then the differences between winter and summer become greater. These three gravitational influences lead to complex interactions, so the cycles of ice-ages are not precisely regular, but for this story about trees and people just the last major ice-age is the relevant biological focus.



About every one hundred thousand years another ice age grips both the north and south poles. In the north the small Arctic Ocean holds insufficient heat energy to prevent ice sheets from extending far onto the vast lands of North America and Eurasia. During the last ice age the ice crept southwards in a varied zone thousands of kilometres wide in many places. Not everywhere: some northern parts of Siberia, China, and Alaska had a climate too dry for enough ice to form. The amount of Earth's water trapped on land as ice became so great that the oceans dropped by one hundred metres below their current level. Waters of the Bering Straight became land of Beringia, connecting Asia and America.

Before this latest full ice age developed, these northern lands resembled what is there currently in important ways. What are now the northern states of the USA, all of Canada, Greenland, all of northern Europe and most of northern Russia were once covered in tundra. This was thinly vegetated by grasses and low woody shrubs. Often this ancient landscape is called mammoth tundra – it used to be inhabited by huge woolly herbivores resembling modern elephants. Further south was taiga vegetation, comprising mainly conifer forests. In warmer more southerly latitudes were mixtures of steppe grasslands, with forests dominated by broad-leaf trees.

Last glacial maximum from north polar perspective; grey/brown shading for approximate-extent of ice-sheets; black for current ice-sheets and glaciers. Credit: Wikimedia, Hannes Grobe.



Our early ancestors were there as well. The most northerly record found so far of our early ancestors, of our own genus *Homo* (biological tribe Hominini) is a group of footprints left eight hundred thousand years ago in seashore mud at 52° north. There now lies the village of Happisburgh on the east coast of England, at roughly the same latitude as Amsterdam. Probably a roaming group of *Homo antecessor* left them, possibly as they foraged for shellfish to eat.

As the ice advanced, living things retreated southward. Animals simply walked or flew away; we humans went with them. Plants failed to flourish in the north. Some of them went extinct as species, but many of the populations of species survived by seeding, maturing, and reproducing better in the lands to the south rather than those to the north. Thus forests migrated, advancing tree by tree as they reproduced. Species by species they moved at their separate vegetative paces, depending on how their seeds happened to flourish where they landed.

Palaeolithic hand-axes of flint rock, discovered at Happisburgh, east coast of England. Credit: Wikimedia, Portable Antiquities Scheme.

Ice retreated and plants reclaimed the barren land.

Eventually the ice-sheets retreated as they melted, although they remain still on Greenland and Antarctica. Microorganisms started recolonization of the barren lands. The spores of bacteria, algae and fungi are minute – they are blown on the wind along with the larger grains of pollen and minerals. These wind-borne (or aeolian) life forms are adapted for wide and random spread. Most individual organisms fail to land at a favourable spot, but they disperse by the trillion. Cyanobacteria were the earliest to arrive and get a hold on bare rock. These bacteria, minute single celled organisms, became the most important living things on Earth for vast spans of time. They lived on the energy of sunlight, the material of carbon dioxide, plus a few nutrient minerals. They excreted their waste product as another gas.

That waste was oxygen that we animals, and the plants, now use for respiration. Cyanobacteria evolved the ability to live by photosynthesis long before plants did. Their molecular machinery for this is held on inner folds of their outermost membrane. Botanists understand the photosynthetic units of plants, the organelles called chloroplasts, as derived from cyanobacteria that invaded the cells of the earliest plants. That happened two billion years ago, sometime during the Precambrian aeon. Now these bacteria continue to live separately in the harshest environments, as well as the lushest. And on stony wastes near the edge of the ice sheets about twelve thousand years ago they grew as thin filaments and crusts of organic matter, just a smear of life on the rock.

Fungi and algae, either separately or in the symbiotic combined forms called lichen, followed the cyanobacteria. Species of the lichen genus *Peltigera* that can now be seen as broad gray or green lobes growing on rocks or soil may then have been typical colonizers. Lichens are tough and often expand into roughly surfaced or branching forms above their rocky substrate. Airborne dust entangled amongst the lichenous surfaces and more lichen grew on the old consolidated lumps. The mass of organic matter not only grew, it was mixed with minerals from the dust. Most of this dust came from the top layer of soils present further south, the type called loess.

Peltigera lichen as grey sheets growing on rock; also moss amongst the lichen. Credit: Wikimedia, Jerzy Opiola.

The first animals to arrive in the barrens were insects, also spiders that preyed on the insects. Summertime air swarms with insects on the move. They fly or are simply swept up and away on the wind. Spiders float under threads of their silk. If you now climb up onto glaciated mountains you may see butterflies flapping their own way across to the next valley. Researchers who look for plant and animal fossils in lake sediments that formed near the ice sheets find remains of the major groups (Orders) of insects: beetles, two-winged flies, bees, and caddis-flies. As they lived and died among the bacterial and lichenous mats their remains added nitrogen, and compounds containing phosphorus, to the young soils.

Amongst earliest plants colonizing the new lands those that look to us like ordinary plants were prominently the mosses. Woolly moss (*Racomitrum* species) and fern moss (*Drepanocladus* species) were typical. They arrived on the wind as spores. As soon as a spore landed it hatched as a rhizoid (root-like structure) that clung to the bare rock and then grew into a horizontal shoot. The shoots spread and developed a bud that grew upwards. The familiar furry mat of a moss developed. The vertical shoots produced extensions like miniature leaves and these fed on sunlight and carbon dioxide. The furry mats trapped more dusty loess from the wind.

Fungal spores had arrived with the cyanobacteria, so by the time there were lichens and mosses and insects dying, the fungi had something to feed on. The normal mass of a fungus is a tangle of minutely fine threads, hyphae, that form a functional network as a mycelium. This network grows through soil and penetrates any dead organic matter it finds. There the fungi use powerful enzymes to digest then absorb this food.

Mats of *Racomitrum* moss colonizing lichenous volcanic rock in Iceland. Credit: Wikimedia, Manfred Morgner.

Trees migrated northwards.

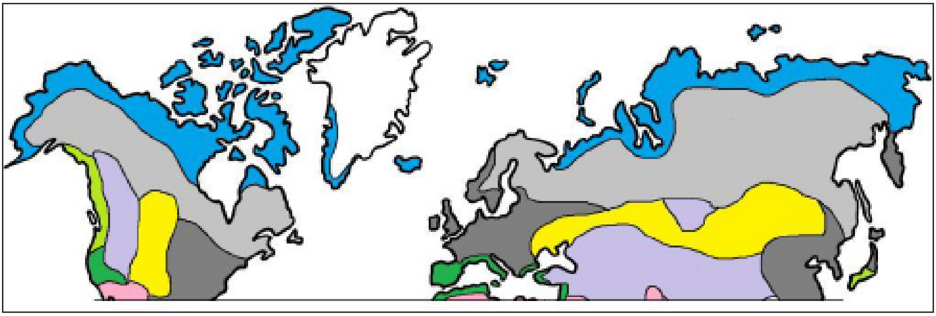
As millennia passed and the Earth tilted more on its axis the northerly winters became milder and the summers warmer. Seed producing plants – the gymnosperms with cones and the angiosperms with flowers –

migrated northward. Those of their seeds that settled onto patches of soil clear of lichen or moss germinated in the primitive soils. As centuries passed these thinly spread patches of pioneer trees became a little denser as they were joined by more coniferous trees. White spruce (*Picea glauca*) in North America, or Scots pine (*Pinus sylvestris*) in Eurasia, reproduced with small wind borne seeds that could establish on the new soils, anywhere that the mosses and grasses would not smother the seedlings during their first spring growth. Other conifers, in lesser numbers, arriving from southerly isolated habitats were hemlocks (*Tsuga*) and silver firs (*Abies*). As the trees best adapted to cold climates migrated northward their forests in the south slowly died as the climate became too warm and broad-leaf trees out-competed them. Spruce trees grow as high as thirty metres, a simple narrow cone on a relatively thin stem. A natural forest of them resembles an array of green pencils balanced on their bases. The needle-like leaves have a bluish tinge to their basic green colour. The seeds are produced in large hanging cones and the small seeds each have a single membranous wing for dispersal on the wind.

White spruce in taiga zone of Alaska. Credit: Wikimedia.

Accounts of these ancient histories of plants often seem as if they were first recorded by people then living there. Nobody there but the plants left evidence as pollen grains and other remains of tough tissues that become incorporated in soil. Mires and bogs are eagerly sought by ecologists, who drill out core samples of mud to search for evidence.

Pollen has a tough, resistant, outer coat that is finely patterned and can be closely studied under a microscope. A genus of trees, or sometimes a species, will have pollen of a characteristic pattern, indicating the general types of trees present in a geographical area and at a time that can be estimated by other techniques. Huge sets of this information (of the science of palynology) have been collected from parts of Eurasia, North America and elsewhere, enabling broad-scale accounts of how trees and other vegetation responded to the climates of ice-ages.



Current vegetation zones of northern hemisphere, generalized from several sources: blue = tundra, light grey = taiga, dark grey = temperate broadleaf forest, light green = temperate rain forest, dark green = evergreen sclerophyllous forest, yellow = temperate steppe.

Taiga vegetation developed: a low layer of mosses, grasses, herbs, and dwarf trees, with thinly spread patches of broad-leaf trees and wider populations of conifers. The land still bore deep scars left by the retreating ice: moraines and drumlins of boulders, interspersed with gravel beds. Ponds and small lakes proliferated in hollows created by the power of melt water that had flowed in complex eddies under melting ice.

As the climate changed to resemble what had prevailed before this ice age, more broad-leaf trees migrated north. They came to dominate the more southerly parts of the boreal zone, at lower latitudes than the conifers of the taiga. Ash (*Fraxinus*), elm (*Ulmus*), lime (linden or basswood, *Tilea*) and oak (*Quercus*) characterized the temperate and montane broad-leaf forests of these gentler southern climates. These types of vegetation, from lichens and mosses to herbs and trees, established on particular areas with particular climates in succession: lichens first, oak trees last. Whether or not the mature assemblage of plants remained in the original proportions and interrelationships depended on the climate. If the climate continued to change the assemblage changed as each separate species either thrived better or worse according to its physiological and ecological needs.

Trees that dropped heavy seeds such as the acorns of oak trees, created dense clumps of the same species that sheltered their seedlings. As broad-leaf trees established their high capacity for capturing energy of sunlight and carbon from air during summer so their many leaves rotted into the soil during winter. The fauna of invertebrate animals in the soil, together with fungal mycelia, circulated carbon and added nitrogen and phosphorus nutrients. Fungi bound together particles of soil into aggregates that were less likely to be eroded away by wind or rain. Humus developed as a loose organic matrix around the mineral grains of soil, and it retained moisture and nutrients in the soil. Birds passed through the forest: their droppings contained nutrients derived from their prey, or possibly contained seeds of additional species of plants.

Two female cones that produced these seeds of Scots pine. Seeds are 15mm long, mostly of one membranous wing for dispersal on wind, and their food reserve is small.

These slow, vast and inexorable changes to the abundance and distribution of living things are the result of what can be thought of as a single driving force. Single, but a combination of gravitation operating at the level of our solar system which creates a slowly repeating pattern of variation in amount and distribution of light energy that Earth receives from our Sun. More than major ecological time-scales are at work here, the longer cycles are sufficient for distinct evolutionary changes in the origin and fate of species.

Herbivores returned to the newly greened lands.

As the forests returned they encountered populations of large animals that fed on plants. These herbivorous mammals had walked into the newly greened lands to eat grass, reeds, and herbs. Some of the herbivores could survive through the winter by eating mainly lichens. Reindeer (= caribou in North America) were well adapted to such a meagre diet. Grasses in general can survive and even thrive under heavy grazing because they grow from their base upward. Graze them with cattle or sheep (or a lawnmower) and they keep growing.

Seeds of sessile oak tree: heavy with food reserves and dispersed by animals. Credit: Wikimedia.

These new grasslands, about thirteen thousand years ago, supported abundant populations of large herbivores. In North America roamed species such as mammoths (*Mammuthus* species) and steppe bison or wisent (*Bison priscus*). Amongst those whose lineage continued to current times are elk (*Cervus canadensis*), moose (*Alces alces*), caribou (*Rangifer tarandi*), and plains bison (*Bison bison*). Down in amongst the grass were numerous smaller plant eaters: shrews, voles, lemmings, squirrels...

In northern Eurasia, from Ireland to the Bering Straits, the large herbivores populating these steppes included mammoths, woolly rhinoceros (*Coelodonta antiquitatis*), steppe bison, and others. Of those that survived or arrived later there remain: roe deer (*Capreolus capreolus*), red deer (*Cervus elephas*), reindeer and moose. The impact of all these hungry plant eaters on the developing boreal vegetation was profound. The youngest seedlings of herbs and trees are eaten whole, or just the softer tips of conifer seedlings are nipped off. An open patchwork of grassy glades with clumps of trees developed. Only the largest herbivores, those with tusks, could tackle entire trees for browse.

People followed the herbivores and trees.

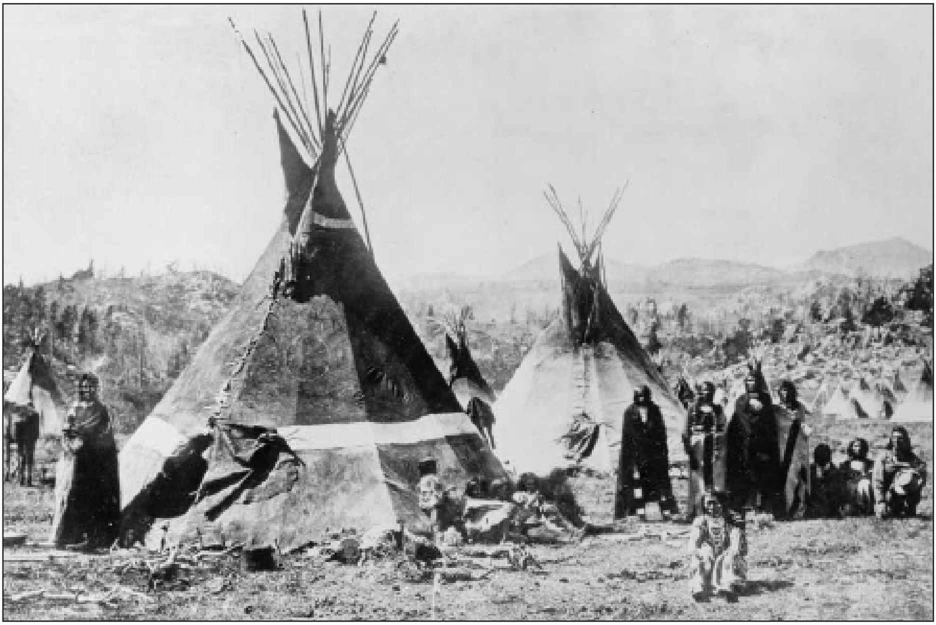
People survived and reproduced well enough in these early landscapes that were thinly covered with sheltering vegetation because they hunted efficiently the numerous plant-eating animals. Moreover they gained greater energy and nutrients from their food by cooking it, making meat and tubers easier to digest. They used fire to manage the forest for easier hunting, creating open areas where the burnt grass rapidly grew and renewed. As mobile questing hunters the people could effectively stalk their prey in open country. Dense forest was little use to them for that style of hunting large prey.

Time line (advancing downwards)

Era: *Cenozoic*, started 66 million years ago.
Period: *Quaternary* period of the Cenozoic era, started 2.58 million years ago.
Epoch: the Quaternary period has two epochs:
1) *Pleistocene* epoch, started 2.58 million years ago and ended 11,700 years ago.
2) *Holocene* epoch, our current times.

Pleistocene events: quaternary ice-age continues; megafauna flourishes, start of human Stone-age.
Holocene events: ice-sheets retreat; agriculture starts; Bronze-age then Iron-age; industrial revolution.

The hominin ancestors of these people, *Homo erectus*, learnt how to use fire, probably one and a half million years ago. The comforting sociability of sitting around a camp fire may have reinforced social cooperation as a route to success of the hominin lineage. They learnt how to capture fire from natural lightning strikes, to tend it as fire-logs, and to create fire using a hand-drill friction stick. *Homo erectus* bands were cooking some of their food by eight hundred thousand years ago. Cooked meat or tubers taste better and are easier to chew. They provide more energy, more joules or calories per gram, than does the same material if eaten raw. The cooks needed a steady supply of fuel: twigs, fallen branches, dried dung. Those of the group taking turns to keep a protective fire going all night needed wood. Not only protection from the cold: the flames deterred predators from attacking people sleeping on the ground. Humankind came to depend on external fuel. Two hundred thousand years ago, probably from somewhere in Africa, we people started on a route leading rapidly to modern civilization through our use of wood for fuel. This was a social transformation of immense power but hidden danger: all because of our use of fire and trees.



Shoshone people encamped in Wyoming during 1870.
Each tipi needed 10 to 15 wood poles. Credit: Wikimedia, W.H.Jackson, Smithsonian Institution.

At the time of the first colonists arriving to North America from Europe, the lands were occupied by various peoples, numbering about twelve million, widely spread as nations with separate languages and customs. Peoples known collectively now, variably as Palaeoindian, Denali, Clovis... Much has been learnt about how these original inhabitants of this sub-continent lived from the detailed written and illustrated accounts of missionaries, explorers, mineral prospectors, and trappers from about the 1550s onwards. Of these early European colonists, some recorded carefully how these original people managed to live well in these new lands. These archives provide a rich resource for modern scholars. The people thrived sufficiently that some nations built towns with large temples, also complexes of burial mounds. They achieved this despite lacking metal tools and domesticated livestock or horses. Their technology was still of the Stone-age but the tools were beautifully crafted and of a type for every purpose needing a sharp edge.

People first walked, or paddled, into North America from Eurasia sometime between sixteen thousand and thirteen thousand years ago. What they found there looked just like what they left behind, it was merely fresh land to explore for new hunting grounds. Except for one thing: this land was empty of humans. There is no evidence any humans, anywhere, anytime, living in this continent before they migrated across from Asia.

These migrants survived in the harsh climate and sparse resources of shelter and fuel to be found on the tundra. Possibly keeping to the southern shore of this beringian land provided the best food: fish, shellfish, crustaceans, sea birds and seals in addition to caribou on the tundra. Migration further eastwards and into warmer regions further south was blocked however. The climate of most of Beringia had been too dry for snow to develop into sheets of ice and so could be occupied. Further east and south the way onward was blocked by arms of the Cordilleran ice-sheet that had grown over the northern chains of mountains. People probably remained in Beringia for another thousand years until either the coastal glaciers retreated or a gap formed between the Cordilleran ice-sheet and the Laurentide sheet that reached to the Atlantic Ocean.

Whichever way these adventurers and explorers travelled, possibly even by sailing across the Pacific Ocean, they found grasslands and scrub and the beginnings of thin open forests. The further south they travelled they found better resources to supplement their hunting with forage as berries, nuts, small game, and fuelwood. The game also could be easy hunting. A group of bison with calves, approached by a pack of wolves, stand their ground in a tight group. They kick and they butt fiercely at the wolves. How long might it take the bison to learn to flee from these weird new mammals who ran upright, hunted as a closely coordinated group, and threw wooden spears tipped with stone blades?

As the people migrated south they used more and more wood. They built larger and weatherproof shelters as huts and tipis. They built with birch bark and animal hides, with saplings and thin tree trunks that they cut with stone axes. The axes were knapped from rock such as flint, chert and obsidian. Stone knappers fashioned tools such as Clovis points, so admirable and important that they were sometimes sacrificed as grave goods, in symbolic hope of a better afterlife. They built canoes of flexible saplings to cover with hides so that they could exploit the many lakes and rivers. Despite their limited resource for making cutting tools they developed advanced woodcraft.

In southern Eurasia, where early humans had migrated from Africa and lived ever since in softer lands free of ice sheets and glaciers, a cultural transition was underway. Hunter gatherer people invented the cultivation of crops and domestication of livestock. They transformed their way of life independently in various regions of the world. This revolution started with domestication of the pig in Mesopotamia through to the potato in South America between ten to seven thousand years ago. The people invented cooking pots made of fired clay. They needed kilns for that, made of rocks and mud, or mud-bricks. A combination of small inlet for air and fluted chimney to draw the air rapidly, forced fuelwood in the form of charcoal to burn intensely hot.

From Stone-age people to people of the Agricultural Revolution. During the last years of the Neolithic times, the New Stone-age, people at various times and places discovered that blazing hot kilns used to bake clay mouldings into ceramic pots might also produce metals. Rocky ores sometimes gave up their content of lead, tin, or copper as gleaming hot liquids. The people were on the cusp of discovering how to smelt metal-containing ore. Once craftspeople operating kilns discovered how malleable the copper was, how it could be worked into shape and polished, then they fashioned the metal into ornaments to wear as torcs, brooches and bracelets. Good for pride and to project status as these ornaments were, this pure copper was too soft to make a knife.

Areas of the world where agriculture was independently invented. Redrawn from map in Wikimedia.

Then, about five thousand three hundred years ago people discovered another character of metals. If tin is smelted at eight to twelve percent into molten copper, the alloy that is then cast is bronze. By some mystery of what was then alchemy, the tin hardens the mixture sufficiently that a sharp edge can be formed and then ground sharper. The bronze smelt could be cast into a mould for an axe head. The mould included a socket to a take a handle made with the wood of hickory or ash trees. If the axe was hafted with a long handle a woodsman could powerfully cut through a tree trunk using both arms. Humankind accelerated faster along this technological revolution.

Before the Bronze-age, people had invented the wheel, about seven thousand years ago. The Eurasian wild horse, *Equus ferus*, was domesticated about six thousand years ago. Now with bronze cutters, choppers, and diggers the work-day productivity of field labourers to gain food and fuel needed for the group increased greatly. They cut trees easily to make timber for use as posts and rafters of houses. People would have observed how some species of broad-leaf trees, such as ash or oak, behave if broken at the trunk during a storm: next spring the remaining stump sprouts vigorously as many green shoots. These grow long, thin and supple, ideal to harvest and weave into panels for a wall. Not all the shoots were cut – the straightest and strongest were left to grow into a size and shape suitable for felling as construction beams. With bronze for axes instead of stone the people no longer needed to wait for a tree to be broken by the wind. They deliberately cut the trunks – they invented the woodcraft of coppicing.

Pigs and cattle churned up and dunged the soil as they foraged and grazed amongst the trees. Around human settlements forests with closed canopies became more open and patchy. Primeval forests became domesticated sources of berries, nuts, mushrooms, and fuelwood. They were managed by controlled firing, livestock grazing, felling and coppicing. People survived better against the winter blizzards, they fed better and so reproduced better and grew in number.

Ash trees managed by repeated coppicing to produce crops of convenient sizes of wooden poles. Credit: Wikimedia.

Three thousand years ago, give or take a century or two, iron was discovered, and then the smelting and working of it in smithies were invented.

Sharp tools were made of steel that forms when about one percent of carbon is added to the smelt. The carbon itself was extracted from wood by partial combustion to turn the cellulose and lignin of trees into charcoal. New ploughs tipped with iron replaced the old clumsy wooden tillers. However, these were still scratch-ploughs or ards, without a mould-board to turn over the soil. Expanses of natural grassland and areas of forest cleared by firing, felling, and grazing could more easily be ploughed into crop fields.

Demands on resources of forests grew as people developed techniques for charcoal burning to manufacture enough fuel for cooking as well as metal smelting. The bark of certain species of trees readily yields enough of its tannin compounds. As the demand for tough shoe leather and longer lasting clothing grew, so the tanbark was stripped from trunks cut also for timber. Particular species of trees provided for particular uses: yew for hunting bows; willow and hazel for the thin supple withes used to weave baskets or the frames of coracles and canoes.

Populations of people grew. People explored and migrated in search of areas empty of competitors and with unexploited resources. The rate of change of technology, population density and cultural norms increased. The changes were slight but older folk in a village or town remembered how things had been before, thus they foresaw how they might be in the future. They listened to the tales of travellers from more populated regions and they predicted that the easy resources they had available no longer went on for ever in space or time. Somehow these resources would have to be managed to avoid open conflict, the people needed to invent new allocations, new concepts, and new norms for effective sharing over a wider span than a family unit.

Agriculture, powered by horses equipped with tanned leather yokes and reins, and pulling iron shod ploughs, expanded because the people grew in number. Or did the people grew in number because their agriculture expanded? Whichever, the impact on trees and forests was the same: they decreased in number and area. Farmer's use of domestic animals, including bullocks, to provide traction power for farming was a crucial precursor of industrialized agriculture. However, horses in particular need large amounts of agricultural land to fuel them with grasses and grains. Cattle have more efficient digestive systems, with their four compartmented stomach and rumination, but are more difficult to control for traction power. Only some more efficient source of power would allow industrialized agriculture to start.

Forests after the Industrial Revolution.

In both Eurasia and North America during the rapid expansion of agricultural populations into sparsely inhabited lands most of the forest lands were replaced with cropland and pasture. Gone was the original natural patchwork of forest, scrub, and grasslands. By about the year 1900 forest and other uncultivated land in many areas occupied less than ten percent of the countries. But now, a century later, no longer are the woods and forests retreating in these northern landscapes. They are, on balance, re-establishing onto their old habitats, or they regain their original distributions. Not everywhere, but this general trend is demonstrated by growing evidence from historical comparisons and simple observation. The social, economic, and technical trends forcing this change are complex and interrelated. One of these counter-intuitive trends derived, indirectly, from industrialization.

The invention of steam-engines started the Industrial Revolution. They were first used for pumping out water that accumulated at the bottom of mine shafts, then as railway locomotives to haul loads between mines and factories. The self propelling steam-powered agricultural tractor was developed in the 1860s from static steam engines that were in common use for threshing and similar work. However, these engines were cumbersome and required much maintenance and refuelling. Agricultural steam tractors remained in use widely until supplanted by internal combustion engines powered with gasoline or diesel fuel in the early 1900s.

Agriculture was made more efficient, especially when coupled with roads paved with bituminous tarmac bearing fleets of transport trucks. Agri-

Broad-leaf trees and bracken fern regenerating naturally on abandoned upland pastures of a livestock farm in Britain.

A study done in Massachusetts exemplifies this trend, using information from land valuation and municipal plans dating from 1730s through to the 1830s when agricultural development here was at its greatest, then continuing to satellite images. If you use the internet to examine a satellite mapping of Earth, search for Petersham, Massachusetts, USA. Zoom down close enough to see the broad-leaf maples and oaks. One hundred years ago most of what you will see there was open farmland, with scattered stands of remaining original woodland. Now it is difficult in many areas to make out the new residential houses, isolated by long driveways. They are hidden amongst wide areas of thick broad-leaf forest, with small lakes that look good for fishing. Forests here appear natural: the reforestation has been mostly by self-seeding. However, they have little resemblance to what was there before colonial farmers started work on the trees.

The woodlands and forests I visit in a day of travel in Scotland show distinct reforestation when compared with maps made during the 1840s to 1880s. Some of these are at scale of 6 inches to 1 mile, sufficient to reveal wide hedgerows. Here in the 1920s national reforestation started as plantations of imported species of conifers, for timber. Modern maps, and clear to see on the ground, reveal large timber plantations, regeneration plantings of Scots pine and native broad-leaf trees, and vigorous natural regeneration of trees in areas with sparse deer or livestock. This forest transition continues at accelerating pace.

Farmlands in Europe that were pastures on the lower slopes of mountains are being abandoned, despite the subsidies available. Tending cattle or sheep on this difficult terrain is neither attractive nor profitable enough for sufficient people to sustain this agriculture. Mountain hamlets and farms decay. Woodlands naturally migrate back onto upland pastures and large tracts of uplands are converted to commercial plantations for both timber and drawing down and storing carbon dioxide from the atmosphere as one method to reduce global heating.

Sitka spruce being harvested from a typical dense plantation.

In many regions where these boreal forests grow there has long been a deep emotional attachment to the beauty and utility of individual trees, to natural broad-leaf woodlands, and even to the austere beauty of the vast expanses of natural conifer forests in the north. Amenity planting was well established in the richer areas of Europe by the mid to late 1700s. This tradition now continues with some of the descendants of these landowners, and with newcomer billionaires, who are enthusiastic about creating natural looking mixed forests on their large remote estates. Typically there seems to be little commercial value or intent in these plantings. Also, volunteer organisations, funded by subscriptions, endowments and grants, thrive with much participation from people who live in towns and cities. They enjoy the idea and practice of new or recreated mixed woodlands, planted to look natural. There is so little truly natural, known to be uninfluenced by humans during recorded history, that one popular way to experience these environments is to create them ourselves. Once planted they will develop following their own natural mechanisms. Welcome to the forests with all their potential, their intriguing complexities, and their enduring calm beauty.

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.)

Ice sheets destroyed the old forests.

Anonymous, 2017. Milankovitch cycles. Wikipedia. [Good source for diagrammatic explanations of these cycles.]

Bennett, K.D., 1990. Milankovitch cycles and their effects on species in ecological and evolutionary time. Paleobiology, 16: 11-21.

Dynesius, M. & Jansson, R., 2000. Evolutionary consequences of changes in species' geographical distributions driven by Milankovitch climate oscillations. Proceedings of the National Academy of Sciences of the United States of America, 97: 9115-9120 [Milankovitch cycles as a driving force of plant distribution and evolution.]

Pedersen, M.W., *et al.*, 2016. Postglacial viability and colonization in North America's ice-free corridor. Nature, 537: 45-49.

Ray, N. & Adams, J.M., 2001. A GIS-based vegetation map of the world at the last glacial maximum (25,000 - 15,000BP). Internet Archaeology, 11.

Early colonization of the barren lands.

Barbour, M.G. & Billings, W.D., 1999. *North American Terrestrial Vegetation*. Cambridge University Press, U.K. ISBN: 0521559863.

Bennett, K.D., 1989. A provisional map of forest types for the British Isles 5000 years ago. Journal of Quaternary Science, 4: 141-144.

Bennike, O., 2000. Palaeoecological studies of Holocene lake sediments from west Greenland. Palaeogeography Palaeoclimatology Palaeoecology, 155: 285-304. [Pdf on Google Scholar.]

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

Bradley, J.A., Singarayer, J.S. & Anesio, A.M., 2014. Microbial community dynamics in the forefield of glaciers. Proceedings of the Royal Society B-Biological Sciences, 281: (online)

Crawford, R.M.M., 2008. *Plants at the Margin: ecological limits and climate change*. Cambridge University Press, U.K. ISBN: 9780521623094. [See Ch. 5, Arctic and sub-arctic treelines and the tundra-taiga interface.]

Huntley, B. & Webb, T., 1989. Migration: species' response to climatic variations caused by changes in earth's orbit. Journal of Biogeography, 16: 5-19.

Hodkinson, I.D., Coulson, S.J., & Webb, N.R., 2003. Community assembly along proglacial chronosequences in the high Arctic: vegetation and soil development in north-west Svalbard. Journal of Ecology, 91: 651-663.

Ingimarsdottir, M., *et al.*, 2013. Food sources of early colonising arthropods: the importance of allochthonous input. Pedobiologia, 57: 21-26.

Jackson, S.T., *et al*. 2000. Vegetation and environment in Eastern North America during the Last Glacial Maximum. Quaternary Science Reviews, 19: 489-508. [Pollen analysis applied to North American historical flora.]

Development of soils and flowering plants on them.

Borin, S., *et al*., 2010. Rock weathering creates oases of life in a High Arctic desert. Environmental Microbiology, 12: 293-303.

Mann, D.H. & Plug, L.J., 1999. Vegetation and soil development at an upland taiga site, Alaska. Ecoscience, 6: 272-285.

Trowbridge, J. & Jumpponen, A., 2004. Fungal colonization of shrub willow roots at the forefront of a receding glacier. Mycorrhiza, 14: 283-293. [Pdf on Google Scholar.]

Tscherko, D. *et al*., 2005. Plant succession and rhizosphere microbial communities in a recently deglaciated alpine terrain. Basic and Applied Ecology, 6: 367-383.

Ecological and evolutionary development of forests.

Chapin, F.S., *et al*., 1994. Mechanisms of primary succession following deglaciation at Glacier bay, Alaska. Ecological Monographs, 64: 149-175.

Dolezal, J., *et al*., 2008. Primary succession following deglaciation at Koryto Glacier Valley, Kamchatka. Arctic Antarctic and Alpine Research, 40: 309-322.

Huntley, B., 1990. European vegetation history: palaeovegetation maps from pollen data - 13,00 yr BP to present. Journal of Quaternary Science, 5: 102-122.

Valiranta, M., *et al*., 2010. Scattered late-glacial and early Holocene tree populations as dispersal nuclei for forest development in north-eastern European Russia. Journal of Biogeography, 38: 922-932.

Impact of early humans on boreal forests.

Bonnicksen, T.M., 2000 *America's Ancient Forests: from the Ice Age to the Age of Discovery*. John Wiley & Sons, Inc., New York. ISBN: 9780471136224.

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

Gavashelishvili, A. & Tarkhnishvili, D., 2016. Biomes and human distribution during the last ice age. Global Ecology and Biogeography, 25: 563-574.

Liu, K-B. 1990. Holocene paleoecology of the boreal forest and Great Lake - St.Lawrence forest in northern Ontario. Ecological Monographs 60: 179-212. [Pollen analysis transect of eastern North America.]

Mason, O.K., Bowers, P.M. & Hopkins, D.M., 2001. The early Holocene Milankovitch thermal maximum and humans: adverse conditions for the Denali complex of eastern Beringia. Quaternary Science Reviews, 20:525-548.

Wygal, B.T. & Heidenreich, S.M., 2014. Deglaciation and human colonization of Northern Europe. Journal of World Prehistory, 27: 111-144.

Human technologies impact the forests.

Crosby, A.W., 1986. *Ecological Imperialism: the biological expansion of Europe, 900-1900*. Cambridge University Press, Cambridge, U.K. ISBN: 0521336139. [Chapters 2, 11, 12 are relevant.]

Cunliffe, B., 2005. *Iron Age Communities in Britain: an account of England, Scotland and Wales from the seventh century BC until the Roman Conquest*. Routledge, Abingdon, U.K. ISBN: 0203326059. [Ch. 16, Food producing strategies, pgs 407-445.]

Fokkens, H. & Harding, A. (eds.). 2013. *The Oxford handbook of the European Bronze Age*. Oxford University Press, U.K. ISBN: 9780199572861. [Chapters: 18, 19, 23.]

Kohl, P.L. 2007. *The making of Bronze Age Eurasia*. Cambridge University Press, U.K. ISBN: 9780521847803. [See Ch. 6. The circulation of peoples and materials – evolution, devolution and recurrent social formations on the Eurasian steppes and in west Asia. Patterns of processes of interconnections during later prehistory.]

Simmons, I.G., 2001. *An environmental history of Great Britain: from 10,000 years ago to the present.* Edinburgh University Press, U.K. ISBN: 9780199572861 [Summarizes historical aspects of this story from a northern European perspective.]

Wrangham, R., 2009. *Catching fire: how cooking made us human*. Profile Books Ltd, London, ISBN: 9781846682865. [A lively account of this proposition.]

Modern boreal forests: their expansion and management.

Anonymous, 2016. *Global Forest Resources Assessment 2015: how are the World's forests changing?* Food and Agriculture Organization of the United Nations, Rome, ISBN: 9789251092835.

Anonymous, 2024. National Library of Scotland, Ordance Survey 6 inch map of woodland in Scotland, 1840s to 1880s. [Access this with internet enquiry: "National Library of Scotland OS first series woodland"}

Flinn, K.M. & Vellend, M., 2005. Recovery of forest plant communities in post-agricultural landscapes. Frontiers in Ecology and Environment, 3: 243-250.

Foster, D.R., Motzkin, G. & Slater, B., 1998. Land-use history as long-term broad-scale disturbance: regional forest dynamics in central New England. Ecosystems, 1: 96-119. [Maps of dramatic changes in tree cover.]

Fuller, R.J. & Gill, R.M.A., 2001. Ecological impacts of increasing numbers of deer in British woodland. Forestry 74: 193-199.

Stanturf, J.A., *et al.* 2003. Innovation and forest industry: domesticating the pine forests of the southern United States, 1920–1999. Forest Policy and Economics, 5: 407-419.