Forests and water

Water and forests are inextricably linked. Forests play a critical role in making it rain, influencing rainfall patterns, giving us drinking water, moderating destructive floods, combatting drought, keeping us cool and helping us adapt to climate change. Forests are thus vital to the livelihoods and well-being of the people downstream from them, performing valuable but often under-appreciated services related to water and our climate, helping societies adapt to climate change and reducing social vulnerability. The loss of forest can have profound effects on both the local and regional climate – effects that exacerbate the impacts changes already being seen from climate change.

Climate change in the Caribbean

In the Caribbean, average temperatures have increased over the past 30 years, and warming is predicted to continue at an accelerated pace (although the climate models vary). Projected decreases in precipitation in the Caribbean suggest drier wet seasons, and even drier dry seasons. Increasing sea surface temperatures may lift the base altitude of cloud formation and alter atmospheric circulation patterns, with any change in the cloud base height further decreasing precipitation. The occurrence of very warm days and nights is accelerating, while very cool days and nights are becoming less common, increasing the likelihood of extreme heat waves. The frequency of extreme precipitation events is expected to increase too, leading to potential increases in inland flooding and landslides. Hurricane events are likely to become less frequent but more severe, with increased wind speeds, rainfall intensity, and storm surge height. As annual rainfall decreases over time in the Caribbean region, longer periods of drought are expected in the future.

Forests make it rain

Healthy trees pump an enormous amount of water from the soil and release it (through transpiration – the process by which plants release water through their leaves) into the atmosphere. This process is called evapo-transpiration (Evans 2012), which is dependent on net radiation, advection, turbulent transport, leaf area, and plant-available water capacity (Zhang et al. 2001). Tree leaves also act as interceptors, catching falling rain, which then evaporates. The relative importance of these factors depends on climate, soil, and vegetation conditions (Zhang et al. 2001). Whatever the complexities of this process, forested catchments have higher evapo-transpiration than, for example, grassed catchments (Zhang et al. 2001). In fact, forest trees are the most efficient vector for evapo-transpiration (Evans 2012). They can evapo-transpire twice as much as agricultural crops and about twice as much as water body surfaces (Evans 2012). In the water cycle, moisture is transpired and evaporated into the atmosphere, forming clouds before being precipitated as rain back onto the forest (Butler 2012). Evapo-transpiration is responsible for a very large component of rain generation: about50% in summer across the globe, and 40% on an annual basis (Evans 2012). Vegetation may contribute as much as 90% of the moisture in the atmosphere derived from land surfaces, with forest trees producing 10 times as much as herbaceous vegetation per unit of land area (Sheil and Murdiyarso 2009). Winds travelling through forests typically produce more than twice as much rain as those that blow over open land, leading to predictions that by 2050 the tropics could see a 12% and 21% decline in wet and dry season precipitation, respectively (Sheil and Murdiyarso 2009, Spracklen et al. 2012). After the oceans, forests are the most efficient sources of rainfall, and results from over 250 catchments worldwide clearly demonstrate the direct correlation between forest cover, long-term average evapo-transpiration and rainfall (Zhang et al. 2001).

With evapo-transpiration having taken place, moving air then transports this water to downwind destinations – a process that has inescapable and profound implications for land management (Meher-Homji 1991). Trees also directly influence cloud formation by emitting carbon-based chemicals called volatile organic compounds (VOC) into the atmosphere (Sheil and Murdiyarso 2009). Some of these compounds are deposited on tiny airborne particles such as dust, bacteria, pollen and fungal spores. As the particles grow with the deposition of the organic compounds, they promote condensation, gather moisture and hasten cloud formation (Sheil and Murdiyarso 2009). So, when forests are cut down, less moisture is evapo-transpired into the atmosphere, less VOC's are emitted, fewer clouds form and precipitation is suppressed (Spracklen et al. 2012). Subsequently there is a decline in rainfall, subjecting the area to drought. If rains stop falling, within a few years the area can become arid with the strong tropical sun baking down on a scrub-land (Butler 2012). Today for example, Madagascar is largely a red, treeless desert from generations of forest clearing with fire (Butler 2012), and in Brazil's Atlantic forests, reduced tree cover has led to increased local inter-annual variation in rainfall (Sheil and Murdiyarso 2009). Indeed, deforestation has already reduced vapour flows derived from forests by almost 5% per year with little sign of this trend slowing (Sheil and Murdiyarso 2009).

The linkage between forests and the water cycle is clear at a large, continental scale, and this translates in a general sense to the local scale although other factors come into play adding complexity at this local scale. Forest clearing and small-scale deforestation may alter precipitation locally, through temperature-driven convection and atmospheric turbulence resulting from canopy roughness (Sheil and Murdiyarso 2009, Spracklen et al. 2012). For example, there is a correlation between land-surface heterogeneity and locally-generated rainfall, with a consistent significant increase in rainfall over forest–cropland boundaries compared to the homogeneous case (Garcia-Carreras and Parker 2011). This is because convection is maximised at these points resulting in a "vegetation breeze" in which moist air is drawn out of the forest, leading to increased cloud depth and thus more rainfall (Sheil and Murdiyarso 2009, Garcia-Carreras and Parker 2011). This relates to locally-generated rainfall, and the total rainfall at a location will therefore depend on the proportion of local versus large-scale propagating convection it receives (Garcia-Carreras and Parker 2011). By planting forests in strategic locations it is, by implication, possible to increase locally-generated rainfall in key areas (Evans 2012).

Forests reduce floods

Tropical forests act as a sort of sponge, soaking up rainfall while anchoring soils and moderating the release of water into rivers (Butler 2012). In terms of consistent water provision, this feature of forest cover is especially important in the dry season when regulation of river flow can help to minimize the risks related to water scarcity (Evans 2012). Loss of forest can mean that during the dry season, villages, cities, and agricultural fields downstream of deforestation will be prone to months-long droughts which interrupt river navigation, wreak havoc on crops, and disrupt industrial operations (Butler 2012). Plato made the link between deforestation and drought over 2,400 years ago when he noted the dried-up springs following deforestation on the Greek peninsula of Attica (Carter and Dale 1955). More recently, Colombia, once second in the world for its freshwater reserves, has fallen to 24th due to its extensive deforestation over the past 30 years (Butler 2012). Similarly, excessive deforestation around the Malaysian capital of Kuala Lumpur, combined with the dry conditions created by El Niño, triggered strict water rationing in 1998, and for the first time the city had to import water (Butler 2012).

Forests also contribute to regulating river flows during high rainfall events (such as tropical storms), thereby minimising risks related to floods (Evans 2012), and help to moderate destructive flood and drought cycles that can occur when forests are cleared (Butler 2012). When forest cover is lost, runoff rapidly flows into streams, elevating river levels and subjecting downstream villages, cities, and agricultural fields to flooding, especially during the rainy season (Butler 2012). Using data collected 56 developing countries for the period 1990 to 2000, flood frequency was shown to be negatively correlated with the amount of remaining natural forest, and positively correlated with natural forest area loss (after controlling for rainfall, slope and degraded landscape area) (Bradshaw et al. 2007). Based on an arbitrary decrease in natural forest area of 10%, the model-based prediction of flood frequency increased between 4% and 28% among the countries modelled (which included Jamaica) (Bradshaw et al. 2007). Using the same hypothetical decline in natural forest area resulted in a 4-8% increase in total flood duration (Bradshaw et al. 2007). Thus unabated loss of forest may increase or exacerbate the number of flood-related disasters, negatively impacting people and inflicting costly damage (Bradshaw et al. 2007). Forests are empirically correlated with flood risk and severity, reinforcing the imperative for forest protection to protect human and economic welfare, or indeed reforestation that can help to reduce the frequency and severity of flood-related catastrophes (Bradshaw et al. 2007). Forests situated on steep slopes (e.g. montane and watershed forests) are especially important in ensuring water flow and inhibiting erosion (Butler 2012). Both at the large scale and local level, land use management and rehabilitation strategies will have an impact on catchment water balance and hence water yield and groundwater recharge (Zhang et al. 2001).

Forests keep it cool

At the local level, “forests keep it cool”. In Puerto Rico, development has resulted in the conversion of forests and grasslands to impervious cover (concrete and asphalt), which in turn has changed the magnitude and geographic extent of the Urban Heat Island (Murphy et al. 2007). It is a well-known phenomenon that urban areas are warmer than surrounding undeveloped, vegetated regions – this is the Urban Heat Island effect. Expanding urbanisation can significant increase geographic extent of this effect, and also its magnitude (i.e. how much warmer it is than surrounding areas). The knock-on effects can be significant. For example, expanding urbanisation encroaching on the Luquillo Mountains in Puerto Rico (which are currently cloaked in cloud-forest) This is impacting the regional climate by decreasing orographic cloud formation, and therefore ultimately the water supply to the San Juan Metropolitan Area (Murphy et al. 2007). Urban Heat Islands exhibit a nocturnal peak in intensity (Murphy et al. 2007), yet forested sites are able to negate the urban warming effect within the canopy throughout the day (Murphy et al. 2007). This effect occurs because of the removal of latent heat via evaporative cooling within the canopy and soil and because the active surface for the forest is within the canopy (Murphy et al. 2007). Grassland sites show significant daytime warming, but also pronounced night-time cooling which results in large diurnal temperature ranges (Murphy et al. 2007). Therefore, maintenance of canopy cover is essential to counteract the urban heat island effect, and mitigate the effects that such heat islands can have on orographic cloud formation (Murphy et al. 2007).

Forests need forests

There is a serious and justified concern that widespread deforestation could lead to a significant decline in rainfall, resulting in increasing desiccation of neighbouring forest cover and indeed watersheds (Butler 2012). High rates of evapo-transpiration (i.e. in forests) result in a reduction of atmospheric density (i.e. low pressure). Moist air (e.g. from the ocean) is then drawn in and, as it rises over forested regions, it condenses and creates a low-pressure area that draws in more moist air, creating a positive feedback loop with a net transfer of atmospheric moisture to the areas with the highest evaporation (Sheil and Murdiyarso 2009). Deforestation breaks this cycle, disrupting precipitation and making it more variable (and, for example, reducing the duration of the wet season), not only by reducing transpiration and cloud formation, but also by slowing or disrupting the flow of air inland from coastal areas (Sheil and Murdiyarso 2009). Clearing enough forest within a larger forest zone may even switch net moisture transport “from ocean to land” into “from land to ocean”, which means less moisture arrives from outside the region to fall as rain, resulting in further drying of the forest, less evapo-transpiration and precipitation, and thus the establishment of a negative feedback loop (Sheil and Murdiyarso 2009). Clearing a band of forest near the coast may suffice to dry out inland areas, as has been seen in Brazil’s Atlantic forest (Sheil and Murdiyarso 2009), and clearing lowland forest can have profound effects on adjacent highland forest areas as has been clearly demonstrated in the cloud-forests of Costa Rica.

Tropical montane cloud forests depend on predictable, frequent, and prolonged immersion in cloud which forms when warm lowland winds blow up against steep mountains, causing the air to rise and condense moisture as clouds (Lawton et al. 2001). One of Costa Rica’s most important cloud forests is the protected area of Monteverde. In 1999 it was discovered that Monteverde's cloudbank was gaining altitude and failing to blanket the mountain in mist, possibly triggering the extinction of several species of frogs (Lawton et al. 2001). Costa Rica has had an aggressive conservation policy focused on montane areas which are covered in a complex of public and private reserves (Lawton et al. 2001). However, the lowlands have received little protection and only 18% of the original forest cover remains (Lawton et al. 2001). These deforested areas of Costa Rica’s Caribbean lowlands (e.g. directly to the east of Monteverde) remain relatively cloud-free when forested regions (such as those in neighbouring Nicaragua) have well-developed dry season cumulus cloud cover (Lawton et al. 2001). The clouds in the deforested Costa Rican lowlands were also higher, at 1,100 m compared to 650 m over Nicaragua’s forested lowlands (Lawton et al. 2001). This phenomenon is due to the air over pastureland being warmer and drier, forcing it to travel higher into the sky before it forms clouds (Lawton et al. 2001). So, land-use in Costa Rica’s tropical lowlands is having a serious impact on the forest ecosystems of the adjacent mountains.

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