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Research Article

Trends in Some Long-term Drought Drivers

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INTRODUCTION

The droughts that hit North and North Western Europe in 2018 and 2019 served as a wake-up call that also temperate regions are affected by this kind of slow progressing or creeping disasters. The impacts of these meteorological droughts may have been exacerbated by long-term drivers, such as land-use changes, changes that are spread over a long time span, even difficult visible for an individual, but make a big difference in how the rare weather event impacts a region. In this paper we introduce three long-term drivers, forest fires in Europe, urbanization, and deforestation. We try to provide a first assessment of their trends, mainly using satellite imagery created statistics. The relationship between drought impact and these land use changes is hardly quantified and probably also impossible to quantify to the extent classical science would require. Therefore we first focus on the trend of this possible drought exacerbating land use changes, hoping that we, for drought combatting do not have to follow the same winded road that open societies followed when combatting lung cancer through smoking bans or climate heating through phasing out fossil gas exhaustion into the atmosphere. Perhaps common sense could be enough this time.

After this short survey we can conclude that the extent and the number of wildfires increased remarkably in Europe. Deforestation is still occurring in the tropics, with a loss of 12% in the last 30 years but halted in the northern regions. Urbanization has more than doubled in the same time span in the tropics and subtropics, mostly at the expense of forests, while in Europe urbanization took place mainly in the northern part of the continent. None of these implicit drought drivers follows a favorable trend, a plea for precise monitoring and a quick curb.

LAND USE CHANGES IN THE LAST 30 YEARS

Drought is often perceived as mainly a meteorological driven disaster. However, the land use can have a significant influence on the impact of a drought. Land use changes over time, due to phenomena like intensification of agricultural practices, irrigation, drainage, urbanisation, de- or reforestation, land abandonment, and disasters such as wildfires. We present here an overview of the most important land use changes in the last decades potentially relevant for the current drought severity and impacts. While the need for quantifying drought impact is felt more and more due to alarming scenarios in climate change models, an overview of trends in land use change during the last 30 years, a period suitable to detect what is changing where, when and into what in often missed out.

Sustainable land use is a prime goal for reaching the Sustainable Development Goals (SDGs) as agreed by all member states of the United Nations in 2015. These goals should be reached in 2030. Goal 15, Life of Land has as mission: ‘Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss’ and therefore directly related to the challenge to make land use less prone to drought impacts.

Since land use change requires decades to unfold, the trends in land use changes are the main indicator for the progress towards sustainable land use. Controversies hampering a sustainable land use in relation to drought are for example, irrigation, helping to curb drought impact and allowing agriculture in dry areas, during dry seasons, but also causing groundwater depletion, salination of soils and maintenance and construction of reservoirs. Another debate regards the role of certain forests, driving evapotranspiration and thus water requirement, while cooling at the same time and decreasing need for water. Such complex balances are heavily dependent on local conditions and land features.

In the following sections some of the main trends in land use changes related to wildfires, de/forestation, and urbanisation are presented. Some important topics that are not covered are soil degradation and compaction, the role of irrigation, for which not enough data could be gathered through satellite imagery. In summary, there is a trend of increasing wildfires in the last five years in Europe. The total land affected by wildfires in Europe was 12.000 km2 in year 2017, more than 3 times the area affected in an average year. Over 5 % of the forest in the tropical zones was deforested during the last 10 years, replaced by croplands and pastures. On the contrary, an increase of natural forest at the expense of Tundra’s and grassland was recorded in

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the Northern Hemisphere. The area impacted by dense urbanization doubled, compared to 1980, especially outside Europe. Regarding soil degradation, drought leads to less vegetation cover of the soil and boosts soil erosion when rainfall returns. On agricultural land, it is estimated a loss of 21 ton/ha soil per year on average, which is up to 16 times the natural weathering process of rocks to form soil. The actual loss depends on tillage, terrain topology and soil type and varies largely between regions and countries. Also, drought can lead to further mineralization of the soil, a process resulting in a lower capacity of the soil to absorb rainwater. Apart from the reforestation in the boreal hemisphere, most of the reported trends can be considered negative for reducing drought impact. Without reversing these trends, the SDG 15 will not be achieved by 2030.

Wildfires coincide often with a dry spell, especially the so-called mega-fires, when fire burns more than 40.000 hectares, and is difficult to control due to the exceptional dryness of the litter. The extensive fires in tropical and sub-tropical forests are often lighted intentionally and may run out of control during the dry season or following an underperforming rainy season. The wildfires in the Western United States are explained primarily by the increased contact between humans and forests and the prolonged dry conditions under high temperatures. The fires in Siberia and other artic fires are mostly related to increased temperatures and availability of dry litter.

WILDFIRES

The relationship between wildfires and drought is complex. Burned ground and mineralization provokes more surface runoff and less groundwater absorption, ultimately leading to a dryer land. In contrast, burned surface might have a higher reflection of sunlight (albedo) and boost cooler temperatures. Of crucial importance for reduction of the impact of drought events is whether a wildfire is followed by vegetation recovery or the land is changed permanently. The bar chart of Figure 1 shows the burned territory for the last 10 years, based on data of the European Forest Fire Information system (EFFIS). The repartition per country over the same period is shown in Figure 2.

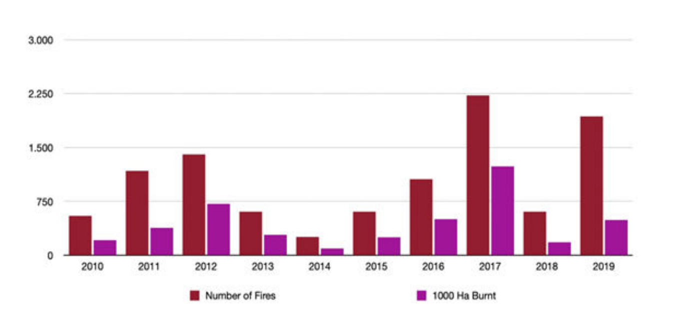

Figure 1: Forest fires above 50 hectares recordedin Europe from 2010 to 2019.

Source: EFFIS, 2020.

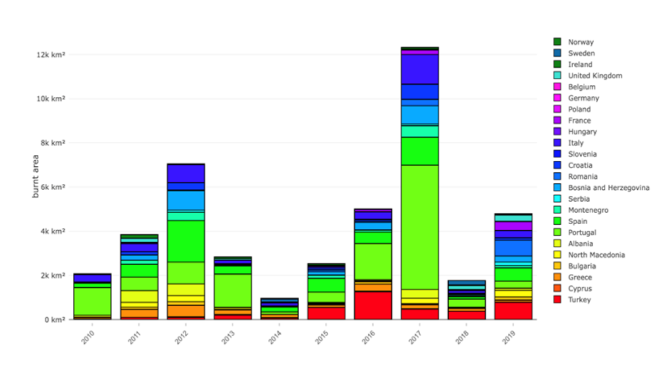

Figure 2: Burnt area by European country from 2019 to 2019.

Source: EFFIS, 2020.

On average Europe suffers from over 1000 fires burning an area larger than 50 hectares per year, with a yearly average total of 300.000 hectares burnt. 2017 was an exceptional year, especially in the south west of Europe, with 2225 fires and a total of 1.236.138 hectares burnt. After a normal 2018, 2019 proved again particularly severe, with 1932 fires and 489.213 hectares burnt. In 2019, the fires were more evenly distributed among countries, unlike 2017 when half of the total area burnt occurred in Portugal. Comparing the first half of the decade, from 2010 to 2014 (1.684.238 hectares), with the second half from 2015 to 2019 an increase of 58 % of area burnt (2.669.816).

DEFORESTATION

Deforestation in the tropics might partly coincide with wildfires, since fire is a common method to clear land from forest for new crops and pastures. Repeated fires may also deplete the seed bank, thus hindering the forest recovery after such events.

At higher latitudes, deforestation appears to be halted, but these forests proved prone to fires due to the specific tree types and monocultures that in most of the northern territories prevail. The current quest for Biofuel, initially intended to be made from litter and leftovers from the wood industry, but now leading to full clearing of forest stands, adds up to the complexity of monitoring deforestation. From the European part, only 4 % of the forest can be considered as forest untouched by human interests; these leftovers are found in Scandinavia, Slovakia and Romania. Moreover, only 2 % of the total forest stands in Europe are protected from human intervention. The restoration of a healthy forest, having enough diversity of species to withstand severe droughts, strong winds, pests or other disasters will be a mayor challenge for the subcontinent.

Regarding droughts, forests contribute to a lowering of the temperature of the landscape thanks to their evapotranspiration and shadow protecting the ground from direct sunlight. Depending on the size, topography and tree types, evapotranspiration may lead to cloud formation, which in turn reduces the heat flux and increases the probability of rainfall.

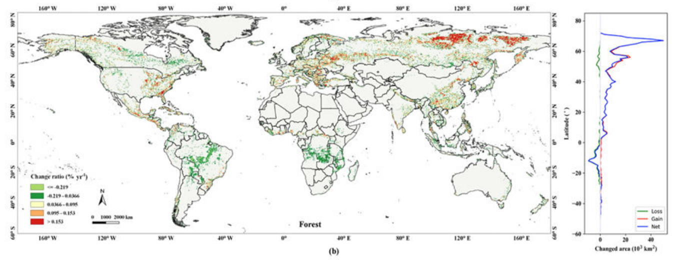

Figure 3: Percentage of annual change in forest covers at global level.

Source: Lui et al., 2020.

The world has a total of about 4000 million hectares (Mha) of forest, slightly less than one third of the inhabited land area. In 2019 it was reported a loss in the order of 4 million hectares in the tropical zone. In total the world lost 178 Mha since 1990, in the order of 5 percent of the total forest, an area the size of Libya (FAO). The global net change was minus 7.8 Mha per year between 1990 and 2000, while it is now at a rate of minus 4.7 Mha per year. The current lower rate of the decline is due to forest expansion, taking place in Northern Russia, China, Ethiopia and India. In this recent study using satellite imagery to classify land uses the increase and decrease in forest cover as presented in Figure 3 is reported. The virgin forests in the Amazon, Congo and South East Asia decreased in area, while forests in the northern latitudes increased at the expense of tundra and barren land. The deforestation in the tropics might exacerbate drought impacts in adjacent regions, due to a reduction in cloud formation and increase of temperature, thus more evapotranspiration of soil-moisture.

There are various tree planting projects planned and taking place across the world. In 2019 Ethiopia claimed to have planted more than 350 million trees in one day. The African nations in the Sahel area are in the process of planting ‘The Great Green Wall’, an 8000 km barrier of trees spanning the length of the African continent from Senegal to Ethiopia. They are currently at 15% completion. China is also building its own ‘Great Green Wall’ called the North Shelter Forest Program, albeit on desert land on which it still isn’t clear whether forest can grow or not. The European Union makes similar pleas, currently up to 36 percent of its territory is forested. The European forests account for less than 4 % of the world forests. From 1990 to 2015 the total growing stock volume increased from 19000 to 26300 Million m3 in the European Union.

URBANISATION

Although urban areas make up a small fraction of the land surface (0.8 %) more than half of the global population lives there. Urbanization’s relevance in relation to drought events is varied. Urban areas tend to heat up more than surrounding areas because of the dark surfaces and cement that absorb the heat of the sun during daytime. Temperatures can be up to 5 degrees Celsius higher in urban areas both in winter and summer. Buildings and paving of the surface prevent rain to reach groundwater underneath, while groundwater levels can be locally lowered on purpose, to build below the surface. Both phenomena may cause subsidence and may damage buildings and trees above. Further, drought events are often accompanied by an increase in air pollution.

Detailed monitoring of urbanisation at global scale is enabled by Earth observation combined with artificial intelligence in the framework of the Global Human Settlement Layer (GHSL). The GHSL produces data on the status and dynamics of human settlements by integrating remote sensing with demographic information. It applies a people-based global definition, the degree of urbanisation method described by EUROSTAT, to the GHSL built-up and population data to delineate three spatial entities for all countries of the world: “Urban Centre”, “Urban Cluster”, and “Rural Clusters” (European Commission). An Urban Centre consists of contiguous grid cells (4-connectivity cluster) with a density of at least 1,500 inhabitants per km2 of permanent land or with a share of built-up surface greater than 0.5 of permanent land and has at least 50,000 inhabitants in the cluster with smoothed boundaries and <15km2 holes filled. This consistent definition allowed delineating more than 10 000 urban centres at global scale.

These spatial entities were combined with the European Space Agency (ESA) Climate Change Initiative (CCI) –Land Cover (LC) annual time series of consistent global LC maps at 300 m spatial resolution from 1992 to 2015. This dataset provides global maps describing the land surface into 22 classes, which have been defined using the United Nations Food and Agriculture Organizations (UN FAO) Land Cover Classification System (LCCS). In order to gain insight, we grouped land-use types of FAO into 6 super classes based on their relevance in Drought impact and Drought relieve.

Urbanization is monitored thanks to the availability of high-resolution satellite data and artificial intelligence algorithms capable of detecting build up areas.

In the following graphs we give an overview of which land use type is transformed into urban and semi urban areas partitioned over the fifth IPCC report climate regions of the world in the last 23 years.

We took the area occupied by the urban area in 2015 and intersected these areas with the land use that was present in these areas in 1992, 2000 and 2015, thus gaining insight at the expense of which land use the city was built in recent decennia.

The map hereunder displays in which Macro regions the urbanization took place. In the analyses here after we detect which land use was transformed into urbanized landscapes with the specific characteristics we mentioned above.

Data are processed at a resolution of 300 meters and give therefore a detailed overview of what has happened. In order to gain insight, land-use types of ESA are grouped into 6 super classes. The classes were grouped based on their relevance in Drought impact and Drought relieve.

Table1: Land use practices and possible drought impacts and mediation methods.

LAND USE TYPE	DROUGHT IMPACT	DROUGHTS RELIEF
Alluvial & coastal plains	Subsidence, Cracking	High groundwater level, cooling through wind
Cropland & Potential cropland	Failing harvest, groundwater depletion through irrigation	Access to crops close to the city, cooling of area
Forest	Ignition of wildfire subsequent air pollution, dying of wild species, trees might die.	Strong cooling, water reserve in groundwater, relaxation, some food (nuts, small animals, fish in creeks)
Grass	Ignition of wildfire subsequent air pollution. Grass recovers, but not all species.	Cooling through wind, access to meat, milk close to the city
Natural open spaces	Ignition of wildfire, dying of wild species.	Cooling through wind, relaxation, some food (berries, small wildlife)
Urban	Extreme temperatures, additional air pollution, groundwater depletion, surface water and reservoir depletion.	Shelter for humans and the animals and plants accompanying them.

The analysis summarised in this chapter, provides an overview of changes in LC within the Urban Centres over three main periods 1992, 2000 and 2015 that are consistent with the GHSL multi-temporal data for 1990, 2000 and 2015 (Corban). Urban centres were aggregated according the climate micro regions identified in the IPCC 5th report (IPCC). These macro regions were defined by the IPCC in order to assess impacts of climate change in regions characterised by similar meteorological processes. The aim is providing insights into the main changes and losses of specific classes of LC that occurred in the urban centres thus allowing understanding the urban encroachment process over the period 1992-2015 and its impacts on droughts.

In the following map the repartition of the mentioned IPCC 5th report macro-regions is displayed. Please find in Annex 1 the full name of the abbreviated macro-regions in the Map.

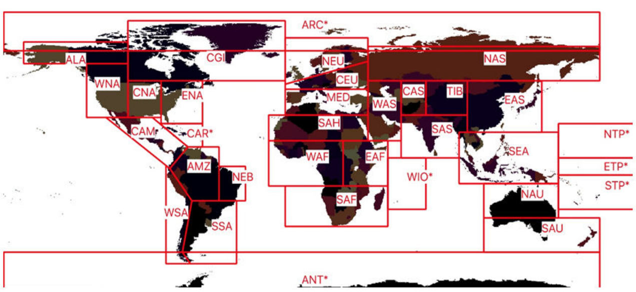

Figure 4: Map of Climate macro regions of the world.

These macro regions were defined by the IPCC in order to assess impacts of climate change in regions characterized by similar meteorological processes. We took the regions of the 5th report on the state of the climate in our analysis.

The three bar plots hereunder show the changes in the proportions of the different land cover classes and the evolution of urban land per macro-region in 1992, 2000 and 2015. It allows identifying in which macro-region, urbanisation has developed the most and at expense of which main land cover type.

Figure 5: Landcover changes in Urban Centres

In Western North America (WNA) we can see a sharp increase of the urban surface mainly at the expense of natural open spaces. Since the climate in this region is marked by hot and dry summers the risks in this region for heat waves and wildfires are increased by an urbanization increasing the so-called Wild land-Urban interface. Western South America (WSA) follows a similar trend, in which urbanization is at the cost of Natural Spaces. In Central North America (CNA) and Easter North America (ENA) we see a similar pattern but at the expense of cropland. In North East Brazil (NEB), a known drought prone area, urbanization was at the expense of cropland as well, the urbanization more than doubled and the forests disappeared completely in the urban area. In ENA cropland disappeared practically in the reach of the urban area, leaving Natural open spaces as the only non-urban class available. In East Asia (EAS) the urbanization more than doubled as well at the expense of all other components. In South Asia (SAS) apparently a very different urban landscape pattern exists leading to a more mixed land use in the urban area, the urbanization took place but not leading to high density urban area with big risks for cementation. The urbanization in South East Asia and in Africa East, West and South follow a similar pattern. Urbanization takes place, it doubles, but the urban area remains scattered with other land uses, with croplands as the main alternative land use. In Central Europe (CEU) and the Mediterranean Area (MED) we see a very limited urbanization mainly at the expense of cropland. In Europe most urbanization took place in the North (NEU) at the expense of grasslands.

The next graph displays the top 20 cities in Northern Europe that that witnessed the greatest increase in the proportion of urban land within the urban centers. It concerns cities in economically perform ant areas around Amsterdam, London, Birmingham, Stockholm, Oslo and Bergen. Interesting is that German cities did not enter the list, suggesting that in Germany the urbanization takes place from reviving existing urban areas. Further we can see that urbanization takes place in small towns like Sodertalje, Alkmaar, Purmerend, Hoorn, Peterborough, Royal Turn bridge Wells or Reddish more than 50 kms from the main urban center.

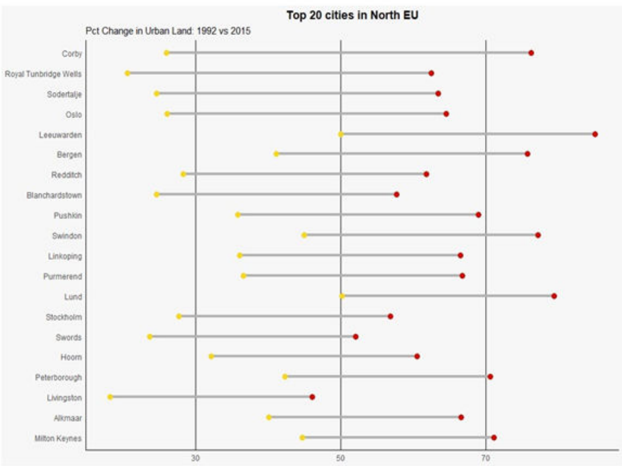

Figure 6: Land use changes in North European cities.

Linking to the subchapter on deforestation we analyzed which urban centers where build in the last 30 years at the expense of forest. Cities with more than 100.000 inhabitants, build at the expense of forest we find in Southern Africa, South Asia and South East Asia. Note that the forest in these urban centers is lost, not only to urbanization, also to croplands or other human intensive uses.

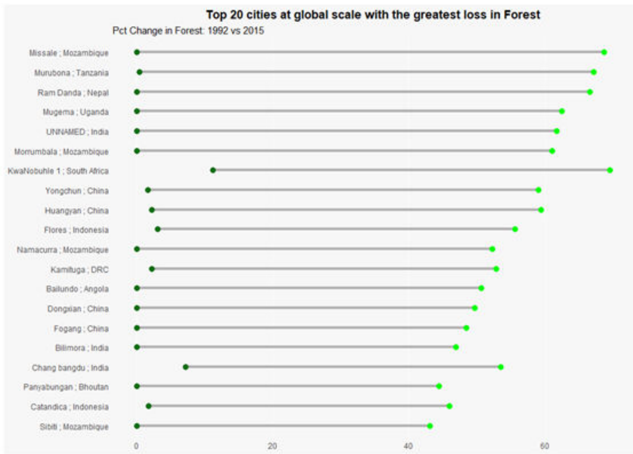

Figure 7: Forest loss due to urbanization.

LAND USE AND DROUGHT

The previous chapters display a sharp increase in urbanization, (doubling in 30 years) wildfires (doubling in last 5 years) and deforestation practices. The relevance of inverting these trends to lessen drought impact lays in two factors. First, the progressive climate heating leads to more intense droughts. Secondly, land use practices that exacerbate drought generate an ever more drought prone landscape.

If the practices surpass a certain threshold the ecosystem services that sustain the landscape can collapse. Such events are well known in recent history, with the dust bowl 90 year ago, in the US, as the most alarming example.

Making the landscape less prone to drought will be a task of major importance in the next decade, since the failure to curb climate change at global level may hamper predictability of droughts. In the table below we list the most detrimental land use practices in relation to drought.

The table is not exhaustive and is published to open the debate and set up monitoring priorities, with new insights and practices reported by the drought community this table can evolve in the future. New research will have to focus on the unknown dimensions of drought, the availability of groundwater and the variability of soils.

In the table we do not list the benefit of the named land use practice. The benefit exists and is relevant otherwise the practice would not exist. The mediation method we list competes with the implicit benefit.

Table2: Land use practices and possible drought impacts and mediation methods.

Land use practice	Drought impact	Mediation method
Deforestation	Less shadow, less cloud formation, less rainwater percolation to groundwater reservoirs, higher average temperatures	Reforestation, rewilding, silvo-pasture, agroforestry, restoration of small landscape elements. Disincentivize relationship deforestation and wildfires, practices of forest

		clearing though fire in the dry season or during a drought.
Reservoir construction	Sediment trapped leading to beach erosion downstream, evaporation of reservoir surface water, less fertilisation of flood plains, fish migration blockage, ecosystem disturbance, loss of fertile land.	Smaller reservoirs, fish access points, sediment outlets, cleaning of reservoirs, and storage of rainwater in groundwater bodies instead of reservoirs.
Road construction, urbanization	Groundwater lowering leading to soil subsidence and less groundwater, Increased temperature (black colour of tarmac) heat island effect, Temporary flooding after heavy rainfall (also related to the subsidence of the soil), No storage of the rainwater in the soil, Additional tree cutting/limited tree planting to save on maintenance costs	Creation of additional holes/lakes in the landscape to collect excess rainwater and resupply to groundwater body. Separation of sewage systems to collect rainwater and resupply groundwater bodies. Systematic tree planting along roads, on south face of buildings to provide shadow. Forbidding of pumping after completion of construction. Concentrate on High rise buildings. Limitation of road construction, favour alternatives for mobility. Grass roofs or white roofs. Construct on soils suitable for construction (protect fertile soils from construction) Allow for wind alleys throughout the urban area. Tax tree covered soils less than covered soils in the urban area.
Irrigation	Loss of water through evapotranspiration, full failure (no harvest at all) during severe drought, groundwater depletion, dependency of glaciers (not sustainable with current lack of climate policy implementation)	Change to crop types needing less water, move to silvopasture and agroforestry, pricing water for agricultural use, desalination of seawater using solar/wind energy
River/streams canalization	Low flow during summer/dry season, ecosystem degradation, loss of peat lands, reduced capacity to store water in the land	Allowing rivers/streams to meander again, compensate landowners losing land, restore peat lands and fauna belonging to peat lands (to curb e.g. mosquito's)
Industrial agricultural practices	Reduction of soil organic matter content leading to less soil moisture, compaction of soils due to heavy equipment, lowering of groundwater table to allow for heavy equipment, additional evapotranspiration and soil erosion due to large size of fields, wind erosion	Stimulate agricultural practices that favour soil quality or tax pesticides. Forbid use of heavy equipment on susceptible soil types, forbid field sizes above a certain threshold, compensate loss of land due to restoration of bushes, hedges and parcel edge vegetation
Wildfires	Increased temperature and wind, heating up the landscape, soil erosion due to lack of vegetation cover during heavy rains, reduced capacity of the soil to buffer rainwater, loss of human and wildlife, ecosystem services loss	Reforestation, rewilding, forestation with tree types less susceptible to fire (broadleaves), less focuses on (wood) production, more on quality. Landscape variation, large mammal reintroduction (to keep the landscape open) Check on relation deforestation and wildfires, disincentive deforestation (animal fodder production in former Amazon forest plots)

REFERENCES

1. Beck PS, Goetz SJ, Mack MC, Alexander HD, Jin Y, Randerson JT, & Loranty MM. (2011). The impacts and implications of an intensifying fire regime on Alaskan boreal forest composition and albedo. Glob Chang Biol.2011; 17(9), 2853-2866.
2. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland. 2014; 151 pp.
3. Corban C, Pesaresi M, Politis P, Syrris V, Florczyk AJ, Soille P, Maffenini L. et al. Big earth data analytics on Sentinel-1 and Landsat imagery in support to global human settlements mapping, Big Earth Data.2017; 1:1-2, 118-144, DOI: 10.1080/20964471.2017.1397899.
4. Crausbay SD, Ramirez AR, Carter SL, Cross MS, Hall KR, Bathke DJ, & Dunham JB. Defining ecological drought for the twenty-first century. Bull Am Meteorol Soc.2017; 98(12), 2543-2550.

5. CSIRO & BoM 2007. Climate Change in Australia: Technical report 2007, CSIRO, Melbourne.
6. de Jager A, Pelaez S. Assets at risk and potential impacts, Environment and Ecosystem services. Science for disaster risk management 2020, acting today protecting tomorrow,2021; chapter 4, pp 436-470, Publication office of the European Union.
7. Dijkstra L, Poelman H. A harmonized definition of cities and rural areas: the new degree of urbanisation. Working papers, European Commission.2014.
8. European Commission, Joint Research Centre. Atlas of the Human Planet 2019 –A compendium of urbanisation dynamics in 239 countries, EUR 30010, European Commission, Luxembourg.2020; ISBN 978-92-76-17418-9, doi:10.2760/014159, JRC118979.
9. FAO, 2020, Global Forest Resources Assessment 2020.
10. EFFIS, European Forest Fire Information System, 2020.
11. Gábor P, Jombach S and Ongjerth R. 2008, The relation between the biological activity and the land surface temperature in Budapest. URBIO 2008 Proceedings.2008.
12. IPCC, 2018: Climate Change and Land, Special Report.
13. Lin M, Horowitz LW, Xie Y, Paulot F, Malyshev S, Shevliakova E & Pilegaard K. Vegetation feedbacks during drought exacerbate ozone air pollution extremes in Europe. Nature Climate Change. 2020; 10(5), 444-451.
14. Masante D, McCormick N, Vogt J, Carmona-Moreno C, Cordano E, Ameztoy I. Drought and Water Crisis in South Africa. JRC Technical Report. European Commission.2018; 31 p., 978-92-79-85851-2 (ISBN)
15. Mietkiewicz N, Balch JK, Schoennagel T, Leyk, S St. Denis, LA, Bradley BA. In the Line of Fire: Consequences of Human-Ignited Wildfires to Homes in the U.S. (1992–2015).2020; Fire 2020, 3, 50.
16. Radeloff VC, Helmers DP, Kramer HU, Mockrin MH, Alexandre PM, Bar-Massada A, et al. Rapid growth of the US wildland-urban interface raises wildfire risk. PNAS, Proceedings National Academy of Sciences USA, Sustainability Science, Environmental Sciences.2018; 115(13): 3314–3319.
17. Sabatini FM, Burrascano S, Keeton WS, Levers C, Lindner M ea. Where are Europe's last primary forests? Diversity and Distributions.2018; 24 (10), 1426-1439
18. Sabha, L. Heatwaves, Government of India, Ministery of Earth Sciences, question answered on 6 February 2019. Retrieved 25 September 2020,
19. Schatz J, Kucharik CJ. Urban climate effects on extreme temperatures in Madison, Wisconsin, USA Environ. Res. Lett. 2015; 10 094024.
20. Spinoni J, Barbosa P, De Jager A, McCormick N, Naumann G, Vogt JV & Mazzeschi M. A new global database of meteorological drought events from 1951 to 2016. J Hydrol: Reg Stud. 2019; 22, 100593.
21. Van Loon AF, Tijdeman E, Wanders N, Van Lanen HJ, Teuling AJ, & Uijlenhoet R. How climate seasonality modifies drought duration and deficit. J Geophys Res: Atmospher.2014; 119(8), 4640-4656.
22. Vicente-Serrano, S. M., Quiring, S. M., Peña-Gallardo, M., Yuan, S., & Domínguez-Castro, F., 2020. A review of environmental droughts: Increased risk under global warming?. Earth-Science Reviews, 201, 102953.
23. Winbourne, J.B., Jones, T.S., Garvey, S.M., Harrison, L., Wang, L, Li, D. Templer, P.H., Hutura, L.R., 2020, Tree Transpiration and Urban Temperatures: Current Understanding, Implications, and Future Research Directions, Bioscience, Vol 70, nr 7.