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Wetlands: Ecosystem Services, Restoration and Wise Use

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Chapter 4
Wetlands and Forests Regulate Climate via Evapotranspiration

Petra Hesslerová, Jan Pokorný, Hanna Huryna, and David Harper

4.1 Introduction

Most assessments of the importance of wetlands in the landscape focus upon their retention role, i.e. their accumulation of organic mass, materials and nutrients. Another important feature is the promotion of biodiversity. A specific wetland environment provides shelter not only for rare and protected species of plants and animals but also for game and fish. Wetlands also have a direct role in retention and accumulation of water in the landscape, affecting its cycling. Relationships between wetlands and the hydrological cycle have been relatively thoroughly investigated, especially in terms of surface and groundwater dynamics. The climate and water regime of wetlands are also covered by a number of studies, as well as the role of wetlands in climate and climate change (Mitsch and Hernandez 2013). In this respect, wetlands are considered primarily as sources, sinks or greenhouse gas sequestration systems, in particular CO_2 or CH_4 (Pokorný et al. 2016). Attention is also paid to wetlands' albedo, i.e. that part of the incident solar radiation which wetlands are able to reflect. The influence of global change on wetlands is described in the literature and summarized in the material published by the Ramsar Convention. Warming, accompanied by thermal and precipitation extremes, has the following effects on wetlands:

1. Higher temperatures and low relative humidity accelerate and increase evapotranspiration.
2. Water level fluctuations (drying and wetting) accelerate the decomposition of organic mass, thereby increasing the trophic status of the habitat.

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Peatlands in the temperate zone, i.e. wetlands with low-water level, will rapidly become terrestrial ecosystems. Global warming influences boreal wetlands most strongly, especially peat bogs with permafrost. There are fears that boreal peat bogs and tundra will turn into carbon dioxide and methane producers, whereas currently organic accumulation predominates over decomposition (Mitsch and Gosseling 2007).

However, in relation to greenhouse gases, we are addressing their indirect role. Wetland responses to the solar energy flows in the landscape are considered as a direct role of wetlands in influencing climate. It is the close relationship between solar energy and phase transitions of water, mediated by plants. Wetlands directly influence the microclimate, the local and regional climate through the process of evapotranspiration. Wet vegetation, transforms (dissipates) solar radiation into the latent heat of water vapour. Solar energy binds in wetlands through plants and water into water vapour. In this way, temperature and air pressure differences and hence air velocity are compensated for in time and space. Evapotranspiration converts many times more energy than photosynthesis. Water and plants are the main regulators of the solar energy flows in the landscape, thus playing an irreplaceable role in climate; for these reasons, our chapter focuses upon the direct function of wetlands and the air-conditioning effect of evapotranspiration.

4.2 Solar Energy Balance on Earth

Solar radiation is the main driver of the processes that take place in the biosphere—the water cycle and the production of biomass are the most important. The Sun radiates energy in the form of shortwave radiation, with a radiation flow of 180,000 terawatts, directly to Earth and its atmosphere. Solar energy, incident on the unit area of the upper boundary of the atmosphere, is called the solar constant. Based on satellite measurements, its value is set at 1367 W m^{-2} ($\pm$20 W m^{-2}) for the average distance from the Sun. The Earth orbits around the Sun along an elliptical orbit, and therefore the amount of solar energy hitting the upper boundary of the atmosphere varies from 1412 W m^{-2} in January to 1321 W m^{-2} in July (Arya 2001).

The energy incident on the Earth's surface is partially absorbed, reflected or transformed into long-wavelength radiation that is emitted back. As solar radiation passes through the atmosphere, due to the presence of cloudiness, different gases, dust and other particles and aerosols, there are changes in its intensity and physical properties. Reflection, diffusion and absorption processes take place in the atmosphere. The difference between the amount of incoming radiation on a clear day (e.g. 8.14 kWh m^{-2}, maximum flow 1000 W m^{-2}) may be one order higher than that of the cloudy day (e.g. 0.78 kWh m^{-2}, maximum flow 100 W m^{-2}) (Pokorný et al. 2016). While scattering mainly changes the properties of radiation, absorption is the cause of energy loss at a given wavelength. The main gases, absorbing sunlight with different intensity and at certain wavelengths, are water vapour, carbon dioxide, methane, ozone and nitrogen oxides. Without the presence of these gases, the average temperature on the Earth's surface would be 33 °C lower (i.e. −18 °C instead of the current 15 °C) (Ahrens 2008). Despite the fact that carbon dioxide is considered the most important greenhouse gas responsible for global warming, 95% of the greenhouse effect and warming of the Earth's surface is attributed to water vapour. Differences in greenhouse gas concentrations are significant—average values for carbon dioxide are 400 ppm, for methane 1.76 ppm; for water vapour, the concentration is very variable (from several hundred to 30,000 ppm) (Harrison and Hester 2014). The residence time of the gases in the atmosphere is also different; for water vapour it is counted in days, but methane and carbon dioxide are in years (Michaels 1998). Water vapour is put into the atmosphere by the processes of evaporation and transpiration. Its circulation in the atmosphere is part of the water cycle, which is related to the conversion of solar radiation on the Earth's surface, whose properties (landscape cover) influence the evaporation and condensation processes.

Approximately 47% of the solar radiation that enters the upper layer of the atmosphere reaches the Earth's surface. The relation of the incident, reflected and emitted solar radiation of the Earth's surface can be expressed by the radiation balance, where the term "net radiation" is defined. Common methods evaluate net radiation by estimating the solar radiation balance (Jensen et al. 1990; Allen et al. 1998; Arya 2001; Kjaersgaard et al. 2007; Kedziora 2011) as:

$$R_n = S_{\downarrow} - S_{\uparrow} + L_{\downarrow} - L_{\uparrow} = S_{\downarrow}(1-\alpha) + L_{\downarrow} - L_{\uparrow} \tag{4.1}$$

where R_n is the net radiation (W m^{-2}); $S_{\uparrow}$ and $S_{\downarrow}$ are the incoming and the outgoing shortwave radiation fluxes (W m^{-2}), respectively; $L_{\uparrow}$ and $L_{\downarrow}$ are the downward and the upward long-wave radiation fluxes measured on the surface (W m^{-2}), respectively; and α is the surface reflectivity (albedo, unitless).

At the surface the net radiation is balanced by turbulent fluxes into the atmosphere, conduction into the ground and accumulation into biomass, according to the law of energy conservation (first law of thermodynamics). The net energy is transformed (dissipated) into the following energy components (Fig. 4.1). Part is consumed for evaporation in the form of latent heat of the vapour; part turns into sensible heat, ground heat flux, surface heating and photosynthesis. This transformation is expressed by the energy balance equation:

$$R_n = \mathrm{LE} + H + G + J + P + A_d \tag{4.2}$$

where LE is the latent heat flux (a product of the latent heat of vaporization of water (L) and the rate of evapotranspiration from the vegetation or the soil (E)), H expresses vertical turbulent fluxes of sensible heat flux into the atmosphere by thermal convection, G is the heat conducted into the soil, J is the small part of solar radiation stored by vegetation, P is the energy consumed by photosynthesis for biomass production (primary production) and A_d is the net loss energy due to the

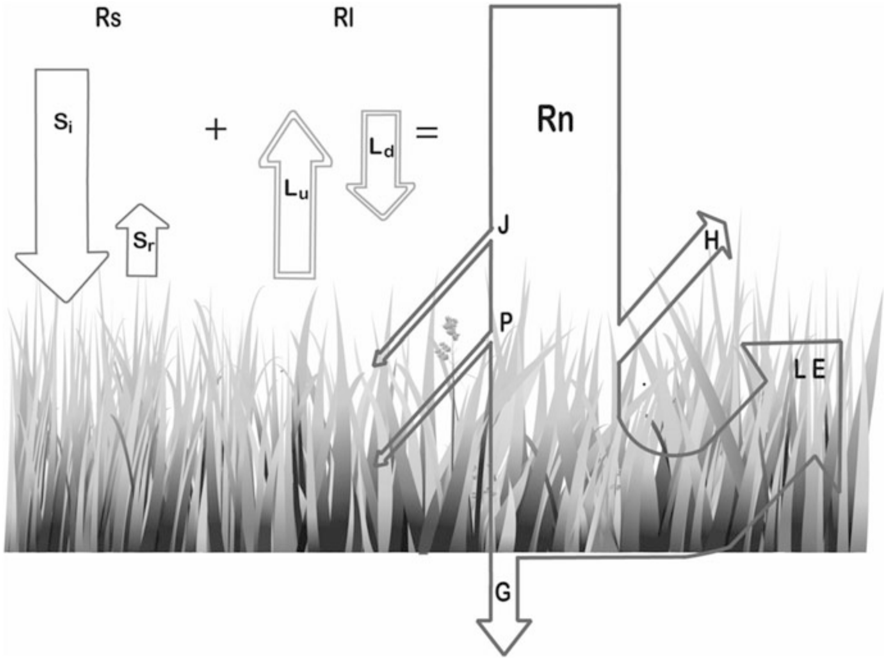


Fig. 4.1 Dissipation of solar energy in a plant stand. R_s net shortwave radiation; S_i incoming shortwave radiation; S_r reflected shortwave radiation; R_l net longwave radiation; L_u upward longwave radiation (flux emitted by ecosystems); L_d downward longwave radiation (flux emitted by the overlying atmosphere); R_n net radiation; J accumulation of heat in biomass; P energy consumption by photosynthesis; G ground heat flux; H sensible heat; LE latent heat of vaporization

horizontal advection (Monteith and Unsworth 1990; Kravčik et al. 2008). The solar energy flow through photosynthesis into biomass comprises a very small part of the total energy balance. It is counted as the amount of solar energy bound in the accumulating biomass. The opposite process is respiration, in which energy is released by the breakdown of organic mass. The amount of energy consumed for heating the vegetation cover depends on the amount of biomass and water content. It reaches a maximum of 20 W m^{-2}. Energy flows J, P and A_d are very small (about 1% of the total balance); therefore, they are mostly neglected, and the energy balance equation is often simplified to the form:

$$R_n = \text{LE} + H + G \tag{4.3}$$

The greatest importance in the transformation of solar energy on the Earth's surface is the latent heat flux of the vapour and the sensible heat flux. The latent heat of vaporization is related to the water vapour, in which, due to the change of phase process, energy is consumed. Phase changes between liquid water and water vapour are linked with the consumption of a large amount of energy. The enthalpy of liquid water is -2.5 kJ g^{-1}. Evapotranspiration (ET) or latent heat flux represents large, invisible fluxes of water and energy in the landscape, the scale of several hundred W m^{-2}. The evaporation of water is not accompanied by temperature increase, because energy is transformed in the change of phase during acceleration of the kinetic movement of molecules, as a result of which the liquid is converted into water vapour. Evaporation cools the environment. On the contrary, condensation of water vapour (e.g. in the night hours) back to the liquid (e.g. dew formation, frost) releases the stored energy as heat, and the surrounding environment is heated.

The sensible heat flux is driven by the temperature differences between the surface and the overlying air. Heat is initially transferred into the atmosphere by conduction. Then, with gradual heating of air, it circulates upwardly through convection. When the surface is warmer than the overlying air, heat will be transferred upwards into the air as positive sensible heat transfer. If the air is warmer than the surface, heat is transferred from the air to the surface creating a negative sensible heat transfer. Sensible heat is therefore part of the energy that warms the environment. We feel increasing surface and air temperature and can measure it with a thermometer.

Ground heat flux (G) is less significant compared to the two previous components of the equation; it accounts for 5–10% of net radiation (Baldocchi et al. 1985). It ranges in summer months from 10 W m^{-2} to 100 W m^{-2} for growing crops (Kustas et al. 1993; Huryna et al. 2014). The magnitude of this flux depends on the temperature gradient and the thermal conductivity that is affected by the mineral composition of the soil, its texture and water content. Its intensity decreases with the density of the vegetation cover; it is low on dry soils (Wierenga et al. 1969).

When evaluating ecosystems in terms of transformation of solar energy, the so-called Bowen ratio is an important variable. It is defined as the ratio of sensible and latent heat flux. A great portion of available energy at the surface is transformed into latent heat if the Bowen ratio is less than one. This is usually observed at wet surfaces, vegetation (forests, wetlands) and open water during a day. A major part of available energy becomes sensible heat flux if ratio is equal or greater than one. This is typical for sealed, vegetation-free and dry surfaces (Huryna et al. 2014).

Another important variable in terms of ecosystems and climate is albedo. Surface albedo determines the actual amount of solar energy available to transfer turbulent heat fluxes and moisture. It is defined as a ratio of reflected radiation from the Earth's surface to total incident solar radiation. It affects the energy partitioning and energy balance on the Earth's surface, so it closely links land cover alteration with the climate change (Betts 2000; Bonan 2008; IPCC 2013). However, its influence is overestimated. The reflection on the total energy balance in the landscape is from 10% to 20%; light concrete surfaces have an albedo of up to 30% and still have a far higher temperature in sunny weather than the surrounding "darker" vegetation, which is cooled by the evaporation of water.

4.3 Role of Wetlands in Solar Energy Distribution

The influence of vegetation on climate and climate change can be both direct and indirect (Pokorný et al. 2016). Indirect influence is related to vegetation as a source, recipient and sink of greenhouse gases, through photosynthesis, respiration and biomass accumulation. Direct influence refers to the role of vegetation in the distribution and transformation (dissipation) of incident solar radiation. This transformation is associated with the processes of reflection, evapotranspiration, the production of sensible heat, ground heat flux and, in a negligible extent, with photosynthesis and heating of the stand. These processes contribute to the local climate (Huryna et al. 2014). Water has a unique feature. It exists in three aggregate states: solid, liquid and vapour. Phase transition from liquid into vapour is associated with changes of volume (18 ml of liquid forms 22,400 ml of vapour) and consumption or release of energy (2.45 MJ kg^{-1} at 20 °C), which is a cooling or heating environment. Water has high heat capacity, so its transformation involves exchange of energy, thus equalizing the temperature differences in time (day and night) and space (between different spaces) (Eiseltová et al. 2012).

Wilhelm Ripl proposed a holistic concept, in order to understand how natural processes are involved and connected in the process of energy dissipation (Ripl 1995). He called it the Energy-Transport-Reaction (ETR) model, describing the relationships between energy, water transport and physical, chemical and biological processes. Water as an energy processor and a dynamic part of the landscape is involved in the dissipation (in the sense of non-equilibrium thermodynamics) of solar energy at three levels:

– Physical processes, which are evapotranspiration and condensation
– Chemical processes, which are dissolution and precipitation
– Biological processes, which are photosynthesis and respiration

The main driver of these processes is the solar energy gradient.

The ETR model (Ripl 1995; Ripl and Hildmann 2000) represents an ecological model of the dissipation of the daily pulse of solar energy, in connection with the nutrients losses from the landscape. Most energy is dissipated through the physical processes of water evaporation (cooling function) and condensation of water vapour.

Through water and vegetation, energy is dissipated to create a dynamic balance of temperature, precipitation, runoff and chemical processes. At the same time, a loss of dissolved mass (nutrients, basic cations) from the upper soil layer is reduced. Soil acidification, reduction of fertility on the one hand and high nutrient content and water eutrophication on the other hand are linked phenomena of mismanagement in the landscape (Ripl and Wolter 2002; Pokorný et al. 2003). The amount of irreversible losses of mass from any landscape system (e.g. river basin) determines the stability of the communities and hence all component ecosystems. The efficiency of such a system and its associated water cycle is determined by the ratio of the amount of cycling mass to its losses at a given amount of supplied energy and is called the ecological efficiency of the landscape (Ripl 1995).

Water is discharged with many tons of dissolved mineral ions per square kilometre every year from fertile agricultural soils. High mineral losses are explained by decomposition processes in the soil (mineralization of organic mass), which produce strong acids (sulphuric, nitric), acidifying soil. Mineralization processes are accelerated in drained and overheated soils, which mean that the intensity of mass losses is directly related to surface temperature (Ripl 2003). This is a positive feedback; drainage leads to overheating of the soil, accelerated decomposition of organic mass and loss of water retention. This results in overheating, i.e. in energy balance shift from the latent heat of vaporization to sensible heat. Retention of water in the soil acts in the opposite direction, i.e. accumulation of organic mass, surface and air cooling.

Vegetation and water are thus inextricably linked through the impacts on energy and hydrological cycle (Nobre et al. 1991; Hutjes et al. 1998; Arora 2002). The water presence is an important factor for the distribution of terrestrial ecosystems, while vegetation structure influences evapotranspiration, and runoff formation (Gerten et al. 2004). Falkenmark and Rockstrom (2004) introduced the concept of “green and blue water flows”. Runoff and groundwater flows are referred to as “blue water flow”, whereas “green water flow” is denoted as evapotranspiration. Plants impact the “blue water flow” through meteorological and biological factors such as albedo (Trimble et al. 1987; Eckhardt et al. 2003), temperature and humidity (Swank and Douglass 1974), stomatal conductance (Field et al. 1995), transpiration (e.g. Wang et al. 1996; Koster and Milly 1997), root systems (Milly 1997) and leaf area index (Peel et al. 2001). Evapotranspiration is a combination of two simultaneous processes: free-water evaporation and plant transpiration from the land surface to the air. It represents not only the largest contribution to the hydrological cycle, but it is also essential for understanding atmospheric circulation and modelling terrestrial ecosystem production (Willmott et al. 1985; Nemani et al. 2003; Heijmans et al. 2004; Schmidt 2010). Evapotranspiration alters regionally and seasonally according to the growing season, climate, available radiation, land cover, soil moisture and land use change. The process of evapotranspiration has been studied thoroughly since the middle of the twentieth century (Budyko 1974; Ryszkowski and Kedziora 1987, 1995; Monteith and Unsworth 1990; Schneider and Sagan 2005; Pokorný et al. 2010; Přibáň et al. 1992), and its quantitative aspects and interrelations with environmental factors and the quality of plant stands are well documented. Few studies however deal with the cooling effect of functional vegetation (e.g. Burba et al. 1999; Herbst and Kappen 1999; Hojdová et al. 2005; Brom and Pokorný 2009; Rejšková et al. 2010).

The distribution of solar energy between a dry surface and vegetation stands supplied with water varies considerably (Fig. 4.2). The reason is the interaction of water molecules and solar radiation. The phase change of water from liquid to gaseous state is associated with the consumption of large amounts of energy. The enthalpy of the liquid water is 2.5 kJ g^{-1}. Evapotranspiration or latent heat of vaporization represents significant flows of energy and water in the landscape, in the order of several hundred W m^{-2}. For example, evaporating 100 mg H_2O m^{-2} s^{-1} consumes 250 W m^{-2}. This represents a vapour of 100 L per second from 1 km^2,

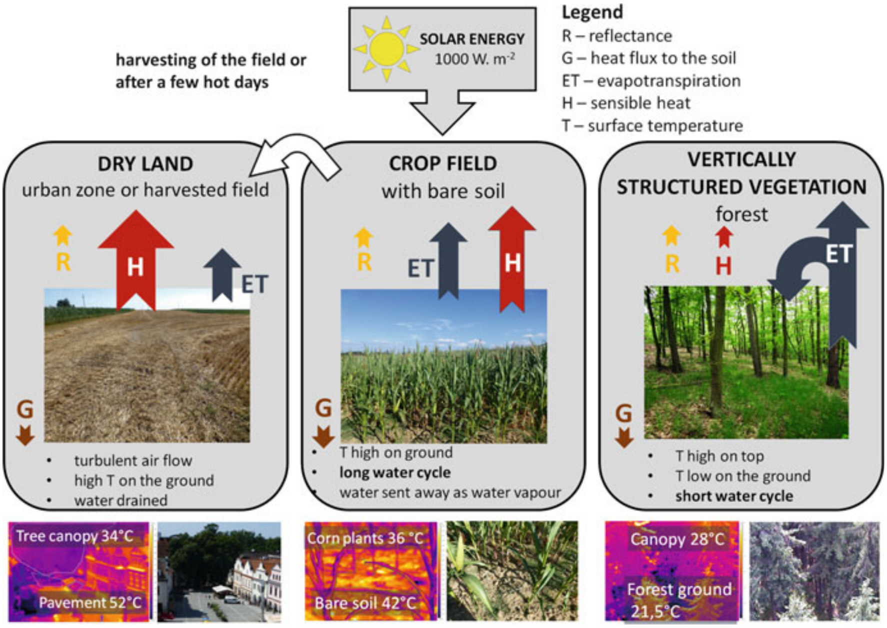


Fig. 4.2 Solar energy distribution on different surfaces—dry land, crop field and forest. Thermal images show the surface temperature and thus provide information how the energy fluxes are distributed. Sensible heat (*H*) provides energy for fast ascending flux of air which transports humidity high into atmosphere. Water vapour released by vertically structured vegetation stays near the canopy and can return back in form of due or light rain

which is more than the surface runoff from the same area, transforming 250 MW km^{-2}. That is the amount of energy that cools 1 km^2 of landscape due to water vapour that would otherwise be released in the form of sensible heat that would warm the landscape. Such an amount of energy is released as heat in summer from the bare soil of harvested fields.

Evapotranspiration is thus a powerful tool that has a double air-conditioning effect in the landscape:

(a) Cools the landscape through the process of water conversion into water vapour; solar energy is consumed for this phase change.
(b) Where water vapour condenses, latent heat is released to heat the surroundings.

Evapotranspiration also reduces gradients, i.e. it compensates for differences in temperature. Evapotranspiration-condensation processes slow down where there is a lack of water. Solar radiation is then transformed into sensible heat. The sensible heat flux is represented by the total amount of all heat exchanges between the Earth's surface and the atmosphere, which are conduction and convection. In the case of dry surfaces, the values of the sensible heat flux reach several hundred W m^{-2}. The overheated surface warms the adjacent air layer. Warm air rises turbulently upwards, which causes instability of the atmosphere. This is then capable of absorbing higher amounts of water vapour, which then transmits to higher levels of the atmosphere where condensation occurs, leading to turbulent rainstorms.

Thus, wetland drainage, deforestation and increasing the share of built-up areas cause changes in the distribution of energy flows in the landscape. There is a change in the ratio of latent and sensible heat fluxes. As a result of the loss of functional vegetation and water, the proportion of latent heat of vaporization decreases, which leads to a reduction in the cooling ability of the landscape and an increase in temperature gradients. The sensible heat flux prevails, with consequences such as temperature rise, turbulent air flow, strong winds and cyclones.

4.4 Do Wetlands Waste Water?

Evapotranspiration is a basic component in water cycle, particularly so in wetland and forest ecosystems (Geiger et al. 2003; Makarieva et al. 2013). In the Czech Republic, the maximum evapotranspiration values for wetlands range from 6 to 11 mm day^{-1}; the average is lower. The annual sum of evapotranspiration from wetland ecosystems is between 1100 and 1600 mm year^{-1}. Extremely high evapotranspiration values (more than 10 L m^{-2} day^{-1}) were measured in artificial wetlands that were islands in dry farmland (Kučerová et al. 2001). Drained, overheated farmland surfaces accelerate the evaporation of neighbouring wetlands and hence desiccate the surrounding vegetation.

Forest stands and wetlands, compared to other ecosystems of the same latitude, show a balanced temperature and humidity regime. They transpire a large amount of water, hence affect the temperature of the surface and air above. With an evapotranspiration rate of 7 mmol m^{-2} s^{-1} (i.e. 126 mg m^{-2} s^{-1}), wetlands are able to convert 315 W m^{-2} into a latent heat of vaporization. A wetland area of 4 km^2 is able to evaporate 500 L of water each second. This value can be imagined as the flow of a smaller river. This is 1260 MW of energy used for evaporation. In this way, a wetland ecosystem regulates surface temperature and water outflow.

In the hydrological balance, evapotranspiration, along with outflow, is classified as the “loss” component. Water managers perceive evapotranspiration as a process which, especially in the absence of precipitation, reduces water outflow in the rivers. Is this really so? Evapotranspiration is essential for plant growth; it is necessary for cooling, balancing temperatures and thus returning water in the form of small precipitation. Limiting evapotranspiration leads to drying and overheating of the landscape.

The fundamental problem is to maintain, or recover, water supplies for evapotranspiration. The release of water through evapotranspiration in a river basin in summer is higher than its surface outflow. For example, at the beginning of June 2016, the flow rate in the Vltava River (the longest river in the Czech Republic) was 150 m^3 s^{-1} at Prague (the capital city). The river basin area of the Vltava River at Prague is 28,000 km^2. Evaporation from the river basin was almost 20 times of the flow of the river—2800 m^3 s^{-1}—with latent heat of 250 W m^{-2} (water vapour 100 mg m^{-2} s^{-1}) on a single sunny day. With an average evaporation of 3 mm, 84 million m^3 of water evaporate per day from the 28,000 km^2 basin, while 13 million m^3 flows through Prague. In both calculations, water vapour (evapotranspiration) is rather underestimated. Reduction of evapotranspiration, i.e. through land cover changes, brings only the extreme water outflows from the landscape and finally its total desiccation. We must thus manage our landscapes, so that the vaporized water returns to local rainfall and drags more water inland from the sea (Makarieva and Gorshkov 2007, 2010; Makarieva et al. 2010, 2013). Reduction of ET results in an increase of sensible heat and accelerates transport of water vapour from surrounding wetlands and forests high into atmosphere.

Forest stands and wetlands greatly regulate temperatures by just water vapour (evapotranspiration). Water is naturally evaporated by crops; their rate of evaporation is often higher than trees. Agricultural crops and simple stands of herbs, without vertical structure, cannot control the discharge of water, so they lose water by evapotranspiration. Full-grown forest water loses are less; however, large areas of the forest attract even more water (Sheil and Murdiyarso 2009; Sheil 2018). Two Russian physicists, Victor Gorshkov and Anastassia Makarieva, evaluated rainfall data at continental scale and showed that the amount of rainfall from the sea to inland does not decrease in the forested areas (Amazon and Congo basins, Siberia); on the contrary, on transects through deforested areas, they found significant decrease of precipitation inland (East Africa, West of North America, Eastern Australia). They elaborated the theory of the "biotic pump", explaining the function of forest in the water regime and climate of continents (Makarieva and Gorshkov 2007, 2010; Makarieva et al. 2010, 2016; Sheil 2018). This theory is based on two phenomena:

(a) During the sunny day, an inverse vertical temperature gradient is created in the forest—the undergrowth temperature is lower than in the canopy. The cooler air is heavier and stays on the ground; it does not carry moisture. Trees control water supply with their crowns. But in crops without undergrowth, and poor grassland, the soil temperature is higher than the surface temperature of the vegetation—the air is heated by the soil; it flows upwards and takes away water vapour, drying the soil.
(b) The water vapour released by tree canopies rises upwards, cools and condenses (the volume of air is reduced), and water returns. In addition, at night the tree canopies cool towards the sky by radiating long-wave radiation. Tree canopies have a high leaf area index, and water vapour is precipitated at the edges of leaves/needles. As a result of condensation of water vapour on tree canopies, air pressure drops slightly, and air is drawn horizontally from the surrounding atmosphere. Makarieva and Gorshkov distinguish the acceptor areas of water (forests) and donor water areas (oceans, lands without forests) and show that, by deforestation, the acceptor regions are transformed into donor regions and dry. Paradoxically, acceptor areas have higher evapotranspiration than donor areas, because evapotranspiration is the "pump" that sucks the air horizontally.

So in the case of a well-structured stand, well-supplied with water, one cannot consider evapotranspiration as the "loss" of water. Well-vegetated ecosystems are able to maintain low surface and air temperature. The cooler air does not absorb large amounts of water vapour (saturated air at 21 °C contains 22,400 ppm water vapour, saturated air at 40 °C 62,200 ppm). These ecosystems are able to control the flow of water in the daytime, changing at night to condensation sites where precipitation forms (dew, fog). The hot air over the agricultural landscape and the built-up areas is the main cause of desiccation (Kučerová et al. 2001).

4.5 Cooling Effect of Wetlands and Forests on Thermal Images

4.5.1 Surface Temperature and Its Measurement

The way that solar energy on Earth is distributed is reflected in the surface temperature. Surface temperature is a functional indicator that expresses the ability of the system to convert (dissipate) solar energy. It provides information about the transformation of solar energy on the Earth's surface, from which it is possible to derive the dominant components of energy balance—either the sensible heat that is responsible for the warming of the environment or the latent heat that is consumed in evaporating water vapour—and the environment cools down. The temperature of the landscape is one of the key characteristics determining the relationships between water cycle, the landscape energy balance and its land cover. It directly and indirectly affects the water cycle and the climate. These relationships have been documented by a number of experimental and field measurements (Ripl 2010; Pokorný et al. 2010; Eiseltová et al. 2012; Huryna et al. 2014; Hesslerová et al. 2013).

A body's temperature represents one thermal state, which is characterized by two physical quantities. The thermodynamic (kinetic) temperature is given by the kinetic energy of the moving particles that form the body and is the internal expression of energy of the body's molecules. It is measured with a thermometer that is in direct contact with the body. The second temperature is represented by the so-called radiation temperature. Every body whose temperature is higher than the absolute zero (−273.15 °C) emits radiation, whose intensity and spectral composition are the functions of its kinetic temperature and the material from which the body is composed. In the thermal part of electromagnetic radiation (from 3 μm), an object radiates above the reflected solar radiation. The intensity of this long-wave radiation is an external manifestation of body temperature and is governed by the basic laws of thermodynamics. For real objects, the kinetic temperature will always be higher than the radiation temperature. For most objects and materials (except for specific ones such as glass, metals, etc.), there is a significant positive correlation between radiation (brightness) and kinetic (thermodynamic) temperature (e.g. water has an almost linear relationship).

The thermodynamic (kinetic) temperature of the atmosphere, measured in a screen at 2 m above ground in meteorological stations and consequently interpolated to large areas, is considered as a landscape temperature. This is the temperature of the air that "heats the thermometer". At this height the effect of the ground surface on the temperature measured is eliminated. Therefore, the temperature of the landscape is better recorded as the radiation temperature, measured by thermal imaging systems on satellite, airborne and unmanned aerial systems, providing spatial information. Here, we are measuring the values that reflect the transformation of solar radiation on the Earth's surface, depending on the surface's properties.

Unlike the kinetic temperature measured by contact (thermometer), the radiation temperature is contactless. For point (ground) measurements, pyrometers (infrared thermometers) can be used, while spatial information provides thermal infrared imaging systems of two types:

– Scanning systems (on board aircrafts and satellites)
– Matrix imaging systems (thermal imaging cameras on different craft types or ground measurements)

Thermal satellite data are based on scanning the intensity of electromagnetic radiation at wavelengths, most often between 7.5–14 μm and 3–5 μm, using different scanning devices. Thermal images are taken in one or more broad-spectrum channels, from which the absolute value of the surface temperature is calculated after radiometric and atmospheric corrections. The spatial resolution of these images is in the range of kilometres down to tens of metres.

Thermal data with higher spatial resolution can be obtained using systems on board airplanes or unmanned aerial vehicles (UAV), i.e. drones, airships and unmanned sailplanes. Thermal broadband cameras (matrix systems) are usually located on these carriers. These cameras record the thermal radiation from the focus area at onetime point on the matrix detector, only in a single spectral channel (about 7.5–14 μm). Depending on the height of the flight and the used optics, the spatial resolution of the thermal images is in the order of metres to centimetres. Another advantage of these data is the possibility of operative and repeated images acquisition of the area of interest. The disadvantage is higher financial costs due to demands for technical equipment and more complicated preprocessing of these data. While processing and interpreting broadband temperature data acquired by thermal imaging cameras, it is necessary to calibrate them. This is particularly the case when the aim of using these data is as precise as possible to determine the surface temperature. Calibration data on the current state of the atmosphere at the time of scanning, including additional data, is also necessary. The thermal imaging camera can be calibrated at the time of taking pictures or during their further processing at the time of data processing (Brom et al. 2014; Hesslerová and Pokorný 2014). Thermovision cameras can also be used for ground temperature monitoring, as shown in pictures taken for the following case studies.

4.5.2 Case Studies

Differences in surface temperature of wetland vegetation, tropical rainforest and farmland are shown on the examples of ground thermal imaging (Figs. 4.3a, b, 4.4a, b, 4.5a, b, 4.6a, b, 4.7a, b, 4.8a, b and 4.9a, b). These model examples come from lakes Naivasha and Victoria in Kenya. To evaluate the surface temperature and to illustrate the cooling ability of different types of vegetation, the following locations were selected:

(a) Indigenous tropical forest—the Mau Forest covers the western slopes of the Mau Escarpment in the Gregory Rift Valley, at altitudes of 1200–2600 m about 150 km northwest of Nairobi. The whole area (mainly the Eastern part) has faced very rapid and extensive deforestation over the past 25 years (2000 km^2 of clear cuts), bringing about changes in the region's climate and hydrology. The locality is situated to the south-eastern edge of the forest, just west of Eburru Forest, in the valley of the Marmanet river.
(b) *Acacia xanthophloea* represent the original tree species of the African savannah with a flattened crown. This riparian vegetation of Naivasha was selected for monitoring.
(c) *Cyperus papyrus*—wetlands of Victoria and Naivasha lakes. Papyrus is a dominant, rapidly growing wetland species of East Africa, with wide use. However, it is frequently destroyed for different reasons (see Pacini et al. 2018).
(d) The landscape around Lake Oloidien—a mosaic of crop fields, bare soil eroded by livestock passage, beside riparian *Acacia* stands.

Ground imagery were acquired in July and November 2012 by the thermographic camera ThermaCAM TM PM695 (Flir Systems, Sweden) which measures and records the infrared radiation emitted by the subject in a spectral range of 7.5 μm to 13 μm with a resolution of 320 × 240 pixels and a thermal sensitivity of 0.08 °C at 30 °C. Surface temperature information was measured for various type of landscape cover and vegetation. The average temperature has been calculated for the sub-sections, marked in the images.

Surface temperature is an indicator expressing distribution of solar radiation on the Earth's surface. Of crucial importance in this process are two energy flows, the ratio of which depends on the amount of available water—sensible heat and latent heat of the water vapour. If the landscape is well supplied with water and covered by (permanent) vegetation, a substantial part of the solar radiation is consumed on the water vapour, which is reflected in the thermal images as low surface temperature. Water is a medium that equalizes temperatures through the evaporation—condensation cycle; plants are processors controlling the release of water vapour.

Forests have a very good ability to reduce and equalize surface temperature due to the vertical structure of the stand. Surface temperature of tropical rainforest canopy is around 18–20 °C, which is at least by 20 °C less than the agriculture land (Fig. 4.3a, b). The change of land cover (deforestation) is accompanied by the energy fluxes change, which is manifested by surface temperature increase. In a

b

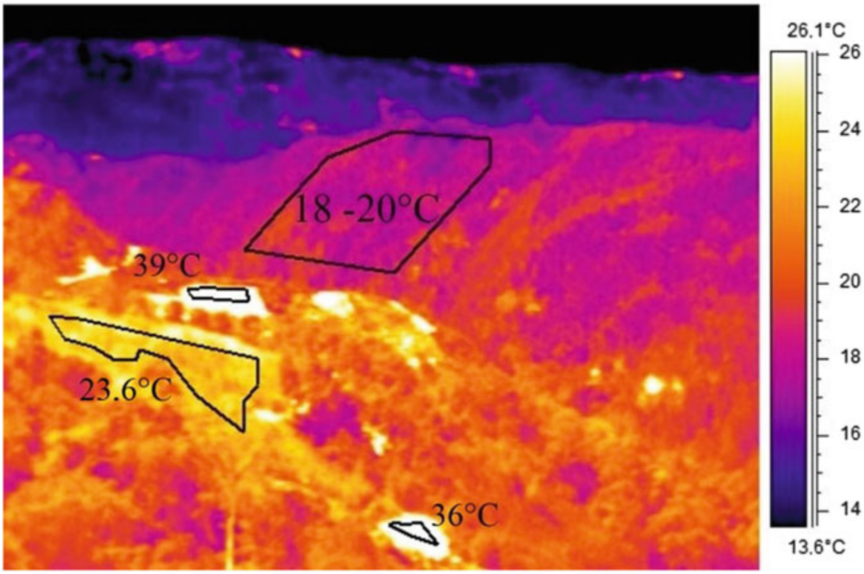


Fig. 4.3 (**a**, **b**) show both the deforested (agriculture) and indigenous parts of the tropical Mau forest. The thermal image represents the temperature differences between the natural stand and the sites that have been converted into agricultural land. Tropical rainforest has an average temperature of 18–20 °C, scrub of 23.6 °C and a ploughed field of 36–39 °C. After deforestation, the surface temperature of the site increased by 20 °C

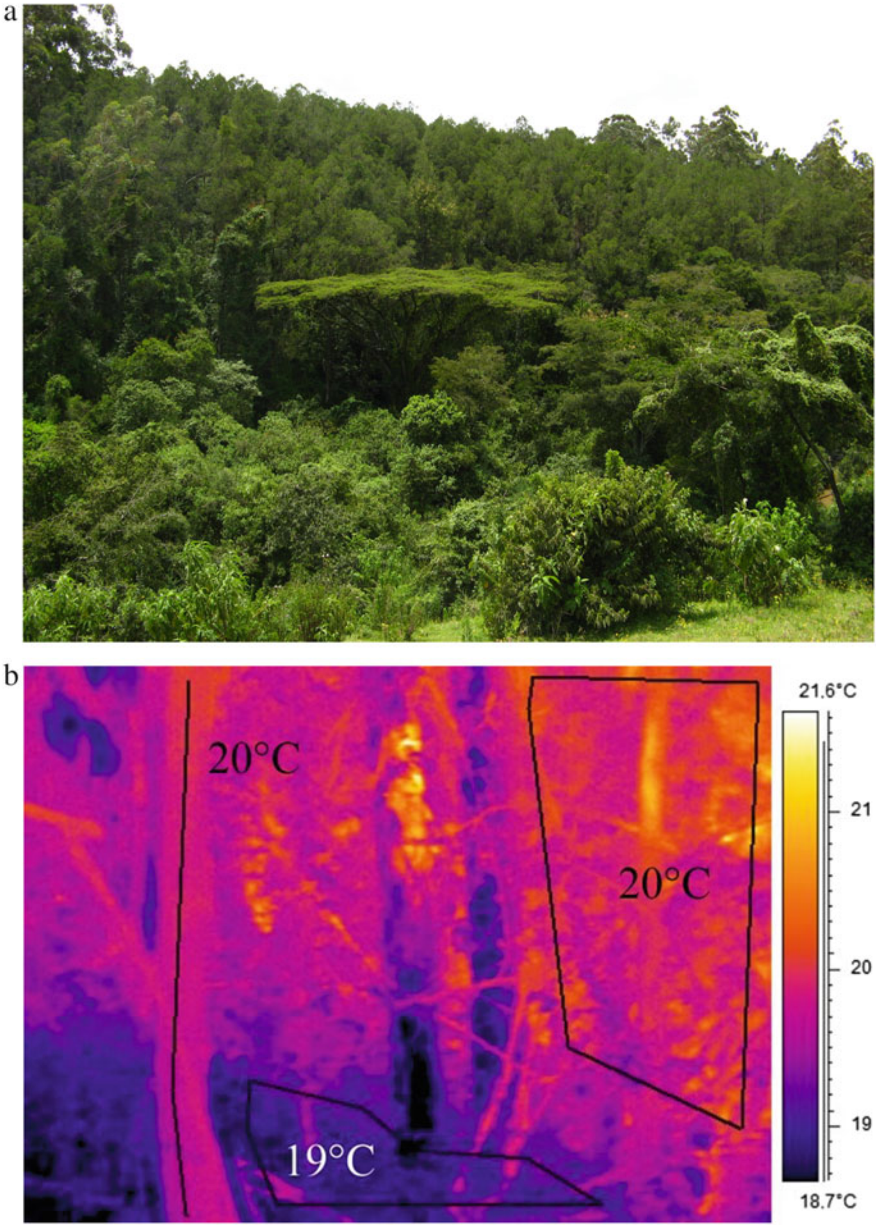


Fig. 4.4 (**a**, **b**) A view into the tropical forest. The temperature of the undergrowth is 19 °C, trunks, branches and shrubs 20 °C. Temperature differences in the image are in the order of 3 °C. The forest equalizes temperatures. Meteorological conditions on 24.11.2012: air temperature 25 °C, relative humidity 40%, sunny

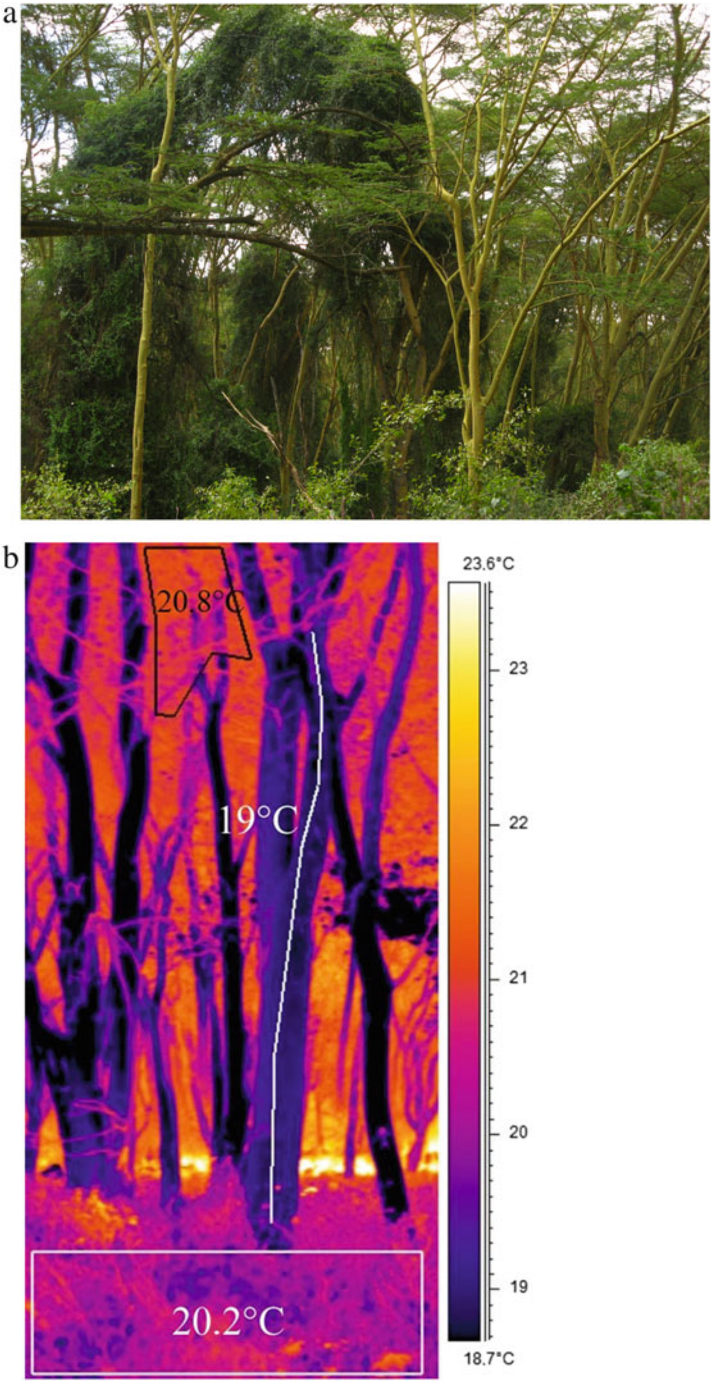


Fig. 4.5 (**a**, **b**) *Acacia* on the shores of Lake Naivasha. The temperature of the undergrowth is 20.2 °C, the tree trunks 19 °C and the crowns 20.8 °C. The temperature range is 19–25 °C, so the difference is 6 °C. Meteorological conditions: sunny, air temperature 30 °C, relative humidity 30%.

addition, due to the well-developed vertical structure of rainforests, there is a temperature inversion inside the forest, i.e. low temperature at bottom and higher temperature in canopy (Fig. 4.4a, b). This temperature stratification prevents water losses as cooler air is heavier and stays on the ground; it does not carry moisture. This is also evident in *Acacia* on the shores of Lake Naivasha. Despite *Acacia* cover does not have a well-developed vertical structure like a tropical forest, it is able to reduce and equalize temperatures (Fig. 4.5a, b). The cooling ability of vertically structured vegetation (*Acacia* forest) is also well demonstrated on Fig. 4.6a, b, which shows almost 40 °C the difference between forest vegetation (22.7 °C) and areas without vegetation (almost 60 °C).

In connection with the water discharge from Lake Naivasha, evapotranspiration is considered as water losses, which is attributed to the increased transpiration of papyrus on the shores of the lake. Thermal images (Figs. 4.7a, b, 4.8a, b and 4.9a, b) show a similar temperature stratification as for forest stands. For papyrus plants, we assume similar behaviour, i.e. controlled discharge of water by the transpiration. Evaporation from water surface is higher.

In general, the thermal images illustrate the cooling ability of forest stands and wetlands, in comparison with overheated surfaces without vegetation. The low surface temperature and its small differences in the landscape indicate that most (70–80%) of the solar radiation is converted into latent heat of vaporization—energy is consumed for the evaporation of water instead of heating the landscape. Ecosystems that are characterized by a balanced temperature regime with low surface temperature are more effectively able to retain water; on the contrary, ecosystems with unbalanced temperature regime (day or seasonal) and high surface temperatures are prone to higher water losses and hence drying. At these locations, from 60 to 70% of solar radiation is converted to sensible heat, which contributes to the warming of the landscape. Hot air released from such overheated areas (bare land, dry vegetation) has an ability to "suck water" from surroundings and transport it into upper atmosphere. This process can be called as water losses, not evapotranspiration from wetlands and forests.

4.6 The Impact of Wetlands on Local Climate

The conversion of ecosystems with structured vegetation, well-supplied with water (forests, wetlands) into agricultural land or built-up urban areas, fundamentally alters the dissipation of solar energy; in particular it changes the ratio of latent and sensible heat fluxes. It further alters the fate of precipitation—between evapotranspiration, soil infiltration and runoff. Plants and soil moisture help to regulate surface

Fig. 4.5 (continued) Taken on 25.11.2012, at 2:00 pm. Low surface temperature of *Acacia* trunks shows transpiration flux from roots to leaves

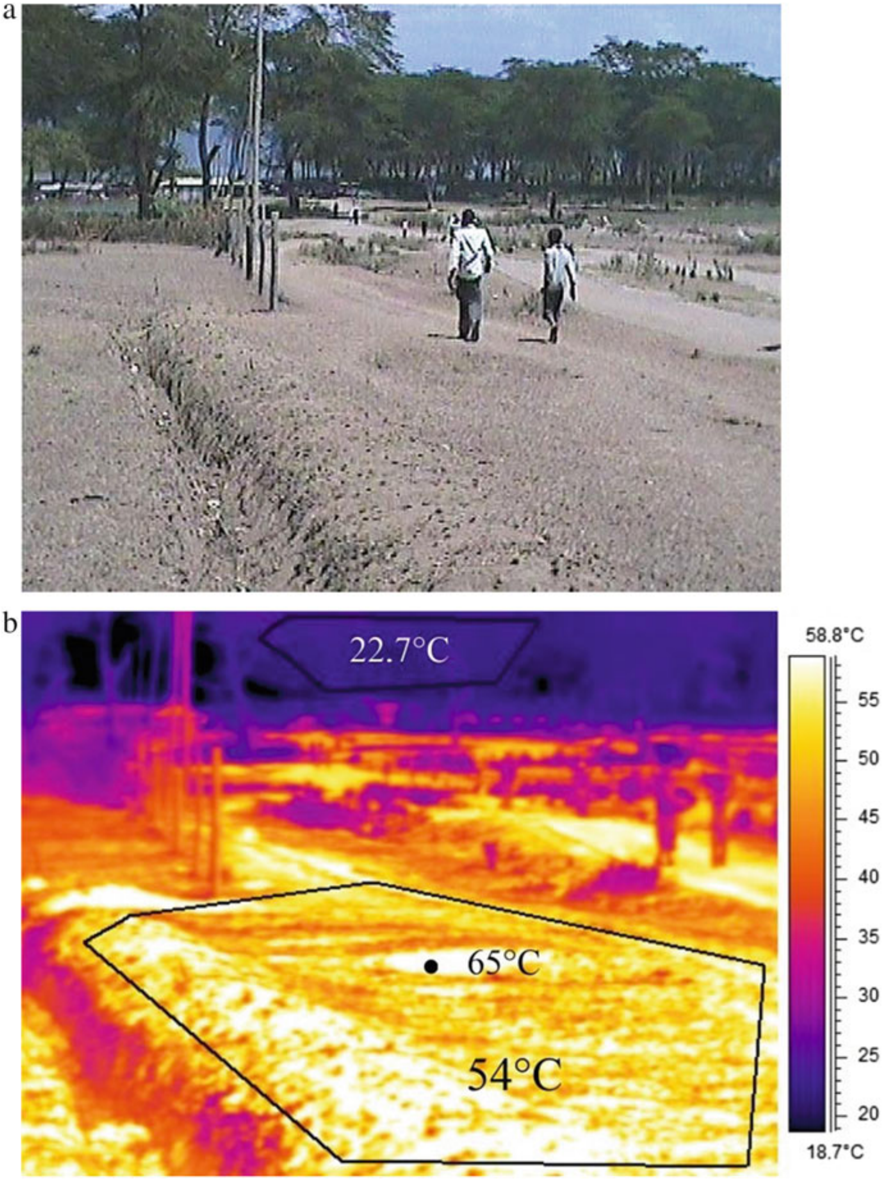


Fig. 4.6 (**a**, **b**) shows the temperature difference between the *Acacia* (canopy temperature 22.7 °C) and bare soil (54 °C), eroded by livestock coming to the lake edge to drink at Lake Oloidien, immediately south-west of Naivasha main lake. Within this image, the temperature difference is 40 °C, because the temperature at some places without vegetation reaches almost 60 °C, in the undergrowth of *Acacia* is 20 °C (Fig. 4.5b). The cooling ability of vegetation is thus evident. Estimated air temperature: 32 °C, relative humidity 30%, sunshine, measured on 25 November 2012, at 1:30 pm

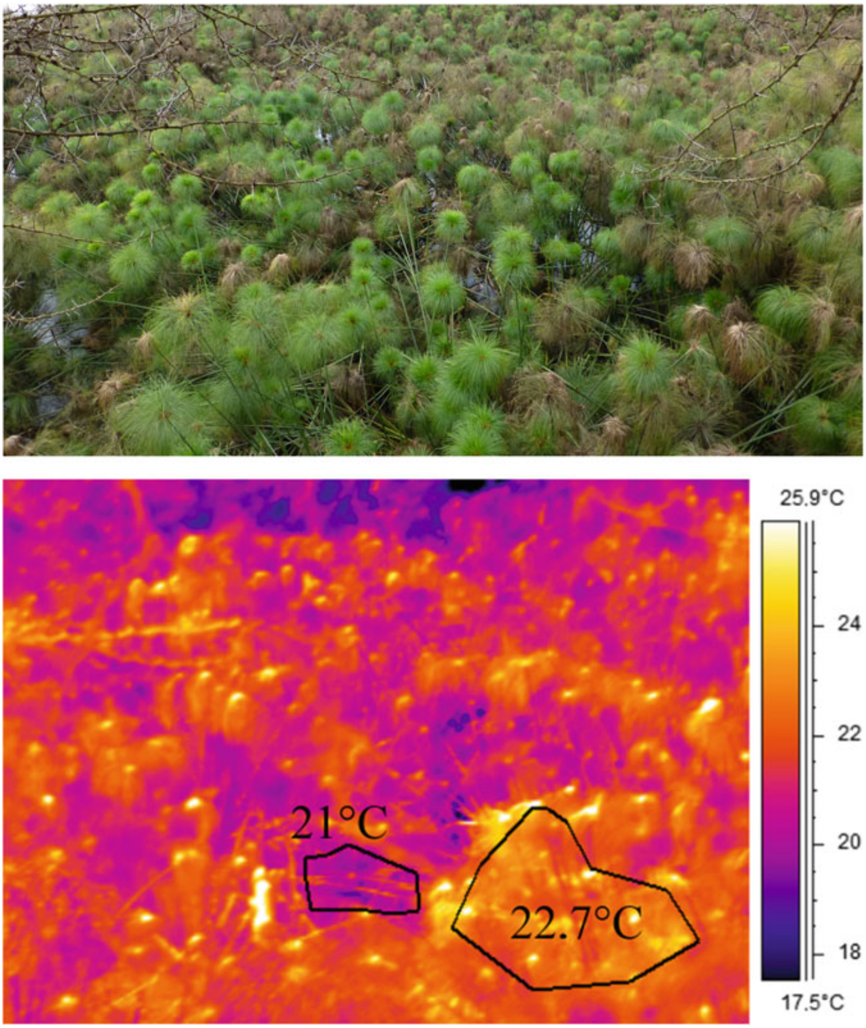
a
b


Fig. 4.7 Papyrus vegetation on Lake Naivasha. The site coordinates S 0° 49′34.38 E 36° 20′22.32. Taken on 30.7.2012 at air temperature 25 °C, relative humidity 85%, partly cloudy, at 2:00 pm. (**a**, **b**) Capture the top of the papyrus. The temperature of the stand's top is 22.7 °C, inside the stand 21 °C

temperature by evapotranspiration—water vapour release—through the heat consumption that is required to phase transitions of water into water vapour. This process leads to a decrease in surface temperature and cooling. In areas lacking vegetation and moisture, solar radiation is not bound into the latent heat by the evaporation of water but into sensible heat release and consequently local temperature increase.

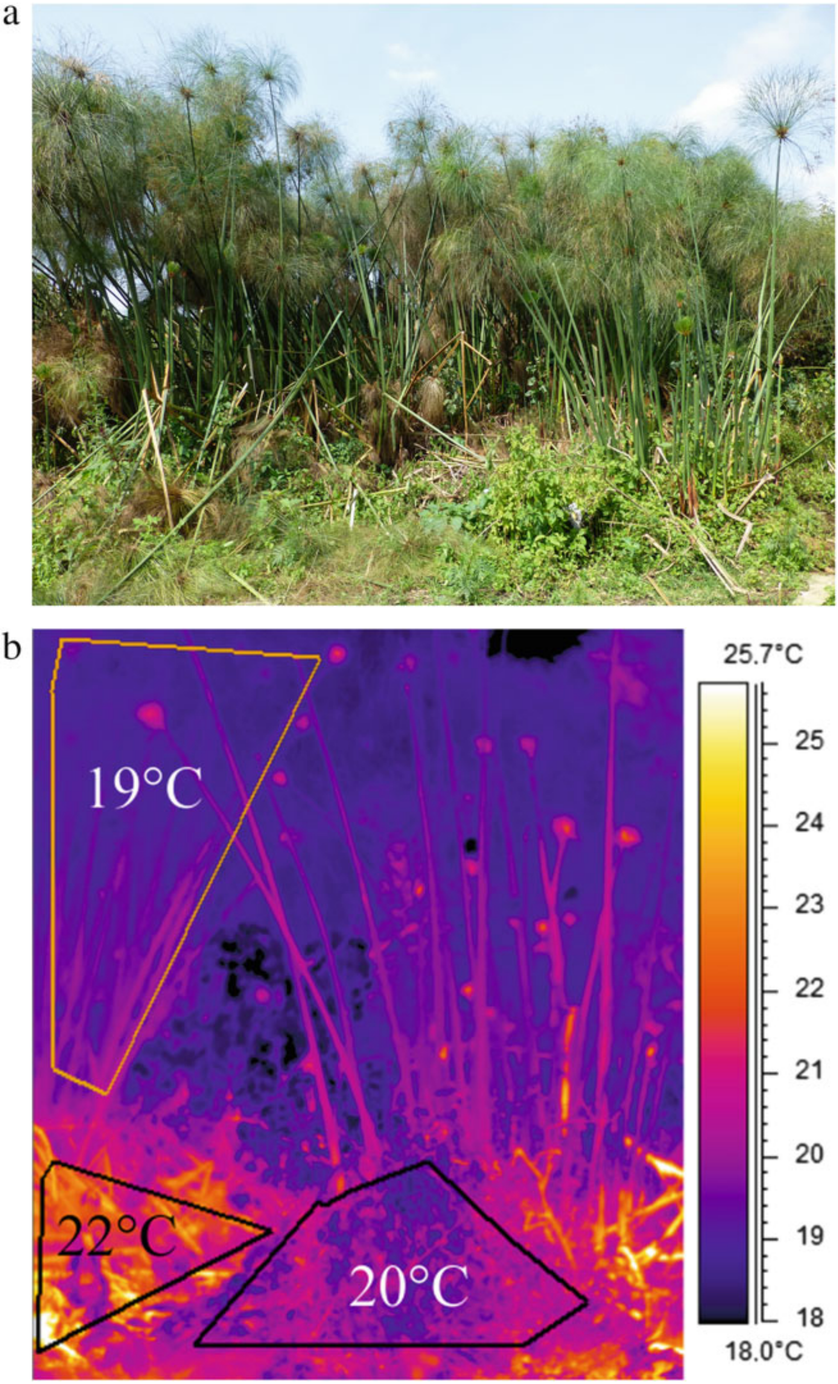


Fig. 4.8 Papyrus vegetation on Lake Naivasha. The site coordinates S 0° 49′34.38 E 36° 20′22.32. Taken on 30.7.2012 at air temperature 25 °C, relative humidity 85%, partly cloudy, at 2:00 pm. The

Just how powerful a tool for the temperature regulation is well-watered vegetation, and what happens when we remove it, is explained by the following example. The built-up areas in the Czech Republic are 2586 km^2 (from a total of 78,866 km^2) (Miko and Hošek 2009). There is almost zero ability to retain water within these areas, with a consequential drop in evapotranspiration and the associated change in the transformation of incident solar radiation into sensible rather than latent heat. The decrease of evapotranspiration by 2 mm km^{-2} day^{-1} corresponds to 2 million L of water that does not evaporate, so 1.4 million kWh of energy has not been used (0.7 kWh is necessary for the evaporation of 1 L of water), so it is released as sensible heat. From this built-up area, every sunny day (spring-autumn) releases 3.6 million MWh. For comparison, the production of the Czech nuclear power plant Temelín in 2010 was 13.7 million MWh.

In the Czech Republic, almost 18,000 km^2 of wheat and rape were harvested in August 2015. The sensible heat released from these harvested and drained areas was 4,500,000 MW. To produce that amount of heat, 4500 power plants, each with a capacity of 1000 MW, would be needed. However, the real value of the sensible heat may be higher. If we consider 1000 W m^{-2} incident on the Earth's surface, 200 W m^{-2} is reflected, 100 W m^{-2} is ground heat flux, 200 W m^{-2} is consumed for evapotranspiration from dry surface, and 500W m^{-2} is released in form of sensible heat that is the cause of atmospheric heating. The consequence is the creation of a large area of high air pressure over the overheated landscape, which subsequently prevents the penetration of humid air from the Atlantic Ocean to Central Europe.

The IPCC argues, and works with the premise, that human activity does not substantially alter the amount of water vapour in the atmosphere. Nevertheless, there is a huge difference between the amount of water vapour and the dynamics of phase changes of water over wetlands or forest stands compared to above the agricultural landscape or sealed surfaces that were created by draining them. Wetlands and forests are characterized by a lower surface and air temperature, higher humidity and tendency to create cloudiness and mist. The documentary evidence may be satellite images (e.g. see Earth Science Data, NASA Archive), where tropical rainforest areas are mostly covered by dense cloud cover. Moreover, the high water vapour content in the form of cloud prevents the direct penetration of solar radiation to the Earth's surface, resulting in a decrease in surface temperature. This is the opposite conclusion to that which would be reached based on an interpretation of the greenhouse effect; conventional thinking says the higher greenhouse effect results in a higher temperature. Wetlands reduce the temperature due to the cooling effect of evapotranspiration and the shading effect of cloudiness and fog that are created by the evaporation of water. The water vapour does not rise quickly into the atmosphere, because there are no hot surfaces on wetlands, as there are on bare

Fig. 4.8 (continued) lateral view of the stand (**a**, **b**) shows the differences between dry papyrus (22 °C) and live one (19 °C). The temperature of the surrounding shrubs is 20 °C

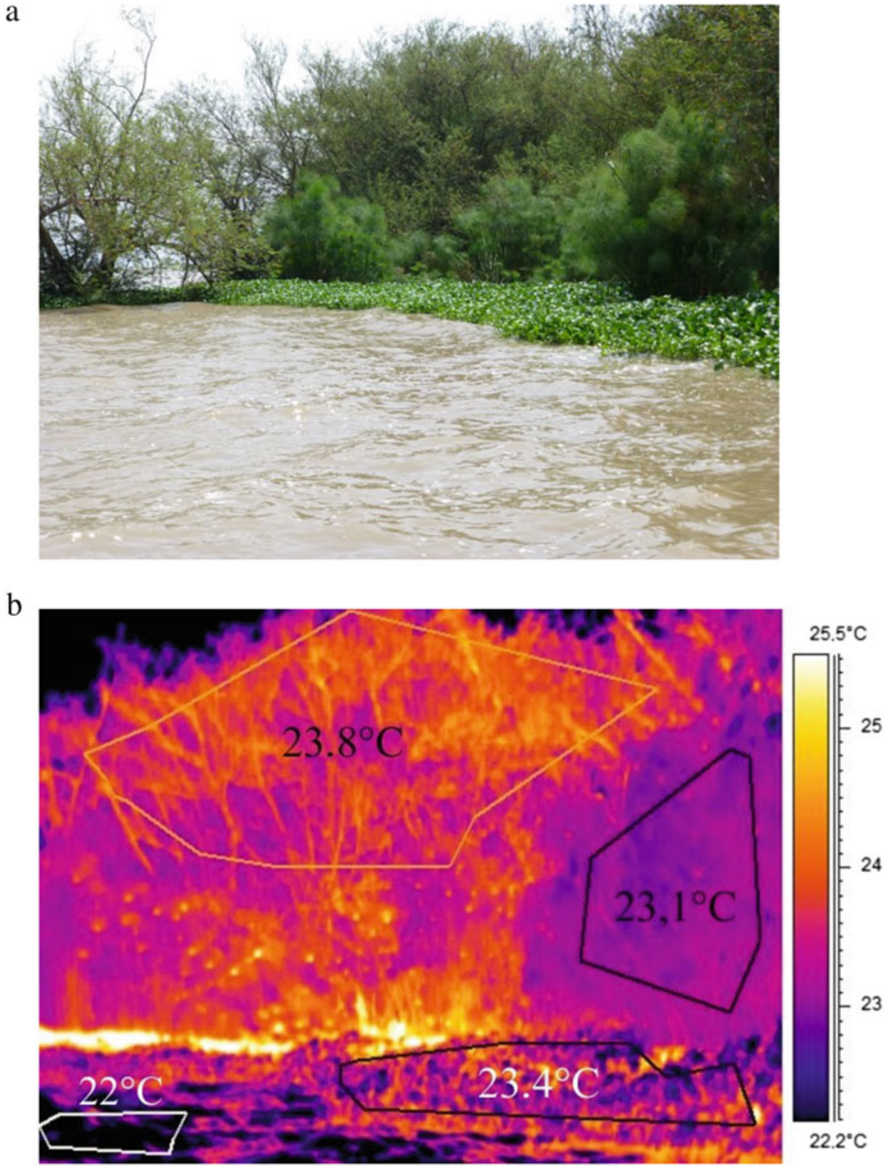


Fig. 4.9 (**a**, **b**) The papyrus vegetation of Lake Victoria. The site coordinates S 0° 09′29.42 E 34° 44′38.68, estimated air temperature: 30 °C, relative humidity 95%, diffuse sunshine—a haze, date of measurement 29 June 2012, at 10: 00 am. The temperatures of the stands are balanced—papyrus 23.1 °C, *Eichhornia* (water hyacinth) 23.4 °C, *Sesbania* (shrub) 23.8 °C. Water temperature 22 °C

ground or urban. It stays at lower elevations, and at night it condenses in these cold places, preventing the return of heat to the atmosphere. This reduces the temperature differences between day and night. An example may be the clearance of the Mau Forest mountain tropical rainforest in Kenya, which resulted in morning frosts that destroyed agricultural production at those altitudes (personal communication with people from Son Koi Kiminta village and Mrs. Sarah Higgins, Naivasha Owl Centre).

Water vapour rises faster from agricultural crops than from wetlands and forests that have dense vegetation and therefore results in a lower temperature at the ground. The conversion of natural vegetation to agricultural crops changes soil surface properties, resulting in redistribution of surface energy components (Esau and Lyons 2002). Following the arrival of Europeans, more than 51% (45.9 × 106 ha) of the total area of wetlands in the USA was replaced by arable land (Mitsch and Hernandez 2013). If we consider the drainage change of such a large area, there was a substantial change in energy balance. About 400 W m^{-2} was moved from latent to sensible heat flux on those days with the highest solar irradiance (Huryna et al. 2014), so it can be calculated that more than 175,000 GW of energy was converted into sensible heat over the USA over the past 200 years, which must have strongly affected the dynamic processes in the atmosphere. Warming of the Northern Hemisphere has been faster than that of Southern Hemisphere (Climatic Research Unit), because the Northern Hemisphere has a substantially higher portion of continents. In addition, more than 90% of the world's population lives there. Changes in landscape coverage, especially deforestation and drainage, are also more intense there. It is time that climate science accurately incorporated these effects into its predictions and recommendations of how to adapt to climate change.

4.7 Positive Examples of Landscape Restoration

Wetlands carry out important hydrological, biological and geochemical functions, and wetland restoration has been considered crucial for sustainable watershed management. The sustainable management is based on the improvement of water quality, increase of groundwater availability, flood control and prevention of soil erosion.

Water harvesting is one of the most effective methods to retain water in semiarid and arid climatic conditions. Tarun Bharat Sangh (TBS), implemented by Rajendra Singh, is the most widely known model. TBS was formed in 1985 in the Alwar district, India. The method is based on the creation of traditional small earthen rainwater-harvesting constrictions, such as johads. They are semi-circular ponds that collect runoff during the monsoon season and ensure water supply all around the year (Balasubramanian et al. 2017). More than 10,000 johads covering 6500 km^2 have been built in the past 25 years. The creation of of johads has led to significant increase in the groundwater table from about 100–120 m depths to 3–13 m. Soil erosion has stopped in the region, fresh soil has accumulated, and soil moisture content has increased. The area under cultivation has increased from 11 to 70%. Increased availability of water has also led to the revival of afforestation—forest cover increased from 7 to 40% (Sinha et al. 2013). The five rivers of the region have become revived (Kashwan 2006; Gupta 2011; Bhattacharya 2015).

Maharashtra is the largest semiarid region in India where the monsoon season is highly unpredictable and limited for a few days per year. It receives less than 400 mm of annual rainwater. Darewadi was a drought-prone village without any assurance of drinking and irrigation water. In 1996, the villagers approached the Watershed Organization Trust for assistance, and they jointly began conserving natural resources and improving livelihood. The water and soil conservation measures involved the creation of continuous trenches that controlled soil erosion and harvested water. Many technical treatments, such as contour trenches, gully plugs, farm bunds, stone bunds, earthen bunds, gabion structures, check weirs and percolation tanks, were constructed. Replanting trees with a temporary ban on tree cutting and grazing have also been implemented (D'Costa and Samuel 2001). As a result, more than 1500 ha of drained land have been revived after 5 years of restoration activities. The groundwater level rose from −6 to −2.5 m. The rise continued even during dry years, despite irrigation. Over 65% of barren hills and wasteland were planted with trees and grasses. Grazing biomass increased by 170%. The area of cultivated land increased from 197 ha to 342 ha (Husain et al. 2015).

The rainwater-harvesting technique has also been carried out in the Gansu province of China. In 1995, the provincial government began to implement the "1-2-1" Rainwater Catchment Project (RWH) (Zhu et al. 2012). Under this project, the government provided a subsidy for each rural household to build one rainwater catchment with an area of 80–150 m^2, two underground water tanks each with storage capacity of 15–20 m^3, for domestic supply and for irrigation, and one piece of land by the side of the house to be irrigated by the stored rainwater (Zhu et al. 2012). The implementation of rainwater harvesting had a profound impact on the development of the province. According to the Gansu Bureau of Water Resources (1997), the RWH irrigation scheme solved the drinking water problem for 1.97 million residents. The water use efficiency and crop yield have significantly improved (Gao et al. 2001).

Water scarcity and water pollution are major issues in Australia. Colin Pirman has implemented a natural solution for harvest urban runoff that purifies polluted water in the Adelaide suburb of Salisbury. He created 53 artificially built wetlands on the Salisbury Plains. The wetlands perform cleaning function by two key components—heavy metals have been removed from storm water by mud and purified by using specially selected macrophytes. Then the water is stored in aquifers where another disinfection process takes place. The purified water is used for irrigation and industrial uses (Barlow 2013).

Natural Sequence Farming (NSF) is a method of landscape regeneration initially devised by Peter Andrews in the 1970s at Tarwyn Park, in the Upper Hunter catchment of New South Wales. The system specially addresses land degradation and biodiversity losses in riparian system. The strategy is based on capturing rainfall runoff and storing it in elaborate networks of natural aquifers connected to landscape habitats. This is carried out primarily by recreating "chain of ponds—swampy meadow complexes", colonized by dense stands of reed. Under NSF, water is stepped slowly down to the stream valley floor from one end of a catchment to other. These structural steps allow shallow aquifer recharge to increase and reduce water velocities. Tarwyn Park was transformed from the most degraded property in the district to the most productive within a few years. The re-establishment of the chain of ponds function maintained high water table and enhanced plant and animal biodiversity. Implementation of NSF reduced channel incision and salt erosion; increased sedimentation, soil organic carbon level and resident time of nutrients; avoided soil compaction; and maintained a soil structure with increased water holding capacity in the stream channel and on the floodplain (Norris and Andrews 2010).

The European Climate Adaptation Platform (CLIMATE-ADAPT) is a partnership between the European Commission and the European Environment Agency that, among others, support implementation projects aimed at water retention and climate change mitigation across Europe. In the database, there is only one project aimed at water cycle and climate recovery through landscape restoration—“Tamera water retention landscape to restore the water cycle and reduce vulnerability to droughts” (implemented in 2006–2014). Tamera is a farm of 154 ha located in the most arid region of Portugal, in Alentejo. This area has shown significant trends of increasing erosion and desertification. “Water Retention Landscape” (WRL) is a system of lakes and of other retention systems such as terraces, swales and rotational grazing ponds constructed to restore water cycle, i.e. increase surface and groundwater retention and mitigation of water-related extreme events such as droughts, water scarcity and floods. Associated phenomena are the regeneration of topsoil, forest, pasture and food production and greater biodiversity. Another goal is to use the Tamera example of landscape restoration as a model that can be implemented in other Mediterranean areas prone to desertification (ECAP 2017a). Other attempts at sustainable landscape management in terms of water retention improvement may be agroforestry, building new reservoirs and river restoration rather than on comprehensive measures across the river basin.

Agricultural systems are less resilient to high temperatures, drought and other extremes related to climate change. Agroforestry provides a different land use option, compared with separated traditional arable and forestry systems, which makes the landscape more sustainable. Montpellier (France) provides an example of agroforestry system in Mediterranean climate. Mixture of crops and forest planting is aimed at the increasing resilience to climate change, in terms of drought and temperature mitigation (ECAP 2017b).

WeForest (2015) is an initiative supporting and developing innovative, scalable and lasting solutions to restore forest landscapes for climate. The reforestation projects are targeted mainly to Africa, Brazil and India. This support of forest development, primarily based on the principle that trees are the best technology to suck carbon dioxide from the atmosphere and reverse global warming, unwittingly supports the climate regulation through evaporation processes and water cycle restoration.

4.8 Discussion and Conclusion

Homo sapiens influence temperatures in the landscape by their changes in water and vegetation management, much more than the standard system of air temperature measurement records. Human decisions affecting the distribution of solar energy, the water cycle and temperatures through large-scale farming have a direct impact on the climate. The IPCC reports (2007, 2013) however, do not take into account this direct effect of water and vegetation on climate. In the recommendations for policymakers, global warming is explained mainly by the increase of greenhouse gases concentration in the atmosphere, and therefore recommendations focus only upon reducing greenhouse gases emissions. In recent years, there have been a growing number of studies that focus on the vegetation cover and its role on a sustainable water cycle. Evaporation and therefore vegetation are considered as effective climate regulators not only locally but also globally.

Vegetation, especially forest and wetland ecosystems:

- Have a direct effect on the distribution of solar radiation on the Earth's surface, reduce thermal gradients and mitigate temperature extremes
- Close water and mass cycling

Changes in ecosystems such as wetland drainage and deforestation have the opposite effect. They reduce precipitation and evapotranspiration, increase drainage and increase surface temperature. This subsequently leads to the destruction of the water cycle, the release of nutrients and climate change.

Intensification of agriculture and urbanization negatively affects the flows and distribution of energy in the landscape. Deforestation and removal of permanent and functional vegetation (forest and wetland vegetation) to create dry and thermophilic crops lead to landscape overheating and degradation, resulting in increased erosion and loss of nutrients (Procházka et al. 2009; Ripl 2003). The temperature of an agricultural landscape at the peak stage of crop ripening and after harvesting is the same as the temperature of an industrial and urbanized landscape (Hesslerová and Pokorný 2010). Therefore, landscape managers (landowners, farmers, foresters, fishermen, etc.) should be considered as significant "controllers" of the distribution of solar energy, i.e. the creators of the local climate. Their aim should be the retention and accumulation of water in a well-structured landscape cover, with a proportion of permanent vegetation (forests, wetlands, wet meadows, scattered greenery), i.e. reasonable management of water and vegetation in the landscape. Unfortunately, forest-driven water and energy cycles are poorly integrated into regional, national, continental and global decision-making regarding climate change adaptation, mitigation, land use and water management (Ellison et al. 2017).

Wetlands and structured vegetation, which are capable of retaining water, are constantly disappearing from the landscape. Above all, the agricultural and urbanized landscape is constantly drying out; in summer it becomes a donor, not an acceptor of humidity and rainfall. Wetlands dry out and are stressed by low air humidity that is heated on large drained areas. Examples we gave from different parts of the world show that the return of functional vegetation to the landscape can help keep the water in the landscape. Restoring the vegetation cover and increasing the water retention capacity of the soil lead to the closure of the water cycle, the recirculation of nutrients and the retention of water in the ecosystem. Higher evapotranspiration leads to surface temperature reduction, mitigation of temperature gradients and thus minimization of nutrients and water loses. Landscape loses water with the upwards flowing warm air driven by sensible heat. The amount of water in the air transported by sensible heat high into atmosphere can be substantially higher than that released by evapotranspiration (Pokorný 2018).

Clearly, the direct role of vegetation must no longer be neglected in connection with climate and its changes. Changes in landscape coverage must be taken into account in both regional and global scenarios for mitigating climate change. Measures to maintain a balanced temperature regime of low-temperature and gradients in landscape consist primarily of retention of water and restoration of permanent vegetation. Staying with the dogma of direct dependence of global warming on the increase of greenhouse gas concentrations in the atmosphere alone leads to a complete neglect of the fundamental and direct effects of vegetation on climate and water cycle. The ignorance of these basic functional relationships in the context of climate change allows drainage, wetland degradation and deforestation to continue, yet these are the processes that we need not only to stop but to reverse increasing global temperatures.

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