Chapter 6 SDG 6: Clean Water and Sanitation – Forest-Related Targets and Their Impacts on Forests and People

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Key Points

- SDG 6 seems unlikely to exert a major influence on forest cover and indeed is unlikely to be pursued with forests in the forefront of consideration.
- Full implementation of Targets 6.1 and 6.2 could positively impact forest people, yet this is not an implementation priority.
- SDG 6 may focus attention on the role of forests (as providers of hydrological ecosystems services) in protecting clean drinking water resources; the exact role of forests here requires careful consideration.
- Particular attention should be given to reforestation strategies to improve water availability in areas with soil degradation and reduced infiltration. Target 6.4 may restrict the spread of new plantations in semi-arid areas and Target 6.5 may drive a more integrated view of catchments and their management.
- It is necessary to consider forest–water interactions at the catchment, regional and continental scales; actions with a beneficial impact at one scale may have an adverse impact at another.

6.1 Introduction

SDG 6 is designed to 'ensure the availability and sustainable management of water and sanitation for all' (UN 2018). It defines clean, accessible water as an essential part of the world we want to live in, one that should be universally and easily accessible across the globe. As we shall see in this chapter, the anthropocentric orientation of the SDG title is later modulated by a more integrative view of some of the specific targets. However, it already shows the potential for conflict in the competition for water under conditions of scarcity. While not a central consideration in the development of SDG 6, there

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are intrinsic links between forests and water. Trees, as living organisms, need water to exist and thrive; as critical landscape components, they strongly influence water availability at local and continental scales. The exact nature of this influence is still a point of scientific debate, although in recent decades we have witnessed the slow emergence of a more nuanced picture of forest–water relationships. Understanding the potential impacts of SDG 6 on forests and people requires a balanced appraisal of these relationships.

The chapter first briefly summarises the current understanding of forest–water interactions in order to identify the critical SDG 6 targets for forestry. An in-depth discussion of target impacts on forest cover focuses on two areas: South America and South Asia. These two areas have diverse conditions where forests play an important role in upstream/downstream and inter-catchment interactions, where achieving SDG 6 will require active interventions. The final section takes a wider perspective to discuss the key considerations for improving SDG 6 and forestry interactions at the global scale.

6.2 Forest and Water Interactions

The traditional understanding of how forests and water interact is influenced by long-standing beliefs regarding the role of forests in the water cycle, which are not always supported by science (Calder 2005). The current scientific understanding is much more nuanced and needs to be stated clearly in order to understand the links with the new requirements on water management emerging from SDG 6, enabling us to distinguish between positive synergies and potential misconceptions. Important initial considerations for this discussion are the big regional differences worldwide in forest cover, climate zones and land-use changes. The following summary considers both the traditional catchment-scale water balance and recent interest in the recycling of evaporated moisture at much larger, inter-catchment scales.

1. At the catchment scale, decades of research with paired catchments and process studies have shown that, relative to shorter vegetation, forest cover *reduces* catchment run-off at the annual scale because trees have higher rainfall interception rates and higher transpiration rates during dry periods (Andréassian 2004, Bosch and Hewlett 1982, Zhang et al. 2017). Dry season flows are particularly likely to be reduced in forest catchments as tree roots can extract soil water from greater depths than shorter vegetation. Reductions in annual run-off for the most extreme change from 100 per cent grass cover to 100 per cent forest cover can be substantial, ranging from 15 per cent to at least 50 per cent (Fahey and Payne 2017, Marc and Robinson 2007). Run-off reduction has been found at catchment scales as large as thousands of square kilometres (Iroumé and Palacios 2013, Silveira and Alonso 2009, Zhang et al. 2017).

2. Run-off reduction is greatest for young, growing forests. The reduction may be smaller for old mature forests with low leaf-area indices. Different tree species take up water at different rates (Huber et al. 2010).

3. In certain cases, by increasing soil infiltration and thus groundwater recharge, forests may allow a temporally more even redistribution of run-off, thus increasing dry season flows (but still with reduced annual flow) (Calder 2005). Most evidence, however, points to a reduction in dry season flows following afforestation, although the pattern in areas with seriously degraded soils is less clear (Bruijnzeel 2004) and the overall effect is likely to vary with tree density (Ilstedt et al. 2016).

4. The special case of cloud forests, which intercept fog and cloud droplets, may possibly increase annual yields in the very specific (typically mountain) locations in which they occur (Bruijnzeel 2001, 2011). However, the fog formation may itself depend in part on recycling of evaporated moisture from upwind forests.

5. At very large (subcontinental) scales, recycling of forest evapotranspiration potentially increases the downwind rainfall (Ellison et al. 2017, Sheil 2018, van der Ent et al. 2010) and thus run-off (after any interception losses in the recipient catchment).

6. The impact of forest cover on flood peaks, as opposed to run-off, is more controversial, both because the effect on extreme flows is uncertain and because the means of quantifying the impact is disputed (see discussion in Alila and Green 2014).

7. Because of the greater evapotranspiration and consequently lower (on average) soil moisture content in forested catchments, the generally higher infiltration capacity of forest soils and the greater carbon sequestration (which aids water storage), forests can absorb more of the rain and so reduce flood peaks for given low to moderate rainfall events. This effect does not occur if the soil is already saturated, for example from a previous rain event or from soil water accumulated over a wet season (Bathurst et al. 2011).

8. Forests may not be effective in reducing flood peaks produced by extreme (but rare) rainfall events as the above absorption effect is overwhelmed by the amount of rain (Bathurst et al. 2011).

9. Forests can reduce the *frequency* with which a given flood peak occurs for all (not just low to moderate) flood sizes (Kuraś et al. 2012).

10. Forest cover often (but not always) reduces sediment yield compared with other land covers, especially those involving soil disturbance. The annual specific sediment yield in a logged catchment may exceed that in an undisturbed forested catchment by up to one order of magnitude under conditions of best management practice or two orders of magnitude in cases of severe ground disturbance or extreme events coinciding with the logged condition (Bathurst and Iroumé 2014). However, in areas of high natural sediment yields or during certain extreme events such as tropical hurricanes, the vegetation cover may have relatively little impact on overall sediment yield (Calder 2005).

11. By excluding other management approaches (e.g. fertiliser application) and limiting soil erosion, forests usually imply less-polluted water. Deposition of most atmospheric pollutants are generally higher to forests and, in regions of high (industrial) pollution, this has historically caused acidification of catchments and run-off, especially with coniferous forest cover (Calder 2005). However, this threat is reducing in the advanced economies as industrial emissions are controlled and energy production moves away from coal and other fossil fuels. In certain areas (e.g. the southwest of Western Australia), the rise in the water table following the removal of forest cover has resulted in a redistribution of soluble salts, causing severe soil salinisation and loss of crop-growing capacity (Peck and Hatton 2003). Lowering of the water table following afforestation of grasslands has also been associated with soil salinisation (e.g. in Brazil and Hungary) (Jobbágy and Jackson 2004, Tóth et al. 2013).

12. Forest–water interactions have traditionally been studied at the river catchment scale, emphasising the impact of forest cover or its absence on downstream water users and communities. The increasing interest in the recycling of forest evapotranspiration at the subcontinental scale, though, highlights the impacts that may be felt downwind over large distances and across catchment and national boundaries (Ellison et al. 2017). Additionally, forestry activities (including forest loss) often take place on a patchwork basis, rather than uniformly across an entire catchment, especially at the larger catchment scale. Moreover, the phenomenon of deforestation and its impacts on landscape and water availability are evident at scales larger than the catchment. It is therefore necessary to consider forest–water interactions at the catchment, landscape and subcontinental scales; actions with a beneficial impact at one scale may have an adverse impact at another.

6.3. Relevance of SDG 6 to Forests and Forest People

SDG 6 is one of the new goals that emerged in 2015. Indeed, water was a notable omission from the SDG predecessors, the Millennium Development Goals (MDGs). In spite of its importance for achieving many of the MDG targets (WWAP 2009), it was hidden within MDG 7 Ensure Environmental Sustainability under the dual Target 7.C: ‘To halve the proportion of the universal population without sustainable access to clean and safe drinking water and basic sanitation by 2015’. This has important implications for SDG 6’s policy context. While most of SDG 6 is new, the goal starts with an inherited focus on the water, sanitation and hygiene (WASH) agenda, which has developed a strong momentum after nearly two decades of MDG work. The drinking-water target was considered a big success as it was met five years before the deadline, but the sanitation target was never achieved. Although the proportion of the global rural population without access to improved sanitation has declined by nearly a quarter, half of people living in rural areas, including forested areas, do not have access to these facilities (UN 2015). Given this failure and the momentum behind the WASH agenda, it seems likely that a large proportion of the resources allocated to SDG 6 will be focused on sanitation. The reality is that the impact of MDG Target 7.C on the forestry sector and related policies was minimal; the same may be expected of the WASH impact. Two exceptions are an increasing interest in (1) the role of forests – as providers of hydrological ecosystem services – in protecting clean drinking water resources (Brauman et al. 2007), and (2) the use of wastewater in forestry (FAO 2018a). In Section 6.5.2 we discuss interest in nature-based solutions, forests’ role therein and the wider role of forests in precipitation recycling.

Pointers towards an increased interaction between global water goals and forestry appear in the final MDG Report (UN 2015). It devotes attention to the 663 million people still using unimproved drinking water sources, mainly in sub-Saharan Africa but also in South Asia, and the shocking 2.4 billion still using unimproved sanitation. It highlights how 30 per cent of the planet’s land area is covered by forests that not only support 1.6 billion people but also help ‘provide additional benefits … such as clean air and water’ (UN 2015: 52) and support river catchments yielding three-quarters of the globally available freshwater. It implicitly assumes that changes in deforestation, afforestation and reforestation rates affect water resources. There are big regional differences in the way these interactions take place. South America and Africa have experienced the larger net losses of forest area, while large-scale afforestation programmes in China have offset continued rates of net loss in Southern and Southeastern Asia, all with corresponding impacts, positive or negative, on water balances. The exact nature of these processes is very important because one of the other key identified global environmental drivers is water scarcity, which affects more than 40 per cent of the global population – a figure that is projected to rise. Although the main problems are in the dry areas of Northern Africa and Western Asia, scarcity affects every continent. Major sectors that compete for water are agriculture (for irrigation, livestock and aquaculture), industries and municipalities. Agriculture, mainly through irrigation, takes nearly 70 per cent of freshwater withdrawals. Forests are not mentioned in the section about scarcity of the MDG 7 report, but their role in determining total water quantity and quality in catchments is critical.

After intense water-sector lobbying and proven interest from the public and governments in the consultations after Rio+20 (UNESCO-IHP 2014), SDG 6 has gone much further than the MDGs, with a set of completely new targets covering the whole gamut of integrated water resources management, as the water sector wanted (Table 6.1). This substantially increases the potential impact of SDG 6 on forests and forestry, as four of the new targets (6.3–6.6) are focused on water resources and not just on WASH. The drinking water and sanitation targets (6.1 and 6.2) are maintained and indeed enhanced with an ambitious 'for all' specification, which substantially increases their difficulty and cost. The means of implementation targets (6.A and 6.B) are neutral for the forest sector, although Target 6.B could have implications for hydrological ecosystems services involving forests. The UN SDG 6 synthesis report (UN 2018) reinforces the message that water management is critical. Water scarcity, flooding and quality are identified as the key determinants in social and economic development, and water efficiency is identified as the main factor to balance growing competing demands. The new SDG 6 targets incorporate all these aspects and, consequently, define the areas where SDG 6 implementation potentially impacts upon forests significantly.

Progress towards achieving each SDG 6 target is quantified by at least one indicator (UN Water 2018a). Section 6.4 assesses target impacts on forests through the actions that will be needed to ensure a positive direction for the respective indicator(s). Indicators 6.3.1–6.6.1 are the main focus of the analysis. Indicators 6.1.1 and 6.2.1 are the proportion of the population using, respectively, safely managed drinking water and sanitation services.

Table 6.1 SDG 6 targets and monitoring indicators for Targets 6.3–6.6

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally *Indicators: 6.3.1 Proportion of wastewater safely treated* *6.3.2 Proportion of bodies of water with good ambient water quality*
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity *Indicators: 6.4.1 Change in water-use efficiency over time* *6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources*
6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate *Indicators: 6.5.1 Degree of integrated water resources management implementation (0–100)* *6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation*
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes *Indicator: 6.6.1 Change in the extent of water-related ecosystems over time*
6.A By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
6.B Support and strengthen the participation of local communities in improving water and sanitation management

Source: https://sustainabledevelopment.un.org/sdg6
(orange = WASH targets; yellow = targets and indicators with potential forest impacts; white background = means of implementation targets)

6.4 SDG 6 and Forests: Key Links

This section examines the potential impacts of SDG 6 on forests (summarised in Table 6.2).

Table 6.2 Potential impacts of SDG 6 indicators on forests

Indicator	Response for favourable indicator score
6.1.1 Proportion of population using safely managed drinking water services	Maintain forest cover to ensure good water quality in water supply catchments. Establish forested riparian buffer strips to maintain stream water quality.
6.2.1 Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water	No direct link but target generally favourable for forest people.
6.3.1 Proportion of wastewater safely treated	Encourage agroforestry schemes using treated wastewater. Maintain forest cover for treating wastewater (e.g. in schemes for induced precipitation recycling).
6.3.2 Proportion of bodies of water with good ambient water quality	Maintain or increase forest cover to enhance water quality. Change plantation tree species to enhance water quality and quantity.
6.4.1 Change in water-use efficiency over time	Require increased water efficiency from forests as forestry is combined with (relatively inefficient) agriculture in allocating available water between economic activities. Change plantation tree species, density and location to improve water-use efficiency.
6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	Restrict establishment and continuation of plantation forest in water-limited areas (e.g. semi-arid regions) to maximise water availability. Maintain forest cover in upwind areas to safeguard downwind water resources dependent on recycled evapotranspiration.

Table 6.2 (cont.)

Indicator	Response for favourable indicator score
6.5.1 Degree of integrated water resources management implementation (0–100)	Integrate forest management with water resources management. Change plantation tree species, plantation characteristics and riparian buffer strips to optimise water availability and quality.
6.5.2 Proportion of transboundary basin area with an operational arrangement for water cooperation	Integrated consideration of forest management, including downstream impacts (within catchment) and downwind impacts (between catchments).
6.6.1 Change in the extent of water-related ecosystems over time	Reforest agricultural land, replace exotic tree plantations with native forests and implement other scenarios to maintain water availability and quality, with potential impacts on forest people.

6.4.1 Access to Safe and Affordable Drinking Water and Adequate and Equitable Sanitation and Hygiene – Targets 6.1 and 6.2

As noted in Section 6.3, Target 6.1 is somewhat neutral regarding the forest sector. Forests do not, of themselves, provide safe drinking water or sanitation services. Nevertheless, to the extent that stream waters in forested catchments tend to be of higher quality than in agricultural or urban environments, the treatment costs to bring them to a safe potable level may be lower, with a beneficial effect on affordability. It is common to find catchments maintained with a forest cover to form a source of clean water for a nearby city (e.g. Valdivia, Chile, receives water from a 12.7 km^2 catchment hosting evergreen native forest). Also, direct extraction of drinking water from streams without treatment is also generally safer in forested catchments than elsewhere (e.g. important for Indigenous populations of tropical forests). The performance of Indicator 6.1.1 (Proportion of population using safely managed drinking water services) could therefore be enhanced by a greater forest cover in water supply catchments. In some regions, forest cover is increasing through natural regeneration following abandonment of agricultural land. In other cases it may be worth deliberately afforesting catchments to provide purer water for water treatment plants, as the cost of treating lower-quality water in the absence of forest cover can be high (hundreds of thousands to millions of US dollars per year for individual cities; Ashagre et al. 2018). That cost would have to be compared with the costs of afforestation (including the potential removal of people from the land and the loss of agriculture). Reduction in run-off, and thus water availability, resulting from the afforestation would also have to be considered (e.g. Target 6.4). A more feasible and cheaper option may be the introduction of forested buffer strips along riparian zones, to reduce or interrupt nutrient fluxes to streams in agricultural catchments and sediment fluxes from both agricultural catchments and forested catchments undergoing logging. In the absence of other pressures, Indicator 6.1.1 is likely to favour maintaining existing forest covers. Given the multiple pressures on land resources, however, it would not be surprising if the forests' (high) worth to drinking-water quality was simply ignored, leaving the successful achievement of Target 6.1 increasingly dependent on artificial water treatment. The target would then be irrelevant to forests. Target 6.2, with its emphasis on sanitation and hygiene *for all*, should have a positive impact on forest people – that is, those who live in forests and whose lives and livelihoods depend directly on the forest environment and forest resources. Difficulties of accessibility, though, are likely to mean that forest people in remote areas will be among the last to benefit from this target (although perhaps being among those least in need of it).

6.4.2 Improving Water Quality – Target 6.3

Indicator 6.3.1 (Proportion of wastewater safely treated) is not closely linked to forests. However, to the extent that there is an interest in using treated wastewater for forestry, this indicator may drive an increase in, for example, agroforestry schemes. Forests have themselves been proposed as treatment areas for wastewater as part of wider schemes for induced precipitation recycling (Layton and Ellison 2016). Indicator 6.3.2 (Proportion of bodies of water with good ambient water quality) is more relevant in view of the potential for land use to affect water quality in rivers, reservoirs, estuaries and downstream wetlands. For example, in streams in native forests in Chile, nitrate (NO_3-N) and ammonium concentrations are very low and nitrogen (N) export is very low (0.2–3.5 kg N ha^{-1} yr^{-1}) (Perakis and Hedin 2001, 2002). The conversion of native forests to other land uses may therefore be expected to lead to increased NO_3-N and total N export. Conversion of native forest to pasture in southern Chile is associated with increased N fluxes and increased dominance of NO_3-N (exports up to 11 kg ha^{-1} yr^{-1}), although some of this increase may be attributable to pasture fertilisation (Oyarzún and Huber 2003). Conversely, afforestation may change soil pH and alter nutrient cycles (Hong et al. 2018). Nevertheless, because fertiliser use in plantation forestry – in terms of total use – involves a lower application frequency and smaller land areas compared with agricultural systems (May et al. 2009), the conversion of crop or pastureland to plantations (or even reverting to natural forest) is expected to improve water quality.

In most cases, logging of planted forests may produce elevated sediment export, mainly because of mechanised site preparation, road building and clear-cutting operations in steep terrain, rather than exposure of soil to rainfall (Bathurst and Iroumé 2014). Research in forest plantations in central Chile found that forest roads produce more sediment than hill slopes; after clear-cutting, the relative contributions increased from 16 per cent to 25 per cent for hill slopes and from 37 per cent to 45 per cent from forest roads (Schuller et al. 2013). Sediment delivery to streams increases if logging operations take place in rainy periods (with adverse impacts on drinking water and aquatic habitats), but the application of contemporary best management practices, which include guidelines for logging during dry periods, can limit logging-related sedimentation (Bathurst and Iroumé 2014). Although forest certification has enhanced the adoption of best management practices in Chile, forestry operations are still associated with increased sediment transport and decreases in water quality relative to unmanaged forests.

Because of forests' generally positive impact on water quality, Indicator 6.3.2 favours maintaining forest cover and increasing cover in protected or degraded catchments. Specifically, achieving good indicator scores for plantation forests will require careful consideration of tree species and the development and implementation of best management practices.

6.4.3 Water Efficiency and Improved Availability – Target 6.4

Indicator 6.4.1 (Change in water-use efficiency over time) tracks the value added (in US dollars) per volume of water withdrawn (cubic metres), by a given economic activity over time (UN Water 2018a). The UN International Standard Industrial Classification of All Economic Activities, Revision 4 code combines forestry with agriculture and fishing. This means that forestry as an economic activity will be considered jointly with agriculture when comparing water use with other sectors. It is already acknowledged that irrigation, as the largest consumer of water by volume, should be one of the big targets for water efficiency (HLPW 2018). There will therefore be increased attention to the efficient use of water in the forestry sector, which may eventually constrain the establishment and continued presence of plantation forests in the water-stressed areas highlighted by Indicator 6.4.2 (Level of water stress: freshwater withdrawal as a proportion of available freshwater resources). This indicator is demand-driven and measures the ratio between withdrawals and the difference between total renewable water resources and the environmental flows (Vanham et al. 2018). Strictly, it considers only blue water: the liquid water in rivers, lakes, wetlands and aquifers. However, the amount of blue water is determined by the upstream flows of green water – rainwater held in the unsaturated zone of the soil and available to plants – which is determined by terrestrial ecosystem functions or natural land use (e.g. forests or natural grasslands) and by consumptive water use in rain-fed agriculture and forest plantations. Therefore, analyses of water-stressed environments may lead to closer examinations of the consumptive use of water by forests.

In terms of biomass production per litre of water, trees are considered efficient users of water. Nevertheless, Soto-Schönherr and Iroumé (2014) found in Chile that water-use efficiency (i.e. kilograms of biomass produced per unit of water consumed) differs only a little between forests and grasslands: forests produce 0.1–4 kg of biomass per cubic metre of water, while grasslands produce 0.5–1.3 kg. However, because trees use more water than shorter vegetation, there is a central inconsistency (at least at the catchment scale) between the aims of maintaining forest cover (desirable for many reasons, including lower soil erosion and higher water quality) and of increasing water availability (which implies reducing forest cover). This is less concerning in high-rainfall areas (where there is enough water for all activities) but could be critical in semi-arid areas. This means that forestry as an economic activity will be compared directly with agriculture and other activities when deciding on use of limited water resources. Replacing forest by agriculture could increase annual run-off (and food supply), but at the expense of the forest ecosystem and timber supply. For example, replacement of natural vegetation with agricultural cover in a 175 360 km^2 catchment in South America produced a significant increase in annual mean discharge and high-flow season discharges because of reduced infiltration and evapotranspiration rates (Costa et al. 2003). Conversion of forest cover may ultimately lead to destruction of the land resource itself (Contreras et al. 2013). Thinning of forests considered unnaturally overgrown as a result of fire-suppression programmes has been proposed to increase water supply, e.g. in North America (Poulos 2018), but this may ignore the many other changes produced by forest management (Jones et al. 2009, NRC 2008). For example, forests play important roles in regulating the world's temperatures and freshwater flows, storing carbon and providing a broad range of important but less recognised benefits (Ellison et al. 2017). At the subcontinental scale, replacement of forests by shorter vegetation could imply less rainfall in downwind regions (Creed and van Noordwijk 2018) and possibly therefore less run-off, although the magnitude of this effect remains to be quantified.

Overall, forest plantations with fast-growing species use more water than native forests, although many of the comparisons are limited to old-growth native forests versus young plantations (Soto-Schönherr and Iroumé 2016). Results from southern Chile, for a wide range of latitudes and forest compositions and ages, showed that annual interception accounts for approximately 21 per cent of incoming precipitation in the mean, albeit with some margin of variation (Soto-Schönherr and Iroumé 2016). Within the range of variation, broad-leaved forests (including native broad-leaved and eucalyptus forests) generally exhibit higher interception losses than conifers. Indicative of the level of uncertainty, Huber et al. (2010) found that interception is lower, and water use is higher, in eucalyptus compared with pine plantations in southern Chile. Because of the relatively limited difference in canopy interception loss between native forests and forest plantations (Huber and Iroumé 2001, Soto-Schönherr and Iroumé 2016), the observed differences in water yield between the two must be explained, at least in part, by different transpiration losses.

Despite the above, forest plantations may not use more water than native forests at all stages of the forest rotation. As expected, water use is highest (and yield lowest) in the late stages of plantation growth, especially in short-rotation plantations with a high tree density, but water yield (especially summer water yield) increases just after clear-cutting, in the early phases of replanting (Iroumé et al. 2005, 2006). Again, variations between plantation species may exist (e.g. pine versus eucalyptus). Thus, water consumption by forests could be moderated by a small amount through careful choice of tree species (with an eye towards suitability to future climates), maintaining a mix of old and new growth (i.e. avoiding large-scale plantation of new growth), regulating tree density and choosing plantation location carefully, possibly implying longer growth periods or reduced timber yield. Nevertheless, such moderation is likely to be small compared with the effect of forest removal. Overall, the demands of Target 6.4 are likely to be inimical towards forest cover in many parts of the world.

6.4.4 Integrated Water Resources Management – Target 6.5

Integrated water resources management (IWRM) is defined as 'a process which promotes the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems' (Global Water Partnership 2017). It acknowledges the interconnected nature of hydrological resources and the interdependence of different water uses. Within the wider requirements of the definition, IWRM implementation implies the integrated management of water supply, water quality, flood management, navigation, hydroelectric power generation and other water provisions and services within a river basin. Within this balancing act, forest cover reduces water supply relative to other vegetation covers (at the annual scale) but has the potential to improve water quality. From points 8 to 10 in Section 6.2 it can be concluded that forest cover could probably be reduced without necessarily increasing damaging flood magnitudes, but flood frequencies might increase, as would soil erosion. These points refer to the catchment scale. At the subcontinental scale, forest evapotranspiration is not lost from the system but may be recycled as precipitation downwind. Water resources management needs to be integrated with forest management, an end likely encouraged by Indicator 6.5.1 (Degree of integrated water resources management implementation). Such integration is most required in regions where there are multiple and conflicting demands for water, where water supplies are restricted and forests account for significant water use (e.g. semi-arid regions) and where soil erosion is a significant problem (e.g. semi-arid regions, degraded lands and areas of unregulated agricultural expansion). The exact impact of Indicator 6.5.1 on forest cover will vary from basin to basin depending on economic, social, political and other circumstances. It seems more likely, though, that IWRM is implemented as a function of whatever level of forest cover happens to exist, and therefore reacts to rather than drives forest cover change.

In South America conversion of forest to agriculture is the major reason for changes in water availability to rivers and streams (Jones et al. 2017). The concept of virtual water (Yang and Zehnder 2007) assesses water-use efficiency based on water used to grow products traded globally. From 1986 to 2007, South America increased its annual use of water from 42 km^3 to 178 km^3 and became the continent using the greatest amount of water in food products traded globally, with significant increases in soy exports to China – which in turn has contributed to deforestation in Amazonia (Dalin et al. 2012).

In the Federal District of Brazil, river basins with substantial expansion of agriculture since the end of the 1970s show a dramatic decrease of base flow discharge by 40–70 per cent – presumably the effect of irrigation extractions more than compensating for the increase in run-off otherwise expected from reduced forest evapotranspiration. Additionally, the run-off ratio is significantly positively related to the cover of natural vegetation (Lorz et al. 2012). In south-central Chile, the run-off ratios in four large catchments were positively related to the area of native forest and negatively related to the area of eucalyptus and pine plantations (Lara et al. 2009).

Careful choice of tree species and plantation characteristics could moderate water consumption by forests. Reducing the area of forest plantations can potentially increase water availability at the catchment scale, as might replacing exotic fast-growing trees with native forest species, although it has yet to be proven that this would allow adequate timber yields to be produced with less water use. Native forest riparian buffers may increase water yield and improve water quality in forest plantations of eucalyptus in south-central Chile (Little et al. 2015) and along rivers in degraded native forest in south-east Brazil (de Souza et al. 2013). Forest thinning (Poulos 2018) should be approached with caution: thinned plantations may initially increase water yield (Forrester et al. 2012), but subsequent forest growth might take up the additional water, depending on the timing and degree of thinning (Perry and Jones 2017).

At the international level, Indicator 6.5.2 (Proportion of transboundary basin area with an operational arrangement for water cooperation) may drive a more integrated consideration of the forest environment, especially where a downstream or downwind state feels adversely affected by the forestry activities of an upstream or upwind state. At the subcontinental scales typical of many politically sensitive transboundary basins, the downstream impacts of upstream forestry activities may not always be significant. For example, there is no clear evidence for the so-called Himalayan environmental degradation theory, which proposes that loss of forest cover caused by a rapidly growing population in the Himalayan headwaters of the Ganges and Brahmaputra Rivers increases soil erosion and flood run-off, thereby generating increased flooding and siltation in the delta regions of Bangladesh (Hofer 1993). Downwind impacts at subcontinental scales are increasingly thought to be important but have yet to be proven conclusively (Creed and van Noordwijk 2018). Large amounts of moisture from evapotranspiration may be recycled within Amazonia and transferred to other parts of South America. However, the extent to which forest conversion has affected this precipitation recycling so far is yet to be clearly quantified (Bagley et al. 2014, Khanna et al. 2017, Spera et al. 2016, Swann et al. 2015). The impact of Target 6.5 is most likely to be a more integrated consideration of forest management, especially with respect to water resources management, both within and among river basins.

6.4.5 Protecting and Restoring Water-Related Ecosystems – Target 6.6

Indicator 6.6.1 (Change in the extent of water-related ecosystems over time) will drive careful consideration of the relationship between forest cover and the health and sustainability of water-related ecosystems. Although the title of Target 6.6 includes forests along with mountains, wetlands, rivers, aquifers and lakes, Indicator 6.6.1 considers only mangroves. The absence of other types of forests severely limits this indicator's degree of protection.

Despite the restricted nature of the indicator, forest-related water ecosystems services form an important underlying concept linked to the essence of Target 6.6. They are indeed one of the most proffered links between SDG 6 and forests, but they are not always properly understood and are difficult to quantify. For instance, not all forested areas safeguard water quality: rapid and aggressive afforestation and reforestation with exotic species reduces water availability, affecting its quality, especially in dry seasons (Filoso et al. 2017). Achieving good indicator scores requires maintenance of water flows – and of good water quality – to wetlands. This could imply reforesting agricultural areas, replacing plantations of exotic tree species and monocultures with a wider range of native trees (which may be slower growing), removing existing plantations or avoiding new plantations (e.g. in peatlands, páramo soils or semi-arid regions) and other scenarios. Such land management could have adverse consequences for livelihoods based on the existing agricultural and plantation activity (and for the production of the associated crops) but might open new employment prospects in forestry activities. Also, there is a high potential for payments for ecosystem services if those services are clearly proven. In the Hindu Kush Himalaya region, research is attempting to show the tangible value of water-related ecosystem services; for example, purification of the downstream water supply via upstream forests is an important ecosystem function that payments for ecosystem services schemes have attempted to quantify and that can contribute to achieving Target 6.3 by natural means (Ashagre et al. 2018). However, there is still a gap in our understanding of how individual attributes (such as changes in land-use patterns) impact ecosystem service flows, including water (Polasky et al. 2011, Nelson et al. 2013, Su and Fu 2013). In particular, it is difficult to correlate change in a land unit with change in the volume of ecosystem services that this unit provides (Bhatta et al. 2017).

Despite these uncertainties, payments are already being made to promote ecosystem services. Recently, the Chilean government, acting according to the UN Framework Convention on Climate Change (UNFCCC), gave a commitment to afforest (mainly with native tree species) 100 000 ha of degraded soils as a contribution to reducing greenhouse gases (CONAF 2016). To this is added some 470 000 ha that were burnt during the 2016–2017 (southern) summer season. Of this, the government will finance the afforestation of 100 000 ha on lands belonging to small- and medium-size owners, while the remaining burnt lands owned by larger forest companies are already being afforested. The aims of these afforestations are mainly to restore and improve the ecosystem services of the degraded areas, except for the afforestation of lands owned by larger private forest companies whose purpose remains timber production. Not all those forested areas would safeguard water quantity;

potentially, there could be resistance to forestry plantations in water-stressed regions, as highlighted by Indicator 6.4.2.

In conclusion, SDG 6 seems unlikely to exert a major influence on forest cover, and indeed is unlikely to be pursued with forests at the forefront of consideration (Table 6.2). Possible exceptions are that Target 6.4 may restrict the spread of new plantations in semi-arid areas and Target 6.5 may drive a more integrated view of catchments and their management. Plantations may be developed with more careful consideration of tree species and plantation characteristics. It seems much more likely, however, that native forest cover in much of the world will continue to decline in the face of pressures greater than SDG 6: (1) to convert forest for food production, driven by population growth and increasing aspirations for living standards worldwide; and (2) to exploit timber and other forest resources, driven first by those seeking a profit but ultimately responding to individual demand globally, with little consideration for the resulting impacts. The decline is exacerbated by the inability or unwillingness of governments in many countries to control such developments, and possibly by climate change reducing or shifting the areas of the world suitable for sustaining the current forests (Guardian 2019, WWF 2019). The extent of monoculture plantations, on the other hand, could increase or decrease: demand for plantation products (e.g. palm oil and timber) is likely to increase, but water efficiency considerations may curtail the spread of plantations in water-stressed areas.

6.5 Future Policy Considerations

6.5.1 Contextual Factors for SDG 6: The Hindu Kush Himalayas

Trying to understand the real impacts that SDG 6 may have on forests and forest people requires a careful evaluation of the context of water–forest interactions, in particular physical and social settings and the interactions with other SDGs. While context is always affected by local conditions, some situations do recur. The Hindu Kush Himalayas case illustrates some of the contextual factors that must be considered in implementing SDG 6 and highlights the upstream/downstream relationships, inherent where forested mountain areas feed major river systems, which can be found on all continents.

The Hindu Kush Himalayas harbour major river systems providing services, particularly in the form of recharge, to a mountain population of 240 million and a downstream population of 1.9 billion. Indirectly, 3 billion people are dependent on numerous ecosystem services, including climate and hydrological services provided at regional and global scales, and harvested commodities traded at multiple economic scales (Kotru et al. 2015). The observed overall increase in forest cover in India does not mean that forest degradation is controlled. An alarming rate of deforestation in parts of the Himalayas, primarily for agricultural land and fuel supply, threatens the sustained flow of forest ecosystem services. As is generally the case in South Asia, multiple sectors and actors influence forests and forest management; it is not only through forest management that the forest–water relationship can be improved for sustained water yield.

Multiple water-related objectives across a portfolio of SDGs present new challenges for policymakers and managers of forests and landscapes with partial tree cover. Hence, SDG 6 cannot be seen in isolation from other key challenges in the Himalayas, such as SDGs 1 (No Poverty), 2 (Zero Hunger) and 5 (Gender Equality). Thus, investments (e.g. in mass tourism) made upstream for addressing other SDGs are not necessarily environmentally friendly or complemented by good governance, making it potentially more difficult to achieve the SDG 6 targets (6.1, 6.3, 6.4 and 6.6). On the other hand, the policies, practices and investments necessary to achieve SDG 6 may not be coordinated with those for other SDGs, so positive outcomes for people are not ensured (Singh and Kotru 2018). The transboundary nature of hydrological resources – overlaying local, regional and national boundaries – make the challenges to safe water access more complex. New institutional responses are needed to tackle multiple water-related objectives across the full portfolio of SDGs, taking a multiple benefits approach (Creed and van Noordwijk 2018). A distinction may be made between a first group of SDGs (SDGs 1, 2, 6, 7) implying an increased demand for clean, reliably flowing water, and a second group of SDGs (5, 10, 12, 16) that stresses a change in power-sharing that allows multi-stakeholder involvement, thus increasing the need for transparency and equity in decision-making.

Several socio-economic and governance realities challenge forest regimes in fulfilling their socio-ecological role (as envisaged under SDG 6) in the Hindu Kush Himalayas (Kotru et al. 2017):

- poverty and inequity are still prevalent in South Asia, a water-deficit area;
- institutional capacities and existing policies are inadequate to meet the future challenge of forest management for sustained water yields;
- research on the forest–water relationship is essentially very limited, with no long-term monitoring data or studies available;
- there are very limited cross-sector policy interfaces (e.g. water policy and forest policy interface) that focus on a forest or landscape approach aimed at sustaining water services;
- sustainable forest management is seriously disadvantaged by a lack of proactive management, itself arising from policy deficits;

- data deficits and a lack of harmonised methodologies and data sharing mean that the planning and application of conservation and development strategies contributing to SDG 6 have only a limited foundation on firm data.

Future progress towards achieving Targets 6.3–6.6 in the Hindu Kush Himalayas will require improved upstream–downstream integration, improved transboundary cooperation and greater coordination and simultaneous progress in the implementation of different SDGs: for example, SDGs 1, 2 and 5 (already mentioned) and SDGs 13 (Climate Action), 15 (Life on Land) and 17 (Partnerships for the Goals). Adoption of a landscape approach would allow stakeholder priority interventions to be matched with public and private investments but, equally, there is a need for an improved understanding of the role of forests in influencing ecosystems services at the larger landscape scale. Greater efforts are required to make the communities struggling on the frontline of sustainable forest management more climate resilient.

6.5.2 Implementation of SDG 6

The final impact of SDG 6 on forests and forest people will be determined by the extent of its implementation. There are four important considerations here: finances, institutions, data and other SDGs. First, implementation costs are increasing: the estimated cost of achieving the WASH targets is USD 1.7 trillion (Hutton and Varughese 2016). While there are no reliable estimates of the whole cost of achieving SDG 6, it is clear that the required threefold increase for Targets 6.1 and 6.2 alone indicates a huge increase in water targets expenditure. As aid is decreasing, it is not at all clear where this money will come from. The UN calls for more technology transfer and new financing mechanisms, with some based on the recognition of the economic value of water and freshwater ecosystems (UN 2018). Forests may eventually benefit from the growing interest in nature-based solutions, which use or mimic natural processes to enhance water availability and water quality and to reduce risks associated with water-related disasters and climate change. The UN High Level Panel on Water specifically mentions that natural capital solutions, including the 'water-retaining abilities of forest', can be used at a fraction of the cost of engineering solutions (HLPW 2018). It labels forests as 'natural infrastructure' required to assure future supplies of water, calling for a better alignment of incentives to recognise the value of these services. It is of the utmost importance that natural capital solutions recognise the nuanced role of forests currently accepted as best practice and take into account local conditions. They should be particularly considered in the context of deforestation and forest degradation while recognising the need to understand water quantity effects at catchment, regional and continental scales. It is important to acknowledge that not all water-poor locations have forests to use as improvement tools.

Second, the success of SDG 6 depends on the existence of national and global institutions able and willing to implement the goal. While the WASH sector has spent nearly 20 years trying to achieve global targets, the level of institutional readiness for the new water resources targets is frequently low or non-existent at the country level. Even with the apparently successful MDG 7.C drinking water target, 53 countries were seriously off-target and 19 could not produce data. Good water governance depends on strong formal and informal institutions and the accompanying human resources. There is an acute lack of capacity across most developing countries, particularly in sub-Saharan Africa and South and Southeast Asia (UN 2018). With low institutional capacity, we can expect a slow articulation of the new targets within SDG 6 and, subsequently, low impact on the forest sector. However, since the creation of UN Water in 2003 as a focal point for coordinating efforts of UN entities and international organisations working on water and sanitation issues, the alignment of global water initiatives has increased (UN Water 2018b). Eventually this will lead to actions on the ground. The existence of SDG 6 in itself is a clear proof of the strength of these efforts. The HLPW (High Level Panel on Water 2018) has identified a number of initiatives especially relevant for states trying to implement SDG 6: the World Water Data Initiative; the OECD Water Governance Initiative; the Delta Coalition; High-level Experts and Leaders Panel on Water and Disasters, including an Alliance of Alliances on disaster risk-reduction researches; the initiative on Financing Water Infrastructure convened by the OECD; and the Water Innovation Engine. Whether these will accelerate SDG 6 implementation is yet to be seen, but they may support natural infrastructure projects with a role for forests.

The third consideration is the challenge of having enough good-quality data for monitoring SDG 6. It took a serious global effort from 1990 onwards to develop the WHO/UNICEF Joint Monitoring Programme, now the custodian of global WASH data for Targets 6.1 and 6.2. The situation is more complicated with the other targets as many countries lack the financial, institutional and human resources to acquire and analyse the required data. Fewer than half of UN member states have comparable data available on progress towards meeting the SDG 6 targets (UN 2018). This is important because countries will focus on being able to report to the Integrated Monitoring Initiative (UN Water 2018a). Accordingly, the factors monitored for each target are likely to become the focus of public policy. It is therefore important to understand how forests relate to this monitoring programme.

The final consideration is the dynamic interdependence between SDG 6 and the other SDGs (UN Water 2018c). The majority of these interlinkages are positive and mutually reinforcing. Since the MDG programme, the WASH targets have been identified as critical to: reducing poverty (SDG 1), malnutrition (SDG 2) and diseases (SDG 3); supporting education (SDG 4); and addressing gender (SDG 5) and other inequalities (SDG 10). Moreover, SDG 6 highlights how water of sufficient quality and quantity is required for food production (Target 2.4) and sustainable consumption and production (SDG 12). However, there are some targets – such as doubled agricultural productivity (Target 2.3), energy for all (Target 7.1) and sustained economic growth (Target 8.1) – that potentially could impact negatively on water resources and water ecosystems and, as such, on forests and forest people. IWRM (Target 6.5) is the appropriate framework to balance all these competing needs, for water and forests.

6.5.3 Integration of SDG 6 and Forests

The discussion of the contextual challenges in South Asia clearly shows both the difficulty and the necessity of aligning SDG 6 and forest policies. For this alignment to succeed in an IWRM framework, we need to follow a landscape approach at all levels. As larger forms of vegetation, trees use great amounts of water to produce biomass and for the process of evapotranspiration, more so than many other vegetation types, including crops and grasses. However, when considering Target 6.4 on increasing water-use efficiency and ensuring sustainable withdrawals and supply of freshwater and how it may impact forests and forest management, several issues need to be considered.

Firstly, most forests or tree-based landscapes are naturally occurring, rainfed systems. Globally, only 7 per cent of forests are planted forests, predominantly found in temperate zones (FAO 2015). Moreover, most of these planted forests are native species: only 20 per cent of planted forests – 1.4 per cent of forests globally – are exotic, and these are located mainly in the southern hemisphere (FAO 2015). It is assumed that natural forests will not be removed for the purposes of achieving Target 6.4 as they provide a wealth of other goods and services, including water-related ecosystem services. Consequently, discussion of water-use efficiency will be limited to planted forests, despite their representing only a small proportion of global forests.

Trees are highly resilient and adaptive organisms that optimise their water use. In other words, they drastically reduce their water consumption in periods of drought and use what they can when water is available (Chaves et al. 2002). This means that during periods without rain trees can use water stored in the soil; they generally have higher annual rates of water use than shallow-rooted, annual cropping and pasture systems. In high-rainfall areas (> 1500 mm per annum), planted forests can use up to 200 mm more water than pastures, but only if the water use is not energy limited. In low rainfall areas (< 600 mm per annum), forest plantations use an amount of water similar to annual crops and pastures. In intermediate rainfall areas, planted forests potentially use more water than annual crops and pastures. If this is in conflict with other demands for water, policies are required to regulate allocation of water to plantations among other uses. Policy instruments to regulate plantation water can be direct (e.g. a moratorium on land concessions) or indirect (e.g. a market for allocable water). For example, South Africa, Australia and India have implemented policies to regulate or limit plantation establishment (Brown et al. 2005, Dye and Versfeld 2007, Farley et al. 2005, van Dijk and Keenan 2007, Whitehead and Beadle 2004).

Even if trees are able to optimise their water use, it is important to note that management can be improved in order to further optimise water-use efficiency – including tailoring species selection, as well as thinning and harvesting techniques – to the environmental conditions such as slope, soil type and condition. More importantly, as planted forests are managed at the stand scale and water is managed at a catchment or basin scale, it is critical when planning to look at planted forests, and even tree-based systems more broadly, at the landscape level, taking into consideration the mosaic of land uses and their effects on water. This requires a cross-sectoral approach to land and water planning and management.

Integrated planning and management may require reframing our approach, taking into account integrated solutions such as agroforestry and the use of recycled wastewater in planted forests. Studies show that agroforestry increases water-use efficiency (Bai et al. 2016, Droppelmann et al. 2000). The recycling of treated wastewater for planted forests can reduce competition for water use (particularly in semi-arid and arid areas where water is scarce), reduce the costs associated with water treatment and reduce downstream contamination (FAO 2018a). Planted forests irrigated with treated wastewater in turn improve soil water-storage capacity, reduce soil degradation and erosion, combat desertification in arid areas and provide essential goods that support livelihoods, such as timber, pulpwood and fuelwood (FAO 2018a). According to FAO's Aquastat database (FAO 2018b), only 52 per cent of the municipal wastewater produced globally is recycled, so there is ample opportunity to explore such options. Egypt, Jordan, Mexico and Spain, among others, are exploring the use of treated wastewater for agroforestry and planted forests. In Jacksonville, North Carolina, USA, upstream forests are being irrigated with treated wastewater, with the forests acting as the final stage of the filtering process and returning water back into the catchment for use downstream (Tew 2016).

Much can be gained from a deeper integration of SDG 6 and forest policies. However, this integration must be guided by a shared understanding of the complex relationships between water and forests and their impacts on both forest people and the communities downstream, and possibly downwind.

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